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Amazonian forest termites: a species checklist from the State of Acre, Brazil

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Abstract: The Brazilian state of Acre is located in the southwestern Amazon and it is characterized by a humid tropical forest vegetation that covers plains and mountains. Up to this point, the composition of termite species in the state is not known. The aim of this study was to provide a checklist of termite species or recognizable taxonomic units for the state of Acre. Sampling was conducted through field expeditions at the Serra do Divisor National Park, Chandless State Park, Humaitá Forest Reserve, and Chico Mendes Environmental Park using a standardized rapid termite inventory protocol in the first two areas and active searching collections in the others, without a specific protocol. This study also included occurrence records published in the scientific literature. A total of 128 species and morphospecies of termites were found in Acre, distributed across 59 genera and four families. The most frequently occurring species in Acre was *Heterotermes tenuis* (Hagen, 1858). The study also identified six new species records for Brazil. The predominant feeding groups were soil-feeders and wood-feeders, as expected from data obtained from surveys in humid tropical forests. Despite the significant number of new records for Acre (112), it is concluded that a larger sampling effort is still required, as many areas of the state have not yet been studied for termites.

Keywords: insect fauna; biodiversity; feeding groups; Isoptera; Neotropics.

Térmitas da Floresta Amazônica: uma lista de espécies do Estado do Acre, Brasil

Resumo: O estado brasileiro do Acre está localizado no sudoeste da Amazônia e é caracterizado por uma vegetação de floresta tropical úmida que cobre planícies e montanhas. Até então, a composição de espécies de térmitas no estado não é conhecida. O objetivo desse estudo foi construir um checklist de espécies ou unidades taxonômicas reconhecíveis de térmitas para o estado do Acre. A amostragem foi conduzida através de expedições de campo no Parque Nacional da Serra do Divisor, no Parque Estadual Chandless, na Reserva Florestal Humaitá, e no Parque Ambiental Chico Mendes utilizando o protocolo rápido de diversidade de térmitas nas duas primeiras áreas e coletas avulsas nas demais, sem um protocolo específico. Este estudo também incluiu registros de ocorrência publicados na literatura científica. Um total de 128 espécies e morfoespécies de térmitas foram encontradas no Acre, distribuídas em 59 gêneros e quatro famílias. A espécie de ocorrência mais frequente no Acre foi *Heterotermes tenuis* (Hagen, 1858). O estudo também identificou seis novos registros de espécies para o Brasil. Os grupos alimentares predominantes foram os humívoros e xilófagos, como esperado a partir de dados obtidos de pesquisas em florestas tropicais úmidas. Apesar do número significativo de novos registros para o Acre (112), conclui-se que ainda é necessário um esforço amostral maior, uma vez que muitas áreas do estado ainda não foram estudadas para térmitas.

Palavras-chave: fauna de insetos; biodiversidade; grupos alimentares; Isoptera; Neotropical.

Introduction

Termites are abundant eusocial insects that act as decomposers and ecosystem engineers in tropical and subtropical regions of the world (Bignell et al. 2011). Their presence alters the environment as a result of their foraging behavior and nest-building, making nutrients trapped in plant organic matter more readily available to the soil, and creating new microhabitats for a wide variety of organisms of different trophic categories (Bignell & Eggleton 2000, Holt & Lepage 2000). Low-latitude regions tend to have higher temperatures and higher precipitation, which contribute to elevated levels of species diversity (Lomolino 2001). This is true for Brazil, one of the countries with the greatest biodiversity, which has a recorded 348 termite species, a value clearly underestimated (Cancello et al. 2014, Constantino 2022). Currently, 2,970 extant termite species are known worldwide, 615 of which species are recorded in the Neotropical region, surpassed only by the Oriental and Ethiopian regions (Constantino 2022).

Termite studies in Brazil have increased our understanding about the diversity of this group and its distribution across different biomes (Constantino 2005, Vasconcellos & Moura 2014, Feitosa et al. 2021, Vasconcellos et al. 2023). Some species lists have already been published for the Amazon (Emerson 1925, Bandeira 1979, Constantino 1992, Constantino & Cancello 1992, Issa 2000, Bahder et al. 2009, Palin et al. 2011, Dambros et al. 2012, Castro et al. 2021a) but to date there are no published checklists for any of the federal states of northern Brazil. The lack of a species inventory is especially detrimental because of the importance of these data for establishing ecological and biogeographical baselines to better inform conservation strategies (Silveira et al. 2010, Koroiva et al. 2020).

The Amazon biome is characterized by dense tropical forests. About 60% of its extent is in Brazil, but it also extends into Peru, Bolivia, Ecuador, Colombia, Venezuela, French Guiana, Guyana and Suriname.

Far beyond its recognized biodiversity, the biome is of great importance to global ecology as it regulates regional hydrological cycles and climate patterns (Hutyra et al. 2007, Silva & Rezende 2022), and stores up to 100 billion tons of carbon (Copertino et al. 2019). However, the Amazon Basin continues to experience rapid deforestation and forest degradation (Vergopolan & Fisher 2016, INPE 2021), which threaten the balance of the entire ecosystem.

The state of Acre, located in the westernmost part of the Brazilian Amazon, has particular environmental characteristics that favor high biodiversity due to the influence of the Andean Cordillera (Sombroek 2000). Despite several protected areas, Acre has experienced particularly high rates of deforestation in recent decades (INPE 2021), highlighting the need to rapidly improve our knowledge of the region. One example is the Serra do Divisor National Park, which harbors some of the greatest biodiversity on earth, and is threatened by proposed bills that seek to reduce its protected status, likely leading to increased degradation within the park boundaries (Koga et al. 2022). For many termite species, there are only a few records from Acre, which suggests an underestimation of termite gamma diversity and highlights the need for further studies to better understand their distribution in the area. Improving the current knowledge of this taxon will be useful in developing conservation strategies and contributing to protected area management plans. Our aim here is therefore to provide a comprehensive checklist of the species or recognizable taxonomic units for termites occurring within four important protected areas within the Brazilian state of Acre.

Material and Methods

1. Study areas

The state of Acre (Figure 1) has an area of 164,173.431 km², is located entirely in the Amazon biome and belongs to the northern region of Brazil.

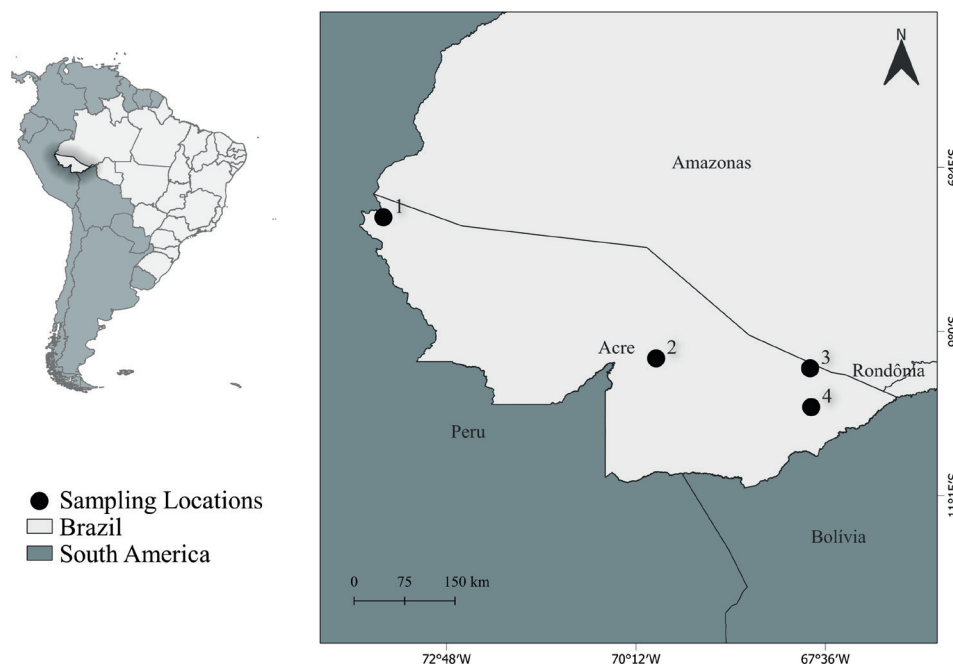


Figure 1. Locality map of the areas where termite sampling was conducted in the state of Acre, Brazil. 1, Serra do Divisor National Park; 2, Chandless State Park; 3, Humaitá Forest Reserve; 4, Chico Mendes Environmental Park.

It borders the Amazon River to the north, Rondônia to the east, and the international borders with Peru to the west and Bolivia to the south. The relief of Acre is mainly composed of depressions, except for a small plateau in the north, and lowlands closely related to the hydrographic basin of the state (Cavalcante 2006). The hydrography of Acre consists of extensive rivers that are part of the Amazon River system, flowing from the southwest to the northeast and forming two important hydrographic basins for the state: the Acre-Purus Basin and the Juruá Basin.

According to Köppen's climate classification, Acre has a tropical savanna, equatorial and monsoon climate, with an average temperature of 25.1 °C, an annual precipitation of 2,169 mm. Although the vegetation of Acre is predominantly humid tropical forest, it has variations that include 11 forest typologies (IBGE 2005). Acre is the second-largest state in the legal Amazon region in terms of vegetation coverage, with 86% of its territory covered by the Amazon rainforest, second only to the state of Amazonas, which boasts 91% coverage (INPE 2021).

For this study, sampling was conducted in four protected areas across the state of Acre: Serra do Divisor National Park (SDNP—8°02'39.0" S 73°33'55.0" W), Chandless State Park (CSP—9°55'15" S 70°09'45" W), Humaitá Forest Reserve (HFR—9°45'49" S 67°38'40" W) and Chico Mendes Environmental Park (CMEP—10°02'14" S 67°47'38" W). The SDNP and CSP protected areas are under special protection regimes that aim to preserve biodiversity, natural ecosystems, and unique environmental characteristics. These areas are recognized as important for the preservation of biological diversity and have a territorial extension of 843,012.28 ha and 695,303.00 ha, respectively. In contrast, HMF (2,000 ha) is located in a forest fragment near the state capital of Rio Branco, and CMEP (57 ha) is an urban park located in the Rio Branco suburbs. These two sites have lower protected status and clearly present different environmental pressures than those observed at SDNP and CSP.

2. Species sampling

Five sample expeditions were carried out in May and December 2019. In May, collections were carried out in SDNP, CSP, HFR, and CMEP, and in December, an additional collection was conducted in SDNP. The rapid inventory protocol adapted by Cancellato et al. (2014) was applied twice in SDNP and once in CSP. The application of this protocol is important not only because it captures a high number of species and feeding groups with a quick field effort, but also because it is a standardized method that allows for more reliable comparisons between different locations, enabling the development of ecological studies at larger scales. This protocol consists of six transects spaced at least 100 m apart, and divided into five plots of 5 × 2 m spaced 10 m apart. Sampling effort was 1 hour/plot/person, searching in all possible environments within the plot, such as on the ground, in fallen logs, in the leaf litter, under rocks, and on trees up to about 2 m high. Collected material was placed in flasks containing 80 °GL ethyl alcohol for sorting in the laboratory. In HFR and CMEP, collections were conducted using active searching for termites along the path traversed in those areas, without a specific protocol. The reduced number of days in the HFR and CMEP expeditions restricted the implementation of the rapid inventory protocol at these sites.

Termite sampling and transport were authorized by the Brazilian Biodiversity Information and Authorization System (SISBIO), Chico Mendes Institute for Biodiversity Conservation (ICMBio), Ministry of Environment (MMA) (SISBIO authorization number 68077-1, 50565-2 and 72337-1). All specimens sampled in this project were deposited in

the Termite Collection of the Department of Systematics and Ecology at the Federal University of Paraíba (UFPB).

Identification of species and morphospecies was based on material available in the scientific literature (Constantino 1998, 2002, Bourguignon et al. 2016a, Carrijo et al. 2023), and comparison of specimens with previously identified material deposited in the UFPB termite collection. Given the limited identifiability of specimens of the soldierless subfamily Apicotermitinae, it was necessary to dissect their enteric valves (see Supplementary Material, Figures S1, S2 and S3), which contain essential taxonomic characters for this subfamily, in addition to their gut topology (Bourguignon et al. 2016b). This necessitates the loss of specimens subjected to this procedure because part of their intestine is destroyed. Therefore, nine termite samples deposited in the UFPB termite collection were not included in this checklist because they contained five or fewer specimens, and as a result, could not be identified.

To complete the list, data were added from the Taxonomic Catalog of Isoptera from Brazil (Constantino 2022) and from the Web of Science (Clarivate Analytics 2023) and Google Scholar (Google Scholar 2023) databases using the keywords "Termite" and "Acre state". Of the termites found in the scientific literature for the state of Acre, only those represented at the species or genus morphotype level that were not part of the sampling conducted in this work are considered, since it is impossible to know whether the morphotypes designated in third party studies are different from those analyzed in this work.

3. Feeding groups

Termites were classified into feeding groups according to the proposals of Plaza (2019) and Donovan et al. (2001). The first classification of feeding groups (FG1) is part of one of the criteria analyzed for the characterization of Amazonian termite guilds (Plaza 2019). The characterization of these feeding groups follows criteria adapted from earlier studies (De Souza & Brown 1994, Eggleton et al. 1995, Vasconcellos et al. 2010, Cancellato et al. 2014). Although it is gray literature, the use of this classification was appropriate due to the regional proximity of the studied material, i.e., termites from the Amazon. Five categories are proposed, considering the feeding habits of termites: (1) W = wood-feeders that feed on wood and litter, regardless of the stage of decomposition; (2) L = leaf-feeders that cut living plant material during foraging to feed; (3) S = soil feeders that feed on decaying organic material and soil; (4) W/S = wood/soil interface feeders that use wood in an advanced stage of decomposition, already in the phase of incorporation into the soil; and (5) I = obligate inquiline termites that feed on organic compounds of the nest-building species of which they are inquilines. The second food group classification (FG2) establishes a humification gradient and divides termites into four groups based on differences in stomach contents, morphology, and internal anatomy (Donovan et al. 2001).

Results

For the state of Acre, a total of 128 species and morphospecies of termites were recorded, including those from this study and from other previously published studies. Of these, 89 species (69%) could be identified at the species level, while for 39, it was only possible to identify morphospecies (for 17 it was possible to identify the genus level, for 15 it was possible to identify only the subfamily level, and for the remaining

seven species, there was some uncertainty, and we attributed a qualifying word, like aff. and cf., to each to indicate the degree of uncertainty).

In this study, 59 genera were recorded distributed across four families: Kalotermitidae (four genera, six species), Rhinotermitidae (four genera, six species), Serritermitidae (one genus, one species), and Termitidae (50 genera, 115 species and morphospecies). The high diversity within the Termitidae can be examined at the subfamily level, with 15 genera and 40 species and/or morphospecies for Apicotermitinae, 12 genera and 31 species and/or morphospecies for Nasutitermitinae, 12 genera and 23 species and/or morphospecies for Syntermitinae, and 11 genera and 21 species and/or morphospecies for Termitinae. The resulting checklist, across all families, includes 112 new records of termite species for Acre and six new records of termite species for Brazil (Figures 2–6).

The SDNP was the site with the greatest species richness (89), followed by CSP (62), HFR (19) and CMEP (4). Literature data registered

only 16 species for the whole of Acre. Of the 128 records for Acre, 52 were collected only in the SDNP, 22 only in the CSP, two species in the HFR, two in the CMEP and four only found in the literature. Only nine species occurred in three or more localities. Seventy-four species (58%) were exclusively sampled through the rapid inventory protocol, while 27 species (21%) were exclusively sampled through active searching. Overall, 23 species were recorded building conspicuous nests, both in this study and in the literature (Mathews 1977, Bandeira & Fontes 1979, Constantino 1991, 1992, 1995, Laffont et al. 2004, Fougeyrollas et al. 2017).

The soil-feeding termites (category S from FG1) were predominant across Acre, representing 42% of the species found in samples from this study, followed by wood-feeders, represented by 34% of the species. According to the classification based on worker morphology by Donovan et al. (2001) (FG2), feeding groups II and III were most represented, with 28% and 46% of the species found, respectively (Table 1).

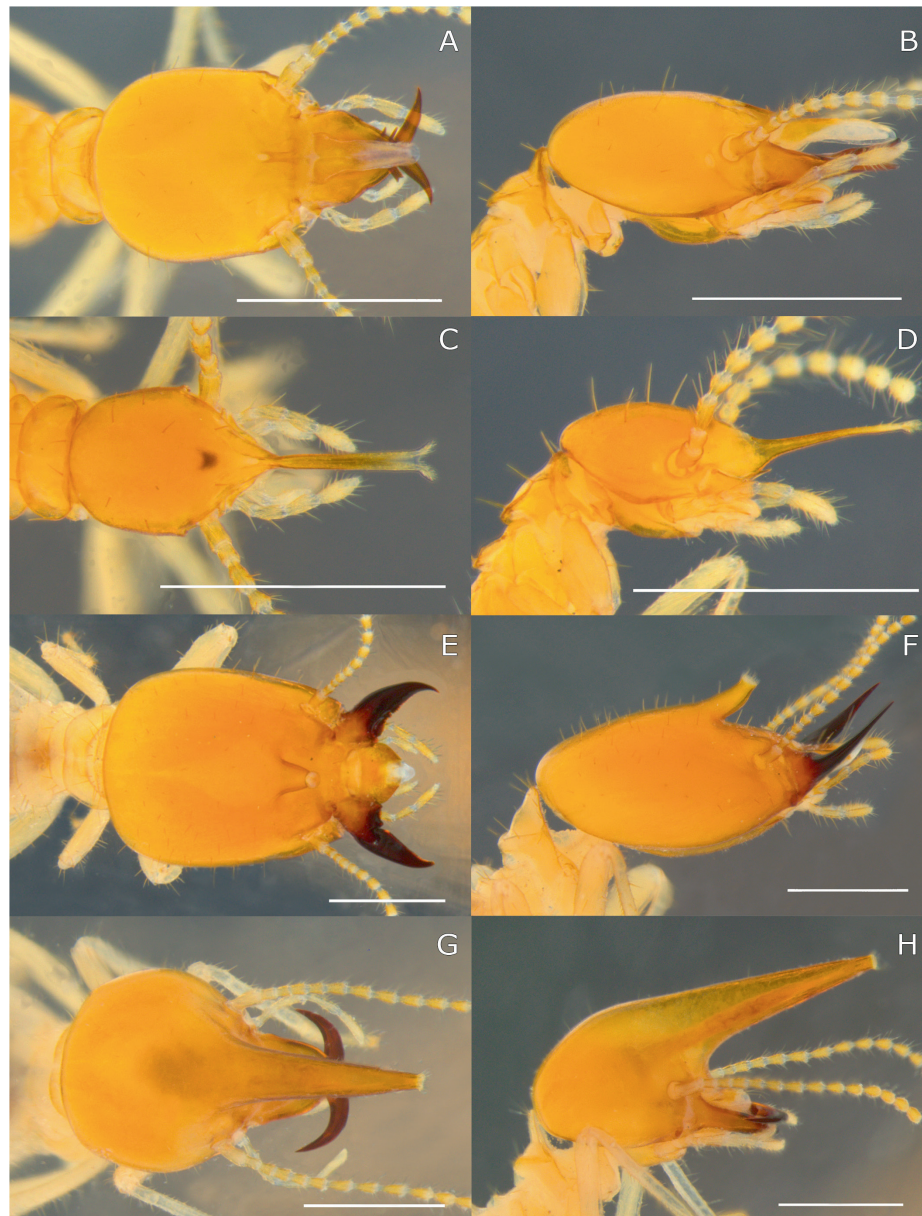


Figure 2. Soldiers of termite species with a new occurrence record for Brazil. *Dolichorhinotermes tenebrosus* major soldier (A, B); *Dolichorhinotermes tenebrosus* minor soldier (C, D); *Cornitermes bolivianus* (E, F); *Uncitermes almeriae* (G, H). Scale bar: 1 mm.

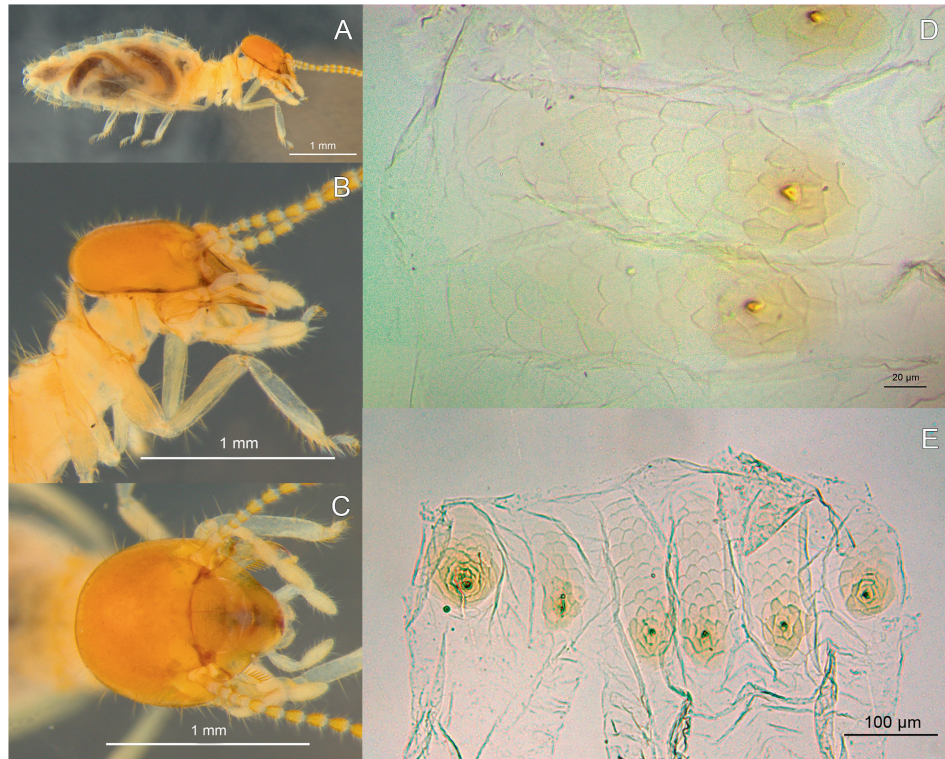


Figure 3. *Aparatermes thornatus* worker, new occurrence for Brazil. Lateral view of habitus (A); profile view, with lateral view of head and thorax (B); dorsal view of head (C); enteric valve in detail (D); complete view of enteric valve cushions (E).

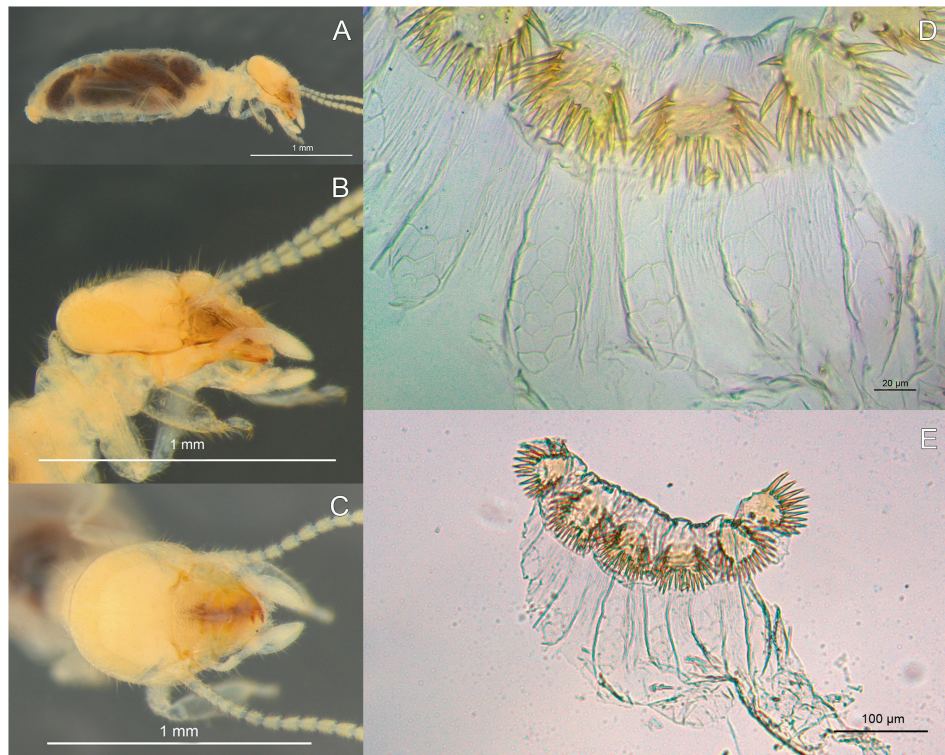


Figure 4. *Humutermes krishnai* worker, new occurrence for Brazil. Lateral view of habitus (A); profile view, with lateral view of head and thorax (B); dorsal view of head (C); enteric valve in detail (D); complete view of enteric valve cushions (E).

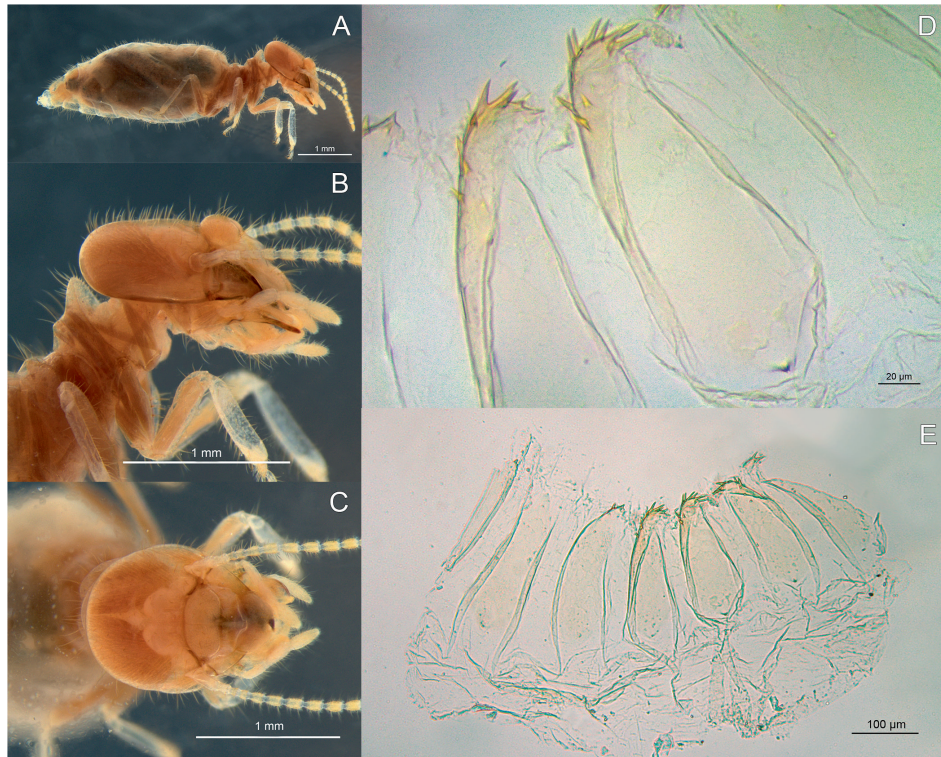


Figure 5. *Rubeotermes jheringi* worker, new occurrence for Brazil. Lateral view of habitus (A); profile view, with lateral view of head and thorax (B); dorsal view of head (C); enteric valve in detail (D); complete view of enteric valve cushions (E).

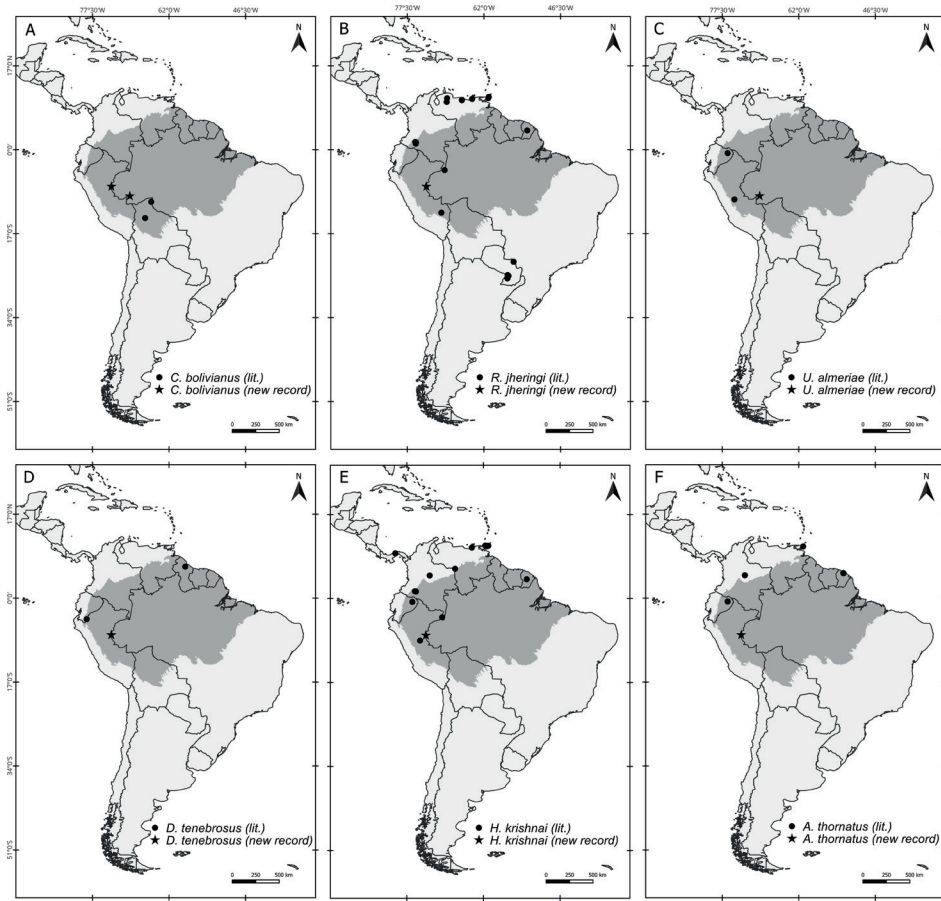


Figure 6. Location map of new records for Brazil of the species *Cornitermes bolivianus* (A), *Rubeotermes jheringi* (B), *Uncitermes almeriae* (C), *Dolichorhinotermes tenebrosus* (D), *Humitermes krishnai* (E), *Aparatermes thornatus* (F). Dark grey: Amazonia.

Table 1. List of termite species from the state of Acre, Brazil, and classification of feeding groups. Sampling locality: SDNP, Serra do Divisor National Park; CSP, Chandless State Park; HFR, Humaitá Forest Reserve; CMEP, Chico Mendes Environmental Park. Previously published records (Literature): 1, (Santos et al. 2022); 2, (Constantino 2022); 3, (Thomazini & Thomazini 2002); 4, (Santos 2022). FG, Feeding-Groups: FG1 (Plaza 2019): L, leaf-feeders; S, soil-feeders; I, inquiline; W/S, wood/soil interface feeders; W, wood-feeders. FG2: (Donovan et al. 2001). ¹Rapid termite inventory protocol (Canello et al. 2014). *New incident record for Brazil. ^{*}Species that build conspicuous nests according to literature records. ^{**}Species that were collected in conspicuous nests in this study.

Family/subfamily/species	Sampling locality				Literature	Feeding groups	
	SDNP	CSP	HFR	CMEP		FG1	FG2
KALOTERMITIDAE							
<i>Calcaritermes rioensis</i> Krishna, 1962		X ¹				W	I
<i>Calcaritermes</i> aff. <i>temnocephalus</i> (Silvestri, 1901)		X	X			W	I
<i>Eucryptotermes hagenii</i> (Müller, 1873)	X ¹					W	I
<i>Glyptotermes</i> sp.	X					W	I
<i>Rugitermes</i> sp.1		X ¹				W	I
<i>Rugitermes</i> sp.2		X ¹				W	I
RHINOTERMITIDAE							
<i>Coptotermes testaceus</i> (Linnaeus, 1758)	X ¹	X ¹	X		1;2	W	I
<i>Dolichorhinotermes longilabius</i> (Emerson, 1924)	X ¹	X ¹	X		2	W	I
<i>Dolichorhinotermes tenebrosus</i> (Emerson, 1925)*	X ¹					W	I
<i>Heterotermes tenuis</i> (Hagen, 1858)	X ¹	X ¹	X		2;3;4	W	I
<i>Rhinotermes hispidus</i> Emerson, 1925	X				2	W	I
<i>Rhinotermes marginalis</i> (Linnaeus, 1758)	X ¹	X ¹			2	W	I
SERRITERMITIDAE							
<i>Glossotermes sulcatus</i> Canello & DeSouza, 2005	X ¹					W	I
TERMITIDAE							
Apicotermatinae							
<i>Anoplotermes banksi</i> Emerson, 1925**	X ¹					S	III
<i>Anoplotermes meridianus</i> Emerson, 1925	X ¹	X ¹				S	III
<i>Anoplotermes</i> sp.1	X ¹	X ¹	X			S	III
<i>Anoplotermes</i> sp.2	X ¹					S	III
<i>Anoplotermes</i> aff. <i>pacificus</i> Müller, 1873	X ¹					S	III
<i>Anoplotermes susanae</i> Scheffrahn, Carrijo & Castro, 2023	X ¹					S	III
<i>Aparatermes silvestrii</i> (Emerson, 1925)		X		X		W/S	III
<i>Aparatermes thornatus</i> Pinzon & Scheffrahn, 2019*	X ¹					W/S	III
Apicotermatinae sp.1	X ¹					S	III
Apicotermatinae sp.2	X ¹	X ¹				S	III
Apicotermatinae sp.3	X ¹	X ¹				S	III
Apicotermatinae sp.4	X ¹	X ¹	X			S	III
Apicotermatinae sp.5		X ¹				S	III
Apicotermatinae sp.6	X ¹					S	III
Apicotermatinae sp.7	X ¹					S	III
Apicotermatinae sp.8	X ¹					S	III
Apicotermatinae sp.9	X ¹					S	III
Apicotermatinae sp.10		X ¹				S	III
Apicotermatinae sp.11	X ¹					S	III
Apicotermatinae sp.12		X				S	III
Apicotermatinae sp.13	X ¹	X ¹	X			S	III

Continue...

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Family/subfamily/species	Sampling locality				Literature	Feeding groups	
	SDNP	CSP	HFR	CMEP		FG1	FG2
Apicotermitinae sp.14		X ¹				S	III
Apicotermitinae sp.15		X ¹	X			S	III
<i>Compositermes vindai</i> Scheffrahn, 2013	X ¹				2	S	IV
<i>Disjunctitermes</i> aff. <i>insularis</i> Scheffrahn, 2017	X ¹					S	IV
<i>Disjunctitermes insularis</i> Scheffrahn, 2017	X					S	III
<i>Grigiotermes hageni</i> (Snyder & Emerson, 1949)					2	S	IV
<i>Hirsutitermes kanzakii</i> Scheffrahn, Carrijo & Castro, 2023	X					S	III
<i>Humutermes krishnai</i> Bourguignon & Roisin, 2016*	X ¹					S	IV
<i>Hydrecotermes kawaii</i> Bourguignon & Roisin, 2016	X ¹					S	III
<i>Krecekitermes daironi</i> Scheffrahn, Carrijo & Castro, 2023	X ¹					S	III
<i>Longustitermes manni</i> (Snyder, 1922)	X ¹					S	IV
<i>Mangolditermes curveileum</i> Scheffrahn, Carrijo & Castro, 2023	X ¹	X ¹				S	III
<i>Patawatermes nigripunctatus</i> (Emerson, 1925)	X	X				S	IV
<i>Patawatermes turricola</i> (Silvestri, 1901)	X ¹					S	IV
<i>Rubeotermes jheringi</i> (Holmgren, 1906)*	X ¹					S	IV
<i>Ruptitermes franciscoi</i> (Snyder, 1959)	X ¹					L	III
<i>Ruptitermes piliceps</i> Acioli & Constantino, 2015	X ¹	X ¹				L	III
<i>Ruptitermes</i> sp.	X ¹					L	III
<i>Rustitermes boteroi</i> Constantini, Castro & Scheffrahn, 2020	X ¹		X			W/S	III
Nasutitermitinae							
<i>Agnathotermes</i> aff. <i>crassinus</i> Constantino, 1990				X		S	IV
<i>Agnathotermes glaber</i> (Snyder, 1926)	X ¹					S	IV
<i>Atlantitermes oculatissimus</i> (Emerson, 1925)	X ¹					W/S	IV
<i>Atlantitermes osborni</i> (Emerson, 1925)		X ¹				W/S	IV
<i>Atlantitermes</i> sp.	X ¹					W/S	IV
<i>Coatitermes clevelandi</i> (Snyder, 1926)	X ¹	X				W/S	III
<i>Coatitermes kartaboensis</i> (Emerson, 1925)	X	X ¹				W/S	III
<i>Constrictotermes cavifrons</i> (Holmgren, 1910)**	X					W	II
<i>Convexitermes convexifrons</i> (Holmgren, 1906)	X	X ¹				W/S	III
<i>Diversitermes diversimiles</i> (Silvestri, 1901)		X				W	II
<i>Hyleotermes brevipilus</i> (Emerson, 1925)	X ¹					W	II
<i>Nasutitermes acangussu</i> Bandeira & Fontes, 1979*	X	X ¹			2	W	II
<i>Nasutitermes banksi</i> Emerson, 1925	X ¹					W	II
<i>Nasutitermes callimorphus</i> Mathews, 1977		X ¹	X			W	II
<i>Nasutitermes</i> cf. <i>bivalens</i> (Holmgren, 1910)	X	X ¹	X			W	II
<i>Nasutitermes</i> cf. <i>bolivari</i> (Snyder, 1959)		X ¹				W	II
<i>Nasutitermes chaquimayensis</i> (Holmgren, 1906)	X ¹					W	II
<i>Nasutitermes corniger</i> (Motschulsky, 1855)*		X ¹	X		1;2	W	II
<i>Nasutitermes ephratae</i> (Holmgren, 1910)**		X ¹				W	II

Continue...

...Continuation

Family/subfamily/species	Sampling locality				Literature	Feeding groups	
	SDNP	CSP	HFR	CMEP		FG1	FG2
<i>Nasutitermes guayanae</i> (Holmgren, 1910)**	X ¹	X ¹				W	II
<i>Nasutitermes longirostratus</i> (Holmgren, 1906)		X ¹	X			W	II
<i>Nasutitermes rotundatus</i> (Holmgren, 1906)		X ¹	X			W	II
<i>Nasutitermes</i> sp.	X ¹					W	II
<i>Nasutitermes surinamensis</i> (Holmgren, 1910)*	X ¹	X ¹				W	II
<i>Nasutitermes wheeleri</i> Emerson, 1925*		X				W	II
<i>Rotunditermes bragantinus</i> (Roonwal & Rathore, 1976)*	X					W	II
<i>Subulitermes</i> sp.			X			S	III
<i>Triangularitermes triangulariceps</i> Mathews, 1977	X ¹					S	III
<i>Velocitermes</i> sp.1	X ¹	X ¹				W	II
<i>Velocitermes</i> sp.2	X ¹	X ¹				W	II
<i>Velocitermes</i> sp.3			X			W	II
Syntermitinae							
<i>Armiterms</i> sp.					1	S	III
<i>Cornitermes bequaerti</i> Emerson, 1952**	X				2	L	II
<i>Cornitermes pugnax</i> Emerson, 1925*	X	X ¹	X			L	II
<i>Cornitermes bolivianus</i> Snyder, 1926*	X ¹	X ¹				L	II
<i>Cornitermes pilosus</i> Holmgren, 1906		X				L	II
<i>Curvitermes odontognathus</i> (Silvestri, 1901)				X		S	III
<i>Cyrellitermes angulariceps</i> (Mathews, 1977)	X ¹					S	III
<i>Embriatermes neotenicus</i> (Holmgren, 1906)**	X ¹	X				W/S	III
<i>Embriatermes</i> sp.	X ¹					S	III
<i>Labioitermes labralis</i> (Holmgren, 1906)*		X				S	IV
<i>Mapinguaritermes peruanus</i> (Holmgren, 1906)	X ¹					W/S	III
<i>Rhynchotermes amazonensis</i> Constantini & Canello, 2016	X ¹					L	II
<i>Silvestritermes heyeri</i> (Wasmann, 1915)*	X ¹	X				W/S	III
<i>Silvestritermes minutus</i> (Emerson, 1925)*	X ¹					W/S	III
<i>Synterms aculeosus</i> Emerson, 1945*	X ¹					L	II
<i>Synterms brevimalatus</i> Emerson, 1945	X ¹					L	II
<i>Synterms chaquimayensis</i> (Holmgren, 1906)*					2	L	II
<i>Synterms molestus</i> (Burmeister, 1839)	X ¹	X ¹				L	II
<i>Synterms spinosus</i> (Latreille, 1804)*		X				L	II
<i>Synterms</i> cf. <i>terratus</i> Emerson, 1924	X ¹					L	II
<i>Uncitermes almeriae</i> Carrizo, 2016*		X				W/S	III
<i>Uncitermes teevani</i> (Emerson, 1925)	X	X				W/S	III
<i>Vaninitermes ignotus</i> (Constantino, 1991)	X ¹					S	III
Termitinae							
<i>Cavitermes tuberosus</i> (Emerson, 1925)		X		X		S	III
<i>Cornicapritermes mucronatus</i> Emerson, 1950	X ¹					S	III
<i>Crepititermes verruculosus</i> (Emerson, 1925)	X ¹					S	III

Continue...

...Continuation

Family/subfamily/species	Sampling locality				Literature	Feeding groups	
	SDNP	CSP	HFR	CMEP		FG1	FG2
<i>Cylindrotermes flangiatus</i> Mathews, 1977	X ¹					W	II
<i>Cylindrotermes parvignathus</i> Emerson, 1949	X ¹					W	II
<i>Inquilinitermes</i> sp.					1	I	III
<i>Microcerotermes arboreus</i> Emerson, 1925*		X ¹				W	II
<i>Microcerotermes strunckii</i> (Sørensen, 1884)*	X ¹	X ¹	X		1	W	II
<i>Neocapritermes guyana</i> Krishna & Araujo, 1968	X ¹					W	III
<i>Neocapritermes pumilis</i> Constantino, 1991	X ¹				2	W	III
<i>Neocapritermes talpa</i> (Holmgren, 1906)		X ¹	X		2	W	III
<i>Neocapritermes talpoides</i> Krishna & Araujo, 1968	X ¹					W	III
<i>Neocapritermes utiariti</i> Krishna & Araujo, 1968		X				W	III
<i>Orthognathotermes</i> sp.1		X				S	IV
<i>Orthognathotermes</i> sp.2		X				S	IV
<i>Planicapritermes planiceps</i> (Emerson, 1925)	X ¹					W	III
<i>Spinitermes trispinosus</i> (Hagen, 1858)	X ¹					S	III
<i>Termes ayri</i> Bandeira & Cancellato, 1992	X ¹	X				S	III
<i>Termes fatalis</i> Linnaeus, 1758*		X				S	III
<i>Termes hispaniolae</i> (Banks, 1918)*		X ¹				S	III
<i>Termes medioculatus</i> Emerson, 1949**	X ¹	X ¹				S	III
Species Richness	89	62	19	4	16		

Discussion

Considering the data presented in this study, together with the species and morphospecies already published (Thomazini & Thomazini 2002, Constantino 2022, Santos 2022, Santos et al. 2022), there are a total of 128 species recorded for the Brazilian state of Acre, representing an increase of 112 new species now known in Acre. Six species are new records for Brazil, revealing that although much is already known about Brazilian biodiversity, improved sampling in even a few sites can contribute new records for Brazil, plus new taxa to science.

The geographic proximity of Acre state to other South American countries, such as Peru and Bolivia, means that species already known to occur in these countries may also occur in Brazilian territory, since the similar climatic conditions and the short distance between these countries can favor their dispersion (Tatem & Hay 2007, Seebens et al. 2013, 2015). An example of this is the species *Uncitermes almeriae* Carrijo, 2016 (Figure 2G, 2H), which was recorded here in Brazil for the first time but which was detected previously in Peru and Ecuador in 2016 (Carrijo et al. 2016). Faunal inventories, such as this one, can decrease gaps in sampling (*Wallacean shortfall*), improving information on the geographical distribution of taxa. They can also provide important taxonomic contributions, especially considering that, in the case of termites, the precise and correct identification of some taxa can be complicated, and specific groups have many species still undescribed (*Linnean shortfall*) (Hortal et al. 2015).

Although not a megadiverse insect group, termite taxonomy is relatively difficult. Considering the new vouchers found here for the state of Acre, 32 morphospecies are identified at the genus (17) and subfamily (15) levels. The subfamily Apicotermittinae has the largest number of morphotyped records, 18, including all morphospecies at the subfamily level. In many published termite species lists, the subfamily Apicotermittinae appears with notable taxonomic inaccuracies (Bandeira & Vasconcellos 2002, Bandeira et al. 2003, Vasconcellos 2010, Araújo et al. 2015, Couto et al. 2015, Silva et al. 2019). This problem is largely due to the absence of the soldier caste in Neotropical species of the subfamily Apicotermittinae, since this caste comprises the main morphological characters important for termite taxonomy (Carrijo et al. 2023). Identification in this subfamily is also difficult due to differences among workers of the same species, which can indicate intrapopulation variations (Bourguignon et al. 2016b). As a result, comparative analyses at the species level are not always possible, making it harder to carry out ecological studies for different assemblages using literature data (Dambros et al. 2017, Cerezer et al. 2020).

The pattern of species richness for sites sampled in this study roughly follows those found in other studies conducted in humid forests (Roisin et al. 2006, Jones & Eggleton 2011), where Termitidae has the highest species richness, with Apicotermittinae being the most species-rich subfamily within this family. Regarding feeding groups, a similar pattern to literature data is also observed, where the majority of

termite species feed on soil (42%) and wood (34%) (Davies et al. 2003, Ernesto et al. 2014, Silva et al. 2019, Castro et al. 2021b).

The higher species richness of soil-feeders is possibly related to soil type and use of sampling protocols that use time per area, which favors more soil sampling in search of termite colonies. In general, sandy soils provide little stability for building tunnels and underground nests by termites, disfavoring soil-feeders, which apparently prefer clayier soils (Lee & Wood 1971, Vasconcellos et al. 2005). Several other studies carried out in Amazonia also found a higher proportion of soil-feeder species (Davies 2002, Bourguignon et al. 2011). Termite soil-feeders tend to be more abundant and more evenly distributed in areas with denser forests because environmental conditions favor the development of more humus-rich soils (Davies et al. 2021). In other ecosystems in Brazil, there are records of higher species richness of wood-feeders, such as in the Caatinga and some locations in the Atlantic Forest (Vasconcellos 2010, Souza et al. 2012, Canello et al. 2014).

Regarding the presence of conspicuous nests, most nest-building species are widely distributed throughout the Amazon Rainforest (Constantino 1992, Palin et al. 2011, Dambros et al. 2012, Castro et al. 2021b). Termite nests, both active and abandoned, are part of the structure of tropical ecosystem and can serve as shelter and sites for predation and reproduction for various species of distinct functional groups, including other insect, arachnids, amphibians, reptiles, and birds (Cunha & Brandão 2001, Vasconcelos et al. 2015). Furthermore, the type (epigeal, arboreal, etc.) and density of nests, in addition to the composition of the building termite community, can provide relevant information about the levels of anthropogenic disturbance at local and regional scales (Vasconcellos et al. 2008).

This study provides an essential contribution to our knowledge of biodiversity in Acre and Brazil, even though only four areas were sampled, and only two of these using the rapid termite inventory protocol. Thus, in the case of the Amazon, which hosts the greatest species diversity on Earth (Flores et al. 2010), the number of species presented here is certainly less than the actual diversity. The Amazon hosts about 70% of all termite species known in Brazil (Constantino 2022), yet many species are still unknown in the Amazon. In addition to Serra do Divisor National Park, there are ten other federal protected areas in Acre, as well as state parks such as Chandless State Park and other smaller protected areas such as Humaitá Forest Reserve and Chico Mendes Environmental Park, which were sampled in this study. Conducting and expanding expeditions beyond these areas is essential for improving our knowledge of termite diversity in Acre and Brazil.

The urgent need for these studies is exemplified by the case of Serra do Divisor National Park, considered one of the most diverse areas in the world (Koga et al. 2022) but now threatened by a highway development to connect the municipalities of Cruzeiro do Sul, in Acre, and Pucallpa, in Peru, that would cross the park, causing irreparable environmental impacts (Koga et al. 2022). Limited species inventories have been conducted here for some groups, such as bats (Nogueira et al. 1999), but the biodiversity for SDNP is still notably undersampled in comparison to other areas of Acre that have been better covered by surveys for taxa including ants (Miranda et al. 2012), snakes (Silva et al. 2010, Bernarde et al. 2011), butterflies (Mielke et al. 2010), mammals (Botelho et al. 2012), scorpions (Lira et al. 2021) and dragonflies (Miranda Filho et al. 2022). New inventories contribute not only to

biodiversity knowledge for the area, but also influence conservation policies for protected areas.

The SDNP has a high rate of endemism (Souza et al. 2003, Almeida et al. 2022). One of the key factors that make this area special is the influence exerted by the Andes Mountains. Currently, through paleoclimatic modeling and molecular analyses, it is known that geomorphological and phylogenetic modifications in the Amazon occurred in parallel (Hoorn et al. 2010). The uplift of the Andes created an orographic barrier, altering the influence of moisture from the Pacific Ocean on the Amazon (Poulsen et al. 2010), and changes in the topography affected the direction of river flow within the Amazon basin (Costa et al. 1996, Figueiredo et al. 2009). All of these dynamics also influenced the composition of the soil in the region, with the soil in the western portion being much richer than that in the eastern portion (Quesada et al. 2010).

Among the nine existing state Conservation Units in Acre, CSP presents the highest known biodiversity, with 1,392 species including insects, reptiles, amphibians, birds, mammals, and plants, and this value is obviously underestimated (Lacerda et al. 2022). This study contributes to the knowledge of the park's biodiversity, adding to its preservation as a Conservation Unit, which provides important socio-environmental services such as protection of flora and fauna, an area for scientific research, significant for the development of environmental education activities, ecotourism, protection and maintenance of water sources, and the promotion of health and well-being for those who interact with the natural landscape (Lacerda et al. 2022).

The HFR and CMPEP areas, despite being smaller, encompass important diversity of animal and plant groups, having already been the subject of several studies (Pinheiro et al. 2015, Venâncio & Souza 2016, Lima et al. 2021). However, termites had not yet been sampled in these areas, given the importance of this work for the knowledge of biodiversity in these forest fragments. Being smaller and relatively closer to urban centers, these protected areas are excellent spaces for the development of environmental education activities, especially with children, since they are close to schools, making the fragments accessible didactic resources for the production of local environmental knowledge (Cerati & Lazarini 2009). Additionally, urban forest fragments, such as CMPEP, promote sociability by providing environments that stimulate physical exercise, reduce stress and attention deficit in adolescents and children, contributing to the improvement of the population's well-being by enhancing the city's environmental quality, regulating temperature and air humidity, protecting water bodies, reducing pollution, among many other benefits (Rosso et al. 2021).

Species inventories are important and have an impact on several areas of knowledge beyond taxonomy, being fundamental to compose ecological analyses (Wijas et al. 2022), for example. In this study, we have an increase of 128 species for one Brazilian state, plus six new records for the country. Because it harbors the greatest biodiversity on the planet (Vieira et al. 2005), it is crucial to know which species exist in the Amazon, so that new and rare species can be identified, helping to conserve entire ecosystems (Ngiam & Cheong 2016). Species inventories can help to understand the degree of threat that species face and as a consequence, guide conservation efforts and allocate resources more effectively to protect biodiversity, as many species may be at risk of extinction but not yet identified as threatened or endangered (Costello et al. 2013).

In addition, knowledge of the diversity of the Amazon can reveal the presence of bioindicator species (Rodríguez et al. 1998), contributing to the monitoring of environmental changes, such as habitat loss, climate change, as well as other factors that affect biodiversity.

Supplementary Material

The following online material is available for this article:

Figure S1 – Enteric valves of Apicotermitinae morphospecies presented in this article. Apicotermitinae sp.1 (A), Apicotermitinae sp.2 (B), Apicotermitinae sp.3 (C), Apicotermitinae sp.4 (D), Apicotermitinae sp.5 (E), Apicotermitinae sp.6 (F), Apicotermitinae sp.7 (G), Apicotermitinae sp.8 (H), Apicotermitinae sp.9 (I), Apicotermitinae sp.10 (J), Apicotermitinae sp.11 (K), Apicotermitinae sp.12 (L), Apicotermitinae sp.13 (M), Apicotermitinae sp.14 (N) and Apicotermitinae sp.15 (O).

Figure S2 – Enteric valves and junction S/P3 (only A) of Apicotermitinae species presented in this article. *Compositermes vindai* (A, B), *Longustitermes manni* (C), *Hirsutitermes kanzakii* (D), *Patawatermes turricola* (E), *Rustitermes boteroi* (F), *Mangolditermes curveileum* (G), *Aparatermes silvestrii* (H), *Anoplotermes banksi* (I), *Krecekitermes daironi* (J), *Anoplotermes susanae* (K), *Anoplotermes* aff. *pacificus* (L), *Anoplotermes meridianus* (M), *Disjunctitermes* aff. *insularis* (N), *Disjunctitermes insularis* (O), *Hydrecoetermes kawaii* (P) and *Patawatermes nigripunctatus* (Q).

Figure S3 – Enteric valves of *Anoplotermes* morphospecies presented in this article. *Anoplotermes* sp.1 (A) and *Anoplotermes* sp.2 (B).

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Author Contributions

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Renato Almeida de Azevedo: sampling; writing – original draft; writing – review & editing.

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Conflicts of Interest

The authors declares that they have no conflict of interest related to the publication of this manuscript.

Ethics

This study did not involve human beings and/or clinical trials that should be approved by one Institutional Committee.

Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

During the preparation of this work, the author(s) used ChatGPT-3.5, an AI language model developed by OpenAI, exclusively for the purpose of enhancing readability and language quality during the writing process. After using this AI tool, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

Data Availability

The datasets generated during and/or analyzed during the current study are available at: <https://doi.org/10.48331/scielodata.ENCMUK>.

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