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**ECOSYSTEMS**

# Richness and similarity of Passalidae (Coleoptera: Scarabaeoidea) from biological collections in the Brazilian Amazon

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**Abstract:** Scientific collections are important sources of information on biodiversity that can be useful for faunistic, taxonomic and phylogenetic studies. The aim of this study was to investigate the fauna of Passalidae deposited in the zoological collections in the States of the Brazilian Amazon. 14,652 Passalidae specimens are deposited in scientific collections, distributed in two subfamilies, 7 genera and 82 species. The species that had the highest number of deposited individuals were: *Passalus interstitialis*, *Passalus interruptus*, *Veturius transversus* and *Paxillus leachi*. Passalinae was the richest subfamily (n = 57) species, followed by Proculinae (n = 25). *Passalus* was the richest genus (n = 39) followed by *Veturius* (n = 21). The State of Amazonas was the richest (s = 67) followed by Pará (s = 45). The Instituto Nacional de Pesquisas da Amazônia was the institution with the highest number of deposited specimens. The species accumulation curve did not reach asymptote and Chao2 estimated 142 species more than the observed richness (s = 82 species). The richness of the bess beetle fauna from the Brazilian Amazon may be greater than recorded. The scientific collections provided quantitative and important data that allowed to determine a large fraction of the Amazon bess beetle fauna.

**Key words:** Biodiversity, saproxylophagous, Passalinae, Proculinae, database.

## INTRODUCTION

Among the greatest phytogeographic domains in the world, the Amazon is considered the largest tropical forest (Oliveira et al. 2017), sheltering a significant portion of biodiversity with different levels of richness (Vieira et al. 2018). The variability of fauna and flora species of different taxonomic groups in this region has been lost with deforestation, a consequence of anthropic spatial occupation that is one of the most predatory forms of land use (Yanai et al. 2015).

The biological collections are one of the bases of knowledge on biodiversity from anywhere, which are present in most research institutions around the world (Peixoto et al. 2016) and certifies the diversity and richness of a particular region (Pyke & Ehrlich 2010). To these collections be a potential scientific knowledge resource on biodiversity, minimal information is required (Albuquerque et al. 2010). This information is essential to compare data from different sources, biotic and abiotic, which surveys researches to model the distribution of species and make predictions about the spatial occupancy dynamics of the taxa as the environment changes (Zaher & Young 2003).

Among the terrestrial arthropods, some groups have important roles in the decomposition of forest litter and are considered bioindicators of environmental changes (Oliveira et al. 2014). In this context, the beetles of Passalidae family compose one group taxonomically well studied. These family roles directly on the decomposition of dead wood, assisting in nutrient recycling (Castillo & Reyes-Castillo 2003).

Passalidae beetles are associated with forest habits, mainly those with few variations of humidity and temperature (Fonseca & Reyes-Castillo 2004, Fonseca 2009). They are commonly found associated to fallen tree trunks, where it happens almost entire life cycle, takes place and individuals find food, shelter and microenvironmental conditions for breeding (Reyes-Castillo 2000). When breeding occurs, the Passalidae beetles present subsocial and parental cooperative behavior extended to adulthood (Schuster 2002).

Passalidae is considered a small group in terms of richness, comprising approximately 930 known species described (Boucher 2006), with only two subfamilies (Passalinae and Proculinae) occurring in the Neotropical region (Fonseca et al. 2011). Studies emphasizing the distribution of Passalidae from the Americas suggest that the number exceeds 330 species (Boucher 2006, Amat-García & Reyes-Castillo 2007, Jiménez-Ferbans & Amat-García 2010), where in Brazil over 100 species are recorded and for the Brazilian Amazon, approximately 60 of these (Fonseca & Reyes-Castillo 2004, Bevilaqua & Fonseca 2019).

In Brazil, the most recent works on Passalidae discussing diversity data and geographic distribution is concentrated to Southeast (Mattos & Mermudes 2013, 2014, 2015, 2016). From the Brazilian Amazon, only Mouzinho & Fonseca (1998) and Mouzinho et al. (2010) discussed diversity indices, while many others faunal studies have focused on geographic distribution (Fonseca 1989, 1990a, b, 1992, 1999, Fonseca & Reyes-Castillo 1994, Fonseca & Ribeiro 1993, Bührnheim & Aguiar 1995, Aguiar & Bührnheim 2011, Boucher et al. 2016, Bevilaqua & Fonseca 2019).

Faunal studies always improve scientific collections, being important sources of information on biodiversity, as well biogeographic records that consider the descriptive aspects, classification and phylogenetic of a particular ecosystem (França & Callisto 2007, Marinoni & Peixoto 2010). Thus, knowledge of the fauna of a region is essential to guide public policies and decision making (Scherer et al. 2015), especially for poorly studied groups in regions with unique diversity (Sarmento-Soares & Martins-Pinheiro 2014).

From this perspective, the aim of this study was to carry out a overview of the taxonomic determinations of Passalidae species deposited in zoological collections and research institutions based on which we investigate the Amazon bess beetle fauna, in order to explore its richness and similarity, in the States of Brazilian Amazon.

## MATERIALS AND METHODS

Data were collected through personal consultation in collections at Universidade Federal do Amazonas (UFAM), Instituto Nacional de Pesquisas da Amazônia (INPA), Museu Paraense Emílio Goeldi (MPEG), Museu de Zoologia da Universidade de São Paulo (MZUSP), Instituto Biológico de São Paulo (IBSP) and Museu Nacional do Rio de Janeiro (MNRJ) (Supplementary Material - Table SI). It was also decided to consult the national (*speciesLink*) and international (*Global Biodiversity Information Facility*) online databases and bibliographic searches of articles, dissertations and theses about Passalidae, in order to expand the most pertinent information for the Brazilian Amazon (Table SI).

In the collections visited, individuals of Passalidae deposited in dry way were examined, considering only those collected in the legal Brazilian Amazon. All adult specimens already identified by taxonomists who previously worked on this material were considered and from the information written on the labels attached to specimens with geographic references at least at the municipality level were used to prepare a Microsoft Excel® platform database.

From the database the species were organized into a list of species in increasing alphanumeric order for estimate abundance (Σ), mean ($\bar{x}$), standard deviation (σ) and relative frequency (Fr) of species recorded by State level (Table SII).

The "observed richness" (Sobs) was determined from the "number of species" registered (n) in each State (Table SII) and the estimated richness was analyzed through the "Chao2" estimator, which incorporates species that only appear in one sample or species that are shared in more than one sample (Chao et al. 2000), which calculates the incidence between the number of unique species (appearing only in one sample) and the number of duplicate species (which are shared at least in two samples) using the EstimateS version 9 program (Colwell et al. 2004, Colwell 2016), where also riches by States were compared by the species accumulation curve (ACE) (Gotelli 2009), from the number of species occurrence by State.

The "similarity" was analyzed through the Jaccard index (SJ), based on the number of common species environments (Jaccard 1901) and calculated using Past, version 3.23 (Hammer et al. 2019). This index ranges from 0 to 1 and the closer to one, the more similar are the sampled areas are (Krebs 1989, Legendre et al. 2005). The resulting similarity matrix was used for cluster analysis by the method of weighted arithmetic means (UPGMA) and creating a dendrogram (Sneath & Sokal 1973).

The study was carried out from March 2016 to December 2018. The map (Figure 1) was made with QGIS version 2.18, where the Brazilian Amazon is highlighted containing the States of Acre (AC), Amazonas (AM), Amapá (AP), Maranhão (MA) Mato Grosso (MT), Pará (PA), Rondônia (RO), Roraima (RR) and Tocantins (TO) and divided into areas of endemism following Silva et al. (2005) classification.

## RESULTS

### Characterization and species richness

There were 14,652 Passalidae specimens deposited in scientific collections (Tables SI and SII), distributed in two subfamilies, 7 genera and 82 species. Passalinae Leach 1815 was the subfamily with the largest number of species (n=57), comprising 76.58% of the total number of registered individuals, followed by Proculinae Kaup 1868 registered 25 species and 23.42% the number of individuals (Table SII).

*Passalus* Fabricius 1792 (n=39) was the richest genus, followed by *Veturius* Kaup 1871 (n=21), *Paxillus* (MacLeay 1819) (n=11), *Passipassalus* Fonseca & Reyes-Castillo 1993 (n=4), *Spasalus* Kaup 1869 and *Popilius* Kaup (n=3) species and *Verres* Kaup (n=1) (Table SII).

The species that had the highest numbers of specimens deposited were: *Passalus interstitialis* Eschshcoltz (2,546), *Passalus interruptus* (Linnaeus) (1,875), *Veturius transversus* (Dalman) (1,443), *Paxillus leachi* MacLeay (1,183), *Passalus punctiger* Lepeletier & Serville (1,013) and *Passalus convexus* Dalman (726). While *Passalus aduncus* Erichson, *Passalus barrus* Boucher & Reyes-Castillo 1991, *Passalus punctatostriatus* Percheron, *Paxillus uaupesensis* Mattos & Mermudes (2013) and *Veturius ecuadoris* Kuwert

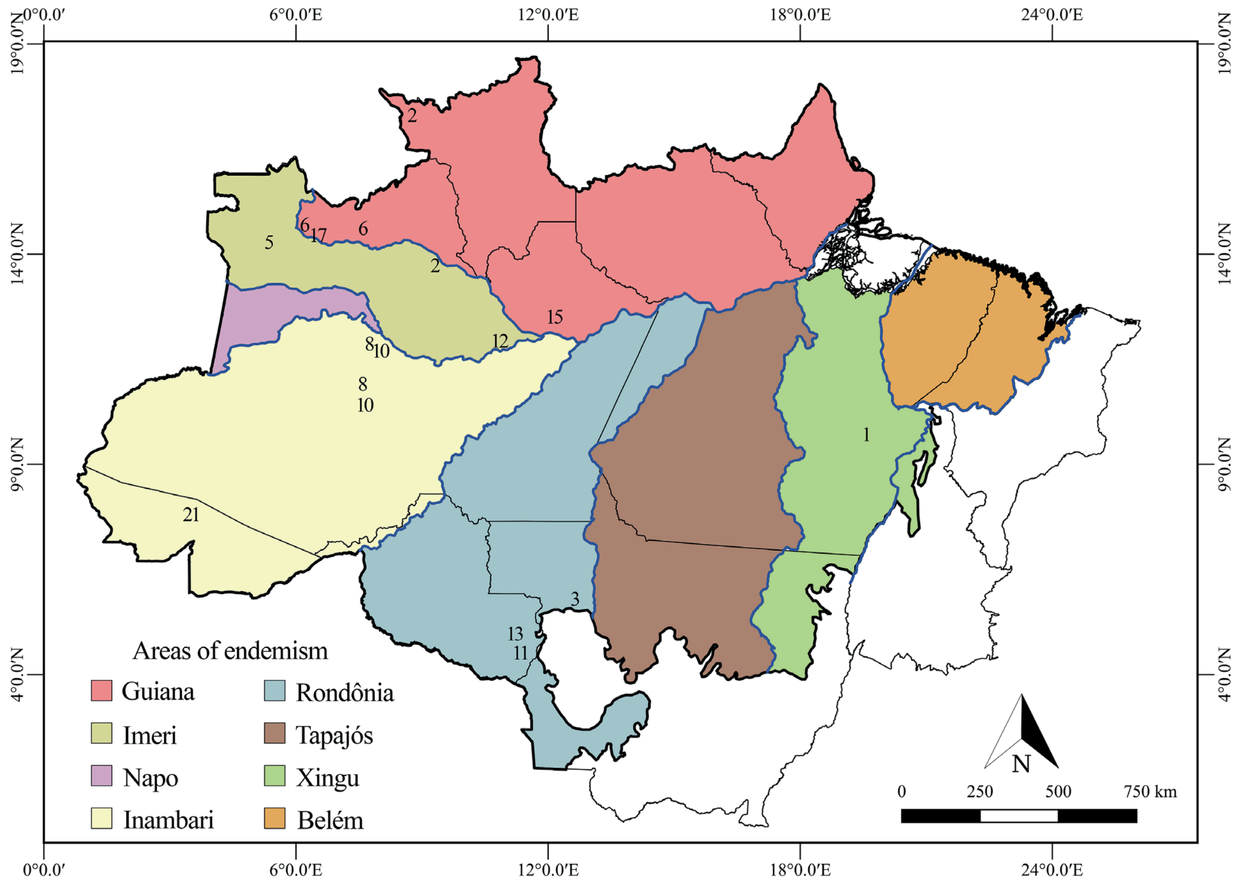


**Figure 1.** Brazilian Amazon map divided into areas of endemism according to Santos et al. (2005). Endemic species of the Brazilian Amazon bess beetles: 1. *Passalus carajaensis*, 2. *P. fustigatus*, 3. *P. hylaius*, 4. *P. neivai*, 5. *P. nodifer*, 6. *Passipassalus brevicornis*, 7 P. *buhrnheimi*, 8. *P. corniculatus*, 9. P. *macrocerus*, 10. *P. manauensis*, 11. *P. uaupesensis*, 12. *Spasalus aquinoi*, 13. *S. elianae*, 14. *Veturius lepidus*, (15) *V. magdalenae* and (16) *V. urucuensis*.

represent the lowest results this study (Table SII).

*Popilius marginatus* (Percheron), *Verres furcilabris* (Eschscholtz) and *Veturius sinuosus* (Drapiez), showed high occurrence in seven States. *Passalus punctiger* was the only recorded species with occurrence for all the States render this species the most representative of the Brazilian Amazon, representing 6.94% of the reviewed specimens (Table SII).

The calculation of the mean and standard deviation used to obtain the degree of dispersal and uniformity of the species showed that *Passalus interstitialis* ($\bar{x}$ = 282.89, σ ± 400.75) *Passalus interruptus* ($\bar{x}$ = 208.33, σ ± 244.15) *Veturius transversus* ($\bar{x}$ = 160.56, σ ± 183.65) *Paxillus leachi* ($\bar{x}$= 131.44, σ ± 177.12) and *Passalus punctiger* ($\bar{x}$ = 112.56, σ ±159.35) presented the highest values; while *Passalus aduncus*, *P. barrus*, *P. punctatostriatus*, *Paxillus uaupesensis* and *Veturius ecuadoris* presented the lowest results respectively ($\bar{x}$ = 0.11, σ ± 0.33 ) (Table SII).

The greatest "richness of species observed" for the States of AM (Sobs=67), PA (Sobs=45), AC and RR (Sobs=32), followed by RO (Sobs= 31) and MT (Sobs =27); while the AP (Sobs =21), MA (Sobs 12) and TO (Sobs =2) were the States with the lowest richness observed (Table SII).

The estimated richness obtained by the "Chao2" method indicates that up to 142 species

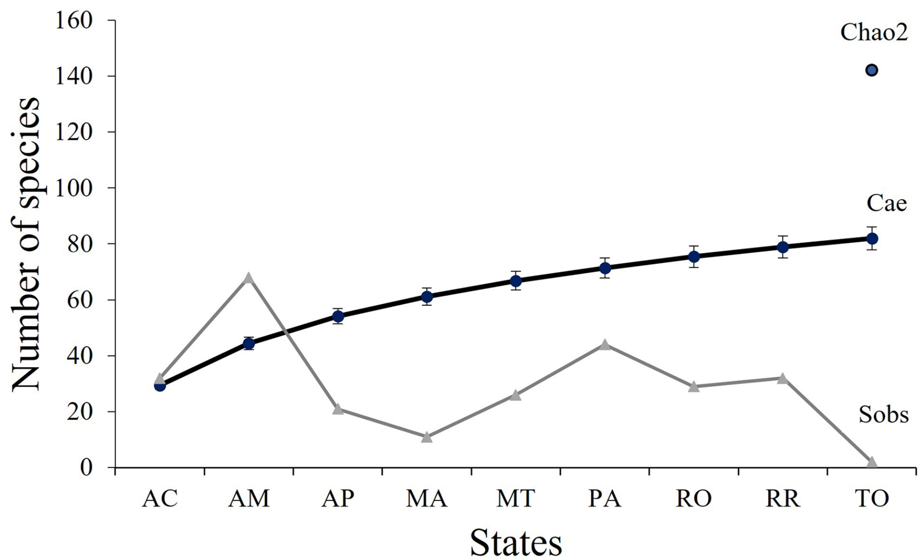


**Figure 2. Accumulation curve of species and number of the observed and estimated richness to Brazilian Amazon.**

of Passalidae could be found in the Brazilian Amazon. This result seems to be consistent when we related it to the total observed species richness (Sobs = 82) and compared it with the recorded species accumulation curve (Figure 2). The fact that the species accumulation curve did not reach an asymptote indicates that more sampling effort is needed in the study region to include more species. However, a substantial and significant part of the Passalidae species of the Legal Amazon is already deposited in the consulted collections and this represents 57.75% of the estimated richness.

The Instituto Nacional de Pesquisas da Amazônia was the institution with highest number of deposited specimens (n = 9, 542), followed by the Museu Paraense Emilio Goeldi (n = 2, 587), Museu de Zoologia da Universidade de São Paulo (n = 1, 235) and Universidade Federal do Amazonas (n = 1, 007). Among the international institutions consulted in online databases (*SpeciesLink* and *GBIF*) that have presented specimens of Passalidae collected from Brazilian Amazon we high light: Muséum National d'Histoire Naturelle (MNHN), (n= 38), Instituto de Ecología, Xalapa, México (INECOL), (n=31), Magyar Természettudományi Múzeum, Budapest, Hungria (MTMA), (n=13) and the American Museum of Natural History, New York, USA (AMNH), (n=10), (Table SI).

### *Species similarity*

In the analysis of the similarity, it was possible to distinguish three distinct groups. The first one is composed by the States of AM and PA (SJ= 0.6) in relation to AC (SJ =0.45); as well as the States of AP and RR are similar to each other (SJ = 0.59). MT and RO are closer (SJ = 0.45) than the other States. On the other hand, MA and TO showed low binding similarity (SJ> 0.3 and SJ>0.1 respectively) compared to all other States (Figure 3).

The AM and PA States registered 42 species shared among each other, the AC registered 23 species shared in relation to the States of AM and PA (Figure 4). The AP and RR States registered 19 species shared among each other, while MT and RO had 16 species. MA and TO shared only one species (*Passalus punctiger*) (Figure 4).

*Passalus barrus*, *P. occipitalis* Eschscholtz, *P. pubicostatus* (Kuwert), *Passipassalus brevicornis* (Jiménez-Ferbans et al. 2016), *P. corniculatus* (Fonseca et al. 2008), *Paxillus manauensis* (Mattos & Mermudes 2013), *P.*

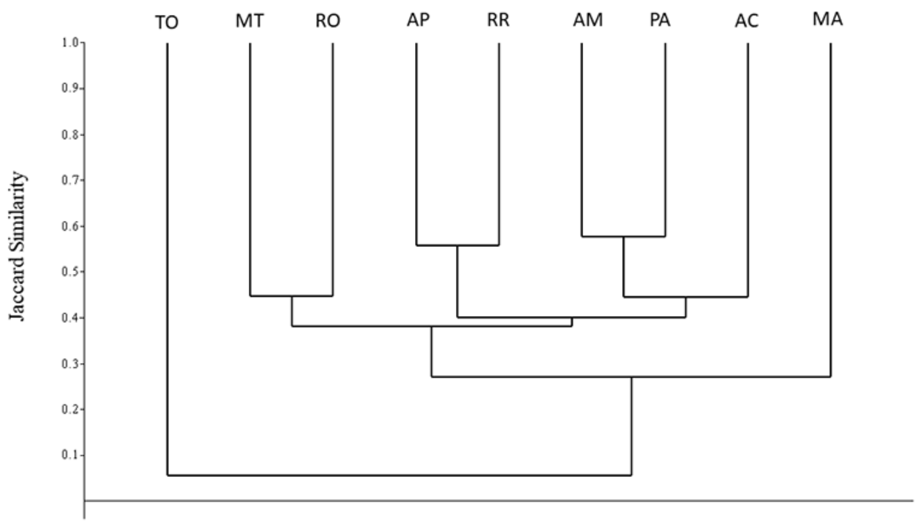


**Figure 3.** Similarity of Jaccard among the States of the Brazilian Amazon.

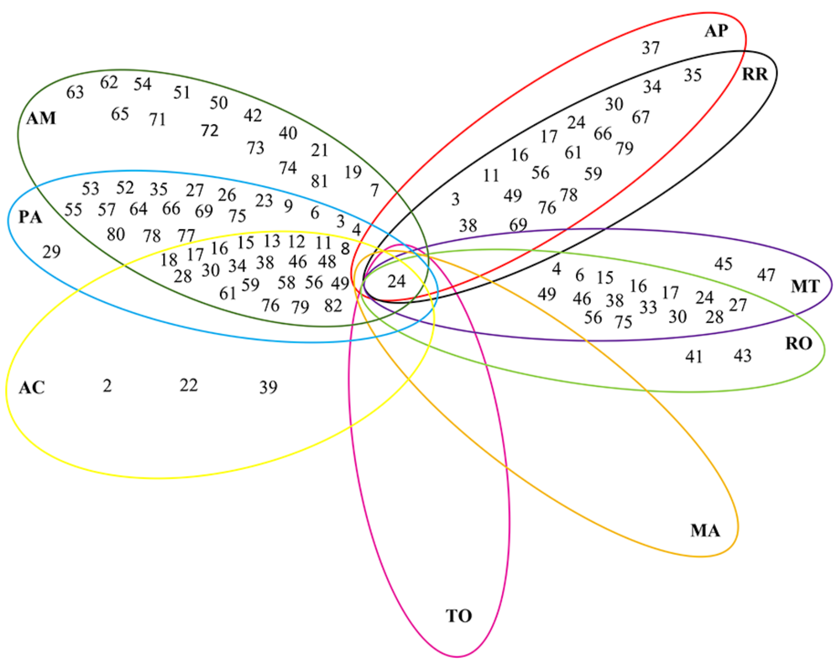


**Figure 4.** Venn Diagram produced from the shared and exclusive species of Passalidae among States in the Brazilian Amazon. The species numbers given in the dataset are represented in (n) of (Table SII).

*pentaphylloides* Luederwaldt, *P. uaupesensis* (Mattos & Mermudes 2013), *Popilius magdalenae* (Boucher 1987), *Veturius amazonicus* (Boucher 2006), *V. magdalenae* (Boucher 2006), *V. oberthuri* Doesburg, *V. christiani* (Boucher 1987), *V. ecuadoris*, *V. jolyi* (Boucher 2006), *V. lepidus* (Fonseca 1999), *V. urucuensis* (Boucher et al. 2016) were exclusive to the State of the AM; while the PA had only *Passalus carajaensis* (Fonseca & Reyes-Castillo 1994) as exclusive species (Figure 4).

*Passalus nodifer* Bevilaqua & Fonseca 2017, *P. pugionifer* (Kuwert) and *P. umbriensis* Hincks were exclusive to the State of AC and *Passalus punctatostriatus* to the AP. *Passipassalus bührnheim* Fonseca & Reyes-Castillo 1993 and *P. macrocerus* (Reyes-Castillo & Fonseca 1992) exclusive to RO and *Passalus aduncus*, *P. quadricollis* Eschscholtz, *P. hylaius* and *Paxillus* *borellii* Pangella to MT. The States of MA, RR and TO did not present any exclusive species (Figure 4).

## DISCUSSION

From the results obtained from the consulted collections, it was possible to note some relevant factors that deserve to be discussed, even if in a general framework, in order to raise issues that were not addressed yet when it comes to Amazon bess beetles.

### Diversity, colonization factors and dispersion capacity

Our results indicate that the Amazon forest has a high diversity of Passalidae compared to other Brazilian biomes. Amazon species represented here by 80.39% of the passalids known from Brazil, a higher percentage than that from Southeast region, that owns 42% of the species (Mattos & Mermudes 2015).

In this analysis, the most frequent genera were *Passalus* (64.86%), *Veturius* (17.59%) and *Paxillus* (9.79%) (Table SII), corroborating studies by, Fonseca (1988), Bührnheim & Aguiar (1991, 1995), Mouzinho & Fonseca (1998), Fonseca & Reyes-Castillo (2004), Jiménez-Ferbans & Amat-Garcia (2009), Aguiar & Bührnheim (2011), Jiménez-Ferbans et al. (2018) and Bevilaqua & Fonseca (2019). These genera occur from Mexico to Argentina (Hincks & Dibb 1935, Fonseca & Reyes-Castillo 2004), thus having a wide distribution, being insects that can support different reliefs and phytophysiognomies, variables that, according to Morrone (2006), can direct spatial occupations by taxa.

The wide distribution of these genera may be related with the high dispersion capacity achieved through flight (Bührnheim & Aguiar 1995) or the simple locomotion on the ground. The dispersion capacity favours strategies of reproduction and colonization of the species individuals (Fonseca 1981, 1988). Morphological characteristics such as size of prothorax and elytra allow inductions per flight as the dispersibility, since there is a relation between size of the elytra and prothorax with the flight range (Li et al. 2010), this relation may enable individuals to find new substrates easily (Reyes-Castillo 1970, Mouzinho & Fonseca 1998). These factors justify the high presence of *Passalus interstitialis*, *P. interruptus*, *P. punctiger*, *P. convexus*, *P. rhodocanthopoides*, *Paxillus leachi* and *Veturius transversus*, that are characterized by their large size (> 20 mm), increasing aggressiveness and strength to open of tunnels for nesting and reproduction (Fonseca 1988).

*Passalus* is considered to be less tolerant to temperature and humidity variations, therefore individuals of this genus prefer trunked tunnels with more stable climatic variables (Fonseca 1988). *Passalus* species have been found colonizing different trunks in various stages of degradation (Luederwaldt 1931, Fonseca & Reyes-Castillo 2004, Abreu et al. 2017), suggesting that some individuals are able to colonize several plant species, and this way, seem to be generalists regarding to their habitat. However, Alencar (2018), verified that *P. rhodocanthopoides* presents preferences for trunks of intermediate diameters (16–30 mm), while *P. abortivus* and *P. epiphanoides* for large diameter trunks (> 30 cm), when establishing colonies in xerophytic environments (sandy environments locally called *campina* and *campinarana*), possibly to compensate for external climatic variations. Therefore, *P. abortivus* and *P. epiphanoides* are considered habitat specialists.

For the genera *Veturius*, Boucher (2006) States that few species remain unknown, and that some old taxonomic identifications need to be reviewed. However, of the 86 species known for the Neotropical region (Salazar & Boucher 2018, Boucher & Salazar 2018), 21 were registered for the Brazilian Amazon deposited in the collections visited, with distributed in eight States, representing 17.59% of the total number of specimens deposited.

The occurrence of *Veturius platyrhinus* and *V. transversus* for Brazilian Amazon was questioned due to the taxonomic revision carried out by Boucher (2006), where it determined that *V. transversus* occurs only in the Caatinga, Cerrado and Atlantic Forest and *V. platyrhinus* in a region of Colombia. However, the taxonomic issue is not under discussion in the scope of this work, since the data that are on the labels of the specimens deposited in the collections are the ones that are under consideration. In the entomological collections of INPA, *Veturius transversus* is the species with the highest immature density collected (personal communication Dr. Claudio Ruy Fonseca); and in all collections consulted, adults of *Veturius cephalotes* (6 ± 40), *V. platyrhinus* (6 ± 82) and *V. transversus* (6 ± 184) were the species with the highest number of individuals and standard deviation. This dispersal index seems to indicate that these species have a high capacity to move to different places, as long as they find the environmental conditions and resources necessary for nesting and reproduction (Martins 2011); as an example, we quote the specie of *V. transversus* identified from the States of Mato Grosso and Tocantins (Boucher et al. 2016, Boucher & Salazar 2018), which justifies the probability that *V. transversus* and *V. platyrhinus* also can be found in other States of the Brazilian Amazon.

Of all the collections consulted, *Paxillus leachi* represents 8.07% of individuals, is one of the species with wide distribution in the Brazilian Amazon.

*Popilius* is distributed in Central and South Americas and can be found up to altitudes close to 1500 m, according to the literature (Jiménez-Ferbans & Amat-García 2009, Jiménez-Ferbans et al. 2018). In the collections studied *Popilius magdalenae*, *P. marginatus* and *P. tetraphyllus* drew attention for their representativeness (Σ = 654) occurring in regions with similar phytophysiognomic and phytogeographic characteristics. Especially *P. magdalenae* which was registered only for the Anavilhanas National Park (AM), which is an island region and suffers seasonal variation with water level (full and dry), characterized by high temperatures and abundant rainfall throughout the year (Scabin et al. 2012).

*P. marginatus* and *P. tetraphyllus* were widely distributed in the Brazilian Amazon, they are widely distributed in South America and considered typical of tropical moist forests (Reyes-Castillo 1973, Jiménez-Ferbans et al. 2013). For the Brazilian Amazon, *P. marginatus* and *P. tetraphyllus* were widely distributed in eight and five States respectively: in campinarana areas *P. tetraphyllus* preferentially exploring the soil-trunk regions (Alencar 2018).

### Similarity between States and areas of endemism

The similarity between the States of MA and TO (Figure 3) may be influenced by the low number of collect. Collections with low number of deposited specimens or without taxonomic identification, as indicated by Silveira et al. (2010) in a study of what the inventories are for. This lack of information impedes the knowledge of the spatial distribution in regions with diverse phytophysiognomies, such as transitional forests where coconut, mangrove and Cerrado forests appear in the State of MA (Lima & Almeida Jr 2018), besides remnants of

Atlantic forest, Cerrado and Pantanal that occur in TO (Lemos 2017).

On the other hand, the high similarity between AM and PA States may be associated to the collection effort, as well as to the AC, AP and RR States. This effect is determined by the presence of large research institutions in these regions (Panzu 2015), in addition to scientific cooperation, which permitted taxonomic works in collaboration with other States (Toni & Velho 1996, Vanz & Stumpf 2010). On the other hand, the similarity between MT and RO States tends to be influenced by sampling, but also related to the transitional environment from the Amazon forest to the Cerrado and more recently by anthropogenic activities by the primary sector, represented by livestock rearing and cultivation of soybeans that advance in land use from the Center-West to the North (Yanai et al. 2015, Pontes et al. 2016). Therefore, due to deforestation, there is more substrata supply and in these condition, generalist species tend to have higher density (Lanuza-Garay & Vargas-Cusatti 2011), as is the case of *Passalus interstitialis*, *P. interruptus*, *P. punctiger* and *Paxillus leachi*.

The fact that some species of passalids are exclusive to the States of AC, AP, AM, RO and MT allows us to consider the assumptions made by Reyes-Castillo et al. (2005), who studied the parsimony of endemism in the Amazon region and considered that the distribution of organisms is related to the complexity of the river network; fact related to the geological dynamics that formed the drainage network of the Amazon basin (Igreja 2012).

Since 1852, Wallace and other researchers are noting that rivers serve as a barrier to the distribution of birds, primates and insects. Haffer (1969) attempts to explain the origin of diversity and distribution with the Refugia Hypothesis, where open areas would have expanded and, with drier climate, small areas of forest would have become refugia of the diversity of species. In the same way that Tuomisto & Poulsen (1996) studied the influence of soil specialization on the distribution of pteridophytes, they concluded that edaphic characteristics and vegetation type are geological units that cause specialization by natural selection. For Silva et al. (2005) the Amazon is divided by large rivers and there are eight large areas of endemism: Guyana (interfluve between the Amazon and Negro Rivers), Imeri (Negro and Solimões), Napo (Napo and Solimões), Inambari (Madeira and Solimões), Rondônia (Madeira and Tapajós), Tapajós (Tapajós and Xingu), Xingu (Tocantins and Xingu) and Belém (basin between the Amazon and Tocantins Rivers), each with its own biota and evolutionary relationships, sheltering a set of unique and irreplaceable species, fact already observed by Igreja (2012).

Several studies have reinforced this hypothesis that the Amazonian rivers represent separate units and with unique selection pressures, a fact that makes these interfluves important areas of endemism. Authors as Patton et al. (2000) (Mammals), Reyes-Castillo et al. (2005) (Coleoptera), Silva et al. (2005) (Primates, Butterflies, Birds and Small mammals), Juen (2011) (Odonata), Dornas et al. (2012) (Birds), Oliveira et al. (2015) (Bees, Ants and Wasps), De Paiva (2017) (Trichoptera) and Ovalle (2016) (Birds), have demonstrated that the interfluvials correspond to geological units with endemisms, which must be considered when it is intended to explain spatial occupation exhibited by Amazonian taxa.

Following this proposal, it was possible to identify the species *Passalus carajaensis*, *P. fustigatus*, *P. hylaius*, *P. neivai*, *P. nodifer*, *Passipassalus brevicornis*, *P. bührnheimi*, *P. corniculatus*, *P. macrocerus*, *P. manauensis*, *P. uaupesensis, Spasalus aquinoi, S. elianae*, *Veturius lepidus*, *V. magdalenae* and *V. urucuensis*as endemic to the Brazilian Amazon. And that the Inambari interflow is the most diverse region in number of endemic species (Figure 1).

Inambari sheltered the species *Passalus neivai*, *P. nodifer*, *Passipassalus brevicornis* and *Veturius urucuensis*, whereas Imeri sheltered *Passipassalus corniculatus*, *Spasalus elianae* and *Veturius lepidus*. The Guyana interfluvial had *Passalus fustigatus*, *Paxillus manauensis* and *P. uaupesensis*, while the Rondônia interfluvial sheltered *Passipassalus bührnheimi* and *P. macrocerus* and Xingu sheltered only *Passalus carajaensis* exclusevely.

The main reason of the diversity of species in the regions of the Amazon and Negro Rivers (Guyana), Madeira and Solimões (Inambari) is mentioned by Menin (2007) in his study on the biological diversity and geological history of the Amazon. In this research, the author exposed that it is necessary to consider the influence of the events occurred over time in the terrestrial formation of these regions to understand the evolution of the environments and relate it to the dynamics of the Amazon Basin. For Antonelli et al. (2009) the formation of the Andes influenced strong climatic changes with the increase of the precipitation that caused changes in the drainage system of the rivers with the sediment transport. While Filizola & Guyot (2011) also consider that fragmentation of the Amazon forest was caused by the sediment drainage, being responsible for the diversity of soils that influenced the spatial occupation of the taxa.

From these considerations, we ponder that species diversity in the Brazilian Amazon may be associated with geological events that to the west are still active (Igreja 2012). Therefore, the movement of tectonic plates may have driven speciation in the Amazon basin (Szatmari et al. 2018). The force derived from the friction between the Nazca and the Caribbean plates had caused a twist in the South American plate, what created fractures in the Amazonian craton. These fractures formed the crevices through which the great rivers have become geological units with different selection pressures, giving interfluves a particular fauna and flora (Anelli 2016).

## Biological collections and reliability in taxonomic determinations

Researchers have been collecting and accumulating biological specimens even before the advent of naturalists of the centuries XVIII e XIX, being the Muséum National d'Histoire Naturelle, established in Paris in 1635, the first museum that would now be recognized as a museum of natural history (Nishida 2009). Such museums and biological collections are undoubtedly the major repositories of scientific knowledge, and the processing of this material allows the extraction of important information about the biota of a certain region (Peixoto et al. 2016). However, the storage of this material without taxonomic commitment may lead to insufficient or misleading data.

Our results confirm that the species most represented in the collections analyzed are the same considered common for the Neotropical region (Fonseca & Reyes-Castillo 2004, Fonseca 2009, Mattos & Mermudes 2015, Bevilaqua & Fonseca 2019). However, less frequent species that may be interpreted as rare may reflect the low sample sufficiency or biological material that may be taxonomic misidentified and have inaccurate geographic information. In addition, we can cite the few number of specialists instead of the rarity of the species itself (Di Domenico et al. 2016).

The collections of INPA, MPEG, MZUSP and UFAM presented the highest richness of passalid species, probably because there're scientists interested in the group in these institutions (Fonseca & Reyes-Castillo 1993, Panzu 2015). Also, scientific cooperations among them allowed works of taxonomic of the group in partnership (Toni & Velho 1996, Vanz & Stumpf 2010). However, this richness must be carefully considered because it evidences the sampling effort. On the other hand, some regions have not yet received taxonomic attention, where sample collections are deposited without taxonomic information (De Marco & Vianna 2005). States such as the AP, MA and TO, that have diverse ecosystems, are practically unstudied by researchers, as well as the northeast and center-west region of the country.

Unfortunately, some national and international biological collections that have deposited Passalidae specimen did not provided lists of species or lend material for our identification. The lack of access to these collections prevents data to be widely studied and disseminated, not contributing to the establishment of strategies for selecting priority areas for conservation. The scientific exchange between institutions is part of the text of the Convention on Biological Diversity (CBD), an event that tried to accord the integration of technical knowledge and research (Peixoto et al. 2016). Despite of this, the taxonomic identification had been made through individual effort of researchers interested in the target groups and not as a result of an institutional integration policy data (Ronsom & Amaral 2017). Camargo et al. (2015) considered that each curator is responsible for evaluating and state collection policy, involving exchanges, loans, donations and interaction with other institutions. In this way, it is necessary to provide resources to the curators and staff in order to have a regular exchange of materials not identified by specialists. It is also important to note that taxonomic determinations are susceptible to errors and or disagreements regarding the research line of each researcher. As an example, species belonging to *Veturius* and *Passalus* can be interpreted in different ways, which motivated us to preserve the data from the specimens collections labels and thus motivate researchers to know the collections o in order to question, corroborate or even increase the taxonomic knowledge of the species deposited.

**Conservation Implications**

In order to minimize the impacts of the degradation of natural resources and protection of the regions with relevant characteristics, the government created an alternative to the Conservation Units (UCs) (Cunha et al. 2017). Of the 742 UCs of total protection recognized in the country, the Amazon has 89 registered ones. This number is considered low when compared to the current rates of deforestation that has been occurring in the region, reaching a loss of 7,900 km² of forests in 2018 (Brasil 2019).

Deforestation is one of the greatest obstacles to understand biodiversity, as it generates a number of negative impacts ranging from the degradation of soil, lakes, river landings to temperature changes (Fearnside 2010).

The biological collections are important because they can contribute with the knowledge of the taxonomic diversity, since they facilitate faunistic studies and favor conservation programs and environmental education (Marinoni & Peixoto 2010). Information obtained from specimens collected, identified, and deposited in collections, are relevant to understand the overview of diversity, as well as allowing the systematization of data to visualize scenarios that may indicate actions of exploitation and/or preservation of biological richness (Barros 2014). It is essential to observe priorities such as: encouragement of public and private collections, incentives to research and scientific expeditions, training of taxonomists and computerization of data. It is evident that not only areas lacking in information should be considered as priorities, but also areas that have characteristics of regeneration, management and sustainable use.

The organization of collection data is also crucial for generating species distribution models, as well as creating a solid foundation for decision-makers in the choices to focus efforts (Iwashita 2008). Currently, few invertebrate groups have reasonably complete databases, so that priority areas have been chosen based on mammal and bird data primarily, and sometimes with information on reptiles and amphibians (De Marco & Vianna 2005). This information should be constantly updated in digital repositories such as *SpeciesLink* and *GBIF* which provides data on the collections of the main world collections, enabling research and knowledge of biodiversity.

Fearnside (2018) points out that, in the foreseeable future, the global and national environmental problems caused by the loss of the Amazon Forest tend to increase, leading species to extinction before they are even scientifically described. Unfortunately, we believe that this reality is already a fact for some species of passalids collected in regions with high rates of deforestation, such as those occurring in the AC, PA, MT e RO, considering that Passalidae species live within decomposing logs, there is no call for preservation as for other biodiversity groups. However, this group of insects provides essential environmental services, recycling dead wood and identifying points where species richness is high becomes important for conservation politics.

De Marco & Vianna (2005) also points that it is important to consider areas described as lacking in data as those that may be considered priority in future surveys, once they may be the richest areas of the country. It can be evidenced by Passalidae studies in poorly known areas, as showed by Jiménez-Ferbans et al. (2018) and Bevilaqua & Fonseca (2019). Therefore, we expect to inspire new studies on the fauna composition based on collections data to increase knowledge publication and information exchange among researchers interested in certain national and international collections.

The richness of the Passalidae from the Brazilian Amazon deposited in collections was high and determined where the most abundant and similar species are concentrated, where the most probable reason for this are the sample effort and the difference of sampling focus among the States. The richness of species recorded in the collections seems to represent the taxonomic reality of the region and that species as *Passalus interstitialis, Passalus interruptus, Paxillus leachi, Veturius transversus, Passalus punctiger*, *Popilius marginatus* and *Verres furcilabris* may be considered representative of the Amazonian passalid fauna, with high probabilities of being found in any coordinate that limits its territory. From our observations, it was possible to found that there is still a need for data collection since the Amazon has areas with difficult access away from the large urban centers, that are not sampled. Also, the lack of information for these regions is a limiting factor in the understanding endemism. Finally, this study shows a diagnosis of the species richness of the Amazon passalids and the importance of analyzing with from biological collections, but also points the necessity to provide means to the curators and technical staff to provide regular exchange of materials not identified by specialists.

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## SUPPLEMENTARY MATERIAL

**Table SI. Zoological Institutions where the registered copies are deposited: 1. American Museum of Natural History, New York, USA (AMNH); 2. Vladislav Malý collection, Praha, Czech Republic (VMCP), 3. Coleção Entomológica do Instituto Oswaldo Cruz, Rio de Janeiro, Brazil (CEIOC); 4. Senckenberg Museum of Natural History, Frankfurt, Germany (FISF); 5. Field Museum of Natural History, Chicago, USA (FMNH); 6. Florida State Arthropod Collection, Florida, USA (FSCA); 7. Instituto Biológico de São Paulo, São Paulo, Brazil (IBSP); 8. Instituto de Ecología, Xalapa, Mexico (IEXA); 9. Instituto Nacional de Pesquisas da Amazônia, Manaus, Brazil (INPA); 10. Royal Belgian Institute of Natural Sciences, Bruxelles, Belgium (IRSN); 11. Department of Agricultural Zoology, Zagreb, Croatia (IZAM); 12. Canadian Museum of Nature, Ottawa, Canada (MCNO); 13. Entomological Museum, Leon, Nicaragua (MELN); 14. Museum of Natural History of Basel, Basel, Switzerland (MHNB); 15. Natural History Museum of Geneva, Geneva, Switzerland (MHNG); 16. Natural History Museum Berlin, Berlin, Germany (MNHB); 17. National Museum of Natural History of France, Paris, France (MNHN); 18. Museu Nacional do Rio de Janeiro, Rio de Janeiro, Brazil (MNRJ); 19. Museu Paraense Emílio Goeldi, Belém, Brazil (MPEG); 20. Civic Museum of Natural History Giacomo Doria, Genoa, Italy (MSNG); 21. Magyar Természettudományi Múzeum, Budapest, Hungria (MTMA); 22. Historical Museum of the University of Manchester, Manchester, England (MMUE); 23. Museu de Zoologia da Universidade de São Paulo, São Paulo, Brazil (MZUSP); 24. Swedish Museum of Natural History, Stockholm, Suécia (NHRS); 25. State Museum of Zoology Dresden, Germany (SMTD), 26. Universidade Federal do Amazonas, Manaus, Brazil (UFAM); 27. Universidade Federal do Paraná, Curitiba, Brazil (UFPR); 28. University of Minnesota Insect Collection, Saint Paul, USA (UMSP); 29. Cambridge University Museum of Zoology, Cambridge, England (UMZC); 30. Universidade de Campinas, Campinas, Brazil (UNICAMP); 31 Smithsonian Institution, Washington, USA (USNM); 32. Utah State University, Logan, USA (USU); 33. Institute of Zoology, University of Hamburg, Germany (ZINH) and 34. Bavarian State Collection of Zoology, Munique, Germany (ZSM).**

**Table SII.** **List of Passalidae species recorded in biological collections with references to the States that compose the Brazilian Amazon, with the respective averages (X), standard deviation (6) and individual relative frequency (FR%) by species, where: (Acre = AC, Amazonas = AM, Amapá = AP, Maranhão = MA, Mato Grosso = MT, Pará = PA, Rondônia = RO, Roraima = RR and Tocantins = TO).**

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## Author contributions

E.G.B. Kubatamaia planned and executed the Project, collect data, analyzed and wrote the article. C.R.V. Fonseca, M.V.O. Bevilaqua and F.O.G. Figueiredo reviewed the manuscript for publication.