UNIVERSIDADE FEDERAL DO ESPÍRITO SANTO
CENTRO DE CIÊNCIAS HUMANAS E NATURAIS
PROGRAMA DE PÓS-GRADUAÇÃO EM CIÊNCIAS BIOLÓGICAS

VICTOR VALE

INFLUÊNCIA DA ALTITUDE NA DISTRIBUIÇÃO DE PEQUENOS MAMÍFEROS NÃO-VOADORES

VITÓRIA
2024

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INFLUÊNCIA DA ALTITUDE NA DISTRIBUIÇÃO DE PEQUENOS MAMÍFEROS NÃO-VOADORES

Tese submetida ao Programa de Pós-Graduação em Ciências Biológicas (Biologia Animal) da Universidade Federal do Espírito Santo como requisito parcial para obtenção do grau de Doutora em Biologia Animal.
Orientador: Prof. Dra. Leonora Pires Costa

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ATA DE DEFESA DE TESE DO CURSO DE DOUTORADO EM BIOLOGIA ANIMAL DO PROGRAMA DE PÓS-GRADUAÇÃO EM CIÊNCIAS BIOLÓGICAS DO CENTRO DE CIÊNCIAS HUMANAS E NATURAIS DA UNIVERSIDADE FEDERAL DO ESPÍRITO SANTO - ATA Nº 72 – 27/02/2024.

Em sessão pública ocorrida no dia 27 de fevereiro de 2024, através de webconferência, conforme previsto na Portaria Normativa nº 08, da Pró-Reitoria de Pesquisa e Pós-Graduação/UFES de 01 de julho de 2021, procedeu-se a avaliação da tese do aluno **Victor Vale**. Às treze horas, a Profª Drª Leonora Pires Costa, Orientadora e Presidente da Comissão Examinadora de Defesa de Tese, deu início aos trabalhos, convidando a tomar assento à mesa o Prof. Dr. Alan Gerhardt Braz Magalhães (INMA), a Profª Drª Cibele Rodrigues Bonvicino (UFES), o Prof. Dr. Carlos Eduardo de Viveiros Grelle (UFRJ) e a Profª Drª Roberta Paresque (UFES). A seguir, a presidente solicitou ao doutorando que fizesse uma explanação de seu trabalho intitulado **“INFLUÊNCIA DA ALTITUDE NA DISTRIBUIÇÃO DE PEQUENOS MAMÍFEROS NÃO-VOADORES”.** Finda a apresentação, a presidente passou a palavra aos examinadores, que procederam a arguição do candidato. Ao final, a Comissão, em sessão reservada, deliberou pela **APROVAÇÃO** da referida tese nos termos do Regimento Interno do Programa de Pós-Graduação em Ciências Biológicas e alertou que o aprovado somente terá direito ao título de Doutor após a entrega da versão final de sua tese, em meio digital, à Secretaria do Programa. Encerrada a sessão, eu, Profª Drª Leonora Pires Costa, presidente da Comissão Examinadora, lavrei a presente ata que vai com as devidas assinaturas.

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PROGRAMA DE PÓS-GRADUAÇÃO EM CIÊNCIAS BIOLÓGICAS
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CERTIFICADO DE APROVAÇÃO

Título: “Influência Da Altitude Na Distribuição De Pequenos Mamíferos Não-Voadores”

AUTOR: VICTOR VALE
ORIENTADOS: LEONORA PIRES COSTA

Aprovado como parte das exigências para a obtenção do título de DOUTOR EM BIOLOGIA ANIMAL, ÁREA DE CONCENTRAÇÃO EM BIOLOGIA ANIMAL, pela comissão examinadora.

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Dr. Calos Eduardo de Viveiros Grelle
Membro externo

“A descrição do mundo e a história do mundo estão
em um mesmo nível da empiria”.
(von Humboldt, 1855)

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SUMÁRIO

Sumário

ÍNDICE DE TABELAS:

Capítulo 1:

Capítulo 2:

Capítulo 3:

Capítulo 4:

ÍNDICE DE FIGURAS:

Apresentação:

Capítulo 1:

Capítulo 2:

Capítulo 3:

Capítulo 4:

Considerações finais:

ÍNDICE DE ANEXOS:

Capítulo 1:

Capítulo 1:

Capítulo 3:

Capítulo 4:

RESUMO

Regiões montanhosas exibem uma notável diversidade de pequenos mamíferos não-voadores, com a altitude associada a montanhas desempenhando um papel fundamental e uma abordagem multiciplinar humboldtiana é ideal para entender esses fatores. Na Mata Atlântica, a diversidade é mais pronunciada em altitudes intermediárias, com um padrão conhecido como efeito de domínio médio na biogeografia. Didelphiomorpha e Rodentia ocupam faixas altitudinais distintas, refletindo substituições e sobreposições de espécies ao longo do gradiente altitudinal. Gêneros como *Akodon* e *Delomys* apresentam respostas distintas à altitude. *Akodon* exibe variação de espécies relacionada à competição, enquanto *Delomys altimontanus* é restrita a picos de altitude, indicando refúgios específicos em regiões montanhosas. Mudanças tectônicas e climáticas no final do Neógeno influenciaram a especiação em *Trinomys*. Considerando uma área montanhosa em particular, a Serra do Caparaó destaca-se com 27 espécies de pequenos mamíferos não-voadores, sendo um centro de diversidade na Mata Atlântica. A riqueza e a abundância variam com a altitude, revelando padrões divergentes. Paisagens como floresta ombrófila densa montana, floresta ombrófila densa altimontana e campos de altitude contribuem para essa diversidade. Pressões antrópicas afetam a riqueza e a diversidade de áreas de conservação, como o Parque Estadual Mata das Flores (PEMF) e o Parque Estadual Forno Grande (PEFG). PEMF, com maior influência humana, exibe menor diversidade. Em contraste, PEFG, mais isolado, apresenta riqueza significativa, incluindo espécies ameaçadas. Santa Teresa, no Espírito Santo, destaca-se como um local estratégico, abrigando uma riqueza de 33 espécies de pequenos mamíferos não-voadores e uma rica diversidade em altitudes intermediárias e em ambiente preservados. De forma geral, a altitude influencia a distribuição desses mamíferos na Mata Atlântica, respondendo a fatores abióticos, como área, temperatura e relevo, e fatores bióticos, como à ocupação humana em diferentes elevações. Este estudo destaca a importância da biogeografia e de áreas naturais na compreensão da biodiversidade em regiões montanhosas.

ABSTRACT

Mountainous regions show a remarkable diversity ofnonn-volant small mammals, with the altitude associated with mountains playing a key role, and a Humboldtian multidisciplinary approach is ideal for understanding these factors. In the Atlantic Forest, diversity is more pronounced at intermediate altitudes, a pattern known as the mid-domain effect in biogeography. Didelphiomorpha and Rodentia occupy distinct elevational ranges, reflecting species replacement and overlap along the elevational gradient. Genera such as *Akodon* and *Delomys* show distinct responses to elevation. *Akodon* shows species variation related to competition, while *Delomys altimontanus* is restricted to elevation peaks, suggesting specific refugia in mountainous regions. Tectonic and climatic changes at the end of the Neogene influenced the speciation of *Trinomys*. In particular, the Serra do Caparaó stands out as a center of diversity in the Atlantic Forest, with 27 species of non-volant small mammals. Richness and abundance vary with altitude, showing different patterns. Landscapes such as montane dense ombrophilous forest, altitudinal dense ombrophilous forest and high altitude grasslands contribute to this diversity. Anthropogenic pressures affect the richness and diversity of protected areas such as Parque Estadual Mata das Flores (PEMF) and Parque Estadual Forno Grande (PEFG). PEMF, with greater human influence, has lower diversity. In contrast, PEFG, which is more isolated, has significant biodiversity, including endangered species. Santa Teresa, in Espírito Santo, stands out as a strategic location, with a richness of 33 species of non-volant small mammals and a rich diversity at intermediate altitudes and in preserved environments. In general, altitude influences the distribution of these mammals in the Atlantic Forest, responding to abiotic factors such as area, temperature and relief, and biotic factors such as human occupation at different elevations. This study highlights the importance of biogeography and wild areas in understanding biodiversity in mountainous regions.

APRESENTAÇÃO

Estudos sobre padrões de diversidade, principalmente o altitudinal, estão fortemente associado aos trabalho de Alexander von Humboldt, o explorador alemão do século XIX, nascido em 14 de setembro de 1769 e falecido em 6 de maio de 1859. O aspectos-chave da ciência humboldtiana, enfatiza a relação entre biodiversidade e processos geológicos, geomorfológicos, pedológicos e hidrológicos, abrangendo aspectos da biogeografia e macroecologia, com uma abordagem holística e transdisciplinar (Schrodt et al., 2018). A ênfase na ligação entre os organismos e o seu ambiente, com incorporação de informações sobre elevação, temperatura, cultivo do solo, fauna típica, geologia e outros (von Humboldt & Bonpland, 1807), é precursora do conceito de nicho Hutchinsoniano (Schrodt, et al 2018). Consequentemente, os modelos de distribuição de espécies e sua aplicação nas tentativas de compreender e prever os efeitos das alterações climáticas na biodiversidade são reconhecidamente humboldtianos (Morueta-Holme & Svenning, 2018).

No que tange gradientes altitudinais, as descrições de Humboldt são fundamentais para as abordagens modernas de modelagem e previsão, além de padrões de elevação na biodiversidade relacionando ao clima (Alexander et al., 2018; Fadrique et al., 2018; Santos, et al; 2017; Steinbauer et al., 2018). Observando as práticas altamente erosivas da monocultura, da pesca e caça excessiva na América do Sul ele reconheceu e alertou sobre o grau em que os humanos poderiam agir como agentes de mudança e destruição da biodiversidade (Buttimer, 2001; Egerton, 2009), algo notável para um estudioso do século XVIII (Schrodt, et al 2018). Dito isso, o pensamento mais humboldtiano em biogeografia leva em consideração as conexões entre todos os fenômenos naturais e humanos (Buttimer, 2012), principalmente quando poucos estudos deste tipo incorporam alterações no uso e ocupação dos solo e mudanças na paisagem (Schrodt, et al 2018).

Em conformidade com os princípios da abordagem científica humboldtiana, este estudo visa aprofundar a análise dos padrões de diversidade e biogeografia de pequenos mamíferos não-voadores nas regiões da Mata Atlântica, considerando o impacto do antropoceno. Principalmente pelos escassos estudos da amstofauna a respeito de montanhas da Mata Atlântica. Assim, estruturamos a tese em quatro capítulos, guiados pelas seguintes questões: (1) Emerge um padrão distinto na distribuição da fauna de pequenos mamíferos não-voadores ao longo do gradiente altitudinal na Mata Atlântica?; (2) Existe uma consistência na distribuição da fauna de pequenos mamíferos não-voadores na Serra do Caparaó (área montanhosa da Mata Atlântica) ao longo de dois períodos temporais distintos e como se comporta a distribuição da riqueza e abundância do conjunto das espécies encontradas ao longo da montanha?; (3) A composição da fauna de pequenos mamíferos não-voadores varia em relação ao uso e ocupação do solo ao longo do gradiente altitudinal, dentro de duas áreas de conservação inseridas na Mata Atlântica (Parque Estadual Forno Grande e Parque Estadual Mata das Flores)?; Por fim, (4) Conduziu-se um levantamento da riqueza e composição da fauna de pequenos mamíferos não-voadores em uma área de altitude e preservadas para a Mata Atlântica, o município de Santa Teresa, Espírito Santo.

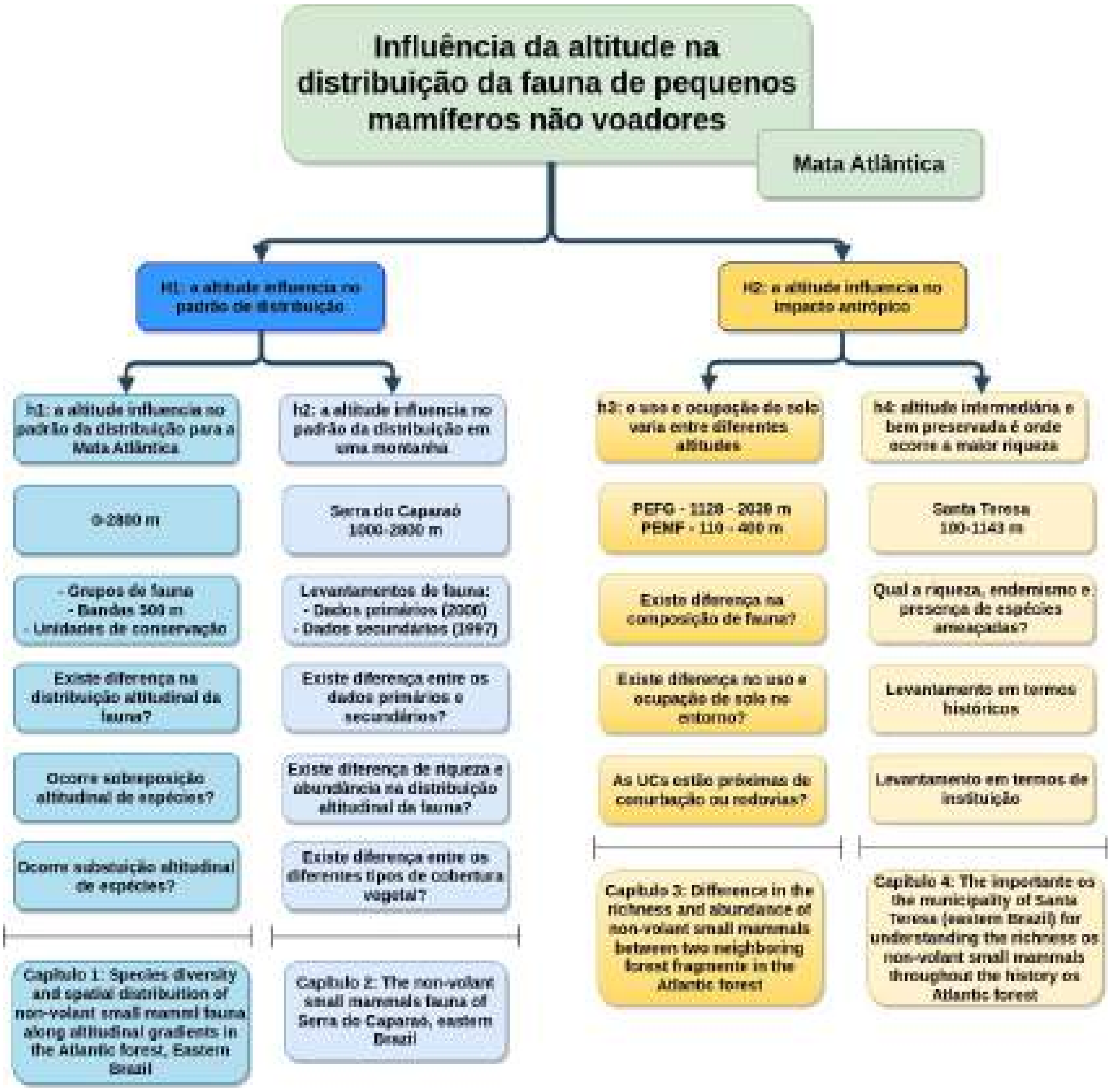

Figura 1: Diagrama com as hipóteses e questões formuladas para a tese resultando e cada capítulo.

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Capítulo 1

SPECIES DIVERSITY AND SPATIAL DISTRIBUTION OF NON-VOLANT SMALL MAMMAL FAUNA ALONG ALTITUDINAL GRADIENTS IN THE ATLANTIC FOREST, EASTERN BRAZIL

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I. ABSTRACT

The Atlantic Forest is the biome with the largest elevational gradient in Brazil, and areas in the Espírito Santo state alone cover the whole gradient. This makes the state an ideal region to investigate the effects of the elevational gradient on the richness, diversity and differential composition of non-volant small mammals communities. We tested the mid-elevation peak hypothesis for non-volant small mammal richness and composition and evaluated the influence of elevation, area and sampling effort on distribution patterns. A survey was conducted in three protected areas (Parque Estadual Mata da Flores: 110-440 m; Parque Estadual Forno Grande: 1,128-2,892 m; Parque Nacional do Caparaó: 957-2,892 m) and we used data either from the literature and/or from zoological collections databases available online, totaling seven protected areas in different altitudinal gradients. Richness and estimated richness were calculated per three treatments: i.

Groups based on Jaccard similarity for faunal composition called Bottom (30-631 m), Intermediary (935-1,465 m), and Upper (1,800-2,700 m); ii. Bands of 500 m intervals; and iii. Per Conservation Unit (CU). Bottom has larger richness and diversity than Intermediary and Upper, as expected due to bigger sampling effort. Regarding the altitudinal bands, mid-range have bigger richness and diversity. The top-range presented the lowest richness and diversity, but also the lowest sampling effort. Regarding the localities, Parque Nacional do Caparaó had the bigger diversity, having both the highest elevational gradient and sampling effort. Lower levels of diversity and richness were recorded by Conservation Units in Bottom areas. Rodentia have a higher altitudinal average (1,322.45 m), greater species richness, abundance and habit over a wider altitudinal range than Didelphimorpha. Meanwhile, Didelphimorphia is more frequent at lower altitudes (average altitude distribution in 669,89 m), with altitudinal ranges between 1,000 and 2,000m showing the greatest overlap between the two orders. The turnover of species within the same genus along an altitudinal gradient occurred especially in mid-altitudes. Therefore, mountain ranges can act as good systems and operation units in studies aiming to understand the non-volant small mammal's fauna distribution on a natural gradient and uncover the effects of climate change on the species distribution in the Atlantic Forest.

II. HIGHLIGHTS

i. Biogeographic current hypotheses for geographical patterns of species diversity fail to explain the high biodiversity of mountain regions, particularly in the tropics. We call this challenge "Humboldt's enigma".

ii. The non-volant small mammal fauna follows a downward shifted pattern of mean dominance. This pattern was as expected for tropical regions and when sampling was conducted in a mountain range.

iii. Among the groups, rodents show a medium dominance pattern, whereas marsupials follow a downward shifting pattern. Rodents show great capacity to occupy areas at high altitudes, Marsupials do not, and decrease in richness both at high elevations, demonstrating a weak predisposition to low temperatures.

iv. The most diverse gradients (between 1,000-1,500 and 1,500-2,000 m) show the overlapping altitudinal distribution of two assemblages, one at lowlands and the other at higher altitudes. 0-500 m shows a fauna richer in marsupials and above 2,000 m are exclusively rodents.

v. At altitudes between 1,000-2,000 and higher, there is also a turnover of rodent species within the same genus, in which the species is replaced by another better adapted to this environment.

III. KEYWORDS:

Central Atlantic Forest Corridor; Marsupial; Rodentia; Wallacean shortfall; Humboldt’s enigma

IV. INTRODUCTION

Some of the general characteristics of life on Earth are the patterns of abundance, distribution, and diversity of organisms across an environmental gradient. The altitudinal gradient was one of the first topics addressed by what is now known as biogeography (Brown, 2001) and has been carried out since the 17th century, according to the seminal works by Alexander von Humboldt’s in the South America (1849), Charles Darwin in the Chilean Andes (1859), Alfred R. Wallace in Indonesia (1876), and C. Hart Merriam in the United States (1890). Mountain regions-slopes, peaks, and adjacent foothills-contain approximately 87% of the world's amphibian, bird, and mammal species, while occupying only about 25% of the terrestrial landmass (excluding Antarctica), and a large number of these species are endemic to these regions (Rahbek et al., 2019). Current hypotheses for large-scale geographic patterns of species diversity cannot explain the extraordinarily high biodiversity of mountain regions, especially in the tropics (Rahbek, 2001; Jetz & Rahbek, 2007). Rahbek and co-authors (2019) refer to this challenge as "Humboldt's enigma".

At an elevation gradient, the species richness falls into four common patterns: decreasing, low plateau, a low plateau with a mid-elevational peak, and mid-elevation peak. i. "Decreasing richness", species numbers decline, generally monotonically, with increasing elevation. ii. "Low plateau", high richness across all lower portion of the gradient and thereafter decreasing species richness. iii. "Low plateau patterns with a mid-elevation peak", high richness across low elevations with a diversity maximum found more than 300m from the base. iv. "Mid-elevation peaks" or “Mid-domain effect”, a unimodal peak in diversity at intermediate elevations with 25% or more species than at the base and top of a mountain (McCain, 2009). Rarely, species richness increases with elevation (e.g., for salamanders and lichens; Carr, 1959; Wake et al., 1992; Grytnes et al., 2006).

Although most research aims to document species richness and patterns of endemism, interest over the past three decades has increasingly focused on explaining these patterns, but the mechanisms or processes that determine these patterns of richness remain largely unexplored (Kessler & Kluge, 2008), especially for elevational distribution, known as Wallacean deficit (Hortal et al., 2005). First, researchers have been primarily concerned with documenting the patterns, which is an arduous undertaking in tropical mountains. Second, testable hypotheses regarding potential mechanisms are largely insufficient. Finally, methodological limitations have prevented testing several hypotheses, especially those related to evolutionary processes (Evans et al., 2005)).

In Brazil, the Atlantic Forest is ideal for analyses of this pattern. However, few studies have investigated these montane regions, especially in Caparaó National Park (Bonvicino et al., 1997), Itatiaia National Park (Geise et al., 2004), Morro Grande Forest Reserve (Pardini & Umetsu, 2006), and Serra do Brigadeiro State Park (Moreira et al., 2008). The biome is one of the most threatened in the world, being identified as a biodiversity hotspot (Mittermeier et al., 2004). The high degree of species endemism is latent (Mittermeier et al., 2004), which rivals in proportion with a significantly larger area of tropical rain forest, the Amazon Rain-forest (Rahbek et al., 2019). Furthermore, the Atlantic Forest occupies a relatively narrow strip of territory, spreading from the coastal plains to the inland plateaus, and encompasses some of the highest mountains in the country, seven of the ten highest peaks in Brazil. In addition, the state of Espírito Santo encompasses the entire altitudinal gradient for the biome and a restricted latitude range (between parallels 18°S and 21°S). Thus, we intend to test the mid-peak hypotheses for richness and composition along the Atlantic Forest elevational gradient for small non-volant mammals and the influence of elevation, area and sampling effort.

V. MATERIALS AND METHOD

We used primary and secondary data sources (Figure 1). The primary data are surveys of non-volant small mammals carried out during the present study in areas of higher altitudes not yet sufficiently inventoried in Espírito Santo state. The sampled areas were the Parque Estadual Forno Grande (PEFG), the

Parque Estadual Mata das Flores (PEMF), and Parque Nacional do Caparaó (PNC), all Conservational Units (CUs) (Figure 2, Appendix 1 and 2).

The PEFG is located between latitudes 20º30’5" and 20º32’5" and longitudes 41º08’5"W and 41°01’0’’ W (Figure 2, Appendix 1), in the municipality of Castelo. With an area of 800 hectares and characterized by a pronounced relief, with elevation varying between 1,128–2,039 m, culminating in Pico do Forno Grande, the second highest mountain range of Espírito Santo (IDAF, 2000). Although it is considered an Atlantic Forest priority area for conservation (MMA & Brasil, 2000), it was object of only scarce fauna surveys, which either were not made systematically or done in the past two decades (for example, (IDAF, 2000, 2006)). The PEMF is also located in Castelo and has 800 hectares (latitudes 20º35'35"S and 20º38’16” longitudes and 41º11'45"W and 41º12’04” - Figure 2, Appendix 1), but a small altimetric variation, between 110–400 m. Our work consists of the first survey of small non-volant mammals carried out in the area. PNC is located in nine municipalities between 20º19'0" and 20º37'0" latitude and 41º43'0" W and 41º53'0' W longitude (Figure 2, Appendix 1), four in Minas Gerais (Alto Caparaó, Caparaó, Espera Feliz and Alto Jequitibá) and five in Espírito Santo (Divino de São Lourenço, Dores do Rio Preto, Ibitirama, Iúna and Irupi). Of the 26,000 hectares, about 70% are in the State of Espírito Santo and 30% in Minas Gerais. Its geographical relief is mountainous, with altitudes ranging from 800 to 2,892 m at Pico da Bandeira, the third highest peak in Brazil.

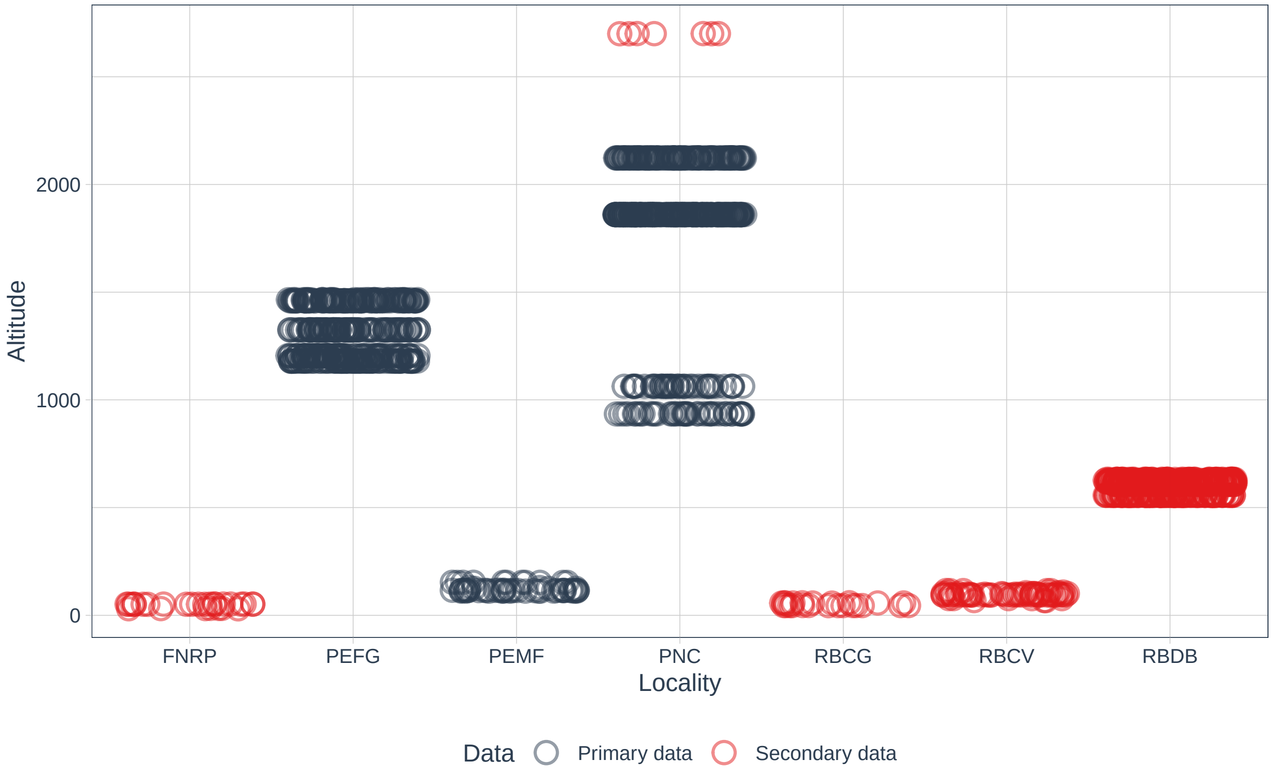

Figure 1: Primary and secondary data in elevation gradient in the study area per Conservational Units, where each dot is an altitude sampled. Legend: FNRP = Floresta Nacional do Rio Preto; PEFG = Parque Estadual do Forno Grande; PEMF = Parque Estadual da Mata das Flores; PNC = Parque Nacional do Caparaó; = RBCG = Reserva Biológica do Córrego Grande; RBCV = Reserva Biológica Córrego do Vedo; and, RBDB = Reserva Biológica de Duas Bocas.

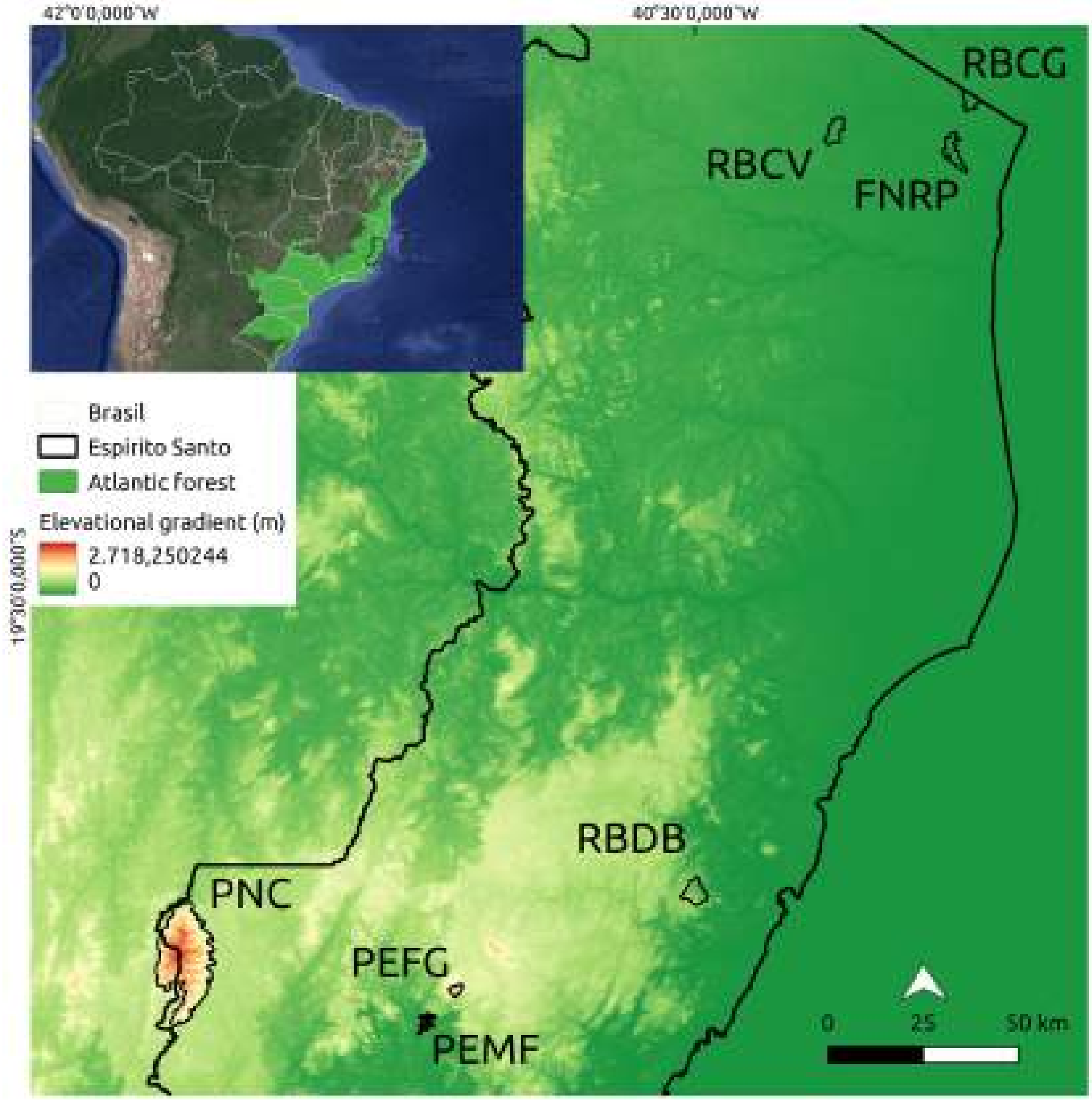

Figure 2: Map of the study area showing the area of Brazil in South America, the Atlantic Forest, the federation unit, the conservation units and the elevation gradient. Legend: FNRP = Floresta Nacional do Rio Preto; PEFG = Parque Estadual do Forno Grande; PEMF = Parque Estadual da Mata das Flores; PNC = Parque Nacional do Caparaó; = RBCG = Reserva Biológica do Córrego Grande; RBCV = Reserva Biológica Córrego do Vedo; and, RBDB = Reserva Biológica de Duas Bocas.

We collected non-volant small mammals at different altitude ranges: one location in the PEMF (between 112-153 m); and two locations in the PEFG (one in the range between 1,180–1,305 m and the other, between 1,460–1,465 m). For each CU we established three 100 m transects where eleven 60-liter buckets (40 cm in diameter by 54 cm in depth) were installed, 10 m apart. The buckets were connected by 50 cm-high drift fences secured by wooden stakes (Pardini & Umetsu et al. 2006). In addition, we installed lines of conventional live traps for small, non-flying mammals consisting of points with three types of traps. For each point, we installed two Shermans (23 × 9 × 9 cm) and two wire cages-Tomahawks (32 × 15 × 15 cm)-

placed approximately five meters from each pitfall trap, one on each side and alternating between the ground and understory. We set a total of three 10 m lines of live traps with eleven points. These traps were baited with pineapple and peanut butter. The fieldwork was conducted at each CU between September and November 2013, and February and September 2014, in four campaigns, totaling 58 sampling days, 29 at each CU. Series of specimens were collected to serve as museum vouchers (listed in Appendix 1) and were prepared according to standard techniques (Auricchio & Salomão 2002). Vouchers are deposited in the mammal collection at Universidade Federal do Espírito Santo, Vitória, Brazil (UFES-MAM). Species identification follows Wilson & Reeder (2005), and recent updates (Bonvicino et al., 2008)). For PNC, the primary data were collected in partnership with the Laboratório de Biologia Anumal (LGA - UFES) using Sherman traps (23 × 9 × 9 cm) and two-wire Tomahawk traps (32 × 15 × 15 cm) baited with bananas, oats, sardines and peanut butter. There were surveys at four localities: i. "Santa Marta" (42º43'46"W, 20º29'40"S), located in the municipality of Ibitirama, characterized by mid-elevation area (800-1,000 m), sampled on 04-12 March 2006 with 1,740 traps-night; ii. "Pedra Roxa" (41º44'5"W, 20º23'44"S), located in the municipality of Irupi, another mid-eleavtion area (945-1095 m), sampled on 02-09 September 2006 with 1,726 traps-night; iii. "Macieira" (41º49'50"W, 20º28'42"S), located in the municipality of Dores do Rio Preto, plateau area (1,788-1,938 m), sampled from 28 May to 3 June 2006 with 1103 traps-night; iv. "Casa Queimada" (2,123 m), located in the municipality of Ibitirama, sampled from 13 to 22 September 2006 with 1,347 traps-night.

Secondary data was gathered from published articles from other CUs in the target area and with a similar sampling effort (SaE). They are: Parque Nacionao do Caparaó (PNC), for altitudes above 2500 meters (Bonvicino et al., 1997); Reserva Biológica Duas Bocas (RBDB, altitude varying from 69-800 m - Carão, 2007; Tonini et al., 2010), Reserva Biológica Córrego do Veado (RBCV, altitude varying from 52-132 m), Floresta Nacional do Rio Preto (FNRP, altitude varying from 0-70 m), and, Reserva Biológica Córrego Grande (RBCG, altitude varying from 14-80 m) (all data from the last three from Conde 2016). Maps of the location of these CUs in Espírito Santo were constructed highlighting their limits, altitude, and vegetation cover (Figure 2, Appendix 1, 2, 4, 5), with the Quantum Geographic Information System (QGIS Development Team, version 3.22) software.

We grouped the elevation data into 100-meter intervals, using the upper interval as the reference measurement and we organized the data into three treatment groups (Appendix 4 and 5). The first treatment was based on a Jaccard similarity analysis (Seger et al., 2005) composition of the non-volant small mammals in a dendrogram representation: Bottom (0 -700 m), Intermediary (1,000 - 1,500 m), and Upper (1,800 - 2,800 m) (Figure 3). The second treatment consisted of an arbitrary division into elevation bands based on elevation values at 500 m intervals (Figure 1). And, the third treatment regards the Conservation Units.

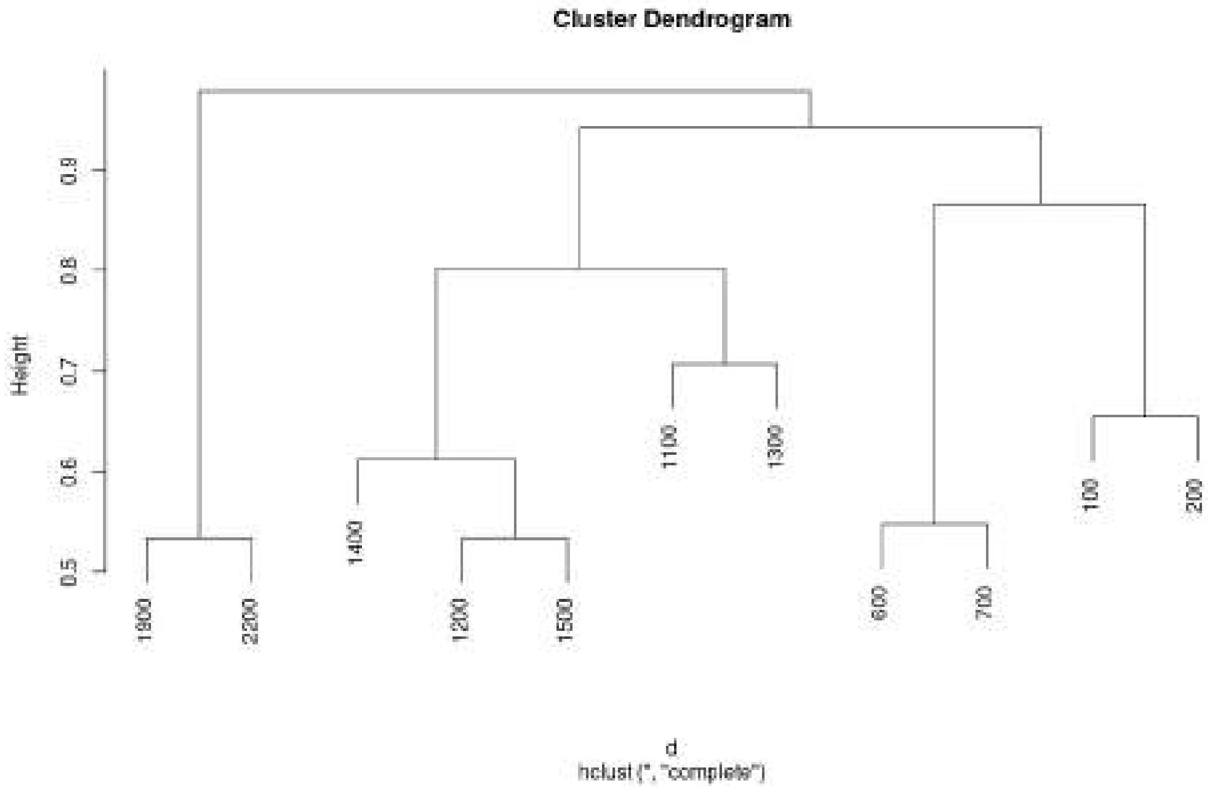

Figure 3: Dendrogram of Jaccard similarity index for each 100-m elevation band for non-volant small mammals composition grouped on three groups: Bottom between 0-700m; Intermediary between 1,000-1,500m; and, Upper between 1,900-2,700 m.

We extracted a polygon from a Copernicus Digital Elevation Model (DEM) raster with a resolution of 30 m, taking into account the area of the conservation units, in order to create a smaller square polygon covering all the areas of these CUs. From this extracted polygon, we calculated the total area and the area per treatment group using the tool “r.reporter” of GRASS that generated a Raster Map Category Report. The choice of extracting this square polygon was not to limit the analysis to the area of the CUs and this resulting maps were generate with QGIS (version 3.22.4) (Figure 2, Appedix 1 and 2). To calculate captures success, we multiply the number of traps by the number of nights used and then divide the number of captures by the result of this product. Next, we calculated species richness, abundance, and the nonparametric richness estimator first-order Jackknife, (Heltshe & Forrester, 1983) in relation to each treatment, in order to evaluate if elevation gradients influence fauna composition (Appendix 4). In addition, LOWESS regressions were computed between mean elevation of species occurrence and richness, and linear regression analysis was computed between area and richness. The former uses locally weighted sums of squares to identify the underlying trend in a data set without requiring the prediction of a specific linear model or polynomial (Cleveland, 1979; Hintze, 1998); and the latter is a linear relationship between two variables (Brower & Zar, 1984). Nonetheless, we reunited and compared to observe overlap areas on altitude and locality, and the occurrence of species turnover on each genus. All these analyses and graphs were performed using R software 4,2 in ambient RStudio (R Development Core Team, 2020), package "vegan" (Oksanen et al., 2022) and "ggplot2" (Wickham, 2016).

VI. RESULTS

The trapping effort in PEMF was 4,312 trap-nights resulting in 54 captures (1.25% success) with the richness of three species to PEMF; and in PEFG, the effort was 4,172 trap-nights, resulting in 402 captures (9.63% success), and 14 species (Appendix 4), concurrently between the months of November 2013 and October 2014. The PEFG had larger species richness including some with relatively few documented localities with voucher specimens, therefore resulting in imprecise range boundaries and many distribution gaps, such as *Rhagomys rufescens* and *Rhipidomys tribei,* while more common and widely distributed species, such as *Oligoryzomys nigrips* and *Akodon cursor,* were dominant. Parque Estadual Mata das Flores (PEMF) presented the lowest species richness, with a massive dominance of *Marmosops incanus*. In the Parque Nacional do Caparaó (PNC), the trapping effort was 5,952 traps-night resulting in 24 species and 426 records (7.15% success – Appendix 4), with the most abundant species being *Delomys altimontanus* (25.58%) followed by by *Castoria angustidens* (18.07%) and *Oxymycterus caparaoe* (12.91%) of total, all of them species being restricted to an altitudinal distribution. In addition to the presence of *Rhipidomys tribei*, already mentioned, and *Marmosops paulensis* and *Juliomys ossitenuis*, all species that were registered at the northern limit of their known. In relation to the secondary data, Reserva Biológica de Duas Bocas (RBDB) presented 393 records and 19 species (SaE = 5960 traps/night), Reserva Biológica do Córrego Grande

(RBCG) 20 records and 7 species (SaE = 5101 traps/night), Reserva Biológica Córrego do Veado (RBCV) 67 records and 9 species (SaE = 5101 traps/night), and Floresta Nacional do Ro Preto (FNRP) 27 and 5 species (SaE = 5101 traps/night) (Appendix 4). In addition, regarding secondary data, PNC showed an increase of 126 records, but no species were added to the total richness. (Table 1).

Regarding the altitudinal groups, Bottom group has larger richness and diversity than Intermediary group and Upper group, as expected due to a greater sampling effort (Figure 4). Bottom group is composed of FNRP, PEMF, RBDB, RBCG, and RBCV, with an altimetric amplitude of 30 to 631 m and a slightly larger area than Upper group. The observed richness of 25 species (SaE = 25,575 traps/night and 2.2% success) and an estimated first-order jackknife richness of 29.96 (Figure 4). Marsupials had the largest proportion in the faunal composition (47.6%) and the three most abundant species were *Metachirus myosurus*, *Marmosa incanus* and *Monodelphis iheringi*. More than 33% species are unique to this group, including *Cryptonanus agricolai*, *Marmosa murina*, *Marmosa paraguayana, Blarinomys breviceps*, *Calomys cerqueirai, Calomys tener, Cerradomys subflavus, Juliomys pictipes, Necromys lasiurus*, *Oecomys catherinae, Rhipidomys mastacalis*, *Phyllomys pattoni*, and *Rattus rattus,* the last one and exotic specie. Relating fauna composition in according to Jaccard similarity relationship, the group Bottom is considered an external group (0,93) in relation to the sister groups Intermediary and Upper (Figure 3).

The Intermediary group presents the lowest altimetric variation (amplitude of 1,000 to 1,500 m) and is composed of PEFG and PNC. There was biggest sampled area and observed richness of 21 species (a SaE = 9,018 traps/night and 5.42% success), an estimate of 27.86 from the above estimator and seven species are exclusive (38.1%) (Figure 4, Appendix 4). Of this richness, 33.3% of the sampled species are marsupials, with *Monodelphis scalops* being the only exclusive representative of this order for the group. In addition, *Delomys sublineatus, Euryoryzomys russatus, Oxymcterus dasytrichus, Rhagomys rufescens, Rhipidomys tribei, Sooretamys angouya* and *Trinomys gratiosus* are exclusive rodents. *Oligoryzomys nigripes* and *Akodon cursor* are the most abundant rodent species, representing 69% of the total. The *Marmosops incanus* and *Philander quica* are the most abundant marsupial species.

Table 1. Species abundance per treatment in group, elevational band, 100-m elevation, and Conservation Unit (CU). Legend: FNRP = Floresta Nacional do Rio Preto; PEFG = Parque Estadual do Forno Grande; PEMF = Parque Estadual da Mata das Flores; PNC = Parque Nacional do Caparaó; RBCG =; Reserva Biológica Córrego Grande; RBCV = Reserva Biológica do Córrego do Veado; RBDB = Reserva Biológica de Duas Bocas.

Group	**Bottom**					**Intermediary**						**Upper**			**Total**
Elevational bands		**0-500**		**500-1000**		**1000-1500**					**1500-2000**	**1500-2000**	**2000-2500**	**2500-3000**	
100-m		**100**	**200**	**600**	**700**	**1000**	**1100**	**1200**	**1300**	**1400**	**1500**	**1900**	**2200**	**2800**	
DIDELPHIOMORPHIA															
DIDELPHIDAE															
Cryptonanus agricolai	RBCG	1													1
	RBCV	1													1
Didelphis aurita	FNRP	1													1
	PEFG								1						1
	PEMF		9												9
	PNC											1			1
	RBDB			2	3										5
Gracillinanus microtarsus	PEFG										1				1
	PNC						2					2			4
	RBCG	1													1
	RBCV	5	6												11
	RBDB			2	8										10
Marmosa murina	FNRP	4													4
	RBCV	2													2
Marmosa paraguayana	RBDB			2	4										6
Marmosops incanus	FNRP	20													20
	PEFG							3	9	1	17				30

Group		Bottom				Intermediary						Upper			Total
Elevational bands		**0-500**		**500-1000**		**1000-1500**					**1500-2000**	**1500-2000**	**2000-2500**	**2500-3000**	
100-m		**100**	**200**	**600**	**700**	**1000**	**1100**	**1200**	**1300**	**1400**	**1500**	**1900**	**2200**	**2800**	
	PEMF		42												42
	PNC					3	2								5
	RBCG	4													4
	RBCV	1	1												2
	RBDB			6	10										16
Marmosops paulensis	PNC											4			4
Metachirus myosurus	FNRP	1													1
	RBCG	2													2
	RBDB			41	61										102
Monodelphis americana	PEFG									1					1
	RBCV	4	3												7
	RBDB			19	51										70
Monodelphis iheringi	PNC					1									1
	RBDB			4	4										8
Monodelphis scalops	PNC					2									2
Philander quica	PEFG							3	5	2	20				30
	PNC					2	2								4
	RBDB			1											1
RODENTIA															
CRICETIDAE															
Akodon cursor	PEFG							9	37	18	15				79

Group		**Bottom**				**Intermediary**						**Upper**			**Total**
Elevational bands		**0-500**		**500-1000**		**1000-1500**					**1500-2000**	**1500-2000**	**2000-2500**	**2500-3000**	
100-m		**100**	**200**	**600**	**700**	**1000**	**1100**	**1200**	**1300**	**1400**	**1500**	**1900**	**2200**	**2800**	
	PNC					15	14								29
	RBDB			1	2										3
Akodon mystax	PNC						1					7	21	4	33
Blarinomys breviceps	RBCG	3													3
	RBDB				2										2
Brucepattersonius griserufescens	PNC											2	19		21
Calomys cerqueirai	FNRP	2													2
Calomys tener	RBCV	4	3												7
Castoria angustidens	PNC											60	18	1	79
Cerradomys subflavus	RBCG	4													4
	RBCV	9													9
Delomys altimontanus	PNC											82	27	1	110
Delomys dorsalis	PNC											1			1
Delomys sublineatus	PEFG								1		2				3
	PNC						3								3
Euryoryzomys russatus	PEFG								1						1
Juliomys ossitenuis	PNC											1	1		2
Juliomys pictipes	RBDB			1	1										2
Necromys lasiurus	RBCG	5													5
	RBCV	20	4												24
Nectomys squamipes	PEMF		5												5

Group	**Bottom**					**Intermediary**						**Upper**			**Total**
Elevational bands		**0-500**		**500-1000**		**1000-1500**					**1500-2000**	**1500-2000**	**2000-2500**	**2500-3000**	
100-m		**100**	**200**	**600**	**700**	**1000**	**1100**	**1200**	**1300**	**1400**	**1500**	**1900**	**2200**	**2800**	
	PNC					6									6
	RBCG	3													3
	RBCV	4													4
	RBDB				13										13
Oecomys catherinae	RBCG	1													1
	RBDB				2										2
Oligoryzomys flavescens	PNC						1					25	4		30
Oligoryzomys nigripes	PEFG							75	20	72	56				223
	PNC					4	6					4	2		16
	RBDB			11	17										28
Oxymycterus caparaoe	PNC					4	1					21	29		55
Oxymycterus dasytrichus	PEFG								1	5	14				20
	PNC						4								4
Rhagomys rufescens	PEFG										1				1
Rhipidomys mastacalis	RBDB			8	10										18
Rhipidomys tribei	PEFG										3				3
	PNC					2									2
Sooretamys angouya	PNC					2	1								3
Thaptomys nigrita	PEFG							1	2	1					4
	PNC											3	5	1	9
	RBDB				2										2

Group		Bottom				Intermediary						Upper			Total
Elevational bands		**0-500**		**500-1000**		**1000-1500**					**1500-2000**	**1500-2000**	**2000-2500**	**2500-3000**	
100-m		**100**	**200**	**600**	**700**	**1000**	**1100**	**1200**	**1300**	**1400**	**1500**	**1900**	**2200**	**2800**	
ECHIMYIDAE															
Phyllomys pattoni	RBDB			3	4										7
Trinomys gratiosus	PEFG								5						5
	PNC					3	6								9
Trinomys paratus	RBDB			28	69										97
MURIDAE															
Rattus rattus	RBDB			1											1
Total		102	73	130	263	44	43	91	82	100	129	213	126	7	1403

The Upper group, represented only by PNC (SaE = 1,698 traps/night and 20.25% success) presents an altimetric variation of 1,800–2,700 m, the lowest species richness (13 with 14.88 of richness estimate) (Figure 4, Appendix 4), and a marsupial proportion representing 23% of the total richness, represented by *Didelphis aurita*, *Gracilinnaus microtarsus* and *Marmosops paulensis*, the last one being exclusive. Rodentia, we registred five exclusive species (*Brucepattersonius griserufescens*, *Castoria angustidens*, *Delomys altimontanus, Delomys dorsalis* and *Juliomys ossitenuis*). Intermediary and Upper are considered sister groups on Jaccard similarity (0.87).

In terms of elevation bands, the middle bands (1,000-1,500 m and 1,500-2,000 m), followed by the 500-1,000 m band (lowland areas) showed the greatest richness and diversity, as well as the largest sampling area. Next, the 0-500 m band (lowlands) showed intermediate richness despite the greater sampling effort. Finally, 2,000-2,500 m and 2,500-3,000 m (plateau area) had the lowest richness and diversity, the lowest sampling effort and the smallest sampling area (Figure 4, Appendix 4).

The 1,000-1,500 m band (SaE = 5,552 traps/night and 6.4% success) was the most species rich and together with 1,500-2,000 m has a richness of 20 species (Figure 4), but a higher richness estimates of 26.85 (Appendix 4). For the firs band, 35% are marsupials, *Monodelphis scalops* were the only exclusive marsupial species, besides three rodents (*Euryoryzomys russatus*, *Sooretamys angouya* and *Trinomys gratiosus*). It is noteworthy that 49.16% of the species records were of *Oligoryzomys nigripes*. As mentioned, the 1,500-2,000 m band (SaE = 3,189 traps/night and 10.66% success) present the same values of species richness of the 1,000-1,500 m. However, it has a lower estimated richness value (23.87) and lower abundance (342 records) (Figure 4, Appendix 4). In terms of richness, 25% are marsupials with *Marmosops paulensis* being an exclusive species. As for Rodentia, *Delomys dorsalis* and *Rhagomys rufescens* are exclusive and *Delomys altimontanus* is the most abundant species with 23.9% of all captures.

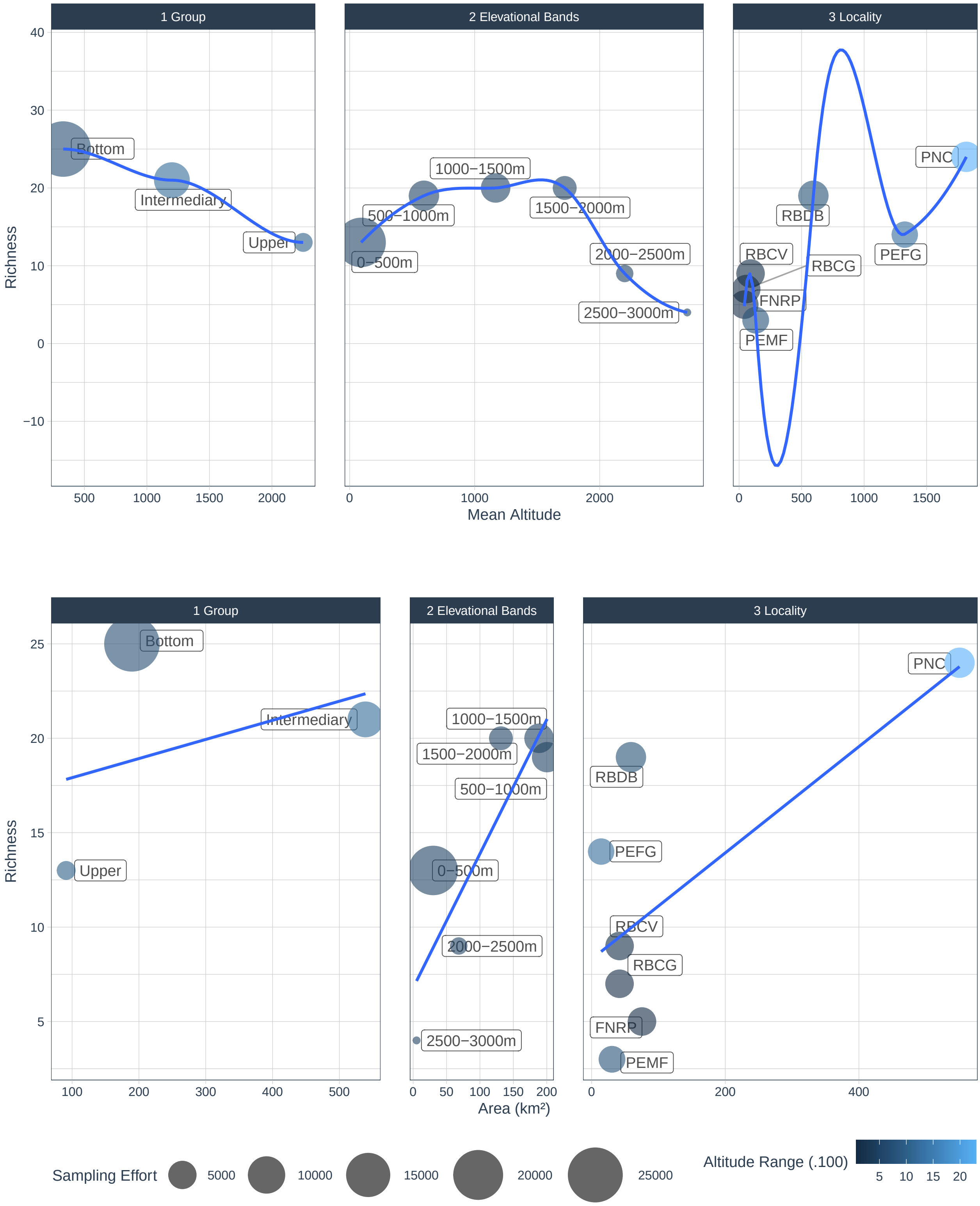

Figure 4: Relationship between richness and elevation with LOESS linear regression (first line) and richness and area with linear regression (second line), with emphasis on sampling effort and elevation range. Legend: FNRP = Floresta Nacional do Rio Preto; PEFG = Parque Estadual do Forno Grande; PEMF = Parque Estadual da Mata das Flores; PNC = Parque Nacional do Caparaó; RBCG =; Reserva Biológica Córrego Grande; RBCV = Reserva Biológica do Córrego do Veado; and, RBDB = Reserva Biológica de Duas Bocas.

The 500-1,000 m elevation range had the second highest richness with 19 species and an estimated richness of 21.94 (SaE = 5,560 traps/night and 6.59% success) (Figure 4, Appendix 4). The marsupials represent 42.1% of the richness, with the most abundant species in this altitudinal group being *Metachirus myosurus* (25.35% of the total) and an exclusive species, *Marmosa paraguayana*. Among the rodents, *Juliomys pictipes*, *Rhipidomys mastacalis*, *Phyllomys pattoni* and *Trinomys paratus* are exclusive species, the latter being the most abundant rodent with 97 records. Still considering lowland areas, the 0-500 m band (SaE = 19,615 traps/night and 0.86% success – Appendix 4) presents a larger proportion of marsupials with half of the richness, with two exclusive species (*Cryptonaus agricolai* and *Marmosa murina*), and four rodents that only occur in this altitude range (*Calomys cerqueirai, Calomys tener, Cerradomys subflavus, Necromys lasiurus*).

For the higher elevations, 2,000-2,500 m (SaE = 351 traps/nigth and 9.3% success) showed nine species (9.88 estimated richness) in 126 records (Figure 4, Appendix 4). There were no exclusive species, no Didelphidae, and with *Oxymycterus caparaoe* and *Delomys altimontanus* being the most abundant species with 23% and 20.9% of records, respectively. Finally, the 2,500-3,000 m band registered four species, none of them exclusive (SaE = 351 traps/nigh and 1.99% success) (Figure 4, Appendix 4).

Considering the species accumulation in the altitudinal gradient from sea level, the initial richness is 13 species with the addition of 10 species for the 500-1,000 m range, being this the largest richness increase of new species in this gradient. From this elevation, the addition of new species becomes more gradual up to the limit of 42 species in 2,400m (Figure 5).

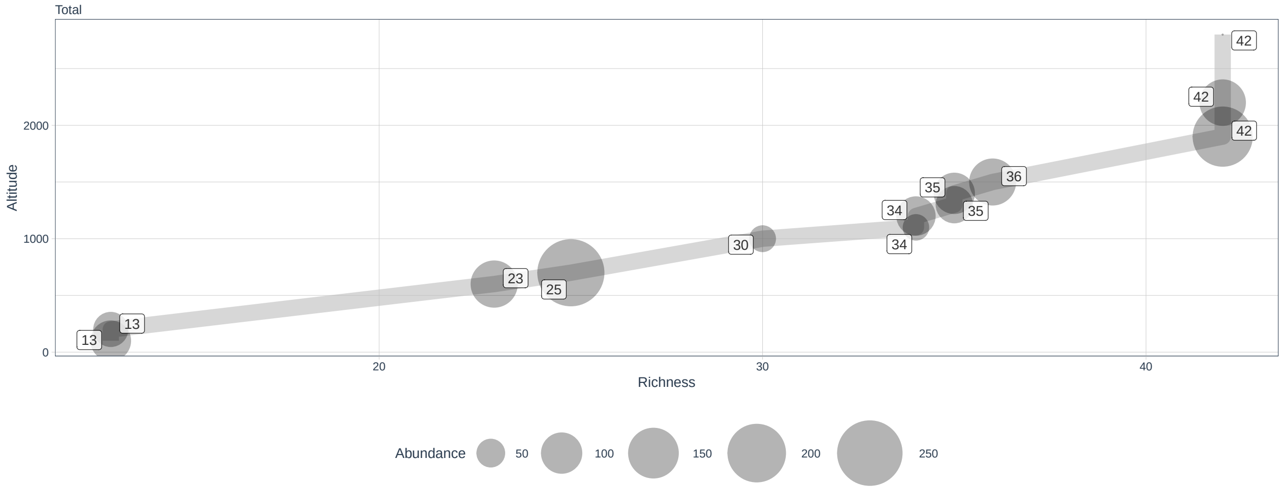

Figure 5: Species accumulation curve in the elevation gradient with emphasis on richness and abundance at 100-m elevation in the Atlantic forest elevational range.

Regarding the taxonomic composition, Rodentia presents an elevational mean of 1,297.89 m, while Didelphimorpha has 619.04 m. The first group has larger species richness, 30 species to 12, estimated richness of 35,95 to 12,99, a large abundance varying for 987 to 409, and inhabiting a large elevational amplitude, but mostly between 1,500-2,000 m (Appendix 4). Meanwhile, Didelphimorphia is more frequent at lower altitudes, mainly 0-500m. The altitudinal bands with the greatest overlap of the two orders are those between 0 and 1,000 m (Figure 6). The turnover of species within the same genus along an altitudinal gradient occurred mainly in the middle elevations, such as *Akodon* spp (1,500-2,000 m), *Delomys* spp (1,500-2000 m), *Rhipidomys* spp (500-1,000 m), *Oxymycterus* spp (1,500-2,000 m), *Trinomys* spp (500-1,000 m) and the marsupials *Marmosa* spp (0-500 m), Marmosops spp (1,000-1,500 m) and *Monodelphis* spp (1,000 m). As for the genera *Oligoryzomys* there is an overlap in the altitudinal distribution of species, but there is a change in the proportion of species within the same genus, with *O. nigripes* occurring in lower altitudes (500-1,000 m) while *O. flavescences* was only registered after 1,000 m, with both overlapping almost entirely in the intermediary level, while the former can co-occur with the latest reaching the highest altitudes (Figure 6). Looking at the grouping of species, *Marmosops* (Intermediary to Upper groups), *Rhipidomys* (Bottom to Intermediary groups), *Trinomys* (Bottom to Intermediary groups) and *Delomys* are the genera that have experienced turnover: *M. incanus* and *T. paratus* are clearly species of low altitudes, while their congeners *M. paulensis* and *T. gratiosus* occurred only above the 1,000 m. *Rhipidomys tribei* seems also to be a species that occur mainly in higher altitudes, above 1,000 m, while *R. mastacalis* inhabits much lower altitudes (Figure 6). According to our data, *Delomys* genus presents itself as a true mountain genus: all three species registered were captured above de 1,000 m, but there is also almost no altitudinal overlap between them: *D. sublineatus* occurs only in the intermediary levels, from 1,000 m to 1,500 m, while *D. altimontanus* was only captured above 1,800 m, but *D. dorsalis* was also registered in sympatry with *D. altimonanus*, in the lowest point where *D. altimontanus* was registered. *Akodon cursor* and *Akodon mistax* also broadly overlap in the intermediary level, but only *A. cursor* occurs in the bottom level, while *A. mistax* is the only one that occurs above 1,500 m.

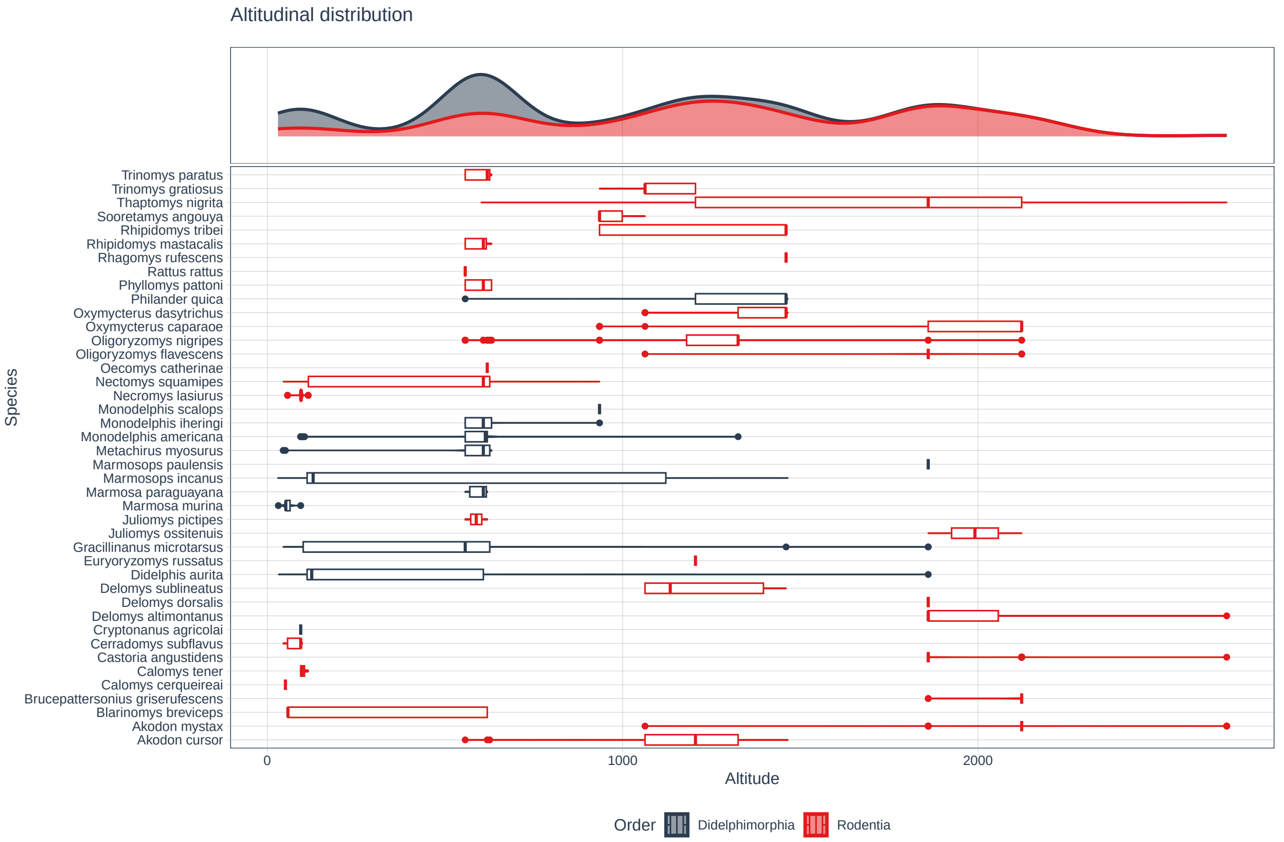

Figure 6: Boxplot of the elevational distribution of Didelphimorphia and Rodentia with emphasis on the overlap of elevational distribution. The y-axis shows the species and the x-axis shows the elevation, separated by 1,000 m blocks. In the graph, the median of the elevation distribution is the central line, the quartiles are represented by the boxes, and the outliers are the dots.

In Conservation Units comparisons, the PNC had the highest species richness (24 species) and estimated richness (29.92), with the largest sampling area and altimetric range, spanning the four highest elevation gradients (1,000-3,000 m) (Appendix 4). It also led in sampling effort, with a success rate of 7.24%. Although other CUs were generally similar in size to PNC, RBDB and PEFG stood out in terms of richness and estimated richness, with values of 19 and 21.4 for the former and 14 and 18.83 for the latter

(Appendix 4). These specific areas, located at altitudes between 557 and 1,490 m, exhibited wide richness ranges (500-1,000 m and 1,000-1,500 m) and belonged to the Bottom faunal group for RBDB and the Intermediate group for PEFG. Notably, PEFG outperformed RBDB with a higher capture rate (9.63% vs. 6.5%). The remaining CUs represented the first band of elevation, characterized by lower richness, particularly evident in the case of PEMF, which had a richness and estimated richness equal to three species (Figure 4).

VII. DISCUSSION

Considering the total composition of the fauna covered, the area studied represents 31.8% of the species found in the Atlantic Forest and 74.4% of the fauna of non-volant small mammals found in the State of Espírito Santo, 45.7% of the species are endemic to the Atlantic Forest and the same proportion to Brazil (Abreu et al., 2023). For this region of the Atlantic Forest, species richness has a mid-domain effect, with the highest diversity found almost at 1,000-1,500 and 1,500-2,000 m (Figures 4 and 6). This richness was strongly influenced by the overlap between the upland and lowland communities, and at this level species turnover also occurs, showing a division of the communities. On a regional scale, richness is strongly influenced by area (Rahbek, 2005; McCain, 2007), and these are the altimetric bands with the largest area. The second peak in diversity occurs between 500-1,000 m (Figure 4), an expected pattern where greater area at the base of mountains increases richness estimates at lower elevations (McCain, 2009). In this pattern, in addition to the overlapping altitudinal distribution of lowland fauna, there was a high diversity of marsupials.

Didelphiomorphia and Rodentia occupy the altitude gradient differently (Figure 4, Appendix 3). Marsupials have a low occurrence at higher altitudes, with higher species richness and diversity in low bands, mainly up to 500 m (Low plateau patterns with a mid-elevation peak), while rodents have species richness and diversity peaks corresponding to the mid-domain effect pattern, at 1,500 m band. They demonstrate the importance of analyzing these orders separately and the complexity of elevational richness and diversity patterns. The low diversity of marsupials in high altitude areas can be explained by different rates of metabolism, and competition in relation to eutherians (McNab, 2005). Marsupials show lower basal rates (Martin, 1902; MacMillen & Nelson, 1969; McNab, 2005), and this difference in energy expenditure can generate two ecological consequences: the low tolerance of marsupials to cold environments; and the limited ability of marsupials to compete with eutherians in these conditions (McNab, 2005). Comparing these two groups of small mammals in tropical South America, we observe that a small number of marsupials can reach elevations up to 3,800 m; only a few species of the Caenolestidae (e.g. *Caenolestes caniventer* and *Caenolestes fuliginosus*) occur in the Andes (Eisenberg, 1989; Albuja & Patterson, 1996; Eisenberg & Redford, 1999; Alberico et al., 2000; Gardner, 2007). However, eutherians are found at much higher altitudes, up to 5,000 m, such as *Necromys lactens* (Redford & Eisenberg, 1989; Eisenberg & Redford, 1999; Wilson, 2005).

Lowland's CUs are usually characterized by their small and fragmented areas. This habitat fragmentation and the negative impact of human actions are therefore reflected in the composition of small mammal fauna associated with the understory in a lowland area, as already reported in comparative studies of altered and/or fragmented areas of the Atlantic Forest (Fonseca & Kierulff, 1989; Stallings, 1989; Stevens & Husband, 1998). This fragmentation scenario can be responsible for the phenomenon known as density compensation (Crowell 1962, MacArthur et al. 1972), in which a high abundance of a few species in a fragmented area due to competition release, like *Marmosops incanus* in the lowland CUs analyzed (Weber et al., 2020), especially in the PEMF. The same phenomenon could explain the high catch rates at higher altitudes, where a few species are very dominant, especially between 1,500-2,500 m.

Regarding species turnover, we analyze four genera in particular: *Akodon*, *Delomys*, *Rhipidomys* and *Trinomys*. For the first, the presence of *Akodon cursor* is recorded up to an altitude of 1,000-1,500 m in PNC and up to 1,500-2,000 m in PEFG, and *Akodon mystax* occurs beyond 1,500 m, except for one individual. There is a low phylogenetic correlation between these species (Gonçalves et al., 2007), indicating that the occupation of these gradients has a little phylogenetic relationship. *A. mystax* is more closely related to another species of the Cerrado biome, *Akodon lindberg* (Gonçalves, et al., 2007), suggesting a recent separation between the strains, probably as the result of altitudinal isolation and adaptation to the xeromorphic environment of the altitude fields, somewhat similar to that of the Cerrado (Ribeiro, 1999; Gonçalves et al., 2007). It can be seen that *A. cursor* occupies mostly lower altitudes and also co-occur in sympatry with *Akodon mystax*, at intermediate altitudes, but in the absence of *A. mystax*. it can reach higher altitudes. Competitive exclusion is cited in situations of contiguous allopatry of closely related species. This phenomenon occurs when closely related species, descended from a common ancestor, share many morphological, behavioral, and trophic similarities. As a result, they compete for much of the same resources where secondary contact occurs (Grant, 1972; Jaeger, 1974; Terborgh, 1971). This competition may explain the uneven distribution of *A. cursor* in sympatry with *A. mystax*.

Delomys sublineatus occur around 1,000-1,500 m (PEFG and PNC), *Delomys altimontanus* occur around 1,500-3,000 m and *Delomys dorsalis* has just a record at 1,860 m, in the study area, this last ones only in PNC. *D. altimontanus* has a distribution restricted to two mountain massifs, Itatiaia National Park and PNC (Gonçalves & De Oliveira, 2014), with the low divergence between these populations possibly due to recent gene flow. This link is due to the expansion in the distribution of these species with the decrease in temperature in the last glacial period (Gonçalves, et al., 2014), which allowed the contact of these populations through the interconnection between open fields (*campos de altitude*) that reached lower altitude gradients in the past (Bonvicino, et al., 1997; Behling, 2002). Considering that *D. altimontanus* is not present in the PEFG, its absence in this altitudinal range may have allowed the expansion of the *D. sublineatus* altitudinal occupation area above at 1,800 m, in this area. When phylogenetically close species, with similar habitat requirements, occur in sympatry, replacement of species along an altitudinal gradient is often observed (Patton et al., 2008), as observed in this study. *D. altimontanus* shows sympatry with *D. sublineatus* in lower elevations of the Caparaó mountain range (Gonçalves & Oliveira, 2014) and with *D. dorsalis* in the Itatiáia mountain range (Gonçalves & Oliveira, 2014). However, for this study, the presence of a single record of *D. dorsalis* at 1,900 m should be re-examined. In any case, for the study area, the massive abundance of *D. altimontanus* (corroborated by the presence of *Akodon mystax*), specie restricted to high altitudes and adapted to lower temperatures, is consistent with the theory of allopatric refugia (Roy 1997; Gonçalves et al. 2007; Smith and Patton 2007; Safford 1999, 2007). The exclusion of *D. sublineatus* from higher elevations is due to allopatric exclusion (Grant, 1972; Jaeger, 1974; Terborgh, 1971), and the paucity of records at other elevations may be due to the species' sensitivity to open environments and adaptation to forest environments without anthropogenic intervention (DeVictor et al., 2008; Patton et al., 2015; Püttker et al., 2019) and more vulnerable to local extinction due to climate change (Rosa, 2023).

The genus *Rhipidomys* presents an area of overlapping geographic distribution in the study area, but with clear altitudinal separation. For this work, the separation occurred both for the treatment of groups and for altitude bands, with *Rhipidomys mastacalis* present only for the lower group and band of 500-1,000 m and *Rhipidomys tribei* for the intermediate group and band of 1,000-1,500 m and 1,500-2,000 m. *R. tribei* occurs in a few localities at altitudes ranging from 900 to 2,000 m in Serra do Espinhaço and Mata do Paraíso, both in the municipality of Viçosa, south of Minas Gerais (Pereira & Geise, 2007). In addition to Serra do Brigadeiro, Minas Gerais and Rio de Janeiro (Costa et al., 2011). New records extended the distribution of the species to locations in Espírito Santo (Thomazini 2009; Zanchin et al., 1992; Carvalho, 2009; Gouveia 2007), including this work for PEFG, and re-identification for PNC (Carvalho 2017). *R. mastacalis* has a wider distribution, occurring from Ceará to Rio de Janeiro (Carvalho 2017), always at low altitudes. This arboreal rodent genus does not reach altitudes above 1,500 m, a limit established as the beginning of *campos de altitude* (Vasconcelos 2011), a landscape dominated by mosaics of herbaceous-shrub communities (Safford 1999). The lack of tree extract may be the predominant factor for this absence.

For the genus *Trinomys*, Dalapicolla and Leite (2015) had already found a clear altitudinal separation between *T. paratus* from the lowlands and *T. gratiosus* from the highlands. They found an overlap between 500 and 580 meters, but no cases of syntopy were detected. For this genus, the tectonic and climatic changes that occurred in southern and southeastern Brazil at the end of the Neogene, which fragmented the Atlantic Forest, separated clades by vicariance and promoted large genetic divergence among populations (Lara & Patton, 2000). For the study area, as well as for the genus *Rhipidomys*, T*rinomys* there was a clear separation between the Bottom and Intermediate groups, as well as between the 500-1,000 m and 1,000-1,500 m elevation bands, confirming the division already reported. Another important factor is that this is a species whose distribution is limited to the Serra do Mar and Serra da Mantiqueira, being endemic to Brazil and the Atlantic Forest (Abreu et al., 2023). *T. gratiosus* is a species associated with forested environments with rocky outcrops and sparse undergrowth, generally reaching 1.5 m in height, with abundant arboreal lichens and many palm and fruit trees (Leite 2003). The predominance of open areas above 1,500 m can be a strong barrier to occupying areas above this altitude.

The genera *Akodon*, *Delomys*, *Rhipidomys* and *Trinomys* represented a complete species replacement across the altitudinal gradient, but other species showed a change in occurrence density. *Oligoryzomys nigripes*, abundant in the ranges between 500-2,200 m, appear in sympatry with *Oligoryzomys flavescens* between 1,100-2,200 m, having not been registered above this altitude limit. The distribution of *O.*

flavescens occurs mainly south of the study area (latitude 20 to 21° S) with records reaching the pampas of Argentina (Weksler & Bonvicino, 2005), a region of higher latitudes and lower minimum temperatures. Its occurrence between 1,500-2,000 m is probably associated with the congruence between the vegetation type of the southern fields and the *campos de altitude* (Ribeiro, 1999; Gonçalves, 2007). *Oligoryzomys nigripes* has a wide geographic distribution, reaching latitudes from hot areas in northeastern Brazil to colder areas at the mouth of the River Plate between Argentina and Uruguay (Patton et al., 2015). This large occupancy capacity can also be seen in altitudinal terms, as it reaches a large distributional range overlapping with *O. flavescens*, in addition to occupying lower altitudes (Figure 6).

Oxymycterus dasytrichus is a species characteristic of medium altitudes, being rare above 2,000 m (Geise et al., 2004), but mainly occurs between 1,000-1,500 m as showed here (Figure 6), a range in which it occurs in sympatry with *Oxymycterus caparaoe* (Table 1). Above 2,000 m, only the latter species occurs, because it is specialized in high altitude environments (Bonvicino et al., 2002), and is probably derived from allopatric speciation (Gonçalves, 2007), and its great abundance in this area (Table 1).

Finally, *Marmosops paulensis* is a small nocturnal marsupial that occurs in the southeastern part of the Brazilian Atlantic Forest and is restricted to montane forests above 800 m (Tribe 1996; Mustrangi and Patton 1997), with the PNC being the northern limit of its distribution. Similarly to the genus *Trinomys*, the phylogeographic clades show cohesive structuring with the major topographic complexes of the Atlantic Forest (Ribeiro 2022), another example of the importance of tectonic events in shaping lineage differentiation. These tectonic and climatic changes separated several clades by vicariance and promoted large genetic divergence between populations, as in *Trinomys* (Lara & Patton 2000), anuran amphibians (Thomé et al. 2010; Tonini et al. 2013), and demographic modeling studies for birds (Amaral et al. 2018; Thom et al. 2020). The strong geographic and altitudinal structure, in addition to genetic divergence consistent with these historical processes (Ribeiro 2022), suggests allopatric speciation for the genus, consistent with the genera *Akodon*, *Delomys*, *Rhipidomys*, and *Oxymycterus*, in addition to the aforementioned *Trinomys*.

As we have show, the patterns of diversity in the altitudinal gradient is different here studied differs between Rodentia, this conforming according to the mid-domains effect pattern; and, Didelphide, this according to low elevation plateau with a mid-peak. The same can be said for the different types of treatment. For the groups created based on the composition of the fauna, Bottom group showed greater richness than Intermediary level and the latter showed greater richness than the Upper group, in a pattern of decreasing richness. Bottom group had the greatest sampling effort, and even though the capture success was not the greatest, this greater effort was reflected in greater richness. When considering the 500 m altimetric bands, those with greater area also showed greater richness, confirming the classic prediction of island biogeography (McCarthy & Wilson, 1967) and highlighting the low plateau pattern with a mid-elevation peak pattern. The same pattern occurs in the CUs, with the PNC showing greater richness, greater area, and greater elevational range.

In 2001, Heaney formulated hypotheses for a study in the Philippines to understand what phenomena are associated with patterns of diversity considering different altitudes. His hypotheses are: H0: There is no significant variation; H1: diversity decreases with increasing elevation; H2: Diversity peaks in areas of community interdigitation; H3: Diversity increases in areas of rare disturbance; H4: Diversity increases with increasing area; H5: Diversity increases with overall productivity; H6: Diversity increases with increasing rainfall; H7: Diversity increases with increasing abundance and/or biomass; H8: Diversity increases with increasing resource diversity; H9: Diversity increases with increasing habitat complexity; H10: Diversity increases with increasing habitat diversity; H11: Diversity increases in areas of reduced competition; and, H12: Diversity is highest in areas that have experienced the highest rates of speciation.

Hypotheses H3, H5, H6, H7, H8, H9, H10, H11 and H12 were not tested in the present study. Hypothesis H0 was rejected, as we found changes in richness patterns across an altitudinal gradient for the total set and all treatments.

H1 was confirmed for the species group treatment, with the Bottom level having higher richness than the Intermediary and Upper groups. This diversity decreases with increasing elevation hypotheses is most common for patterns of diversity along elevational gradients, and is often formulated as an empirical pattern rather than a causal relationship (e.g., MacArthur, 1972; Brown & Gibson, 1983). Hypothesis H2 (diversity peaks in aeras of community interdigitaion) was accepted too. Species richness reached areas where two distinct communities intermingled (Brown, 1995, 2001), for the altitudinal band's treatment, especially for 500-1500 m (Figure 6). These data are consistent with Heaney (2001), where the same occurs in higher mountains (2,900 m) in Mindanao and Borneo (the latter, Md. Nor, 2001). Hypothesis H4 was also confirmed for the altitudinal bands and the UCs. This hypothesis is derived from the area curves of the equilibrium model of MacArthur & Wilson (1967). Authors such as MacArthur (1972) and Rahbek (1995 and 1997) have suggested that the decrease in area in elevational bands with increasing altitude may lead to a decrease in richness due to ongoing processes of colonization and extinction, and is therefore a variation of H1 (Williamson, 1988).

There is a complexity of factors associated with the pattern of biological richness in the mountains. Richness gradients are often explained by ambient temperature (Currie, 1991; Hawkins et al. 2003) since mean temperature decreases with altitude (Körner, 2007), mirroring the latitudinal gradient in decreasing order (Rahbek, 1995; Stevens, 1992). However, empirical data have shown that the species richness gradient can take many forms, but most often assumes a hump-shaped pattern (Rahbek, 1995; McCain, 200), as we have seen in this work for the altitudinal bands. Topographically complex tropical mountains can contain a remarkable volume of different climate types, equivalent to the climatic volume of large geographic areas in lowland regions (von Humboldt & & Bonpland, 2010).

In addition, mountainous regions bring together climatic zones that are clearly distinct from one another (Rahbek, 1995; Hoorn, 2018; von Humboldt, 2009; Körner, 2004). The juxtaposition of different climatic zones in the mountains is a consequence not only of the fact that the altitude gradient is short in absolute and planimetric terms, but also of the complexity of the gradient, which is necessarily much less gradual than these changes in lowland areas. Because they are not idealized cones, they have a complex landscape with deep erosion gullies that can act as dispersal barriers for species that inhabit more mesic habitats, such as the rocky outcrops of cloud forest that characterize many low-latitude mountains, as seen for *Oligoryzomys flaviceps* and *Marmosops paulensis*.

These aspects of spatial and temporal variation, as well as the geophysical variation of mountains in terms of different slopes and aspects, interact to create many rare and unique climate types (Ohlemüller et al., 2008). Some mountain climates are rare only in the sense that they are confined to mountains, but because of the many particular combinations of appearance, location, and local weather patterns, even small mountain ranges can create globally exceptional combinations of weather factors, provided the topography is sufficiently rugged. In the Atlantic Forest, moisture condenses directly on the vegetation, creating the characteristic cloud forest habitat. These cloud forests are characterized by consistently high humidity. Fog formation plays a fundamental role in the formation of many of the vegetation types characteristic of mountains and is probably related to the extremely high spatial rotation rate of species composition (Rahbek, 1997).

The climatic characteristics of mountains, which allow the coexistence of many species with slightly different climatic niches, can lead to a dense packing of species at local scales. The pronounced climatic changes along steep altitudinal gradients are associated with a striking turnover of species over short distances, which further enhances regional diversity. The turnover and distinctiveness of mountain climates across elevational gradients are pronounced in the tropics. Janzen in 1967 argued that species inhabiting tropical mountains experience a relatively smaller seasonal temperature range than species at comparable elevations at higher latitudes and may therefore evolve narrower physiological tolerances, although thermodynamic constraints may also play a role (Payne, 2017, Polato et al. 2018). Tropical mountains favor physiological specializations that act as effective dispersal barriers, resulting in relatively smaller elevational ranges (Janzen, 1967). This effect, combined with the complex mosaic of mountain microclimates, creates a patchy distribution of suitable habitats that may be isolated from each other, even when in close geographic proximity. This could be an explanation for the distribution an high abundance of *D. altimontanus* in PNC. This isolation could potentially increase opportunities for allopatric speciation. And relict populations may accumulate in places that remain climatically stable due to local topography (Fjeldså, 1999). Therefore, the creation of barriers and isolation promote allopatric speciation and the increase of species in mountain regions, as seen for *Delomys*, as well for *Oxymycterus* and *Akodon*.

The Atlantic Rain forest has all these complexities mentioned above. The study of non-volant small mammals in the mountains of this biome contributes to the discussion of Humboldt's enigma, helping to understand the reasons for this pattern of richness, which includes everything from isolation and allopatric evolution to the proximity of different environments that allow the altimetric distribution of species to overlap In addition, although this work focuses on the altitudinal distribution of species, it also contributes to the Wallacean deficit, because addres the research bias effort in different localities and due to the difficulty of accessing mountainous areas. Tropical mountain areas have been considered the apex of diversity by several classic authors (such as MacArthur, 1972; Brown & Gibson, 1983; Wilson, 1988; Patterson et al., 1996, 1998), although some authors have noted the scarcity of reliable data on elevation patterns (Colwell & Hurtt, 1994; Rahbek, 1995, 1997; Brown & Lomolino, 1998). This work exemplified how these areas show high diversity and how this pattern presents complex correlations ranging from the choice of study area, altitude, areas and sampling effort. Rodentia and Didelphidae also differed in their diversity patterns, revealing the need for these groups to be viewed individually.

VIII. ACKNOWLEDGEMENTS

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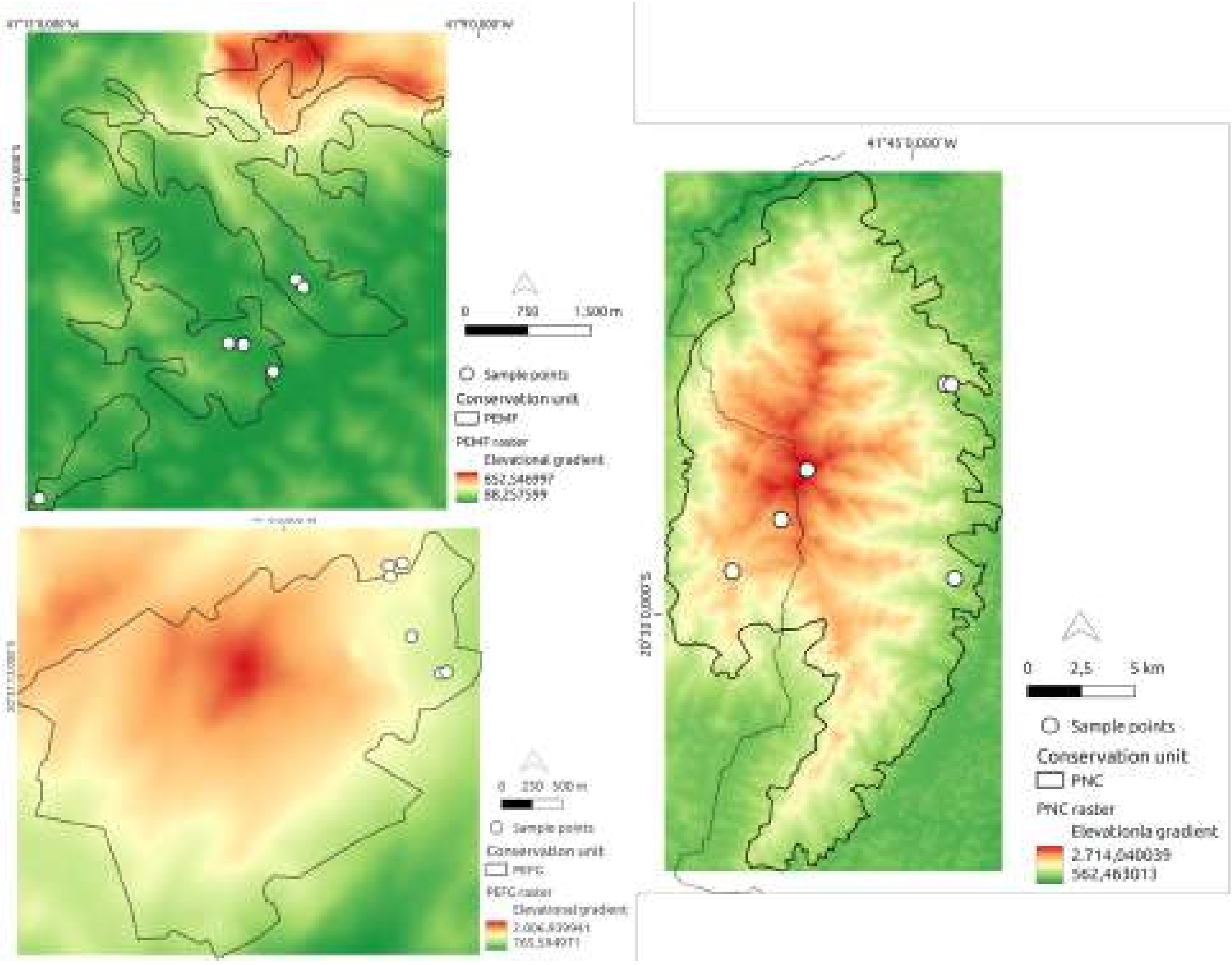
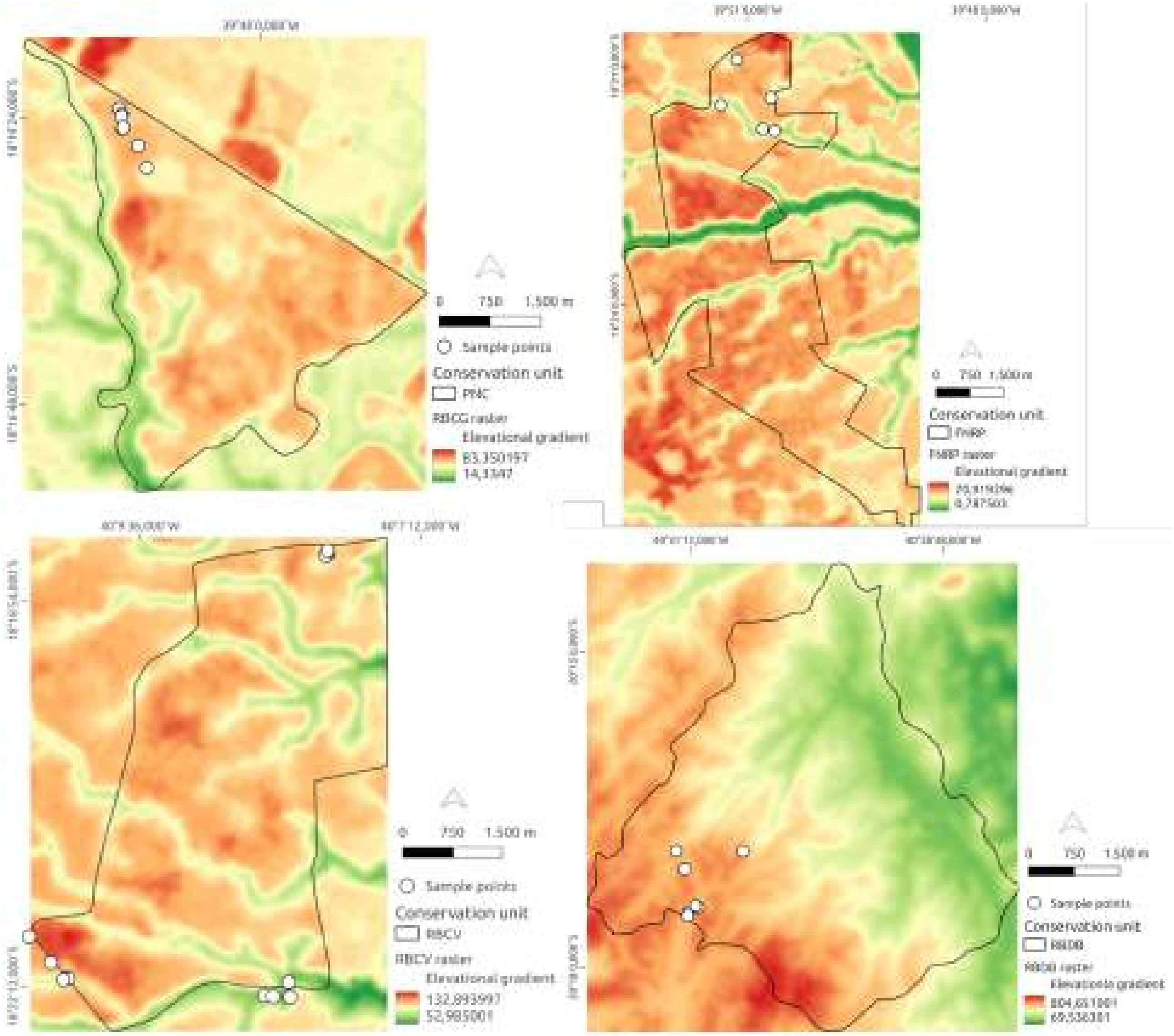
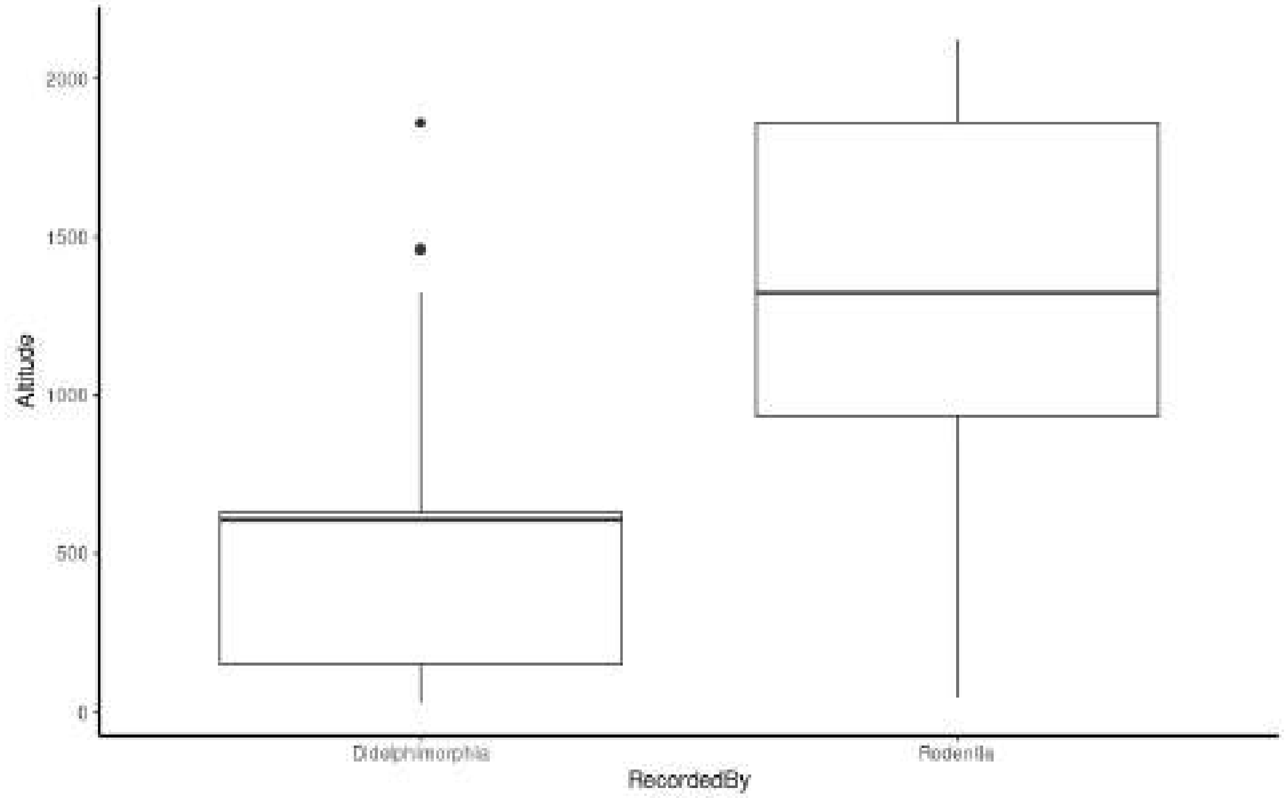
X APPENDIX



Appendix 1: Map showing sampling points and conservation units with elevation gradient highlighted. PEMF = Parque Estadual da Mata das Flores; PEFG = Parque Estadual do Forno Grande; PNC = Parque Nacional do Caparaó.



Appendix 2: Map showing sampling points and conservation units with elevation gradient highlighted. FNRP = Floresta Nacional do Rio Preto; RBCG = Reserva Biológica do Córrego Grande; RBCV = Reserva Biológica Córrego do Vedo; e, RBDB = Reserva Biológica de Duas Bocas.



Appendix 3: Kruskal-Wallis plot of the median altitudinal distribution of orders Didelphiomorphia and Rodentia elevational data along the Atlantic Forest range.

Appendix 4: Abundance (A), richness (R), sampling effort (SaE), minimum altitude (Min-A, in meters), maximum altitude (Max-A, in meters), mean altitude (Mean-A, in meters), area (in km²) and elevation range (in meters), for the different treatments for the fauna of non-volant small mammals in the study area in the Atlantic Forest, eastern Brazil.

Treatments	**Locality**	**A**	**R**	**SaE**	**J 1**	**Min-A**	**Max-A**	**Mean-A**	**Area**	**A R**
Locality	FNRP	27	5	5101	7,76	30	52	41	75,38	0,66
	PEFG	402	14	4172	18,83	1160	1490	1325	14,24	12,31
	PEMF	56	3	4312	3	112	153	132,5	30,49	7,64
	PNC	431	24	5952	29,92	935	2700	1817,5	550,6	23
	RBDB	393	19	5960	21,94	557	631	594	58,85	7,23
	RBCG	20	7	5101	8,8	45	68	56,5	41,79	0,69
	RBCV	67	9	5101	9,94	68	115	91,5	41,86	0,8
Elevational Bands	0-500m	170	13	19615	15,95	30	153	91,5	30,04	5
	500-1000m	393	19	5960	21,94	557	631	594	200,48	5
	1000-1500m	360	20	5552	26,85	935	1400	1167,5	188,52	5
	1500-2000m	342	20	3189	23,87	1460	1980	1720	131,43	5
	2000-2500m	126	9	1347	9,88	2000	2400	2200	68,3	5
	2500-3000m	7	4	351	4	2700	2700	2700	5,16	5
Group	Bottom	563	25	25575	29,96	30	631	330,5	189,51	7
	Intermediary	489	21	9018	27,86	935	1465	1200	539,03	12
	Upper	344	13	1698	14,88	1800	2700	2250	91,13	10
Order	Didelphomorphia	409	12	18145	12,99	30	2100	1065	767,27	20,7

Rodentia	987	30	18145	35,95	30	2700	1365	819,68	26,7

Appendix 5: List of fauna with collector code, geographical coordinates in decimal numbers and locality in conservation units. FNRP = Floresta Nacional do Rio Preto; PEFG = Parque Estadual do Forno Grande; PEMF = Parque Estadual da Mata das Flores; PNC = Parque Nacional do Caparaó; RBCG =; Reserva Biológica Córrego Grande; RBCV = Reserva Biológica do Córrego do Veado; RBDB = Reserva Biológica de Duas Bocas.

Species	**Locality**	**Latitude**	**Longitude**	**Record Number**
Didelphiomorphia				
Didelphidae				
Cryptonanus agricolai	RBCG	-18.23818	-39.81944	LPC 1604
	RBCV	-18.30792	-40.1328	LPC 1636
Didelphis aurita	FNRP	-18.36303	-39.84390	LPC 1675
	PEFG	-20.51917	-41.08722	LPC 1542
	PEMF	-20.61167	-41.16944	LPC 1510
		-20.61833	-41.17639	LPC 1502
				LPC 1507
			-41.17806	LPC 1503
		-20.62139	-41.17306	LPC 1500
				LPC 1501
				LPC 1506
				LPC 1512
	PNC	-20.42778	-41.86972	LGA 1595
		-20.48000	-41.83028	LGA 1285
	RBDB	-20.28111	-40.51138	LPC 1035
				LPC 1141
				LPC 1128
				LPC 1257
				LPC 993
Gracillinanus microtarsus	PEFG	-20.51083	-41.09139	LPC 1547
	PNC	-20.39611	-41.73472	LGA 1599
				LGA 1600
		-20.48000	-41.83028	LGA 1291
				LGA 1326
	RBCG	-18.2434	-39.81677	LPC 1625
	RBCV	-18.3075	-40.132833	LPC 1579
				LPC 1676
		-18.36836	-40.16996	LPC 1657

Species	Locality	Latitude	Longitude	Record Number
		-18.36847	-40.16987	LPC 1631
				LPC 1641
				LPC 1648
				LPC 1649
		-18.368633	-40.17055	LPC 1582
		-18.368967	-40.138417	LPC 1584
		-18.37097	-40.14063	LPC 1630
		-18.37109	-40.1382	LPC 1591
	RBDB	-20.28111	-40.51138	LPC 1091
				LPC 1265
				LPC 1098
				LPC 1112
				LPC 1140
				LPC 1074
				LPC 1133
				LPC 1256
				LPC 1262
				LPC 1071
	RBS	-18.3075	-40.132833	LPC 1676
Marmosa murina	FNRP	-18.34809	-39.85192	LPC 1666
				LPC 1676
		-18.36262	-39.84643	LPC 1674
	PEFG	-18.34809	-39.85192	LPC 1676
	RBCV	-18.368967	-40.138417	LPC 1576
		-18.37097	-40.14063	LPC 1626
Marmosa paraguayana	RBDB	-20.28111	-40.51138	LPC 1000
				LPC 1061
				LPC 1006
				LPC 1069
				LPC 1048
				LPC 1248
Marmosops incanus	FNRP	-18.34809	-39.85192	LPC 1667
				LPC 1668
				LPC 1669
				LPC 1671
				LPC 1672
				LPC 1673

Species	Locality	Latitude	Longitude	Record Number
		-18.35583	-39.84472	LPC 1606
				LPC 1607
				LPC 1608
				LPC 1609
				LPC 1610
				LPC 1611
				LPC 1613
				LPC 1614
				LPC 1615
		-18.35766	-39.85520	LPC 1664
				LPC 1665
		-18.36262	-39.84643	LPC 1662
		-18.36303	-39.84390	LPC 1663
				LPC 1670
	PEFG	-20.51056	-41.09028	LPC 1557
		-20.51083	-41.09139	LPC 1421
				LPC 1432
				LPC 1447
				LPC 1484
				LPC 1530
				LPC 1556
		-20.51167	-41.09111	LPC 1558
		-20.51639	-41.08944	LPC 1543
		-20.51917	-41.08722	LPC 1541
				LPC 1544
				LPC 1563
		20.51917	-41.08667	LPC 1526
				LPC 1538
	PEMF	-20.61083	-41.17056	LPC 1508
				LPC 1511
		-20.61167	-41.16944	LPC 1510
		-20.61833	-41.17639	LPC 1499
				LPC 1534
			-41.17806	LPC 1513
				LPC 1498
				LPC 1504
				LPC 1505

Species	Locality	Latitude	Longitude	Record Number
				LPC 1509
				LPC 1534
		-20.62139	-41.17306	LPC 1512
				LPC 1514
		-20.63611	-41.20000	LPC 1532
	PNC	-20.39611	-41.73472	LGA 1594
				LGA 1597
		-20.39861	-41.80972	LGA 1595
		-20.41000	-41.83778	LGA 1595
				LGA 1595
		-20.42139	-41.84444	LGA 1595
			-41.85111	LGA 1595
		-20.48333	-41.73028	LGA 1188
				LGA 1226
				LGA 1227
	RBCG	-18.23818	-39.81944	LPC 1604
		-18.23897	-39.81901	LPC 1604
	RBCV	-18.36847	-40.16987	LPC 1575
		-18.37109	-40.1382	LPC 1594
	RBDB	-20.28111	-40.51138	LPC 1169
				LPC 1220
				LPC 1236
				LPC 1239
				LPC 1249
				LPC 994
				LPC 1175
				LPC 1209
				LPC 1080
				LPC 1123
				LPC 1160
				LPC 1168
				LPC 1174
				LPC 1206
				LPC 1214
				LPC 1231
Marmosops paulensis	PNC	-20.48000	-41.83028	LGA 1310
				LGA 1339

Species	Locality	Latitude	Longitude	Record Number
				LGA 1340
				LGA 1350
Metachirus myosurus	FNRP	-18.35583	-39.84472	LPC 1612
	RBCG	-18.23818	-39.81944	LPC 1604
		-18.2434	-39.81677	LPC 1625
	RBDB	-20.28111	-40.51138	LPC 1011
				LPC 1030
				LPC 1042
				LPC 1047
				LPC 1060
				LPC 1077
				LPC 1078
				LPC 1094
				LPC 1172
				RBDB 118
				RBDB 12
				RBDB 13
				RBDB 18
				RBDB 23
				RBDB 40
				RBDB 58
				RBDB 60
				RBDB 65
				RBDB 67
				RBDB 71
				RBDB 75
				RBDB 90
				RBDB 92
				RBDB 99
				LPC 1013
				LPC 1088
				LPC 1101
				LPC 1173
				LPC 1260
				RBDB 102
				RBDB 110
				RBDB 111

Species	Locality	Latitude	Longitude	Record Number
				RBDB 112
				RBDB 117
				RBDB 38
				RBDB 43
				RBDB 63
				LPC 1019
				LPC 1075
				LPC 1079
				RBDB 109
				RBDB 31
				RBDB 50
				RBDB 61
				RBDB 71
				RBDB 99
				LPC 1059
				LPC 1093
				LPC 1174
				LPC 1213
				LPC 995
				RBDB 110
				RBDB 115
				RBDB 116
				RBDB 63
				RBDB 64
				RBDB 67
				RBDB 77
				RBDB 79
				LPC 1032
				LPC 1041
				LPC 1073
				LPC 1095
				LPC 997
				LPC 998
				RBDB 04
				RBDB 112
				RBDB 113
				RBDB 114

Species	Locality	Latitude	Longitude	Record Number
				RBDB 43
				RBDB 46
				RBDB 51
				RBDB 55
				RBDB 64
				RBDB 76
Monodelphis americana	PEFG	-20.51639	-41.08944	LPC 1548
	RBCV	-18.3075	-40.132833	LPC 1604
		-18.30814	-40.13312	LPC 1652
				LPC 1653
		-18.36836	-40.16996	LPC 1647
				LPC 1655
		-18.368633	-40.17055	LPC 1585
				LPC 1596
	RBDB	-20.28111	-40.51138	LPC 1028
				LPC 1029
				LPC 1081
				LPC 1088
				LPC 1129
				LPC 1130
				LPC 1144
				LPC 1211
				LPC 1221
				LPC 1226
				LPC 1246
				LPC 1258
				LPC 989
				LPC 999
				RBDB 103
				RBDB 73
				RBDB 98
				RBDB 99
				LPC 1045
				LPC 1119
				LPC 1138
				LPC 1142
				LPC 1217

Species	Locality	Latitude	Longitude	Record Number
				LPC 1219
				LPC 1232
				LPC 1240
				LPC 1247
				RBDB 101
				RBDB 104
				RBDB 105
				RBDB 85
				LPC 1014
				LPC 1131
				LPC 1178
				LPC 1243
				LPC 990
				RBDB 49
				RBDB 70
				RBDB 81
				RBDB 83
				RBDB 88
				RBDB 89
				RBDB 90
				RBDB 99
				LPC 1157
				LPC 1244
				LPC 1245
				LPC 1281
				LPC 991
				RBDB 94
				RBDB 96
				LPC 1018
				LPC 1125
				LPC 1158
				LPC 1159
				LPC 1181
				LPC 1222
				LPC 1227
				LPC 1228
				LPC 1230

Species	**Locality**	**Latitude**	**Longitude**	**Record Number**
				RBDB 53
				RBDB 91
Monodelphis iheringi	PNC	-20.48333	-41.73028	LGA 1195
	RBDB	-20.28111	-40.51138	LPC 1114
				LPC 1132
				LPC 1253
				RBDB 86
				LPC 1155
				LPC 1124
				LPC 1044
				LPC 1110
Monodelphis scalops	PNC	-20.39917	-41.72167	LGA 1595
		-20.42139	-41.84444	LGA 1595
		-20.48333	-41.73028	LGA 1224
				LGA 1236
Philander quica	PEFG	-20.51056	-41.09028	LPC 1557
		-20.51083	-41.09139	LPC 1431
				LPC 1445
				LPC 1556
		-20.51167	-41.09111	LPC 1443
				LPC 1444
				LPC 1476
				LPC 1528
				LPC 1558
		-20.51639	-41.08944	LPC 1433
				LPV 1467
		-20.51917	-41.08722	LPC 1417
				LPC 1518
				LPC 1563
		20.51917	-41.08667	LPC 1538
	PNC	-20.39611	-41.73472	LGA 1565
				LGA 1567
		-20.39917	-41.72167	LGA 1595
		-20.41000	-41.83778	LGA 1595
		-20.42139	-41.84444	LGA 1595
			-41.85111	LGA 1595
		-20.42778	-41.86972	LGA 1595

Species	**Locality**	**Latitude**	**Longitude**	**Record Number**
		-20.48333	-41.73028	LGA 1196
				LGA 1237
	RBDB	-20.28111	-40.51138	LPC 1127
Rodentia				
Cricetidae				
Akodon cursor	PEFG	-20.51056	-41.09028	LPC 1557
		-20.51083	-41.09139	LPC 1465
				LPC 1556
		-20.51167	-41.09111	LPC 1558
		-20.51639	-41.08944	LPC 1458
				LPC 1459
				LPC 1474
				LPC 1483
				LPC 1487
				LPV 1467
		-20.51917	-41.08722	LPC 1415
				LPC 1416
				LPC 1426
				LPC 1563
		20.51917	-41.08667	LPC 1450
				LPC 1451
				LPC 1453
				LPC 1529
				LPC 1538
	PNC	-20.3964	-41.7317	LGA 1556
				LGA 1558
				LGA 1559
				LGA 1560
				LGA 1561
				LGA 1562
				LGA 1563
				LGA 1564
				LGA 1579
				LGA 1580
				LGA 1583
				LGA 1584
				LGA 1586

Species	Locality	Latitude	Longitude	Record Number
				LGA 1595
		-20.39917	-41.72167	LGA 1595
		-20.42139	-41.84444	LGA 1595
			-41.85111	LGA 1595
		-20.48333	-41.73028	LGA 1187
				LGA 1193
				LGA 1203
				LGA 1206
				LGA 1207
				LGA 1211
				LGA 1217
				LGA 1218
				LGA 1219
				LGA 1220
				LGA 1221
				LGA 1222
				LGA 1223
				LGA 1231
				LGA 1234
	RBDB	-20.28111	-40.51138	LPC 1149
				LPC 1264
				LPC 1017
Akodon mystax	PNC	-20.39694	-41.78972	LGA 1595
		-20.42806	-41.82806	LGA 1595
		-20.43444	-41.79639	LGA 1595
		-20.45694	-41.80833	LGA 1605
				LGA 1617
				LGA 1619
				LGA 1621
				LGA 1643
				LGA 1656
				LGA 1657
				LGA 1672
				LGA 1682
				LGA 1686
				LGA 1702
				LGA 1704

Species	Locality	Latitude	Longitude	Record Number
				LGA 1706
				LGA 1711
				LGA 1713
				LGA 1715
				LGA 1716
				LGA 1719
				LGA 1720
				LGA 1724
				LGA 1731
				LGA 1740
				LGA 1748
		-20.48000	-41.83028	LGA 1515
				LGA 1315
				LGA 1325
				LGA 1327
				LGA 1328
				LGA 1330
				LGA 1391
				LGA 1461
Blarinomys breviceps	RBCG	-18.240833	-39.818889	LPC 1623
				LPC 1624
				LPC 1625
	RBDB	-20.28111	-40.51138	LPC 1242
				LPC 1259
Brucepattersonius griserufescens	PNC	-20.39917	-41.72167	LGA 1595
		-20.41000	-41.83778	LGA 1595
		-20.42139	-41.84444	LGA 1595
		-20.42778	-41.86972	LGA 1595
		-20.45694	-41.80833	LGA 1609
				LGA 1610
				LGA 1644
				LGA 1650
				LGA 1651
				LGA 1653
				LGA 1655
				LGA 1663
				LGA 1664

Species	Locality	Latitude	Longitude	Record Number
				LGA 1665
				LGA 1671
				LGA 1685
				LGA 1687
				LGA 1692
				LGA 1696
				LGA 1697
				LGA 1721
				LGA 1722
				LGA 1729
				LGA 1733
				LGA 1737
		-20.48000	-41.83028	LGA 1383
				LGA 1496
Calomys cerqueirai	FNRP	-18.35583	-39.84472	LPC 1605
	PNC	-20.39861	-41.80972	LGA 1595
Calomys tener	RBCV	-18.3075	-40.132833	LPC 1580
		-18.3625	-40.175383	LPC 1577
		-18.366183	-40.1723	LPC 1589
		-18.36836	-40.16996	LPC 1642
				LPC 1651
				LPC 1660
		-18.36847	-40.16987	LPC 1650
Castoria angustidens	PNC	-20.39694	-41.78972	LGA 1595
		-20.39861	-41.80972	LGA 1595
		-20.39917	-41.72167	LGA 1595
		-20.41000	-41.83778	LGA 1595
				LGA 1595
		-20.42139	-41.84444	LGA 1595
			-41.85111	LGA 1595
		-20.42778	-41.86972	LGA 1595
		-20.42806	-41.82806	LGA 1595
		-20.43444	-41.79639	LGA 1595
		-20.45694	-41.80833	LGA 1602
				LGA 1611
				LGA 1614
				LGA 1638

Species	Locality	Latitude	Longitude	Record Number
				LGA 1641
				LGA 1642
				LGA 1645
				LGA 1646
				LGA 1647
				LGA 1659
				LGA 1661
				LGA 1679
				LGA 1681
				LGA 1683
				LGA 1691
				LGA 1699
				LGA 1714
				LGA 1725
		-20.48000	-41.83028	LGA 1290
				LGA 1298
				LGA 1300
				LGA 1301
				LGA 1302
				LGA 1303
				LGA 1305
				LGA 1306
				LGA 1316
				LGA 1317
				LGA 1318
				LGA 1319
				LGA 1320
				LGA 1321
				LGA 1322
				LGA 1324
				LGA 1334
				LGA 1335
				LGA 1336
				LGA 1337
				LGA 1341
				LGA 1349
				LGA 1351

Species	Locality	Latitude	Longitude	Record Number
				LGA 1355
				LGA 1384
				LGA 1385
				LGA 1386
				LGA 1387
				LGA 1388
				LGA 1389
				LGA 1390
				LGA 1392
				LGA 1393
				LGA 1394
				LGA 1395
				LGA 1396
				LGA 1397
				LGA 1398
				LGA 1399
				LGA 1400
				LGA 1401
				LGA 1402
				LGA 1403
				LGA 1408
				LGA 1411
				LGA 1414
				LGA 1415
				LGA 1456
				LGA 1457
				LGA 1458
				LGA 1459
				LGA 1460
				LGA 1462
				LGA 1463
				LGA 1464
				LGA 1465
				LGA 1490
				LGA 1494
				LGA 1502
				LGA 1503

Species	Locality	Latitude	Longitude	Record Number
				LGA 1504
Cerradomys subflavus	RBCG	-18.23897	-39.81901	LPC 1604
		-18.24083	-39.81889	LPC 1619
				LPC 1621
				LPC 1622
	RBCV	-18.3075	-40.132833	LPC 1597
				LPC 1598
				LPC 1599
		-18.30792	-40.1328	LPC 1638
		-18.36836	-40.16996	LPC 1656
				LPC 1659
				LPC 1661
		-18.37088	-40.14182	LPC 1627
				LPC 1629
Delomys altimontanus	PNC	-20.39694	-41.78972	LGA 1595
		-20.39861	-41.80972	LGA 1595
		-20.41000	-41.83778	LGA 1595
				LGA 1595
		-20.42806	-41.82806	LGA 1595
		-20.43444	-41.79639	LGA 1595
		-20.45694	-41.80833	LGA 1603
				LGA 1604
				LGA 1616
				LGA 1626
				LGA 1630
				LGA 1634
				LGA 1639
				LGA 1658
				LGA 1660
				LGA 1668
				LGA 1669
				LGA 1670
				LGA 1673
				LGA 1674
				LGA 1675
				LGA 1676
				LGA 1677

Species	Locality	Latitude	Longitude	Record Number
				LGA 1684
				LGA 1690
				LGA 1698
				LGA 1701
				LGA 1707
				LGA 1708
				LGA 1717
				LGA 1723
				LGA 1726
				LGA 1728
				LGA 1736
				LGA 1741
				LGA 1743
		-20.48000	-41.83028	LGA 1286
				LGA 1289
				LGA 1293
				LGA 1296
				LGA 1297
				LGA 1299
				LGA 1308
				LGA 1309
				LGA 1311
				LGA 1312
				LGA 1314
				LGA 1333
				LGA 1338
				LGA 1344
				LGA 1346
				LGA 1348
				LGA 1356
				LGA 1357
				LGA 1378
				LGA 1379
				LGA 1380
				LGA 1381
				LGA 1409
				LGA 1410

Species	Locality	Latitude	Longitude	Record Number
				LGA 1412
				LGA 1416
				LGA 1420
				LGA 1421
				LGA 1422
				LGA 1423
				LGA 1424
				LGA 1425
				LGA 1426
				LGA 1427
				LGA 1428
				LGA 1429
				LGA 1430
				LGA 1431
				LGA 1432
				LGA 1433
				LGA 1434
				LGA 1435
				LGA 1436
				LGA 1437
				LGA 1438
				LGA 1439
				LGA 1440
				LGA 1441
				LGA 1442
				LGA 1443
				LGA 1444
				LGA 1445
				LGA 1446
				LGA 1447
				LGA 1448
				LGA 1449
				LGA 1451
				LGA 1452
				LGA 1466
				LGA 1467
				LGA 1468

Species	**Locality**	**Latitude**	**Longitude**	**Record Number**
				LGA 1473
				LGA 1474
				LGA 1475
				LGA 1476
				LGA 1477
				LGA 1478
				LGA 1479
				LGA 1480
				LGA 1481
				LGA 1482
				LGA 1483
				LGA 1484
				LGA 1485
				LGA 1488
				LGA 1489
				LGA 1493
				LGA 1497
				LGA 1498
				LGA 1499
				LGA 1500
				LGA 1501
				LGA 1505
Delomys dorsalis	PNC	-20.48000	-41.83028	LGA 1287
Delomys sublineatus	PEFG	-20.51083	-41.09139	LPC 1554
		-20.51167	-41.09111	LPC 1558
		-20.51917	-41.08722	LPC 1536
	PNC	-20.39611	-41.73472	LGA 1576
				LGA 1577
				LGA 1598
Euryoryzomys russatus	PEFG	-20.51917	-41.08722	LPC 1563
	PNC	-20.39917	-41.72167	LGA 1595
Gracillinanus microtarsus	RBCV	-18.3075	-40.132833	LPC 1676
	RBS	-18.3075	-40.132833	LPC 1676
Juliomys ossitenuis	PNC	-20.45694	-41.80833	LGA 1718
		-20.48000	-41.83028	LGA 1360
Juliomys pictipes	RBDB	-20.28111	-40.51138	LPC 1010
				LPC 1207

Species	**Locality**	**Latitude**	**Longitude**	**Record Number**
Necromys lasiurus	RBCG	-18.23818	-39.81944	LPC 1604
		-18.24083	-39.81889	LPC 1616
				LPC 1617
				LPC 1620
	RBCV	-18.3075	-40.132833	LPC 1581
				LPC 1587
				LPC 1590
				LPC 1600
				LPC 1601
				LPC 1602
		-18.30792	-40.1328	LPC 1632
				LPC 1633
				LPC 1637
				LPC 1639
				LPC 1640
				LPC 1654
				LPC 1658
		-18.3625	-40.175383	LPC 1578
				LPC 1586
				LPC 1595
				LPC 1603
		-18.36836	-40.16996	LPC 1634
				LPC 1635
				LPC 1643
				LPC 1644
				LPC 1646
				LPC 1653
		-18.37088	-40.14182	LPC 1628
Nectomys squamipes	PEMF	-20.61833	-41.17639	LPC 1534
			-41.17806	LPC 1533
		-20.63611	-41.20000	LPC 1532
	PNC	-20.42778	-41.86972	LGA 1595
		-20.48333	-41.73028	LGA 1191
				LGA 1215
				LGA 1216
				LGA 1233
				LGA 1238

Species	Locality	Latitude	Longitude	Record Number
				LGA 1239
	RBCG	-18.23818	-39.81944	LPC 1604
		-18.240833	-39.818889	LPC 1618
		-18.24649	-39.81556	LPC 1625
	RBCV	-18.368967	-40.138417	LPC 1593
		-18.37109	-40.1382	LPC 1583
				LPC 1588
				LPC 1592
	RBDB	-20.28111	-40.51138	LPC 1117
				LPC 1118
				LPC 1143
				LPC 1146
				LPC 1165
				LPC 1166
				LPC 1177
				LPC 1229
				LPC 1233
				RBDB 99
				LPC 1122
				LPC 1145
				LPC 1109
Oecomys catherinae	RBCG	-18.23818	-39.81944	LPC 1604
	RBDB	-20.28111	-40.51138	LPC 1163
				LPC 1164
Oligoryzomys flavescens	PNC	-20.39611	-41.73472	LGA 1575
		-20.39861	-41.80972	LGA 1595
		-20.41000	-41.83778	LGA 1595
				LGA 1595
		-20.42806	-41.82806	LGA 1595
		-20.45694	-41.80833	LGA 1618
				LGA 1625
				LGA 1629
				LGA 1710
				LGA 1734
				LGA 1738
				LGA 1747
		-20.48000	-41.83028	LGA 1304

Species	Locality	Latitude	Longitude	Record Number
				LGA 1307
				LGA 1313
				LGA 1329
				LGA 1332
				LGA 1354
				LGA 1358
				LGA 1359
				LGA 1362
				LGA 1364
				LGA 1365
				LGA 1366
				LGA 1367
				LGA 1368
				LGA 1377
				LGA 1404
				LGA 1417
				LGA 1418
				LGA 1419
				LGA 1450
				LGA 1453
				LGA 1454
				LGA 1455
				LGA 1469
				LGA 1470
				LGA 1471
				LGA 1472
Oligoryzomys nigripes	PEFG	-18.34809	-39.85192	LPC 1676
		-20.51056	-41.09028	LPC 1419
				LPC 1439
				LPC 1440
				LPC 1557
		-20.51083	-41.09139	LPC 1420
				LPC 1479
				LPC 1480
				LPC 1521
				LPC 1556
		-20.51167	-41.09111	LPC 1558

Species	Locality	Latitude	Longitude	Record Number
		-20.51639	-41.08944	LPC 1422
				LPC 1423
				LPC 1424
				LPC 1434
				LPC 1435
				LPC 1441
				LPC 1442
				LPC 1446
				LPC 1454
				LPC 1455
				LPC 1456
				LPC 1457
				LPC 1466
				LPC 1468
				LPC 1469
				LPC 1481
				LPC 1482
				LPC 1485
				LPC 1522
				LPV 1467
		-20.51917	-41.08667	LPC 1428
			-41.08722	LPC 1427
				LPC 1519
				LPC 1563
		20.51917	-41.08667	LPC 1429
				LPC 1430
				LPC 1436
				LPC 1449
				LPC 1452
				LPC 1461
				LPC 1462
				LPC 1463
				LPC 1464
				LPC 1477
				LPC 1515
				LPC 1523
				LPC 1524

Species	Locality	Latitude	Longitude	Record Number
				LPC 1525
				LPC 1527
				LPC 1538
	PNC	-20.39611	-41.73472	LGA 1574
				LGA 1585
				LGA 1592
				LGA 1593
				LGA 1601
		-20.39861	-41.80972	LGA 1595
		-20.39917	-41.72167	LGA 1595
		-20.41000	-41.83778	LGA 1595
				LGA 1595
		-20.42139	-41.84444	LGA 1595
			-41.85111	LGA 1595
		-20.45694	-41.80833	LGA 1703
				LGA 1732
		-20.48000	-41.83028	LGA 1570
				LGA 1361
				LGA 1363
				LGA 1382
				LGA 1413
		-20.48333	-41.73028	LGA 1194
				LGA 1200
				LGA 1201
				LGA 1204
				LGA 1228
	RBDB	-20.28111	-40.51138	LPC 1005
				LPC 1027
				LPC 1037
				LPC 1048
				LPC 1100
				LPC 1120
				LPC 1147
				LPC 1148
				LPC 1152
				LPC 1182
				LPC 1212

Species	Locality	Latitude	Longitude	Record Number
				LPC 1058
				LPC 1126
				LPC 1151
				LPC 1216
				LPC 1237
				LPC 1001
				LPC 1115
				LPC 1161
				LPC 1171
				LPC 1218
				LPC 1136
				LPC 1162
				LPC 1224
				LPC 1250
				LPC 1009
				LPC 1153
				LPC 1156
Oxymycterus caparaoe	PNC	-20.39611	-41.73472	LGA 1571
		-20.39861	-41.80972	LGA 1595
		-20.41000	-41.83778	LGA 1595
		-20.42806	-41.82806	LGA 1595
		-20.45694	-41.80833	LGA 1606
				LGA 1608
				LGA 1613
				LGA 1615
				LGA 1622
				LGA 1623
				LGA 1624
				LGA 1627
				LGA 1628
				LGA 1631
				LGA 1633
				LGA 1637
				LGA 1640
				LGA 1648
				LGA 1649
				LGA 1654

Species	Locality	Latitude	Longitude	Record Number
				LGA 1662
				LGA 1666
				LGA 1667
				LGA 1680
				LGA 1688
				LGA 1689
				LGA 1694
				LGA 1695
				LGA 1700
				LGA 1705
				LGA 1709
				LGA 1712
				LGA 1727
				LGA 1730
				LGA 1735
				LGA 1739
				LGA 1742
				LGA 1744
				LGA 1745
				LGA 1746
		-20.48000	-41.83028	LGA 1288
				LGA 1292
				LGA 1294
				LGA 1295
				LGA 1323
				LGA 1331
				LGA 1347
				LGA 1352
				LGA 1353
				LGA 1369
				LGA 1370
				LGA 1371
				LGA 1372
				LGA 1373
				LGA 1374
				LGA 1375
				LGA 1405

Species	**Locality**	**Latitude**	**Longitude**	**Record Number**
				LGA 1406
				LGA 1407
				LGA 1487
				LGA 1495
		-20.48333	-41.73028	LGA 1210
				LGA 1229
				LGA 1230
				LGA 1232
Oxymycterus dasytrichus	PEFG	-20.51056	-41.09028	LPC 1550
				LPC 1557
		-20.51083	-41.09139	LPC 1470
				LPC 1471
				LPC 1472
				LPC 1473
				LPC 1520
				LPC 1552
				LPC 1553
				LPC 1555
				LPC 1556
		-20.51639	-41.08944	LPC 1517
				LPC 1531
				LPC 1535
				LPC 1546
				LPC 1562
		-20.51917	-41.08722	LPC 1418
	PNC	-20.39611	-41.73472	LGA 1572
				LGA 1581
				LGA 1587
				LGA 1588
		-20.39694	-41.78972	LGA 1595
		-20.39861	-41.80972	LGA 1595
		-20.41000	-41.83778	LGA 1595
		-20.42806	-41.82806	LGA 1595
Rhagomys rufescens	PEFG	-20.51083	-41.09139	LPC 1475
Rhipidomys mastacalis	RBDB	-20.28111	-40.51138	LPC 1052
				LPC 1053
				LPC 1054

Species	Locality	Latitude	Longitude	Record Number
				LPC 1076
				LPC 1084
				LPC 1121
				LPC 1150
				LPC 1257
				LPC 1051
				LPC 1055
				LPC 1083
				LPC 1102
				LPC 1103
				LPC 1150
				LPC 1049
				LPC 1106
				LPC 1234
				LPC 1067
Rhipidomys tribei	PEFG	-20.51083	-41.09139	LPC 1448
				LPC 1486
				LPC 1556
	PNC	-20.48333	-41.73028	LGA 1202
				LGA 1205
Sooretamys angouya	PNC	-20.39611	-41.73472	LGA 1569
		-20.39917	-41.72167	LGA 1595
		-20.42139	-41.84444	LGA 1595
		-20.42778	-41.86972	LGA 1595
		-20.48333	-41.73028	LGA 1186
				LGA 1190
Thaptomys nigrita	PEFG	-20.51639	-41.08944	LPC 1425
		-20.51917	-41.08722	LPC 1537
				LPC 1545
		20.51917	-41.08667	LPC 1516
	PNC	-20.39861	-41.80972	LGA 1595
		-20.41000	-41.83778	LGA 1595
		-20.42139	-41.84444	LGA 1595
		-20.42806	-41.82806	LGA 1595
		-20.43444	-41.79639	LGA 1595
		-20.45694	-41.80833	LGA 1632
				LGA 1635

Species	Locality	Latitude	Longitude	Record Number
				LGA 1652
				LGA 1678
				LGA 1693
		-20.48000	-41.83028	LGA 1376
				LGA 1486
				LGA 1491
				LGA 1492
	RBDB	-20.28111	-40.51138	LPC 992
				LPC 1050
Echimyidae				
Trinomys gratiosus	PNC	-20.48333	-41.73028	LGA 1199
Trinomys paratus	RBDB	-20.28111	-40.51138	RBDB 99
Euryzygomatomys spinosus	PNC	-20.42806	-41.82806	LGA 1595
Phyllomys pattoni	RBDB	-20.28111	-40.51138	LPC 1127
				LPC 1167
				LPC 1238
				LPC 1105
				LPC 1215
				LPC 1223
				LPC 1235
Trinomys gratiosus	PEFG	-20.51917	-41.08722	LPC 1437
				LPC 1438
				LPC 1460
				LPC 1478
				LPC 1537
	PNC	-20.39611	-41.73472	LGA 1557
				LGA 1566
				LGA 1568
				LGA 1573
				LGA 1578
				LGA 1596
		-20.39917	-41.72167	LGA 1595
		-20.48333	-41.73028	LGA 1198
				LGA 1212
				LGA 1213
Trinomys paratus	RBDB	-20.28111	-40.51138	LPC 1002
				LPC 1008

Species	Locality	Latitude	Longitude	Record Number
				LPC 1020
				LPC 1033
				LPC 1034
				LPC 1039
				LPC 1043
				LPC 1063
				LPC 1064
				LPC 1065
				LPC 1096
				LPC 1097
				LPC 1241
				RBDB 100
				RBDB 36
				RBDB 39
				RBDB 60
				RBDB 68
				RBDB 79
				RBDB 97
				RBDB 99
				LPC 1007
				LPC 1021
				LPC 1024
				LPC 1070
				LPC 1082
				LPC 996
				RBDB 37
				RBDB 47
				RBDB 62
				RBDB 82
				RBDB 99
				LPC 1015
				LPC 1038
				LPC 1066
				LPC 1099
				RBDB 05
				RBDB 19
				RBDB 20

Species	**Locality**	**Latitude**	**Longitude**	**Record Number**
				RBDB 31
				RBDB 38
				RBDB 41
				RBDB 44
				RBDB 99
				LPC 1003
				LPC 1012
				LPC 1016
				LPC 1022
				LPC 1056
				LPC 1057
				LPC 1062
				LPC 1068
				LPC 1085
				LPC 1086
				LPC 1090
				LPC 1104
				RBDB 17
				RBDB 32
				RBDB 33
				RBDB 35
				RBDB 48
				RBDB 52
				RBDB 78
				RBDB 99
				LPC 1004
				LPC 1023
				LPC 1025
				LPC 1026
				LPC 1031
				LPC 1072
				LPC 1089
				RBDB 42
				RBDB 45
				RBDB 93
Muridae				
Rattus rattus	RBDB	-20.28111	-40.51138	LPC 1225

Capítulo 2

THE NON-VOLANT SMALL MAMMAL FAUNA OF SERRA DO CAPARAÓ, EASTERN BRAZIL

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I. ABSTRACT

Mountainous regions, from slopes to peaks and valleys, contain more than 87% of the terrestrial vertebrate fauna, occupying only 25% of the Earth's surface, except for Antartica, and little is known about the reason for this concentration of richness. This doubt is called Humboldt's puzzle. This high diversity is mainly found in the tropics, with the Serra do Caparaó in the Atlantic Rainforest being an important example. This region, characterized by fragments of forest and altitude fields, once used for cattle ranching, is home to the Parque Nacional do Caparaó, which was created to preserve the local unique flora and fauna and make possible the development of studies. Given the importance of the region, a survey of non-volant small mammals was conducted and compared with secondary data to understand the fauna and changes in its composition along the altitudinal gradient and forest cover. A total of 27 species out of 827 records were recorded, 24 from primary data and 20 from secondary sources, including species that are typical for the area as well as endangered species. If we group the altitude distribution in 500-m intervals, there is a decreasing pattern of richness with increasing altitude. But if we look at the Jaccard similarity for richness by altitude, two groups are formed: one of specialist species inhabiting the highest level and the other inhabiting the lowest level, which is intermediate for the whole range of the Atlantic Forest and where most of the marsupials occur. Altitude was found to be significantly important for the distribution of 17 species (*Akodon cursor*, *Akodon mystax*, *Brucepattersonius griserufescens*, *Calomys cerqueirai*, *Castoria angustidens*, *Delomys altimontanus*, *Delomys dorsalis*, *Euryzygomatomys spinosus*, *Juliomys ossitenuis*, *Marmosops incanus*, *Marmosops paulensis*, *Nectomys squamipes*, *Oligoryzomys flavescens*, *Oligoryzomys nigripes*, *Oxymycterus caparaoe*, *Oxymycterus dasytrichus*, and *Thaptomys nigrita*) with species of the genera *Akodon*, *Delomys*, *Marmosops*, *Oligoryzomys*, and *Oxymycterus* separated by elevation. For Serra do Caparaó, richness demonstrated a decreasing pattern, while abundance demonstrated an increasing pattern, in relation to increasing altitude.. These altitude fields ("Campos de altitudes") species are more closely associated with species from the open areas of southern Brazil, the open areas of Argentina, and the Andes.

II. HIGHLIGHTS

i. With 27 registered species, including many rare and endemic, Serra do Caparaó is an important refuge for non-volant small mammals in the Atlantic Forest.

ii. A decreasing pattern of richness was observed with increasing altitude, but the lowest values for the Serra do Caparaó correspond to intermediate altitudes for other studied localities in the Atlantic Forest.

iii. Two communities of non-volant small mammal fauna were observed, one corresponding to the intermediate portion of the Atlantic Forest and the other of endemic species adapted to high altitudes. Faunas from adjacent altitudes overlap in this intermediate community.

iv. Richness demonstrated a decreasing pattern, while abundance demonstrated an increasing pattern, in relation to increasing altitude.

v. Rodents showed a larger altimetric distribution than marsupials, being able to colonize even the highest points. Didelphiomorphia was more closely related to Atlantic rainforest.

III. KEYWORDS:

Mountains; Atlantic Forest; High altitude grassland; Humboldt’s enigma, non-volant small mammal.

IV. INTRODUCTION

The world's mountain regions, ranging from slopes and peaks to valleys and adjacent foothills, contain approximately 87% of the world's amphibian, bird, and mammal species, many of them endemic, even though they occupy only about 25% of the land mass if we exclude Antarctica (Rahbek,et al., 2019). However, current hypotheses for large-scale geographic patterns of diversity cannot explain this difference, which has become known as "Humboldt's enigma" (Rahbek & Graves, 2001; Jetz & Rahbek, 2002; Rahbeck et al., 2007; Antonelli et al., 2018). This diversity is found primarily in the tropics, with the high diversity of the Atlantic Forest highlands of eastern Brazil being particularly intriguing because it is one of the least topographically complex mountain regions (Rahbek et al., 2019).

One important tropical highland area is Serra do Caparaó, with the highest peak in the Atlantic Forest, “Pico da Bandeira” (2,892 m), being this also the third tallest point in Brazil (IBGE 2012, ICMBio 2015). This region is under heavy anthropogenic pressure, which led to the creation of the Parque Nacional do Caparaó (PNC) in 1961 (ICMBio 2015), although it only became effective in 1979 (IBDF, 1981), even though efforts to create it began in 1948 but were postponed due to lack of resources (Pádua & Coimbra, 1979). According to Santos (1973) based on interviews carried out in the region and taken by researches of the "Caparaó Project" - COLTEC/UFMG, the impacts suffered in the area date back to the 19th century, when the region was used as a collective pasture for extensive cattle ranching, when it was previously known only as "Campo", which led to friction with the surrounding population with the creation of the conservation unit and retaliation through arson (Santos 2013). Another impact on the area was coffee cultivation, which has expanded with the rise in temperature and the reduction of frosts up to 1,200 m above sea level, as perceived by the inhabitants (Santos 2013). More recently, there has been an increase in real estate occupation and coffee monoculture (ICMBio 2015).

Despite these impacts, the region is of great ecological importance, with the first scientific expedition recorded in the 1880s by Schwacke. In his report, he lamented that until recently "the Serra could not be known because of the hordes of Indians that crossed it" (Derby 1889). In 1922, there was a Belgian-Brazilian mission where the explorers supported the creation of a reserve (Santos 2013). At the beginning of the 1940s, the "Forestry Service" - the Brazilian federal agency in charge of environmental issues at that time - carried out an excursion to scientifically map the Serra do Caparaó (Brade 1942) and already emphasized how much the Serra had already been devastated. Regarding mammals, the first faunal list available for Caparaó was published by Ruschi (1978), who mentioned eight marsupials and thirteen species of small rodents. Posteriorly, between 1979-1980, Blair (1989) used the region to argue for the greater diversity of tropical habits and many endemic species compared to the Nearctic. More recently, there have been publications by Bonvicino et al. in 1997 and Ventura et al. in 2012. These expeditions resulted in recently described species that have the Serra do Caparaó as their type locality, such as *Delomys altimontanus* (Gonçalves & Oliveira, 2014), *Akodon mystax* (Hershkovitz, 1998), *Brucepattersonius griserufescens* (Hershkovitz, 1998) and *Oxymycterus caparaoe* (Hershkovitz, 1998), all specialists species of high altitudes.

Given the ecological importance of the Serra do Caparaó, this work aims to test two hypotheses: (1) that we will find the same pattern of altimetric distribution of non-volant small mammals in two independent faunal surveys; and (2) that richness will increase with increasing sampling effort. In addition, we will use the data set to characterize this fauna and analyze whether there have been changes in the composition of this fauna over two time intervals.

V. MATERIALS AND METHOD

The Parque Nacional do Caparaó (PNC) is a conservation unit (CU) located a mountain region in the border of Minas Gerais and Espírito Santo states, southeastern Brazil, reaching almost 3,000 m above sea level. It encompasses nine municipalities between 20º19'0" and 20º37'0" latitude and 41º43'0" W and 41º53'0' W longitude (Figure 1, Appendix 1), four in Minas Gerais state (Alto Caparaó, Caparaó, Espera

Feliz and Alto Jequitibá) and five in Espírito Santo state (Divino de São Lourenço, Dores do Rio Preto, Ibitirama, Iúna and Irupi). Of the 26,000 hectares, about 70% are in the State of Espírito Santo and 30% in Minas Gerais. Its relief is mountainous, with altitudes ranging from 800 to 2,892 m at Pico da Bandeira, the third highest peak in Brazil. The physiognomic-ecological vegetation classification system for the Dense Ombrophilous Forest of the Atlantic Rainforest can be ordered according to topographic hierarchies, due to the progressive decrease in soil depth, which leads to a decrease in the height of the vegetation canopy (Veloso 1992). Thus, in the Serra do Caparaó region, the vegetation can be classified as Atlantic Rainforest "Montana", between 500 and 1,200 m; Atlantic Rainforest "Altimontana", between 1,200 and 2,000 m (Veloso 1992); and; "Campos de altitude" (altitude fields) above 2,000 m (Cosenza et al. 2007). On the tops of mountain massifs with a worn and flattened surface, it can be divided by better drained valleys where altimontane forests penetrate (Brade, 1956; Segadas-Vianna, 1965; Martinelli & Bandeira, 1989; Veloso et al. 1992; Dean, 1996). And, the seasonal regime for the PNC are divided in a rainy summer (from November to March) and a wet winter (from April to October) (Machado et al. 2016).

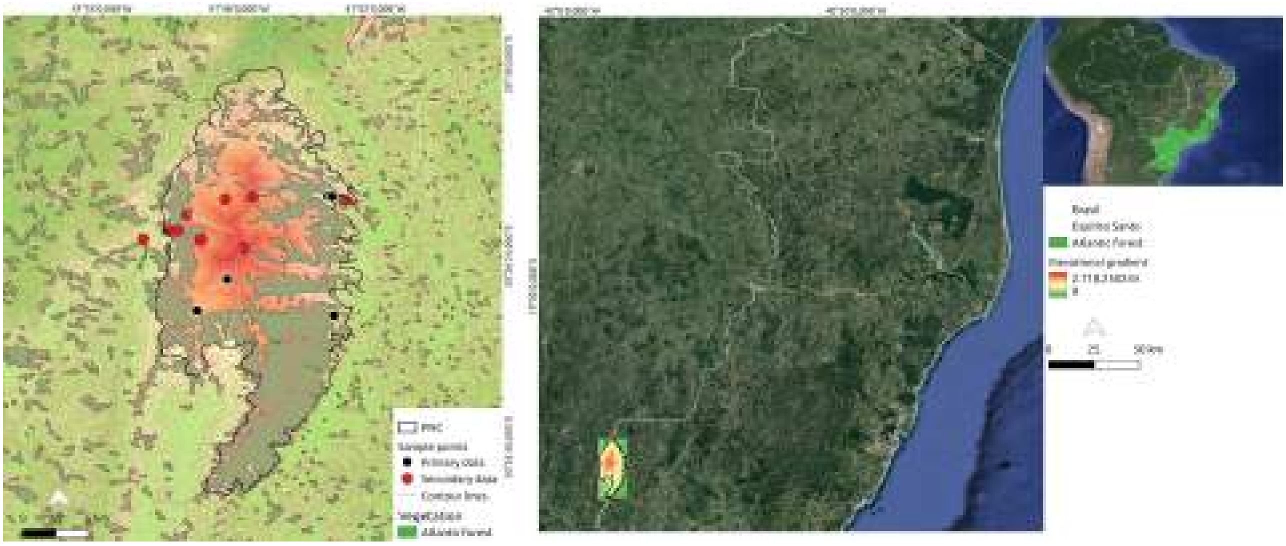

Figure 1: From right to left, maps showing the area of Brazil in South America, limits of federation units and the Atlantic Forest cover in bright green; the localization of Parque Nacional do Caparaó (PNC), on the limits of Minas Gerais and Espírito Santo states; and the elevation gradient in PNC, with primary and secondary sampling points.

The primary data were collected in partnership with the Laboratório de Biologia Animal (LGA - UFES) during field campaigns in 2006, when Sherman traps (23 × 9 × 9 cm) and two-wire Tomahawk traps (32 × 15 × 15 cm) baited with bananas, oats, sardines and peanut butter were used in each trapping sttaion to collect small mammals. The at four localities: i. "Santa Marta" (42º43'46"W, 20º29'40"S), located in the municipality of Ibitirama, characterized by mid-elevation area (800-1,000 m), sampled on 04-12 March/2006 with 1,740 traps-night; ii. "Pedra Roxa" (41º44'5"W, 20º23'44"S), located in the municipality of Irupi, another mid-elevation area (945-1095 m), sampled on 02-09 September/2006 with 1,726 traps-night; iii. "Macieira" (41º49'50"W, 20º28'42"S), located in the municipality of Dores do Rio Preto, plateau area (1,788-1,938 m), sampled from 28 May to 3 June/2006 with 1103 traps-night; iv. "Casa Queimada" (2,123 m), located in the municipality of Ibitirama, sampled from 13 to 22 September/2006 with 1,347 traps-night.

Based on the primary data, we calculated the species richness, abundance, and the nonparametric richness estimator first-order Jackknife (Heltshe & Forrester, 1983). Rarefaction and collecting curves were generated. Along with secondary data we created a Jaccard similarity cluster (Seger et al., 2005) based on altitude to check for clusters in the community of non-volant small mammals (Figure 2). We also measred the richness according to 500-meter bands, including the lowest point of 935 meters, included in the upper band of 1,000-1,500 m. In addition, data normality was assessed using Shapiro-Wilk's test, and only variables with normal distributions were used in subsequent non-parametric tests (Appendix 2 and 3). Kruskal-Wallis was used to determine if there was a difference in mean elevation for both the non-volant small mammal assemblage and for each species (Appendix 4). The R software (version 4.3.2) was used in the R Studio environment (version 2023-12-0) for analysis and graphics. Maps of the location of this area are constructed by the program QGIS (version 3.22.4), were made highlighting their boundariesand altitude from a raster of the Digital Elevation Model (DEM), we calculated the elevation using the Zonal Statistics tool and then generated lines (Contour tool). Vegetation cover based of vegetation covered provided (SOS Mata Atlântica & INPE, 2017). Species were classified according to their level of threat at the global (IUCN, 2023), national (MMA, 2022), and state (Espírito Santo, 2022) levels.

VI. RESULTS

Our primary data, derived from a trap effort of 5,952 traps/night result in 24 registered species in 441 records (7.4% success) (Table 1, Appendix 6), between the months of March and September 2016. The most abundant species was *Delomys altimontanus* (25.39%) followed by *Castoria angustidens* (17.68%) and *Oxymycterus caparaoe* (13.83%), all three species being restricted to a specific altitudinal distribution. On 39 sampling days, the rarefaction curve did not reach the asymptote, although it showed a tendency to do so, and did not show a new accumulation of species in the last part of the collector curve (Figure 2). The estimated first-order Jackknife richness for the primary data was 26.92 ± 1.68 in 39 days of sampling, which was consistent with the observed total richness. When considering the orders, the estimated and observed richness were also similar, with seven Didelphiomorphia for an estimate of 8.84 ± 1.30 in 13 days of sampling and 17 Rodentia for 17.97 ± 0.97 in 37 days of sampling.

Table 1: Species abundance per 500 m band, 100-m elevation and data type (P = Primary, S = Secondary) in the Serra do Caparaó, Eastern Brazil.

Bands (500-m)		**1000-1500**					**1500-2000**			**2000-2500**				**2500-3000**		**Total**
Altitude (100-m)		**1000**	**1100**		**1200**	**1300**	**1500**	**1900**		**2100**	**2200**		**2400**	**2500**	**2800**	
Data type		**P**	**S**	**P**	**S**	**S**	**S**	**S**	**P**	**S**	**S**	**P**	**S**	**S**	**S**	
DIDELPHIOMORPHA																
DIDELPHIDAE	*Didelphis aurita*		2						1							**3**
	Gracillinanus microtarsus			2					2							**4**
	Marmosops incanus	3		2		3	1	10		4	1					**24**
	Marmosops paulensis								4							**4**
	Monodelphis iheringi	1														**1**
	Monodelphis scalops	2			1		1									**4**
	Philander quica	2	3	2	2	1	7	1								**18**
RODENTIA																
CRICETIDAE	*Akodon cursor*	15		14	10	17	20									**76**
	Akodon mystax			1					7			23	8	12	4	**55**
	Brucepattersonius griserufescens		3		3		1	1	2			20				**30**
	Calomys cerqueirai										1					**1**
	Castoria angustidens		1		1	1	2	23	60	4	21	18	5	26	1	**163**
	Delomys altimontanus							16	82	4	15	30	2	27	1	**177**
	Delomys dorsalis								1							**1**
	Delomys sublineatus			3												**3**
	Euryoryzomys russatus				2											**2**
	Juliomys ossitenuis								1			1				**2**
	Nectomys squamipes	6	3													**9**

Bands (500-m)		**1000-1500**					**1500-2000**			**2000-2500**				**2500-3000**		**Total**
Altitude (100-m)		**1000**	**1100**		**1200**	**1300**	**1500**	**1900**		**2100**	**2200**		**2400**	**2500**	**2800**	
	Oligoryzomys flavescens			1				1	25	1	10	7		11		**56**
	Oligoryzomys nigripes	4		6	2	2	3	1	4	4	3	2				**31**
	Oxymycterus caparaoe	4		1				2	21		3	35		13		**79**
	Oxymycterus dasytrichus			4				1			13		4	11		**33**
	Rhipidomys tribei	2														**2**
	Sooretamys angouya	2	1	1	2		3									**9**
	Thaptomys nigrita						4	3	3		1	5		5	1	**22**
ECHIMYIDAE	*Euryzygomatomys spinosus*													1		**1**
	Trinomys gratiosus	3		6	5											**14**
Total		**44**	**13**	**43**	**28**	**24**	**42**	**59**	**213**	**17**	**68**	**141**	**19**	**106**	**7**	**824**

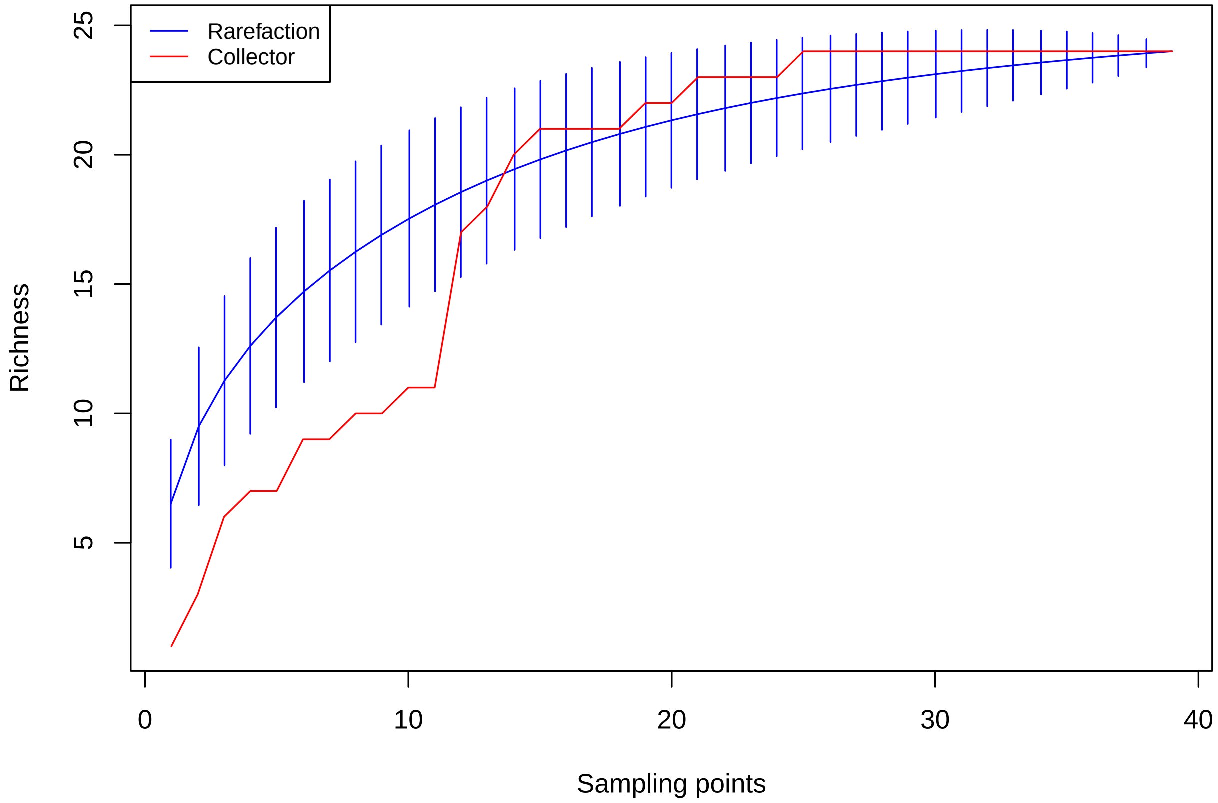

Figure 2: Species rarefaction curve and collector curve to primary data in 39 samples unites in Serra do Caparó, Eastern Brazil.

The total richness found was 27 species in 824 records (Table 1), including all those with the type locality for Serra do Caparaó. Among the species listed, *Akodon mystax* and *Brucepattersonius griserufescens* are considered critically endangered in the Espírito Santo state, and *Delomys altimontanus* and *Oxymycterus caparaoe* are considered vulnerable (Espírito Santo, 2022). Nationally, *Akodon mystax* is listed as vulnerable, *Rhipidomys tribei* as endangered and *Oxymycterus caparaoe* as near threatened (MMA 2022). In addition, the IUCN (2023) considers *Akodon mystax*, *Bruceparttersonius griserufescens*, *Rhipidomys tribei* and *Monodephis iheringi as* data deficient

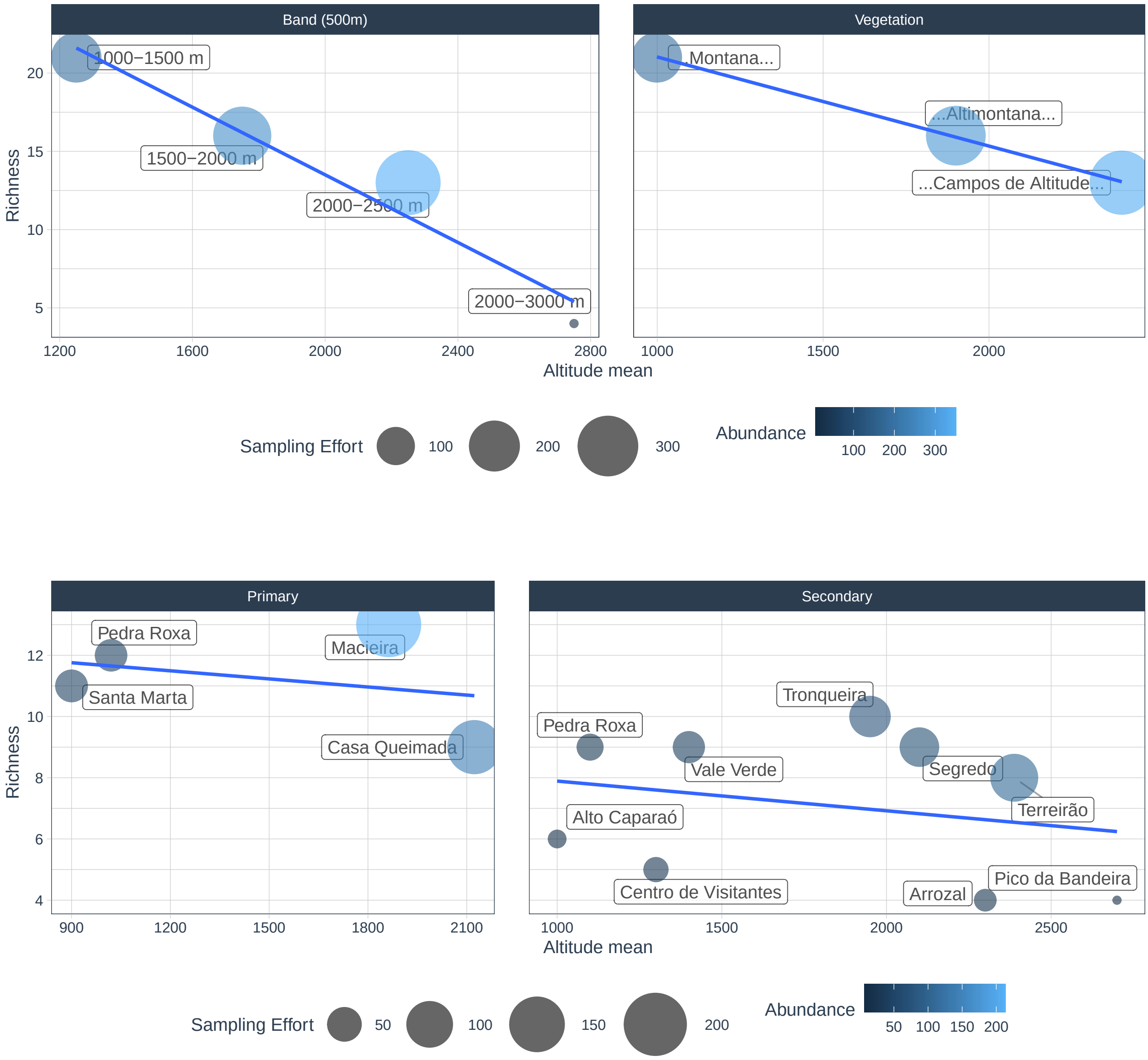

Figure 3: Relationship between richness and elevation with linear regression with emphasis on sampling effort and abundance for altimertric bads, vegetation and for primary and secondary data.

A Jaccard similarity dendogram showed that, even with different collection efforts between altitudes, there was a separation into two faunal groups, one for the lower altitudes (925-1,400 m) and one for the higher altitudes (1,800-2,700m) within the same mountain massif. These groups had different elevational ranges, with 475 m for the lowest and 900 m for the highest altitudes (Figure 4).

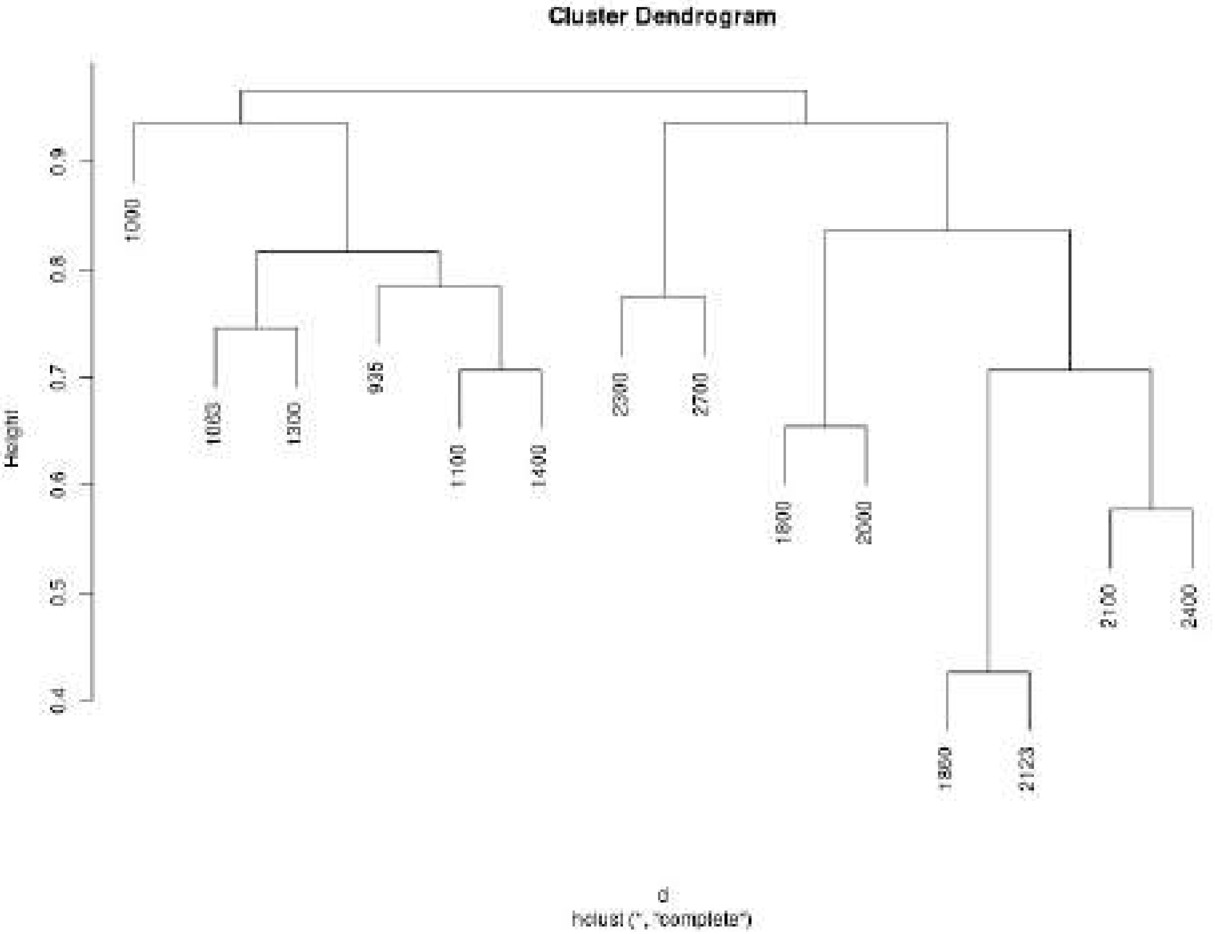

Figure 4: Dendrogram of Jaccard similarity index for each 100-m elevation band for non-volant small mammals composition in Serra do Caparaó, Brasil.

Both data collections have a similar pattern of altitudinal distribution. The distribution of the data wasn't considered normal (Shapiro-Wilk, W = 0.88699, p-value = $2.2e^{-16}$). And there was a significant difference in the median altimetric distribution of the small mammal fauna in Serra do Caparaó (Kruskal-Wallis chi-squared = 395.73, df = 26, p-value < $2.2e^{-16}$), in particular for several species such as *Akodon cursor* (p = $2e^{-16}$), *Akodon mystax* (p = $2e^{-16}$), *Brucepattersonius griserufescens* (p = 2e-16), *Calomys cerqueirai* (p = 0.00127), *Castoria angustidens* (p = $2e^{-16}$), *Delomys altimontanus* (p = $2e^{-16}$), *Delomys dorsalis* (p = 0.01724), *Euryzygomatomys spinosus* (p = $1.97e^{-05}$), *Juliomys ossitenuis* (p = $6.75e^{-05}$), *Marmosops incanus* (p = $5.98e^{-10}$), *Marmosops paulensis* (p = $3.32e^{-06}$), *Nectomys squamipes* (p = 0.02195), *Oligoryzomys flavescens* (p = $2e^{-16}$), *Oligoryzomys nigripes* (p = $5.58e^{-08}$), *Oxymycterus caparaoe* (p = $2e^{-16}$), *Oxymycterus dasytrichus* (p = $2e^{-16}$) and *Thaptomys nigrita* (p = $2e^{-16}$). No significant relationship was found for the other species.

Considering the altimetric distribution of the species (Figure 5), Didelphiomorpha (1,428.93 m) had a lower average distribution than Rodentia (1,871.14 m). For them, *Didelphis aurita* had only three records and its average altimetric distribution was 1,286.6 m, although it was 1,860 m for primary data and 1,000 m for secondary data. For *Gracilinanus microtarsus*, there were only four primary records and the average altitude was 1,461.5 m, with a range of 1,000 and 1,860 m. The genus *Marmosops* was represented by two species. *Marmosops incanus* had an average elevation of 1,597.12 m, but with average primary data of 986.2 m and secondary data of 1757.89 m, with a range from 935 to 2,100 m, the last one being the highest altitude. *Marmosops paulensis* was registered only I the primary data with an average of 1,860 m and four records, the highest average altitude. The genus *Monodelphis* also had two species, with *Monodelphis iheringi* having only one primary record at an elevation of 935 m. On the other hand, *Monodelphis scalops* had an average elevation of 1,092.5 m with four records, but with the average of the primary data also at 935 m and the secondary data at 1,250 m. Finally, *Philander quica* had an average elevation distribution of 1,227.3 m, but for primary data it was 999 m and for secondary data it was 1,292.85 m.

Rodentia had a greater altitude range than marsupials and some species are related to high altitudes (Figure 5). *Brucepattersonius griserufescens* had a mean elevation of 1,857 m and 2,099.09 m for primary data and 1,187.5 m for secondary data. *Castoria angustidens*, a species that until recently was related to the genus *Akodon* (Pardiñas et al. 2016), had a mean altitude distribution of 2,000.7 m, 1,920.69 for primary data and 2,074.11 for secondary data. And *Juliomys ossitenus*, which had two primary records at an average altitude of 1,991.5 m above sea level. Futhermore, *Thaptomys nigrita*, with a mean height distribution of 1,999.77 in 22 records, the means being 2,024.37 for the primary data and 1,985.71 for the secondary data.

Some rodent species within the same genus showed a considerable distinction in the altitudinal distribution (Figure 5). The genus *Akodon* presented two species, *A. cursor* with an average altitude distribution of 1,184.3 m with 76 records, but with differences between the data, the average for primary data being 996.79 m and secondary data 1,300 m; and, *Akodon mystax* with an average of 2,198.4 m, the highest average of all species considering both data, and for primary and secondary data an average of 2,029.41 m and 2,416.66 m respectively. The genus *Delomys* presents three species, all recorded in the Serra do Caparaó. *Delomys dorsalis* had only one record, being this one primary, at 1,860 m. *Delomys sublineatus* had three primary records at 1,063 m, and *Delomys altimontanus* had a total of 177 records, with a mean altimetric distribution of 2,014.74 m, the average being 1,930.44 for primary data and 2,160 m for secondary data. Two species of the genus *Oxymycterus* were recorded: *Oxymycterus dasytrichus* had 33 records with an altimetric mean of 2,089.75 m, with a mean of 1,063 m for primary data and 2,031.03 m for secondary data; and, *Oxymycterus caparaoe* had an average altimetric distribution of 1,016.05 m, but 1,937.18 m for primary data and 2,283.33 m for secondary data. Another noteworthy genus is *Oligoryzomys: Oligoryzomys nigripes* presentng an average of 1,513 m in 31 records, 1,362.45 m for the primary data and 1,673.33 m for the secondary data; while *Oligoryzomys flavescens* had an average altimetric distribution of 2,029 m, 1,891.63 m for the primary records and 2,226.08 m for the secondary records.

Other species were recorded only at lower altitudes, such as *Nectomys squamipes*, with an altimetric average of 956.6 m, with 935 m and 1,000 m for the primary and secondary data, respectively. And *Trinomys gratiosus*, with an average of 1,048.78 m, 1,020.33 m for primary data and 1100 m for secondary data. There were also species with few records, such as *Calomys cerqueirai* that had only one secondary record at 2,200 m; *Euryzygomatomys spinosus*, with a secondary record at 2,400 m; and, *Euryoryzomys russatus* with two secondary records at 1200 m.

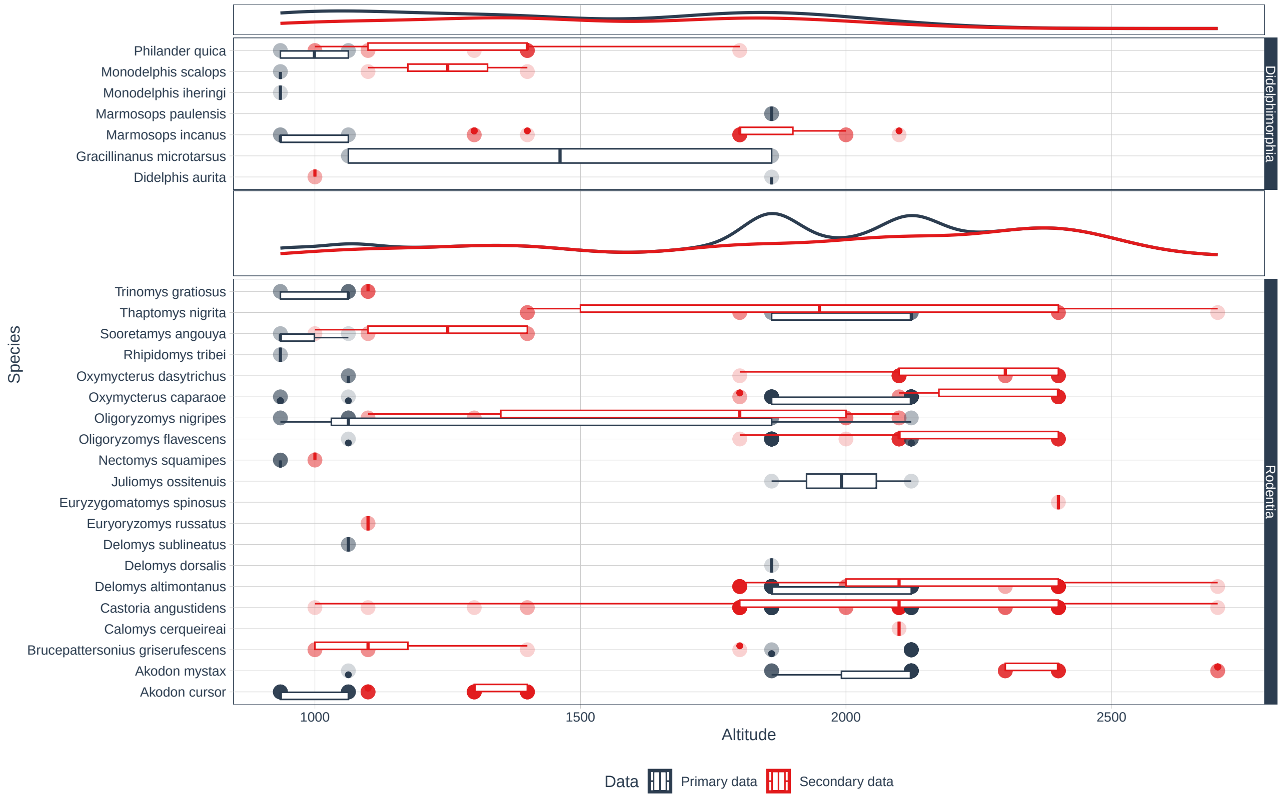

Figure 5: Altitudinal distribution of primary and secondary data with emphasis on the altitudinal distribution overlap in Serra do Caparaó, Brazil. The y-axis shows the species and the x-axis shows the elevation, separated by 500 m blocks. In the graph, the median of the elevation distribution is the central line, the quartiles are represented by the boxes, and the outliers are the dots.

Considering the bands of 500 meter (Figure 3), we observed a decrease in richness with increasing altitude. We found 21 species between 1,000-1,500 m, with 194 records and an effort of 4,770 traps/night. This was followed by 16 species with 272 records for the 1,500-2,000 m band and an effort of 1,820 traps/night. And 13 species with 351 records and an effort of 2,458 traps/night for the 2,000-2,500 m band. Finally, only four species with seven records for the last band of 2,500-3,000 m, and effort os 117 traps/nights.

About the physiognomic-ecological vegetation classification (Figure 3 and 6, Appendix 5), Ombrophilous Dense Forest “Montana” showed "a richness of 21 species (77% of the richness) with an abundance of 194 records (23.54% of the total). Of this total, nine species are exclusive to this vegetation (*Monodelhis ihenringi*, *Monodelphis scalops*, *Akodon cursor*, *Delomys sublineatus*, *Euryoryzomys russatus*, *Nectomys squamipes*, *Rhipidomys tribei*, *Sooretamys angouya* and *Trinomys gratiosus*), with *Akodon cursor* being the most abundant with 39.17% of the total recorded for this vegetation. For Ombrophilous Dense

Forest "Altimontana", there was a richness of 16 species (59.25% of the richness) with an abundance of 289 records (35.05% of the total). Two species were exclusive to this vegetation (*Marmosops paulensis* and *Delomys dorsalis*) and the most abundant species was *Delomys altimontanus* with 35.29% and *Castoria angustidens* with 30.1% of the total records, together representing more than half of the total. The "Campo de altitude" presented a richness of 13 species (48.14%) with 341 records (41.3% of the total). For this vegetation, two species were considered exclusive (*Calomys cerqueirai* and *Euryzygomatomys spinosus*) and the most abundant species were also *Delomys altimontanus* representing 21.99% and *Castoria angustidens* representing 20.8% of the total records, both together with *Oxymycterus caparaoe* (14.95% of abundance) representing more than half of the abundance found.

Figura 6: Altitudinal distribution of orders of non-volant small mammals in the Serra do Caparaó, eastern Brazil. The first row is divided into primary and secondary data. The second line is the total. The sidebar represents the accumulation of records.

VII. DISCUSSION

The Serra do Caparaó, with 27 species, accounts for 57.44% of species of non-volant small mammals recorded in Espírito Santo, and 24.5% of species recorded in the Atlantic Forest, of these 51.1% are endemic to Brazil and 59.2% are endemic to the Atlantic Forest (Abreu et al., 2023), showing great relevance in terms of richness of small mammals compared to other sites in this biome. The primary identified 24 and the secondary data 20 species (Bonvicino et al., 1997). In its surroundings, Parque Estadual Forno Grande (PEFG), with an altitude range of 1,128-2,039 m, had 14 species; Parque Estadual Mata das Flores (PEMF, 110-400 m), only three species (for both, Vale & Costa, 2024 - chapter 3); Estação Ecológica de Santa Lúcia (EESL, 550-950 m), 21 species (Passamani et al., 2000); Reserva Biológica Duas Bocas (RBDB, 69-800 m), 19 species (Carão, 2007; Tonini et al, 2010); Reserva Biológica Córrego do Veado (RBCV, 52-132 m), nine species; Floresta Nacional Rio Preto (FNRP, 0-70 m), five species; and Reserva Biológica Córrego Grande (RBCG, 14-80 m), seven species (Conde 2016). Considering other mountainous regions, Parque Estadual Serra do Brigadeiro (PESB, 1,200-1,800 m) had a richness of 22 species (Moreira et al, 2008); Reserva Florestal Morro Grande (RFMG, 860-1,060 m), 23 species (Pardini & Umetsu, 2006); Parque Estadual Rio Preto (PERP, 800-1,832 m), 16 species (Andrade, 2017); Parque Nacional Serra do Cipó (PNSC, 900-1,800 m), with 24 species (Câmara & Oliveira 2012); Parque Nacional Sempre-Vivas (PNSV, 800-2,000 m), with 26 species (Leal et al. 2008); and Serra do Ouro Branco (800-1,500 m), with 17 (Braga et al. 2016). The only mountainous area that pesents more richness than Parque Nacional do Caparaó is Parque Nacional do Itatiaia (PNI, 900-2,700m), which showed 33 species of small mammals (didelphid marsupials, cricetids, and echimyid rodents) (Geise et al., 2004).

Despite the stabilizing trend of the rarefaction curve of the primary data, the addition of secondary data revealed the high richness of the area, but the absence of arboreal echimids (such as *Kannabateomys amblyonyx* and *Phyllomys pattoni*), relatively common marsupials (*Caluromys philander* and *Metachirus myosuros*) and some rodents (*Blarinomys breviceps* and *Rhagomys rufescens*) found in other surrounding areas (Passamani, 2000; Tonini et al., 2010, Vale & Costa 2024 – Chapter 1), indicate that further efforts may be promising in revealing new records. Altitude is an important factor for the composition of fauna found in the Serra do Caparaó, and there is a decrease in the number of species with increasing altitude, suggesting a pattern of decreasing richness (McCain, 2009), with the greatest richness observed in the altitude range between 1,000 and 1,500 m. It is worth mentioning that this range of 1,000-1,500 m represents the median altitude of the Atlantic Forest as a whole, suggesting a mid-range effect for the biome (Colwell et al., 2004, Vale & Costa 2024 – Chapter 1). For Didelphiomorphia, which presented an average altitude distribution of 1,429 m with a peak at 2,100 m, the abundance was predominant in the range of 1,000-1,500 m (Figure 6), although a significant part of the occurrences was registered between 1,750-2,000 m. For the faunal composition, it was observed the formation of two distinct faunal groups, one with species adapted to higher altitudes (Campo de Altitude and Atlantic Rainforest “Altimontana” – Figure 6), with the presence of *Akodon mystax*, *Delomys altimontanus*, *Castoria angustidens* and *Oxymycterus caparaoe*. And another with species that occur in the intermediate altitudes of the Atlantic Forest (Atlantic Rainforest “Montana” – Figure 6), reaching adjacent altitudes limits such as marsupials and rodents like *Delomys sublienatus*, *Juliomys ossitenuis* and *Rhipidomys tribei*. This distribution is consistent with McCain's 2004 ecotone or community overlap hypothesis. However, collection efforts were not uniformly distributed, so the observed pattern may represent a sampling artifact (Lomolino, 2001).

A relevant factor for Serra do Caparaó are the representatives of a typical Atlantic Forest fauna, since their distribution is limited to the limits of this biome. These mammals include *Akodon mystax, Brucepattersonius griserufescens, Castoria angustidens, Delomys altimontanus, Delomys sublineatus, Juliomys ossitenuis, Marmosops paulensis, Monodelphis iheringi, Monodelphis scalops, Oxymycterus dasytrichus, Oxymycterus caparaoe,* and, *Rhipodomys tribei*, these taxa also represent a geographically more restricted group of endemics, as their distributions rarely extend further north into the northeastern part of the Atlantic Forest (Moreira et al., 2008). *Brucepattersonius griserufescens*, *Delomys sublineatus*, *Juliomys ossitenuis*, *Marmosops paulensis*, *Monodelphis iheringi*, and *Monodelphis scalops* are found only in submontane and montane forests of southeastern and southern Brazil (Mustrangi & Patton, 1997; Costa et al., 2007; Patton et al., 2015). *Akodon mystax* and *Oxymycterus caparaoe* are more associated with higher elevations environments (Gonçalves et al., 2007; Patton et al., 2015).

In terms of vegetation, "Campo de altitude" presented a lower richness, but a higher abundance in relation to the Atlantic Rainforests "Montana" and "Altimontana". This landscape of altitude fields is typical of the highest points of the mountains, which rose mainly during the Tertiary in Serra do Mar and Serra da Mantiqueira, generally over 1,500 m above sea level, but over 2,000 m in Serra do Caparáo (according to the UC Management Plan, see Cosenza et al. 2007) and associated with igneous or metamorphic rocks such as granite or gneiss (Petri & Fúlfaro 1988; Martinelli & Orleans and Bragança 1996). This landscape shows an affinity with the Andean-Patagonian region and the mountain ranges of southern Brazil (Martinelli & Orleans e Bragança 1996; Safford 1999, 2007), as it has floristic, physiognomic, climatic, and edaphic similarities with the higher regions of the Andes and the mountains of Central America (Safford 1999, 2007). Examples include the presence of *Oligoryzomys flavecens*, which is common in the Argentine pampas (Weksler & Bonvicino, 2005), *Oxymycterus caparaoe* is more closely related to *Oxymycterus nasutus*, a species found in the fields and steppes of southern Brazil and Uruguay (Hershkovitz, 1998); and, the genus *Brucepattersonius*, which is widely represented in southern Brazil and northern Argentina (Patton et al., 2015). This pattern has also been recognized in some plant genera (Simpson, 1979; Safford, 1999), bees (Silveira & Cure, 1993), and other rodents (Gonçalves et al., 2007, Vale & Costa 2024 – Chapter 1), suggesting that these taxa probably had larger ranges during the Pleistocene (Simpson, 1979; Silveira & Cure, 1993; Safford, 1999, 2007; Gonçalves et al., 2007). During interglacial periods, when warmer climates predominated, the ranges of these taxa would have retreated southward and upward, with several taxa likely trapped in the "glacial refugia" provided by the mountaintops of southeastern Brazil (Vasconcelos & Rodrigues, 2010).

The high density of these species that occurs at high altitudes may be related to adaptive responses to this cold climate environment, which depends both on their physiological requirements, such as temperature and humidity, and on their interactions with the ecological environment, such as interspecific interactions and availability of resources (Chase and Leibold 2003), leading to allopatric speciation for few lineages. Populations of these species can reach maximum abundance due to the release of competition, a phenomenon known as density compensation (Crowell 1962, MacArthur et al. 1972). We noted this in the high abundance of *Delomys altimontanus*, *Castoria angustidens*, *Akodon mystax*, and *Oxymycterus caparaoe* at the highest elevation gradients. The presence of some forest species in "Campos de altitude" occurs because about 55% are shared with adjacent forests (Safford, 1999), the remainder being species more associated with the páramos, as already mentioned (Brade, 1956; Safford, 1999).

The Serra do Caparaó, like other mountainous areas, has proven to be extraordinarily biodiverse, with aggregations of multiple evolutionary mechanisms, such as high rates of speciation and a landscape that provides distinct opportunities for the coexistence and persistence of lineages, shaped by long-term climatic changes and topographically dynamic landscapes. This in addition to the coexistence of species with small distributions that form centers of endemism (Rahbek et al., 2019). Thus, mountain biodiversity bears the signature of profound evolutionary and ecological processes, a history worth preserving (Rahbek et al., 2019). However, the massive presence of visitors and campers, threatening the fragile native vegetation and causing fire hazards, is a strong impact factor (Vasconcelos, 2003, Santos, 2013). To help these tourists, it was common for mules and horses to crush and graze the flora, which consists of endemic and rare plant species (Leoni, 1997). In addition, some tourists collect endemic plants such as orchids and bromeliads (Conceição, 2000; Vasconcelos, 2000). Many fires are started accidentally in camps, by farmers renewing their pastures, or by disatisfied landowners. Environmental changes caused by fire in high altitude grasslands include floristic depletion and the subsequent appearance of invasive plant species that compete for space and light with native and endemic species (Martinelli & Orleans e Bragança, 1996; Safford, 1999; Vasconcelos, 2000).

To better understand the pattern of diversity and altimetric distribution of non-volant small mammals in Serra do Caparaó, is essential that studies and analysis take into account both the species and their interactions, as well as the abiotic environment, such as vegetation and relief. This multidisciplinary approach, inspired by Humboldt's approach, can also contribute to the solution of Humboldt's enigma. Given rhe high biodiversity of the Serra do Caparaó and the Parque Nacional do Caparaó, with its unique and rich fauna and flora, survey efforts and ecological studies in this important CU should be encouraged and intensified, aiming to better understand the composition and evolutionary history of the species that inhabit this area are and inorder to support and promote conservation measures.

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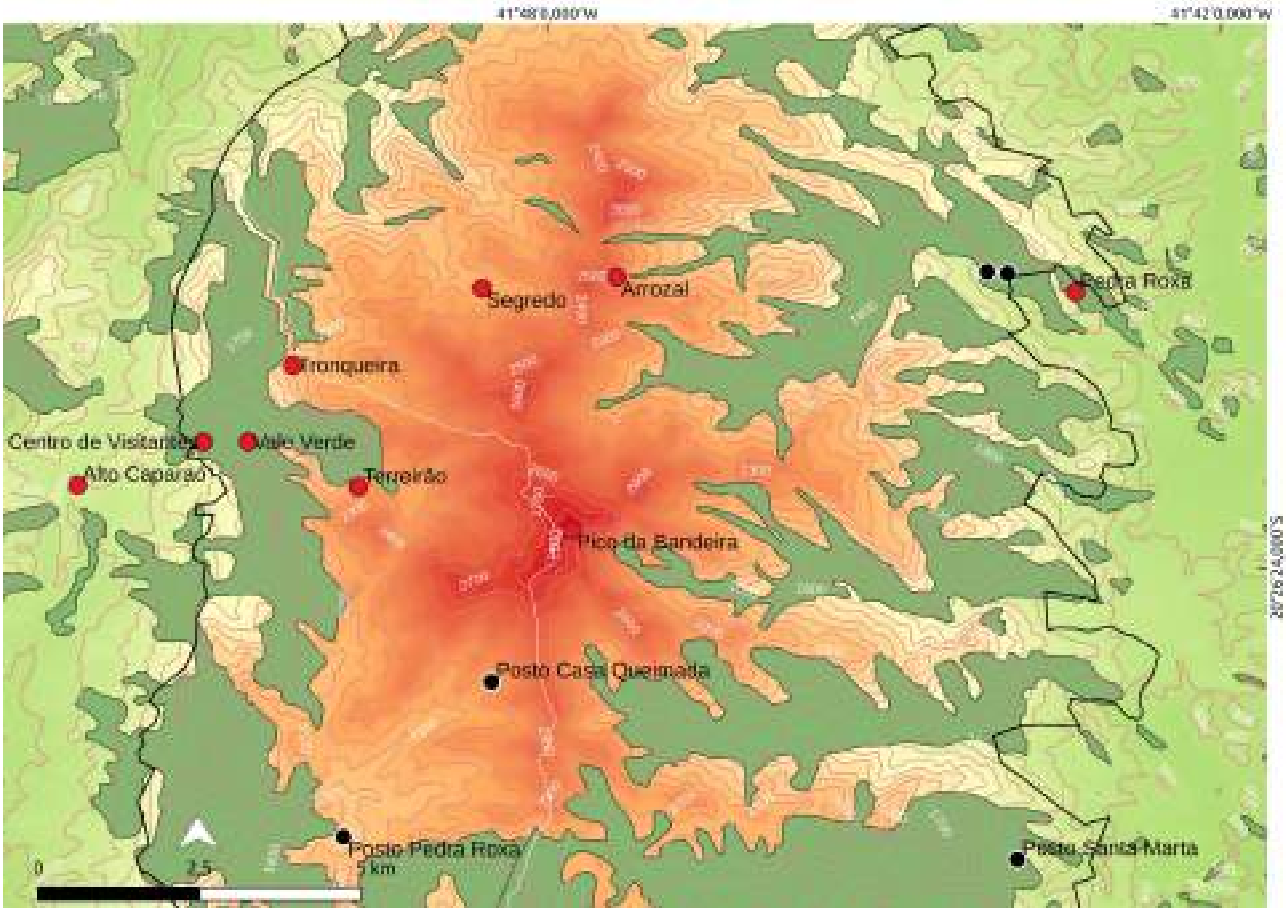
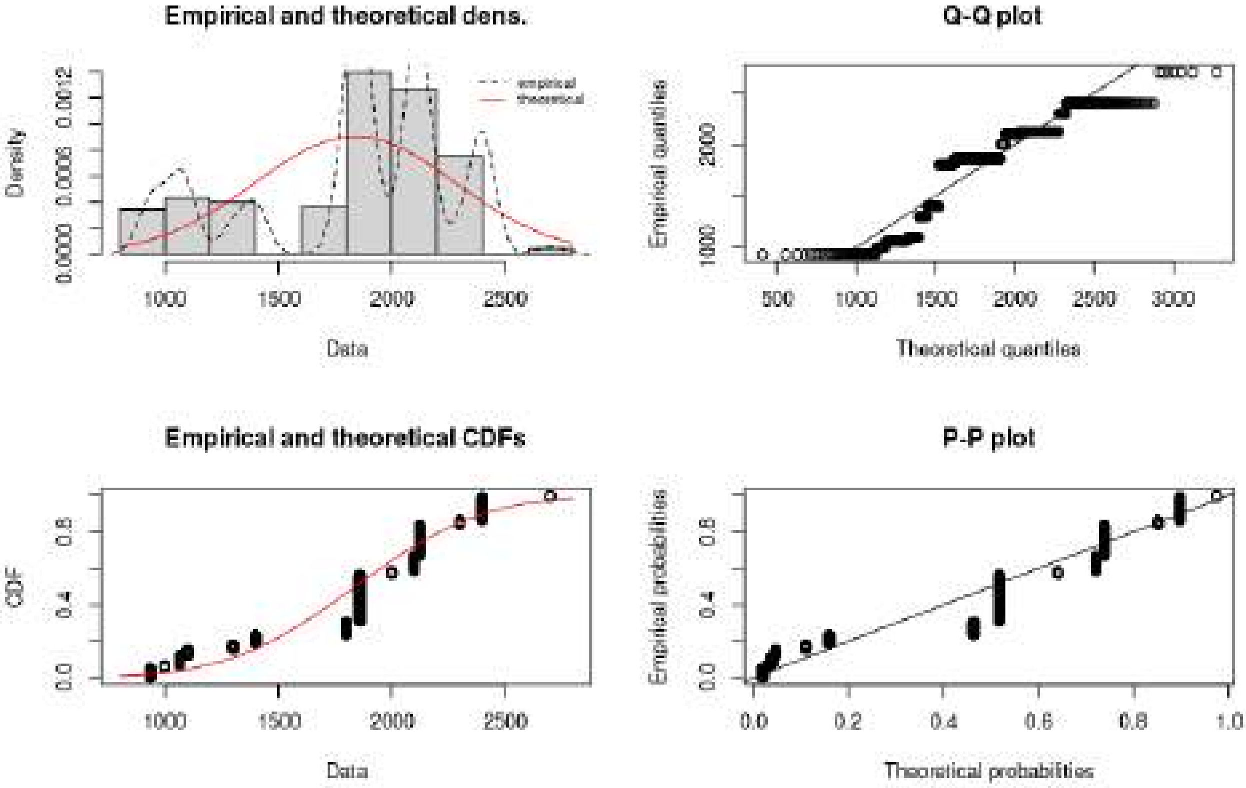
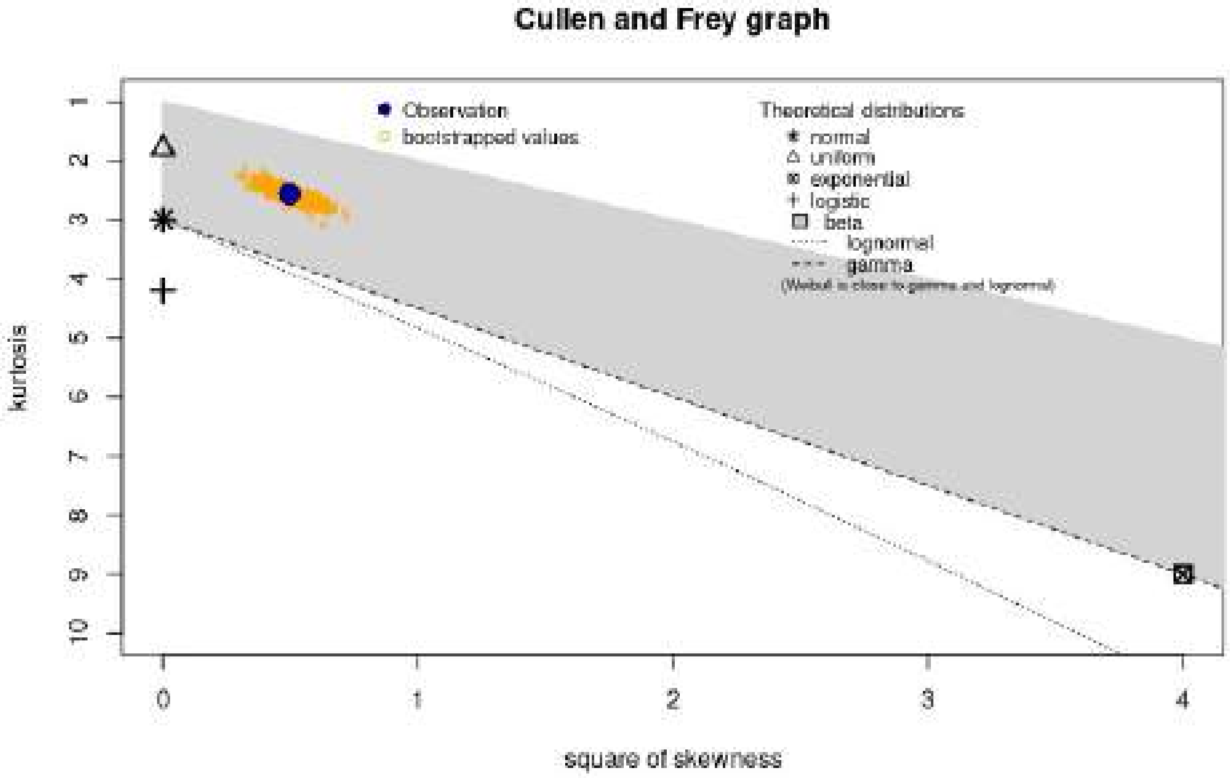
X. APPENDIX



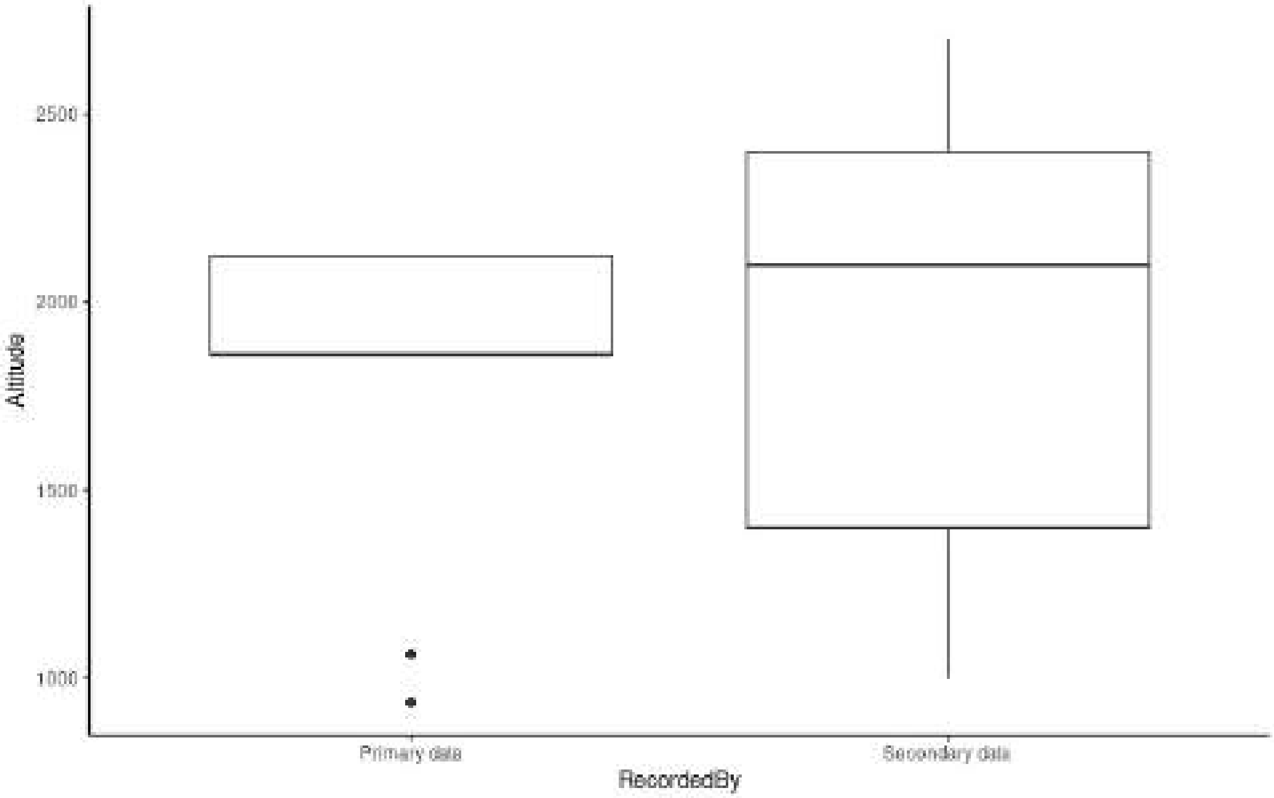
Appendix 1: Map of the Parque Nacional do Caparaó showing the area of Brazil in South America, the Atlantic Forest, the federal unit and the elevation gradient. Datail of sampling transpet for primary and secondary data.



Appendix 2: Normality analysis of altitudinal samples with comparison between Empirical Density, QQPlot, Empirical and theoretical CDFs and P-P Plot, along the Serra do Caparaó range.



Appendix 3: Graph of Cullen and Frey about normality of altitudinal samples along the Serra do Caparaó range.



Appendix 4: Kruskal-Wallis plot of the median altitudinal distribution of primary and secondary data along the Serra do Caparaó range.

Appendix 5: Species abundance Atlantic Forest physiognomic-ecological vegetation classification in the Serra do Caparaó, Eastern Brazil.

Family	**Species**	**Campo de Altitude**	**Altimontana**	**Montana**	**Total**
DIDELHPIOMORPHIA					
Didelphidae	*Didelphis aurita*		1	2	**3**
	Gracillinanus microtarsus		2	2	**4**
	Marmosops incanus	1	14	9	**24**
	Marmosops paulensis		4		**4**
	Monodelphis iheringi			1	**1**
	Monodelphis scalops			4	**4**
	Philander quica		1	17	**18**
RODENTIA					
Cricetidae	*Akodon cursor*			76	**76**
	Akodon mystax	47	7	1	**55**
	Brucepattersonius griserufescens	20	3	7	**30**
	Calomys cerqueirai	1			**1**
	Castoria angustidens	71	87	5	**163**
	Delomys altimontanus	75	102		**177**

Family	Species	Campo de Altitude	Altimontana	Montana	Total
	Delomys dorsalis		1		**1**
	Delomys sublineatus			3	**3**
	Euryoryzomys russatus			2	**2**
	Juliomys ossitenuis	1	1		**2**
	Nectomys squamipes			9	**9**
	Oligoryzomys flavescens	28	27	1	**56**
	Oligoryzomys nigripes	5	9	17	**31**
	Oxymycterus caparaoe	51	23	5	**79**
	Oxymycterus dasytrichus	28	1	4	**33**
	Rhipidomys tribei			2	**2**
	Sooretamys angouya			9	**9**
	Thaptomys nigrita	12	6	4	**22**
Echimyidae	*Euryzygomatomys spinosus*	1			**1**
	Trinomys gratiosus			14	**14**
Total		**341**	**289**	**194**	**824**

Appendix 6: List of fauna with collector code, elevation and geographical coordinates in decimal numbers.

Species	Latitude	Longitude	Altitude	Record Number
Didelphiomorphia				
Didelphidae				
Didelphis aurita	-20.48000	-41.83028	1860	LGA 1285
	-20.42778	-41.86972	1000	LGA 1595
Gracillinanus microtarsus	-20.39611	-41.73472	1063	LGA 1599
				LGA 1600
	-20.48000	-41.83028	1860	LGA 1291
				LGA 1326
Marmosops incanus	-20.39611	-41.73472	1063	LGA 1594
				LGA 1597
	-20.48333	-41.73028	935	LGA 1188
				LGA 1226
				LGA 1227
	-20.39861	-41.80972	2100	LGA 1595
	-20.41000	-41.83778	1800	LGA 1595
			2000	LGA 1595
	-20.42139	-41.84444	1400	LGA 1595

Species	Latitude	Longitude	Altitude	Record Number
		-41.85111	1300	LGA 1595
Marmosops paulensis	-20.48000	-41.83028	1860	LGA 1310
				LGA 1339
				LGA 1340
				LGA 1350
Monodelphis iheringi	-20.48333	-41.73028	935	LGA 1195
Monodelphis scalops	-20.48333	-41.73028	935	LGA 1224
				LGA 1236
	-20.39917	-41.72167	1100	LGA 1595
	-20.42139	-41.84444	1400	LGA 1595
Philander quica	-20.39611	-41.73472	1063	LGA 1565
				LGA 1567
	-20.48333	-41.73028	935	LGA 1196
				LGA 1237
	-20.39917	-41.72167	1100	LGA 1595
	-20.41000	-41.83778	1800	LGA 1595
	-20.42139	-41.84444	1400	LGA 1595
		-41.85111	1300	LGA 1595
	-20.42778	-41.86972	1000	LGA 1595
Rodentia				
Cricetidae				
Akodon cursor	-20.3964	-41.7317	1063	LGA 1556
				LGA 1558
				LGA 1559
				LGA 1560
				LGA 1561
				LGA 1562
				LGA 1563
				LGA 1564
				LGA 1579
				LGA 1580
				LGA 1583
				LGA 1584
				LGA 1586
				LGA 1595
	-20.48333	-41.73028	935	LGA 1187
				LGA 1193

Species	Latitude	Longitude	Altitude	Record Number
				LGA 1203
				LGA 1206
				LGA 1207
				LGA 1211
				LGA 1217
				LGA 1218
				LGA 1219
				LGA 1220
				LGA 1221
				LGA 1222
				LGA 1223
				LGA 1231
				LGA 1234
	-20.39917	-41.72167	1100	LGA 1595
	-20.42139	-41.84444	1400	LGA 1595
		-41.85111	1300	LGA 1595
Akodon mystax	-20.45694	-41.80833	2123	LGA 1605
				LGA 1617
				LGA 1619
				LGA 1621
				LGA 1643
				LGA 1656
				LGA 1657
				LGA 1672
				LGA 1682
				LGA 1686
				LGA 1702
				LGA 1704
				LGA 1706
				LGA 1711
				LGA 1713
				LGA 1715
				LGA 1716
				LGA 1719
				LGA 1720
				LGA 1724
				LGA 1731

Species	Latitude	Longitude	Altitude	Record Number
				LGA 1740
				LGA 1748
	-20.48000	-41.83028	1063	LGA 1515
			1860	LGA 1315
				LGA 1325
				LGA 1327
				LGA 1328
				LGA 1330
				LGA 1391
				LGA 1461
	-20.39694	-41.78972	2300	LGA 1595
	-20.42806	-41.82806	2400	LGA 1595
	-20.43444	-41.79639	2700	LGA 1595
Brucepattersonius griserufescens	-20.45694	-41.80833	2123	LGA 1609
				LGA 1610
				LGA 1644
				LGA 1650
				LGA 1651
				LGA 1653
				LGA 1655
				LGA 1663
				LGA 1664
				LGA 1665
				LGA 1671
				LGA 1685
				LGA 1687
				LGA 1692
				LGA 1696
				LGA 1697
				LGA 1721
				LGA 1722
				LGA 1729
				LGA 1733
				LGA 1737
	-20.48000	-41.83028	1860	LGA 1383
				LGA 1496
	-20.39917	-41.72167	1100	LGA 1595

Species	Latitude	Longitude	Altitude	Record Number
	-20.41000	-41.83778	1800	LGA 1595
	-20.42139	-41.84444	1400	LGA 1595
	-20.42778	-41.86972	1000	LGA 1595
Calomys cerqueirai	-20.39861	-41.80972	2100	LGA 1595
Castoria angustidens	-20.45694	-41.80833	2123	LGA 1602
				LGA 1611
				LGA 1614
				LGA 1638
				LGA 1641
				LGA 1642
				LGA 1645
				LGA 1646
				LGA 1647
				LGA 1659
				LGA 1661
				LGA 1679
				LGA 1681
				LGA 1683
				LGA 1691
				LGA 1699
				LGA 1714
				LGA 1725
	-20.48000	-41.83028	1860	LGA 1290
				LGA 1298
				LGA 1300
				LGA 1301
				LGA 1302
				LGA 1303
				LGA 1305
				LGA 1306
				LGA 1316
				LGA 1317
				LGA 1318
				LGA 1319
				LGA 1320
				LGA 1321
				LGA 1322

Species	Latitude	Longitude	Altitude	Record Number
				LGA 1324
				LGA 1334
				LGA 1335
				LGA 1336
				LGA 1337
				LGA 1341
				LGA 1349
				LGA 1351
				LGA 1355
				LGA 1384
				LGA 1385
				LGA 1386
				LGA 1387
				LGA 1388
				LGA 1389
				LGA 1390
				LGA 1392
				LGA 1393
				LGA 1394
				LGA 1395
				LGA 1396
				LGA 1397
				LGA 1398
				LGA 1399
				LGA 1400
				LGA 1401
				LGA 1402
				LGA 1403
				LGA 1408
				LGA 1411
				LGA 1414
				LGA 1415
				LGA 1456
				LGA 1457
				LGA 1458
				LGA 1459
				LGA 1460

Species	Latitude	Longitude	Altitude	Record Number
				LGA 1462
				LGA 1463
				LGA 1464
				LGA 1465
				LGA 1490
				LGA 1494
				LGA 1502
				LGA 1503
				LGA 1504
	-20.39694	-41.78972	2300	LGA 1595
	-20.39861	-41.80972	2100	LGA 1595
	-20.39917	-41.72167	1100	LGA 1595
	-20.41000	-41.83778	1800	LGA 1595
			2000	LGA 1595
	-20.42139	-41.84444	1400	LGA 1595
		-41.85111	1300	LGA 1595
	-20.42778	-41.86972	1000	LGA 1595
	-20.42806	-41.82806	2400	LGA 1595
	-20.43444	-41.79639	2700	LGA 1595
Delomys altimontanus	-20.45694	-41.80833	2123	LGA 1603
				LGA 1604
				LGA 1616
				LGA 1626
				LGA 1630
				LGA 1634
				LGA 1639
				LGA 1658
				LGA 1660
				LGA 1668
				LGA 1669
				LGA 1670
				LGA 1673
				LGA 1674
				LGA 1675
				LGA 1676
				LGA 1677
				LGA 1684

Species	Latitude	Longitude	Altitude	Record Number
				LGA 1690
				LGA 1698
				LGA 1701
				LGA 1707
				LGA 1708
				LGA 1717
				LGA 1723
				LGA 1726
				LGA 1728
				LGA 1736
				LGA 1741
				LGA 1743
	-20.48000	-41.83028	1860	LGA 1286
				LGA 1289
				LGA 1293
				LGA 1296
				LGA 1297
				LGA 1299
				LGA 1308
				LGA 1309
				LGA 1311
				LGA 1312
				LGA 1314
				LGA 1333
				LGA 1338
				LGA 1344
				LGA 1346
				LGA 1348
				LGA 1356
				LGA 1357
				LGA 1378
				LGA 1379
				LGA 1380
				LGA 1381
				LGA 1409
				LGA 1410
				LGA 1412

Species	Latitude	Longitude	Altitude	Record Number
				LGA 1416
				LGA 1420
				LGA 1421
				LGA 1422
				LGA 1423
				LGA 1424
				LGA 1425
				LGA 1426
				LGA 1427
				LGA 1428
				LGA 1429
				LGA 1430
				LGA 1431
				LGA 1432
				LGA 1433
				LGA 1434
				LGA 1435
				LGA 1436
				LGA 1437
				LGA 1438
				LGA 1439
				LGA 1440
				LGA 1441
				LGA 1442
				LGA 1443
				LGA 1444
				LGA 1445
				LGA 1446
				LGA 1447
				LGA 1448
				LGA 1449
				LGA 1451
				LGA 1452
				LGA 1466
				LGA 1467
				LGA 1468
				LGA 1473

Species	Latitude	Longitude	Altitude	Record Number
				LGA 1474
				LGA 1475
				LGA 1476
				LGA 1477
				LGA 1478
				LGA 1479
				LGA 1480
				LGA 1481
				LGA 1482
				LGA 1483
				LGA 1484
				LGA 1485
				LGA 1488
				LGA 1489
				LGA 1493
				LGA 1497
				LGA 1498
				LGA 1499
				LGA 1500
				LGA 1501
				LGA 1505
	-20.39694	-41.78972	2300	LGA 1595
	-20.39861	-41.80972	2100	LGA 1595
	-20.41000	-41.83778	1800	LGA 1595
			2000	LGA 1595
	-20.42806	-41.82806	2400	LGA 1595
	-20.43444	-41.79639	2700	LGA 1595
Delomys dorsalis	-20.48000	-41.83028	1860	LGA 1287
Delomys sublineatus	-20.39611	-41.73472	1063	LGA 1576
				LGA 1577
				LGA 1598
Euryoryzomys russatus	-20.39917	-41.72167	1100	LGA 1595
Juliomys ossitenuis	-20.45694	-41.80833	2123	LGA 1718
	-20.48000	-41.83028	1860	LGA 1360
Nectomys squamipes	-20.48333	-41.73028	935	LGA 1191
				LGA 1215
				LGA 1216

Species	Latitude	Longitude	Altitude	Record Number
				LGA 1233
				LGA 1238
				LGA 1239
	-20.42778	-41.86972	1000	LGA 1595
Oligoryzomys flavescens	-20.39611	-41.73472	1063	LGA 1575
	-20.45694	-41.80833	2123	LGA 1618
				LGA 1625
				LGA 1629
				LGA 1710
				LGA 1734
				LGA 1738
				LGA 1747
	-20.48000	-41.83028	1860	LGA 1304
				LGA 1307
				LGA 1313
				LGA 1329
				LGA 1332
				LGA 1354
				LGA 1358
				LGA 1359
				LGA 1362
				LGA 1364
				LGA 1365
				LGA 1366
				LGA 1367
				LGA 1368
				LGA 1377
				LGA 1404
				LGA 1417
				LGA 1418
				LGA 1419
				LGA 1450
				LGA 1453
				LGA 1454
				LGA 1455
				LGA 1469
				LGA 1470

Species	Latitude	Longitude	Altitude	Record Number
				LGA 1471
				LGA 1472
	-20.39861	-41.80972	2100	LGA 1595
	-20.41000	-41.83778	1800	LGA 1595
			2000	LGA 1595
	-20.42806	-41.82806	2400	LGA 1595
Oligoryzomys nigripes	-20.39611	-41.73472	1063	LGA 1574
				LGA 1585
				LGA 1592
				LGA 1593
				LGA 1601
	-20.45694	-41.80833	2123	LGA 1703
				LGA 1732
	-20.48000	-41.83028	1063	LGA 1570
			1860	LGA 1361
				LGA 1363
				LGA 1382
				LGA 1413
	-20.48333	-41.73028	935	LGA 1194
				LGA 1200
				LGA 1201
				LGA 1204
				LGA 1228
	-20.39861	-41.80972	2100	LGA 1595
	-20.39917	-41.72167	1100	LGA 1595
	-20.41000	-41.83778	1800	LGA 1595
			2000	LGA 1595
	-20.42139	-41.84444	1400	LGA 1595
		-41.85111	1300	LGA 1595
Oxymycterus caparaoe	-20.39611	-41.73472	1063	LGA 1571
	-20.45694	-41.80833	2123	LGA 1606
				LGA 1608
				LGA 1613
				LGA 1615
				LGA 1622
				LGA 1623
				LGA 1624

Species	Latitude	Longitude	Altitude	Record Number
				LGA 1627
				LGA 1628
				LGA 1631
				LGA 1633
				LGA 1637
				LGA 1640
				LGA 1648
				LGA 1649
				LGA 1654
				LGA 1662
				LGA 1666
				LGA 1667
				LGA 1680
				LGA 1688
				LGA 1689
				LGA 1694
				LGA 1695
				LGA 1700
				LGA 1705
				LGA 1709
				LGA 1712
				LGA 1727
				LGA 1730
				LGA 1735
				LGA 1739
				LGA 1742
				LGA 1744
				LGA 1745
				LGA 1746
	-20.48000	-41.83028	1860	LGA 1288
				LGA 1292
				LGA 1294
				LGA 1295
				LGA 1323
				LGA 1331
				LGA 1347
				LGA 1352

Species	Latitude	Longitude	Altitude	Record Number
				LGA 1353
				LGA 1369
				LGA 1370
				LGA 1371
				LGA 1372
				LGA 1373
				LGA 1374
				LGA 1375
				LGA 1405
				LGA 1406
				LGA 1407
				LGA 1487
				LGA 1495
	-20.48333	-41.73028	935	LGA 1210
				LGA 1229
				LGA 1230
				LGA 1232
	-20.39861	-41.80972	2100	LGA 1595
	-20.41000	-41.83778	1800	LGA 1595
	-20.42806	-41.82806	2400	LGA 1595
Oxymycterus dasytrichus	-20.39611	-41.73472	1063	LGA 1572
				LGA 1581
				LGA 1587
				LGA 1588
	-20.39694	-41.78972	2300	LGA 1595
	-20.39861	-41.80972	2100	LGA 1595
	-20.41000	-41.83778	1800	LGA 1595
	-20.42806	-41.82806	2400	LGA 1595
Rhipidomys tribei	-20.48333	-41.73028	935	LGA 1202
				LGA 1205
Sooretamys angouya	-20.39611	-41.73472	1063	LGA 1569
	-20.48333	-41.73028	935	LGA 1186
				LGA 1190
	-20.39917	-41.72167	1100	LGA 1595
	-20.42139	-41.84444	1400	LGA 1595
	-20.42778	-41.86972	1000	LGA 1595
Thaptomys nigrita	-20.45694	-41.80833	2123	LGA 1632

Species	Latitude	Longitude	Altitude	Record Number
				LGA 1635
				LGA 1652
				LGA 1678
				LGA 1693
	-20.48000	-41.83028	1860	LGA 1376
				LGA 1486
				LGA 1491
				LGA 1492
	-20.39861	-41.80972	2100	LGA 1595
	-20.41000	-41.83778	1800	LGA 1595
	-20.42139	-41.84444	1400	LGA 1595
	-20.42806	-41.82806	2400	LGA 1595
	-20.43444	-41.79639	2700	LGA 1595
Echimydae				
Trinomys gratiosus	-20.48333	-41.73028	935	LGA 1199
Euryzygomatomys spinosus	-20.42806	-41.82806	2400	LGA 1595
Trinomys gratiosus	-20.39611	-41.73472	1063	LGA 1557
				LGA 1566
				LGA 1568
				LGA 1573
				LGA 1578
				LGA 1596
	-20.48333	-41.73028	935	LGA 1198
				LGA 1212
				LGA 1213
	-20.39917	-41.72167	1100	LGA 1595

Capítulo 3

INHABITING IN THE ANTHROPOCENE: ECOLOGICAL AND HUMAN RELATED FACTORS INFLUENCING NON-VOLANT SMALL MAMMAL SPATIAL USE PATTERNS

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I. ABSTRACT

The Atlantic Forest, a South American biome, is facing significant challenges due to forest fragmentation caused by various factors, including the expansion of urban areas. This phenomenon has a direct impact on the biodiversity of the region, especially since this biome hosts the highest number of endangered species in the country. The objective of this study was to evaluate the differences in richness and abundance of non-volant small mammals between two adjacent forest fragments in the Atlantic Forest. Both fragments are similar in size and sampling effort, but differs in shape, altitude, and proximity to urban areas. The ecological analysis included the calculation of richness, estimated richness and abundance, and the generation of sampling rarefaction curves for each fragment. Simultaneously, the landscape analysis included mapping the fragments, examining their design, land use, and proximity to urban areas. Results showed that

Parque Estadual Mata das Flores had lower species richness and abundance due to higher edge density, an anthropogenic surrounding matrix, and proximity to urban areas compared to Parque Estadual Forno Grande. These factors increase the probability of defaunation in the former fragment.

II. HIGHLIGHTS

i. The Parque Estadual Forno Grande (PEFG) and Parque Estadual Mata das Flores (PEMF), two nearby areas of similar size and sampling effort, show great differences in the richness and abundance of small, non-volant mammals.

ii. PEMF consists of more than one patch of native forest, mainly surrounded by pastures and coffee plantations, and is irregular in shape, as well as being close to developed areas and crossed by aroad.

iii. PEFG has a circular shape and is mainly surrounded by native forest, providing an important ecological corridor with the other CUs.

iv. Differences in richness and abundance are due to greater anthropogenic impacts in lowland areas.

III. KEYWORDS:

Conservation units; Defaunation; Atlantic Forest; Edge effect.

IV. INTRODUCTION

The Atlantic Forest exhibits some of the highest rates of species diversity and endemism on the globe (Myers et al. 2000, Rezende et al., 2018), with 8% of the world’s vertebrate species occurring in this biome, 3% of those being endemic (Passamani, 2003; Figueiredo et al. 2021). It originally covered more than 1.3 million km² in 17 states and extended over a large part of the country's coastline (MMA, 2021). Currently, the biome has a remaining vegetation cover of approximately 28% (Rezende et al., 2018). The main factors identified as responsible for this current scenario are forest fragmentation due to agricultural activities and urban expansion, which includes hunting and trapping (ICMBIO, 2018). Due to the disturbed state of this biome, protected areas have been established, called conservation units (CU), which are an important tool for the conservation of biodiversity (Fonseca et. al., 2010). They allow the maintenance of wildlife and the conservation of rare, endemic, vulnerable or endangered species, as well as promoting the sustainable use of natural resources and the management of fauna and flora (Hassler, 2005).

In this context, non-volant small mammals are important indicators of the progress of deforestation due to the loss of their richness and abundance in fragmented environments (Pardini et al., 2005), which is are frequently taken into account in management plans for conservation units (Junior & Leite, 2007). There are approximately 762 species of mammals in Brazil, of which 329 are small mammals (Abreu et al., 2023). Of the total number of species, 110 occur in the Atlantic Forest (Abreu et al., 2023), of which 45 are globally threatened with extinction , of these, 13 are non-volant small mammal and 110 are endemic to the biome (Abreu, 2023). However, the paucity of studies on the geographic distribution, natural history, biogeography and systematics of most small mammal species makes it difficult to make conservation decisions (Costa et al. 2005).

Inserted in the central corridor of the Atlantic Forest, the state of Espírito Santo originally had almost 90% of its territory covered by Atlantic Forest (Thomaz, 2010), but currently the forest remains are estimated at approximately 35% (Rezende et al., 2018). Another characteristic of the state is its high altitude, which varies from sea level to approximately 3,000 m, in less than 130 kilometers, the same latitude. An example of this variation in altitude is found in two forest fragments that currently correspond to the two UCs, the Parque Estadual Forno Grande (PEFG) and the Parque Estadual Mata das Flores (PEMF). The former has an area of 913.15 ha and an elevation range of 1128-2039 m, and the second has an elevation range of 110-400 m, with 800 ha. Both the altimetric variation and the low number of studies on non-volant small mammals in these conservation units (CUs) mean that the work is important for a better understanding of the regional fauna and elevetional patterns. (Vale & Costa, 2024 – chapter 1). It consists of the first survey of non-volant small mammals carried out in the PEMF and the second study that includes the non-volant small mammal fauna of the PEFG.

Giving the differences in environmental characteristics, levels of anthropogenic disturbance, proximity among the areas, along with the paucity of surveys in these two important remnants in the south area of the Espírito Santo state, this work proposes to test the hypothesis that the preserved matrix, the lower edge effect and the distance from urban centers are determining factors in the disturbance of the composition and abundance of the fauna of non-volant small mammals in two conservation units located in the Atlantic Forest, southeastern Brazil.

V. MATERIALS AND METHOD

The Parque Estadual Forno Grande is located in the municipality of Castelo, in the south of Espírito Santo (Figure 1). Founded in October 1960 as a Forest Reserve, it became a State Park in 1988 under State Law Nº. 7,528 (IEMA, 2020), receiving several additions to its original area up to its current size. It covers an area of 913.15 hectares (20º31'18"S and 41º08'05"W) and is characterized by a very pronounced relief, with elevations ranging from 1,128 to 2,039 m, culminating in Pico do Forno Grande, the second highest peak in Espírito Santo (IDAF, 2000). The CU is part of the Atlantic Forest biome, in the domains of dense montane, high montane ombrophilous forests and fragments of high altitude forests (Espírito Santo, 2008), being considered as a priority area for the conservation of the biome (IEMA, 2020). Despite its extremely high potential for ecological diversity, only 29 studies on fauna and flora have been carried out within its boundaries, of which 16 are related to flora and only one to non-volant small mammals (IEMA, 2020).

The Parque Estadual Mata das Flores is also located in the municipality of Castelo - ES (Figure 1), was created by State Law Nº. 4.617 of January 1992, has an area of 800 hectares (20º35'54"S and 41º10'53"W) and an altimetric variation between 110 and 400 m (IEMA, 2020). The predominant vegetation, according to the Espírito Santo Atlas of Ecosystems (Sossai et al., 2018), is classified as semi-deciduous Atlantic Forest. There are few studies on fauna and flora developed in its area, with only 16 studies listed, of which 8 are related to flora (IEMA, 2020). Its location allows the formation of an ecological corridor from the lower and warmer areas to the higher and colder areas of PEFG and Parque Estadual Pedra Azul (Mamíferos do Espírito Santo, 2021). Furthermore, PEMF shows that small fragments of Atlantic Forest still have a very rich flora (Hollunder et al., 2013) and preserve important processes for maintaining diversity related to variations in soil fertility across topographic gradients (Garbin et al., 2015). In addition, these fragments are refugee for species that we don't yet know or know very little about (IEMA, 2020).

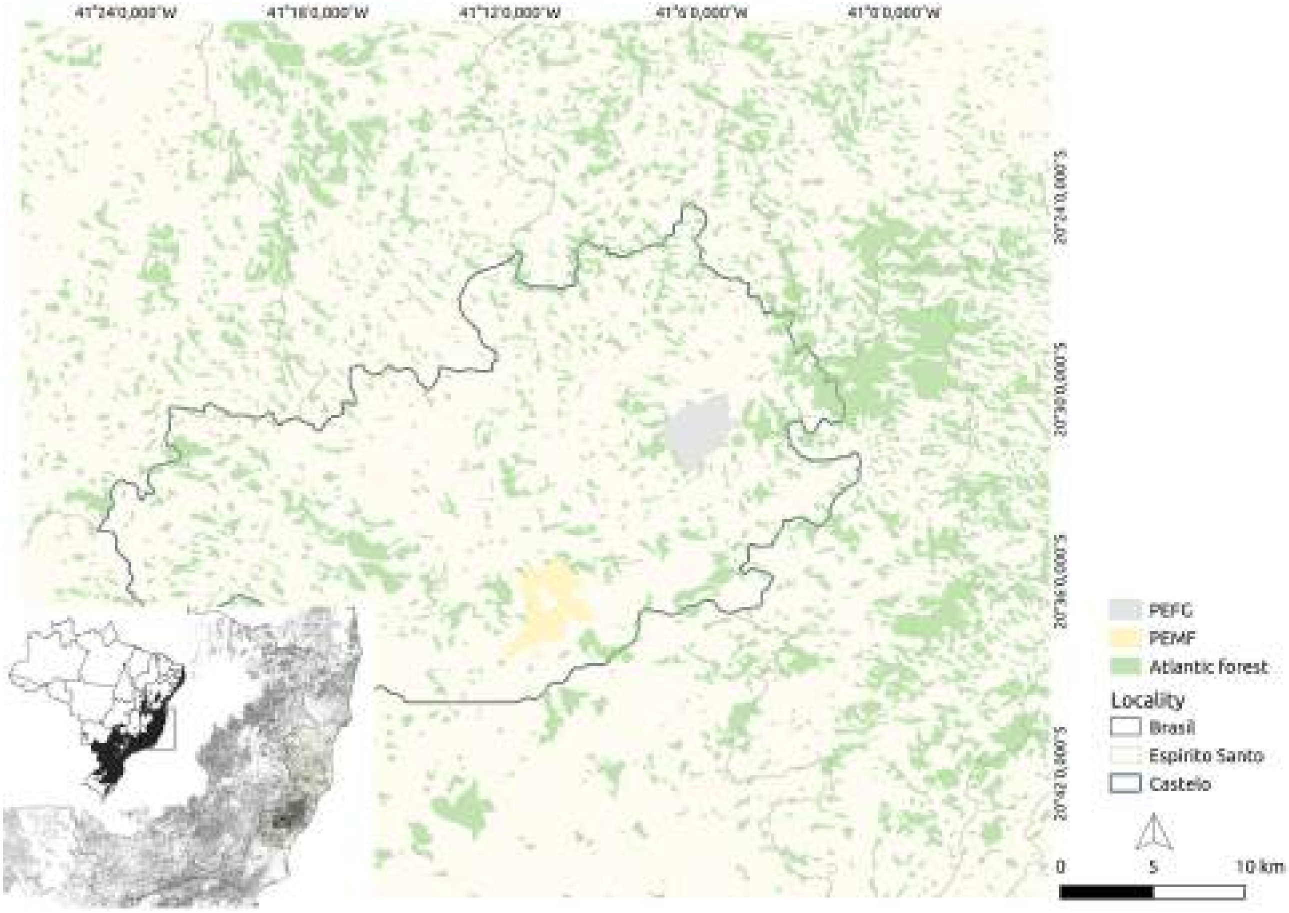

Figure 1: Location and boundaries of Parque Estadual Forno Grande (PEFG) and Parque Estadual Mata das Flores (PEMF), Castelo Municipality, Espírito Santo, Brazil. Detail of Atlantic Forest fragments.

For ecological analyses, we calculated first-order Jackknife richness estimates (Heltshe & Forrester, 1983) and generated a sampling rarefaction curve (Sanders 1968) for each CU. This richness estimator is based on the number of species observed in a single sample (uniques species) and is considered by Palmer (1990) to be the most accurate and least biased estimator compared to other extrapolation methods (Provete et al. 2020). In addition, a normality test was performed and we found that the nature of the abundance data is non-parametric. Thus, a Mann-Whitney test of variance was performed to compare median daily abundance between each study area (Wilcoxon, 1945) ad the density o this abudance (Appendix 1). Analyses were performed using the R program, version 4.1.0, in an RStudio environment.

And for the landscape analysis, the QGis program (version 3.16.8) was used to create maps and for the main landscape analyses. Shapefiles provided by IEMA (2011) at https://geobases.es.gov.br/links-para-mapes 1215 were used. One file contains the CUs and their land use and occupation, which have different classes, and another contains the buffer zones (BZ) of the CUs. We also used the edge density (ED) metric, which represents the number of edges relative to the area of the CU (Juvanhol et al., 2012), onsidering the perimeter/area (m/m²), so that we could check in which forest fragment the edge effect is more likely, since it has a larger area exposed to the surrounding matrix. Based on the mapping of fragments and using the landscape use and occupation shape (LUO) divided into different classes, it was possible to calculate the total area of each class and identify the three classes that represent more than 75% of the lande use total area (coffee, native forest and pasture). The selected classes were then examined at three different scales. Scale 1, called Periphery, included the landscapes within and on the periphery of the studied fragments. Scale 2, called Buffer Zone, extended to the officially designated buffer zone as defined in the management plans of the Conservation Units (CUs). Scale 3, called 10 km radius, extended to a radius of 10 km, a parameter derived from the now repealed CONAMA Resolution 13/1990, which established a buffer zone of 10,000 meters for conservation units without a management plan (MMA, 2010). These three scales were chosen to provide a comprehensive insight into the different pressure vectors affecting these areas.

Proximity to agglomerations, which includes built-up areas and roads, was obtained by mapping the forest fragments using the functions available in QGis 3.16.8 (creating a grid in km² and a measuring line in km). The grid of 1 km² cells and the baseline were used as proximity criteria, measuring the shortest straight-line distance between the areas with the lowest number of cells between the fragment and the agglomerations.

VI. RESULTS

Considering the richness of 14 species and the total absolute abundance of 273 specimens for the PEFG, the richness of 3 species and the total absolute abundance of 54 specimens for the PEMF (Table 1), and the days of collection, we generated a species r curve for both CUs (Figures 2). It can be observed that for the PEMF, the curve reached its asymptote on the 24th day of collection, indicating that sampling sufficiency had been reached. While PEFG did not reach the asymptote after 30 days of sampling, suggesting that there may be species not yet sampled.

Table 1: Richness and absolute abundance of small mammals non-volant recorded in the Parque Estadual Mata das Flores (PEMF) and Parque Estadual Forno Grande (PEFG).

Order	**Family**	**Species**	**PEMF**	**PEFG**	**Total**
Didelphimorphia	Didelphidae	*Didelphis aurita*	9	1	10
		Gracillinanus microtarsus	-	1	1
		Marmosops incanus	40	30	70
		Monodelphis americana	-	1	1
		Philander quica	-	30	30
Rodentia	Cricetidae	*Akodon cursor*	-	79	79
		Delomys sublineatus	-	3	3
		Euryoryzomys russatus	-	1	1
		Nectomys squamipes	5	-	5
		Oligoryzomys nigripes	-	223	223
		Oxymycterus dasytrichus	-	20	20
		Rhagomys rufescens	-	1	1
		Rhipidomys tribei	-	3	3
		Thaptomys nigrita	-	4	4
	Echimyidae	*Trinomys gratiosus*	-	5	5
Total			**54**	**273**	**456**

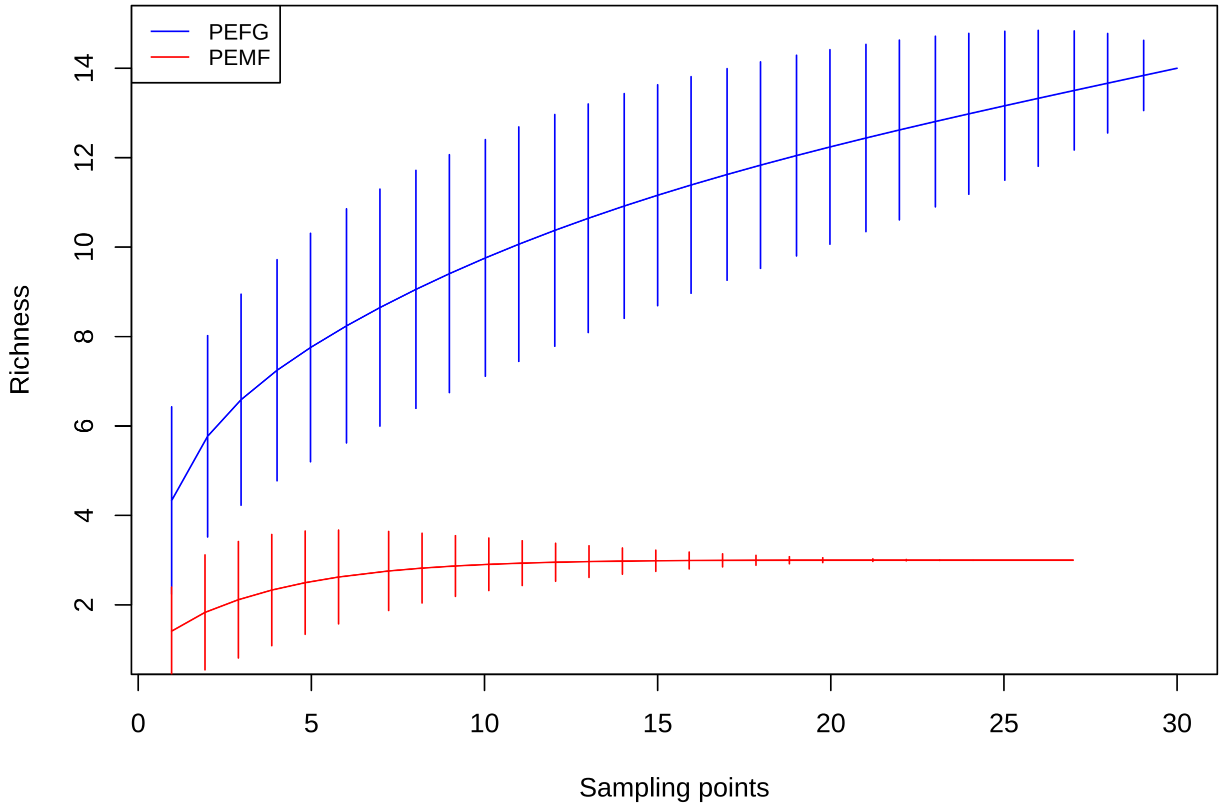

Figure 2: Rarefactions curves from Parque Estadual Forno Grande (PEFG) and Parque Estadual Mata das Flores (PEMF).

In terms of estimated richness, PEMF showed an estimate of three species, which is the same as the observed richness. While the estimated richness for PEFG was 16.85 ± 2.37 species, which is higher than the observed richness, confirming the sampling rarefection curve (Figure 2). In addition to the richness, the mean abundance per day was also compared between the forest fragments using the Mann-Whitney test, where the total absolute abundance of small mammals in the forest fragments was significantly different ($p = 4.729e-11$, $W = 1945$). The median abundance per sampling day was 2 species for the PEMF and 10 species for the PEFG (Figure 3).

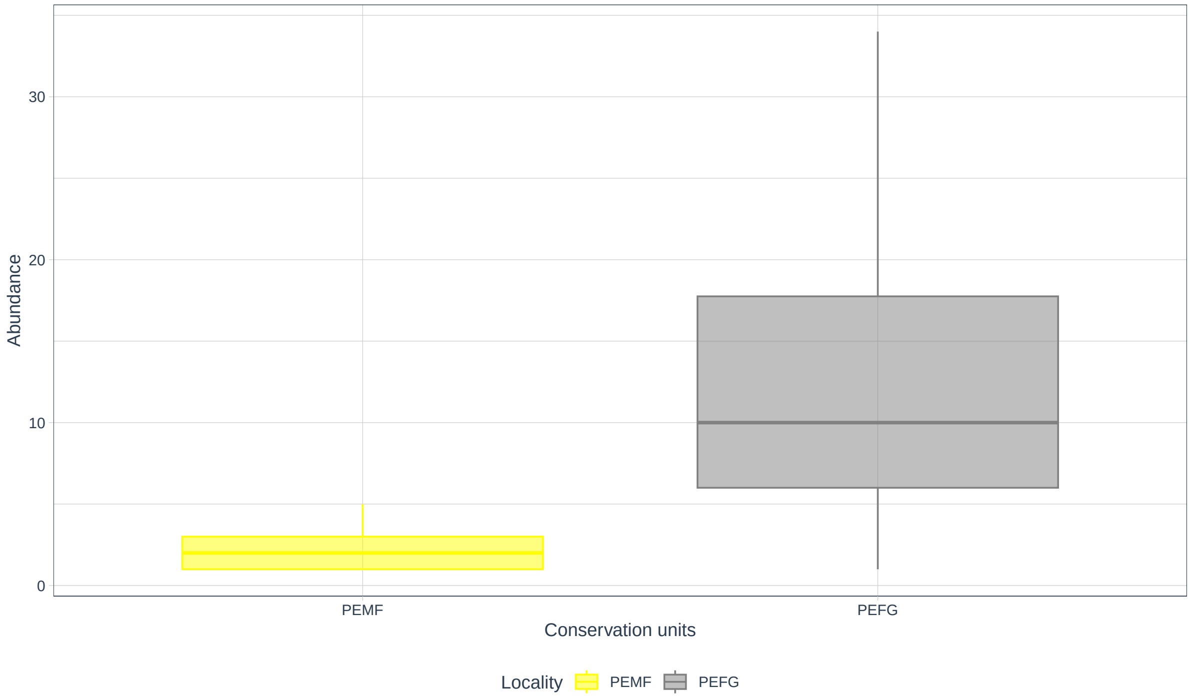

Figure 3: Boxplot comparing median abundance between Parque Estadual Forno Grande (PEFG) and Parque Estadual Mata das Flores (PEMF). The x-axis shows the conservation units and the y-axis shows the abundance. In the graph, the median of the abundance is the central line, the quartiles are represented by the boxes, and the outliers are the dots.

Based on the mapping of the forest fragments, it was possible to obtain results for the design of the fragments, land use and occupation, and proximity to human settlements (built-up area and roads). After applying the ED metric of perimeter/area (m/m²), it was found that for each m² of area, the PEFG has 0.00193 m of edge density, while the PEMF has 0.00475 m, which is 146% higher, even though it has a smaller area than the PEFG (Table 2).

Table 2: Edge density (ED) of Parque Estadual Forno Grande (PEFG) and Parque Estadual Mata das Flores (PEMF).

CUs	**Area (m²)**	**Perimeter (m)**	**Edge Density (ED)**
PEFG	9.127.970,85	17.653,407	0,00193
PEMF	8.296.531,44	39.453,690	0,00475

Based on the mapping of the two CUs and the identification of the landscape use and occupation classes (LUO), the proportion of each LUO was calculated at the three scales: the first, called the Periphery, corresponds to the LUO in the central and peripheral areas of each CU; the second, called the Buffer Zone, is based on the buffer area provided by the CUs management; and called 10 km radius, it is based on a radius of the same value commonly used as a buffer area when this is not available. We calculate the sum of LUO of each class (Table 3, Figure 4).

Table 3: Percentage of three landscape use and class (Coffe growing, Native forest and Pasture) at the 3 scales for Parque Estadual Forno Grande (PEFG) and Parque Estadual Mata das Flores (PEMF).

	Scale 1 (%) Periphery		**Scale 2 (%) Buffer Zone**		**Scale 3 (%) 10 km radius**	
	PEFG	PEMF	PEFG	PEMF	PEFG	PEMF
Coffee growing	0,00	5,89	9,81	10,25	13,21	13,47
Native forest	51,78	27,78	25,11	22,21	31,59	17,86
Pasture	32,85	58,17	38,64	52,65	29,40	50,26
Total	84,63	91,84	73,56	85,11	74,20	81,59

In terms of proximity to human settlements, the PEMF is only a few meters from the built-up area and has a road cutting through the fragment, while the PEFG has a greater distance from the built-up area and the nearest road (Table 4, Figure 5). Similar results were found using either he grid (km²) and or he straight line (km).

Table 4: Distance between Parque Estadual Forno Grande (PEFG) and Parque Estadual Mata das Flores (PEMF) with human settlements in number of rasters and distance in kilometers as the straight line.

Conservation units	**PEFG**		**PEMF**	
Human settlements	**Grid**	**Straight line (km)**	**Grid**	**Straigth line (km)**
Built-up	8	11,42	0	0,29
Road and	5	5,41	0	0,00

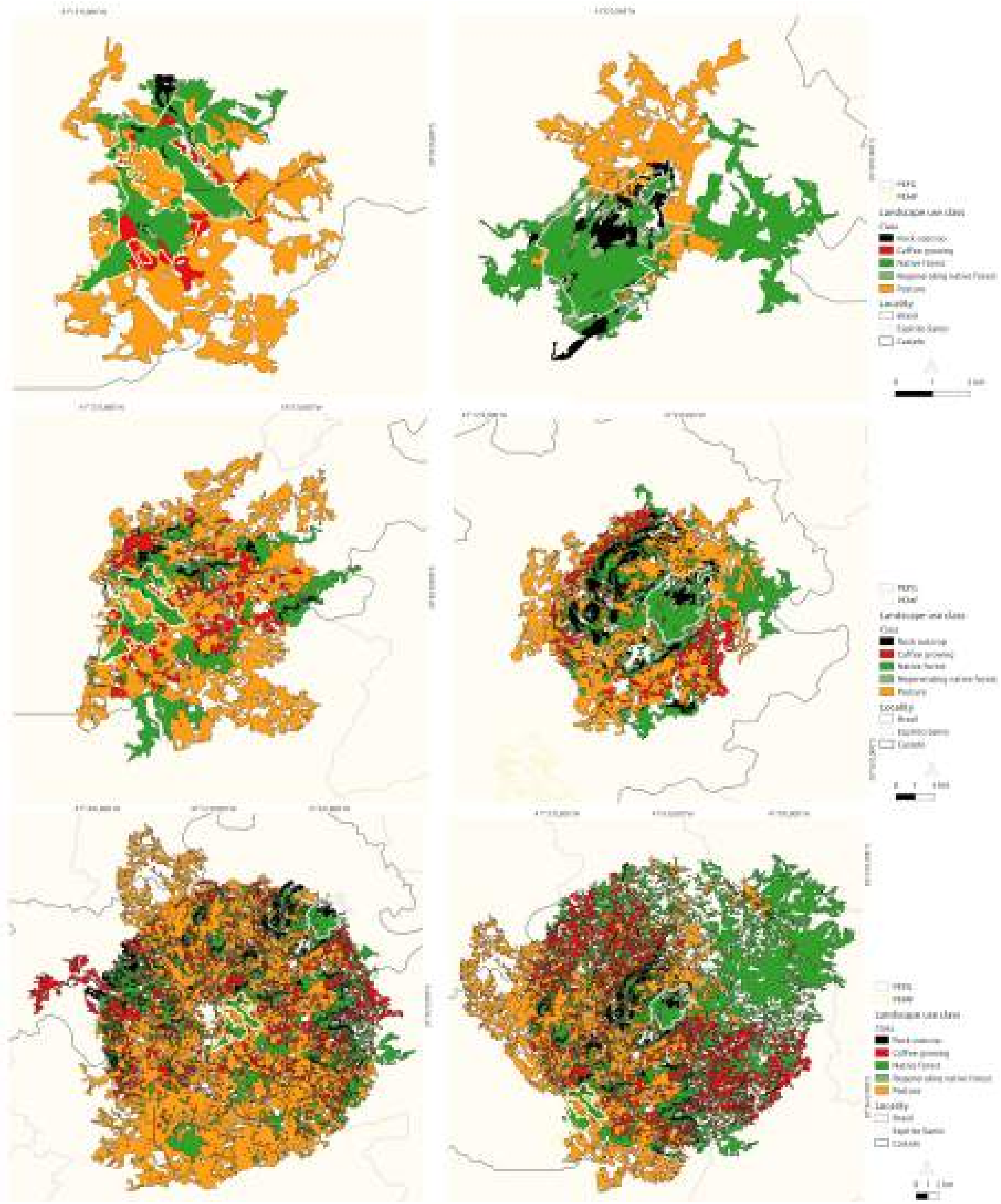

Figure 4: Landscape use and occupation of Parque Estadual Forno Grande (left) and Parque Estadual Mata Das Flores (right) at scale 1 (top), scale 2 (middle) and scale 3 (bottom). Scale 1 represents the LUO boundary of the conservation units, scale 2 that of the buffer zone, and scale 3 that of a 10 km radius.

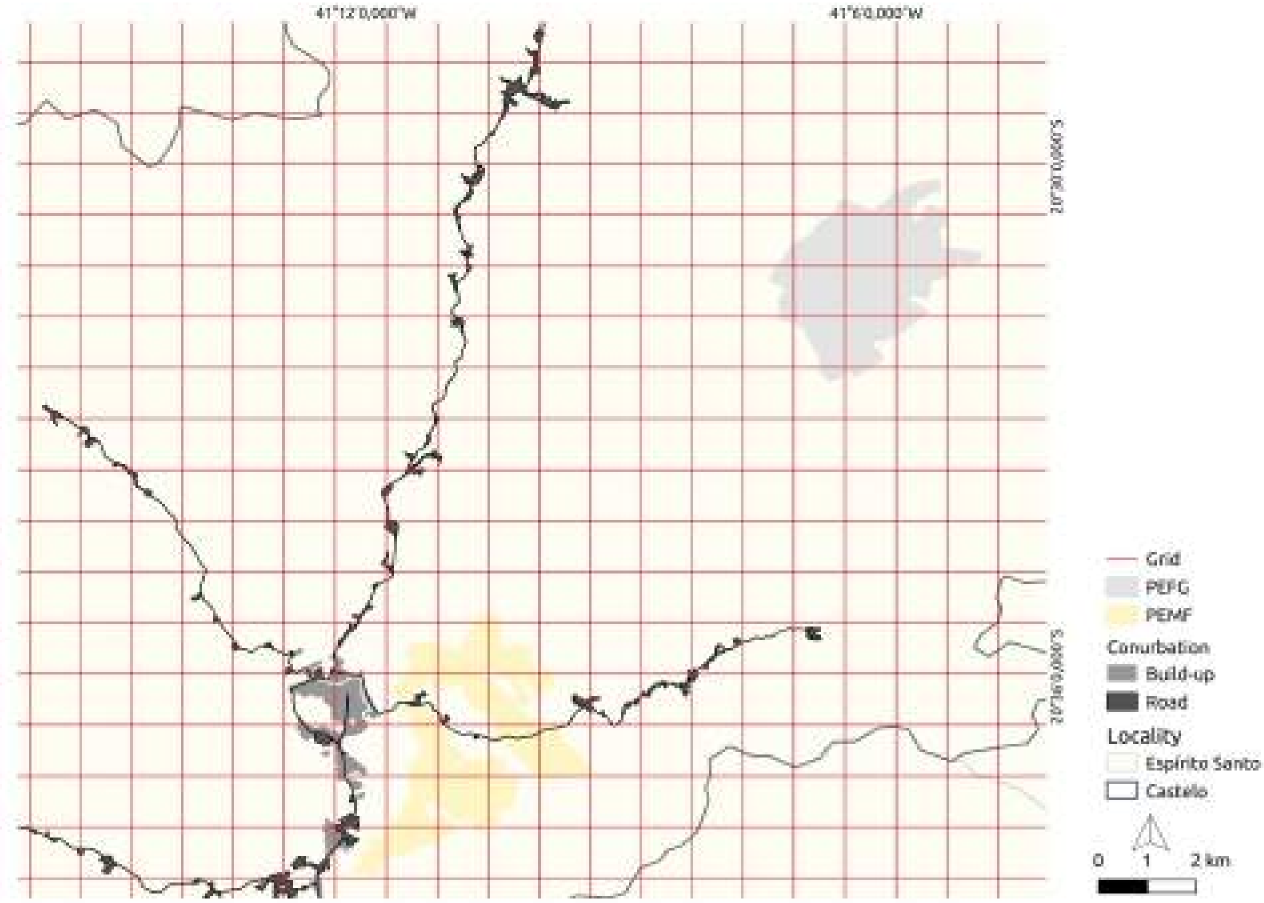

Figure 5: Location of Parque Estadual Forno Grande and Parque Estadual Mata das Flores, focusing on built-up areas and roads classed on a 1 km² grid.

VII. DISCUSSION

Species richness, diversity and abundance differes between PEFG and PEMF, with the former showing higher indices than the second. We believe that the reason for this is the design of the CUs, the type and proportion of the surrounding matrix, and the proximity to human settlements.

Considering the diversity indices, both CUs and all of theris scales are located in a region where the number of records and the richness of mammals are classified as intermediate, according to Moreira et al. 2008, with 46-60 mammals species. However, considering the studied CUs, the PEMF showed a reduced richness of non-volant small mammals with only 3 species, none endemic to the Atlantic Forest and only one to Brasil (Abreu, et al. 2023). In contrast, 14 species were registered in the PEFG, comprising 29.7% of the species of non-volant small mammal recorded in Espírito Santo and 12,72% of Atlantic Forest, with 28,5% endemic to this biome and 57,1% endemic to Brazil (Abreu et al., 2023). In relation to the richness, and in comparison with other areas nearby surveyed CUs in Espírito Santo, the Reserva Biológica Duas Bocas has

23 identified species (Carão, 2008; Tinini et al. 2010), 11 was were registred in Reserva Biológica Córrego do Veado (Conde, 2016), 13 in Reserva Biológica Sooretama/Parque Natural Vale (Alves, 2013) and, 27 in the Parque Nacional Caparaó(Bonvicino et al., 1997, Vale et al., 2024 – chapter 2).

Looking at the composition of the small mammal fauna in the analyzed fragments,, of the three species sampled in the PEMF, two belong to the order Didelphimorphia, namely *Marmosops incanus* (74.07% relative abundance) and *Didelphis aurita* (16.67%), while only *Nectomys squamipes* (with 9.26%) belongs to the order Rodentia. According to Braz et al. (2020), the abundance of *M. incanus* tends to decrease with a greater abundance of potential competitors, reaching its maximum abundance only when interspecific competition is weak. Dalmaschio & Passamani (2003) state that didelphids are more abundant in secondary areas with strong anthropogenic influence, which could be the case in the PEMF, since it is more subject to anthropization and consequently has a lower species richness. The same pattern was shown by Santos et al. (2004) in their study of the Parque Estadual Fonte Grande, also an urban fragment in the heart of the city of Vitória. For this urban conservation unit, 48.5% of all captures were of the marsupial *Marmosa murina,* a species very similar to *Marmosps incanus* (Emmons & Feer, 1997), both of which are favored in secondary forests (Stallings, 1989). It is also noteworthy that the PEMF, despite being a forest fragment, has no strict arboreal species among the three recorded, although both marsupials are scansorial.

On the other hand, the highest richness registered in PEFG implies that the environmental changes and impacts in this fragment were much less substantial than in ones PEMF endured, since the more significant rich small mammal fauna registered also includes rare species with restricted distribution, such as *Rhipidomys tribei* and *Rhagomys rufescens* (Paglia et al, 2012), both arboreal (De Carvalho & Pires, 2012) with restricted distribution in the Atlantic Forest (Patton et al., 2015), as well as *Trinomys gratiosus* and *Delomys sublineatus*, which have beem found only in intermediary elevational ranges in Espírito Santo (Dalapicolla & Leite, 2015; Vale & Costa, 2024 – chapter 1). The PEFG also showed a greater richness and abundance of species belonging to the order Rodentia (4,28% of richness), another difference between it and the PEMF, which may have contributed to the greater abundance per day (Figure 4). The species *Oligoryzomys nigripes* and *Akodon cursor* represent 66.22% of the relative abundance, while the 5 species of Didelphimorphia sampled represent only 13.81% of the total abundance.

Another way to understand the richness and abundance of the small mammal fauna in these fragments is to approach at the theory of island biogeography, proposed in 1960 by Robert MacArthur and Edward O. Wilson, where the richness of species on an island depends on its size and distance from the mainland. Because they are isolated and surrounded by a different type of habitat, forest fragments were considered "habitat islands" (Wilcox, 1980; Lovejoy, 1986). Some landscape ecological principles based on the theory of island biogeography that are used in conservation planning to maximize species richness and minimize the role of disturbance and edge effects on ecological processes may be one of the answers to the difference in richness and abundance found in the fragments that make up the PEFG and PEMF. These ecological principles suggest that one large patch is better than several small patches of the same total size, and that circular or square patches are better than rectangular or extended patches with many edges (McCartney & Wilson, 1960). These principles represent some of the differences in the conformation of the two fragments studied here, where the PEFG fragment can be considered a large, circular patch with less exposed edge density, while the PEMF is composed of the junction of several smaller, extended patches with a lot of exposed edge density (Figure 1 and 5).

According to Pires and co-authors (2006), an inevitable consequence of forest fragmentation is a drastic increase in the total number of habitat edges, since the high perimeter/area ratio of the fragments leads to the creation of large contact zones between the original habitat and the altered habitats surrounding it. As a result, the populations of animals and plants in the fragments are reduced. This community can be modified according to the type of matrix surrounding it, for example, the structural similarity between the matrix and the habitat of the fragments influences the ability of each species to cross the matrix (Ricketts, 2001). However, the extent to which each type of matrix is a barrier to biological flow depends not only on the characteristics of the habitat, but also on the biological characteristics of each species, due to its tolerance and ability to inhabit or simply cross the matrix. Individuals of some species cross the matrix more frequently than individuals of other species, such as *Didelphis aurita* and *Philander quica,* which are scansorial species and are not restricted to a single extract for locomotion (Pires et al., 2002). Thus, the matrix may act as a selective filter for the dispersal of individuals, determining which species are able to cross it and how often.

Species that manage to use the modified habitats of the matrix tend to have stable populations in the fragments, while species that avoid the matrix tend to disappear from the forest fragments (Laurance et al., 2002; Gascon et al., 1999; Pires et al., 2006). Matrix tolerance is the main factor determining the probability of extinction of marsupial and rodent populations (De Castro & Fernandez, 2004). The PEFG included many typical terrestrial species (*Monodelphis americana*, *Euryoryzomys russatus*, *Thaptomys nigrita*, *Trinomys gratiosus*, and *Akodon cursor*) that could potentially colonize the relatively nearby PEMF, but they appear to be intolerant of the pasture matrix surrounding this CU. According to Cáceres (2013), the degree of habitat specialization is the ecological trait associated with the vulnerability of species to environmental fragmentation.

The PEFG has a more diverse faunal composition, including arboreal species such as *Gracillinanus microtarsus*, *Rhagomys rufescens* and *Rhipidomys tribei*, due to the fact that the surrounding matrix has a high percentage of other smaller forest fragments, allowing these animals to take refuge and colonize the forest fragment. Other species associated with native forests were recorded, such as *Delomys sublineatus*, which are also favored by this forest matrix. In addition, there is a greater variety of landscapes, including high altitude grasslands, which according to Vasconcelos (2011), have a wide range of plant physiognomies, from areas covered by grasses to habitats with dense shrubs. The most abundant species in the PEFG, *Oligoryzomys nigripes* is associated with pastures or open areas (Machado et al, 2011).

The low species richness and the matrix with few forest fragments found in the PEMF are indicative of the anthropogenic pressure suffered by the fragment. According to Mendes-Oliveira et al. (2015), anthropogenic impacts on natural environments cause different changes in the structure of habitats. Depending on the intensity of the impact, habitats can be modified (historical deforestation), completely replaced (in the case of coffee monocultures) or extremely simplified (pasture). The response of the communities of non-volant small mammals to these impacts can vary according to the type of disturbance and the ecological characteristics of the species. This was very clear for this CU, since at the scale closest to the landscape profile of the fragment (scale 1 - Periphery) it shows the highest richness and as this scale increases, little of this proportion changes, with pastures always dominating (scales 2 – Buffer zone and 3 –

10 km radius) (Figure 4). In addition, this forest fragment borders the municipality of Castelo and is crossed by a road.

As for the PEFG, the forest matrix is mainly composed of a single fragment, as well as being located in an upland area, geographically isolated, with several points of difficult access (Meirelles & Goldenberg, 2012), which limits human settlement. The PEFG is close to the Parque Estadual Pedra Azul and the Reserva Particular do Patrimônio Natural Águia Branca, forming a very important ecological corridor in the region (IEMA, 2020), increasing the chances of species flow between these areas. In scales 1 and 3, the matrix with the highest proportion found in the PEFG is native forest, while in scale 2, pasture predominates. This scale 2 – Buffer zone, Based on the buffer zone defined by CU management defined, shows the priority area for restoration around the forest fragment, thus ensuring the conservation of the species found there (Figure 4 and Table 4).

Other impacts on wildlife related to the proximity of metropolitan areas are road accidents and hunting. The roads that cross habitats hinder the movement of species, resulting in road-kills, which is considered one of the main anthropogenic factors responsible for the death of wildlife (Oliveira, 2015). In addition, the roads found near the fragments increase the hunting rate because they make it easier to move around these areas. Another problem, according to Oliveira (2015), is the demographic pressure caused by the growth of cities around forest fragments, which causes serious damage to nature, including deforestation and pollution of the atmosphere, water and soil, which directly affects the richness and abundance of wildlife. According to Rodrigues et al. (2019), the proximity of metropolitan areas causes several other negative effects on forest fragments, such as soil impermeability, noise, solid waste and leaching, which directly affects the natural resources and fauna present in these fragment, mainly in lowlands.

Therefore, the low richness and abundance of non-volants small mammals found in the forest fragment that composes the Parque Estadual Mata das Flores is probably due to its higher fragmentation, which results in high edge density, causing the forest to be more exposed to the surrounding anthropomorphic conditions. The proximity to the town and composition of the matrix with a predominance of pastures around the CU restricts the flow of species in the region, in addition to the presence of the road cutting through the interior of the fragment, which increases both the rates of road accidnts, as well as hunting and generating various vectors of anthropic pressure on the wildlife of the region, culminating in its defaunation. In contrast, the fragment that composes the Parque Estadual Forno Grande is more isolated from the urban areas, which reduces the number of vectors of anthropic pressure in the area, as well as being part of an important ecological corridor, which increases the flow of species between the fragments. The PEFG has a lower perimeter/area ratio, which is a positive factor for the maintenance of fauna due to a lower edge effect, indicating a higher degree of conservation, in addition to the area of native forest representing the highest percentage of the matrix composition found in the CU region. In this way, the data presented here represent an important diagnosis of the loss of faunal richness or protected areas nearby settlements in the Atlantic Forest in, as well as highlighting the importance of more effective conservation and restoration actions in these environments, which are still a refuge for the fauna of non-volants small mammals. It is therefore necessary to carry out further studies on this fauna and to propose measures to preserve these remaining species and restore corridors among isolated fragments. Also, highlights the importance of the PEFG as an extremely relevant UC in the south of Espírito Santo, with a rich and diverse small mammal fauna, but that has not being received enough attention in order to better be known in terms of its local fauna and flora.

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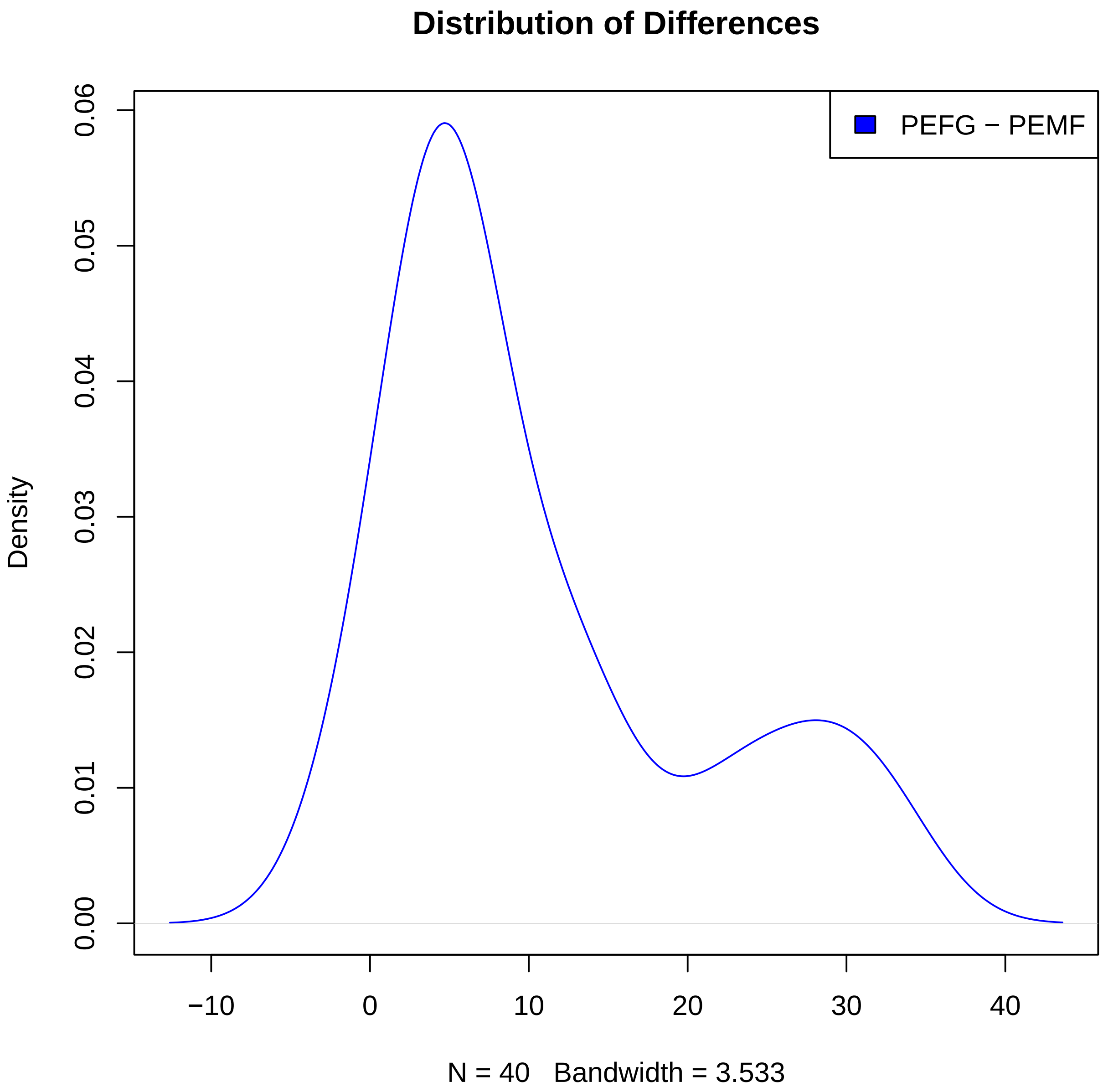
X. APPENDIX



Appendix 1: Density distribution of abundance differences for Parque Estadual Forno Grande and Parque Estadual Mata das Flores.

Appendix 2: List of fauna with record numbers, elevatoin and geographical coordinates in decimal numbers.

Species	Locality	Latitude	Longitude	Altitude	Record Number
Didelphiomorphia					
Didelphidae					
Didelphis aurita	PEFG	-20.51917	-41.08722	1205	LPC 1542
	PEMF	-20.61167	-41.16944	125	LPC 1510

Species	Locality	Latitude	Longitude	Altitude	Record Number
		-20.61833	-41.17639	116	LPC 1502
					LPC 1507
			-41.17806	115	LPC 1503
		-20.62139	-41.17306	112	LPC 1500
					LPC 1501
					LPC 1506
					LPC 1512
Gracillinanus microtarsus	PEFG	-20.51083	-41.09139	1460	LPC 1547
Marmosa murina	PEFG	-18.34809	-39.85192	52	LPC 1676
Marmosops incanus	PEFG	-20.51056	-41.09028	1465	LPC 1557
		-20.51083	-41.09139	1460	LPC 1421
					LPC 1432
					LPC 1447
					LPC 1484
					LPC 1530
					LPC 1556
		-20.51167	-41.09111	1460	LPC 1558
		-20.51639	-41.08944	1325	LPC 1543
		-20.51917	-41.08722	1205	LPC 1541
					LPC 1544
					LPC 1563
		20.51917	-41.08667	1180	LPC 1526
					LPC 1538
	PEMF	-20.61083	-41.17056	129	LPC 1508
					LPC 1511
		-20.61167	-41.16944	125	LPC 1510
		-20.61833	-41.17639	116	LPC 1499
					LPC 1534
			-41.17806	112	LPC 1513
				115	LPC 1498
					LPC 1504
					LPC 1505
					LPC 1509
					LPC 1534
		-20.62139	-41.17306	112	LPC 1512
					LPC 1514
		-20.63611	-41.20000	153	LPC 1532

Species	Locality	Latitude	Longitude	Altitude	Record Number
Monodelphis americana	PEFG	-20.51639	-41.08944	1325	LPC 1548
Philander quica	PEFG	-20.51056	-41.09028	1465	LPC 1557
		-20.51083	-41.09139	1460	LPC 1431
					LPC 1445
					LPC 1556
		-20.51167	-41.09111	1460	LPC 1443
					LPC 1444
					LPC 1476
					LPC 1528
					LPC 1558
		-20.51639	-41.08944	1325	LPC 1433
					LPV 1467
		-20.51917	-41.08722	1205	LPC 1417
					LPC 1518
					LPC 1563
		20.51917	-41.08667	1180	LPC 1538
Rodentia					
Cridetidae					
Akodon cursor	PEFG	-20.51056	-41.09028	1465	LPC 1557
		-20.51083	-41.09139	1460	LPC 1465
					LPC 1556
		-20.51167	-41.09111	1460	LPC 1558
		-20.51639	-41.08944	1325	LPC 1458
					LPC 1459
					LPC 1474
					LPC 1483
					LPC 1487
					LPV 1467
		-20.51917	-41.08722	1205	LPC 1415
					LPC 1416
					LPC 1426
					LPC 1563
		20.51917	-41.08667	1180	LPC 1450
					LPC 1451
					LPC 1453
					LPC 1529
					LPC 1538

Species	**Locality**	**Latitude**	**Longitude**	**Altitude**	**Record Number**
Delomys sublineatus	PEFG	-20.51083	-41.09139	1460	LPC 1554
		-20.51167	-41.09111	1460	LPC 1558
		-20.51917	-41.08722	1205	LPC 1536
Euryoryzomys russatus	PEFG	-20.51917	-41.08722	1205	LPC 1563
Nectomys squamipes	PEMF	-20.61833	-41.17639	116	LPC 1534
			-41.17806	115	LPC 1533
		-20.63611	-41.20000	153	LPC 1532
Oligoryzomys nigripes	PEFG	-18.34809	-39.85192	52	LPC 1676
		-20.51056	-41.09028	1465	LPC 1419
					LPC 1439
					LPC 1440
					LPC 1557
		-20.51083	-41.09139	1460	LPC 1420
					LPC 1479
					LPC 1480
					LPC 1521
					LPC 1556
		-20.51167	-41.09111	1460	LPC 1558
		-20.51639	-41.08944	1325	LPC 1422
					LPC 1423
					LPC 1424
					LPC 1434
					LPC 1435
					LPC 1441
					LPC 1442
					LPC 1446
					LPC 1454
					LPC 1455
					LPC 1456
					LPC 1457
					LPC 1466
					LPC 1468
					LPC 1469
					LPC 1481
					LPC 1482
					LPC 1485
					LPC 1522

Species	**Locality**	**Latitude**	**Longitude**	**Altitude**	**Record Number**
					LPV 1467
		-20.51917	-41.08667	1180	LPC 1428
			-41.08722	1205	LPC 1427
					LPC 1519
					LPC 1563
		20.51917	-41.08667	1180	LPC 1429
					LPC 1430
					LPC 1436
					LPC 1449
					LPC 1452
					LPC 1461
					LPC 1462
					LPC 1463
					LPC 1464
					LPC 1477
					LPC 1515
					LPC 1523
					LPC 1524
					LPC 1525
					LPC 1527
					LPC 1538
Oxymycterus dasytrichus	PEFG	-20.51056	-41.09028	1465	LPC 1550
					LPC 1557
		-20.51083	-41.09139	1460	LPC 1470
					LPC 1471
					LPC 1472
					LPC 1473
					LPC 1520
					LPC 1552
					LPC 1553
					LPC 1555
					LPC 1556
		-20.51639	-41.08944	1325	LPC 1517
					LPC 1531
					LPC 1535
					LPC 1546
					LPC 1562

Species	Locality	Latitude	Longitude	Altitude	Record Number
		-20.51917	-41.08722	1205	LPC 1418
Rhagomys rufescens	PEFG	-20.51083	-41.09139	1460	LPC 1475
Rhipidomys tribei	PEFG	-20.51083	-41.09139	1460	LPC 1448
					LPC 1486
					LPC 1556
Thaptomys nigrita	PEFG	-20.51639	-41.08944	1325	LPC 1425
		-20.51917	-41.08722	1205	LPC 1537
					LPC 1545
		20.51917	-41.08667	1180	LPC 1516
Echimyidae					
Trinomys gratiosus	PEFG	-20.51917	-41.08722	1205	LPC 1437
					LPC 1438
					LPC 1460
					LPC 1478
					LPC 1537

Capítulo 4

THE IMPORTANCE OF THE MUNICIPALITY OF SANTA TERESA (EASTERN BRAZIL) FOR UNDERSTANDING THE RICHNESS OF NON-VOLANT SMALL MAMMALS THROUGHOUT THE HISTORY OF THE ATLANTIC FOREST

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I. ABSTRACT

The municipality of Santa Teresa, located in the mountainous region of Espírito Santo, between altitudes of 100 to 1,043 m, has preserved 32.1% of its native Atlantic Forest cover, as well as three protected units, the Reserva Biológica Augusto Ruschi, the Estação Biológica Santa Lúcia and the Parque Natural Municipal São Lourenço. It is home to the Museu Biológico Mello Leito, part of the Insituto da Mata Atlântica, and is located a short distance from the Federal University of Espirito Santo (UFES), making it a particularly interesting place to study non-volant small mammals. Therefore, this study aim to list the species of small mammals in the municipality and to analyze their recording history. A total of 33 species were recorded, including 17 Cricetidae, 4 Echimyidae and 12 Didelphidae. Of this recorded fauna, 46.87% are endemic to the Atlantic Forest, 37.5% to Brazil. There are four endangered species: *Rhagomys rufescens* is considered Vulnerable on the IUCN list and Critically Endangered on the state list; *Rhipidomys tribei* is classified as Endangered on the national list; and, *Monodelphis scalops* and *Chironectes minimus*, both as Endangered for the state list. Records date back to 1941, with importants additions in the 1970s by Abravaya J. P., followed by Hoffmann W. A. and Passamani M. in the 1990s, and then Leite Y. L. R., Fagundes V. and Costa L. P. C. in the 2000s. The MBML and UFES are the main institutions that have contributed to the richness and abundance of records, especially the latter recently with two new records for 2019, the last year of this study. Thus, Santa Teresa is an important center of diversity for non-volant small mammals, and much of this is due to the presence of research institutions such as the MBML and, more recently, the UFES.

II. HIGHLIGHTS

i. Santa Teresa has 33 species of small non-volant mammals, making it one of the richest areas in the Atlantic Forest, including five threatened species, 11 endemic to the Atlantic Forest and 14 endemic to the Brasil.

ii. These records are concentrated in the southeast of the municipality, in the areas where the Reserva Biológica Augusto Ruschi, the Estação Biológica Santa Lúcia and the Parque Natural Municipal São Lourenço are located, the region with the highest altitude.

iii. The first records of non-volant small mammals date back to 1941, but there has been a great increase in the volume of these records since the 1980s. In 2019, the last year of registration, there was an increase in two species.

iv. The presence of the Museu Biológico Mello Leitão and the Universidade Federal of Espírito Santo are fundamental for this high number of records and for the realization of new sampling campaigns.

III. KEYWORDS:

Scientific institutions, Conservation units; Historical records.

IV. INTRODUCTION

The municipality of Santa Teresa is an important stronghold of the Atlantic Forest with 32.1% of its native forest cover (Secretaria do Estado do Meio Ambiente e Recursos Hídricos, 2018). It is located in the intermediate altitude of the Atlantic Forest, where the greatest richness is concentrated for biome because it includes species adapted to both the lower and upper parts of the mountain (Vale & Costa, 2024 – chapter 1) and is recognized as one of the regions with the highest species richness, especially in mammals (Moreira et al., 2008), making it a good example of studies for the biome. This status is due, in addition to the conservation status and altitude, to the intense collection and study efforts carried out in the municipality over the years (Moreira et al., 2008).

These collection efforts and studies are a crucial factor when it comes to taking conservation and sustainability measures, as they provide a basis for the ecology and systematics of organisms and ecosystems (Santos 2004). To organize this accumulation of information, databases have become one of the tools used to analyze data on species richness and distribution. Among these records, those of museums are more reliable because they guarantee that the specimens collected can be consulted (Moreira et al., 2008). Therefore, the presence of the Instituto Nacional da Mata Atlântica (INMA) with the Museu de Biologia Prof. Mello Leitão (MBML) is even more important (Loss et al., 2021). The museum was founded in 1949 by the naturalist and conservationist Augusto Ruschi and was instrumental in the creation of local conservation units (CUs) (Sarmento-Soares & Martins-Pinheiro 2014).

In addition, the municipality of Santa Teresa is only 1.5 hours by car from the capital city of Vitória, where the Universidade Federal do Espírito Santo (UFES) is located, creating a unique set of circumstances for the study of biodiversity (Figueiredo et al. 2021; Moreira et al. 2008; Colli-Silva et al. 2020). Therefore, the objectives of this work are: (1) to provide an updated list of non-volant small mammal species from the municipality of Santa Teresa, highlighting the threat status and endemism of the most recent survey of each species; and (2) to identify the dataset on a temporal scale and by collector.

V. MATERIALS AND METHOD

The city of Santa Teresa (19°56'10"s, 40°35'52"w) is located in the mountainous region of the state of Espírito Santo (Mendes & Padovan, 2000), with a relief that can vary from 100 to 1,143 m above sea level (Tabacow, 1992), and covers an area of 683 km^2 (IBGE, 2019). It borders eight municipalities and, throughout its length, land use and occupation is predominantly forest and agricultural crops (Figure 1). In addition, this municipality covers the southern portion of the Bahia Coastal Forests ecoregion and the northern portion of the Serra do Mar ecoregion in the Atlantic Forest (Olson et al. 2001, Scaramuzza et al. 2011, Campos & Lourenço-de-Moraes 2017, Silva et al. 2018). The predominant vegetation type is Montane and Submontane Rainforest (Rizzini, 1976), which falls within the phytoecological region of Dense Ombrophilous Forest (IBGE, 2004). As mentioned, this municipality is home to preservation areas such as the Reserva Biológica Augusto Ruschi (RBAR - 3,598 ha), the Estação Biológica Santa Lúcia (EBSL - 440 ha) and the Parque Natural Municipal São Lourenço (PNMSL - 22 ha), as well as the museum. This recognition came with the incorporation of the then MBML into the INMA in 2014, placing the institution as a national reference.

Data were collected in two steps. The first was by consulting the online database of specimens collected and deposited in scientific collections. This was done in August 2019 and January 2020 on the speciesLink website (http://splink.cria.org.br/), using the following keywords: "Mammalia", "Santa Teresa" and "Espírito Santo". Then, only the orders Didelphiomorpha and Rodentia of the families Didelphidae, Cricetidae and Echimyidae were selected.

Subsequently, a bibliographic survey was carried out in the scientific literature (scientific articles, theses, dissertations, book chapters, datapapers and citizen science websites - INATURALIST) on the records of mammal occurrences in Santa Teresa. This search was carried out between October 2019 and January 2020, taking into account all the works obtained until that date in CAPES journals, Web of Science, Scopus and Google Scholar. The search terms used were "mammal*" and "Santa Teresa". Based on the information obtained from the different sources, a spreadsheet was created with all the records found for the species, identifying the year of the first and last record for each species, as well as the total number of records based on collections and scientific literature. Records with incomplete taxonomy were discarded.

The taxonomy of this species was verified and validated according to IUCN (2019), Patton et al. (2015), Gardner et al. (2008), ICMBio (2018), and Abreu et al. (2023). In addition, information on endemism of the species was compiled and organized into endemism in the Atlantic Forest and endemism in Brazil (Abreu et al., 2023). In addition to this data set, the threat status of the species was investigated at three levels: international (IUCN, 2019), national (ICMBio, 2022), and state (Espírito Santo, 2022).

levels. In addition, data normality was assessed using Shapiro-Wilk's test, and only variables with normal distributions were used in subsequent non-parametric tests (Appendix 1). Richness and abundance, as well as rarefaction and collector curves, were calculated using the year, month, and day of collection when available. The same data set was used to calculate the non-parametric estimated first-order richness Jackknife (Heltshe & Forrester, 1983) for the non-volant small mammal families. This richness estimator is based on the number of species observed in a single sample (uniques speciess) and is considered the most accurate and least biased estimator compared to other extrapolation methods (Palmer, 1990, Provete et al. 2020). All of these analyses and graphs were performed using R software 4,2 in ambient RStudio (R Development Core Team, 2020), package “vegan” (Oksanen et al., 2022) and “ggplot2” (Wickham, 2016). Maps of the location of Santa Teresa, CUs, their limits, altitude, and vegetation cover based forest fragmentation (MMA, 2008) (Appendix 3 and 4), were drawn up using the QGIS program (version 3.22.4).

VI. RESULTS

A total of 33 species of non-volant small mammals were recorded in 1,518 records for the municipality of Santa Teresa, including Rodentia and Didelphiomorpha. For rodents, two families were identified, Cricetidae being the most abundant with 17 species in 585 records and Echimyidae with four species in 87 records. Marsupials had 12 species in 846 records, all Didelpidae family (Table 1, Appendix 2). In addition to richness and abundance records, the estimated richness of non-volant small mammal families was calculated, taking into account the sampling days (Table 2). Most of the records are concentrated in the southeastern part of the municipality of Santa Teresa, in and around the CUs (Figure 1).

Table 1: A complete list of non-volant small mammals recorded in the municipality of Santa Teresa, Espírito Santo. For each mammal, the date of the first and last record was given, as well as information on the biology of the species, endemism, and the respective threat categories. Legend: Abundance of records (Ab). Endemism (En): (BR) Brazil; (AF) Atlantic Forest. Threat categories (TA): (^{1}) Espírito Santo; (^{2}) Brazil; (^{3}) International Union for Conservation of Nature 2022 [(CP) Critically Endangered; (DD) Data Deficient; (EN) Endangered; (LC) Least Concern; (NC) Not reported; (NT) Near Threatened; (VU) Vulnerable].

Species	Ab	Data		En	TC
		First	Last		
DIDELPHIMORPHIA					
Didelphidae					
Caluromys philander	29	1990	2011		
Chironectes minimus	2	1941	1942		EN^1
Didelphis aurita	174	1942	2019		
Gracilinanus microtarsus	142	1942	2011		
Marmosa murina	11	1943	2014		
Marmosa paraguayana	42	19891	2019		
Marmosops incanus	353	1970	2019	BR	DD^3
Metachirus myosurus	32	1989	2019		
Monodelphis americana	13	1990	2019	BR	
Monodelphis iheringi	2	1999	2001	BR	DD^3
Monodelphis scalops	4	1941	1919	AF	EN^1
Philander quica	46	1940	2019		
RODENTIA					
Cricetidae					
Abrawayomy ruschi				AF	CR^1
Akodon cursor	72	1974	2019	BR	
Blarinomys breviceps	6	1973	2018	AF	DD^1
Cerradomys subflavus	1	2000	2000	BR	
Delomys sublineatus	32	1974	2000	BR/AF	
Euryoryzomys russatus	185	1973	2019	AF	
Juliomys pictipes	3	2001	2019	AF	
Necromys lasiurus	1	1974	1974		
Nectomys squamipes	102	1973	2019		
Oecomys catherinae	15	1990	2005	BR	
Oligoryzomys nigripes	55	1969	2019		
Oxymycterus dasytrichus	39	1973	2019	BR	
Rhagomys rufescens	1	2000	2000	BR/AF	CR^1/VU^3
Rhipidomys mastacalis	55	1990	2019	BR	
Rhipidomys tribei	1	2019	2019	BR/AF	EN^2/DD^3

Species	Ab	Data		En	TC
		First	Last		
Sooretamys angouya	1	1974	1974		
Thaptomys nigrita	51	1974	2019	AF	DD¹
Echimyidae					
Kannabateomys amblyonyx	10	1989	2005		
Phyllomys pattoni	11	1998	2007	BR	
Trinomys gratiosus	48	1970	2019	BR/AF	
Trinomys paratus	36	1971	2001	BR/AF	DD³

Table 2: Richness values (R), estimated richness (J), abundance of records (A) and sampling units in days for the families of non-volant small mammals in the municipality of Santa Teresa.

Families	Richness	Estimate richness	Abundance	Days
RODENTIA				
Cricetidae	17	22,96 ± 2,43	585	170
Echimyidae	4	4 ± 0	83	54
DIDELPHIOMORPHA				
Didelphidae	12	12 ± 0	766	205
Total	33	39,97 ± 2,63	1518	339

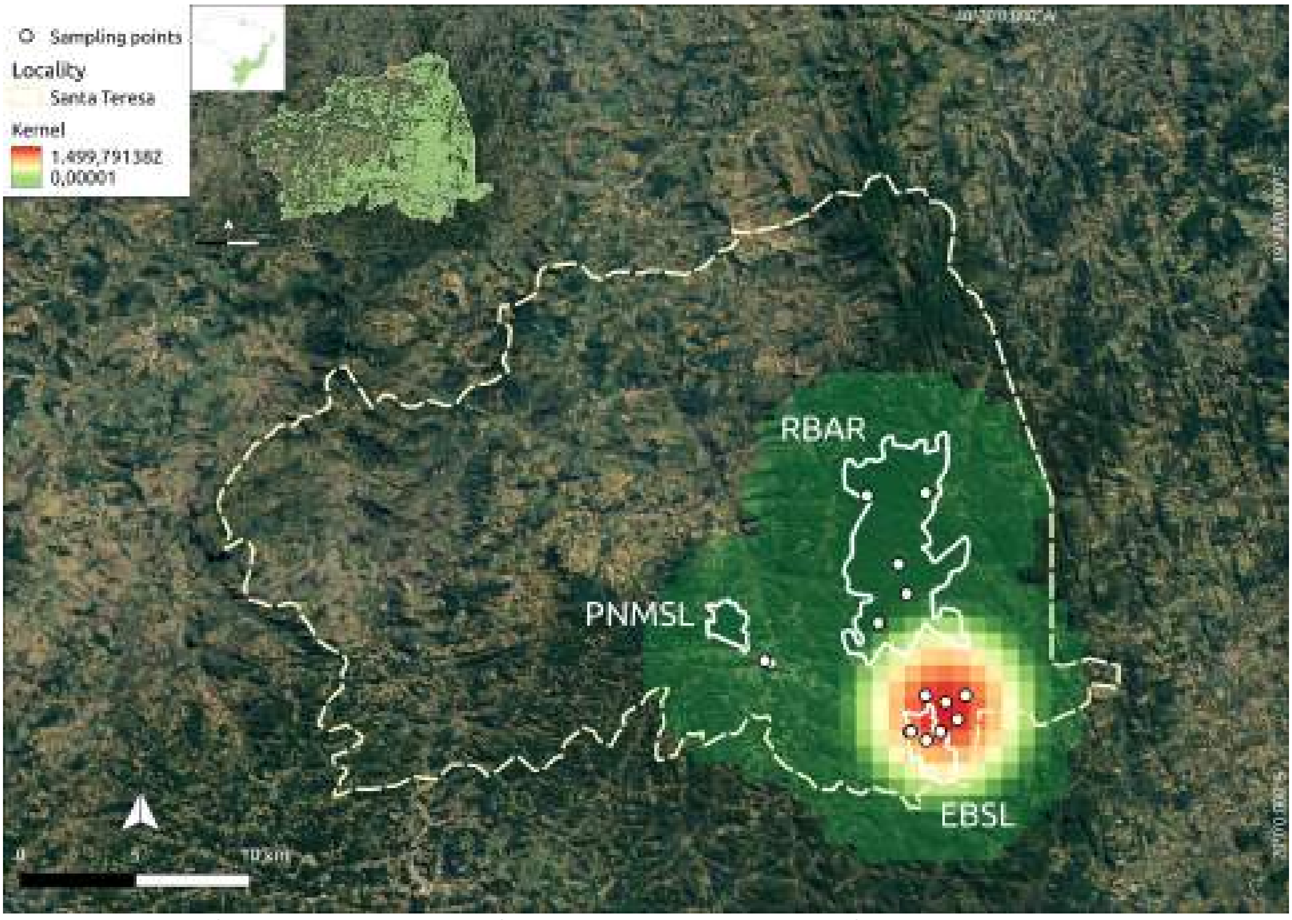

Figure 1: Map of density distribution of sampling points (Kernel) of non-volant small mammals in the Municipality of Santa Teresa, Espírito Santo, Brazil. In detail, the area of the Atlantic Forest in the municipality and in Brazil.

Looking at the temporal record, the rarefaction curve did not reach an asymptote (Figure 2). The distribution of records did not show a normal distribution (Shapiro-Wilk: $W = 0.82403$, p-value $< 2.2e^{-16}$), with the median in 2001, concentrated from the 90s onwards. The years of 1999 and 2001 had the highest richness indices with 21 species, and the year of 2001 was the most abundant year with 476 records (Figure 3). This pattern is repeated when we look at the time period of the main collectors, where most of the collectors also worked from this decade, especially those associated with UFES (Figure 3).

As for the accumulation of new species (Appendix 5), there is only one record in 1940. The years with the highest number of new species were 1989 and 1990 with 4 new species. And the last year with a record was 2019 with the addition of two new species for the municipality: *Abrawayomys ruschi* and *Rhipidomys tribei*. Looking at the decades, the 1970s had the most species additions with 10 new records, the 2000s was the decade with the greatest richness with 26 species recorded (78.78% of the total) and the greatest abundance with 829 records (54.61% of the total).

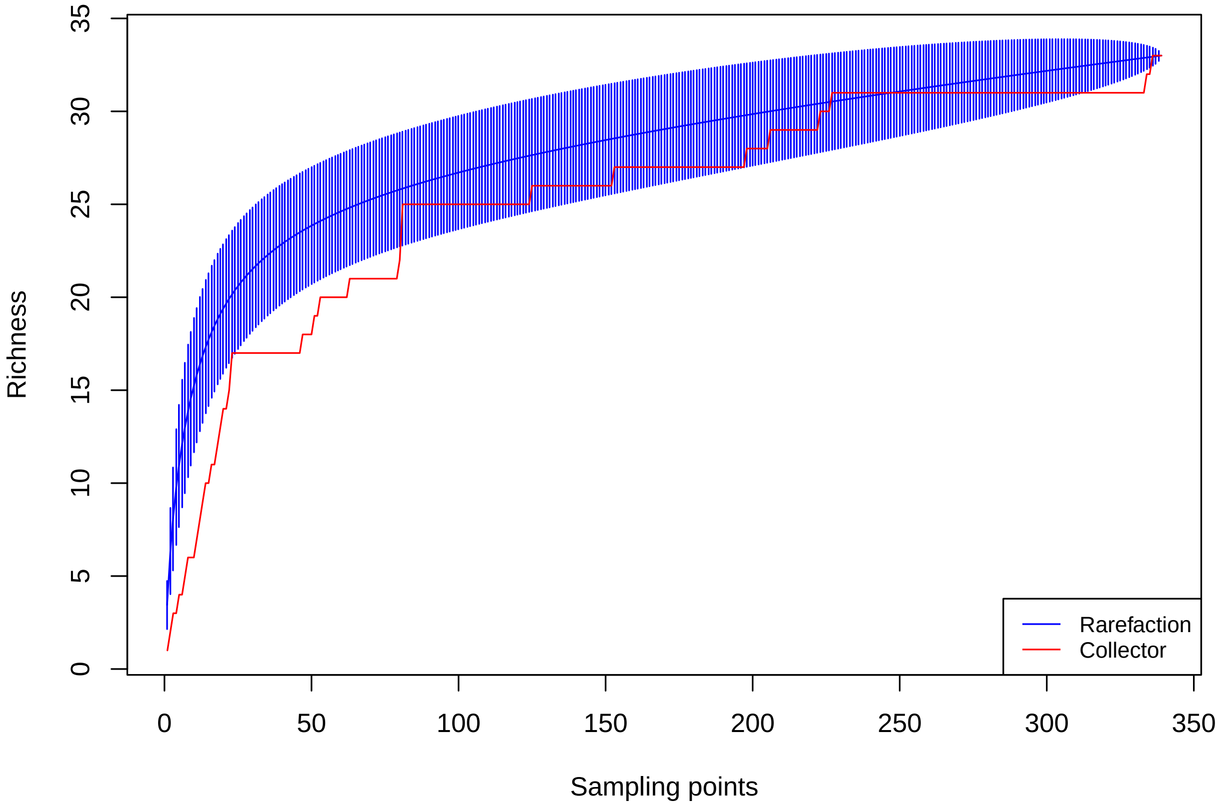

Figure 2: Rarefaction and collector curves of non-volant small mammal sampling points for the Municipality of Santa Teresa, Espírito Santo, Eastern Brazil.

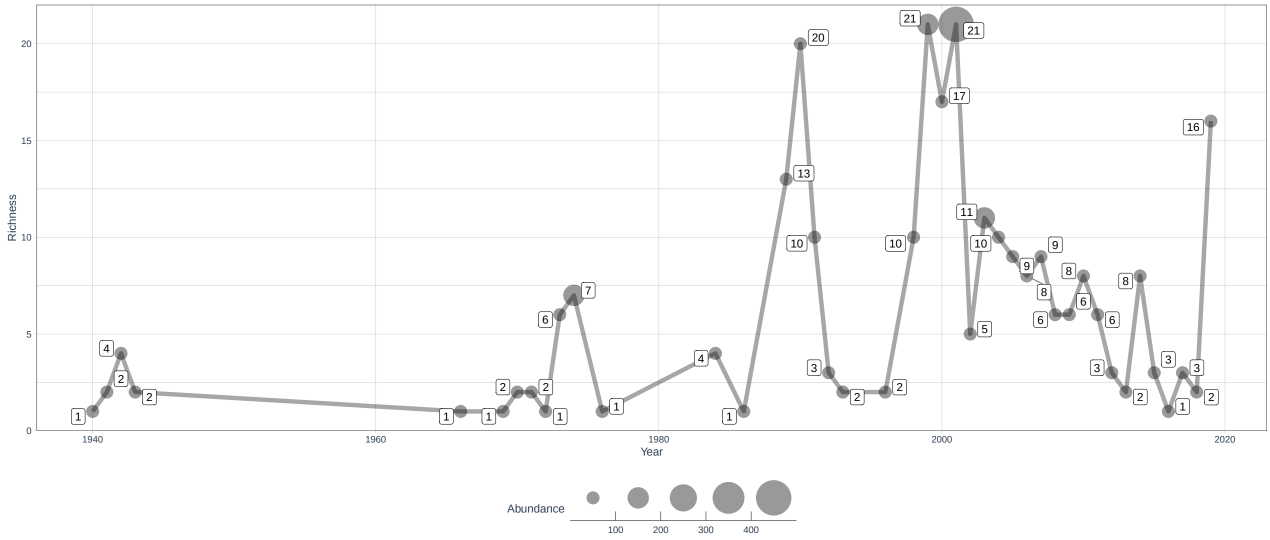

Figure 3: Richness and abundance recorded per year for the Municipality of Santa Teresa, Espírito Santo, Eastern Brazil.

Considering the source of the data, scientific collections presented 31 different species with 600 records, followed by articles with 24 species with 916 records and citizen science with one species with two records. Analyzing the contribution of the main collectors, Passamani M., Abravaya J.P. and Leite Y.L.R. account for 75.5% of the records. In terms of number of species, Passamani was the main contributor with 24 different species, followed by Leite Y.L.R with 21 species. As for the institutions, this result is reflected in the fact that MBML made the greatest contribution to the richness of the municipality of Santa Teresa with 28 species with 1,049 records, followed by UFES with 25 different species with 307 records (Figure 4).

Of the species recorded for the municipality of Santa Teresa, corresponds 30% Atlantic Forest species of non-volant small mammals, 46.87% are endemic to the Atlantic Forest, with rodents being the most representative group with 12 species. In addition, 37.5% of this fauna are endemic to Brazil, of which nine are endemic in both categories. In terms of IUCN status, 84.8% of the species are in the Least Concern category, while one species is in the Vulnerable threat category, *Rhagomys rufescens*. According to the national list, one species is classified as Endangered, *Rhipidomys tribei*. For Espírito Santo, four species appear in the list of threatened species, *Rhagomys rufescens* and *Abrawayomy ruschi* as Critically Endangered and *Monodelphis scalops* and *Chirocentes* minimus is Endangered.

Figure 4: Temporal distribution in boxplot of mammal species records by educational institution by each researcher with accumulation of record abundance for the top graph. In detail, the accumulation by institution. Institutions legend: Museu Biológico Mello Leitão (MBML); Universidade Federal do Espírito Santo (UFES), Universidade de rasília (UNB); Universidade de Vila Velha (UVV).

VII. DISCUSSION

Considering the diversity indices, Santa Teresa are located in a region where the number of records and the richness of mammals are classified as higher according to Moreira et al. in 2008. Located between 100 and 1,143 m above sea level, it is representative of the Serra Capixaba region, at an intermediate altitude for the Atlantic Rainforest. Mountainous regions, especially at intermediate altitudes, have an extraordinarily high biodiversity, especially in the tropics (Rahbek, 2001; Jetz & Rahbek, 2002; Rahbek, 2007), including the Atlantic Fores (Vale & Costa, 2024 – chapter 1).

The municipality has 33 species, both in protected areas and outside them, demonstrated the greatest richness of non-volant small fauna compared with other areas of nearby as with the Serra do Caparaó, with 27 species (Vale et al., 2024 – chapter 2) and surrounding municipalities such as: Castelo, with the Parque Estadual Mata das Flores (3 species) and the Parque Estadual Forno Grande (14 species), for a total of 15 species (Vale et al., 2024 – chapter 3); Cariacica, with the Reserva Biológica Duas Bocas, 23 species; the municipality of Pinheiros, with ten species recorded in the Reserva Biológica Córrego do Veado (Conde, 2016); and, Conceição da Barra, which registred five species in the Floresta Nacional Rio Preto and seven in the Reserva Biológica Córrego Grande, for a total of 10 species (Conde 2016). Considering another regions, there was also greater richness compared to the Serra do Brigadeiro with 22 species (Moreira et al., 2008), the Serra do Cipó with 24 species (Câmara & Oliveira 2012), the Serra do Ouro Branco with 17 species (Braga et al. 2016), and the Serra da Bocaina with 32 (Delciellos et al., 2023). The same richness of the Serra do Itatiaia, with 33 species of non-volant small mammals (Geise et al., 2004).

This richness and diversity for the municipality, despite repeated sampling efforts, although concentrated in some areas, was not enough to stabilize the collector's curve. Of the total species, 6.25% were recorded for the first time in the last 10 years and 15.62% were recorded only once (*Abrawayaomys ruschi*, *Cerradomys subflavus*, *Necromys lasiurus*, *Rhagomys rufescens* and *Rhipidomys tribei*). This highlights the need to focus studies on these rare mammals to understand the reasons for their low numbers and to better assess their threat status. As an example, the *Chironectes minimus* has a distribution throughout the state of Espírito Santo (Pérez-Hernandez et al, 2016), but it has very few records, with the only two specimens deposited in the MBML dating back to the 1940s and the last record for the Reserva Biológica Duas Bocas in 2010 (Tonini et al., 2010). In addition, the catita (*Monodelphis scalops*) also has old records in the municipality and is a species with rare surveys in Brazil (Passamani & Mendes, 2007).

The number of records for the municipality increased significantly in the 1990s, beginning with William Arthur Hoffmann, then of the Universidade de Brasilia (UNB), a botanist who contributed with collections of small non-volant mammals. And at the end of the 1990s, mainly due to the studies carried out by Marcelo Passamani, who presented his doctoral thesis on the area, as well as numerous partnerships and contributions to research in the municipality. Also noteworthy is the high number of specimens recorded for the municipality of Santa Teresa since the 2000s. In this decade, three mastozoologists working with small mammals arrived at the UFES: Leonora Pires Costa, Yuri Luiz Reis Leite and Valéria Fagundes. These researchers have contributed to the increase in the number of animals deposited in the scientific collections, thanks to the infrastructure and logistics offered in the municipality in partnership with the MBML. In addition, the implementation of new capture techniques, such as pitfalls, which increase the efficiency of collection and recording of non-volant small mammals for a given area (Umetsu, et al, 2006), have provided new records, especially of elusive species with low sensitivity to live traps, adding new information to the list.

Although the municipality has a long history of surveying the fauna of small mammals on a temporal scale, these records are concentrated in the southeastern part of the municipality, at altitudes between 550 and 950 m in Estação Ecológica Santa Lúcia and the Reserva Biológica Augusto Ruschi, between 780 and 1,143 m. Surveys in other areas, especially at different altitudes, may reveal a different faunal community (Vale & Costa, 2024 – chapter 1). Therefore, new surveys could contribute to increase the richness of the community, particularly for Cricetidae, which had an estimated richness higher than the observed richness. Thus, Santa Teresa, thanks to the presence of research institutions such as the MBML and, more recently, the UFES, is an excellent model for understanding the mastofauna of non-volant small mammals in the Atlantic Forest, due to its exceptional richness, ideal altitude and history of records, as well as its large native forest cover.

VIII. ACKNOWLEDGEMENTS

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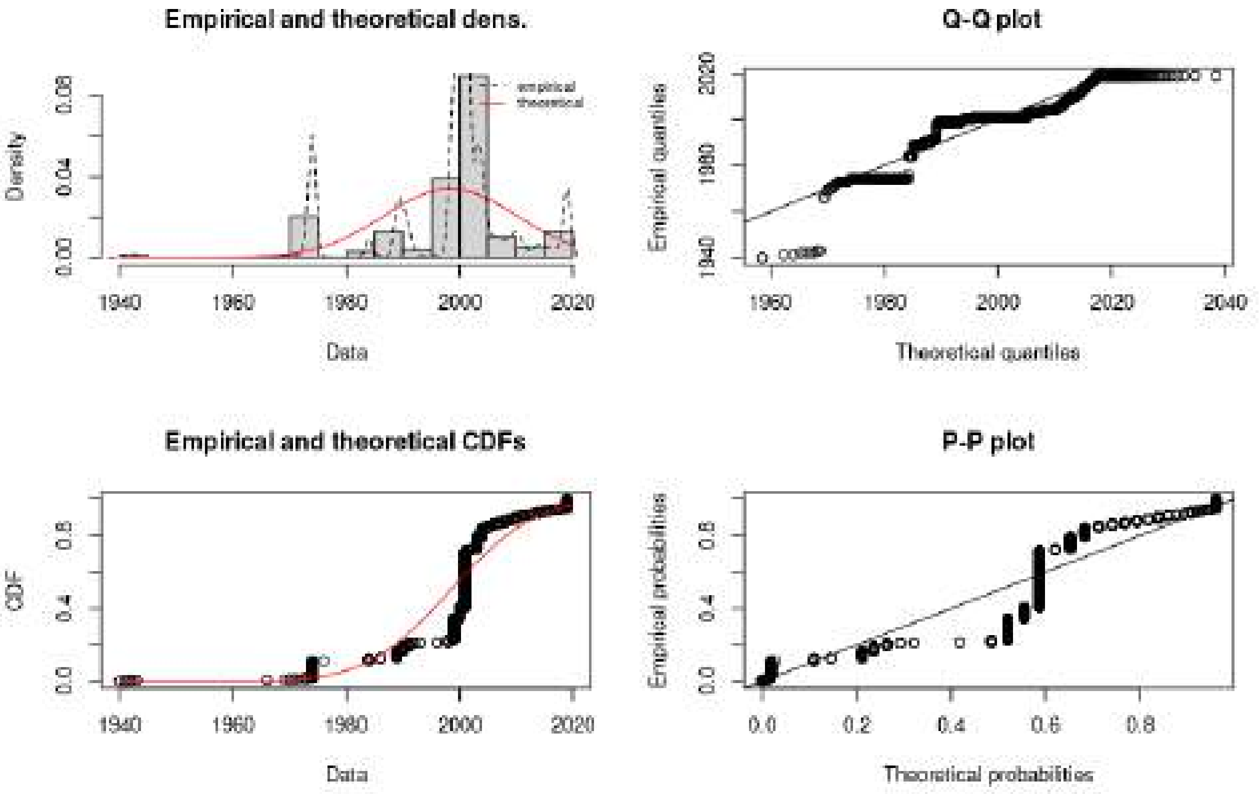
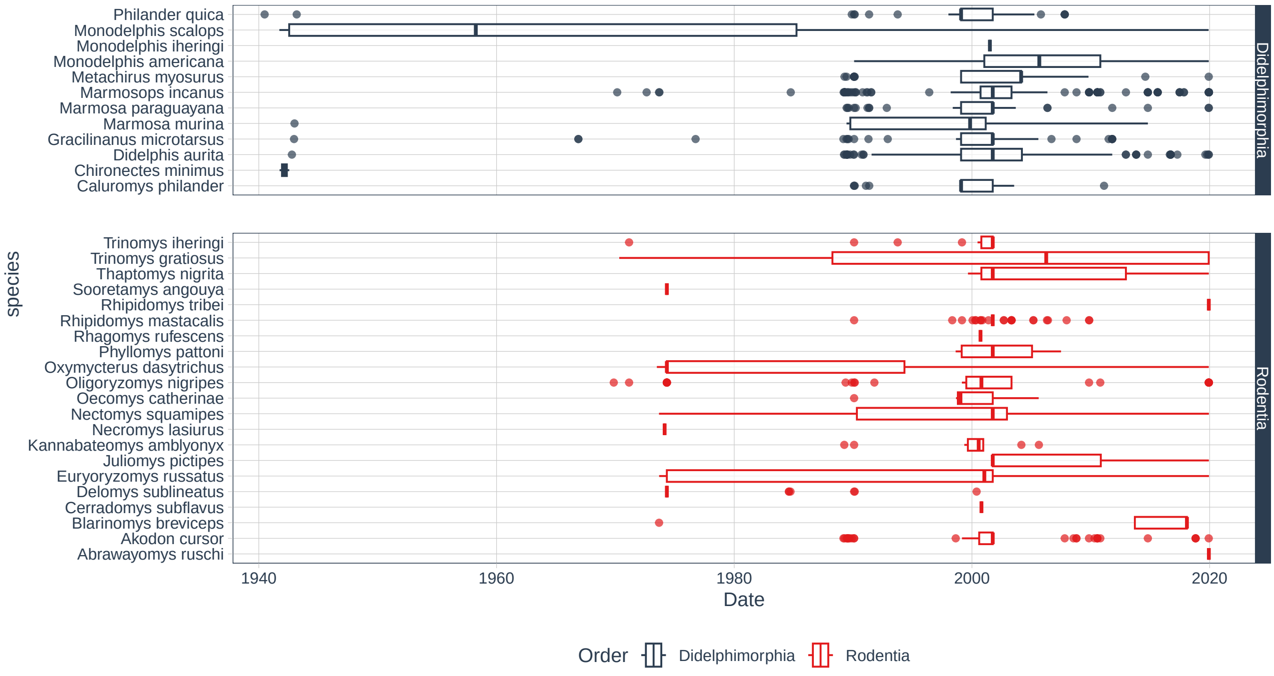
X. APPENDIX

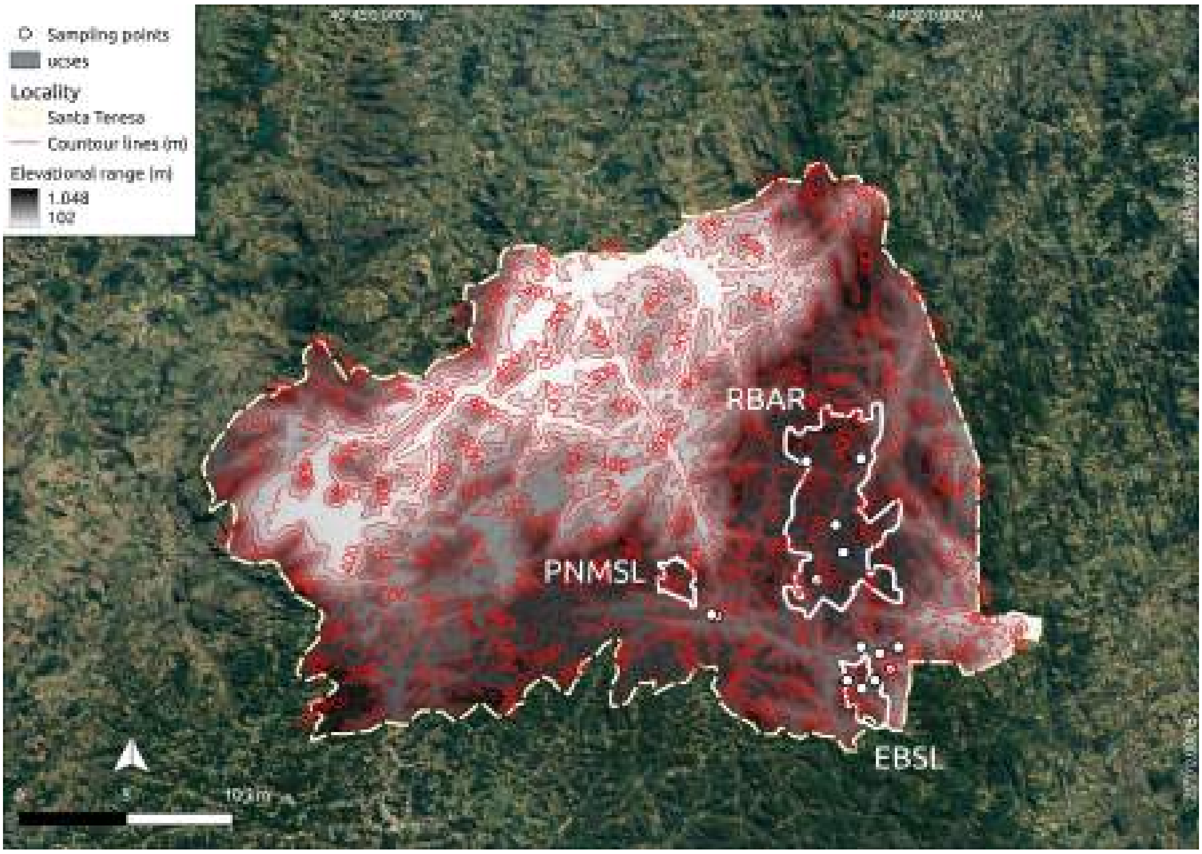


Appendix 1: Normality analysis of altitudinal samples with comparison between Empirical Density, QQPlot, Empirical and theoretical CDFs and P-P Plot, along the Municipality of Sata Teresa data.



Appendix 2: Box plot of the temporal distribution of the records of species of non-volant small mammals for the Municipality of Santa Teresa, in eastern Brazil.

Appendix 3: Atlantic Forest fragments and sampling points of non-volant small mammals in the Municipality of Santa Teresa, Espírito Santo, Brazil.



Appendix 4: Elevational range with countrou lines and sampling points of non-volant small mammals in the Municipality of Santa Teresa, Espírito Santo, Brazil.

Appendix 5: Year (y), Abuncance (A) and Accumulated Richness (AR) per year in Municipality of Santa Teresa (1940-2019).

Y	A	AR	Y	A	AR
1940			**2000**		
1940	1	1	2000	92	30
1941	2	3	2001	476	31
1942	4	5	2002	8	31
1943	2	6	2003	103	31
1960			2004	76	31
1966	2	6	2005	19	31
1969	1	7	2006	15	31
1970			2007	13	31
1970	2	9	2008	15	31
1971	2	10	2009	12	31
1972	1	10	**2010**		
1973	10	14	2010	24	31
1974	142	17	2011	12	31

1976	1	17
1980		
1984	22	17
1986	3	17
1989	55	21
1990	40	25
1991	25	25
1992	3	25
1993	2	25
1996	2	25
1998	22	26
1999	180	28
2012	4	31
2013	4	31
2014	12	31
2015	10	31
2016	6	31
2017	7	31
2018	6	31
2019	80	33

Appendix 6: List of fauna with geographical coordinates in decimal numbers and de locality un Minicipality of Santa Teresa, Eastern Brazil.

Species	**Locality**	**Latitude**	**Longitude**	**MBML**	**Others**	**UFES**	**UNB**	**UVV**	**Total**
Caluromys philander	INMA	-19.952778	-40.525000	1					**1**
	Santa Lúcia	-19.952778	-40.525000	13			2		**15**
	Santa Teresa	-19.952778	-40.525000	12	1				**13**
Chironectes minimus	Santa Teresa	-19.952778	-40.525000		2				**2**
Didelphis aurita	INMA	-19.952778	-40.525000	7	2	1	2		**12**
	Nova Lombardia	-19.952778	-40.525000				1		**1**
	REBIO Augusto Ruschi	-19.952778	-40.525000			4			**4**
	Santa Lúcia	-19.9500000	-40.53333333			1			**1**
		-19.952778	-40.525000	32		25	2	44	**103**
	Santa Teresa	-19.952778	-40.525000	49	2	1	1		**53**
Gracilinanus microtarsus	INMA	-19.952778	-40.525000	2					**2**
	Santa Lúcia	-19.952778	-40.525000	54		8	3		**65**
	Santa Teresa	-19.952778	-40.525000	71	4				**75**
Marmosa murina	Santa Lúcia	-19.952778	-40.525000	4		3	2		**9**
	Santa Teresa	-19.952778	-40.525000	1	1				**2**
Marmosa paraguayana	REBIO Augusto Ruschi	-19.952778	-40.525000			2			**2**
	Santa Lúcia	-19.9500000	-40.53333333			1			**1**
		-19.952778	-40.525000	11		7	4		**22**
	Santa Teresa	-19.952778	-40.525000	18					**18**
Marmosops incanus	INMA	-19.952778	-40.525000	7					**7**
	Nova Lombardia	-19.952778	-40.525000	2		6			**8**

Species	Locality	Latitude	Longitude	MBML	Others	UFES	UNB	UVV	Total
	REBIO Augusto Ruschi	-19.952778	-40.525000			10			**10**
	Santa Lúcia	-19.9500000	-40.53333333			1			**1**
		-19.952778	-40.525000	61		41	13		**115**
	Santa Teresa	-19.952778	-40.525000	211		1			**212**
Metachirus myosurus	REBIO Augusto Ruschi	-19.952778	-40.525000			1			**1**
	Santa Lúcia	-19.952778	-40.525000	3		4	6	15	**28**
	Santa Teresa	-19.952778	-40.525000	3					**3**
Monodelphis americana	Alto Santo Antônio	-19.952778	-40.525000	1					**1**
	REBIO Augusto Ruschi	-19.952778	-40.525000	2		2			**4**
	Santa Lúcia	-19.9500000	-40.53333333			1			**1**
		-19.952778	-40.525000	1		5			**6**
	Santa Teresa	-19.952778	-40.525000	1					**1**
Monodelphis iheringi	Alto Santo Antônio	-19.935556	-40.600278		1				**1**
	Santa Lúcia	-19.935556	-40.600278		1				**1**
Monodelphis scalops	REBIO Augusto Ruschi	-19.952778	-40.525000	1		1			**2**
	Santa Teresa	-19.952778	-40.525000		2				**2**
Philander quica	Nova Lombardia	-19.952778	-40.525000	2					**2**
	Santa Lúcia	-19.9500000	-40.53333333			1			**1**
		-19.952778	-40.525000	22		7	2	1	**32**
	Santa Teresa	-19.952778	-40.525000	8	2				**10**
	Serra	-19.952778	-40.525000		1				**1**
Abrawayomys ruschi	REBIO Augusto Ruschi	-19.8953	-40.5446			1			**1**

Species	**Locality**	**Latitude**	**Longitude**	**MBML**	**Others**	**UFES**	**UNB**	**UVV**	**Total**
Akodon cursor	INMA	-19.952778	-40.525000	1					**1**
	REBIO Augusto Ruschi	-19.865556	-40.533333			3			**3**
		-19.9076	-40.5412			1			**1**
	Santa Lúcia	-19.950000	-40.516667	1					**1**
			-40.533333	1					**1**
		-19.9500000	-40.53333333			1			**1**
		-19.952778	-40.525000	1		3	5		**9**
		-19.96	-40.52			1			**1**
		-19.965	-40.5272222222222			4			**4**
			-40.53944			1			**1**
			-40.5394444444444			2			**2**
			-40.54		1	1	2		**4**
		-19.96858	-40.53296			3			**3**
	Santa Teresa	-19.935556	-40.600278	4					**4**
		-19.950000	-40.516667	22					**22**
		-19.952778	-40.525000	6					**6**
Blarinomys breviceps	INMA	-19.935556	-40.600278	1					**1**
	Nova Lombardia	-19.936389	-40.597778	3					**3**
	Santa Lúcia	-19.965	-40.53944			1			**1**
Cerradomys subflavus	Santa Lúcia	-19.952778	-40.525000			1			**1**
Delomys sublineatus	REBIO Augusto Ruschi	-19.952778	-40.525000	26					**26**
	Santa Lúcia	-19.952778	-40.525000	1			4		**5**

Species	Locality	Latitude	Longitude	MBML	Others	UFES	UNB	UVV	Total
	Santa Teresa	-19.952778	-40.525000	1					**1**
Euryoryzomys russatus	Nova Lombardia	-19.952778	-40.525000			1			**1**
	REBIO Augusto Ruschi	-19.952778	-40.525000	65		23			**88**
	Santa Lúcia	-19.9500000	-40.53333333			1			**1**
		-19.952778	-40.525000	4		20	14		**38**
	Santa Teresa	-19.952778	-40.525000	55		2			**57**
Juliomys pictipes	REBIO Augusto Ruschi	-19.952778	-40.525000			1			**1**
	Santa Teresa	-19.952778	-40.525000	2					**2**
Necromys lasiurus	Santa Teresa	-19.952778	-40.525000	1					**1**
Nectomys squamipes	INMA	-19.952778	-40.525000	2					**2**
	REBIO Augusto Ruschi	-19.952778	-40.525000	20		2			**22**
	Santa Lúcia	-19.9500000	-40.53333333			1			**1**
		-19.952778	-40.525000	5		7	3		**15**
	Santa Teresa	-19.952778	-40.525000	62					**62**
Oecomys catherinae	Santa Lúcia	-19.952778	-40.525000	10		3			**13**
	Santa Teresa	-19.952778	-40.525000	2					**2**
Oligoryzomys nigripes	INMA	-19.952778	-40.525000	1					**1**
	REBIO Augusto Ruschi	-19.952778	-40.525000	6		6			**12**
	Santa Lúcia	-19.9500000	-40.53333333			1			**1**
		-19.952778	-40.525000	4		16	3		**23**
	Santa Teresa	-19.952778	-40.525000	17		1			**18**
Oxymycterus dasytrichus	REBIO Augusto Ruschi	-19.952778	-40.525000	24		1			**25**

Species	Locality	Latitude	Longitude	MBML	Others	UFES	UNB	UVV	Total
	Santa Lúcia	-19.952778	-40.525000	3		7			**10**
	Santa Teresa	-19.952778	-40.525000	4					**4**
Rhagomys rufescens	Santa Teresa	-19.952778	-40.525000	1					**1**
Rhipidomys mastacalis	Nova Lombardia	-19.952778	-40.525000	2					**2**
	REBIO Augusto Ruschi	-19.952778	-40.525000	1					**1**
	Santa Lúcia	-19.952778	-40.525000	3		2			**5**
	Santa Teresa	-19.952778	-40.525000	46		1			**47**
Rhipidomys tribei	REBIO Augusto Ruschi	-19.952778	-40.525000			1			**1**
Sooretamys angouya	REBIO Augusto Ruschi	-19.952778	-40.525000	1					**1**
Thaptomys nigrita	REBIO Augusto Ruschi	-19.8953	-40.5446			1			**1**
		-19.9076	-40.5412			4			**4**
		-19.9198	-40.553			1			**1**
	Santa Lúcia	-19.9500000	-40.53333333			1			**1**
		-19.96	-40.52			1			**1**
		-19.965	-40.5269444444444			1			**1**
			-40.5272222222222			1			**1**
			-40.53944			1			**1**
			-40.54	1		7			**8**
	Santa Teresa	-19.935556	-40.600278	3					**3**
		-19.950000	-40.516667	3					**3**
		-19.952778	-40.525000	1					**1**
Kannabateomys amblyonyx	Santa Lúcia	-19.9500000	-40.53333333			1			**1**

Species	Locality	Latitude	Longitude	MBML	Others	UFES	UNB	UVV	Total
		-19.952778	-40.525000	4		5			**9**
Phyllomys pattoni	Nova Lombardia	-19.952778	-40.525000	1					**1**
	Santa Lúcia	-19.9500000	-40.53333333			1			**1**
		-19.952778	-40.525000	4		4			**8**
	Santa Teresa	-19.952778	-40.525000	1					**1**
Trinomys gratiosus	Alto Santo Antônio	-19.9356002807617	-40.6002998352051			1			**1**
	INMA	-19.935556	-40.600278	1					**1**
		-19.9356002807617	-40.6002998352051	1					**1**
	Nova Lombardia	-19.9356002807617	-40.6002998352051			1			**1**
	REBIO Augusto Ruschi	-19.8668	-40.5578			2			**2**
		-19.8953	-40.5446			2			**2**
		-19.9076	-40.5412			4			**4**
		-19.9198	-40.553			10			**10**
	Santa Lúcia	-19.935556	-40.600278				11		**11**
		-19.965	-40.5269444444444			2			**2**
			-40.5272222222222			2			**2**
			-40.5394444444444			2			**2**
			-40.54	4		1	4		**9**
Trinomys iheringi	INMA	-19.935556	-40.600278	1					**1**
	Santa Lúcia	-19.950000	-40.516667	1					**1**
			-40.533333	1					**1**
		-19.952778	-40.525000	1					**1**

Species	**Locality**	**Latitude**	**Longitude**	**MBML**	**Others**	**UFES**	**UNB**	**UVV**	**Total**
	Santa Teresa	-19.935556	-40.600278	1					**1**
		-19.950000	-40.516667	13					**13**
Total				**1051**	**20**	**310**	**84**	**60**	**1525**

CONCLUSÃO GERAL

Regiões montanhosas exibem uma notável variedade de pequenos mamíferos não-voadores e a altitude atreladas a montanhas é um importante atributo n-fatorial associada a essa diversidade, dessa forma uma abordagem humboldtiana é ideal para o estudo dessas fatores. Na Mata Atlântica a maior riqueza de espécies é encontrada em altitudes intermediárias concentrada principalmente entre 1.000-1.500 m e 1.500-2.000 m, em um padrão conhecido como efeito de domínio médio na biogeografia. Essa riqueza é influenciada não apenas pela área, mas também pela sobreposição entre as comunidades de fauna que habitam terras altas e terras baixas, além de substituições de espécies dentro do mesmo gênero ao longo das diferentes altitudes, indicando uma divisão distinta das comunidades. Didelphiomorpha e Rodentia ocupam as faixas altitudinais de forma distinta. Os marsupiais apresentam baixa ocorrência em altitudes mais elevadas, concentrando sua maior riqueza e diversidade de espécies nas faixas inferiores, principalmente até 500 m padrão pico de riqueza de planície baixa. Em contraste, os roedores exibem picos de riqueza e diversidade de espécies de acordo com o padrão de domínio médio.

Em relação a uma única montanha, a serra do Caparaó apresentou 27 espécies de pequenos mamíferos não-voadores, com 57,44% das espécies registradas no Espírito Santo, 24,5% das espécies registradas na Mata Atlântica, 51,1% endêmicas do Brasil e 59,2% endêmicas da Mata Atlântica, sendo de grande relevância em termos de riqueza de pequenos mamíferos deste bioma. A Serra do Caparaó apresentou padrões parecidos com o da Mata Atlântica como um todo, onde a altitude mostrou-se um fator importante para a composição da fauna com diminuição no número de espécies com o aumento da altitude, sugerindo um padrão de riqueza decrescente. Vale ressaltar que a faixa mais baixa para a montanha corresponde a parte intermediária da Mata Atlântica como um todo, sugerindo um efeito de faixa média para o bioma. Três paisagens distintas se destacaram nessa região montanhosa: a floresta ombrófila densa montana, a floresta ombrófila densa altimontana e os campos de altitude. A riqueza e a abundância demonstraram padrões divergentes, onde a riqueza diminui com o aumento da altitude sendo maior na floresta ombrófila densa montana; já a abundância demonstrou um padrão crescente, com a maior abundância de espécies em campos de altitude.

Além dos fatores abióticos intrínsecos a altitude, como temperatura, umidade e pressão atmosférica, por exemplo, o ocupação da paisagem em áreas montanhosas não são a mesmas nas diferentes elevações. A ocupação humana se concentra em baixadas onde o relevo é mais uniforme para alterações que vão de edificações a substituição da flora nativa por cultivos agrícolas diversos. Analisando duas unidades de conservação (UCs), uma em regiões de baixa altitude – Parque Estadual Mata das Flores (PEMF) - e outra em grandes altitudes – Parque Estadual Forno Grande (PEFG), com o tamanho e esforço de registro semelhantes e próximos entre si, percebemos que há diferentes pressões antrópicas entre elas. O PEMF é formado por três fragmentos florestais de formato irregular trespassado por uma rodovia, apresenta maior áreas de borda e está localizado tangencial a áreas edificadas. Sua matriz de entorno é formado principalmente por pastagem e cultivo cafeeiro em três diferente escalas resultando numa riqueza de apenas três espécies com alta dominância de *Marmosops incanus*. Já PEFG é mais distante de áreas edificadas e rodovias, apresenta um formato único e arredondado, o que diminui o perímetro de bordas, e sua matriz de entorno é formada principalmente por áreas de mata nativa que, inclusive, forma um importante corredor ecológico com outras unidades de conservação, apesar de também apresentar áreas de pastagem e cultivo cafeeiro. Assim, possui uma riqueza de 14 espécies de pequenos mamíferos não-voadores com importantes registros de espécies endêmicas e ameaçadas de extinção, em especial o *Rhagomys rufescens*, espécies de pouquíssimos registros notificados.

Considerando áreas de altitudes intermediárias e com matriz de uso e ocupação do solo predominante de mata nativa, o município de Santa Teresa, na região serrana do Espírito Santo, se torna uma excelente área para analisar a riqueza de pequenos mamíferos não-voadores na Mata Atlântica. Com 33 espécies registradas, incluindo espécies endêmicas e ameaçadas, é uma das regiões de maior diversidade destas espécies no bioma. Mas, além da localização e altitude, a região apresenta um longo histórico de estudos e registros para esta fauna, que dista deste 1941, princialmente por duas instituições de ensino e pesquisa localizados próximas ao município, a Museu de Biologia Mello Leitão (MBML), que faz parte do Instituto da Mata Atlântica (INMA), e a Universidade Federal do Espírito Santo (UFES). A presença destas instituições perpetuam os levantamentos de fauna até a atualidade com novos registro de espécies até o ultimo ano considerado, em 2019, indicando que a totalidade da fauna de pequenos mamíferos não-voadores não foi registrada, principalmente para cricetídeos que possui riqueza estimada maior que a riqueza observada.

Dito isso, a altitude demonstra diferentes influências na distribuição de pequenos mamíferos não-voadores na Mata Atlântica. Influências estas que vão desde a ocupação em diferentes altitudes e a criação de diferentes comunidades de espécies à promoção ou impedimentos de impactos do antropoceno para a área.

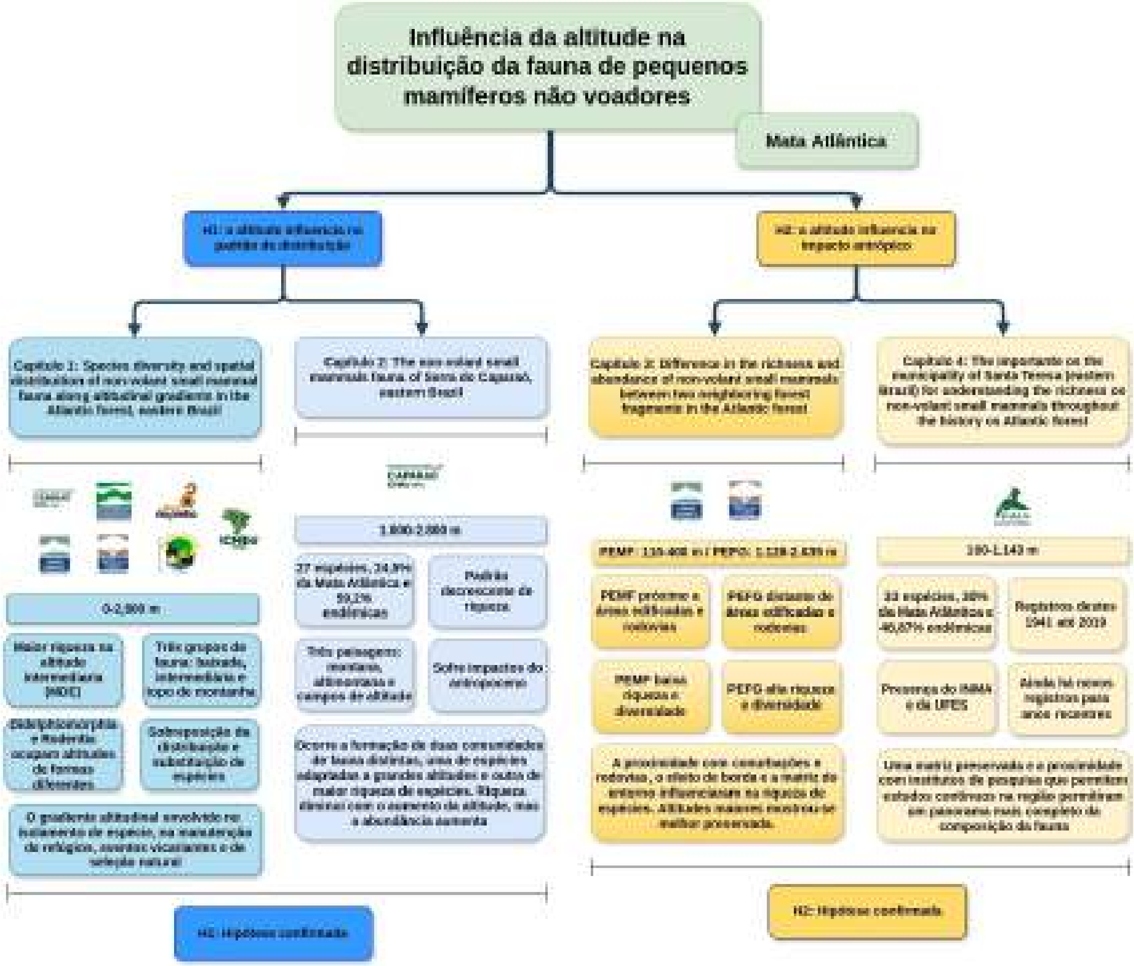


Figura 1: Diagrama com as hipóteses e capítulos com as principais conclusões.