UNIVERSIDADE ESTADUAL PAULISTA
"JÚLIO DE MESQUITA FILHO"
Instituto de Biociências
Câmpus do Litoral Paulista

DIVERSIDADE DE GASTRÓPODES TERRESTRES NO GRADIENTE ALTITUDINAL E LATITUDINAL DE MONTANHAS DA FLORESTA ATLÂNTICA

LARISSA TEIXEIRA DE ANDRADE

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“

“A maneira como eu vejo as coisas é bem simples
O fato de eu estar vivendo enquanto morro nesta terra
Exausta está a natureza, e nossos amigos morrendo
As criaturas vivas que estão do nosso lado.

O modo como eu me vejo, tão confuso e tão sofisticado
Não precisa ficar longe de mim, mas eu ainda não consigo entender
O que ganhamos em destruir todos os mundos?”

Gojira – A sight to Behold

SUMÁRIO

ABSTRACT

Gastropods inhabit different microhabitats-habitats, have different circadian cycles and distinct seasonal activity. As a result, collecting the entire community of terrestrial gastropods from a single place is a challenging task, and it is dependent on improved methods, which have been under discussion since the late 1960s. Two methods are considered the most efficient in gastropod sampling, especially in combination: litter sampling and visual search. However, ecological studies on which of these methods were used are still scarce in South America, and the amount of effort and the areas sampled are not standardized. In addition, the number of studies with the aim to estimate gastropod diversity has greatly increased in the two decades. Among the environments that can harbor a huge diversity of terrestrial gastropods, there are the neotropical mountains. To date, no other study has been carried out to investigate the diversity of gastropods in mountains in the Atlantic Forest, and it is estimated that in Brazil there are still about two thirds of terrestrial gastropod species not yet described. The aim of our study is to evaluate the performance of litter sampling and visual search methods to sample gastropod communities and to investigate diversity of terrestrial gastropods in the mountains of the Atlantic Forest, in an altitudinal and latitudinal approach. We sampled gastropods in 27 localities from northeastern to southern Brazil, of which on 7 we sampled twice and in two we sampled at low and intermediate altitudes. We accessed the localities by car or by hiking on trails. We employed the methods of litter sampling and visual search. In the first method, we collected all litter inside 15 0.5 m x 0.5 m square plots that were allocated every 2 m along a 30 m transection. The litter was examined in the laboratory and then dried, weighed, and sieved to search for shells. In the visual search, we looked for gastropods in microhabitats up to 2 m in height for 30 minutes each in three square plots of 6 m^2 every 10 m along the transect. We took notes of environment descriptions, time, temperature, humidity, and soil pH. The material was identified at the lowest possible taxonomic level based on the literature. We divided the species into microgastropods (< 5 mm) and macrogastropods (> 5 mm) and estimated the gastropod density per m^2, per kg of dried litter, and the sampling time. Species richness in the litter sampling was evaluated using Chao2 and Rarefaction Extrapolation. We analyzed similarity between localities using Unweighted Pair-Groups Method Average (UPGMA) and β diversity. We calculated alfa diversity for each locality and analyzed its correlation with altitude and latitude using Pearson correlation. We recorded 2,268 individuals, belonging to 75 species in 13 families. The litter sampling method revealed 61 species (39 exclusive), which comprised 87.7% of all individuals, 97.9% of all microgastropods, and 47.1% of all macrogastropods collected. The visual search revealed 35 species (13 exclusive). In 12 samplings, the visual search method did not yield results. The evaluation of the performance of the litter sampling method revealed that most localities reached the asymptote on Chao2 estimator. However, in most localities, it reached after the 15th plot (up to the 29^{th} plot). Both methods were efficient in revealing gastropod communities on mountains in the Atlantic Rainforest. Based on our results, we suggest the use of the litter sampling method in 30 0.5 m x 0.5 m plots with 15 per campaign combined with the visual search method in 3 plots (6 m x 6 m) to sample gastropod communities on mountaintops in the Atlantic Rainforest. This methodology could also maximize the chances of good weather (i.e., temperature > 19 ºC and humidity > 70%), which would benefit the visual search. We classified terrestrial gastropods in three types of communities: mid-montane, upper-montane and highland, based on the species composition. Although with similar representatives, communities of Atlantic rainforest showed great dissimilarity between each other even for mountaintops near to each other, mainly because of turnover. The species turnover may be caused by speciation in families Scolodontidae, Helicinidae and Charopidae. We did not find correlation between diversity and altitude or latitude. We found that higher richness in mountains studied occurred at intermediate altitudes, and there was a negative correlation between species richness and altitude.

Keywords: sampling effort, rarefaction curve, sampling methodology, species richness, altitudinal gradient, mountaintops, UPGMA, microgastropods, Sorensen index, alpha diversity.

RESUMO

Os gastrópodes habitam diferentes microhabitats-habitats, têm diferentes ciclos circadianos e atividades sazonais distintas. Como resultado, coletar toda a comunidade de gastrópodes terrestres de um único local é uma tarefa desafiadora e depende de métodos aprimorados, que estão em discussão desde o final da década de 1960. Dois métodos são considerados os mais eficientes na amostragem de gastrópodes, especialmente combinados: coleta de serapilheira e busca visual. No entanto, estudos ecológicos utilizando estes métodos ainda são escassos na América do Sul, e o volume de esforço e as áreas amostradas não são padronizados. Além disso, o número de estudos com o objetivo de estimar a diversidade de gastrópodes aumentou muito nas duas décadas. Entre os ambientes que podem abrigar uma grande diversidade de gastrópodes terrestres, estão as montanhas neotropicais. Até o momento, nenhum outro estudo foi realizado para investigar a diversidade de gastrópodes em montanhas da Mata Atlântica, e estima-se que no Brasil ainda existam cerca de dois terços das espécies de gastrópodes terrestres ainda não descritas. O objetivo do nosso estudo é avaliar o desempenho da coleta de serapilheira e busca visual para amostrar e investigar a diversidade de gastrópodes terrestres nas montanhas da Mata Atlântica, em uma abordagem altitudinal e latitudinal. Amostramos gastrópodes em 27 localidades do nordeste ao sul do Brasil, das quais em sete amostramos duas vezes e em duas amostramos em altitudes baixas e intermediárias. Acessamos as localidades de carro ou por trilhas. Empregamos os métodos de amostragem de serapilheira e busca visual. No primeiro método, coletamos toda a serapilheira em 15 parcelas quadradas de 0,5 m x 0,5 m que foram alocadas a cada 2 m ao longo de uma seção transversal de 30 m. A serapilheira foi examinada em laboratório e depois seca, pesada e peneirada em busca de conchas vazias. No método de busca visual, nós procuramos gastrópodes em microhábitats de até 2 m de altura por 30 minutos cada em três parcelas quadradas de 6 m² a cada 10 m ao longo da transecção. Tomamos notas de descrições do ambiente, tempo, temperatura, umidade e pH do solo. O material foi identificado no menor nível taxonômico possível com base na literatura. Dividimos as espécies em microgastrópodes (<5 mm) e macrogastrópodes (> 5 mm) e estimamos a densidade de gastrópodes por m², por kg de cama desidratada e o tempo de coleta. A riqueza de espécies na amostragem da serapilheira foi avaliada usando Chao2 e Extrapolação de Rarefação. Analisamos a similaridade entre as localidades usando o Unweighted Pair-Groups Method Average (UPGMA) e a diversidade β. Calculamos a diversidade alfa para cada localidade e analisamos sua correlação com a altitude e latitude usando a correlação de Pearson. Registramos 2.268 indivíduos, pertencentes a 75 espécies em 13 famílias. O método de amostragem da serapilheira revelou 61 espécies (39 exclusivas), que compreenderam 87,7% de todos os indivíduos, 97,9% de todos os microgastrópodes e 47,1% de todos os macrogastrópodes coletados. A busca visual revelou 35 espécies (13 exclusivas). Em 12 localidades nós não obtivemos gastrópodes pelo método de busca visual. A avaliação do desempenho do método de amostragem de serapilheira revelou que a maioria das localidades atingiu a assíntota no estimador Chao2. Porém, na maioria das localidades, atingiu após a 15ª parcela de serapilheira (até a 29º parcela). Ambos os métodos foram eficientes em revelar comunidades de gastrópodes em montanhas da Mata Atlântica. Com base em nossos resultados, sugerimos o uso do método de amostragem de serapilheira em 30 parcelas de 0,5 m x 0,5 m com 15 parcelas por amostragem combinadas com o método de busca visual em 3 parcelas (6 m x 6 m) para amostrar comunidades de gastrópodes no topo das montanhas na Floresta Atlântica. Essa metodologia também poderia maximizar as chances de bom tempo (ou seja, temperatura> 19 ºC e umidade> 70%), o que beneficiaria a pesquisa visual. Classificamos os gastrópodes terrestres em três tipos de comunidades: médio-montano, alto-montano e de cume, com base na composição das espécies. Embora com representantes semelhantes, as comunidades de montanhas da Floresta Atlântica apresentaram grande dessemelhança entre si mesmo para em topos de montanhas próximos uns aos outros, principalmente por causa da substituição de espécies. A substituição pode ter sido causada por especiação nas famílias Scolodontidae, Helicinidae e Charopidae. Não encontramos correlação entre diversidade e altitude ou latitude. Descobrimos que a maior riqueza das montanhas estudadas ocorre em altitudes intermediárias, e houve uma correlação negativa entre a riqueza de espécies e a altitude.

Palavras-chave: esforço amostral, curva de rarefação, método de amostragem, riqueza de espécies, gradiente altitudinal, topos de montanha, UPGMA, microgastrópodes, índice de Sorensen, diversidade alfa.

INTRODUÇÃO GERAL

Gastropoda é uma importante classe de moluscos, com representantes no ambiente marinho, dulcícola e terrestre. Eles podem viver em uma grande quantidade de habitats, climas e microclimas (Sólymos & Nagy, 1997; Coppolino, 2010; Kemencei et al., 2014). Em uma mesma floresta, eles podem ser encontrados vivendo entre troncos, rochas, folhas, briófitas, vegetação úmida e raízes de árvores (Sólymos et al., 2009a; Coppolino, 2010). As preferências de habitat dos gastrópodes terrestres refletem suas necessidades básicas: umidade, comida, abrigo e necessidade de cálcio (Burch & Pearce, 1990; Nekola, 1999; Sólymos et al., 2009a; Coppolino 2010). O período de atividade deles também pode variar. Algumas espécies acompanham as temperaturas diárias, enquanto outras são estritamente noturnas (Fontenelle & Miranda, 2017), e algumas espécies podem mudar seu período de atividade de acordo com a estação do ano (Cameron, 1970; Coppolino, 2010).

A classe conta com cerca de 24 mil espécies terrestres e estima-se haver outras 11 a 40 mil por serem descobertas (Lydeard et al. 2004; Colley 2013). No Brasil, há aproximadamente 740 espécies de gastrópodes terrestres descritas (Simone 2006; Birckolz et al. 2016; Salvador et al. 2017; Salvador 2019) e estima-se que essa riqueza represente um terço do que devem ocorrer desse grupo no país (Simone 1999; Salvador 2019). Dentre lugares que podem abrigar expressiva riqueza ainda não documentada de gastrópodes, tem-se as regiões montanhosas (Solem 1984; Salvador 2019).

O número de estudos dedicados a estimar a riqueza e diversidade de gastrópodes em montanhas têm aumentado ao redor do mundo (Tattersfield et al. 2001; Labaune & Magnin 2002; Sólymos et al. 2004; Aubry et al. 2005; Hausdorf 2006; Tattersfield et al. 2006; Oroño et al. 2007; Müller et al. 2009; Liew et al. 2010; Miranda & Cuezzo 2010; Wronski & Hausdorf 2010; Hoffman et al. 2011; Nunes & Santos 2011; Nunes & Santos 2012; Albano et al. 2014; Boxnick et al. 2015; Nägele & Hausdorf 2015; Gheoca 2016; Wronski et al. 2016; Gheoca & Popescup 2018). Dentre as montanhas mais estudadas, têm-se as situadas na Europa, como nas Ilhas Britânicas, França, Finlândia, Polônia, Eslováquia, Hungria, Noruega, Áustria e Suíça (Hausdorf 2003; Hausdorf 2006), montanhas do sudeste França (Labaune & Magnin 2002; Aubry et al. 2005) e montanhas da África, como Monte Kenya, Quênia (Verdcourt 1983; Warui 1998; Tattersfield et al. 2001). Na América do Sul, dois conjuntos montanhosos se destacam: a Cordilheira dos Andes, a oeste, e a Serra do Mar, a leste. Não existem estudos sobre a riqueza ou diversidade de gastrópodes da Cordilheira dos Andes (Brehm et al. 2008), com exceção dos trabalhos realizados na província de Túcuman, Argentina (Oroño et al. 2007; Miranda & Cuezzo 2010) e poucos trabalhos taxonômicos pontuais (Ramírez et al. 2003; Stuardo & Vega 1985; Breure 2008; Breure & Avila 2016). Situação similar se passa com a Serra do Mar. Igualmente inexistem estudos com a fauna de gastrópodes, somente poucos inventários realizados no domínio da Floresta Atlântica, onde a Serra do Mar se insere (Santos & Monteiro 2001; Nunes & Santos 2012). Abordando o domínio da Floresta Atlântica, têm-se, no Brasil, inventários e trabalhos taxonômicos com gastrópodes de Alagoas (Salvador et al. 2018), de Ilha Grande, Rio de Janeiro (Nunes & Santos 2012), do Paraná (Colley 2013) e da Floresta Atlântica meridional (Miquel et al. 2007) e, na Argentina, inventário da província de Misiones (Gregoric et al. 2013).

A distribuição dos gastrópodes em ambientes montanhosos é afetada pela combinação da heterogeneidade topográfica e microclimática (Solem 1984; Ström 2004). Os microclimas de uma mesma montanha podem ser muito diferenciados ao longo do gradiente altitudinal (Solem 1984). A temperatura tende a decrescer com o aumento da altitude, variando entre 0,4 a 0,7 °C a menos a cada 100 m a mais de altitude em florestas tropicais (Walsh 1979) e 0,56 ºC a menos a cada 100 m a mais de altitude na Serra do Mar paranaense (Roderjan 1994). O relevo montanhoso ainda ocasiona chuvas orográficas, pelo resfriamento das massas de ar que se elevem em confronto com o relevo, resultando condensação e precipitação aumentadas nos topos das montanhas (Pellegatti & Galvani 2010). Na Serra do Mar, o gradiente pluviométrico caracteriza-se por um incremento de cerca de 40 mm na média anual de precipitação a cada 100 m a mais de altitude (Roderjan 1994). As variações abióticas implicam, ainda, na formação de diferentes ambientes florestais ao longo do gradiente altitudinal (Solem 1984; Veloso et al. 1991).

A particularidade climática das grandes elevações pode fazer com que os ambientes dos topos de montanhas fiquem isolados pelos climas mais quentes e menos úmidos das menores altitudes, atuando como se fossem ilhas isoladas por massas de água (*sky islands*; *sensu* Howell [1947] e McCormack et al. [2009]). Isso favorece o endemismo de fauna com limitada capacidade de dispersão, como constatado em alguns grupos de aves (e.g., Bornschein et al. 2007; Mata et al. 2009; Maurício et al. 2014; Pulido-Santacruz et al. 2016) e anfíbios (Bornschein et al. 2015; 2016a; 2019; Ribeiro et al. 2015; 2017; Firkowski et al. 2016; Pie et al. 2018). Os gastrópodes terrestres são associados a microclimas particulares (Ström 2004) e apresentam limitada capacidade de dispersão (Watters et al. 2005), podendo tratar-se de outros organismos com alto potencial de endemismo nos topos de montanhas da Serra do Mar.

Além de as montanhas poderem gerar mosaicos de padrões de distribuições (Solem 1984) e endemismos, há outros padrões verificados em gastrópodes terrestres. Destaca-se a redução da riqueza de espécies com o aumento da altitude (Stevens 1989; Tattersfield et al. 2001; Müller et al. 2009; Liew et al. 2010; Miranda & Cuezzo 2010), diminuição da riqueza de espécies com o aumento da latitude (Hausdorf 2006), diminuição do volume da concha com o aumento da latitude ou altitude (Hausdorf 2003), aumento da riqueza em altitudes médias em bosques montanos de regiões temperadas (Labaune & Magnin 2002; Aubry et al. 2005; Hausdorf 2006) e aumento da riqueza em locais de maior concentração de chuvas orográficas (Tattersfield et al. 2006).

Espera-se que as montanhas da Floresta Atlântica apresentem um gradiente de diversidade inversamente proporcional com a altitude (Tattersfield et al. 2001; Müller et al. 2009; Liew et al. 2010; Miranda & Cuezzo 2010) e latitude (Hausdorf 2006). Hipotetiza-se que a diversidade de montanhas de menor altitude se comporte diferenciadamente, apresentando semelhante diversidade ao longo de todo o seu gradiente (Figura 1B). Isso seria uma resposta à suposta atenuação ou mesmo ausência do efeito da orografia sobre a temperatura e pluviosidade nessas montanhas de menor altitude. Altitudes intermediárias em montanhas elevadas sofrem queda de temperatura e ganhos de umidade pelo escoamento do ar frio e úmido decorrente do contato das massas de ar nas maiores altitudes (Roderjan 1994).

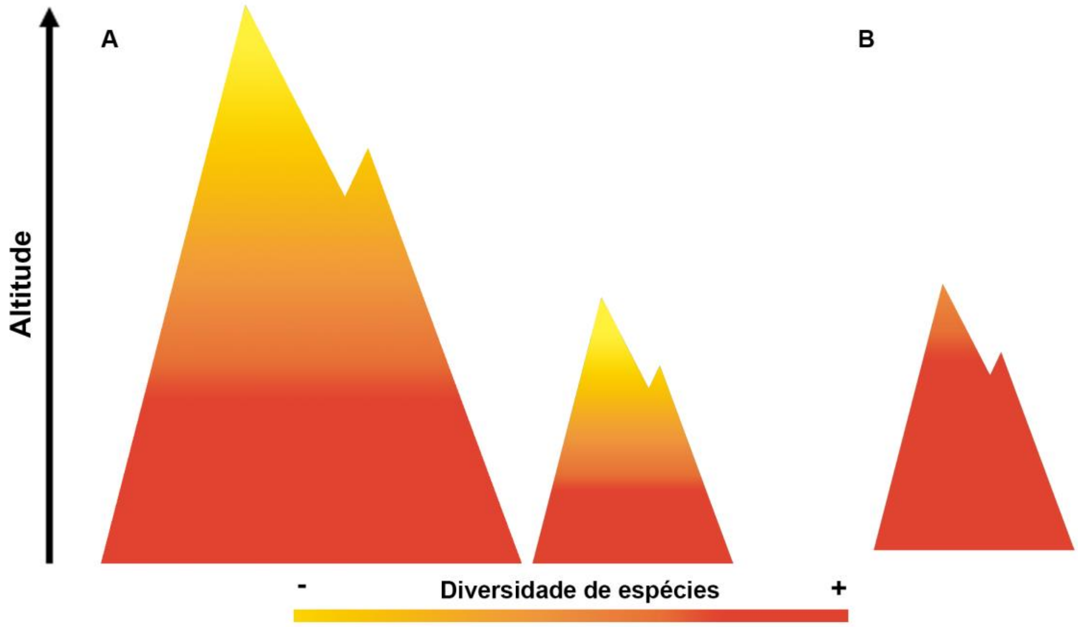

Figura 1. A. Representação teórica da diversidade esperada de gastrópodes no gradiente altitudinal de montanhas da Floresta Atlântica. B. Hipótese do presente estudo de diversidade em montanhas menores similar ao longo de todo o gradiente.

CAPÍTULO 1

How Much is enough? Performances of litter sampling and visual searching methods in revealing the diversity of gastropod on mountaintops of the Atlantic Rainforest

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Abstract

Background: Gastropods inhabit different habitats and microhabitats, have different circadian cycles, and exhibit distinct seasonal activity. Consequently, collecting an entire community of terrestrial gastropods from a single place is a challenging task, dependent on improved methods, which have been under discussion since 1960s. Two methods are considered particularly efficient for gastropod sampling, especially in combination. However, ecological studies that use these methods are still scarce in South America, and the efforts and areas sampled are not standardized. The aim of our study was to evaluate the performance of litter sampling and visual search methods for sampling gastropod communities in the Atlantic Rainforest. **Methods:** We sampled gastropods in 27 localities from northeastern to southern Brazil, of which in seven we samlpled twice. We accessed the localities by car or by hiking and employed litter sampling and visual search methods. For the first method, we collected all the litter inside 15 0.5 m x 0.5 m2 plots that were distributed every 2 m along a 30 m transection. The litter was examined in the laboratory and then dried, weighed, and sieved to search for shells. For the visual search, we looked for gastropods in microhabitats up to 2 m in height for 30 min each in three 6 m² plots every 10 m along the transection. We noted environmental conditions, time, temperature, humidity, and soil pH. The material was identified at the lowest possible taxonomic level based on the literature. We divided the species into microgastropods (< 5 mm) and macrogastropods (> 5 mm) and estimated the gastropod density per m², per kg of dried litter, and according to the sampling time. Species richness in the litter sampling was evaluated using Chao2 and rarefaction extrapolation. **Results**: We recorded 1664 individuals (1331 microgastropods and 333 macrogastropods) belonging to 73 species from 12 families. The litter sampling method revealed 60 species (39 exclusive), which comprised 87.7 % of all individuals, 97.9 % of all microgastropods, and 47.1 % of all macrogastropods collected. The visual search revealed 35 species (13 exclusive). For 12 sampling sessions, the visual search method yielded no results. The evaluation of the performance of the litter sampling method revealed that most localities had the expected richness according to the Chao2 estimator; however, in most localities, the richness reached at least the 15th plot (up to the 29th plot). Both methods efficiently revealed gastropod communities on mountains in the Atlantic Rainforest. Based on our results, we suggest the use of the litter sampling method with 30 (0.5 m x 0.5 m) plots at 15 per campaign combined with the visual search method with 3 (6 m x 6 m) plots to sample gastropod communities on mountaintops in the Atlantic Rainforest. This methodology could maximize

the benefits of good weather (i.e., temperature > 19 ºC and humidity > 70 %), benefiting the visual search.

Introduction

Terrestrial gastropods can live in a wide range of habitats, climates, and microclimates (Sólymos & Nagy, 1997; Coppolino, 2010; Kemencei *et al.*, 2014). In a single forest, they can be found living among logs, rocks, leaf litter, bryophytes, moist vegetation, and tree roots (Sólymos *et al.*, 2009a; Coppolino, 2010). Terrestrial gastropods habitat preferences are reflected in their basic survival requirements: moisture, food, shelter, and calcium supply (Burch & Pearce, 1990; Nekola, 1999; Sólymos *et al.*, 2009a; Coppolino 2010). Their periods of activity can also vary: some species follow daily temperatures, others are strictly nocturnal (Fontenelle & Miranda, 2017), and some species can change their activity periods according to the season (Cameron, 1970; Coppolino, 2010).

Besides their habitat plasticity, terrestrial gastropods can vary considerably in size. In a single community of terrestrial gastropods, the length of shells can vary from less than 5 mm to about 100 mm (Salvador *et al.*, 2018). Because of their considerable size range, terrestrial gastropods are divided into microgastropods with shells less than 5 mm in length (Emberton *et al.*, 1996) and macrogastropods with shells greater than 5 mm in length. The division of terrestrial gastropods according to shell length reflects the interesting ecological relationship of a greater abundance of macrogastropods in temperate forests (Horsák *et al.*, 2018) and a greater abundance of microgastropods in tropical forests (Emberton *et al.*, 1996; Salvador, 2019).

Sampling terrestrial communities of tropical forest gastropods is challenging due to the microgastropods richness and wide range of lifestyles (Coppolino, 2010; Salvador, 2019), which have been discussed since 1969 (see Coppolino [2010] and Kemencei *et al.* [2014] for a review). Cameron and Pokryszko (2005) listed various reasons for the sampling of terrestrial gastropods being frustrating: 1) species can be seasonal with short life cycles; 2) species can be patchily distributed across microhabitats; 3) species can present variable patterns of seasonal aggregation; 4) large species have fewer individuals and are more likely to agglomerate; and 5) some species apparently decline in density under unfavorable conditions. In response to these difficulties, two methods have been considered appropriate for sampling terrestrial gastropod communities (Coppolino, 2010): visual search, which is sometimes associated with microhabitat description (Sólymos, 2009a; Kemencei *et al.*, 2014), and litter sampling (Emberton *et al.*, 1996; Pearce & Örstan, 2006; Coppolino, 2010). Visual search facilitates coverage of a wider range of microhabitats than litter sampling does, and it tends to be more efficient for collecting live snails. Although a great deal of time can be spent in the field, this method could be extended to the sampling of microgastropods (Emberton *et al.*, 1996; Coppolino, 2010). The second method, litter sampling, tends to be a fast and easy way to sample in the field. Although it allows microgastropods to be collected more efficiently, this method is less efficient for sampling live specimens (Coppolino, 2009; Coppolino, 2010). Additionally, litter sampling involves considerable effort to sort samples in the laboratory (Coppolino, 2009; Coppolino, 2010; Durkan *et al.*, 2013). Ideally, the two methods should be combined to sample and describe gastropod communities (Emberton *et al.*, 1996; Hotopp, 2002; Ström, 2004; Pearce & Örstan, 2006; Oroño *et al.*, 2007; Coppolino, 2009; Sólymos, 2009a, 2009b; Coppolino, 2010; Salvador, 2019). However, the effort required to conduct the visual search and litter sampling is not standardized (Coppolino, 2010; see also Santos & Monteiro, 2001; Oroño *et al.*, 2007; Miranda & Cuezzo, 2010; Gregoric *et al.*, 2013; Salvador *et al.*, 2018). Some studies have focused on either litter sampling (Emberton *et al.*, 1996; Oroño *et al.*, 2007; Coppolino, 2009; Sólymos *et al.*, 2009b) or visual search (Santos & Monteiro, 2001), and others have used only litter sampling (Salvador *et al.*, 2018).

Although research on terrestrial gastropod communities has increased worldwide, there are gigantic sampling gaps in under-sampled regions, such as in the tropical regions of Brazil. In Brazil, one study used only the leaf litter sampling method (Salvador *et al.*, 2018), and two other studies combined this method with visual search (Santos & Monteiro, 2001; Nunes & Santos, 2012). These three previous studies were conducted in the Atlantic Rainforest—one of the largest forested areas in Brazil.

The Atlantic Rainforest originally occupied 1,290,000 km^2 (Varjabedian, 2010) along the Atlantic coast from northeastern to southern Brazil and inland into the center of the country, eastern Paraguay, and northeastern Argentina (Oliveira-Filho & Fontes, 2000). Because this biome includes high levels of endemism and threats, especially from deforestation, it is a global “biodiversity hotspot” (Mittermeier *et al.*, 2004; Mittermeier *et al.*, 2011; Rezende *et al.*, 2018). In the Atlantic Rainforest, high endemism exists in several groups, including trees (40 % of species), amphibians (62 % of species), birds (16 % of species), and mammals (15 % of species; Mittermeier *et al.* 2011). The endemism rate of terrestrial gastropods in the Atlantic Rainforest has not yet been estimated, but it is likely to be high because the nearly 700 species of terrestrial gastropods described in Brazil represent only one third of the total number of species not yet described in the country (Simone, 1999; Salvador, 2019).

At present, only 28 % of the original Atlantic Rainforest cover remains, in fragments of different sizes (Rezende *et al.*, 2018) and with different degrees of conservation. Most of these fragments are located in inaccessible mountain regions, such as the Serra do Mar, which comprises 36.5 % of the remaining forest fragments (Silva *et al.*, 2007; Ribeiro *et al.*, 2009). The Serra do Mar is one of the relief units that characterize the Brazilian Atlantic Rainforest. It includes the Pré-Litorâneas, Serra da Mantiqueira, Paranapiacaba, and Leste Catarinense relief units (IBGE, 2016; Rezende *et al.*, 2018), which are the most significant mountain ranges in northeastern, southeastern, and southern Brazil. The highest peak in the Serra da Mantiqueira is of 2,892 m altitude, and in the Serra do Mar relief unit, the highest peak is of 2,230 m altitude at the northern limit and 1,922 m altitude at the southern limit (Bornschein *et al.*, 2016).

Mountains typically promote speciation because of the isolation of altitudinal habitats, particularly for low-dispersal taxa, such as small invertebrates, small vertebrates, and birds with low flying capacity (Lydeard *et al.*, 2004; Mittermeier *et al.*, 2004; 2011; Mata *et al.*, 2009; Bornschein *et al.*, 2015; 2016; 2019; Firkowski *et al.*, 2016; Pulido-Santacruz *et al.*, 2016; Pie *et al.*, 2018, 2019). The microclimates on a single mountain can differ along the altitudinal gradient (Solem, 1984); for example, in tropical forests, the temperature tends to decrease as the altitude increases, varying from 0.4–0.7 ºC every 100 m above sea level (Walsh, 1979). On the southern limit of the Serra do Mar, the temperature decreases by 0.56 ºC per 100-m increase in altitude (Roderjan, 1994). Mountain altitudes also cause orographic rainfall because cooling air masses elevate as the altitude of the relief increases, resulting in higher amounts of precipitation and condensation on mountaintops (Pellegatti & Galvani, 2010). On the southern relief of the Serra do Mar, precipitation increases by an annual mean of 40 mm per 100 m increase in altitude (Roderjan, 1994). Because of these variations, different types of forests occur along the altitudinal gradient (Solem, 1984; Veloso *et al.*, 1991).

Due to these conditions, mountaintops act as sky islands (*sensu* Howell [1947] and McCormack *et al.* [2009]), and those in the Atlantic Rainforest are no exception. They have played an important role in the diversification of taxa with low dispersion, such as frogs and small birds with low flying capacity (Cruz & Feio, 2007; Mata *et al.*, 2009; Brunes *et al.*, 2010; Thomé *et al.*, 2010; Bornschein *et al.*, 2015; 2016; 2019; Firkowski *et al.*, 2016; Pulido-Santacruz *et al.*, 2016; Pie *et al.*, 2018; 2019). To investigate whether Atlantic Rainforest mountaintops have promoted the diversification of terrestrial gastropods, we conducted a study of dozens of mountains in the Brazilian Atlantic Rainforest over five years. We evaluated the performance of combined litter sampling and visual search methodologies for revealing the richness of terrestrial gastropod communities. We also determined the trade-off between an expanded sample size and the difficulty of transporting samples down mountains.

Materials & Methods

Characterization of the study region

We surveyed 27 localities at high altitudes on mountains or plateaus (“planaltos”) in the Atlantic Rainforest from northeastern to southern Brazil (12–27°S; Figure 1), including five states: Bahia (two localities); Rio de Janeiro on the border with São Paulo (one locality); São Paulo (eight localities); Paraná (seven localities); and Santa Catarina (nine localities; see Table 1 and Figure 1). The extreme points were separated by 2,200 km from north to south in an imaginary straight line, and their distance from the coastline ranged from 3.4–72.3 km. The localities were included in the following relief units: Depressão do Rio Jequitinhonha/Pardo, Depressão dos Rios Paraguaçu/Itapicuru, Serra do Mar, and Serra do Leste Catarinense (IBGE, 2016; Rezende *et al.*, 2018). This entire region, which is included in the subregions of “Bahia” and “Serra do Mar”, is characterized by faunal endemism and unique biological phenomena (Silva & Casteleti, 2003).

According to Koppen’s criteria for classifying climates from north to south, we sampled localities that were characterized by the following climates: Af (tropical without a dry season) in Bahia state; Cfb (humid subtropical oceanic climatic, without a dry season but with a temperate summer) in the Rio de Janeiro and north São Paulo states; and Cfa (humid subtropical oceanic climatic with no dry season and a hot summer) in the southern São Paulo, Paraná, and Santa Catarina states (Alvares *et al.*, 2013). The mean annual temperature varies from 17–25 ºC across the entire region: in the north, the mean is 24 ºC (Bahia state); in the center, the mean is 17–22 ºC (Rio de Janeiro and São Paulo states); and in the south, the mean is 23–25 ºC (Paraná and Santa Catarina states; Martineli [2010], Wrege *et al.* [2012], Bahia [2021]). The average annual rainfall varies from 1,500–4,000 mm: in the north, it is 1,600–2,000 mm (Bahia state); in the center, 1,500–4,000 mm (Rio de Janeiro and São Paulo states); and in the south, 1,700–2,400 mm (Paraná and Santa Catarina states; Martineli [2010], Wrege *et al.* [2012], Bahia [2021]).

In all regions, we performed sampling in the same type of forest: the ombrophilous dense forest (*sensu* Veloso *et al.*, 1991). According to latitudinal differences in altitude, we sampled localities where this forest was subdivided as follows: highland dense ombrophilous forest on mountains at higher altitudes; montane dense ombrophilous forest on mountains at median altitudes; and submontane dense ombrophilous forest on mountains at lower altitudes (*sensu* Veloso *et al.*, 1991). We were cautious about sampling only primary forest or, at least, secondary forest that had regenerated to a forest stage (instead of secondary arboreal formations that had not regenerated to a forest stage; see Bornschein [2015]).

Sampling methodology

We sampled forests on mountaintops and mountain slopes when we could not reach mountain peaks, when mountain peaks were covered by natural grassland, and when plateaus were at high altitudes. We accessed these localities by car, by trekking along preexisting trails, or by creating trails in the forest (Table 1). When we trekked to localities, we fixed the sample points according to the time required for sampling and the need to return at least two hours after sunset for personal safety reasons. To maintain personal safety, each sampling session was conducted by two or more trained researchers. At one of the sampling points, we had to camp near the summit so the site could be accessed during daylight hours. When possible, we conducted sampling in the early morning, but because of the travel time, we conducted sampling primarily from mid-morning until noon, avoiding sunny hours and hot days (Table 1).

We conducted most fieldwork during the rainy and hot months (Table 1). In southeastern and southern Brazil, the rainy months occur from October to February or March (Martineli, 2010; Wrege *et al.*, 2012). In Bahia, we sampled during the hot early spring to avoid the warm weather and absence of rain during the dry season (Bahia, 2021). Our collection period extended from December 2017 to March 2020 in southeastern and southern Brazil and to October 2019 in northeastern Brazil. Early spring occurs in October, and late spring and summer occur from December to March.

In the field, we applied litter sampling and visual search in different microhabitats of terrestrial gastropods (modified from Sólymos *et al.* [2009a]). First, we selected a relatively gentle slope at the highest point that we could reach on each mountain. We stretched a 30 m rope and allocated square plots of 50 x 50 cm every 2 m (starting at the second meter), totaling 15 square plots. The squares were positioned opposite where we had stepped. We collected all the litter inside the squares and stored it in labeled plastic packages. For the visual search, we sampled a 6 m x 6 m square every 10 m along the rope (starting at 10 m and ending at 30 m), totaling three square plots. We spent 30 min in each square searching every available microhabitat (e.g., rocks, dead wood, living trees, branches, leaves, moss, litter, and tree trunks) up to 2 m in height among the vegetation and rocks. When two or three researchers were present during the sampling, each conducted a visual search for 15 min or 10 min to avoid transposing 30 min of searching. The collected live specimens were stored in small receptacles separated by the square plots and the microhabitats.

Because our study locations were on mountain peaks and at the top of slopes, we were not concerned about shells being imported from another community higher up. Additionally, the localities where we worked had acid pH (Roderjan, 1994; Table 2), which increased the rate of dissolution of shells (Cleassen, 1998), decreasing the chances of collecting shells deposited on litter years earlier.

At each locality, we used a portable thermohygrometer (Datallogger Instrutherm HT-500; Table 1) to collect data on air temperature 30 cm above the soil as well as the humidity of the litter and air during the sampling period. We measured the pH of each sample twice, once at the beginning of the transect and once at the end at a depth of at least 5 cm in the litter or soil using a portable pH meter (SONDATERRA® pH 2500; Table 2). We described the vegetation type according to Veloso *et al.* (1991) criteria and took notes of vegetation height; the abundance of botanical families; and the presence, absence, or abundance of bamboos, terrestrial bromeliads, and epiphytes (Table 2). Meteorological conditions (wind and rain) and sampling time (beginning and end) were also noted during the sampling (Table 1). We then noted the geographical coordinates of the first and last meter of the rope using a global positioning system (GPS; Garmin Etrex® 10; Table 1), and we photographed the environments and microhabitats to document them. Only the first geographical coordinates were given.

Resampled localities

We replicated samples in seven localities on different days to extend the analysis to method performance. At each locality, we applied the methods described above, taking care to sample a few meters away from the first sample point where the litter had been removed. We resampled three localities in the state of São Paulo, two in Paraná state, and two in Santa Catarina state (Table 1). We did not have the time or the resources to resample all localities, and the criterion for resampling the seven localities was their logistical acessibility.

Laboratory procedures

In the laboratory, we inspected each package of litter to remove the live gastropods, then dried the litter at 39 ºC in a stove and measured its dry weight (g). The dried litter was then dry-sieved through 0.5 mm mesh. The retained material was carefully examined under a stereomicroscope with the aim of finding smaller empty shells.

We photographed the live specimens and preserved them in 95 % ethanol after euthanizing them in distilled water (following Thomé [1975]). We also photographed each morphotyped shell under a stereomicroscope ZEISS™ Stemi™ DV4 mounted with a DLSR camera with an 18–55 mm lens (Nikon D300S).

Based on the coloration while alive, habitat, microhabitat, shell morphology, and body morphology of the collected material, in association with the description in the literature, we identified specimens at the lowest possible taxonomic level using several bibliographies (e.g., Schileyko, 1998–2007; Salgado & Coelho, 2003; Simone, 2006; Birckolz *et al.*, 2016). Names were organized according to Bouchet and Rocroi (2005) and MolluscaBase (2021). The collected gastropods were stored in malacological collections at the Museu de Zoologia da Universidade de São Paulo (MZSP) and the Museu Nacional do Rio de Janeiro (MNRJ) when our analyses had been completed.

Data analysis

We counted individual terrestrial gastropods both by empty shells and live individuals found. We then calculated the mean density of the gastropods collected by litter sampling per package, per area (m^2), and per biomass (kg) of dried litter. We calculated the mean number of individuals obtained by visual search according to time and area (m^2). For both collection groups, we separated the number of individuals into categories of microgastropods and macrogastropods.

We used estimations of the expected number of species in each location together with rarefaction and extrapolation richness curves (Colwell *et al.* 2012) to analyze the performance of the litter sampling and visual search methodologies. Calculations were performed using Estimate S 9.1.0 (Colwell, 2013). We employed Chao2 as the estimator for the expected number of species—a sample-based estimator calculated according to the amount of uniques (species that occurred only in one sample) and duplicates (species that occurred in only two samples; Chao, 1987; Gotelli & Colwell, 2011). For each reference sample, we calculated the

Chao2 standard deviation, whereas we obtained the 95 % log-linear confidence intervals and Chao2 rarefaction values numerically (Chao, 1987; Colwell, 2013).

We modeled the rarefaction and extrapolation richness curves using a Bernoulli product model (BPM). Rarefaction (interpolation) values were based on the incidence frequencies of the reference sample, whereas extrapolation values were calculated from the reference sample considering Chao2 as the community richness estimator (Colwell *et al.* 2012). In both cases, unconditional variances were calculated following Colwell *et al.* (2012). We made all extrapolations considering 15 additional samples for the litter sampling and 10 samples for the visual search method (an additional 7 or an additional 4 for resampled localities). Localities with replicated samples were analyzed by considering both samples as a single sample of 30 square plots for the litter sampling and of 6 square plots for the visual search.

Chao2 calculations were based on the number of species observed in each sample, and if the unconditional confidence interval was close to zero, we assumed that the number of species found in the sample was compatible with the expected species richness. If the number of species found in the sample was compatible with the expected species richness, the extrapolated richness was equal to the current species richness for all additional samples beyond the original sample (Colwell *et al.* 2012). We also viewed as compatible in richness those samples in which the mean observed richness and estimated richness (Chao2) curves and standard deviations overlapped. Richness extrapolation (Colwell *et al.* 2012) uses the Chao2 results for the reference sample and predicts the number of species as a function of the number of species in a "t" pooled sample, where t is the number of given hypothetical additional samples and the total species richness is a function of Chao2. For those localities that did not have the expected richness, we calculated the number of samples needed to reach it.

Results

We collected 34 samples of forest gastropod communities on mountains in the Brazilian Atlantic Rainforest by combining litter sampling and visual search methods. Of these samples, 27 were collected in different localities, and seven of these localities were resampled once (Table 1; Figure 1). The Bahia subregion comprised two localities, and the Serra do Mar subregion comprised the 25 remaining localities. This sampling grid excluded another three locations that we reached only during the hot hours of the day, which prevented the sampling: two in São Paulo state and one in Paraná state.

We sampled 3,799.5 m² using both methods. We obtained 1,665 terrestrial gastropod individuals (including shells and live specimens; Table 3), and we recorded 73 species (Table 3–4). By combining the litter sampling and visual search methods, we sampled 117.7 m² per locality, collected 2–297 individuals per locality, and recorded 1–18 species per locality (Table 3).

The 74 recorded species were from 12 families (Table 4). The majority of the recorded species were macrogastropods (39 species), and the remaining 35 species were microgastropods. Forty-eight species were registered only at the genus level (Table 4), which indicated a need to continue the analyses to identify these samples and describe new species found in the data set.

Litter sampling method

We collected 127.5 m² of litter (3.7 m² per locality; Table 3), which constituted 52.9 kg of dried litter or 862.1–2,615.4 g per locality ($\bar{x}$ = 1,552.5 ± 414.5 g/locality) and 32.4–341.6 g per square plot ($\bar{x}$ = 103.9 ± 43.6 g/square plot). On average, we spent 7.5 h sieving and sorting the litter samples collected from each locality (about 255 h in total).

Using the litter method, we obtained 1,457 terrestrial gastropod individuals, of which 1,303 were microgastropods and 157 were macrogastropods (Table 5). These individuals belonged to 60 species from 10 families (Table 4). All sampling sessions resulted in the collection of individuals. In each sampling session, we collected 2–233 microgastropods and 0–34 macrogastropods, 0.1–15.8 individuals per square plot (Table 5), and found gastropods in 13–100 % of the square plots. In each square plot, regardless of locality, we collected 0–62 individuals (2.9 ± 5.7 individuals/square plot). We estimated the abundance of the species at 0.3–63.2 individuals/m^2 and 0.4–137.6 individuals/kg of litter in the various localities (Table 5).

Visual search method

We covered an area of 3,672 m² (108 m² per locality) in a total of 51 h (1.5 h per sampling session). In only 22 of our 34 sampling sessions did we obtain gastropods using this method. We collected 208 terrestrial gastropod individuals, of which 176 were macrogastropods and 32 were microgastropods (Table 6). These individuals belonged to 35 species and were from 11 families (Tables 4 and 6). In each sampling session, we collected 0–64 gastropod individuals, including 0–9 microgastropods and 0–61 macrogastropods (Table 6). We obtained gastropod individuals from only 39.2 % of the square plots. By sampling, we collected individuals from 0–100 % of the square plots and obtained 0–21.3 individuals per square plot (Table 6). By hour, each sampling session resulted in a mean collection of 0–42.7 individuals (Table 6). We estimated mean densities per sampling session at 0–59.3 individuals per 100 m² (Table 6).

Resampled localities

The results for the seven resampled localities are summarized in Tables 5 and 6 (see Tables 1 and 2 for the resampled localities). In three of these localities, we observed an increase in the mean number of individuals per square plot of litter sampled. In four localities, we observed a decrease in these values (Table 5). In one of the localities, six species were recorded, and in the remaining localities, 1–4 species were collected, which resulted in an accumulation of 3–12 species.

Homogeneity of samplings and methods performance

The comparison between the number of individuals and the weight of leaf litter collected per square plot is shown in Figures 2–6. Both the number of individuals and the weight of leaf litter could have been homogeneously reduced along the transect (Figure 2, locality 01B; Figure 3, localities 11B and 20B; Figure 4, localities 26 and 27; Figure 5, locality 09) or homogeneous (Figure 2, locality 05B). By contrast, it could have been more expressive of the litter weight, but with a low number of gastropods collected by sampling (Figure 2, locality 01A; Figure 4, locality 02; Figure 5, locality 13), or expressive of the number of gastropods collected, but with only intermediate weights of litter (Figure 2, locality 05B; Figure 3, locality 12A).

Table 6 indicates the heterogeneity of the visually collected specimens per square plot. Twelve samples (35 %) showed no gastropods collected. We collected individuals in all square plots in only seven sampling sessions (Table 6, localities 05A, 08, 11A, 12A-B, 17 and 26). The visual search method is climate sensitive. Figure 7 shows that the number of specimens collected relative to the air temperature during sampling and for sampling hours showed no clear relationship. Localities with higher results for the visual search method were sampled at temperatures above 17.9 ºC and between 11:40–16:50 h (Figure 8).

We calculated the Chao2 values (Figure 9–14, Table 7) for the two methods independently. For the litter sampling method, 11 of 27 localities did not have the expected richness, with an estimated richness of about 0.23–5.6 species above that observed for reference samples. For the remaining 16 localities (localities 1AB, 2, 05A+B, 8, 9, 13, 14, 15, 17, 20A+B, 21A+B, 22, 23, 26 and 27; Table 7), the expected richness was observed between 9 and 29 plots (Figures 8–11). Of these samples, 37.5 % (including three resampled localities) were located in highland dense ombrophilous forest, and 62.5 % (including one resampled locality) were in montane dense ombrophilous forest. Using the visual search method, 14 of 18 localities (Figures 13 and 14) did not have the expected richness according to the Chao2 estimator, and a richness of about 0.83–8.33 above was observed for the reference samples. The remaining four localities (localities 01AB, 07, 09, and 10; Figure 12 Table 7) had the expected richness: 50 % were located in highland dense ombrophilous forest (including one resampled locality) and 50 % in montane dense ombrophilous forest.

We calculated rarefaction extrapolation (Colwell *et al.* 2012) for 18 localities sampled using the litter sampling method and 14 using the visual search method. For the litter sampling, we observed an increased species richness below one (0.23–0.92 species) for nine localities (localities 05AB, 08, 11AB, 14, 17, 18, 20AB, 21AB, and 23) and from one to three species for 14 localities. Using visual search, we observed an increased species richness below one species (0.33–0.83 species) for six localities (localities 03AB, 04, 08, 18, 19 and 24) and from 1.3–6.83 species for seven localities.

Discussion

Although both methods were successful in collecting terrestrial gastropods in the Atlantic Rainforest mountains, the respective performance was distinct, supporting their combined use in South America (see Cameron & Pozrysko, 2005; Coppolino, 2009; Schilthuizen, 2011; Durkan *et al.*, 2013). The size of the area sampled, however, was not standard because previous sampling areas in South America have ranged from 7.5–2.518 m² (Table 3). The number of individuals collected per locality was in the intermediate range compared with those in previous South American studies (Table 3).

Our study revealed that microgastropods were the dominant group in gastropod communities on Atlantic Rainforest mountains (89.2 % of the total number of individuals we collected and 47 % of the recorded species), confirming that they are dominant in tropical regions (Schilthuizen, 2011; Durkan *et al.*, 2013). This finding indicated that litter sampling was an essential method for analyzing mountain communities in the Atlantic Rainforest regardless of the considerable amount of time required in the laboratory to analyze the collected litter samples (Durkan *et al.*, 2013). Additionally, because individual shells remain on the litter after the death (Gargominy & Ripken, 1998; Sólymos, 2009b), the litter sampling method neutralized the species seasonality (Cameron, 1970; Coppolino, 2010) in revealing communities.

In our Chao2 and rarefaction extrapolation analyses, we observed the expected richness for the litter-sampling method at most localities between the 9th and 29th square plots (Table 7). Although 15 litter sampling plots may not have been sufficient to sample gastropod communities in areas forested with montane dense ombrophilous forest, 30 square plots of litter were enough for most localities, especially those covered with highland dense ombrophilous forest.

For most of our litter samplings, the presence and abundance of individuals tended to be concentrated in one plot (locality 21A, Figure 2; localities 27, 23, 04 and 06, Figure 4; locality 14, Figure 5; locality 19, Figure 6) or a few square plots (localities 01A, 01B, 21B, Figure 2; localities 20A and 12B, Figure 3; localities 04 and 24, Figure 4; localities 22, 09, 10 and 15, Figure 5), probably because the run-off from rain transported the shells. On rainy days, shells can be washed down with the litter and accumulate (Cameron, 2008). Moreover, in places with sloping terrain and a thin layer of leaf litter, gastropods can be washed away during rainfall (Coppolino, 2008). This aspect was important to consider, although the allocation of random square plots on mountains did not necessarily provide flat terrain that was less susceptible to the loss of shells due to rainwater.

The results of our study revealed that visual search could be a better method for collecting bigger species or species with fragile or absent shells, such as slugs and semi-slugs, which are difficult to collect using litter sampling (Cameron & Pozrysko, 2005; Coppolino, 2009; Schilthuizen, 2011; Durkan *et al.*, 2013). In a megadiverse region such as the Atlantic Rainforest and its mountains, which can harbor countless new species, the visual search method combined with litter sampling can provide anatomical characteristics for taxonomy through the collection of live specimens, which is important for identification and anatomical description. Table 6 demonstrates that our results varied between samples. We suggest that visual search should not use a larger area (our plot was 36 m^2) because of the human tiredness resulting from a continuous search over a large area. However, it would be interesting to divide visual search into a greater number of plots and/or make replicas. This could also provide access to different microhabitats, thus facilitating the registration of different distributions and local abundances between species (Cameron & Pozrysko, 2005).

Other factors could have potentially influenced the great fluctuation in the results for the visual search method, such as variations in the microclimate at the time of sampling or in previous hours. Great decreases in humidity and air temperature could have made individuals aestivate and burrow in the soil (Coppolino, 2009) or litter, which is a stable microhabitat that can maintain humidity better than the surrounding air (Sólymos, 2009b). Periods of intense rain with a drop in temperature could also trigger aestivation, making small or medium-sized species less conspicuous and more difficult to find; for example, we conducted sampling during more than 10 h of continuous rain at temperatures of 13–19 ºC, and on these occasions we mainly recorded microgastropods (in the southeast, at locality 01A on the border between the states of Rio de Janeiro and São Paulo; at localities 03-A, 03-B, and 24 in the state of São Paulo; and in the south, at locality 07 in the state of Paraná and 11B in the state of Santa Catarina; Table 1). In fact, the Atlantic Rainforest is humid, and according to the altitudinal gradient, mean annual precipitation increases by 40 mm for every 100 m of altitude (Roderjan, 1994). Moreover, the mountains are more prone to humidity fluctuations because of the greater incidence of winds, greater intensity of solar radiation, and higher luminosity due to the absence of clouds (Roderjan, 1994; Rizzini, 1997). In montane forests, humidity can vary widely during the day, and periods of low humidity can persist for days, causing water stress in plants (e.g., Roderjan, 1994; Rapp & Silman, 2012).

Conclusions

Both litter sampling and visual search methods were used to reveal communities of gastropods in mountains of the Atlantic Rainforest. Our findings indicated that both methodologies were important for revealing forest communities of mountain gastropods in the Atlantic Rainforest. Litter sampling was essential for revealing microgastropods, which are the predominant shelled fauna in the study region. Moreover, in our study, the highly variable climatic conditions on mountain terrain were an additional challenge in sampling terrestrial gastropods by visual search, which revealed another benefit of litter sampling. Nonetheless, the visual search method is a beneficial procedure that should be considered because of its positive cost–benefit ratio. This method does not require a great deal of time to process samples, and it may reveal additional species for the inventory of live specimens, which is important for taxonomy and identification, especially in biodiversity hotspots such as the Atlantic Rainforest (Mittermeier *et al.* 2011), where the gastropod fauna remains unexplored.

For the litter sampling method, 15 (0.5 m x 0.5 m) square plots were sufficient to reach the expected richness at localities with altitudes above 1,100 m in Southern Brazil and above 800 m in South Brazil and/or at localities covered with highland dense ombrophilous forest. The limited ability of humans to conduct sampling on mountains in often unpredictable weather must be seriously considered. People must be physically conditioned to access hard-to-reach places, expend considerable effort, and carry the additional backpacks necessary to transport litter down mountains. Thirty square plots divided into two areas of 15 plots each were tested. The cumulative curves in the performance tests revealed that a maximum of 29 plots was needed to reach the expected richness for most localities; thus, we recommend this sampling effort for similar future studies. Two campaigns would also provide a better chance of obtaining favorable climatic conditions at the time of sampling, which would facilitate the highly weather-dependent visual search method.

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TABLES WITH CAPTIONS

Table 1. Localities sampled and sampling conditions for terrestrial gastropods in mountains of the Atlantic Rainforest of northeastern to southern Brazil. Localities are arranged by chronological order of sample. Hour refers to the beginning of the sample. Code in bold indicate resampled localities. Hour and wet conditions of second sampling per locality were cited after a bar ("/"). Trekking time considered the whole route (going and back), without sampling time.

Code	Locality	Sample date	Hour	Temperature °C	Humidity (%)	Access	Trekking time (h)
01	Morro Cuscuzeiro (23°17'59''S, 44°47'12''W), municipality of Paraty, state of Rio de Janeiro, and municipality of Ubatuba, state of São Paulo	12/12/2017 / 03/30/2019	16:00 / 10:40	13.0 / 21.0	73 / ---	trekking	8
02	Trilha do Ipiranga (23°20'41''S, 45°08'21''W), Núcleo Santa Virgínia, Parque Estadual da Serra do Mar, municipality of São Luiz do Paraitinga, state of São Paulo	12/18/2017	18:20	---	55	car	---
03	Morro do Corcovado (23°27'07''S, 45°12'03''W), Parque Estadual da Serra do Mar, municipality of Ubatuba, state of São Paulo	12/14/2017 / 03/31/2019	12:20 / 15:00	16.5 / 19.0	60 / ---	trekking	8
04	Pico São Sebastião (23°52'09''S, 45°22'51''W), Parque Estadual de Ilhabela, municipality of Ilhabela, state of São Paulo	12/16/2017	14:10	21.5	70	trekking	7
05	Torre Embratel (24°52'46''S, 48°15'27''W), Parque Estadual do Rio Turvo, municipality of Cajati, state of São Paulo	01/27/2018 / 01/25/2020	15:30 / 09:30	16.3–19.4 / ---	78 / 78	car	---
06	Serra Pelada (24°58'49''S, 48°28'43''W), municipality of Barra do Turvo, state of São Paulo	02/04/2018	14:00	15.2–17.5	70	trekking	6
07	Morro Anhangava (25°23'16''S, 49°00'15''W), Serra	02/13/2018	13:10	13.0–14.0	77	trekking	4

Code	Locality	Sample date	Hour	Temperature °C	Humidity (%)	Access	Trekking time (h)
	da Baitaca, municipality of Quatro Barras, state of Paraná						
08	Estância Hidroclimática Recreio da Serra (25°27’22’’S, 49°00’16’’W), municipality of Piraquara, state of Paraná	01/19/2018	12:40	22.0–23.5	77	trekking	1
09	Morro dos Perdidos (25°53’11’’S, 48°57’32’’W), municipality of Guaratuba, state of Paraná	01/13/2018	09:00	22.0–23.3	83	car	---
10	Morro Garuva (26°02’35’’S, 48°53’38’’W), municipality of Garuva, state of Santa Catarina	02/10/2018	15:00	25.8	59	trekking	5
11	Morro Boa Vista (26°30’58’’S, 49°03’10’’W), boundary of the municipalities of Jaraguá do Sul and Massaranduba, state of Santa Catarina	01/13/2018 / 02/05/2019	16:30 / 08:20	23.7–24.7 / 19.5	71 / 100	car	---
12	Morro Santo Anjo (26°37’43’’S, 48°55’49’’W), municipality of Massaranduba, state of Santa Catarina	01/14/2018 / 02/05/2019	11:40 / 09:50	26.0 / 20.7	64 / ---	car	---
13	Pico Paraná (25°15’10’’S, 48°48’28’’W), municipality of Antonina, state of Paraná	11/10/2018	15:50	15.5–17.3	100	trekking	16*
14	Serra do Pico (26°08’32’’S, 48°57’19’’W), municipality of Joinville, state of Santa Catarina	12/18/2018	11:40	26.5–28.0	---	trekking	5
15	Morro do Schmidt (26°39’55’’S, 49°12’55’’W), municipality of Pomerode, state of Santa Catarina	12/19/2018	11:20	21.6–24.7	---	car	---
16	Morro do Cachorro (26°46’42’’S, 49°01’57’’W), boundary of the municipalities of Blumenau, Gaspar, and Luiz Alvez, state of Santa Catarina	12/20/2018	10:50	26.0	99	car	---

Code	Locality	Sample date	Hour	Temperature °C	Humidity (%)	Access	Trekking time (h)
17	Morro do Spitzkopf (27°01’32’’S, 49°07’49’’W), municipality of Blumenau, state of Santa Catarina	02/03/2019	12:10	19.3	96	trekking	3
18	Morro Spitz (26°52’03’’S, 49°24’02’’W), municipality of Blumenau, state of Santa Catarina	02/04/2019	10:20	18.4–18.6	93	car	---
19	Morro Braço da Onça (26°44’58’’S, 48°55’41’’W), municipality of Luiz Alvez, state of Santa Catarina	12/22/2018	08:20	22.0	85	trekking	2
20	Serra do Araçatuba (25°54’06’’S, 48°59’42’’W), municipality of Tijucas do Sul, state of Paraná	03/02/2019 / 01/15/2020	15:50 / 15:30	17.9–18.8 / 23.5	84 / ---	trekking	5
21	Morro dos Padres (25°36’40’’S, 48°51’24’’W), Serra da Igreja, municipality of Morretes, state of Paraná	03/03/2019 / 03/10/2020	16:50 / 16:30	19.9 / 17.3–19.8	82 / 70	trekking	8
22	Caratuva (25°14’25’’S, 48°49’51’’W), municipality of Campina Grande do Sul, state of Paraná	03/06/2019	11:53	20.0	85	trekking	8
23	Serra da Bocaina (22°44’28’’S, 44°39’20’’W), municipality of São Luís do Paraitinga, state of São Paulo	03/27/2019	08:50	---	82	car	---
24	Trilha do Rio Bonito (23°14’33’’S, 45°00’58’’W), Parque Estadual da Serra do Mar, Núcleo Cunha, municipality of Cunha, state of São Paulo	03/29/2019	08:10	17.0	100	trekking	1
25	Pico do Baepi (23°47’36’’S, 45°19’55’’W), Parque Estadual de Ilhabela, municipality of Ilhabela, state of São Paulo	04/02/2019	15:10	21.0	---	trekking	6
26	Serra da Jibóia (12°51’21’’S, 39°28’34’’W), municipality of Varzedo, state of Bahia	08/02/2019	14:00	19.5–20.0	80	car	---

Code	Locality	Sample date	Hour	Temperature °C	Humidity (%)	Access	Trekking time (h)
27	Serra Bonita (15°23’28’’S, 39°33’59’’W), Reserva Serra Bonita, municipality of Camacãn, state of Bahia	08/10/2019	16:35	16.3–18.2	96	trekking	1

* We had to camp in this locality (camping hours were not counted).

Table 2. Characterization of localities sampled for terrestrial gastropods in mountains of the Atlantic Rainforest of northeastern to southern Brazil. Some localities were sampled twice (locality code in bold). Altitude is in meters above sea level (a.s.l.). Abundance classes for bromeliads observed on a 36 m^2 square plot are as follows: a few ≤ 10 individuals; abundant = 11–29 individuals; very abundant ≥ 30 individuals. Soil pH data were obtained at 5 cm of depth in soil or litter. See Table 1 for toponymy and localization of localities. Abbreviations: Y = yes; N = no.

Locality code	Altitude (m a.s.l.)	Forest type[1]	Presence of bromeliads	Presence of bamboos	Soil pH
01-A	1140	Highland dense ombrophilous forest	Epiphytes (abundant)	Y	2.0; 2.5
01-B	980	Montane dense ombrophilous forest	Epiphytes (few)	N	6.8; 7.0
02	940	Montane dense ombrophilous forest (secondary forest)	Epiphytes (few) and terrestrials (abundant)	N	6.8; 7.0
03-A	1050	Montane dense ombrophilous forest	Epiphytes (few) and terrestrials (abundant)	N	1.2; 1.4
03-B	1056	Montane dense ombrophilous forest	Epiphytes (few) and terrestrials (abundant)	N	6.6; 7.0
04	1070	Montane dense ombrophilous forest	Epiphytes (few) and terrestrials (abundant)	N	6.7; 6.9
05-A	990	Montane dense ombrophilous forest	Epiphytes (abundant) and terrestrials (very abundant)	N	6.1; 6.2
05-B	990	Montane dense ombrophilous forest	Epiphytes and terrestrials (very abundant)	N	---
06	1140	Transition between Highland and Montane dense ombrophilous forest	Epiphytes (few) and terrestrials (few)	Y	5.8; 7.0
07	1400	Highland dense ombrophilous forest	Epiphytes (few) and terrestrials	N	5.9; 6.4
08	1210	Transition between Highland and Montane dense	Epiphytes (few) and terrestrials (few)	Y	5.3; 6.2

Locality code	Altitude (m a.s.l.)	Forest type[1]	Presence of bromeliads	Presence of bamboos	Soil pH
		ombrophilous forest			
09	1350	Montane dense ombrophilous forest	Epiphytes (few)	Y	6.8; 7.0
10	750	Montane dense ombrophilous forest	Epiphytes (very abundant) and terrestrials (very abundant)	Y	6.6; 6.9
11-A	780	Montane dense ombrophilous forest	Epiphytes and terrestrials (few)	N	6.9; 4.2
11-B	780	Montane dense ombrophilous forest	Epiphytes and terrestrials (few)	N	6.0
12-A	540	Montane dense ombrophilous forest	Epiphytes (few)	N	---
12-B	538	Montane dense ombrophilous forest	Epiphytes (few)	N	4.4; 7.0
13	1800	Highland dense ombrophilous forest	Epiphytes (few)	Y	---
14	705	Montane dense ombrophilous forest	Epiphytes (few)	N	6.2; 6.9
15	847	Montane dense ombrophilous forest	Epiphytes (very abundant)	Y	6.2; 6.9
16	775	Montane dense ombrophilous forest	Epiphytes and terrestrials (very abundant)	N	6.2; 6.8
17	839	Montane dense ombrophilous forest	Epiphytes (few)	N	5.2; 6.4
18	916	Montane dense ombrophilous forest	Epiphytes (few)	N	6.0; 6.4
19	534	Montane dense ombrophilous forest	Epiphytes (few)	N	6.0; 6.8
20-A	1627	Highland dense ombrophilous forest	Epiphytes (few)	Y	6.0; 6.8
20-B	1627	Highland dense ombrophilous forest	Epiphytes (few)	Y	---
21-A	1280	Highland dense ombrophilous forest	Epiphytes (few)	Y	6.2; 6.8

Locality code	Altitude (m a.s.l.)	Forest type[1]	Presence of bromeliads	Presence of bamboos	Soil pH
21-B	1280	Highland dense ombrophilous forest	Epiphytes (few)	Y	---
22	1795	Highland dense ombrophilous forest	Epiphytes (very abundant) and terrestrials (few)	Y	6.9; 7.0
23	1658	Montane dense ombrophilous forest	Epiphytes (few)	Y	---
24	1193	Montane dense ombrophilous forest	Epiphytes (few)	N	5.8; 6.6
25	999	Montane dense ombrophilous forest	Epiphytes (very abundant) and terrestrials	N	5.8; 7.0
26	802	Montane dense ombrophilous forest	Epiphytes (very abundant)	N	2.0
27	906	Montane dense ombrophilous forest	Epiphytes (very abundant)	N	4.5

[1] According to Veloso et al. (1991).

Table 3. Comparison of terrestrial gastropods collected in South American studies by litter sampling and visual searching methods. Fields indicated with "---" refer to data not provided in the source.

Region	Area (m^2) and range of total weight (kg) or total time (h) per method						Collections				Source
	Per locality			All localities			Per locality		All localities		
	Litter sampling (m^2)	Visual searching (m^2)	Total m^2 / weight (kg) / time (h)	Litter sampling (m^2)	Visual searching (m^2)	Total m^2 / weight (kg) / time (h)	Number of species	Number of individuals	Number of species	Number of individuals	
Atlantic Rainforest, Brazil	3.7	108.0	111.7 / 1.0–3.7 / 1.5	127.5	3672.0	3799.5 / 52.9 / 51	1–7	2–297	74	1664	This study
Atlantic Rainforest, Brazil	0.5	---	0.5 / --- /---	2.5	---	7.5 / --- / 3.5	8–24	21–261	38	951	Nunes & Santos 2012
Atlantic Rainforest, Argentine	15.0	600.0	615.0 / --- / 12	30.0	1200.0	1230.0 / --- / 24	14–17	126–210	23	336	Santos & Monteiro 2001
Atlantic Rainforest, Brazil	3.0	---	3.0 / --- / ---	120.0	---	120.0 / --- / ---	0–32	0–107	36	495	Gregoric et al. 2013
Atlantic Rainforest, Brazil	---	---	--- / 10 / ---	---	---	--- / 400–500 / 560	0–26	---	47	1831	Salvador et al. 2018
Yungas, Argentine	0.7	100.0	100.7 / --- /	18.7	2500.0	2518.7 / --- /750	4–14	16–809	21	7741	Oroño et al. 2007
Yungas, Argentine	0.7	100.0	100.7 / --- / 2	18.7	2500.0	2518.7 / --- / 344	6–20	224–3805	32	22169	Miranda & Cuezzo 2010

Table 4. Terrestrial gastropods recorded in mountains of the Atlantic Rainforest of northeastern to southern Brazil, by region. Abbreviation: Micro = microgastropods; Macro = macrogastropods (see Methodology for definition). Family arrangements and order of species according to Bouchet & Rocroi (2005) and Simone (2006). See Table 1 for toponymy of localities.

Family / Species	Shell size		Localities of Atlantic Rainforest sampled			Method of record	
	Micro	Macro	Northern portion (Bahia state)	Central portion (Rio de Janeiro and São Paulo states)	Southern portion (Paraná and Santa Catarina states)	Litter sampling	Visual searching
Megalobulimidae							
Megalobulimus lopesi Leme, 1989		x		04			x
Strophocheilidae							
Mirinaba sp.		x		05			x
Strophocheilus sp.		x			12		x
Bulimulidae							
Aposculatus atlanticus Dutra & Leme, 1985		x		06		x	
Bulimulus sp.		x		05	14; 17	x	
Macrodontes sp.		x			09	x	x
Bulimulidae 1		x	26, 27				x
Simpulopsidae							
Simpulopsis sulculosa (Férussac, 1821)		x			12	x	x
Simpulopsis decussata L. Pfeiffer, 1857		x		01		x	x
Simpulopsis rufovirens (S. Moricand, 1846)		x	26				x
Simpulopsis ovata (G.B. Sowerby I, 1820)		x			08; 09	x	x
Simpulopsis sp. 1		x			14	x	x
Simpulopsis sp. 2		x		02; 04; 05; 06	07; 09; 10; 11; 12; 17	x	x
Simpulopsis sp. 3		x		03; 04; 05; 23		x	x
Simpulopsis sp. 4		x	26			x	x
Rhinus sp. 1		x	26, 27				x
Rhinus sp. 2	x				12		x

Family / Species	Shell size		Localities of Atlantic Rainforest sampled			Method of record	
	Micro	Macro	Northern portion (Bahia state)	Central portion (Rio de Janeiro and São Paulo states)	Southern portion (Paraná and Santa Catarina states)	Litter sampling	Visual searching
Eudioptus sp. 1	x			05; 24; 25		x	
Eudioptus sp. 2	x				11; 12; 18; 22	x	
Streptaxidae							
Streptaxis hylephitus (Orbigny, 1837)		x		06			x
Streptaxis pfeifferi (Pilsbry, 1930)		x		02		x	
Streptaxidae 1		x	26				x
Streptaxidae 2		x	26			x	
Subulinidae							
Subulinidae 1		x	26				x
Veronicellidae							
Phyllocaulis sp.		x			11	x	
Euconulidae							
Pseudoguppya semenlini (Moricand, 1846)	x		27	02; 03; 06; 23; 25	07; 10; 12; 14; 16; 19; 20	x	x
Charopidae							
Lilloiconcha superba (Thiele, 1927)	x			23	12; 16; 17	x	
Lilloiconcha sp. 1	x				19	x	
Lilloiconcha sp. 2	x				11	x	
Lilloiconcha sp. 3	x				13; 20; 21; 22	x	
Radiodiscus promatensis Miguel, Ramírez & Thomé, 2004	x				11; 12	x	
Radiodiscus costeliffer Scott, 1957	x			01; 02; 05; 06; 23		x	x
Radiodiscus sp. 1	x			04	07; 08; 10; 16; 18	x	
Radiodiscus sp. 2	x		26			x	
Radiodiscus sp. 3	x		26, 27			x	
Radiodiscus sp. 4	x			05		x	
Rotadiscus sp. 1	x			05		x	
Rotadiscus sp. 2	x				12;14; 16	x	
Zilchogyra sp. 1	x				10; 19; 20; 21	x	
Zilchogyra sp. 2	x			05; 23		x	

Family / Species	Shell size		Localities of Atlantic Rainforest sampled			Method of record	
	Micro	Macro	Northern portion (Bahia state)	Central portion (Rio de Janeiro and São Paulo states)	Southern portion (Paraná and Santa Catarina states)	Litter sampling	Visual searching
Scolodontidae							
Guestieria sp.	x				08	x	
Happia vitrina (Wagner, 1827)		x			12; 16	x	x
Happia sp. 1		x		02; 03; 06		x	x
Happia sp. 2		x		23		x	
Happia sp. 3	x				11	x	
Happiella sp. 1		x			08; 09; 21		x
Happiella sp. 2		x		01; 05; 06		x	
Happiella sp. 3	x				07; 20		x
Tamayoa banghaasi (Thiele, 1927)	x				18	x	
Tamayoa sp. 1	x			24	17	x	
Tamayoa sp. 2	x				13	x	
Scolodonta sp. 1	x			05; 25	11; 14; 17; 19	x	x
Scolodonta sp. 2	x				08	x	x
Scolodonta sp. 3	x				22	x	
Scolodonta sp. 4	x		27			x	x
Miradiscops sp.	x		27	02; 04; 05; 23; 25	07; 11; 15; 18; 20; 21	x	
Helicinidae							
Alcadia aff. hirsuta	x				10	x	
Alcadia sp. 1	x			04		x	
Alcadia sp. 2		x	27			x	
Helicina schereri F. Baker, 1914		x		02		x	x
Helicina cf. *inaequistriata*		x			11; 12; 16	x	x
Helicina cf. *iguapensis*		x		03; 05	12	x	x
Helicina sp. 1		x		03		x	x
Helicina sp. 2		x		03			x
Helicina sp. 3		x			12	x	x
Helicina sp. 4		x		05		x	x
Helicina sp. 5		x		06		x	x
Helicina sp. 6		x	26			x	

Family / Species	Shell size		Localities of Atlantic Rainforest sampled			Method of record	
	Micro	Macro	Northern portion (Bahia state)	Central portion (Rio de Janeiro and São Paulo states)	Southern portion (Paraná and Santa Catarina states)	Litter sampling	Visual searching
Helicinidae 1		x	26, 27			x	x
Diplommatinidae							
Adelopoma brasiliense Morretes, 1954	x				21	x	
Adelopoma paulistanum Martins & Simone, 2014	x			04; 05		x	
Adelopoma sp.	x				12; 16; 19	x	
Phylomycidae							
Meghimatium pictum (Stoliczka, 1873)		x			11		x
Total	35	39	15	30	41	61	35

Table 5. Terrestrial gastropods collected by litter sampling, frequency (%) of square plots (n = 15) with at least one gastropod collected, and density of individuals in mountains of the Atlantic Rainforest of northeastern to southern Brazil. Some localities were sampled twice (locality code in bold). Abbreviations: Micro = microgastropods; Macro = macrogastropods; SD = standard deviation. See Table 1 for toponymy and localization of localities.

Locality code	Number of species	Number of individuals			Square plots		Density of individuals	
		Total	Micro	Macro	Frequency (%) with gastropods	Mean individuals per square plot	m² of litter	kg of litter
01A	2	2	2	0	13	0.1	0.3	0.4
01B	3	16	15	1	60	1.1	4.3	10.7
02	6	35	32	3	80	2.3	6.4	11.5
03A	2	14	13	1	53	0.9	3.7	9.7
03B	4	5	4	1	7	0.3	0.3	4.1
04	6	39	39	0	93	2.6	10.4	22.1
05A	7	120	106	14	100	8.0	32.0	58.9
05B	11	237	203	34	100	15.8	63.2	137.6
06	7	45	37	8	87	3.0	12.0	23.5
07	5	29	22	7	93	1.9	7.7	18.4
08	4	22	17	5	60	1.5	5.9	10.7
09	2	16	13	3	60	1.1	4.3	11.6
10	4	11	11	0	40	0.7	2.9	8.3
11A	6	64	51	13	87	4.3	17.1	39.9
11B	4	26	20	6	67	1.7	6.9	21.3
12A	9	233	216	17	100	15.5	62.1	112.9

Locality code	Number of species	Number of individuals			Square plots		Density of individuals	
		Total	Micro	Macro	Frequency (%) with gastropods	Mean individuals per square plot	m² of litter	kg of litter
12B	6	61	61	0	67	4.0	16.3	37.6
13	2	27	27	0	93	1.8	7.2	11.5
14	4	16	16	0	33	1.1	4.3	8.4
15	1	2	2	0	13	0.1	0.5	1.8
16	7	70	64	6	80	4.7	18.7	50.1
17	3	5	2	3	27	0.3	1.3	4.6
18	3	8	8	0	40	0.5	2.1	6.4
19	5	15	15	0	40	1.3	5.1	12.9
20A	2	5	5	0	27	0.3	1.3	4.8
20B	5	24	24	0	73	1.6	6.4	21.2
21A	4	23	23	0	40	1.5	6.1	26.7
21B	4	19	19	0	60	1.3	5.1	18.8
22	3	10	10	0	40	0.7	2.7	6.1
23	7	169	164	5	93	11.3	45.1	99.8
24	4	7	5	2	40	0.5	1.9	4.0
25	2	25	24	1	73	1.7	6.7	21.6
26	7	34	28	6	73	2.3	9.1	19.6
27	6	23	5	21	73	1.7	6.9	23.6

Locality code	Number of species	Number of individuals			Square plots		Density of individuals	
		Total	Micro	Macro	Frequency (%) with gastropods	Mean individuals per square plot	m² of litter	kg of litter
Total	61	1460	1303	157	---	---	---	---
Range	1–11	2–233	2–216	0–34	13–100	0.1–15.8	0.3–63.2	0.4–137.6
Mean	4.6	42.9	38.3	4.6	61.3	2.7	11.3	25.83
SD	2.2	59.4	54.1	7.4	---	4.0	15.8	31.9

Table 6. Terrestrial gastropods found by visual searching, frequency (%) of square plots (n = 3) with at least one gastropod, and density of individuals per m^2 in mountains of the Atlantic Rainforest of northeastern to southern Brazil. Some localities were sampled twice (locality code in bold). Abbreviations: Micro = microgastropods; Macro = macrogastropods; SD = standard deviation. See Table 1 for toponymy and localization of localities.

Locality code	Number of species	Number of individuals			Square plots		Individuals per hour	Individuals per 100 m^2
		Total	Micro	Macro	Frequency (%) with gastropods	Mean individuals per square plot		
01A	1	1	1	0	33	0.3	0.7	0.9
01B	0	0	0	0	0	0.0	0.0	0.0
02	2	2	0	2	33	0.7	1.3	1.9
03A	0	0	0	0	0	0.0	0.0	0.0
03B	2	2	1	1	67	0.7	1.3	1.9
04	2	3	0	3	67	1.0	2.0	2.8
05A	8	38	0	38	100	12.7	25.3	35.2
05B	1	1	0	1	33	0.3	0.7	0.9
06	4	4	0	4	67	1.3	2.7	3.7
07	1	1	0	1	33	0.3	3.3	0.9
08	2	8	0	8	100	2.7	5.3	7.4
09	1	1	0	1	33	0.3	0.7	0.9
10	1	1	1	0	33	0.3	0.7	0.9
11A	5	6	2	4	100	2.0	4.0	5.6
11B	0	0	0	0	0	0.0	0.0	0.0
12A	9	64	3	61	100	21.3	42.7	59.3
12B	5	9	1	8	100	3.0	6.0	8.3

Locality code	Number of species	Number of individuals			Square plots		Individuals per hour	Individuals per 100 m^2
		Total	Micro	Macro	Frequency (%) with gastropods	Mean individuals per square plot		
13	0	0	0	0	0	0.0	0.0	0.0
14	3	4	1	3	67	1.3	2.7	3.7
15	0	0	0	0	0	0.0	0.0	0.00
16	0	0	0	0	0	0.0	0.0	0.00
17	4	14	0	14	100	4.7	9.3	13.0
18	0	0	0	0	0	0.0	0.0	0.00
19	2	10	9	1	67	3.3	6.7	9.3
20A	1	1	1	0	33	0.3	0.7	0.9
20B	0	0	0	0	0	0.0	0.0	0.00
21A	0	0	0	0	0	0.0	0.0	0.00
21B	0	0	0	0	0	0.0	0.0	0.00
22	1	4	0	4	67	1.3	2.7	3.7
23	0	0	0	0	0	0.0	0.0	0.00
24	2	5	0	5	33	1.7	3.3	4.6
25	0	0	0	0	0	0.0	0.0	0.00
26	8	17	2	15	100	5.7	11.3	15.7
27	3	7	6	2	33	2.7	2.0	7.4
Total	35	204	28	176	---	---	---	5.6
Range	0–9	0–64	0–9	0–61	0–100%	0.0–21.3	0.0–42.7	0.0–59.3
Mean	2.0	6.0	0.8	5.2	39.2%	2.0	0.7	5.6

Locality code	Number of species	Number of individuals			Square plots		Individuals per hour	Individuals per 100 m^2
		Total	Micro	Macro	Frequency (%) with gastropods	Mean individuals per square plot		
SD	2.5	12.6	1.9	12.2	---	2.5	1.8	11.7

Table 7. Comparison of estimated richness and observed richness of localities (n = 27) sampled for terrestrial gastropods in mountains of the Atlantic Rainforest of northeastern to southern Brazil. We utilized Chao2 and Richness Extrapolation (Colwell 2012) to estimate richness, according to the Estimate S 9.10 program. See table 1 for toponymy and localization of localities.

Locality code	Forest type[1]	Litter sampling			Visual searching		
		Observed richness	Chao2	Richness Extrapolation	Observed richness	Chao2	Richness Extrapolation
01AB	DAM/DM*	3	3.00	-	1	1.00	-
2	DM(Sec)	6	6.00	-	2	2.67	2.67
3	DM	5	6.45	7.50	2	2.83	2.83
4	DM	6	6.93	7.50	2	2.67	2.67
05AB	DM	11	11.00	11.50	9	12.13	13.81
6	DAM*	7	8.4	9.50	4	8.00	7.70
7	DAM	5	10.6	9.21	1	1.00	-
8	DAM*	4	4.47	4.50	2	2.33	2.33
9	DM	2	2.00	-	1	1.00	-
10	DM	4	6.80	6.50	1	1.00	-
11AB	DM	6	6.97	6.50	5	13.33	11.83
12AB	DM	12	14.90	13.90	11	13.22	13.22
13	DAM	2	2.00	-	-	-	-
14	DM	4	4.23	4.23	3	4.30	4.30
15	DM	1	1.00	-	-	-	-
16	DM	7	8.87	8.63	-	-	-
17	DM	8	8.23	8.23	-	-	-
18	DM	3	3.93	3.92	4	4.67	4.67
19	DM	5	6.87	6.63	2	2.30	2.30
20AB	DAM	5	5.48	5.42	-	-	-
21AB	DAM	5	5.48	5.42	-	-	-
22	DAM	3	3.00	-	-	-	-
23	DM	7	7.23	7.23	-	-	-
24	DM	2	2.00	-	2	2.67	2.70
25	DM	4	5.87	5.63	-	-	-
26	DM	7	7.00	-	8	14.00	13.55

27	DM	6	6.00	-	3	4.33	4.33

[1]DAM: highland dense ombrophilous forest; DM: montane dense ombrophilous forest; DAM*: transition between highland dense ombrophilous forest and montane dense ombrophilous forest, with predominance of the first; DM*: transition between highland dense ombrophilous forest and montane dense ombrophilous forest, with predominance of the second; DM(Sec): secondary forest regenerating into montane dense ombrophilous forest.

FIGURES WITH CAPTIONS

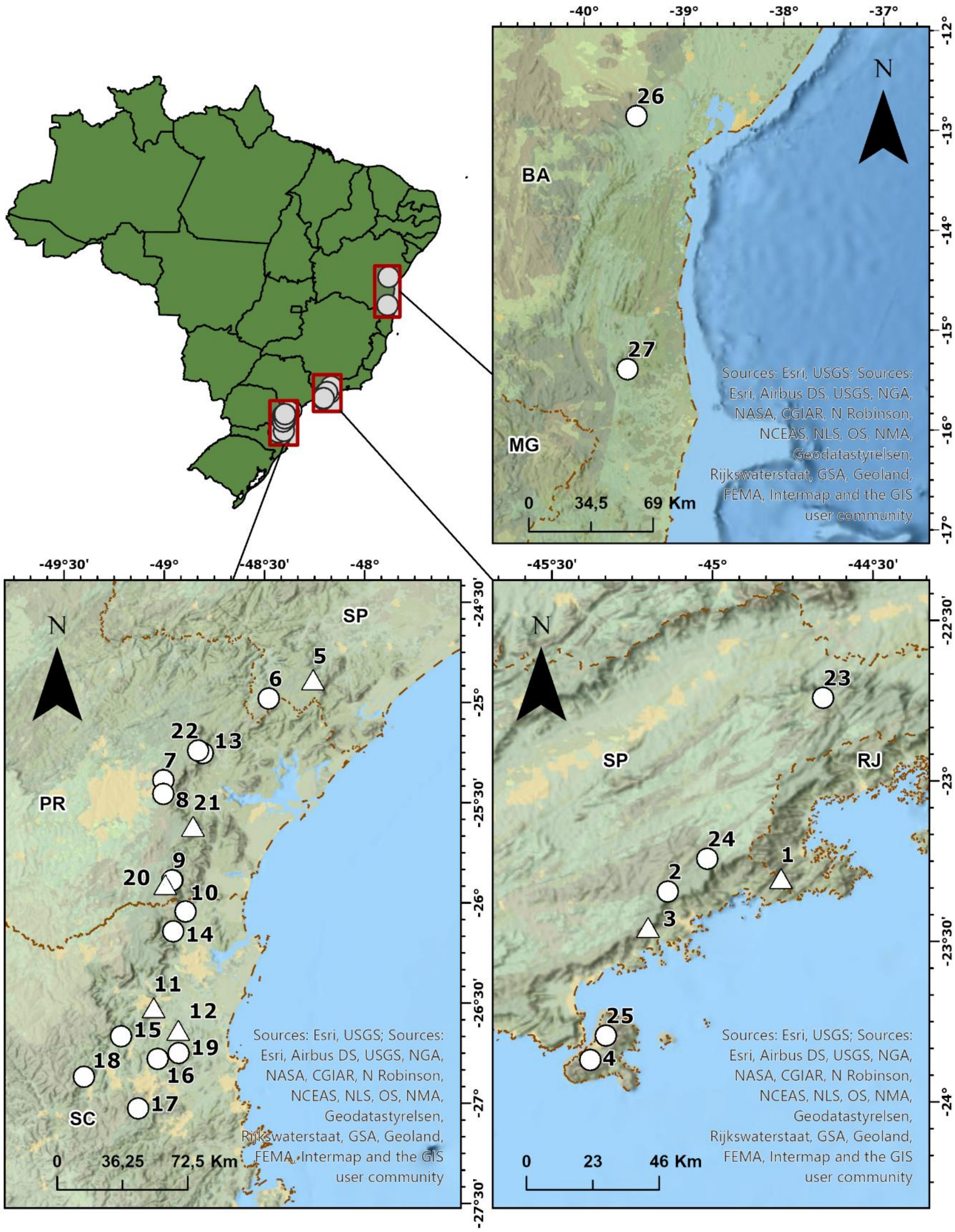

Figure 1. Map showing localities sampled in search of terrestrial gastropods in the mountains of the Atlantic Rainforest of northeastern to southern Brazil. Triangles represent localities with two samples. Abbreviations: BA = Bahia, MG = Minas Gerais, RJ = Rio de Janeiro, SP = São Paulo, PR = Paraná, SC = Santa Catarina. Image sources: Environmental System Research Institute (Esri), Urban Green Space (UGS), and Instituto Brasileiro de Geografia e Estatística (IBGE).

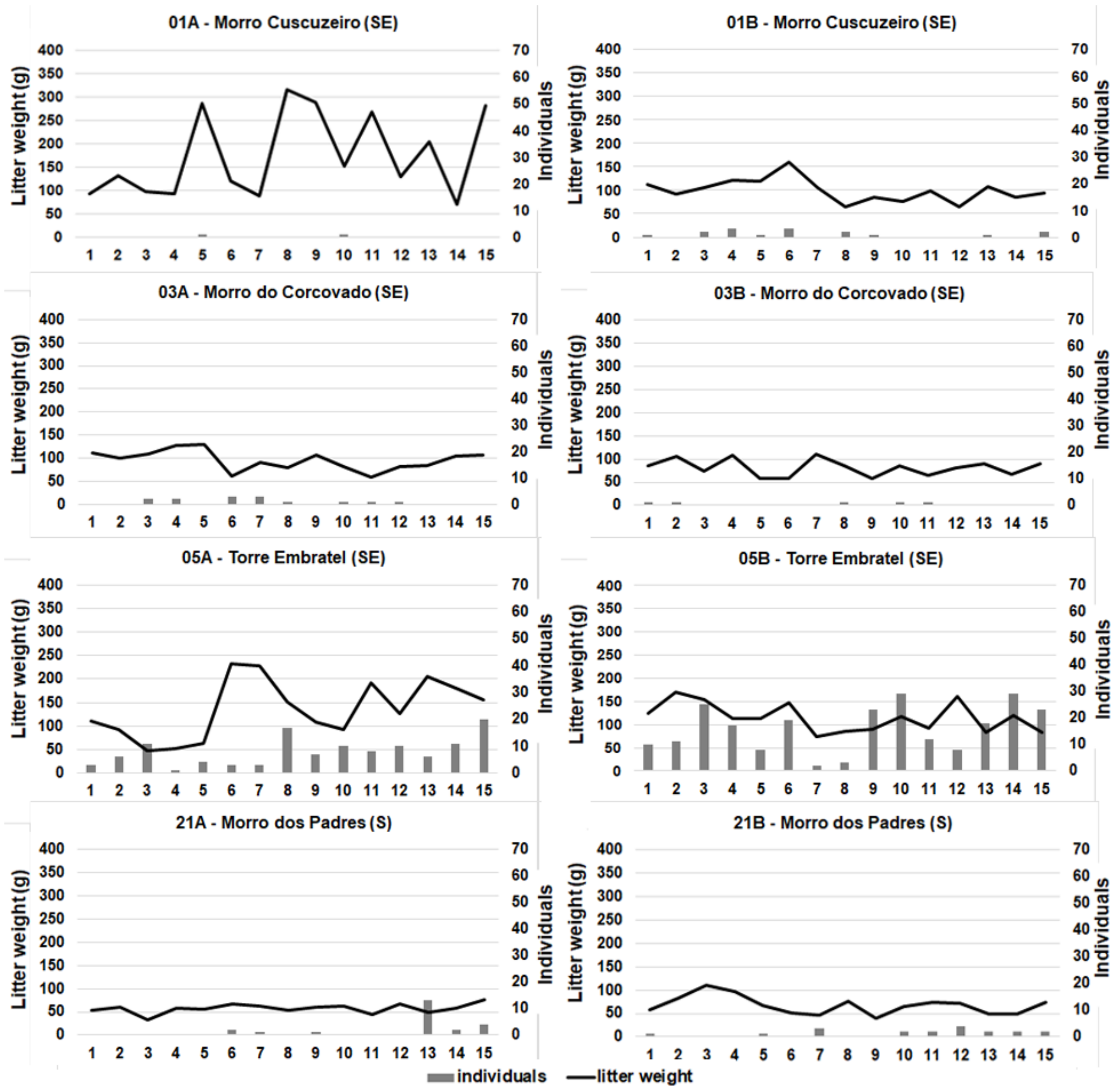

Figure 2. Terrestrial gastropods collected per square plot (vertical bars) versus weight of dried litter collected from each respective plot (black line) in four resampled localities (first sampled under A and second under B) in southeastern (SE) and southern (S) Brazil, organized from north to south. For information about each locality, see Table 1.

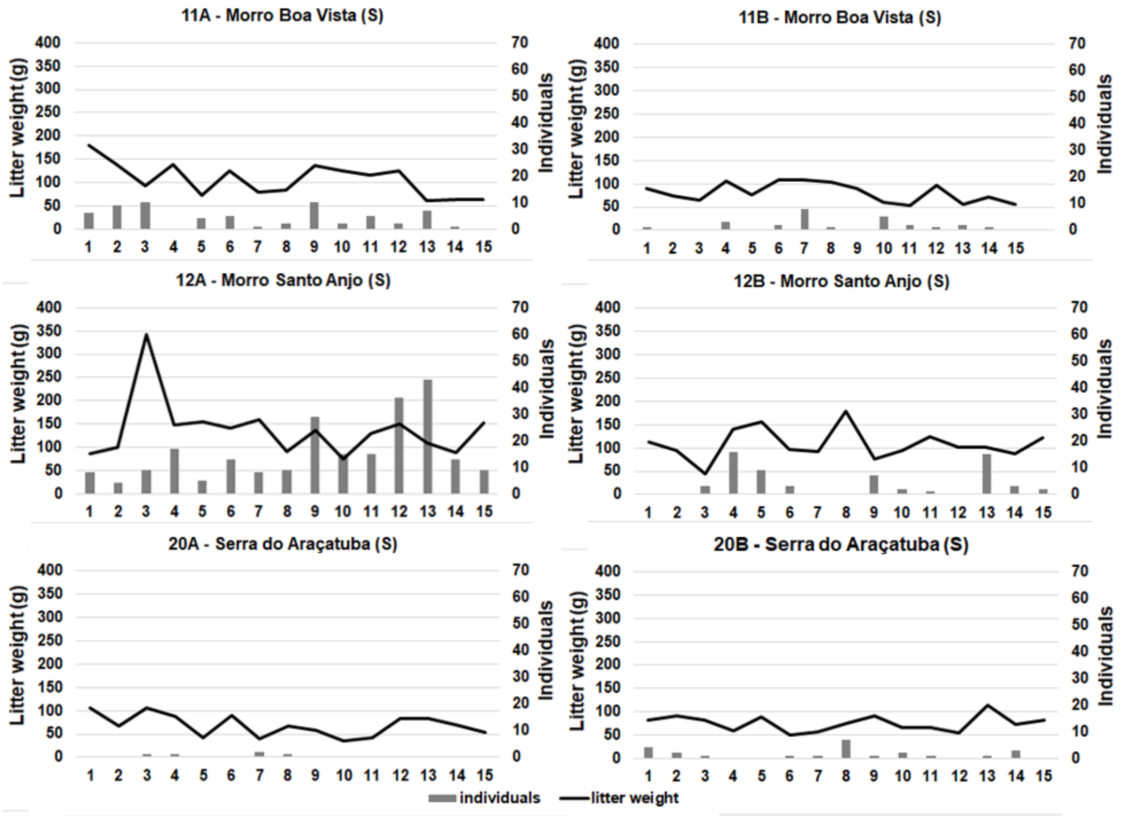

Figure 3. Terrestrial gastropods collected per square plot (vertical bars) versus weight of dried litter collected from each respective plot (black line) in three resampled localities (first sampled under A and second under B) on southern (S) Brazil, organized from north to south. For information about each locality, see Table 1.

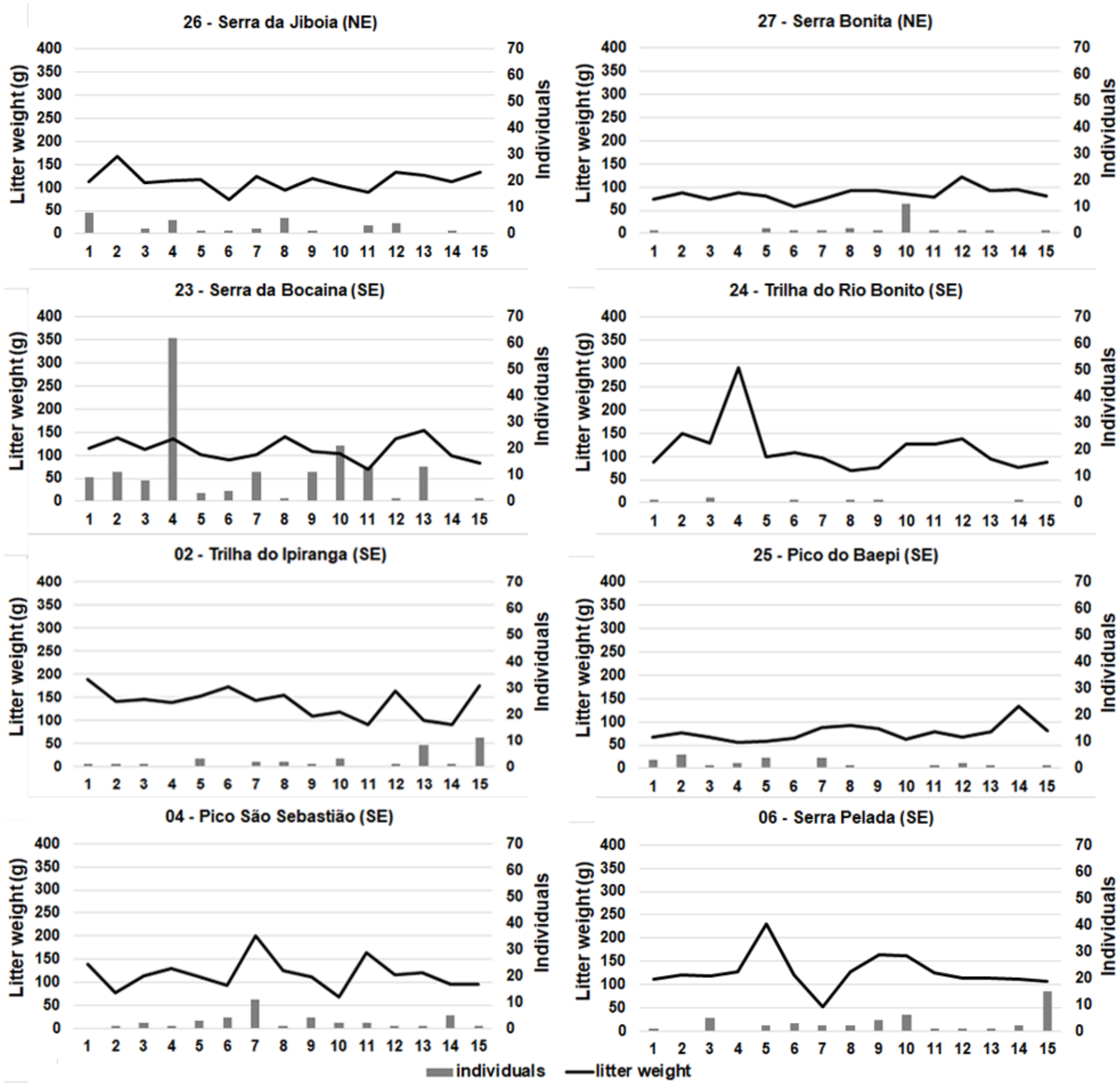

Figure 4. Terrestrial gastropods collected per square plot (vertical bars) versus weight of dried litter of each respective plot (black line) in localities of northeastern (NE) and southeastern (S) Brazil, organized from north to south. For information about each locality, see Table 1.

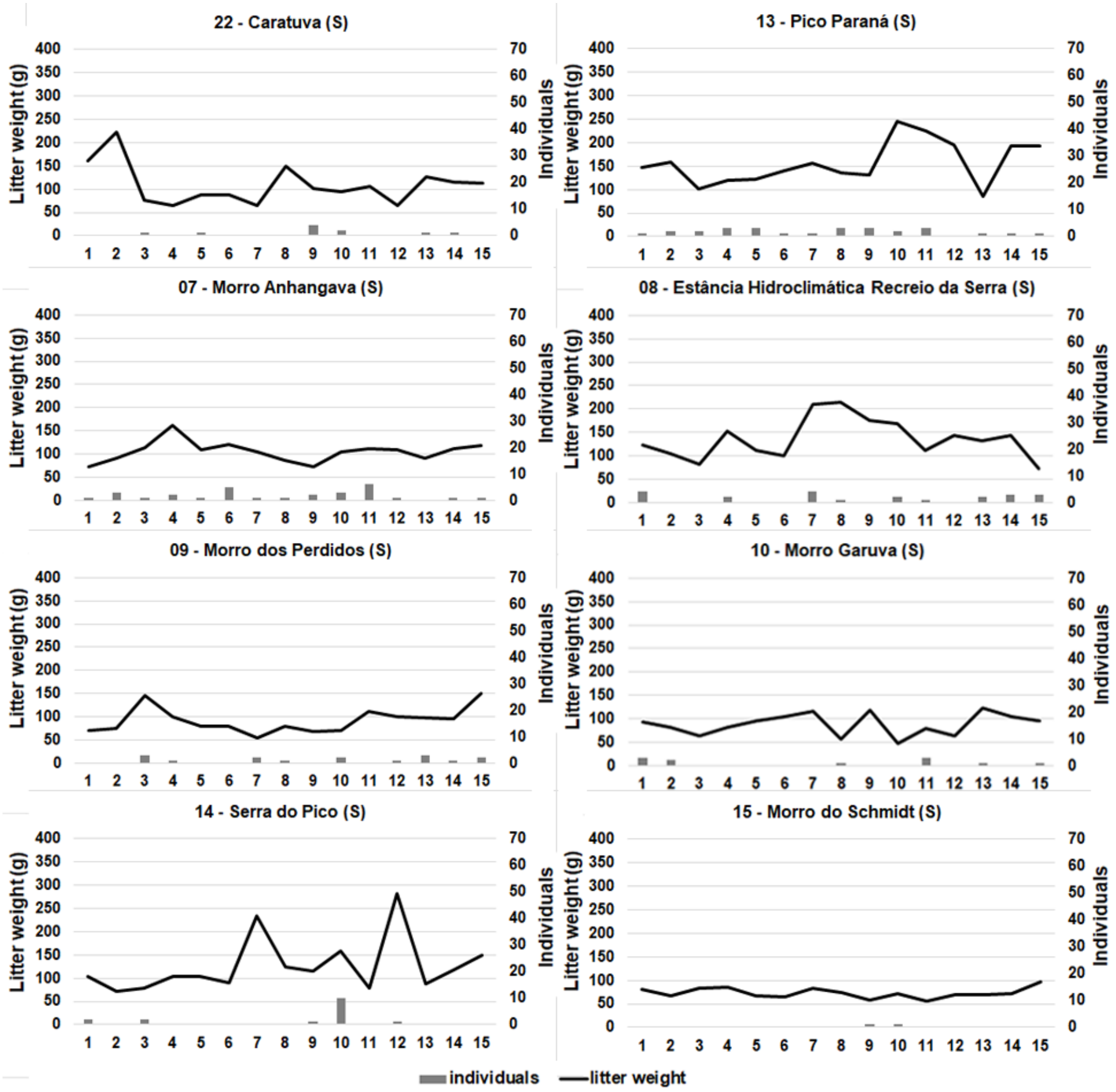

Figure 5. Terrestrial gastropods collected per square plot (vertical bars) versus weight of dried litter of each respective plot (black line) in eight localities of southern Brazil (S), organized from north to south. For information about each locality, see Table 1.

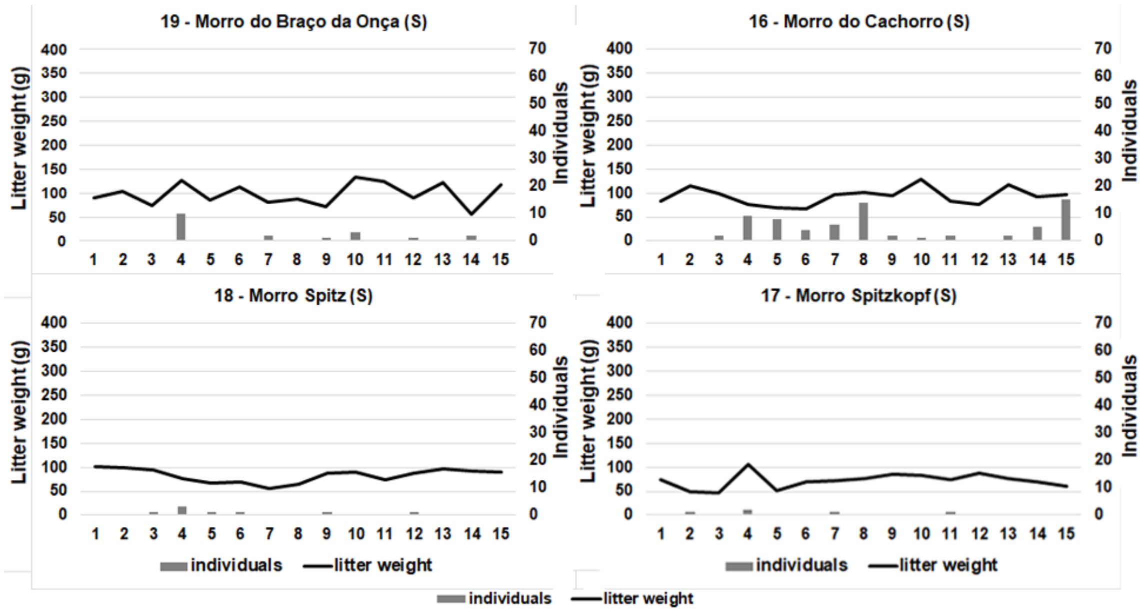

Figure 6. Terrestrial gastropods collected per square plot (vertical bars) versus weight of dried litter of each respective plot (black line) in four localities on southern Brazil (S), organized from north to south. For information about each locality, see Table 1.

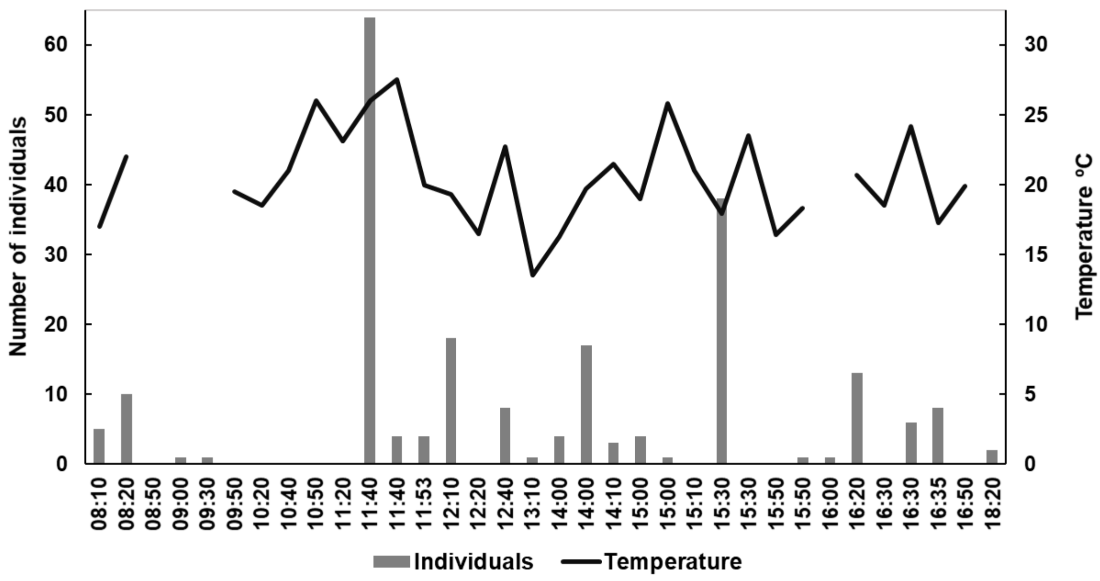

Figure 7. Number of individual terrestrial gastropods collected in each sampling (n = 34) in mountains of the Atlantic Rainforest of northeastern to southern Brazil versus air temperature by visual search methodology, organized by hour of sampling. For information about each locality, see Table 1.

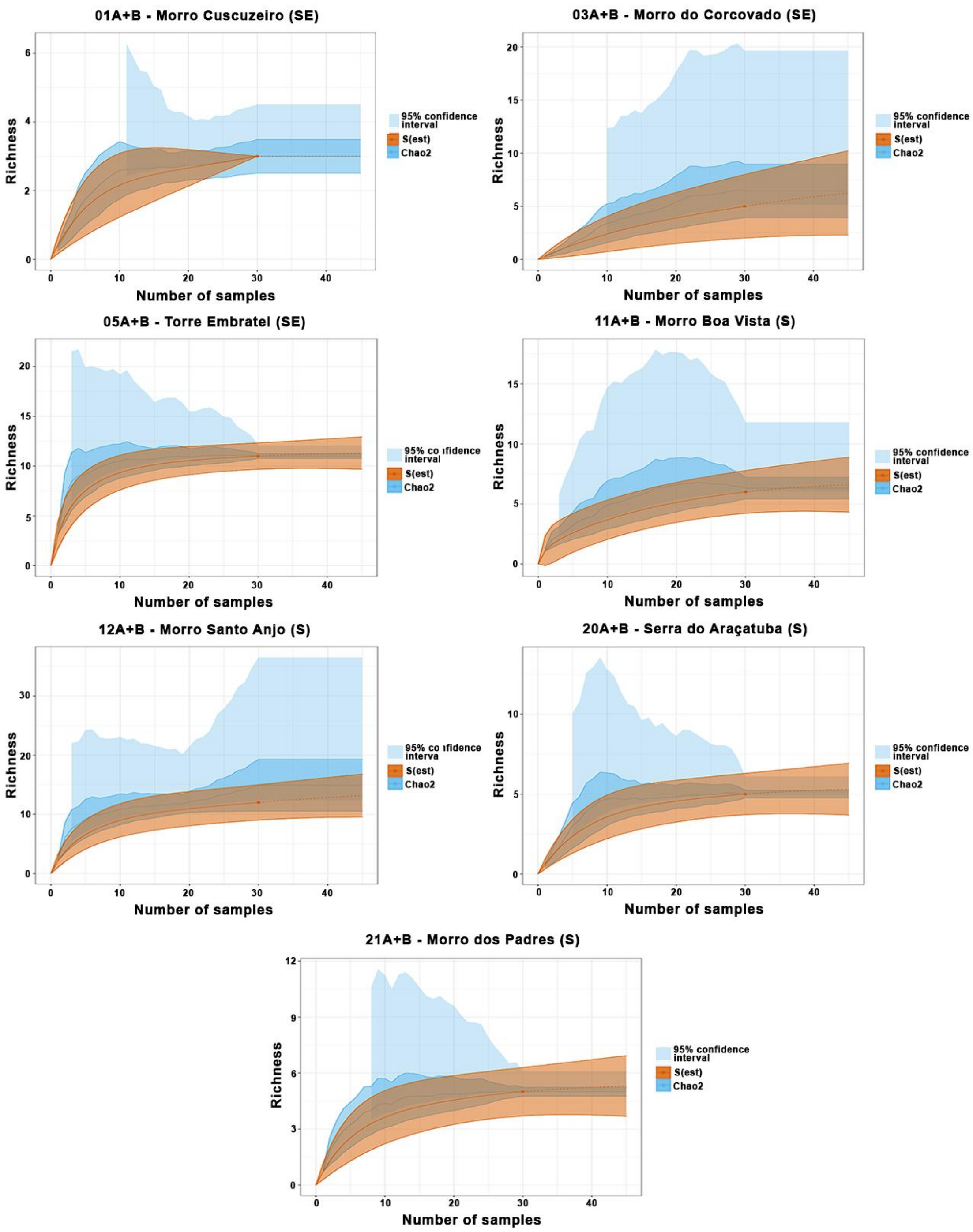

Figure 8. Richness estimation curves of terrestrial gastropod communities in the seven resampled localities by litter sampling (n = 30 square plots), southeastern (SE) and southern (S) Brazil, using Chao2, Rarefaction Extrapolation [S(est)] and its respective 95% confidence interval obtained in Estimate S 9.10. For information about each locality, see Table 1.

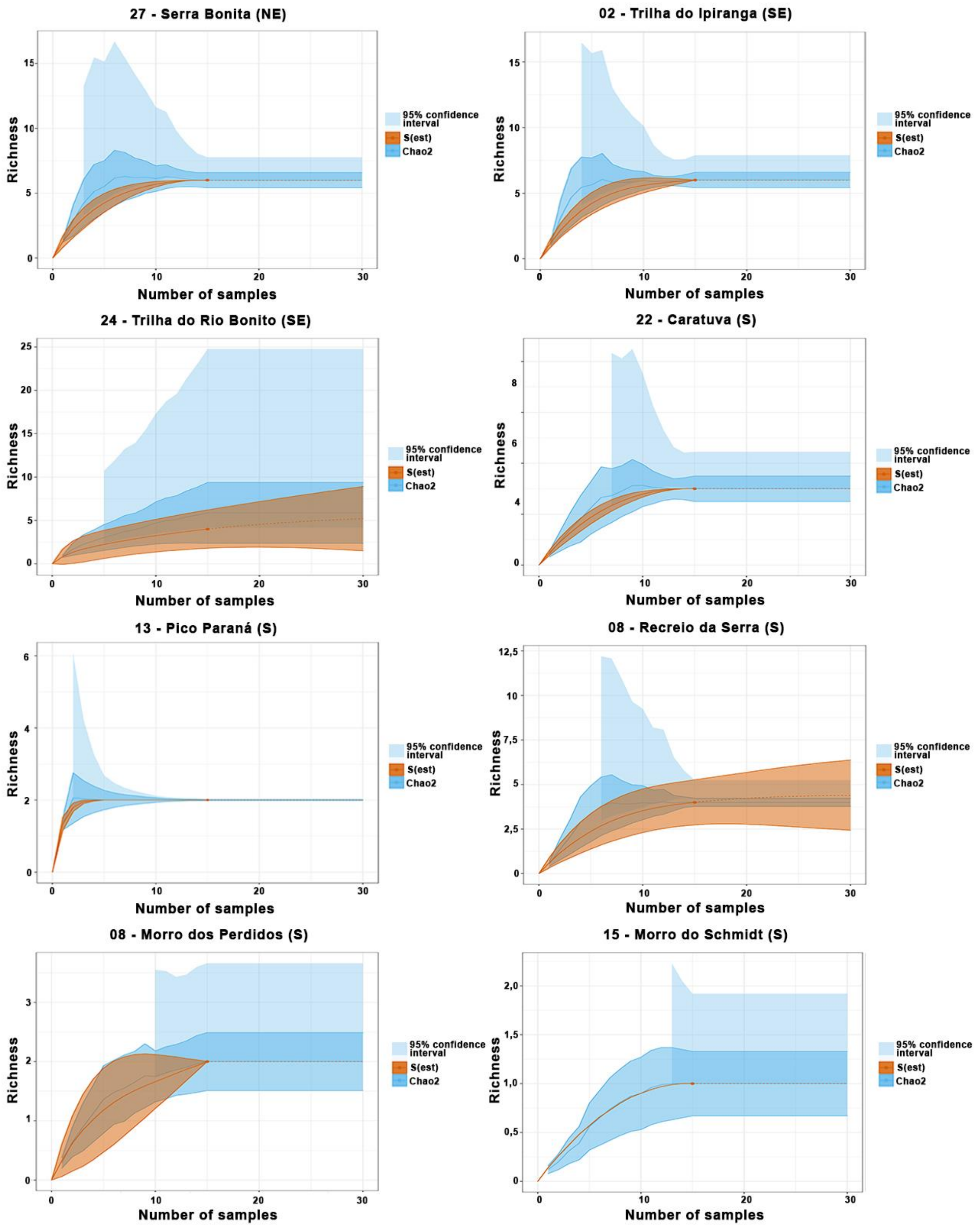

Figure 9. Richness estimation curves of terrestrial gastropod communities sampled once once by litter sampling (n = 15 square plots) in northeastern (NE), southeastern (SE), and southern (S) Brazil using Chao2, Rarefaction Extrapolation [S(est)] and its respective 95% confidence interval obtained in Estimate S 9.10. For information about each locality, see Table 1.

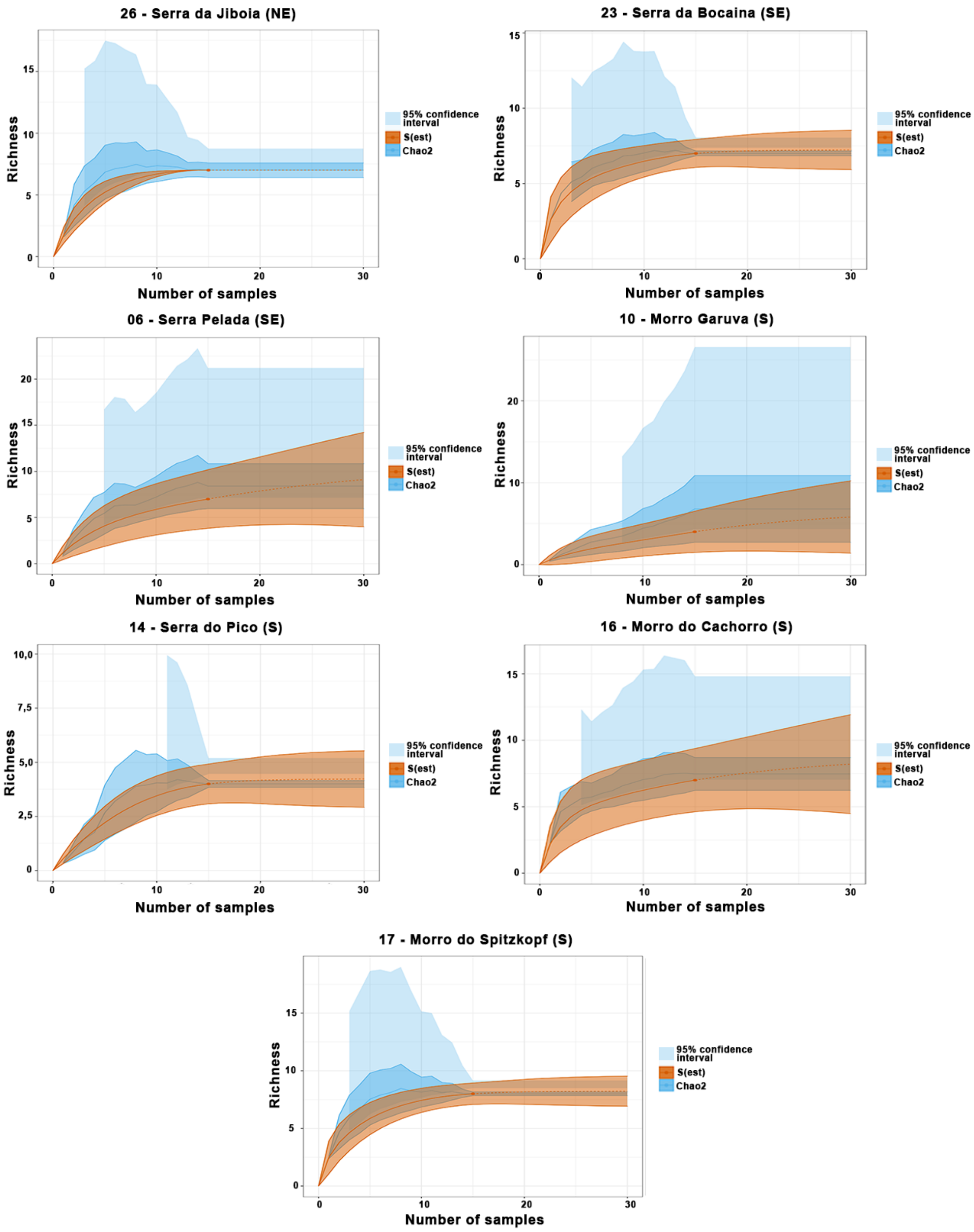

Figure 10. Richness estimation curves of terrestrial gastropod communities sampled once by litter sampling (n = 15 square plots) in northeastern (NE), southeastern (SE), and southern (S) Brazil using Chao2, Rarefaction Extrapolation [S(est)] and its respective 95% confidence interval obtained in Estimate S 9.10. For information about each locality, see Table 1.

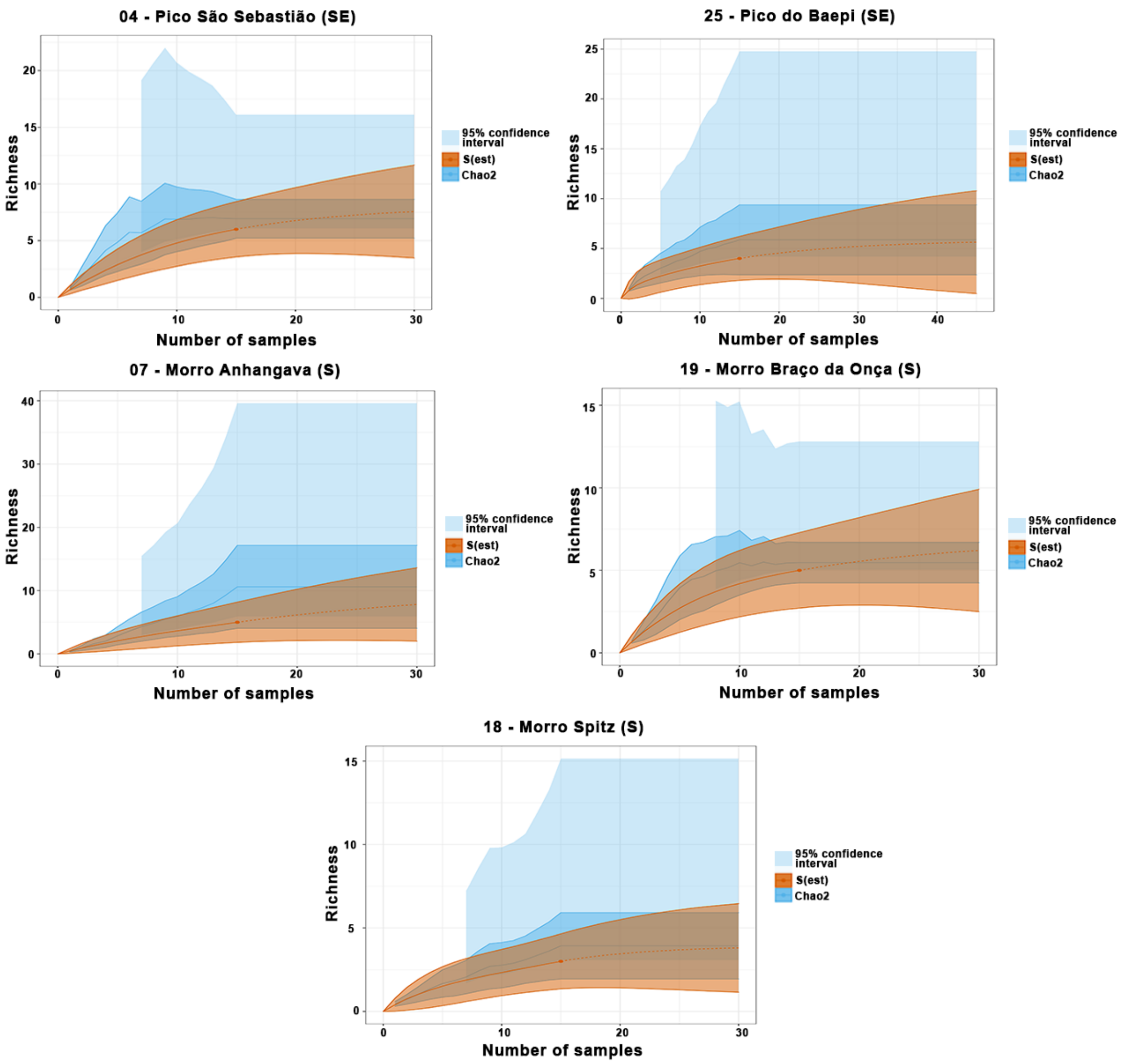

Figure 11. Richness estimation curves of terrestrial gastropod communities sampled once by litter sampling (n = 15 square plots) in southeastern (SE) and southern (S) Brazil using Chao2, Rarefaction Extrapolation [S(est)] and its respective 95% confidence interval obtained in Estimate S 9.10. For information about each locality, see Table 1.

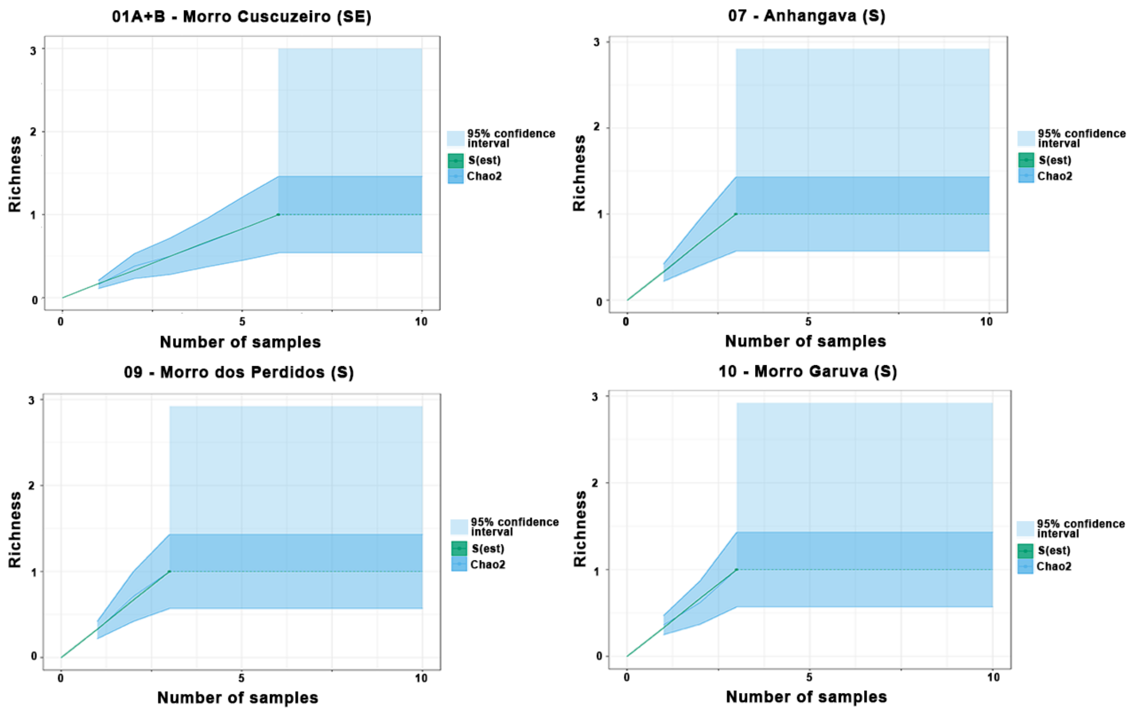

Figure 12. Rarefaction curves of terrestrial gastropod communities sampled by visual searching that reached the asymptote in southeastern (SE) and southern (S) Brazil using Chao2, Rarefaction Extrapolation [S(est)] and its respective 95% confidence interval obtained in Estimate S 9.10. For information about each locality, see Table 1.

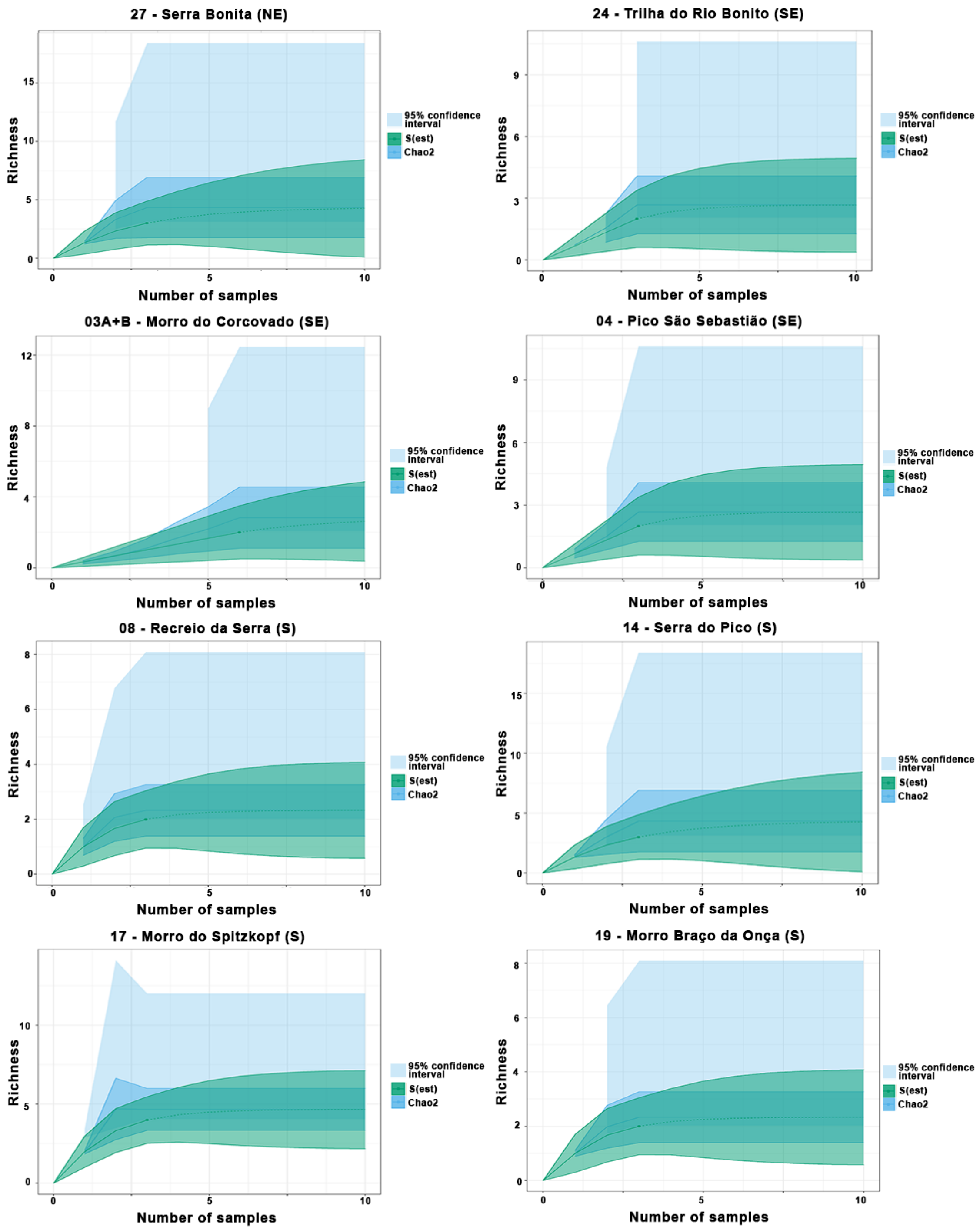

Figure 13. Rarefaction curves of terrestrial gastropod communities sampled by visual searching with extrapolations lower than 3 species above the observed. Samples were collected in northeastern (NE), southeastern (SE) and southern (S) Brazil and analyzed using Chao2, Rarefaction Extrapolation [S(est)] and its respective 95% confidence interval obtained in Estimate S 9.10. For information about each locality, see Table 1

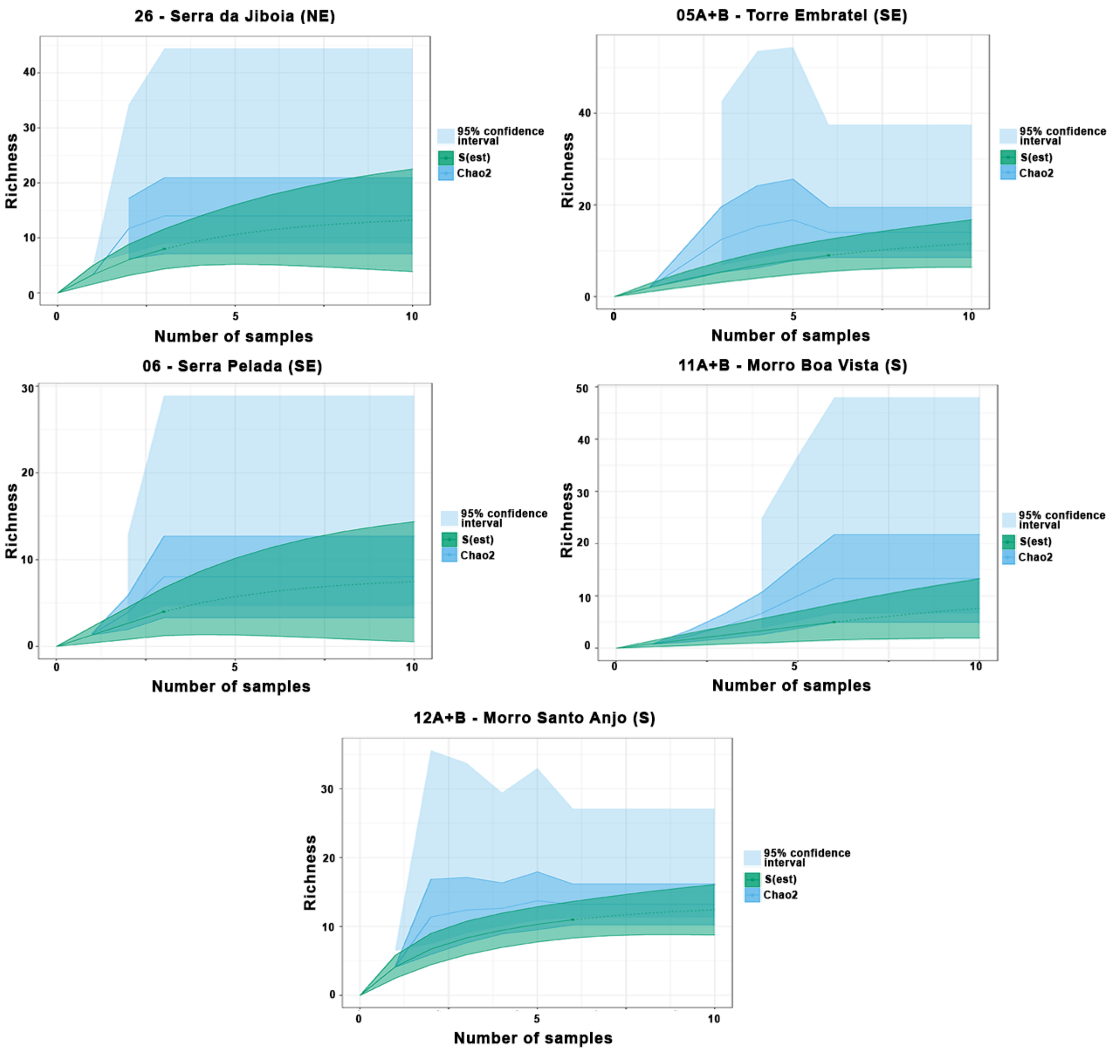

Figure 14. Rarefaction curves of terrestrial gastropod communities sampled by visual searching with extrapolations higher than 3 species above the observed. Samples were collected in northeastern (NE), southeastern (SE) and southern (S) Brazil and analyzed using Chao2, Rarefaction Extrapolation [S(est)] and its respective 95% confidence interval obtained in Estimate S 9.10. For information about each locality, see Table 1

CAPÍTULO 2

Diversity of terrestrial gastropods on altitudinal and latitudinal gradients on mountains of Brazilian Atlantic Rainforest

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Abstract.

Background. The number of studies with the aim to estimate gastropod diversity has greatly increased in the two decades. Among the environments that can harbor a huge diversity of terrestrial gastropods, there are the neotropical mountains. To date, no other study has been carried out to investigate the diversity of gastropods in mountains in the Atlantic Forest, and it is estimated that in Brazil there are still about two thirds of terrestrial gastropod species not yet described. Our aim was to investigate diversity of terrestrial gastropods in the mountains of the Atlantic Forest, from north to south of Brazil, in an altitudinal and latitudinal approach.

Methods. We sampled gastropods in 27 mountains from northeastern to southern Brazil, of which on 2 we sampled in low and intermediate altitudes. We employed the methods of litter sampling and visual search. In the first method, we collected all litter inside 15 0.5 m x 0.5 m square plots that were allocated every 2 m along a 30 m transection. The litter was examined in the laboratory and then dried, weighed, and sieved to search for shells. In the visual search, we looked for gastropods in microhabitats up to 2 m in height for 30 minutes each in three square plots of 6 m² every 10 m along the transection. We took notes of environment descriptions, time, temperature, humidity, and soil pH. The material was identified at the lowest possible taxonomic level based on the literature. We analyzed similarity between localities using Unweighted Pair-Groups Method Average (UPGMA) and β diversity. We calculated alfa diversity for each locality and analyzed its correlation with altitude and latitude using Pearson correlation.

Results. We obtained 1868 individuals belonging to 71 species in 11 families. The families Scolodontidae, Charopidae and Euconulidae alone represented 54,5 % of total individuals collected. We classify terrestrial gastropods in three types of communities: mid-montane, upper-montane and highland, based on the species composition. Although with similar representatives, communities of Atlantic rainforest showed great dissimilarity between each other even for mountaintops near to each other, mainly because of turnover. The species turnover may be caused by speciation in families Scolodontidae, Helicinidae and Charopidae. We did not find correlation between diversity and altitude or latitude. We found that higher richness in Atlantic Rainforest occurs at intermediate altitudes, and there was a negative correlation between species richness and altitude.

Keywords: UPGMA cluster analysis, Shannon index, Simpson index, Equitability, terrestrial gastropods, microgastropods, Sorensen index, pair-to-pair sorensen

1. Introduction

Gastropoda is the most diverse class amongst molluscs, and the only which achieved living in terrestrial environments. There are around 25 to 30 thousand species of terrestrial gastropods described (MolluscaBase 2021), and another 11 to 40 thousand species waiting to be discovered. (Lydeard et al. 2004; Colley 2013). In Brazil, there is nearly 740 described species of terrestrial gastropods (Simone 2006; Birckolz et al. 2016; Salvador et al. 2017; Salvador 2019) and it is estimated that this number represents only a third of species that may occur in the country (Simone 1999; Salvador 2019). Among the places that can harbor a significant number of terrestrial gastropods not yet documented, there are mountains (Solem 1984; Salvador 2019).

In the last two decades, the numbers of studies destinated to explore diversity of montane terrestrial gastropods has been increased (Tattersfield et al. 2001; Labaune & Magnin 2002; Sólymos et al. 2004; Aubry et al. 2005; Hausdorf 2006; Tattersfield et al. 2006; Oroño et al. 2007; Müller et al. 2009; Liew et al. 2010; Miranda & Cuezzo 2010; Wronski & Hausdorf 2010; Hoffman et al. 2011; Nunes & Santos 2011; Nunes & Santos 2012; Albano et al. 2014; Boxnick et al. 2015; Nägele & Hausdorf 2015; Gheoca 2016; Wronski et al. 2016; Gheoca & Popescup 2018). However, the most studied mountains are located either in the Europe (Hausdorf 2003, Hausdorf 2006, Labaune & Magnin 2002, Aubry et al. 2005), or in the African continent (Verdcourt 1983; Warui 1998; Tattersfield et al. 2001). In Brazilian Atlantic Rainforest, only a few studies were conducted in order to explore diversity (Santos & Monteiro 2001, Nunes & Santos 2012, Salvador et al. 2018), but mountains are scarcely studied in this biome (Salvador 2019).

The Atlantic Rainforest is a biome which occupies the eastern portion of South American continent. At present, only 28% of its original 1.290.000 km² (Varjabedian 2010) remains forested (Rezende et al. 2018). Because of its high degree of endemism and threats, it is considered a global "hotspot" (Mittermeier et al. 2004, Mittermeier et al. 2011, Rezende et al. 2018). This Atlantic Rainforest is heterogeneous in topography and contains five principal relief units in its eastern portion: Serra do Mar, Pré-Litorâneas, Serra da Mantiqueira, Paranapiacaba and Leste Catarinense relief units (IBGE 2016, Rezende et al. 2018). These relief units countains the most significant mountain ranges in northeastern, southeastern and southern Brazil, with highest peak of 2.982 m altitude in Serra da Mantiqueira and 2.230 in Serra do Mar (Bornschein et al. 2016).

The distribution of terrestrial gastropods in mountain habitats is affected by the combination of heterogeneity of topography and microclimate (Solem 1984; Ström 2004). The microclimate in a single mountain may differ along the altitudinal gradient (Solem 1984). The temperature tends to decrease with increase in altitude, reducing from 0,4 to 0,7 ºC for each 100 m of increase in altitude of tropical forests (Walsh 1979) and a reducing 0,56 ºC each 100 m of increase in altitude in mountains of Serra do Mar, southeastern Atlantic Rainforest (Roderjan 1994). In addition, due to the cooling of the air masses that collide with relief, mountainous reliefs can cause orographic rains, resulting in increased condensation and precipitation in the mountaintops (Pellegatti & Galvani 2010). In southeastern Atlantic Rainforest, there is an increase of about 40 mm in the annual mean of precipitation for each 100 m of increase in altitude (Roderjan 1994). These abiotic variations also imply in the formation of different forest habitats along the altitudinal gradient (Solem 1984; Veloso et al. 1991).

These microclimatic particularities of high elevations could have promoted isolation of mountaintop habitats during dry and warmer climates, isolating them from surrounding habitats as islands isolated by water masses (sky islands; sensu Howell [1947] e McCormack et al. [2009]). In Atlantic Rainforest, the isolation of altitudinal habitats may have propitiated the speciation of fauna with low capacity of dispersion, limiting them to a few mountain chains as seen for some groups of birds (e.g., Bornschein et al. 2007; Mata et al. 2009; Maurício et al. 2014; Pulido-Santacruz et al. 2016) and from one or two mountains near to each other, as seen in anurans (Bornschein et al. 2015; 2016; 2019; Ribeiro et al. 2015; 2017; Firkowski et al. 2016; Pie et al. 2018).

Although mountains promote mosaics of patterns of distribution (Solem 1984) and endemism, there are other patterns to be verified for terrestrial gastropods communities. Some of those patterns may also affect mountain environments, such as the decrease of species richness with altitude increase (Stevens 1989; Tattersfield et al. 2001; Müller et al. 2009; Liew et al. 2010; Miranda & Cuezzo 2010), the decrease of species richness with the increase of latitude (Rosenzweig 1995), the increase of richness in intermediate altitudes at montane forests in temperate regions (Labaune & Magnin 2002; Aubry et al. 2005; Hausdorf 2006) and the increase of richness in localities with higher concentration of orographic rains (Tattersfield et al. 2006).

In Atlantic Rainforest mountains, one can expect a diversity gradient inversely proportional to the altitude (Tattesfield et al. 2001; Müller et al. 2009; Liew et al. 2010; Miranda & Cuezzo 2010) and latitude (Hausdorf 2006). It is hyphotetized that the diversity of mountains with lower altitudes behave differentially, showing a similar diversity along with their altitudinal gradient. This could be an answer to the supposed attenuation or absence of the effect of orographic rains in the temperature or pluviosity of mountains of lower altitudes. Intermediate altitudes in mountains with high altitude could have decreased temperature and gains of humidity by the cold and humid airflow in because of of the contact of airmasses in higher altitudes. Furthermore, the distribution of communities of terrestrial gastropods could follow the forest type. With this study, our aim is to estimate the diversity of terrestrial gastropods in the Atlantic Rainforest, and verify if there is patterns on richness, diversity and composition of communities of terrestrial gastropods in the Atlantic Rainforest.

2. Materials and methods

Area of study

We surveyed 27 localities located in mountains or plateaus ("planaltos") of the Atlantic Rainforest from northeastern to southern Brazil (Figure 1). The area studied corresponds to the eastern extension of Atlantic Rainforest in Brazil (12–29ºS), and localities sampled at extreme north and south were separated by 2,200 km in an imaginary straight line. The localities studied are included in the following relief units: Colinas e Cristas Pré-Litorâneas, Serra do Mar and Serras do Leste Catarinense (IBGE 2016; Rezende et al. 2018). The area studied is classified in the regions of "Bahia" and "Serra do Mar" accordingly to Silva & Casteleti (2003), characterized by its faunal endemism and unique biological phenomena (Silva & Casteleti 2003).

Localities sampled are characterized according Koppen's criteria for classifying by the following climates: Af (tropical without dry season) in Bahia state; Cfb (humid subtropical oceanic climatic, without dry season with temperate summer) in the Rio de Janeiro and north São Paulo states; and Cfa (humid subtropical oceanic climatic with no dry season and hot summer) in the south São Paulo, Paraná and Santa Catarina states (Alvares et al. 2013). The mean annual temperature varies from 17–25 ºC throughout the entire region: a mean of 24 ºC in the north (Bahia state); means of 17–22 ºC in the middle (Rio de Janeiro and São Paulo states); and means of 23–25 ºC in the south (Paraná and Santa Catarina states) (Martineli 2010; Wrege et al. 2012; Bahia 2021). From north to south, average annual rainfall varies from 1,500–4,000 mm: from 1600–2000 mm in the north (Bahia state); from 1,500–4,000 mm in the middle (Rio de Janeiro and São Paulo states); and from 1,700–2,400 mm in the south (Paraná and Santa Catarina states) (Martineli 2010; Wrege et al. 2012; Bahia 2021).

We performed sampling in Ombrophilous dense forest (sensu Veloso et al. 1991) in all localities. We sampled localities were this type (accordingly to latitudinal and altitudinal differences) is subdivided as follows: Highland dense ombrophilous forest, in mountains at high altitudes; Montane dense ombrophilous forest in mountains at median altitudes; and Submontane dense ombrophilous forest in mountains at lower altitudes (sensu Veloso et al. 1991). We were cautious to only sample in primary forest, or secondary forest that had been regenerated into a forest stage (see Bornschein et al. 2015).

Samplings

Samples were made in forests of mountaintops or mountain slopes when we could not reach mountain peaks, when mountain peaks were covered by natural grasslands, and when plateaus were at high altitudes. Fieldwork was conducted by teams of two to three people during the rainy and hot months from December 2017 to March 2020 on southeastern and southern Brazil, and in October 2019 (hot early spring) on Bahia state (Table 1). In two localities, one in Bahia state and one on Paraná state, we sampled in the altitudinal gradient, performing samplings at mountaintop, intermediate altitudes and low altitudes above sea level. The samplings at intermediate and low altitudes are identified as I (intermediate altitude) and L (low altitude), after the locality code (Table 1). Data from altitudinal gradient was analyzed separately from mountaintops.

Two methods were applied in different microhabitats to sample terrestrial gastropods (modified from Sólymos et al. [2009a]): litter sampling and visual search. By litter sampling method, we stretched a rope of 30 m and allocated square plots of 50 cm x 50 cm on every 2 m (starting at the second meter), sampling on total 15 square plots by locality. We took care to allocate square plots on the opposite side where we had stepped. Then, we collected all litter inside the squares and stored it in identified plastic packages. To sample by visual search method, we searched for terrestrial gastropods in square plots of 6 m x 6 m, placed on every 10 m of the rope (starting at 10 m and ending at 30 m), sampling in total three square plots by each locality. We spent 30 min searching for gastropods on every microhabitat available (e.g. rocks, dead woods, alive trees, branches, leaves, moss, litter, and tree trunks) up to 2 m in height in each square plot. Live specimens collected were stored in small recipients, identified and separated by square plots and microhabitats.

At each locality, we took measurements of pH, temperature and humidity, as well as descriptions of meteorology and vegetation. We measured pH o/f each sampling twice, one at the beginning of the transect and one at the end at a depth of at least 5 cm in the litter or soil, using a portable pHmeter (SONDATERRA pH 2500; Table 2). A portable thermohygrometer (Datallogger Instrutherm HT-500; Table 1) was used to collect data on air temperature at 30 cm above the soil, as well as the humidity of the litter and air during samplings. We made descriptions of the vegetation type according to Veloso et al. (1991). We also took notes on meteorological descriptions and sampling time (beginning and end) during sampling (Table 2). Coordinates were taken using a Global Positioning System (GPS) device (Garmin Etrex 10; Table 1). Collection permits were provided by ICMBio/SISBIO (#57969-1; 58088-1), Instituto Ambiental do Paraná (#08.17) and Secretaria Estadual do Meio Ambiente/SMA (#260108-003.596/2017).

In laboratory, we carefully inspected each package of litter in search of gastropods. Then, we dry-sieved the litter through a 0.5 mm mesh and examined the retained material carefully under a stereomicroscope in search of smaller shells. Live specimens were photographed, euthanized in distilled water (following Thomé [1975]) and preserved in 95% ethanol. Each shell morphotype was photographed under a stereomicroscope ZEISS Stemi DV4 mounted with a DLSR (Nikon D300S) using a 18-55 mm lens. We identified specimens to the lowest taxonomical level possible based on the coloration while alive, habitat, microhabitat and shell morphology, in association with literature (e.g., Schileyko 1998-2007; Salgado & Coelho 2003; Simone 2006; and Birckolz et al. 2016). We organized names according to Bouchet & Rocroi (2017) and MolluscaBase (2021). Collected specimens will be stored in malacological collections of Museu de Zoologia da Universidade de São Paulo (MZSP), and Museu Nacional do Rio de Janeiro (MNRJ) at the end of analysis.

We calculated mean density of gastropods by liter sampling per package, area (m²) and biomass (kg), as well as method performance and richness extrapolation, those analyzed elsewhere (Capítulo 1).

Statistical Analysis

To perform all analysis, we used the software R Studio 4.0.5 (R Core Team 2020). We considered data from both sampling methods together from each locality. Samples made in intermediate and low altitude were analyzed separately.

We performed Unweighted Pair-Groups Method Average (UPGMA) cluster analysis to elaborate a dendrogram of similarity between localities. The UPGMA group localities by clusters based on the average distance of similarity between all species in the two groups (Hammer 2021). We used the R package vegan (Oksanen et al. 2020) to calculate dissimilarity using the Bray-Curtis (Bray & Curtis 1957) and Jaccard method. The Bray-Curtis method uses abundance and species richness of each locality to generate a comparative pair-to-pair matrix of dissimilarity by Euclidian distance between localities (Hammer 2021). The Jaccard method also generates a pair-to-pair matrix of dissimilarity by Euclidian distance, but only takes account of species richness (Hammer 2021). Based on the matrix generated by the two methods, we performed UPGMA cluster analysis and calculated Cophenetic correlation using the R package stats (R Core Team 2020). Cophenetic correlation calculates the amount of similarity between the matrix generated by cluster analysis and the original matrix of dissimilarity (Clark et al. 2016). The results given by Cophenetic correlation are from 0 to 1, were 1 is interpreted as equal matrices and 0 as totally different matrices (Clark et al. 2016).

To estimate α diversity and heterogeneity of terrestrial gastropod communities, we calculated Shannon Index (H'), Simpson Index (D) and Equitabiliy Index (J) for each locality using the R package vegan (Oksanen et al. 2020). The Shannon index determines the α diversity and is influenced by the number of individuals and species richness recorded on a locality. In this index, the diversity goes from 0 to communities with only one species, to more than 1 for communities with a high number of species (Hammer 2021). The greater the number of species and the more homogeneous (similar number of individuals recorded by species) they are, the greater the diversity (H'). Simpson Index (D) estimates the homogeneity of a sample. In this index, the higher the D value, greater the probability that two randomly selected individuals are of the same species. The Equitability index (J) compares the Shannon Index with the uniformity of individuals belonging to the species registered. This index returns values of 0 to 1, were 0 means that there are species more numerous than others and 1 means that all species collected in a locality have the same abundance.

The β diversity was estimated by Sørensen (β_{SOR}) and Simpson (β_{SIM}) dissimilarity indexes using the R package betapart (Baselga et al. 2021). The Sørensen (β_{SOR}) dissimilarity measures the total beta diversity and incorporates dissimilarities resultants of species replacement and nestedness. The Sørensen (β_{SOR}) index can be decomposted in two components (Baselga et al. 2021): Simpson (β_{SIM}) dissimilarity, which describes species replacement; and nestedness (β_{SNE}), which measures absence of species, given by the equation: $\beta_{SNE} = \beta_{SOR} - \beta_{SIM}$ (Baselga, 2021). Then, we generated a graph with a matrix of comparison pair-to-pair of Sorensen dissimilarity and its components independently for each locality.

We used Pearson correlation (R) to perform correlation analysis on latitudinal and altitudinal approaches. This method measures a linear dependence between two variables (x and y). To both approaches, we used data from diversity (H') or species richness as the y value. To analyze correlation with latitude, we used latitudinal coordinates (UTM) as x value. To analyze correlation with altitude, we used altitude values as x. We analyzed data collected on altitudinal gradient separately, comparing altitudes of the same locality. To perform the analysis, we used the R package ggpubr (Kassambara 2020). In Pearson correlation, correlations can be either positive or negative, and the correlation is expressed by values of R from -1 to 1, were -1 is the perfect negative correlation and 1 is the perfect positive correlation (Hammer 2021). We only considered as significant values of R with $p < 0.05$.

3. Results

We made a total of 31 samplings on the 27 localities (Table 1). Combining litter sampling and visual searching methods, we sampled in total 3,464.25 m², of which 116.25 m² was made by litter sampling method (3.75 m² each sampling) and 3,348 m² by visual search method (108 m² each sampling). We sampled mountaintops of 540 m to 1800 m above sea level (a.s.l.), and of 161 m to 644 m in samples at intermediate and low altitude (Table 2).

We obtained 1868 individuals of terrestrial gastropods by both methods combined (1,653 by litter sampling, and 215 by visual searching method), those belonging to 71 species, divided on 11 families (APPENDIX 1). Of those, 60.5% of species were divided on three families: Scolodontidae (18 species), followed by Charopidae (14 species) and Helicinidae (11 species). All species encountered were native, with exception of the exotic invasive slug *Meghimatium pictum* (Stoliczka, 1873), found in Morro do Boa Vista (locality 11) and Morro do Spitzkopf (locality 17; Table 4).

Three families were dominant in our samples, represented by 54.5 % of the individuals of terrestrial gastropods collected on our study. The family Scolodontidae was the family with the highest number of individuals, represented by 43.1% of the total individuals. Subsequently, Charopidae was the second family with highest individuals, represented by 18% of the total individuals. The family Euconulidae, with only the specie *Habroconus semenlini* (S. Moricand, 1846), was represented by 6.8% of total individuals.

Around 70.4% (n = 50 species) of species of terrestrial gastropods registered were exclusive from one or two localities sampled (Figure 2). The other 21 species were distributed on three to 14 localities. Amongst them, the species distributed on the higher number of localities were *Miradiscops* sp. (14 localities), *Habroconus semenlini* (12 localities) and *Simpulopsis* sp. 2 (11 localities).

We observed differences in structures of terrestrial gastropod communities in Atlantic Rainforest and classified them as follow: Mid-montane, Upper-montane and Highland. Mid-montane communities occur in Submontane and Montane dense ombrophilous forest from 200 m to 775 m a.s.l. and have at least two or more species of families Helicinidae, Charopidae and Simpulopsidae, mostly represented by gastropods with shell of more than 5 mm. Other families as Scolodontidae, Streptaxidae, Diplommatinidae and Bulimulidae may be recorded as well, but in lower abundance. The Upper-montane communities occur in Montane dense ombrophilous forest from 775 m to 990 m a.s.l. and have predominance of families Scolodontidae, Simpulopsidae and Charopidae, with one or two species representing each family, mostly represented by microgastropods. Other families may occur but are rare. Highland communities occurs in either Montane dense ombrophilous forest or Highland dense ombrophilous forest in altitudes above 990 m a.s.l. Families Scolodontidae and Charopidae as predominant in Highland communities, with representatives of one or two species each family by locality, commonly microgastropods. Other families may also occur but are rare. Considering data collected at intermediate and low altitudes, we found nine localities with Mid-montane communities, seven localities with Upper-montane communities and thirteen localities with Highland communities. Two localities have not followed this classification: locality 06 which occurred in the altitudinal range of Upper-montane and their community act as a Mid-montane, and locality 23, which presented a community different from those of mountains.

UPGMA cluster analysis (Figures 3 and 4) revealed that most localities had singular terrestrial gastropod communities, and the Euclidian distance between localities were from 0.6–1 by Jaccard method (cophenetic correlation 0.7627) and 0.4–1 by the Bray-Curtis method (cophenetic correlation 0.7653). Only one group with Euclidian distance by Jaccard method of less than 0.7 was found, uniting localities Trilha do Ipiranga (locality 02) and Serra da Bocaina (locality 23). The same group was encountered through Bray Curtis metho, with Euclidian distance of 0.4. By the Bray-Curtis method, we found seven groups with Euclidian distance of less than 0.6. We identified the localities with groups from A to G (Figure 4), most with distance of no more than 80 km from each other. The comparison of the two methods of UPGMA (Figure 5) showed that both methods had five consistent groups, mixing localities of the three relief units (Figure 5). In both methods the locality Serra da Jiboia (locality 26) has been placed as an outgroup.

The diversity values obtained with Shannon index (H') ranged from 0–2.224 (Table 4). The most diverse localities were Serra da Jiboia (locality 26; H' = 2.224) and Morro Santo Anjo (locality 12; H' = 2.192). These two localities also had lower homogeneity (D = 0.120 and D = 0.136, respectively). In the same way, the less diverse localities were Morro Cuscuzeiro (locality 01; H' = 0) and Morro do Schmidt (locality 15; H' = 0) had higher homogeneity (D = 1).

The values calculated for the Equitability Index (J) ranged from 0.371–0.975 (Table 4). The localities with higher equitability were Pico Paraná (locality 13; J = 0.975) and Caratuva (locality 22; J = 0.966). The localities with lower equitability were Serra do Araçatuba (locality 20; J = 0.371) and Pico do Baepi (locality 25; J = 0.403).

In our analysis of Beta diversity, we found values of Sorensen dissimilarity of β_{SOR} 0.38–1.00 (Figure 3). We found high dissimilarities between localities, mostly decurrent of species turnover, with values of Simpson dissimilarity of β_{SIM} 0–1. However, for the localities Morro do Cuscuzeiro (locality 01) and Morro do Schmidt, most of the dissimilarity with other localities were caused by nestedness (β_{SNE} of 0–0.83; Figure 3).

We found no correlation between latitude and diversity. By testing correlation between species richness and latitude, we found a R = 0.19 (p = 0.35; Figure7). By testing correlation between latitude and alpha diversity, we found a R = 0.22 (p = 0.27). Although the line had a degree of inclination in both tests performed, it was not significative ($p < 0.05$).

We sampled two localities in order to analyze species richness and diversity in the altitudinal gradient: Serra da Igreja (locality 21), localized in Paraná state, Brazil; and Serra Bonita (locality 27), localized in Bahia state, Brazil. When analyzing correlation between altitude and species richness or diversity, we found no correlation in these localities ($p > 0.05$; Figure 8 and 9). Nonetheless, we found a higher species richness and diversity at intermediate altitudes (Figure 5). Although we found no correlation in a local scale, we found a negative correlation between species richness and altitude amongst mountaintops (R = -0.47, p = 0.014; Figure 10).

4. Discussion

In this study, we found a species richness higher than other studies realized on South America (Nunes & Santos 2021, Santos & Monteiro 2001, Gregoric et al. 2013, Salvador et al. 2018; Miranda & Cuezzo 2010; Oroño et al. 2007), but a number of individuals inferior than studies realized in the Yungas Argentinas (Miranda & Cuezzo 2010; Oroño et al. 2007). On each one of the 31 samplings, we studied around 111.75 m², a bigger area than other studies realized in South American (Atlantic Rainforest: Nunes & Santos 2021, Santos & Monteiro 2001, Gregoric et al. 2013, Salvador et al. 2018; Yungas Argentinas: Oroño et al. 2007; Miranda & Cuezzo 2010; see Capitulo 1, Table 1). We obtained number of species compatible with expected richness in sixteen localities by litter sampling method and four by visual searching method (Capitulo 1). Since there was no other study made previously in Atlantic Rainforest mountains, we used all data, including those localities that did not reached expected richness (41% of all localities).

The most speciose families of terrestrial gastropods in our study were Scolodontidae (16 species) and Charopidae (14 species). The family Scolodontidae is the predominant family on inventories made on northern South America (Ramirez et al. 1999 and Ramirez et al. 2003), while the Charopidae family is the dominant and most speciose family of the southern hemisphere (Oroño et al. 2007, see also Miranda & Cuezzo 2010 and Gregoric 2013). On our study, we found that Scolodontidae were predominant at our southern localities and Charopidae at our northern localities, contrary of what was found in the literature (Ramirez et al. 1999, Ramirez et al. 2003, Oroño et al. 2007, see also Miranda & Cuezzo 2010 and Gregoric 2013).

We found a high rate of species turnover between localities, and Scolodontidae was the family with most species exclusive of a single locality (n = 9) or of two localities (n = 3). Most of those exclusive species occurred in the southern portion of the relief unit Serra do Mar and of Leste Catarinense. Other families with a high number of species observed with limited geographic distribution were Helicinidae (n = 11), Charopidae (n = 8) and Simpulopsidae (n = 8). Our observations converge with the speciation pattern observed for toadlets of the genus *Brachycephalus*, were some species have distributions of one to two mountains near to each other in highland forests (e. g. Pie et al. 2013, Bornschein et al. 2016b, Firkowski et al. 2016). The isolation of altitudinal habitats may have propitiated the speciation by vicariance, and the climatic fluctuations may have promoted the isolation of highland forests, once continuous on lower altitudes, now are isolated on mountaintops (Bornschein et al., 2016b, Firkowski et al., 2016) as *sky islands* (sensu Howell, 1947, McCormack et al., 2009). Although the species of terrestrial gastropods encountered with small distribution were not only microgastropods, they were also small (shell of until 12 mm diameter) and with supposed low dispersion capacity. These characteristics could have made them dependents of specific conditions of higher altitudes.

We found similar structures in communities of gastropods occurring in the same locality and forest type. However, gastropod communities does not necessarily follows the forest type. Highland communities were the only exclusive to Highland dense ombrophilous forest, whilst Mid-montane may occur either in Submontane dense ombrophilous forest or Montane dense ombrophilous forest, and Upper-montane occurs only in elevated altitudes of Montane dense ombrophilous forest. The differences in communities of elevated altitudes may be related to the microclimate of mountaintops, with orographic rains, decrease in temperature (Roderjan, 1994) and higher exposition to sun radiation. Comparatively with mid-montane localities, we found lower diversity, reported in other studies. (Stevens 1989; Tattersfield et al. 2001; Müller et al. 2009; Liew et al. 2010; Miranda & Cuezzo 2010).

The UPGMA reflected a high geographic proximity of some localities. Group A is consisted of localities in south of Serra do Mar relief unit and north of Serras do Leste Catarinense, with a distance of 57 km in a straight line between both localities. Group B is consisted of localities (localities 08 and 07) in Serra da Baitaca, state of paraná. Group C is consisted by localities in Serra do Mar (localities 02 and 03) and Serra da Bocaina (locality 23), both regions are 80 km distant from each other. Although the distance in comparative with other groupments, these three localities were the ones with Euclidian distance in both methods of UPGMA. Groups E and F were consisted of localities in Serras do Leste Catarinense relief unit, with no more than 28 km of distance between themselves in a straight line. Group G is consisted of localities in Serra dos Órgãos and Serra da Igreja, both regions only 41,34 km distant from each other. The two localities of Ilhabela island (Table 1, Figure 1), Pico São Sebastião (locality 04) and Pico do Baepi (locality 25) showed distinct species of terrestrial gastropods, indicating very different fauna on each side of the island. By the UPGMA cluster analysis, these two localities were more similar to localities further south than to each other (Figure 4). The locality of north portion of ilhabela, Pico do Baepi was grouped with a locality at north of Santa Catarina, and both localities were 472.73 km distant from each other. The locality of south Ilhabela, Pico São Sebastião, was grouped with the localities in Serra da Baitaca, state of Paraná, both regions 407.81 km distant from each other. However, the different fauna composition of both sides of the island could be related to differences in atmospheric temperature, litter depth, soil temperature and relative air humidity (Nunes & Santos 2012). In both methods of UPGMA Serra da Jiboia (locality 26) was left as an outgroup. In this locality, there is a transition with deciduous seasonal forest at its north portion and narrow strips of rupestrian fields with typical vegetation at higher altitudes (Queiroz et al. 1996, Sobrinho & Queiroz 2005). The singularity of the forest and dysconnectivity with other localities may have been the reason for the unique herpetofauna (Freitas et al. 2018) and also a unique community of terrestrial gastropods.

We found a mean alfa diversity lower than studies realized in Yungas Argentinas (H’ ± 2,35 in Oroño et al., 2007; H’ ± 1,95 in Miranda & Cuezzo, 201, H’ ± 1.19 in our study). In our study, we also found fewer individuals and species by locality than those studies, indicating that communities of terrestrial gastropods of Atlantic Rainforest are less abundant than those of Yungas Argentinas. This could be caused because of the higher altitudinal range studied in work in comparison: we sampled localities from 540 m to 1800 m a.s.l., while these studies sampled from 450 m a.s.l. to 1460 m a.s.l. (Oroño et al. 2007) and 770 m a.s.l. to 1175 m a.s.l (Miranda & Cuezzo, 2010).

In the two localities sampled in the altitudinal gradient, we observed a higher species richness and diversity at intermediate altitudes, pattern found in works on temperate regions (Labaune & Magnin 2002, Aubry et al. 2005, Hausdorf 2006) and different from other studies realized in South America (Oroño et al. 2007, Miranda & Cuezzo 2010). Although we did not find a correlation with diversity and altitude locally, we found a negative correlation between diversity and altitude amongst mountaintops, observed on other mountain studies (Rahbek 1995, Hausdorf 2003; Oroño et al. 2007; Muratov et al. 2012).

For many groups of organisms, the amount of species richness in communities is higher in the tropics and diminish with increase latitude (Rosenzweig 1995). We found no correlation between latitude and species richness nor latitude and diversity in our study with terrestrial gastropods. The analysis could have not shown this relationship because our sampling extension was not bigger enough in terms of geographic extension, and very heterogeneous in altitude. not enough in terms of localities because of gaps in geographic range and very heterogeneous in relation to altitude. To fill these gaps, more projects in order to investigate localities never sampled before are needed.

5. Conclusions

We found a negative correlation between richness and altitude of terrestrial gastropods in mountaintops of Atlantic Rainforest. Intermediate altitudes had a higher richness, pattern equal to studies performed in temperate regions. However, we did found and relationship within latitude or altitude and diversity.

We observed changes in communities of terrestrial gastropods through altitude and forest type, and were able to characterize three types of communities occurring in mountains of Atlantic Rainforest: mid-montane (Submontane and Montane dense ombrophilous forest up to 775 m a.s.l.), upper-montane (Montane dense ombrophilous forest from 775 m to 990 m a.s.l.) and highland (Highland dense ombrophilous forest above 990 m). However, this classification considers the mountain slope and localities in plateaus or flat terrains should be analyzed differently. Although we similar community structures, we found a high rate of species turnover when comparing localities. We recorded species of families Scoldontidae, Helicinidae and Charopidae limited to one or two localities in mountains in the relief of Serra do Mar and Leste Catarinense, which may have been acting as a speciation center to these groups. As our studies in terrestrial gastropods in Atlantic Rainforest are still scarce, we recommend that future studies should be focused in filling sampling gaps in order to understand the group diversity in the biome.

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TABLES WITH CAPTIONS

Table 1. Localities sampled and sampling conditions for terrestrial gastropods in mountains of the Atlantic Rainforest of northeastern to southern Brazil. Localities are arranged by chronological order of sample. Hour refers to the beginning of the sample. Code of localities in bold indicates localities sampled in three different altitudes.

Code	Locality	Sample date	Hour	Temperature °C	Humidity (%)	Weather observations
1	Morro Cuscuzeiro (23°17’59’’S, 44°47’12’’W), municipality of Paraty, state of Rio de Janeiro, and municipality of Ubatuba, state of São Paulo	12/12/2017	16:00	13.0 / 21.0	73 / ---	Constant and light rain during the sample.
2	Trilha do Ipiranga (23°20’41’’S, 45°08’21’’W), Núcleo Santa Virgínia, Parque Estadual da Serra do Mar, municipality of São Luiz do Paraitinga, state of São Paulo	12/18/2017	18:20	---	55	Cloudy. It rained hours before the sample.
3	Morro do Corcovado (23°27’07’’S, 45°12’03’’W), Parque Estadual da Serra do Mar, municipality of Ubatuba, state of São Paulo	12/14/2017	12:20	16.5 / 19.0	60 / ---	Cloudy, without rain in sight.
4	Pico São Sebastião (23°52’09’’S, 45°22’51’’W), Parque Estadual de Ilhabela, municipality of Ilhabela, state of São Paulo	12/16/2017	14:10	21.5	70	Sunny, with dry leaf litter and vegetation.
5	Torre Embratel (24°52’46’’S, 48°15’27’’W), Parque Estadual do Rio Turvo, municipality of Cajati, state of São Paulo	01/27/2018	15:30	16.3–19.4 / ---	78 / 78	Cloudy, with wet vegetation.
6	Serra Pelada (24°58’49’’S, 48°28’43’’W), municipality of Barra do Turvo, state of São Paulo	02/04/2018	14:00	15.2–17.5	70	Sunny during the morning, cloudy during the sample.

Code	Locality	Sample date	Hour	Temperature °C	Humidity (%)	Weather observations
7	Morro Anhangava (25°23’16’’S, 49°00’15’’W), Serra da Baitaca, municipality of Quatro Barras, state of Paraná	02/13/2018	13:10	13.0–14.0	77	Constant and light rain, with strong winds.
8	Estância Hidroclimática Recreio da Serra (25°27’22’’S, 49°00’16’’W), municipality of Piraquara, state of Paraná	01/19/2018	12:40	22.0–23.5	77	Cloudy before the sample, sunny during the sample.
9	Morro dos Perdidos (25°53’11’’S, 48°57’32’’W), municipality of Guaratuba, state of Paraná	01/13/2018	09:00	22.0–23.3	83	Strong winds with fog and light rain in the begginning of the sample. Cloudy and windless from the middle to the end of the sample.
10	Morro Garuva (26°02’35’’S, 48°53’38’’W), municipality of Garuva, state of Santa Catarina	02/10/2018	15:00	25.8	59	Sunny, with dry leaf litter and vegetation.
11	Morro Boa Vista (26°30’58’’S, 49°03’10’’W), boundary of the municipalities of Jaraguá do Sul and Massaranduba, state of Santa Catarina	01/13/2018	16:30	23.7–24.7 / 19.5	71 / 100	Sunny at the begginning of the sample, cloudy from the middle to the end.
12	Morro Santo Anjo (26°37’43’’S, 48°55’49’’W), municipality of Massaranduba, state of Santa Catarina	01/14/2018	11:40	26.0 / 20.7	64 / ---	Sunny
13	Pico Paraná (25°15’10’’S, 48°48’28’’W), municipality of Antonina, state of Paraná	11/10/2018	15:50	15.5–17.3	100	Cloudy, windless. It rained during two days after the sample.
14	Serra do Pico (26°08’32’’S, 48°57’19’’W), municipality of Joinville, state of Santa Catarina	12/18/2018	11:40	26.5–28.0	---	Cloudy and windless during all day.
15	Morro do Schmidt (26°39’55’’S, 49°12’55’’W), municipality of Pomerode, state of Santa Catarina	12/19/2018	11:20	21.6–24.7	---	Cloudy, windless.

Code	Locality	Sample date	Hour	Temperature °C	Humidity (%)	Weather observations
16	Morro do Cachorro (26°46’42’’S, 49°01’57’’W), boundary of the municipalities of Blumenau, Gaspar, and Luiz Alvez, state of Santa Catarina	12/20/2018	10:50	26.0	99	Cloudy.
17	Morro do Spitzkopf (27°01’32’’S, 49°07’49’’W), municipality of Blumenau, state of Santa Catarina	02/03/2019	12:10	19.3	96	Cloud, wth wind.
18	Morro Spitz (26°52’03’’S, 49°24’02’’W), municipality of Blumenau, state of Santa Catarina	02/04/2019	10:20	18.4–18.6	93	Cloudy during the morning, sunny during the samples.
19	Morro Braço da Onça (26°44’58’’S, 48°55’41’’W), municipality of Luiz Alvez, state of Santa Catarina	12/22/2018	08:20	22.0	85	Cloudy. It rained the day before the sample.
20	Serra do Araçatuba (25°54’06’’S, 48°59’42’’W), municipality of Tijucas do Sul, state of Paraná	03/02/2019	15:50	17.9–18.8 / 23.5	84 / ---	Sunny during the sample, with clouds at the mountaintop during the morning. Very wet.
21	Morro dos Padres (25°36’40’’S, 48°51’24’’W), Serra da Igreja, municipality of Morretes, state of Paraná	03/03/2019	16:50	19.9 / 17.3–19.8	82 / 70	Cloudy during the sample, wet vegetation. It rained at the late afternoon.
21I	Viaduto dos Padres (25°56'26"S, 48°52'25"O) Serra da Igreja, municipality of Morretes, state of Paraná	10/03/2020	09:30	---	92	Cloudy during the morning, sunny during the sample.
21L	Serra da Igreja (25°34'05"S, 48°47'17"O) Serra da Igreja, municipality of Morretes, state of Paraná	11/03/2020	11:40	---	86	Sunny, with dry leaf litter and veetation.

Code	Locality	Sample date	Hour	Temperature °C	Humidity (%)	Weather observations
22	Caratuva (25°14’25’’S, 48°49’51’’W), municipality of Campina Grande do Sul, state of Paraná	03/06/2019	11:53	20.0	85	Cloudy, windy.
23	Serra da Bocaina (22°44’28’’S, 44°39’20’’W), municipality of São Luís do Paraitinga, state of São Paulo	03/27/2019	08:50	---	82	Cloudy.
24	Trilha do Rio Bonito (23°14’33’’S, 45°00’58’’W), Parque Estadual da Serra do Mar, Núcleo Cunha, municipality of Cunha, state of São Paulo	03/29/2019	08:10	17.0	100	Cloudy, with light rain during the sample. It had rained the night before.
25	Pico do Baepi (23°47’36’’S, 45°19’55’’W), Parque Estadual de Ilhabela, municipality of Ilhabela, state of São Paulo	04/02/2019	15:10	21.0	---	Sunny, windy, with dry superficial leaf litter and vegetation.
26	Serra da Jibóia (12°51’21’’S, 39°28’34’’W), municipality of Varzedo, state of Bahia	08/02/2019	14:00	19.5–20.0	80	Sunny, wet vegetation.
27	Serra Bonita (15°23’28’’S, 39°33’59’’W), Reserva Serra Bonita, municipality of Camacãn, state of Bahia	08/10/2019	16:35	16.3–18.2	96	Sunny during the sample, but it has rained every day in the past two weeks.
27I	Serra Bonita (meia altura; 15°23'11"S, 39°33'27"O), Reserva Serra Bonita, municipality of Camacãn, state of Bahia	08/08/2019	14:00	20.4–21.4	87	Sunny during the sample, but it has rained every day in the past two weeks.
27L	Serra Bonita (base da montanha; 15°27'36"S, 39°32'44"O), , municipality of Camacãn, state of Bahia	10/08/2019	16:00	23.3	79	Sunny during the sample, but it has rained every day in the past two weeks.

Table 2. Characterization of localities sampled for terrestrial gastropods in mountains of the Atlantic Rainforest of northeastern to southern Brazil. Altitude is presented as meters above sea level (a.s.l.). Two localities were sampled in intermediate and low altitudes, identified as I for intermediate and L for low altitude. Abundance classes for bromeliads observed on a 36 m² square plot are as follows: a few 10 individuals; abundant = 11–29 individuals; very abundant 30 individuals. Soil pH were obtained at 5 cm of depth in soil or litter. See table 1 for toponymy and localization of localities. Abbreviations: Y = yes, N = no.

Locality code	Altitude (m a.s.l.)	Forest type[1]	Presence of bromeliads	Presence of bamboos	Soil pH
01	1140	Highland dense ombrophilous forest	Epiphytes (abundant)	Y	2.0; 2.5
02	940	Montane dense ombrophilous forest (secondary forest)	Epiphytes (few) and terrestrials (abundant)	N	6.8; 7.0
03	1050	Montane dense ombrophilous forest	Epiphytes (few) and terrestrials (abundant)	N	1.2; 1.4
04	1070	Montane dense ombrophilous forest	Epiphytes (few) and terrestrials (abundant)	N	6.7; 6.9
05	990	Montane dense ombrophilous forest	Epiphytes (abundant) and terrestrials (very abundant)	N	6.1; 6.2
06	1140	Transition between Highland and Montane dense ombrophilous forest	Epiphytes (few) and terrestrials (few)	Y	5.8; 7.0
07	1400	Highland dense ombrophilous forest	Epiphytes (few) and terrestrials	N	5.9; 6.4
08	1210	Transition between Highland and Montane dense ombrophilous forest	Epiphytes (few) and terrestrials (few)	Y	5.3; 6.2
09	1350	Montane dense ombrophilous forest	Epiphytes (few)	Y	6.8; 7.0

Locality code	Altitude (m a.s.l.)	Forest type[1]	Presence of bromeliads	Presence of bamboos	Soil pH
10	750	Montane dense ombrophilous forest	Epiphytes (very abundant) and terrestrials (very abundant)	Y	6.6; 6.9
11	780	Montane dense ombrophilous forest	Epiphytes and terrestrials (few)	N	6.9; 4.2
12	540	Montane dense ombrophilous forest	Epiphytes (few)	N	---
13	1800	Highland dense ombrophilous forest	Epiphytes (few)	Y	---
14	705	Montane dense ombrophilous forest	Epiphytes (few)	N	6.2; 6.9
15	847	Montane dense ombrophilous forest	Epiphytes (very abundant)	Y	6.2; 6.9
16	775	Montane dense ombrophilous forest	Epiphytes and terrestrials (very abundant)	N	6.2; 6.8
17	839	Montane dense ombrophilous forest	Epiphytes (few)	N	5.2; 6.4
18	916	Montane dense ombrophilous forest	Epiphytes (few)	N	6.0; 6.4
19	534	Montane dense ombrophilous forest	Epiphytes (few)	N	6.0; 6.8
20	1627	Highland dense ombrophilous forest	Epiphytes (few)	Y	6.0; 6.8
21	1280	Highland dense ombrophilous forest	Epiphytes (few)	Y	6.2; 6.8
21I	644	Montane dense ombrophilous forest	Epiphytes (few) and terrestrials (few)	N	---
21L	161	Submontane dense ombrophilous forest	Epiphytes (few)	N	---

Locality code	Altitude (m a.s.l.)	Forest type[1]	Presence of bromeliads	Presence of bamboos	Soil pH
22	1795	Highland dense ombrophilous forest	Epiphytes (very abundant) and terrestrials (few)	Y	6.9; 7.0
23	1658	Montane dense ombrophilous forest	Epiphytes (few)	Y	---
24	1193	Montane dense ombrophilous forest	Epiphytes (few)	N	5.8; 6.6
25	999	Montane dense ombrophilous forest	Epiphytes (very abundant) and terrestrials	N	5.8; 7.0
26	802	Montane dense ombrophilous forest	Epiphytes (very abundant)	N	2.0
27	906	Montane dense ombrophilous forest	Epiphytes (very abundant)	N	4.5
27I	443	Submontane dense ombrophilous forest	Epiphytes (very abundant)	N	5.8
27L	208	Submontane dense ombrophilous forest (secondary)	Epiphytes (very abundant)	N	6.5

Table 3. Matrix of terrestrial gastropods collected and localities sampled in mountains of the Atlantic Rainforest of northeastern to southern Brazil. Family arrangements and order of species according to MolluscaBase (2021). See Table 1 for toponymy of localities.

Species/Localities[1]	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	21I	21L	22	23	24	25	26	27	27I	27L
Adelopoma brasiliense	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17	0	0	0	0	0	0	0	0	0	0
Adelopoma paulistanum	0	0	0	5	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Adelopoma sp.	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Alcadia aff. *hirsuta*	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Alcadia sp. 1	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Alcadia sp.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Helicina cf. *iguapensis*	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Helicina cf. *inaequistrata*	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Helicina schereri	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Helicina sp.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	0	0	0	0	0	0	0	0
Helicina sp. 3	0	0	0	0	0	0	0	0	0	0	0	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Helicina sp. 4	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Helicina sp. 5	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Helicina sp. 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
Helicinidae 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	2	2	0
Subulinidae 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Streptaxidae 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Streptaxidae 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0
Streptaxis hylephitus	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Streptaxis pfeifferi	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Meghimatium pictum	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Habroconus semenlini	0	8	3	0	0	0	0	5	0	2	2	53	0	9	0	22	0	0	1	0	0	0	0	0	2	0	1	0	20	35	127
Megalobulimus lopesi	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bulimulidae 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	5	0	0	2

Species/Localities[1]	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	21I	21L	22	23	24	25	26	27	27I	27L
Bulimulus sp.	0	0	0	0	7	0	0	0	0	0	0	0	0	3	0	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bulimulus sp.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23	9
Odontostomus sp.	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aposculatus atlanticus	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eudioptus sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
Eudioptus sp.2	0	0	0	0	0	0	0	0	0	0	3	1	0	0	0	0	0	1	0	0	0	0	0	5	0	0	0	0	0	0	0
Rhinus sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0
Rhinus sp.2	0	0	0	0	1	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	2	9	0	0	0	0	0	0	0	0
Simpulopsis ovata	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Simpulopsis rufovirens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0
Simpulopsis sp. 1	0	0	0	0	0	3	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Simpulopsis sp. 2	0	1	0	1	6	1	1	1	8	4	0	7	0	0	0	0	6	0	1	0	0	3	0	0	0	0	0	0	0	0	0
Simpulopsis sp. 3	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	0	0	0	0	0
Simpulopsis sp.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0
Simpulopsis sulculosa	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Happia sp. 1	0	7	1	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	67	0	0	0	0	0	0
Happia sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	6
Happia sp. 3	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Happia vitrina	0	0	0	0	0	0	0	0	0	0	0	51	0	0	0	24	0	0	0	0	0	4	23	0	0	0	0	0	0	26	50
Happiella sp. 1	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Happiella sp. 2	0	0	0	0	17	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Happiella sp. 3	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	13	0	0	0	0	0	0	0	0	0	0	0
Happiella sp. 4	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0
Miradiscops sp.	0	4	0	3	21	0	2	3	0	0	2	0	0	0	2	0	11	1	0	0	4	9	50	0	25	0	2	0	2	1	0
Scolodonta sp. 1	0	0	0	0	26	0	0	0	0	0	39	0	0	3	0	0	22	0	7	0	0	0	0	0	0	0	24	0	0	0	0
Scolodonta sp. 2	0	0	0	0	0	0	0	0	0	0	0	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scolodonta sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0

Species/Localities[1]	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**21I**	**21L**	**22**	**23**	**24**	**25**	**26**	**27**	**27I**	**27L**
Scolodonta sp. 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scolodonta sp. 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0
Scolodonta sp. 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	130	23
Tamayoa banghaasi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamayoa sp.1	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	9	0	0	0	0	0	0	0	0	8	0	0	0	0	0
Tamayoa sp.2	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lilloiconcha gordurasensis	0	0	0	0	8	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lilloiconcha sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0
Lilloiconcha sp. 2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lilloiconcha sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	1	1	5	0	3	0	0	0	0	0	0	0
Lilloiconcha superba	0	0	0	0	0	0	0	0	0	0	0	52	0	0	0	15	41	0	0	0	0	0	0	0	31	0	0	0	0	0	0
Radiodiscus costeliffer	2	5	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	27	0	0	0	0	0	0
Radiodiscus promatensis	0	0	0	0	0	0	0	0	0	0	2	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Radiodiscus sp. 1	0	0	0	1	0	0	1	5	0	0	0	0	0	0	0	1	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Radiodiscus sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0
Radiodiscus sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	3	69	7
Radiodiscus sp. 4	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rotadiscus sp. 2	0	0	0	0	0	0	0	0	0	0	0	26	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zilchogyra sp.1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	1	4	7	0	0	0	0	0	0	0	0
Zilchogyra sp.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0
Total individuals	2	28	4	19	97	41	11	22	10	9	60	276	27	19	2	76	196	8	23	14	23	28	103	14	170	12	28	51	34	293	224
Total species	1	6	2	7	11	9	5	6	2	5	8	14	2	5	1	7	9	3	6	2	4	7	7	3	7	3	4	11	6	8	7

[1]Localities with I and L indicate intermediate and low altitudes. See Table 1 for more information.

Table 4. Calculated values of Shannon Index (H'), Simpson (D) and equitability (J) of gastropod communities of each sampled locality in Atlantic Rainforest of northeast and southern Brazil. See table 1 for toponymy and localization of localities.

Locality code[1]	Simpson (D)	Shannon (H)	Equitability (J)
01	0	0	
02	0.7908	1.648	0.92
03	0.75	0.5623	0.8113
04	0.8199	1.809	0.9297
05	0.8296	1.978	0.825
06	0.8031	1.816	0.8264
07	0.7107	1.414	0.8787
08	0.7727	1.591	0.8877
09	0.32	0.5004	0.7219
10	0.716	1.427	0.8867
11	0.5433	1.205	0.5795
12	0.8643	2.192	0.8304
13	0.4829	0.6759	0.9751
14	0.7036	1.411	0.8766
15	0	0	---
16	0.7587	1.558	0.8009
17	0.8045	1.843	0.8387
18	0.4063	0.7356	0.6696
19	0.6654	1.336	0.7457
20	0.1327	0.2573	0.3712
21	0.4197	0.8003	0.5773
21I	0.7841	1.816	0.8263
21L	0.631	1.344	0.6464
22	0.6429	1.061	0.9657
23	0.7554	1.578	0.8111
24	0.4861	0.824	0.75
25	0.2577	0.5586	0.403
26	0.8804	2.224	0.9274
27	0.6318	1.346	0.7512
27I	0.7188	1.512	0.7272
27L	0.6148	1.267	0.651

[1]Localities with I and L indicate intermediate and low altitudes. See Table 1 for more information.

FIGURES WITH CAPTIONS

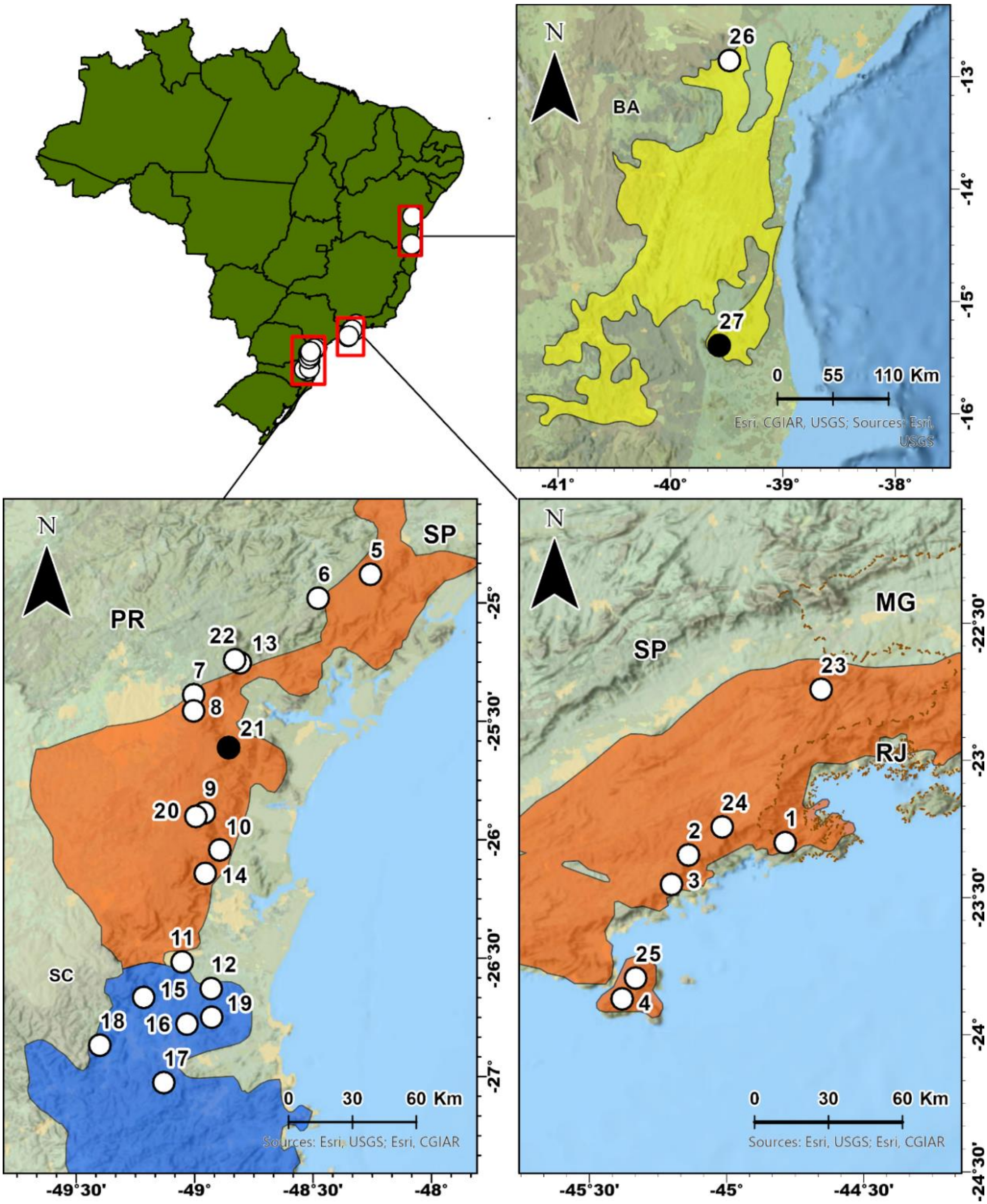


Figure 1. Map showing localities sampled in search of terrestrial gastropods in the mountains of the Atlantic Rainforest of northeastern to southern Brazil. Polygons represent relief units according to IBGE (2016): Yellow = Colinas e Cristas Pré-Litorâneas, Orange = Serra do Mar, Blue = Serras do Leste Catarinense. Black dots represent localities with samples in three different altitudes above sea leve. Abbreviations: BA = Bahia, MG = Minas Gerais, RJ = Rio de Janeiro, SP = São Paulo, PR = Paraná, SC = Santa Catarina. Polygons were provided by IBGE. Image sources: Environmental System Research Institute (Esri), Urban Green Space (UGS) and Instituo Brasileiro de Geografia e Estatística (IBGE).

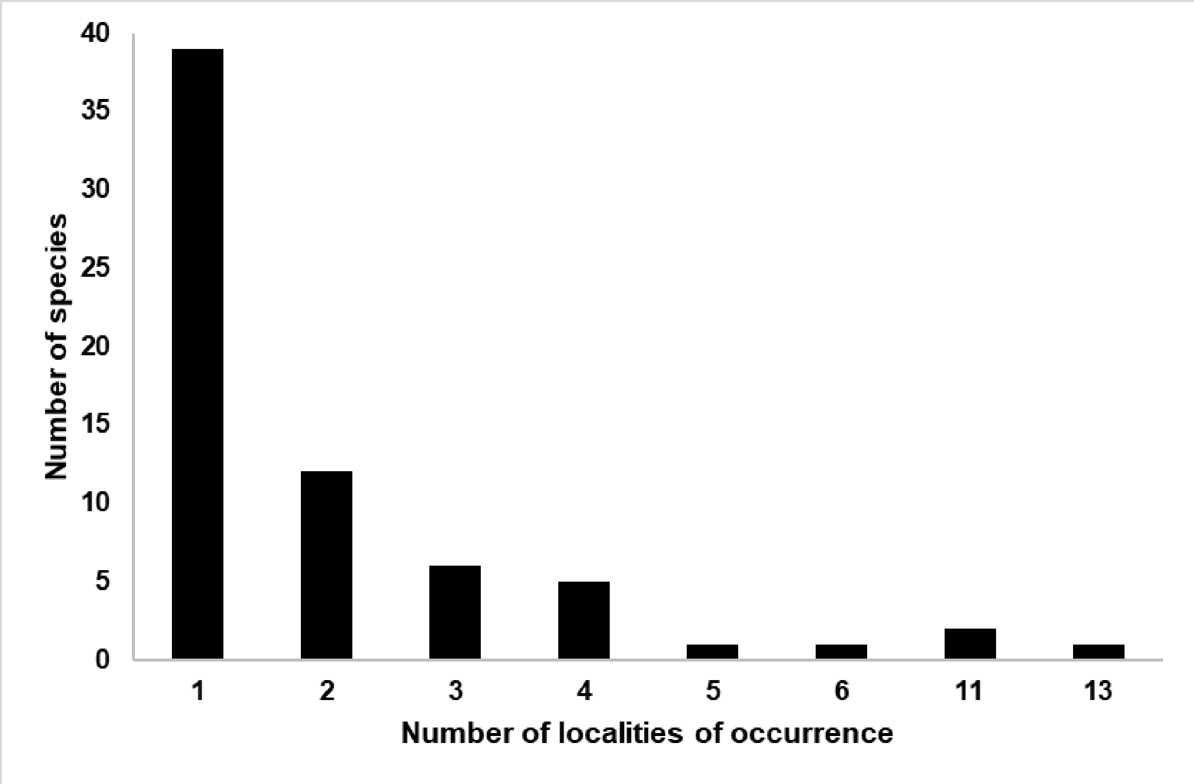


Figure 2. Number of terrestrial gastropod species by the number of localities they occur in mountaintops of Atlantic Rainforest from northeast to southern Brazil. See Table 1 for information about localities. See Table 3 and 4 for information about species.

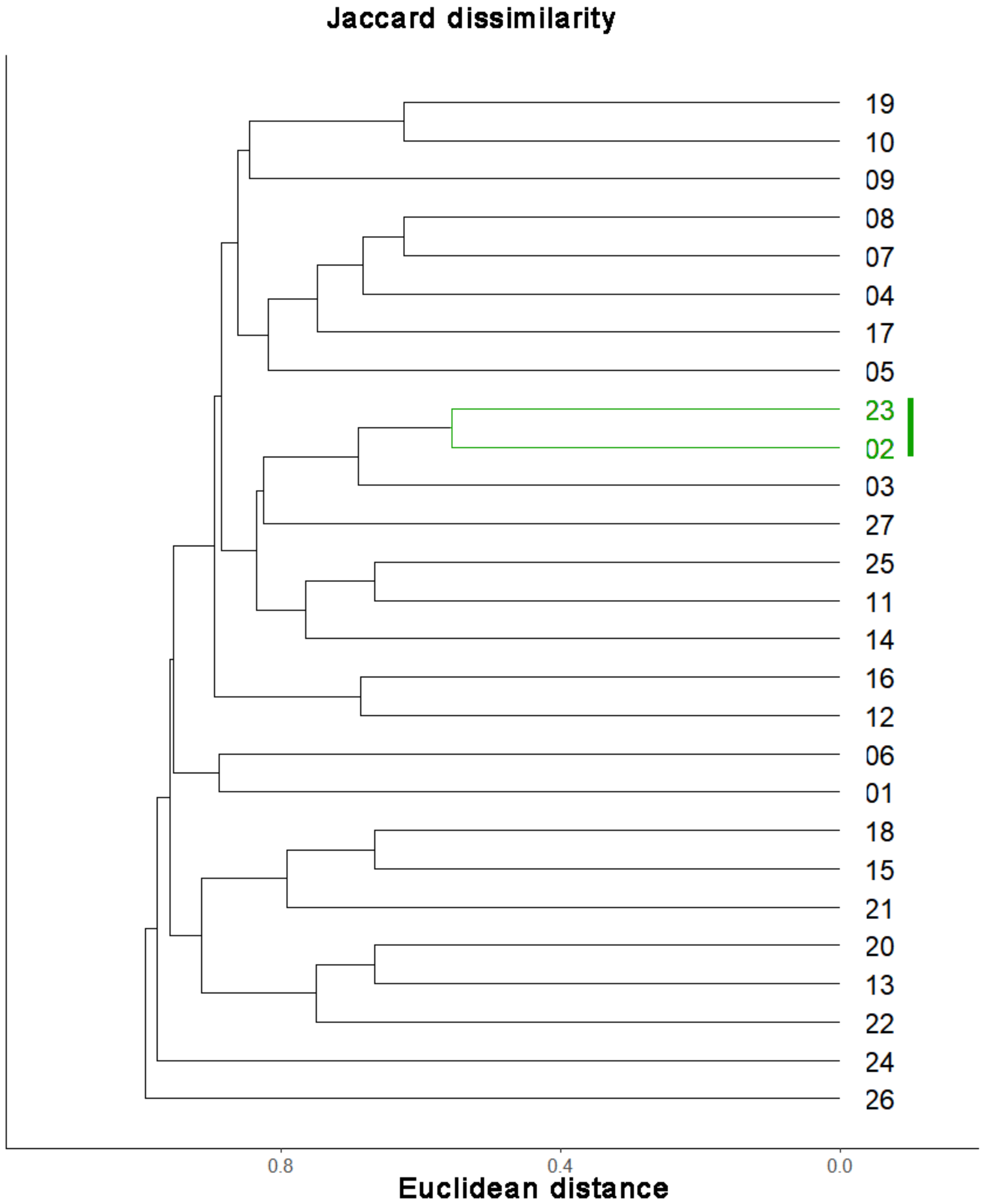


Figure 3. Unweighted Pair-Groups Method Average (UPGMA) cluster analysis using Jaccard Index (Cophenetic Correlation 0.762) to analyze dissimilarity of localities sampled in looking of terrestrial gastropods, from notheastern to southern Brazil. Groups of localities with less than 0.6 Euclidian distance are highlighted. Locality codes are represented by numbers of 01 to 27. For more information about localities, see Table 1.

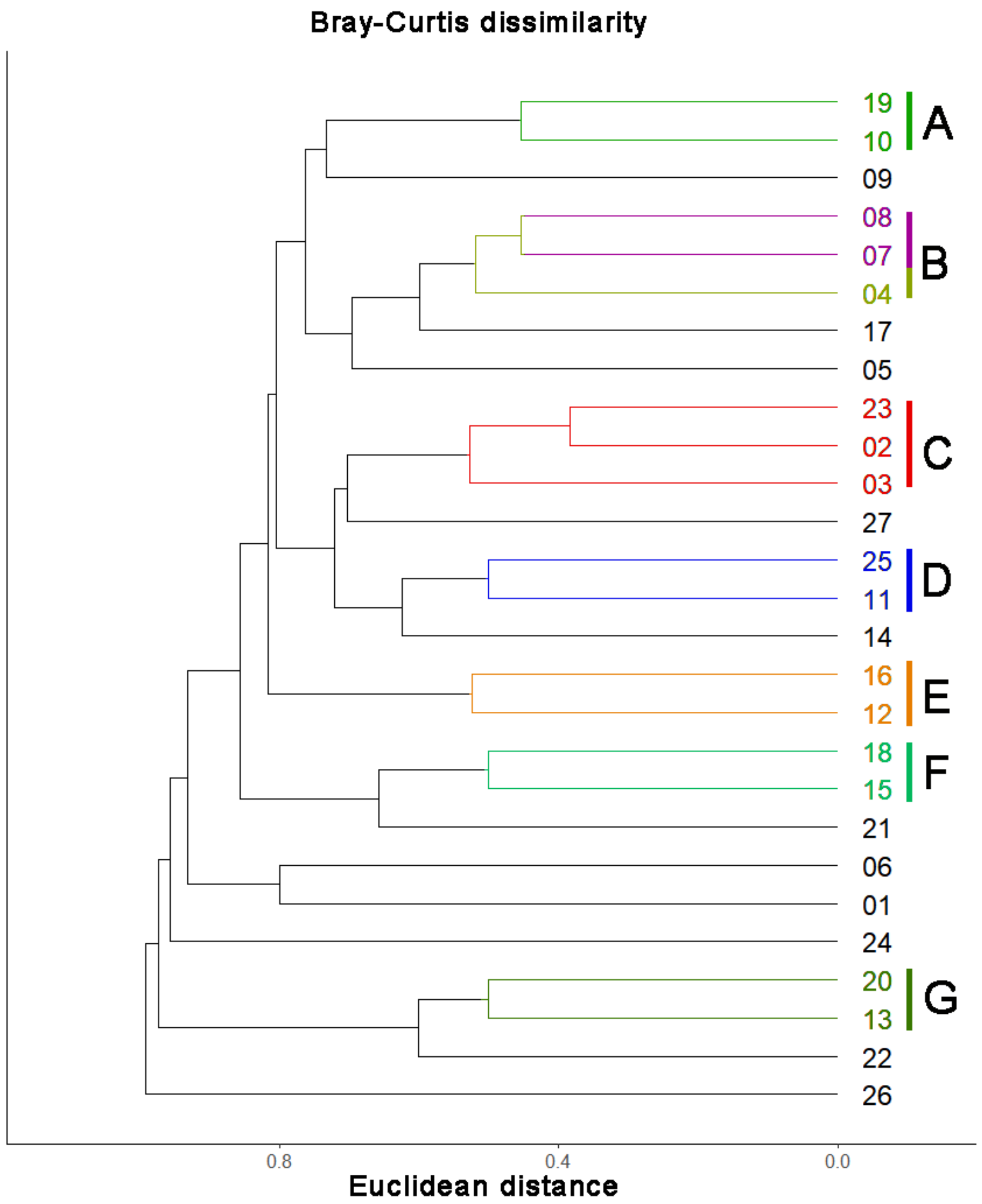


Figure 4. Unweighted Pair-Groups Method Average (UPGMA) cluster analysis using Bray-Curtis Index (Cophenetic Correlation 0.769) to analyze dissimilarity of localities sampled in looking of terrestrial gastropods, from notheastern to southern Brazil. Groups of localities with less than 0.6 Euclidian distance are highlighted. Locality codes are represented by numbers of 01 to 27. For more information about localities, see Table 1.

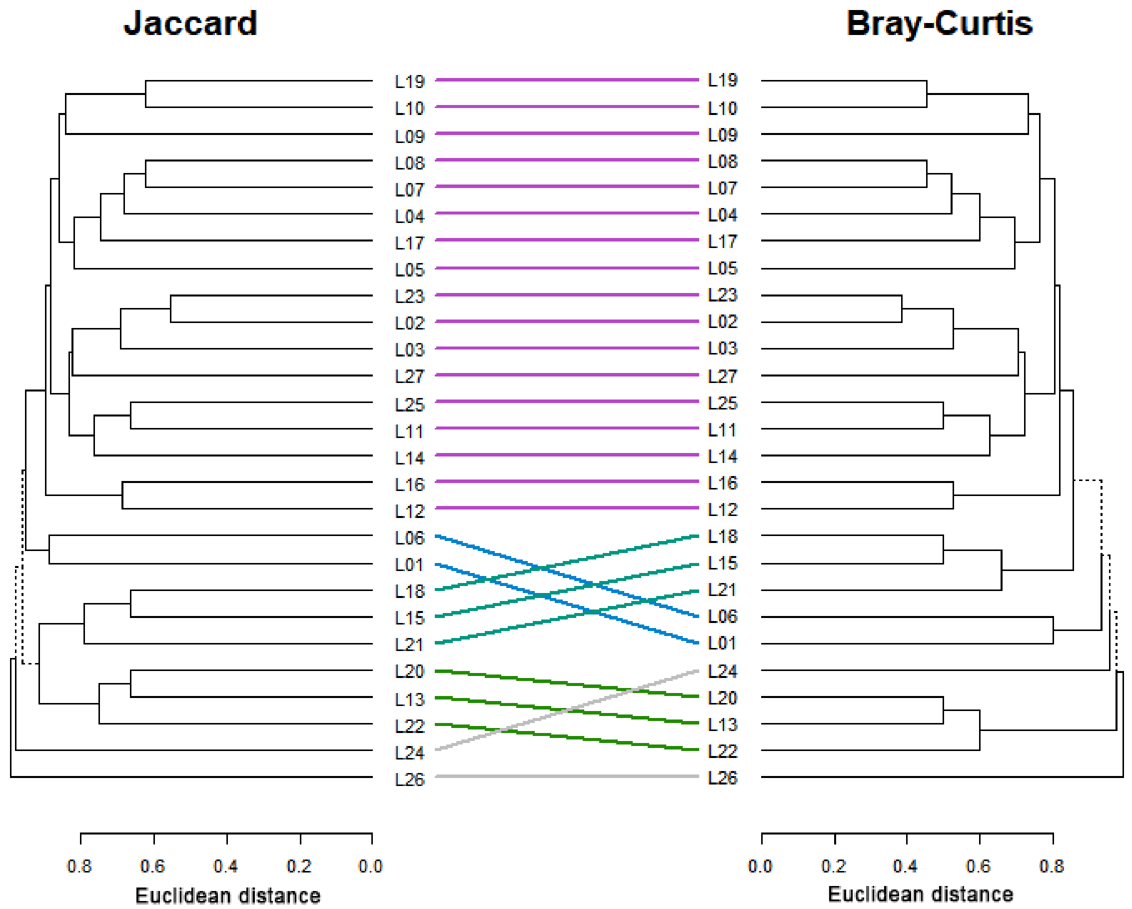


Figure 5. Comparison between dendrograms elaborated by Unweighted Pair-Groups Method Average (UPGMA) cluster analysis using two dissimilarity indexes performed to analyze similarity between terrestrial 27 gastropod communities. The x axis represents distance given by each index. Communities of terrestrial gastropods were sampled from northeastern to southern Brazil, and locality codes are represented by numbers of 01 to 27. For more information about localities, see Table 1.

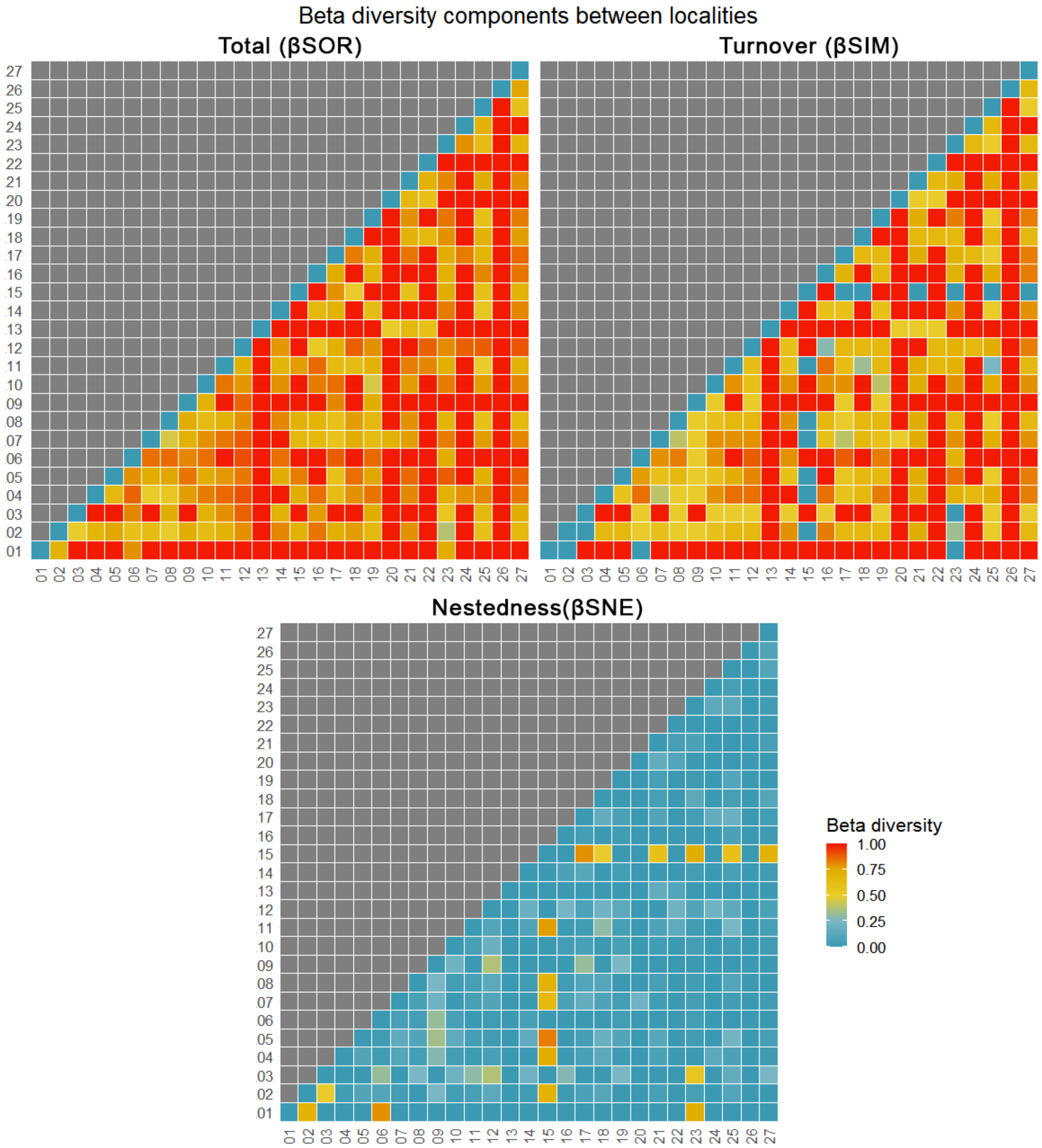
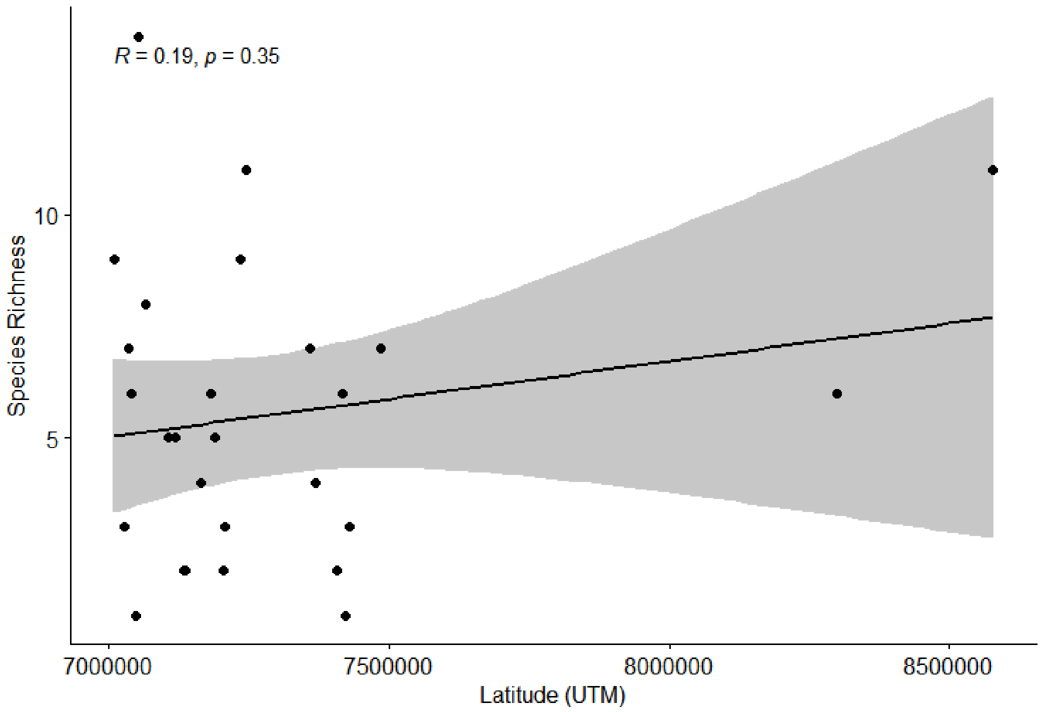


Figure 6. Pair-to-pair comparison of β diversity and its components for communities of terrestrial gastropods sampled from northeastern to southern Brazil. We utilized Sorensen index to calculate total β diversity for each locality, Simpson dissimilarity for turnover component and the resultant fraction between the two others as nestedness. Higher values of β indicates more dissimilarity between pairs and are represented by the red color, while the lower values β were represented by the blue color. Localities are represented by codes of 01 to 27. For more information about localities, see Table 1.

Correlation of Species Richness X Latitude



Correlation of alpha diversity X Latitude

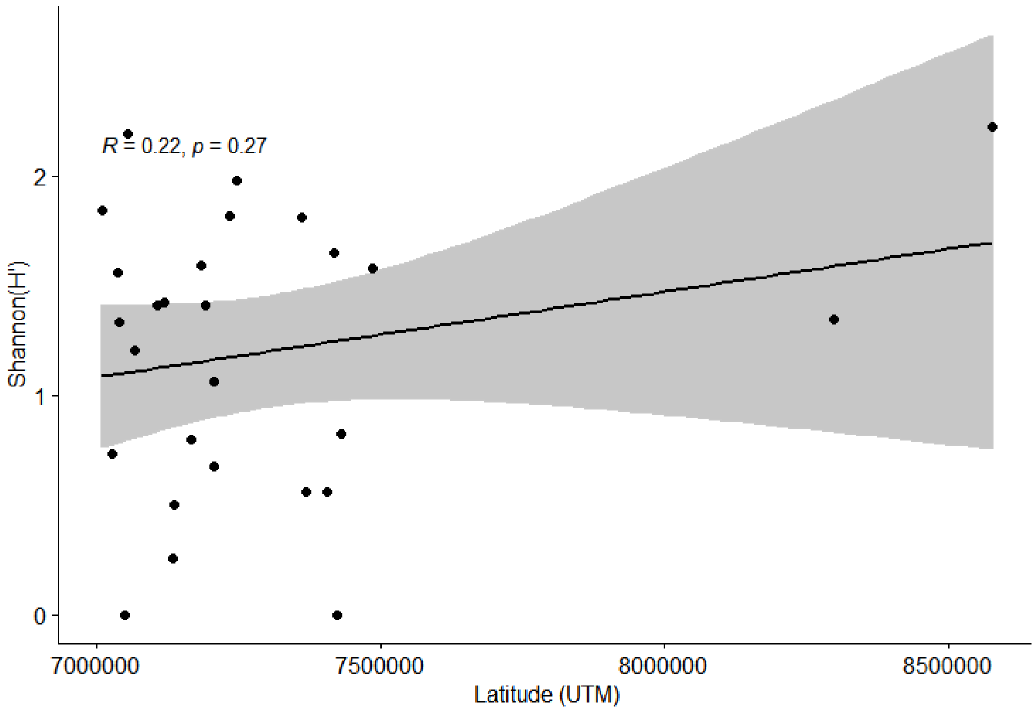


Figure 7. Evaluation of Pearson correlation between alpha diversity/richness and latitude in terrestrial gastropod communities of mountains of Atlantic Rainforest from northeast to southern Brazil.

Serra da Igreja (locality 21)

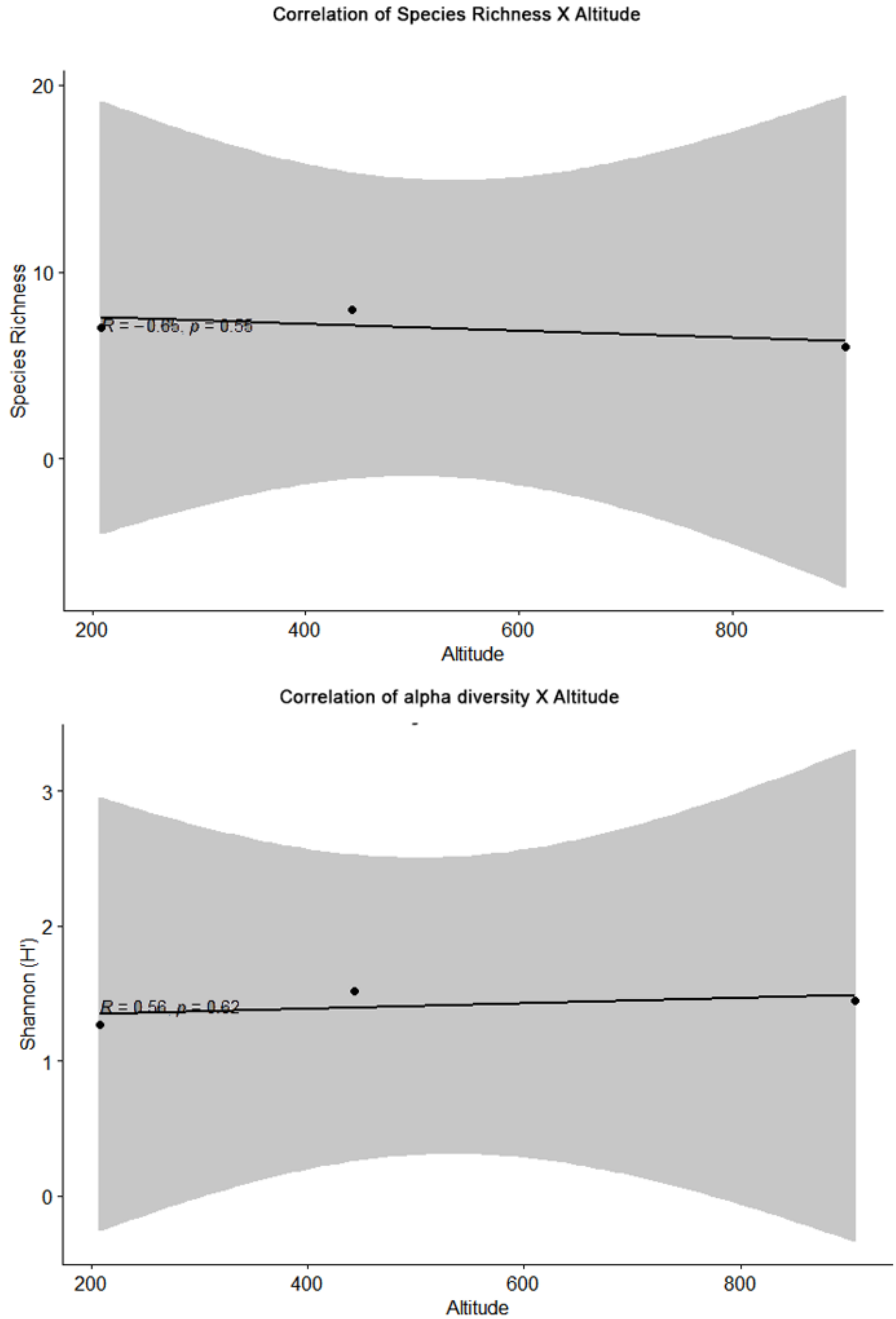


Figure 8. Pearson correlation between alpha diversity/richness and altitude in altitudinal gradient sampled in Serra da Igreja (locality 21), municipality of Morretes, state of Paraná, Brazil.

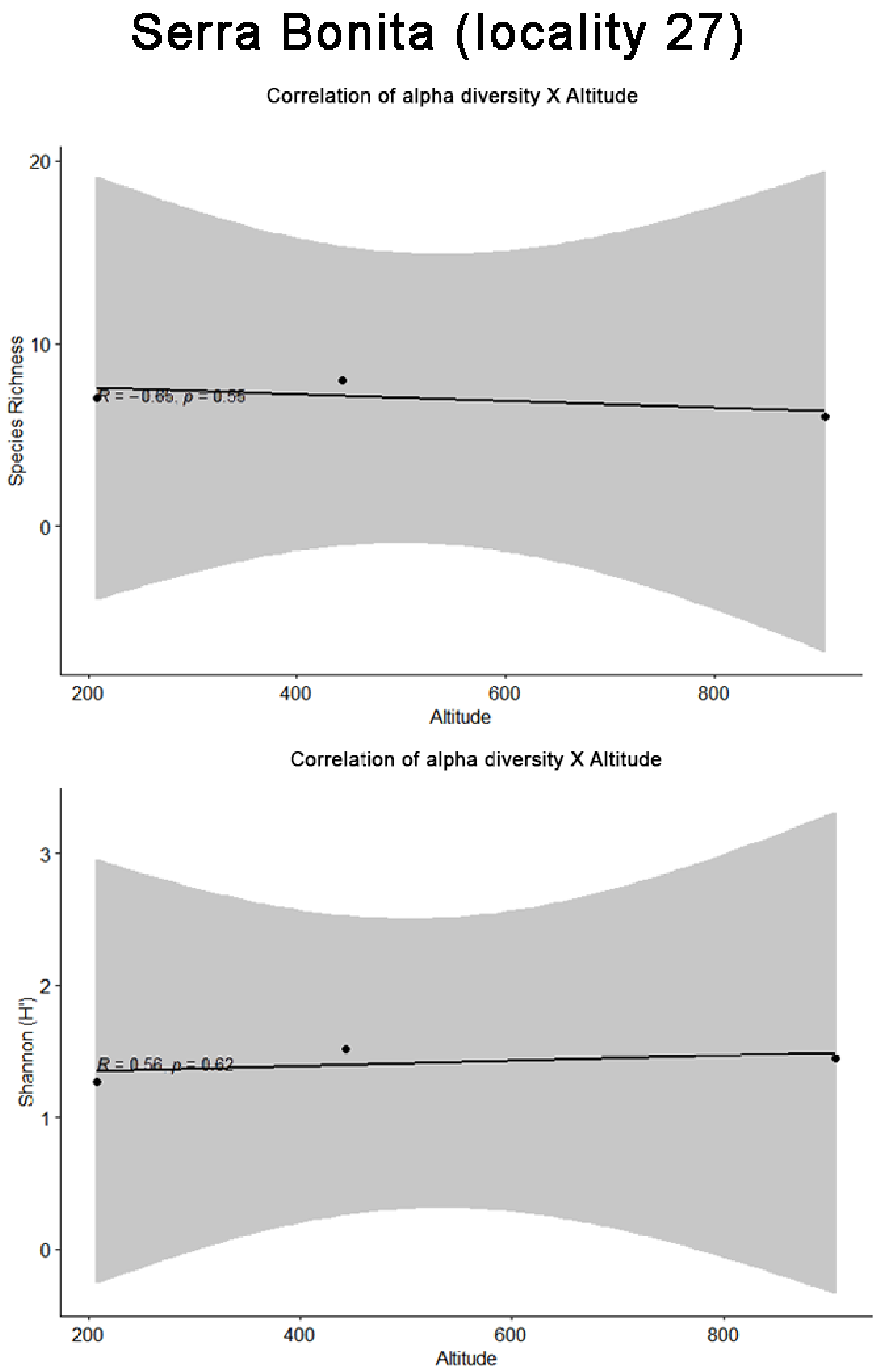
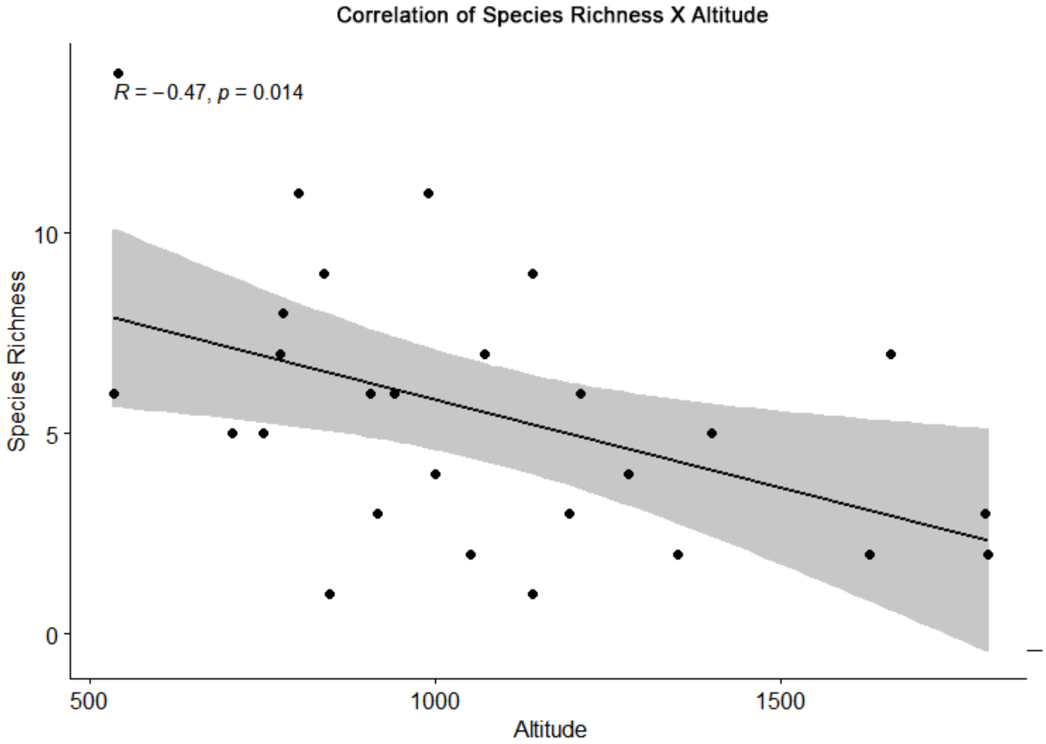


Figure 9. Pearson correlation between alpha diversity/richness and altitude in altitudinal gradient sampled in Serra Bonita, municipality of Camacán, state of Bahia, Brazil.



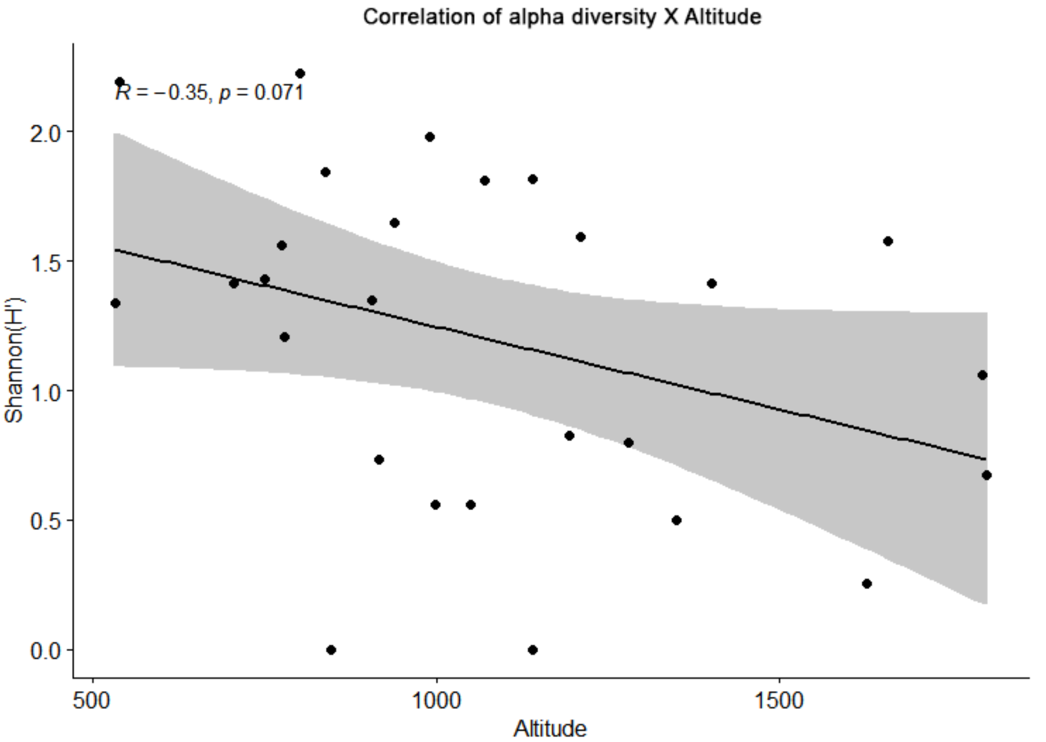


Figure 10. Evaluation of Pearson correlation between alpha diversity/richness and altitude in terrestrial gastropod communities in mountaintops of Atlantic Rainforest from northeast to southern Brazil.

CONCLUSÃO GERAL

Tanto o método de coleta de serapilheira quanto o de busca visual foram importantes em revelar as comunidades de gastrópodes da Floresta Atlântica. O método de serapilheira foi essencial em revelar microgastrópodes, que são grande parte da fauna de gastrópodes dos locais estudados, enquanto o método de busca visual foi crucial na obtenção de espécimes vivos. Pelo método de coleta de serapilheira, consideramos que 15 quadrados de amostragem de 0.5 m x 0.5 m a cada campanha, em duas campanhas são suficientes para que se amostre localidades de 800 m na Floresta Atlântica.

Em nossa área de estudo nós não observamos padrões de diversidade, mas de riqueza. Encontramos uma correlação negativa entre a diversidade das comunidades de gastrópode e a altitude. No entanto, ao amostrar o gradiente altitudinal, as localidades com maior riqueza foram as de altitude intermediária, padrão similar ao encontrado em regiões temperadas.

Observamos grande heterogeneidade entre as comunidades de gastrópodes, que pudemos classificar em três tipos de comunidades. No entanto, a classificação proposta considera locais com relevo montanhoso, e deve ser analisada diferentemente para regiões de platô e baixadas. Essa heterogeneidade foi causada pelas espécies das famílias Scolodontiade, Helicinidae e Charopidae estarem ocorrendo em apenas um ou dois topos de montanha no sul da Serra do Mar e Leste Catarinense. Esta região, que já promove a especiação de pequenos anuros, pode estar também agindo como centro de especiação para gastrópodes terrestres destas famílias.

Como os estudos em amostrar a diversidade Floresta Atlântica ainda são escassos, recomendo que os futuros estudos sejam focados em amostrar grandes regiões não amostradas, com o objetivo de suprir lacunas geográficas na diversidade do grupo e compreender os padrões de especiação de gastrópodes terrestres na Floresta Atlântica.

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