UNIVERSIDADE ESTADUAL PAULISTA
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Câmpus do Litoral Paulista

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LAND GASTROPODS ALONG AN ALTITUDINAL GRADIENT ON THE COAST OF SÃO PAULO, BRAZIL

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LAND GASTROPODS ALONG AN ALTITUDINAL GRADIENT ON THE COAST OF SÃO PAULO, BRAZIL

Trabalho de Conclusão de Curso apresentado como requisito parcial para obtenção do título de bacharel em Ciências Biológicas – Habilitação em Gerenciamento Costeiro – pela Universidade Estadual Paulista “Júlio de Mesquita Filho”.

Orientador: Profº Dr. Marcos Ricardo Bornschein

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Resumo: Fatores ambientais afetam como as espécies se espalham pelo globo. A regra de Rapoport dita que um maior número de espécies é encontrado próximo ao Equador, diminuindo em direção aos polos, e o mesmo pode ser dito, de uma altitude menor, para uma maior. Gastrópodes terrestres são o grupo animal com a maior taxa de extinção, e um dos grupos que podem seguir esta regra. Os gastrópodes terrestres da Serra do Mar, coberta pela Floresta Atlântica, são subestudados; este trabalho busca descrever as comunidades de gastrópodes terrestres de duas áreas protegidas (Parque Estadual da Serra do Mar e Parque Natural Municipal Nascentes de Paranapiacaba) e saber se eles seguem a regra de Rapoport altitudinal. Amostramos quatro pontos em diferentes altitudes, duas em cada área. Coletamos serapilheira e fizemos busca ativa de conchas e indivíduos vivos. Calculamos índices de diversidade α e β, e de equitabilidade. Nós encontramos 1559 indivíduos de 40 espécies; não houve muita mudança de riqueza de espécies em relação à altitude. A diversidade β foi principalmente explicada pelo *turnover* de espécies. As comunidades de gastrópodes terrestres do Parque Estadual da Serra do Mar e do Parque Natural Municipal Nascentes de Paranapiacaba não seguem a regra de Rapoport altitudinal.

Palavras-chave: Diversidade, ecologia, comunidades, caracol, Paranapiacaba, Serra do Mar, Floresta Atlântica

Abstract: Environmental factors affect how species are scattered across the globe. Rapoport's rule states that a greater number of species are found near the Equator, diminishing in direction to the Poles, and the same can be said, from a lower altitude, to a higher one. Land gastropods are the animal group with the highest extinction rate, and one of the groups that can fit under this rule. The land gastropods of Serra do Mar, covered by the Atlantic Rainforest, are understudied; this work seeks to describe the land gastropod communities of two protected areas (Parque Estadual da Serra do Mar and Parque Natural Municipal Nascentes de Paranapiacaba), and to know if they follow altitudinal Rapoport's rule. We sampled at four points in different altitudes, two on each area. We collected leaf litter and did active search of shells and living individuals. We calculated α-diversity, evenness and β-diversity indices. We found 1559 individuals of 40 species; there was not much change in species richness with altitude, changes in α-diversity also did not change with altitude. β-diversity was mainly explained by species turnover. The land gastropod communities of Parque Estadual da Serra do Mar and Parque Natural Municipal Nascentes de Paranapiacaba do not follow altitudinal Rapoport's rule.

Keywords: Diversity, ecology, communities, land snail, Paranapiacaba, Serra do Mar, Atlantic Rainforest

Land gastropods along an altitudinal gradient on the coast of São Paulo, Brazil

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ABSTRACT

Environmental factors affect how species are scattered across the globe. Raapoport's rule states that a greater number of species are found near the Equator, diminishing in direction to the Poles, and the same can be said, from a lower altitude, to a higher one. Land gastropods are the animal group with the highest extinction rate, and one of the groups that can fit under this rule. The land gastropods of Serra do Mar, covered by the Atlantic Rainforest, are understudied; this work seeks to describe the land gastropod communities of two protected areas (Parque Estadual da Serra do Mar and Parque Natural Municipal Nascentes de Paranapiacaba), and to know if they follow altitudinal Rapoport's rule. We sampled at four points in different altitudes, two on each area. We collected leaf litter and did active search of shells and living individuals. We calculated α-diversity, evenness and β-diversity indices. We found 1559 individuals of 40 species; there was not much change in species richness with altitude, changes in α-diversity also did not change with altitude. β-diversity was mainly explained by species turnover. The land gastropod communities of Parque Estadual da Serra do Mar and Parque Natural Municipal Nascentes de Paranapiacaba do not follow altitudinal Rapoport's rule.

KEYWORDS: Diversity, ecology, communities, land snail, Paranapiacaba, Serra do Mar, Atlantic Rainforest

INTRODUCTION

The way organisms and species are scattered across the globe depends on the environmental factors that affect them, such as changes in temperature

O manuscrito foi formatado segundo a revista: Malacologia or precipitation along an altitudinal gradient (Walsh 1979; Pellegatti & Galvani). Eduardo H. Rapoport (Rapoport 1975 apud Stevens 1989) proposed that the distribution of animal species across the globe is uneven, with a greater amount of species found at the Equator, diminishing with increasing latitude, reaching its lowest values at the poles; what became known as Rapoport's rule. This rule was adapted and expanded to cover changes in altitude, in addition to in latitude (Stevens 1992). Rapoport's rule may or may not affect different groups of organisms, and when it does affect them, the results may vary in scale, in terrestrial invertebrates, peaks of abundance and species richness are sometimes expected (Olson 1994).

Land snails and slugs are the only molluscs that can live outside water and not depend on being submerged or under splash. Because of their high sensitivity to the surrounding environment, coupled with their need of high humidity, they are severely threatened, being the animal group with the highest extinction rate, and the taxonomic group with the highest number of documented extinctions, in addition to the problem, Brazilian malacofauna is severely understudied; in Brazil, there are 748 known species of land snails (Lydeard et al. 2004; Salvador 2019; Salvador et al. 2024).

The Atlantic Rainforest is a biome found on the Eastern Coast of Brazil, which used to cover the coastal areas from Rio Grande do Norte to Rio Grande do Sul, and most of São Paulo, Paraná, and Santa Catarina states. Today, only 11,73% of its original coverage remains, mostly in fragments with less than 0,5 km² (Ribeiro et al. 2009). The coast of São Paulo state has the largest contiguous strip of protected Atlantic Rainforest, mainly inside the Parque Estadual da Serra do Mar (PESM); with other protected areas nearby: (ex.:Parque Estadual do Xixová-Japuí, Parque Estadual da Restinga de Bertioga).

This work seeks to study the land gastropod communities of Parque Estadual da Serra do Mar and Parque Natural Municipal das Nascentes de Paranapiacaba, and to test the application of elevational Rapoport's rule to it.

MATERIAL AND METHOD

The work was done on the centre-east part of the Serra do Mar, on four points in four different altitudes: the upper two at Parque Natural Municipal

Nascentes de Paranapiacaba, and the lower two at Parque Estadual da Serra do Mar – Núcleo Itutinga-Pilões. We sampled between March and April 2023. Sampling was always done by at least two people trained in gastropod-collecting.

Study area

Parque Natural Municipal Nascentes de Paranapiacaba (Paranapiacaba Headwaters Natural Municipal Park; PNMNP) is a conservation unit on the municipality of Santo André, São Paulo, Brazil. It is home to over 300 vascular plant species, in 47 families and 103 genera, 27 of them being threatened and 9 are exotic (Santo André 2015). Its phytophysiognomy is dense ombrophilous forest, montane and high-montane, in different regeneration states, ranging from primary succession, restricted to two areas, to advanced secondary succession (Santo André 2015).

Parque Estadual da Serra do Mar (Serra do Mar State Park; PESM) is a state-administered conservation unit spanning over 20 municipalities. We sampled on the Itutinga-Pilões nucleus, near its Guariúma base, that is located on the municipality of Praia Grande, São Paulo, Brazil. Over 500 plant species can be found in it, 61 of them are threatened; exotic species are usually fructiferous or ornamental species, tied to human occupation, sometimes being a common sight (Instituto Florestal 2008). PESM also harbours over 600 species of terrestrial vertebrates (Instituto Florestal 2008).

We sampled on four points (Figure 1), two on each locality. At PNMNP, we sampled at 1185 m (point H) and also at a lower altitude (point MH). At PESM, we sampled at 351 m (point ML) and at 70 m (point L). Points ML, MH and H are covered by montane dense ombrophilous forest, while point L is covered by lowlands dense ombrophilous forest (Instituto Florestal 2008; Santo André 2015).

Sampling methodology

We sampled using two methods: litter leaf collection and active search.

For the leaf litter collection, we collected all the leaf litter of 15 50 cm x 50 cm plots using a square, every two metres, along a 30 m tape measure, starting from the 0th metre. During the active search, we looked for shells and living individuals, on three 36 m² plots, alongside a 30 m tape measure, for half an hour, in pairs, from the 10th metre. We searched through micro-habitats (ex.: below leaves, inside bromeliads), up to 2m in height.

At the laboratory, we searched for living individuals and shells through the leaf litter; then the leaf litter was dried, sifted, and we looked for micromollusc shells. The individuals found were euthanised in water, and conserved in alcohol 70%, while the shells were preserved dry.

From each sampled place, we measured the soil pH (with SONDATERRA PH-2500), variation of air humidity and temperature (with a digital thermohygrometer) during sampling. We took the weather conditions (ex.: rainfall and wind) and descriptions of the environment, including soil covering, epiphyte presence, ground covering, and epiphyte bromeliads. Geographic coördinates of initial sampling points were taken with an Etrex 10 GPS.

Species identification

Taxonomic ordering followed Bouchet et al. (2017), while species are according to MolluscaBase (2023).

Data analysis

We used the software R (R Core Team 2024) to calculate rthe diversity analyses. To analyse α-diversity, we used Simpson (D) and Shannon (H') indices, calculated with the library vegan (Oksanen et al. 2024). We used Sørensen's β index (β_{SOR}) for β-diversity analysis, calculated with the library betapart (Baselga et al. 2023). We also calculated the equitability using Pielou's index (J).

RESULTS

Environmental data

We covered 1115 metres of altitude (Table 1), from 70 m at the lowest height to 1185 m at the highest. Soil pH was always slightly acidic, ranging from 6,4 to 6,8 (Table 2).

For logistic reasons, we did litter leaf collection and active search on different dates on Paranapiacaba. We collected the leaf litter of the highest point on the 1st of March, alongside the first two plots of active search, on the 20th, we finished the active search of the highest point, and collected the leaf litter of point MH, and finally on the 25th, we did the active search on point MH. The litter leaf collection and active search of the respective heights at PESM Itutinga-Pilões was done on the same day. The last sampling occurred a month and 8 days after the autumnal aequinox.

Abundance

We found 51 living individuals (21 by active search and 30 by leaf litter collection) and 1508 shells (5 by active search and 1503 by leaf litter collection); giving a total of 1559 gastropods (Table 3). The most abundant families were Helicinidae, Charopidae and Scolodontidae. The most abundant species was *Alcadia* cf. *iheringi* Wagner, 1911, with 632 individuals.

The most abundant family found trough active search was Simpulopsidae. The most abundant species were *Simpulopsis sp*.1 and cf. Scolodontidae *sp*.15. The most abundant family found by litter leaf collection was Helicinidae. The most abundant species were *Alcadia* cf. *iheringi*, *Radiodiscus sp*.2 and *Radiodiscus sp*.3 (Fig. 2). At point L, the most abundant species was *Radiodiscus sp*.1. At point ML, the most abundant species was Scolodontidae *sp*.7. At point MH, the most abundant species was *Radiodiscus sp*.2. At point H, the most abundant species was *Alcadia* cf. *iheringi*, accounting near two thirds of the collected individuals.

Richness

We have found 40 species, included in 10 families. Only seven species were found by active search (Scolodontidae *sp*.10, cf. Scolodontidae *sp*.15, *Alcadia* cf. *iheringi*, *Simpulopsis sp*.1, Euconulidae *sp*., cf. *Lilloiconcha sp*.1, cf. Cystopeltidae *sp*.5), belonging to five families. By litter leaf collection, we found 39 species, with *Lilloiconcha sp*.1 being the only absence of the total species on the present study. We found a richness of 18 on the highest point. At point L we found 21 species. We encountered 20 species at point MH, but only 10 at point ML.

The most speciose family was Scolodontidae, with 15 species, but only 2 genera were identified, with 12 species not assigned to any (table 3). The genus with the greatest species richness was *Radiodiscus* Pilsbry, 1906, with four species.

Diversity

Alpha-diversity was at its highest at point ML in both Shannon and Simpson indices (H'=2,4317; D=0,8783; Table 4). Individuals of *Alcadia* cf. *iheringi* were responsible for near two thirds of point H's abundance, to avoid skewing and biasing the data, we decided to calculate point H's α-diversity indices with and without *A*. cf. *iheringi* (with: H'=1,3203; D=0,5416; J=0,4568; without: H'=2,0013; D=0,8073; J=0,7064). Overall Sørensen β-diversity was 0,6723. Pairwise differences consistently had much higher species turnover component in comparison to the nestedness component, except for points ML-MH (β_{SNE}=0,2333; β_{SIM}=0,3000).

DISCUSSION

Soil pH did not show much variation with altitude, being slightly acidic, around 6,5. It also did not show an increasing or decreasing trend. The vegetation had suffered anthropic impact before the study area got turned into a conservation unit (Instituto Florestal 2008; Santo André 2015).

We have found 40 species. Perez and Hausdorf (2022) have found 80 species in Ecuador, but only 510 individuals. Our results are closer to the range of 21-33 species of previous studies done on (Southern) South America (Santos & Monteiro 2001; Oroño et al. 2007; Miranda & Cuezzo 2010; Nunes & Santos 2012). The most abundant species was A*lcadia* cf. *iheringi*, with 632 individuals (Fig. 2; 40% of all individuals), 601 of them at point H; Helicinidae was also the most abundant family, with a single species. Charopidae and Scolodontidae were the second and third most abundant families, with respectively 330 and 306 individuals. In Southern South America, Charopidae seems to be the most dominant family, while in Northern South America, Scolodontidae seems to dominate (Oroño et al. 2007). If the high abundance of *A*. cf. *iheringi* were caused by a disturb event (like a fallen tree or an abnormal concentration of leaves on the ground), then the current study fits into the expected pattern, if not, the mountaintops of Paranapiacaba might have a unique community profile; either case could only be demonstrated if the area were to be sampled again.

Differently from Leme and Indrusiak (1990), we did not find any specimens of *Megalobulimus parafragilior* Leme & Indrusiak, 1990 nor of *Megalobulimus fragilior* (Ihering, 1901), if they are actually distinct species. *Helicodiscus* *parallelus* (Say, 1921) is the same species as *H*. *theresa* Thiele, 1927 (Silva et al. 2020). Two species, *H*. *parallelus* and *Deroceras laeve* (Müller, 1774), are nonnative to Brazil. *H*. *parallelus* has been known to occur in Brazil for nearly a century, first thought to be a native species, although its invasive potential is unclear, and the species may have become nativized. *D*. *laeve* is an agricultural pest (Landal et al. 2019; Farias et al. 2023) and known to be a host of parasitic worms (e.g.: Maurer et al. 2002).

Values of α-diversity given by Shannon's index were similar to the ones found by Oroño et al. (2007), and by Miranda and Cuezzo (2010). The diversity and evenness indices showed a great decline at point H (Table 4), which disappeared if the indices were calculated after removing one outlier species; specially Simpson's and Pielou's indices. The closeness of species richness between each sampling point's communities and the absence of a clear trend on diversity, does not corroborate the application of elevational Rapoport's rule, as proposed by Stevens (1989, 1992), to the gastropods of PNMNP and PESM. Sørensen's β-diversity index (Fig. 3) indicates that pair-to-pair community changes were more influenced by species turnover, with Simpson's dissimilarity index values being consistently higher than the values of the nestedness component. Nestedness was higher than 0,2 between points ML-L and ML-MH; the nestedness component was 0,1714 between points ML-H, being lower than 0,05 on all other pairs. This means that the changes along altitude are more influenced by changes in species presence, than by changes in species richness. The higher values of nestedness involving point ML are probably related to the fact that it has the lowest species richness between all points.

CONCLUSION

The gastropods of PESM and PNMNP do not exhibit a distribution pattern in relation altitude.

We recommend that more studies be made on the status of *H*. *parallelus*, to assess if it has been “nativized”, and the extent to which it can be found. Furthermore, we urge that more research be done on land gastropods of the Atlantic Rainforest, mainly descriptive and biogeographic works.

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TABLES

TABLE 1: Point coördinates and fieldwork weather condition.

Locality	Weather	Point	Start/End time	Reference Coördinates	Date
Paranapiacaba	Clear sky	H	7:10/11:00	23°46’43” S 46°17’14” W	2023 III-01
			7:18/8:23		2023- III-20
	Clear sky	MH	12:27/12:00	23°45’52” S 46°17’04” W	
			9:56/11:08		2023-III-25
Guariúma	Clear sky	L	10:20/12:00	24°00’37” S 46°34’06” W	2023- III-30
	Overcast	ML	9:00/11:13	24°00’10” S 46°34’18” W	2023-IV-28

TABLE 2: Soil pH, air humidity, temperature, altitude, and presence of epiphytes at each point.

Locality	pH	Humidity	Temperature (°C)	Epiphytes	Point	Altitude
Paranapiacaba	6,7	53% – 76%	25,5 – 28,7	Present	H	1185 m
	6,4	57% – 66%	22,7 – 24,3	Present	MH	910 m
Guariúma	6,8	53% – 76%	25,6 – 30,2	Present	L	70 m
	6,7	51% – 70%	20,1 – 24,9	Present	ML	351 m

TABLE 3: Land gastropod abundance: total, by point, and by species.

Species	Point H		Point MH		Point ML		Point L		Total
	Shells		Shells		Shells		Shells		
Scolodontidae									
cf. *Happiella sp*.1	0	0	1	1	0	0	0	0	2
cf. *Happiella sp*.2	5	4	0	0	0	0	0	0	9
Miradiscops sp.1	22	0	7	1	1	0	47	0	78
Scolodontidae *sp*.4	6	0	9	0	6	0	0	0	21
Scolodontidae *sp*.5	0	0	10	0	0	0	14	0	24
Scolodontidae *sp*.6	0	0	4	0	0	0	3	0	7
Scolodontidae *sp*.7	1	0	21	0	44	0	25	0	91
Scolodontidae *sp*.8	0	0	0	0	0	0	3	0	3
Scolodontidae *sp*.9	0	0	0	0	4	0	0	0	4
Scolodontidae *sp*.10	0	0	0	0	0	0	4	0	4
Scolodontidae *sp*.11	27	0	0	0	0	0	0	0	27

cf. Scolodontidae *sp*.12	0	0	6	0	0	0	15	0	21
cf. Scolodontidae *sp*.13	0	0	3	0	2	0	0	0	5
cf. Scolodontidae *sp*.14	0	0	0	0	0	0	4	0	4
cf. Scolodontidae *sp*.15	0	0	0	0	0	0	1	5	6
Streptaxidae									
cf. Streptaxidae *sp*.1	0	0	3	0	0	0	0	0	3
Charopidae									
Radiodiscus sp.1	0	0	31	0	0	0	70	0	101
Radiodiscus sp.2	43	0	65	0	2	0	0	0	110
Radiodiscus sp.3	61	0	34	0	16	0	1	0	112
Radiodiscus sp.4	2	0	1	0	0	0	0	0	3
Rotadiscus sp.1	0	0	0	0	0	0	1	0	1
Charopidae sp.6	0	0	0	0	0	0	3	0	3
Cystopeltidae									
cf. *Zilchogyra sp*.1	0	0	1	0	0	0	0	0	1
cf. *Zilchogyra sp*.2	0	0	15	0	0	0	0	0	15
cf. *Zilchogyra sp*.3	1	0	0	0	0	0	0	0	1

cf. *Zilchogyra sp*.4	0	0	0	0	39	0	14	0	53
cf. Cystopeltidae *sp*.5	106	0	0	0	0	0	0	0	106
cf. *Lilloiconcha sp*.1	0	0	0	0	0	0	0	1	1
Helicodiscidae									
Helicodiscus parallelus	0	0	0	0	2	0	18	0	20
Helicinidae									
Alcadia cf. *iheringi*	588	13	3	0	18	0	11	1	634
Euconulidae									
Euconulidae *sp*.1	4	0	0	0	0	0	0	0	4
Euconulidae *sp*.2	3	2	0	0	0	0	0	0	5
Euconulidae *sp*.3	2	0	0	0	0	0	0	0	2
Agriolimacidae									
Deroceras laeve	0	1	0	0	0	0	0	0	1
Simpulopsidae									
Simpulopsis sp.1	9	2	10	5	0	0	0	10	36
Simpulopsis sp.2	4	0	2	2	0	0	0	0	8
cf. *Rhinus sp*.1	0	0	3	0	0	0	1	0	4

Simpulopsidae *sp*.4	1	0	0	0	0	0	1	0	2
Simpulopsidae *sp*.5	0	0	0	0	0	0	1	0	1
Diplommatinidae									
Adelopoma sp.1	0	0	23	0	0	0	0	0	23
Total	910		259		134		256		1559

TABELA 4: Species richness, abundance, evenness, and α-diversity indices for each sampling point.

Point	S	Abundance	H’	D	J
H	18	910	1,3203	0,5416	0,4568
MH	20	259	2,4317	0,8783	0,8117
ML	10	134	1,7170	0,7716	0,7457
L	21	256	2,3486	0,8602	0,7714

FIGURES

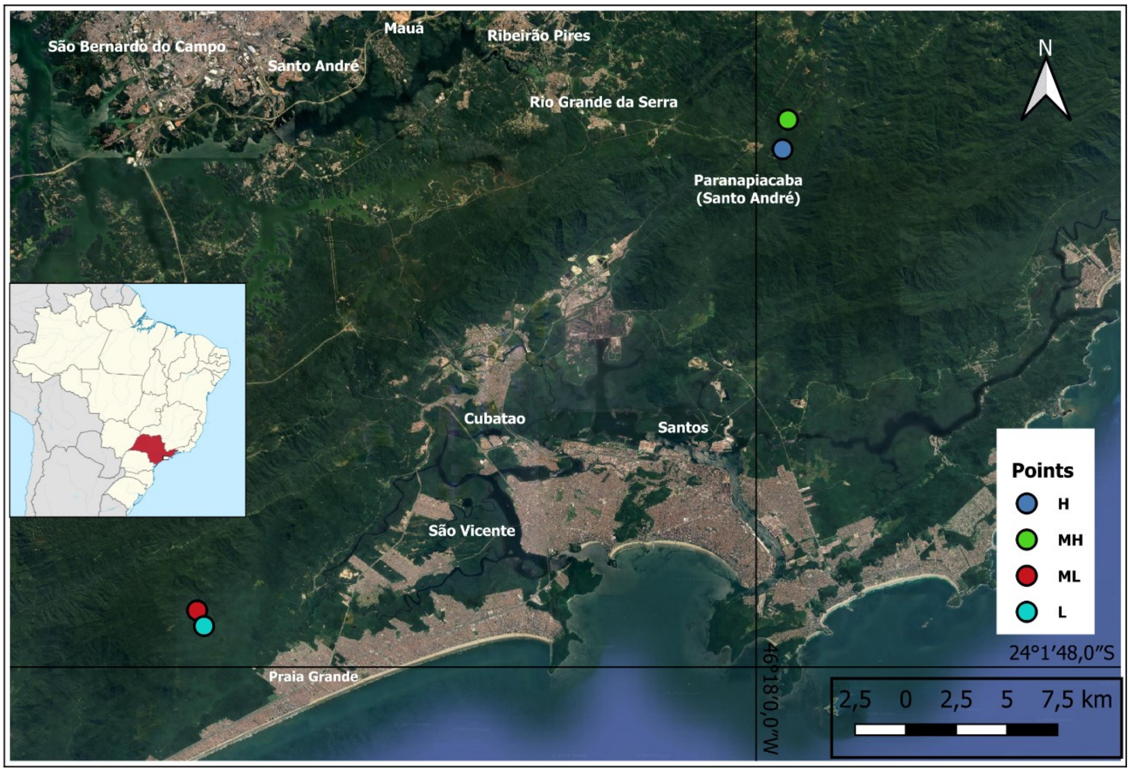

FIG. 1: Location of the four sampling points, with some nearby municipalities indicated. Point H: 1185 m. Point MH: 910 m. Point ML 351 m. Point L: 70 m.

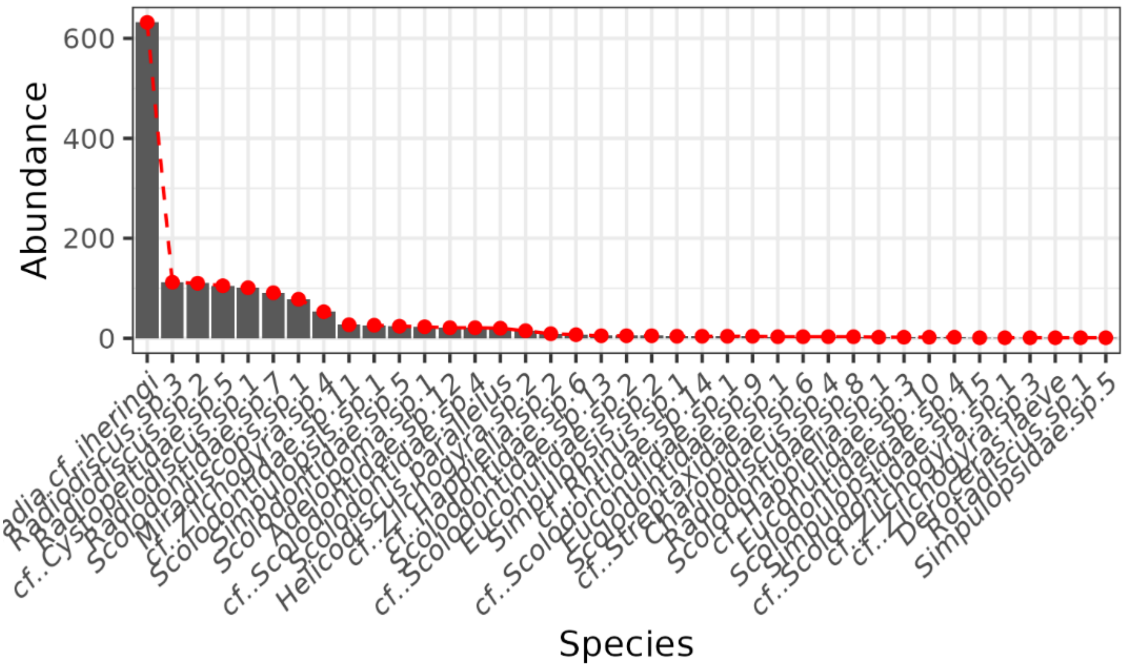

FIG. 2: Total abundance of land gastropods obtained by the leaf litter collection method.

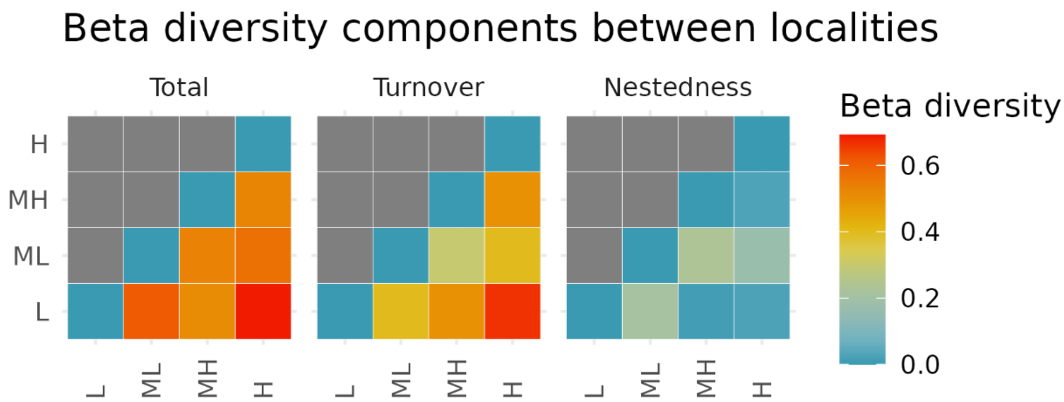

FIG. 3: Graphical representation of Sørensen's β-diversity index and its components, nestedness and species turnover, for each pair of sampling points.

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Orientador: Prof. Dr. Marcos Ricardo Bornschein

Curso/Habilitação: Bacharelado em Ciências Biológicas/Gerenciamento Costeiro

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