Functional Groups of Terrestrial Invertebrates in the Leaf Litter of Atlantic Forest (Bahia, Brazil)

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The study conducted in a native fragment of the Atlantic Forest in Alagoinhas, Bahia, Brazil, aimed to evaluate the action of functional groups of terrestrial invertebrates and the effect of seasonality on their biodiversity. Over 6 months, researchers captured 166 invertebrates representing 9 orders and 17 families. The findings revealed a greater abundance of invertebrates (77) at the edge of the forest fragment. However, the indices of diversity, equity, and richness were similar between the fragment's edge and interior. Notably, at the edge, detritivores (such as little armadillos) and predators (including ants and spiders) exhibited dominance over other functional groups like phytophagous, saprophagous, coprophagous, and bioturbators. Predators of the orders Hymenoptera and Araneae were highlighted for their ecological importance, particularly in biological control, especially of detritivores. Interestingly, the study did not observe the effect of seasonality during the brief inventory period. This suggests that other factors may significantly influence the biodiversity of terrestrial invertebrates in the Atlantic Forest fragment in Bahia, Brazil.

Keywords: Biodiversity. Terrestrial Invertebrates. Atlantic Forest. Leaf Litter.

Introduction

The Atlantic Forest is renowned for its rich biodiversity, making it a global hotspot despite being one of the most threatened ecosystems on Earth. It covers approximately 15% of Brazil's territory [1,2] and harbors numerous endemic species [3]. However, anthropogenic activities pose significant threats to its integrity [4].

The diversity of invertebrates in the Atlantic Forest is intricately linked to the availability and diversity of resources, leading to greater structural complexity and niche diversity. The decline in invertebrate diversity signifies a deterioration of forest quality [5].

Leaf litter plays a crucial role in the ecosystem, serving as a substrate for nutrient recycling. The relationship between invertebrates and leaf litter is essential for nutrient cycling [6,7].

Terrestrial invertebrates are abundant in the forest and contribute significantly to ecosystem functions such as decomposition, nutrient cycling, and seed dispersal [8]. They rely on leaf litter for nutrition and shelter, forming mutualistic relationships vital for ecosystem maintenance [9].

Functional groups of terrestrial invertebrates, categorized based on oral morphology and dietary habits, include detritivores, predators, phytophages, coprophages, saprophages, and bioturbators [9,10].

Given their importance in ecosystem processes, particularly in leaf litter decomposition, this research aims to identify the main functional groups of terrestrial invertebrates and their contributions to nutrient cycling dynamics in a native fragment of the Atlantic Forest.

Materials and Methods

Study Field

The study took place in a native fragment of the Atlantic Forest spanning approximately 343 hectares located within Patioba Farm, situated in the city of Alagoinhas, Bahia (Figure 1). Fragments of this size, termed forest massifs, are considered crucial habitats for rare species and those with substantial carbon reserves [11].

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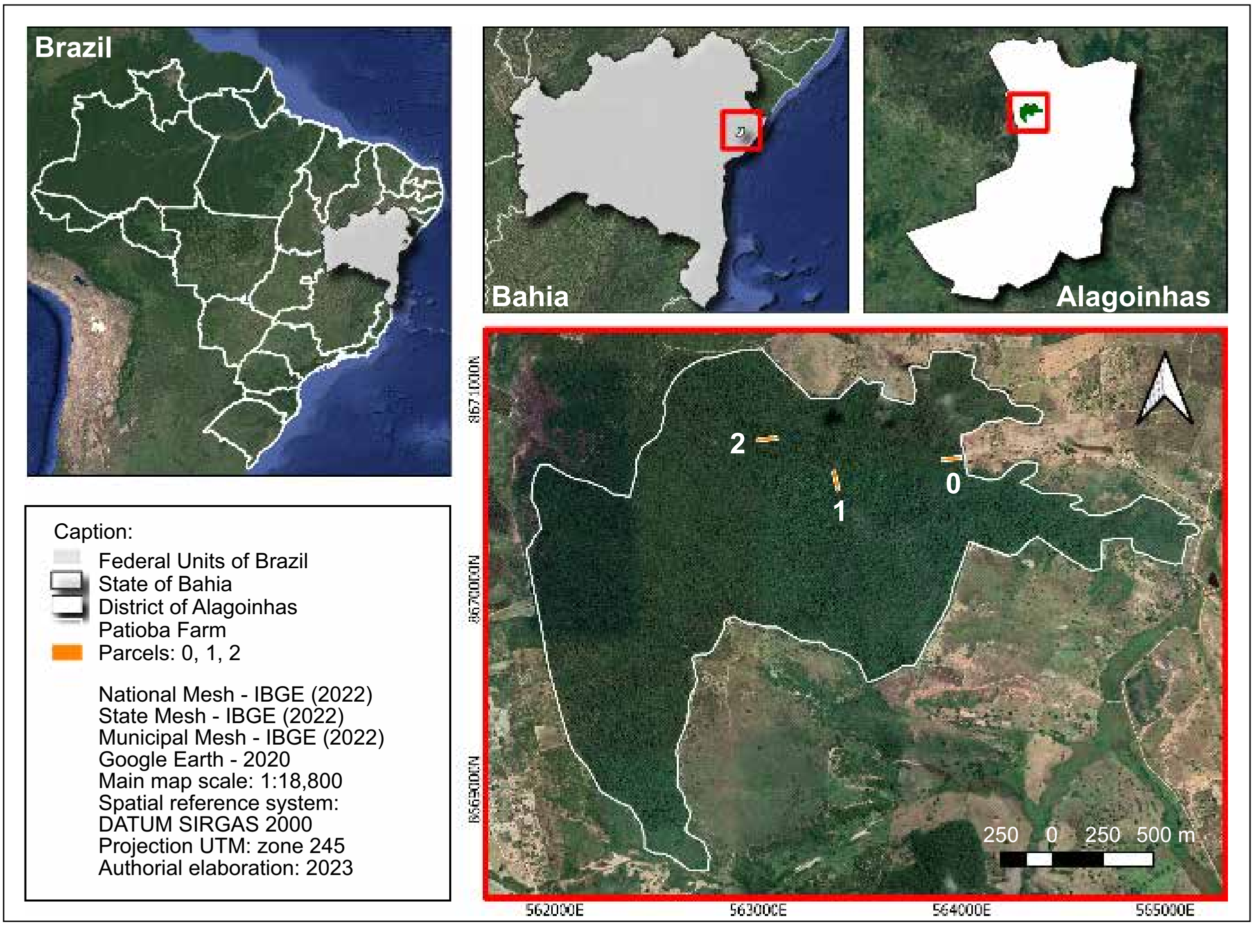
Figure 1. The study field with an indication of the edge environment (T0), intermediary (T1), and interior (T2) is shown in the fragment of the Atlantic Forest from Patioba Farm, Alagoinhas, Bahia (Brazil), 2023.



Collection and Sorting of Leaf Litter

Three plots measuring 100 meters by 20 meters were demarcated at different locations within the forest fragment: one at the edge (P0) and two within the interior (P1 and P2). These plots were spaced 500 meters apart from each other. Over 6 months, monthly leaf litter collections were conducted using a template. Five equidistant points, spaced 20 meters apart, were identified at each plot. Monthly sampling involved collecting leaf litter samples at these five points within each plot. A sample square measuring 0.50 meters by 0.50 meters was used, employing the monthly gradual sampling method. In each plot, five samples of 1 square meter each were collected. To ensure thorough sampling, launches were alternated in subsequent directions each month to refresh the sampled leaf litter.

Identification of Invertebrates

The leaf litter samples were manually sorted in the laboratory to extract the invertebrates. These invertebrates were preserved in a solution of 70% alcohol with 5 drops of glycerin. Subsequently, they were identified to the order, family, and species level using specific literature references [12-15]. Virtual collection images were also consulted to aid in the identification process and to compile a checklist of the species encountered. The taxonomic data obtained from the identification process were then used to classify the invertebrates into functional groups based on their presumed dietary habits. These functional groups included predators, parasites, bioturbators, phytophages, coprophages, and saprophages [10,16].

Data Analysis

The data from the invertebrate community associated with leaf litter was used to calculate various ecological indices using the PAST (Paleontological Statistics) v. 4.10 free software for scientific data analysis. And, the diversity index (Simpson and Shannon-Wiener), equity index (Pielou), and richness index (Chao-1, iChao-1, and ACE) were computed to assess the ecological state of the community.

Additionally, correlation analysis was conducted to explore the relationship between these ecological indices and the precipitation parameter. The precipitation data (mm) utilized in the correlation analysis was obtained from the Weather Spark website for 2023 (Table 1).

Results and Discussion

Diversity of Terrestrial Invertebrates

Over 6 months, 166 invertebrates were captured, representing 9 orders and 17 families in the total sample for edge environments (P0), intermediary (P1), and interior (P2) of the fragment from Atlantic Forest in Patioba Farm (Table 2).

The edge (P0) of the fragment had the highest number of invertebrates (77), with functional groups of detritivores (little armadillos) and predators (ants and spiders) dominating over the others (Figure 2). This result is similar in diversity to Neves (2023) [17] and differs in part from the functional groups recorded by Sá (2023) [18]. When considering the orders in isolation, Hymenoptera (ants) are highlighted (Figure 3).

A greater abundance of invertebrates was registered at the edge (P0); however, the indices from Simpson, Shannon, and Chao showed diversity, equity, and richness similar to the interior (P1 and P2) of the fragment, likely due to the preliminary inventory over only 6 months (Table 3).

Functional Groups

At the edge (P0), the detritivores (little armadillos) and predators (ants and spiders) gained dominance over the other functional groups, namely phytophages, saprophages, coprophages, and bioturbators.

Functional groups were registered among the invertebrates, such as predators, phytophages, detritivores, saprophages, coprophages, and bioturbators.

There was a balance between detritivores and predators in this case because of the ants (Hymenoptera) and spiders (Araneae) (Table 4).

In this analysis of functional groups, predators from the orders Hymenoptera and Araneae stand out for their ecological importance in biological control, especially of detritivores [19].

Detritivores from the orders Isopoda, Stylommatophora, and Diplopoda play a crucial role in the decomposition of organic matter, contributing to the regeneration of the vegetal community [20]. Besides being predators, ants also serve as bioturbators in pedogenesis, particularly leaf litter and soil ants. By turning over leaf litter and soil, ants accumulate plant material as a nutrient

Table 1. Average monthly precipitation (mm) in Alagoinhas, Bahia (Brazil). September 2022 until February 2023.

Parameter	September 2022	October	November	December	January 2023	February
Precipitation (mm)	47.7	42.4	51.8	46.0	43.8	52.1

Figure 2. Correlation analysis between sample areas with differences at the edge (P0), and the interior (P1 and P2) of the Atlantic Forest's fragment.

Class	Order	Sub/Family	Genus	Species	P0	P1	P2
Malacostraca	Isopoda	Philosciidae	Philoscia	*P.muscorum*	30	3	2
Insecta	Blattaria	Blaberidae			9	3	2
		Isoptera			2	7	0
	Hymenoptera	Formicidae			2	4	1
		Ponerinae	Pachycondya	*P.striata*	0	2	0
		Dolichoderinae	Dorymyrmex		0	2	0
		Fornicinae			0	2	18
		Ectatominae			0	1	1
		Myrmicinae	Monomorium	*M.pharaonis*	14	0	0
	Orthoptera	Gryllidae			1	2	0
Arachnida	Araneae	Ctenidae			2	2	1
		Dictynidae			1	0	0
		Theraphosidae			0	1	0
		Phoneutria			0	1	0
		Salticidae			2	2	1
	Opiliones				3	0	0
Gastropoda	Stylommatophora	Achatinidae	Achatina	*A.fulica*	1	3	0
			Neobeliscus	*N.calcareus*	1	4	4
		Bradybaenidae	Bradybaena	*B.similaris*	5	7	6
Diplopoda	Spirostreptida				4	5	2
		Abundance			77	51	38

Table 2. Terrestrial invertebrate checklist associated with the Atlantic Forest's leaf litter in Alagoinhas, Bahia (Brazil). September 2022 until February 2023.

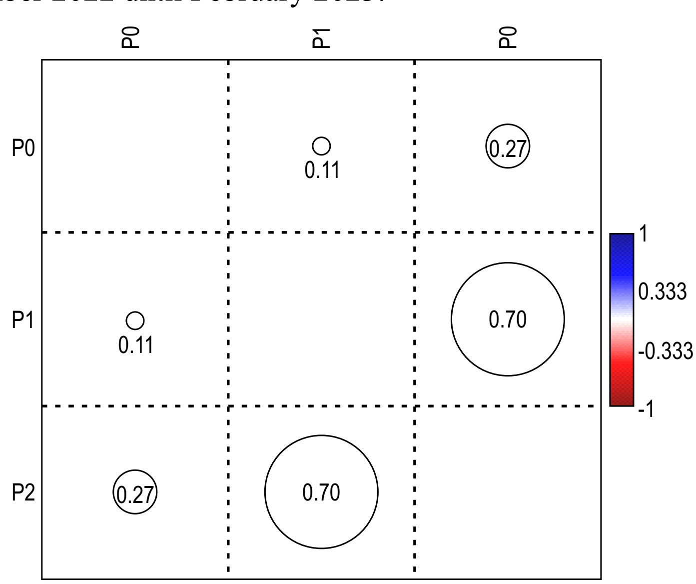


Figure 3. Cluster analysis by similarity with emphasis on Hymenoptera (ants).

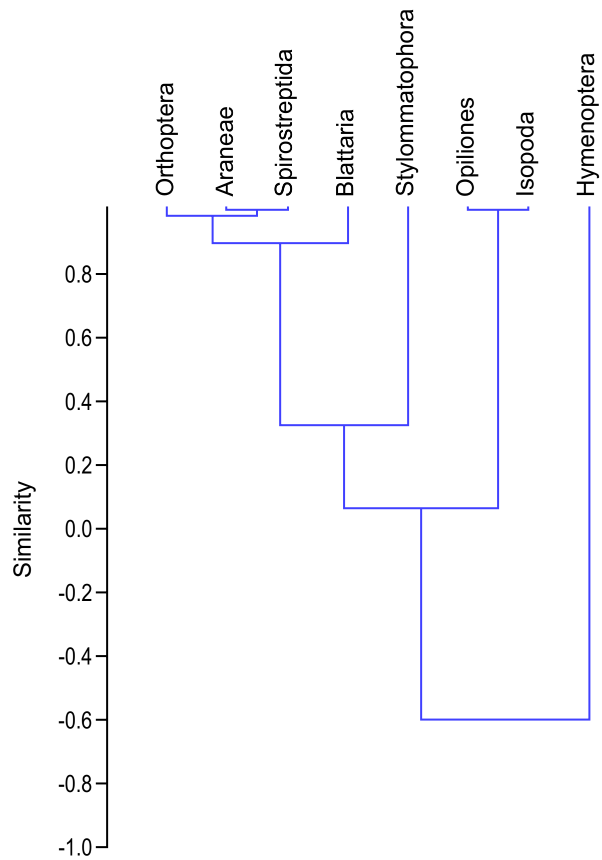


Table 3. Diversity indices of the terrestrial invertebrates associated with the Atlantic Forest's leaf litter in Alagoinhas, Bahia (Brazil). September 2022 until February 2023.

Indexes	Edge (P0)	Intermediary (P1)	Interior (P2)
Rate_S	8	7	6
Individuals	77	51	38
Dominance	0.2221	0.1725	0.3400
Simpson	0.7779	0.8275	0.6600
Shannon	1.7490	1.8370	1.3750
Equity_J	0.8412	0.9441	0.7673
Fisher_alfa	2.2450	2.1960	2.0040
Chao-1	8.00	7.00	6.00
iChao-1	8.24	7.00	6.00
ACE	8.38	7.00	6.00

Table 4. Functional groups registered among terrestrial invertebrates captured in a leaf litter fragment of the Atlantic Forest in Alagoinhas, Bahia (Brazil). September 2022 until February 2023.

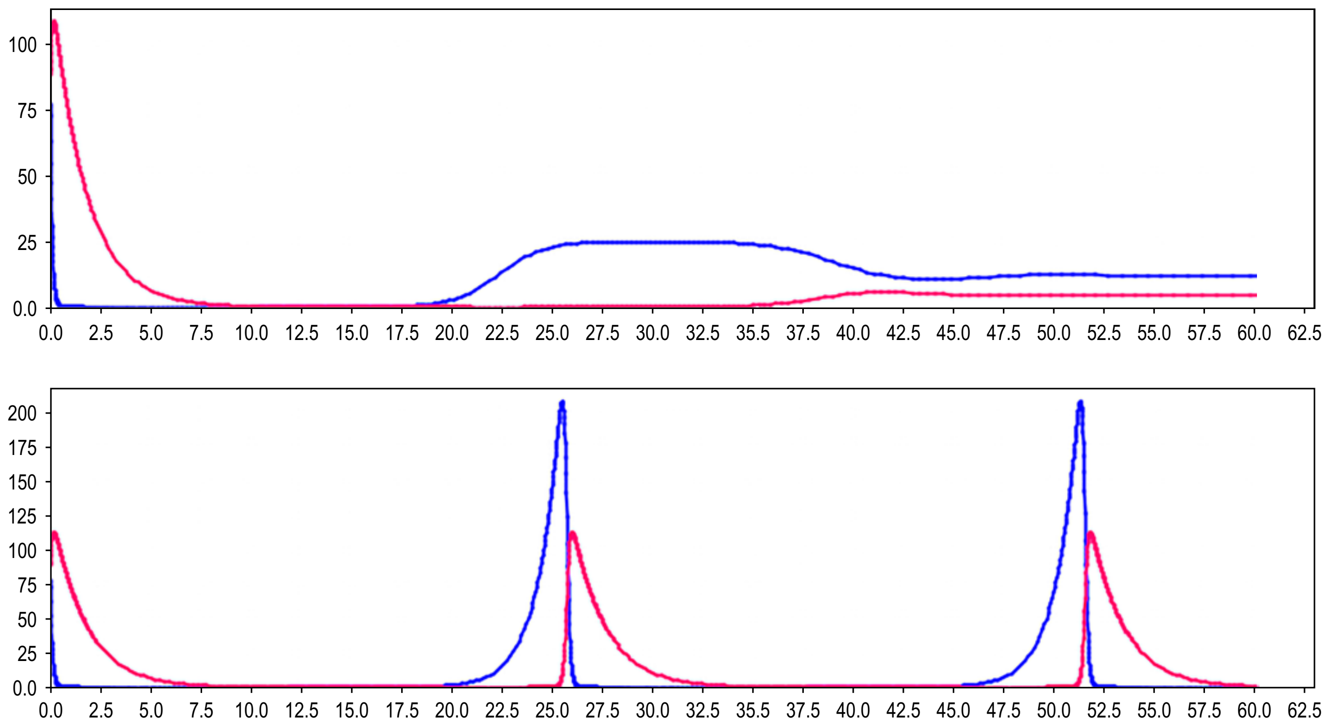
Order	Suborder Family Subfamily	Functional Groups					
		Predator	Phytophage	Detritivore	Saprophage	Coprophage	Bioturbator
Isopoda	Philoscidae			X	X	X	
Blattaria	Blaberidae			X			X
	Isoptera			X			X
Stylommatophora	Achatinidae			X			
	Bradybaenidae			X			
Hymenoptera	Ponerinae	X	X	X			X
	Formicidae	X					X
	Myrmicinae	X					X
	Ectatomminae	X					X
	Dolichoderinae	X	X				X
Arabeae	Ctenidae	X					
	Dictynidae	X					
	Theraphosidae	X					
	Phoneutria	X					
	Salticidae	X					
Opiliones		X					
Orthoptera	Gryllidae		X				
Diplopoda	Spirostreptida		X	X	X		X

source, contributing to soil fertilization. They also increase soil porosity, enhancing soil aeration and permeability for water transport to the atmosphere and edaphic fauna [21-24].

The bioturbators group includes termites (Blattaria: Isoptera) and springtails (Collembola). These organisms disturb and transform the soil through transport and ingestion, promoting soil aeration, recirculation of organic matter, and increasing porosity and water infiltration. Examples include termites, worms, enchytraeids, beetles, millipedes, and low-quality bioindicators [22,25]. Regarding predator-prey interactions, the simple model simulation of the Lotka-Volterra indicated that the community would take approximately 52 days to recover the dynamics of its predator and prey populations in the native fragment without interference from other variables. The abundance of predators directly affects the time needed to recover prey populations. In the continuous flow model of predator-prey interaction, the populations of predators (Pq, n=89) and prey (Nq, q=77) would take at least 52 days to begin their recovery at the edge of the native fragment. In the prey-dependent model, the minimum time needed is 25 days (Figure 4).

Indeed, various ecological factors can influence the population dynamics of predators and prey. Sometimes, these dynamics may follow a continuous flow model, where predator and prey populations fluctuate without external interference. However, in other scenarios, prey availability may regulate the populations, leading to a prey-dependent model. In this case, the populations of predators are influenced by the abundance and availability of their prey, which can be affected by factors such as food availability, competition, predation pressure, and environmental conditions. Prey populations may be reduced as predators consume them, and the system's dynamics are influenced by the structure of the food web [26].

Figure 4. A simulation between 89 predators and 77 prey in the prey-dependent model (inferior) or through a continuous flow model (superior).



Effect of Seasonality

The inability to observe the effect of seasonality on the distribution of invertebrates due to the limited duration of the study (6 months) is a common challenge in ecological research, especially in environments with distinct dry and rainy seasons. Seasonal variations in climate can significantly impact the abundance, diversity, and behavior of invertebrate communities, as well as their interactions with other organisms and the environment.

Typically, longer-term studies spanning multiple years or encompassing complete annual cycles are needed to capture invertebrate populations' seasonal patterns and dynamics adequately. Additionally, comprehensive sampling efforts throughout different seasons are necessary to accurately assess how environmental factors, such as temperature, precipitation, and resource availability, influence the composition and structure of invertebrate communities over time. In future research endeavors, extending the sampling period and incorporating data from multiple years could provide valuable insights into the seasonal dynamics of invertebrate communities in the Atlantic Forest fragment, helping to elucidate their responses to environmental changes associated with different climatic conditions.

Conclusion

The findings of this study indicate that over 6 months, 166 invertebrates belonging to 9 orders and 17 families were captured. Notably, there was a higher abundance of invertebrates (77) at the edge of the fragment compared to the interior. However, despite this difference in abundance, the indices of diversity, equity, and richness were similar between the edge and interior of the fragment.

At the edge of the fragment, detritivores (such as little armadillos) and predators (including ants and spiders) were found to dominate over other functional groups like phytophages, saprophages, coprophages, and bioturbators. This highlights the importance of these functional groups in the ecological dynamics of the fragment.

Predators from the orders Hymenoptera and Araneae were particularly noteworthy for their ecological importance in biological control, especially in regulating detritivore populations.

Simulation of predator-prey interactions suggested that the community would take approximately 52 days to recover the dynamics of predator and prey populations in the native fragment. This underscores the intricate nature of predator-prey relationships within the ecosystem.

However, despite the comprehensive sampling effort, observing the effect of seasonality (dry and rainy seasons) on the distribution of invertebrates in this brief inventory was not feasible. This may suggest the need for longer-term studies to fully understand the influence of seasonal variations on invertebrate communities in the fragment.

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