BAHIA STATE UNIVERSITY
Department of Exact and Earth Sciences - *Campus* II
Program of Post Graduation in
Modeling and Simulation of Biosystems

Jordana Gabriela Barreto de Sá

LITTER PRODUCTION AND ACTION OF FUNCTIONAL GROUPS OF TERRESTRIAL INVERTEBRATES IN A NATIVE FRAGMENT OF THE ATLANTIC FOREST IN BAHIA (BRAZIL)

Alagoinhas - Bahia - Brazil

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Dissertation presented to the Post Graduation Program in Modeling and Simulation of Biosystems at the Bahia State University (*Universidade do Estado da Bahia - UNEB*) as part of the requirements for obtaining the Master's degree in Modeling and Simulation of Biosystems.

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LITTER PRODUCTION AND ACTION OF FUNCTIONAL GROUPS OF TERRESTRIAL INVERTEBRATES IN A NATIVE FRAGMENT OF THE ATLANTIC FOREST IN BAHIA (BRAZIL)

JORDANA GABRIELA BARRETO DE SÁ

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Dedicated to the love of my life, my son João.💖

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Abstract

The objective of this work was to evaluate the relationship between litter production by the tree stratum and the action of functional groups of associated terrestrial invertebrates on the dynamics of nutrient cycling, under the effect of seasonality, in a native fragment of Atlantic Forest in Bahia (Brazil). The monthly litter deposition was regular with some seasonal peaks in the twenty collectors inside the fragment, attributed to the greater structural complexity with plant diversity and large visible size of the plants of the tree stratum in relation to the edge. A total of 192 invertebrates were captured in 11 orders in the monthly collections over 12 months. Hymenoptera, Isopoda, Stylommatophora, and Blattaria had the highest abundance among the orders. There was a higher diversity and richness indices at the edge of the fragment than the two internal environments. The ants at the edge and intermediate sites indicated both good environmental quality. There was a greater diversity of invertebrates at the edge in relation to the interior of the fragment, explained by the low sampling effort with punctual collections as opposed to the greater diversity in the interior. Among the seven functional groups, detritivores predominated over predators (herbivores and carnivores) and other categories. The detritivores of the orders Isopoda, Blattaria, Collembola, Coleoptera, Hymenoptera, Stylommatophora, and Spirostreptida were captured at the edge and in the interior of the native fragment. With fewer predators, less time is required for population recovery of prey, 15 and 10 days respectively, for the edge and interior. This study of plant-animal interaction, through litter production and the action of functional groups of terrestrial invertebrates, aims to contribute to the knowledge about ecosystem processes and biodiversity conservation in the Atlantic Forest.

Keywords: indexes, abundance, diversity, seasonality, precipitation.

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CONAMA, National Council for the Environment.

INPE, National Institute for Space Research.

MMA, Ministry of the Environment.

PELD, long-term ecological research.

Summary

1. Introduction

Litter is a key element in forest ecosystems and can be defined as material that has fallen mainly from vegetation and precipitated in the soil by microorganisms. It is closely related to the nutritional needs of some plant species (FIGUEIREDO FILHO et al., 2003). In this perspective, litter can be considered an ecological subsystem, where the microbiota in association with small invertebrates decomposes organic matter (CORREIA; PINHEIRO, 1999). This deposition is, therefore, the main source of nutrients for the survival and maintenance of the forest (KONIG; SCHUMACHER; SELING, 2002).

The study of nutrient cycling via litter is extremely important for understanding how this matter returns to the forest soil and how this process structures and regulates the functioning of ecosystems (VITAL et al., 2004; ROSA et al., 2017). This process is part of the biogeochemical cycles that occur in nature, fundamental for the synthesis of organic matter by plants through photosynthesis and cycling of nutrients in weathered soils (SCHUMACHER et al., 2003).

Factors such as forest successional status, altitude, temperature, winds, precipitation, herbivory rates and water availability interfere with litter production (PORTES; KOEHLER; GALVÃO, 1996). Considered a bio-indicator of reaction for offering a functional response in the deposition process to environmental variations (KLUMPP, 2001). Furthermore, the production and decomposition of litter have also been used as a primordial indicative parameter in agroforestry systems, aiming for the recovery of degraded areas (ARATO; MARTINS; FERRARI, 2003).

Invertebrates compose an abundant animal group in the forest system, where they perform decomposition, nutrient cycling, dispersion syndromes, and biological control, among others (CORREIA, 2002). Thus, the use of litter as a shelter and nutritional source by functional groups is an essential relationship that stands out, and this coexistence contributes to the maintenance of ecosystem processes (PEREIRA et al., 2013).

1.1 Problem

On the North Coast of Bahia, it is necessary to understand how the arboreal stratum contributes to the supply of material to the litter, and the functional groups of terrestrial invertebrates interact for the cycling dynamics of nutrients as a guarantee of maintenance of ecosystem processes for biodiversity conservation and restoration of degraded areas of the Atlantic Forest biome. Does seasonality, considering only the variables humidity and temperature, influence litter production and the activity of associated terrestrial invertebrates?

1.2 Justification

Litter is the interface between the forest, as a primary production component, and the associated terrestrial invertebrates, as transformation agents for nutrient cycling and soil fertility. In addition to acting as a carbon sink, litter serves as a shelter and food source for the food chain. Therefore, studies associated with vegetation and functional groups of associated invertebrates are the basis for knowledge of ecosystem processes in the conservation of remnants.

Firstly, environmental degradation can affect the composition and structure of plant and animal species occurring in the area, with invasions of exotic species and the consequent imbalance of the ecosystem in medium and long term (COSTA; GALVÃO; SILVA, 2019). Degradation can increase to the point of causing the loss of connectivity between remnants, risking biodiversity conservation, interfering with the natural regeneration dynamics of the fragment, and representing a risk to the survival of these ecosystems (FORTUNATO; QUIRINO, 2016; LORENZO; CAMPAGNARO, 2018).

In Bahia, there are studies on the plant-animal relationship with entomofauna groups, but the arboreal stratum with terrestrial invertebrates associated through the litter in the Atlantic Forest is a pioneer for the north of the state.

1.3 Objectives

1.3.1 General objective

To evaluate the relationship between litter production by the tree stratum and the action of functional groups of terrestrial invertebrates on the dynamics of nutrient cycling, under the effect of seasonality, in a native fragment of the Atlantic Forest in Bahia (Brazil) exposed to the edge effect by the increased forest fragmentation.

1.3.2 Specific objectives

- To estimate litter production by tree stratum in a native Atlantic Forest fragment in Bahia;
- To evaluate the edge effect on litter production and the action of functional groups;
- To analyze the seasonal effect on litter production;
- To identify the main functional groups among terrestrial invertebrates associated with leaf litter;
- To analyze the seasonal effect on the space-time distribution of these functional groups;
- To analyze the contribution of these groups in the cycling dynamics of the litter deposited.

1.4 Hypothesis

In the Atlantic Forest, litter production and the action of functional groups of terrestrial invertebrates are influenced by seasonality and the edge effect.

In the interior of the remnant, a greater richness of functional groups of invertebrates is expected in response to the structural complexity of the vegetation, as opposed to the edge.

In functional groups, more resilient species tend to exclude other more sensitive one when they compete for the same resource, and a lower abundance of predators exerts less pressure on prey, allowing for faster recovery.

2. Theoretical foundation

2.1 Tree stratum in litter production

The Atlantic Forest is considered a global biodiversity hotspot, given its endemic areas threatened with extinction (FORZZA et al., 2012; ZACHOS; HABEL, 2011; PINTO; HIROTA, 2022). One of the biomes with the greatest biodiversity in the world is currently fragmented by environmental degradation caused by human actions, however, it is home to more than 20,000 species of plants, of which more than 8,000 are endemic, that is, they do not exist anywhere else in the world (FUNDAÇÃO SOS MATA ATLÂNTICA; INPE, 2017).

Bahia is in second place among the five states that account for 91% of deforestation in Brazil, with a great threat and risk for the loss of biodiversity. Due to increasing deforestation, the biome was placed on the list of the 10 Brazilian states, from Bahia to Rio Grande do Sul, in priority for necessary restoration due to its high biodiversity (FUNDAÇÃO SOS MATA ATLÂNTICA; INPE, 2021). The restoration of ecosystems in degraded areas in Brazil is portrayed in different biomes, however, due to its importance and current structure, the Atlantic Forest has been the most mentioned in studies related to this theme.

During the development, tree species provide organic matter to the forest floor that serves as a contribution and guarantee of renewal in the rhizosphere (CUNHA NETO et al., 2013). The presence of organic matter is essential for the development of the ecosystem, especially for the production and return of nutrients to the soil, as the material from tree species deposits biomass rich in plant residues in the soil (VOGEL et al., 2013). Vegetable matter with a high lignin content tends to have a slower decomposition process (MARGIDA; LASHERMES; MOORHEAD, 2020). This stage contributes to the maintenance of nutrient cycling from the litter to the soil, being essential for the development of the plant community and the maintenance of ecosystem processes (BOMFIM et al., 2020).

The litter production and decomposition process is essential for nutrient cycling, measuring the flow of organic matter and nutrients from vegetation to the soil surface (MARTINS et al., 2021). In this regar, there is soil fertility, which is also an important nutrient deposit for plant species (ZAGO et al., 2020), protection against erosive effects on the soil (MORAES, 2002), and a carbon reservoir, mainly stored in the biomass of fallen trunks and the continuously supplied foliar fraction (HÄTTENSCHWILER et al., 2011).

Previous events of torrential rains, prolonged droughts, high temperatures and the fall of large trees affect the production and decomposition of plant material, determining the remaining amount available (FACELLI; PICKETT, 1991). Precipitation can cause less or greater deposition of plant material according to the occurrence and intensity of rainfall (MARTINELLI; LINS; SANTOS-SILVA, 2017). Temperatures and humidity affect the decomposition of soil organic residues and can change the composition of the accumulated litter. Locations with higher temperature and humidity favor the action of invertebrates and microbiota (CIANCIARUSO et al., 2006).

The vegetation pattern can be altered due to fragmentation, causing a change in deciduousness and arboreal diversity (VIDAL et al., 2007). No less important is the soil, which harbors a variety of organisms, biological shredders in the process of decomposition of organic matter. The constitution and consequent porosity of the soil affect water retention and cationic exchange capacity, necessary for plant nutrition and growth (BARBOSA; FARIA, 2006).

The litter is composed of branches, leaves, flowers, fruits and seeds, which fall from vegetation and form an organic layer on the forest floor (ESPIG et al., 2009; COSTA et al., 2010). The input of vegetal material by senescence or fall and its consequent accumulation interfere with the population dynamics of the plant community (PORTELA; SANTOS, 2007). Jewell et al. (2017) demonstrated that the diversification of litter and decomposers influences the increase in decomposition rates. Any alteration that causes a nutritional deficiency may affect plant development and the resulting restoration of the plant community in its species richness and diversity (SILVA; VILLELA, 2015).

Litter production and decomposition are affected by the variables of precipitation and temperature, in the so-called seasonality effect (GOMES et al., 2010; OLIVEIRA; MARQUES; MARQUES, 2019). Precipitation promotes greater fall of senescent parts of vegetation to litter and provides the necessary humidity for leaching and fungal growth for decomposition to occur. The temperature favors the hatching of eggs and the transformation of terrestrial mesofauna larvae, influencing the growth of the detritivores population for the degradation of litter and the enzymatic action of microorganisms in the organic matter decomposition (FIGUEIREDO FILHO et al., 2003; REBÊLO et al., 2022).

Predatory activity in the exploitation of natural resources causes changes in natural ecosystems and is one of the greatest consequences of forest habitat fragmentation, with the Atlantic Forest being one of the most affected ecosystems in Brazil (MYERS et al., 2000). The fragmentation widens the forest perimeter exposed to climatic factors such as solar radiation, high temperature, low humidity, winds and dehydration, causing alteration of the microclimate, interference in ecosystem processes and loss of habitats in extensive areas of the forest (RIBEIRO et al., 2009; SCORIZA; PIÑA-RODRIGUES, 2014; SANTOS et al., 2017). The edge is exposed to increased soil degradation, loss of vegetation and hunting, as well as disordered use and occupation (WIRTH et al., 2008). These changes in the edges of native forest fragments cause impacts on the biome that configure the edge effect (NASCIMENTO; LAURANCE 2006).

The edge effect creates an artificial division in the natural environment, which tends to fragment the habitat and change the structure and complexity of niches, leading to a decrease in biodiversity (HOLANDA et al., 2010). The edge effect can facilitate the action of predators and generalist competitors, as the prey are less protected and less resilient species have their populations reduced with the loss of habitats in this environment (RODRIGUES; NASCIMENTO, 2006).

At the edge of the forest fragment, there is a reduction in litter production due to the smaller size of the trees and high solar radiation, which causes desiccation and a lower survival rate. Consequently, the amount of litter biomass is lower in this area (SANTANA et al., 2021). In the interior of the forest, with more shading and humidity, there are species of varied habits that grow slowly and reach larger sizes. Therefore, litter production tends to be higher in this region, generating higher biomass values (SILVA et al., 2019).

2.2 Functional groups of invertebrates

As the litter decomposes, there are variations in its mass and depth resulting from the transformation performed by associated terrestrial invertebrates (PEREIRA et al., 2013). There are several characteristics, both structural and functional of ecosystems, that favor efficient nutrient cycling (VITAL et al., 2004). The leaf litter has an ecological role i) structural, due to the habitats they form for the diversity of terrestrial invertebrates, and ii) functional, for ample nutrition of the trophic network.

Cycling provides mineral nutrients to plants through the decomposition of organic matter by microorganisms and has been considered a fundamental step for high primary productivity in tropical forests (SAYER et al., 2020). In this context, the ecosystem services offered by litter contribute positively to greater soil fertility, in addition to serving as a shelter and nutritional source for edaphic fauna (FUJII; BERG; CORNELISSEN, 2020). Therefore, this relationship between litter and fauna helps to restore and maintain the ecosystem balance (CAMPOS et al., 2012).

Terrestrial invertebrates compose an abundant and diverse animal group that has established itself in almost all terrestrial ecosystems (BARETTA et al., 2011). They play an important role in different ecological niches in forest ecosystems, such as the decomposition of organic matter and nutrient cycling (ROSA et al., 2017). These organisms have particular characteristics in their morphology and behavioral pattern that enabled their establishment in the litter-soil system, becoming essential in various environmental services (PODGAISKI; MENDONÇA JR.; PILLAR, 2011).

The fragmentation process may begin with the action of invertebrates on parts of the living plant (ANDRADE; TAVARES; COUTINHO, 2003). The diversity of terrestrial invertebrates in the leaf litter is due to the availability of food resources (MOÇO et al., 2005). They are classified into functional groups related to their morphology, form of nutrition and food capture. Almost all soil and litter animals are included as detritivores. Along with predators, parasites, geophages, bioturbators, phytophages, coprophages, and microphages were grouped by Pereira et al. (2013) and Parron et al. (2015).

Predators are represented by arachnids, onychophoras, beetles, ants, wasps, centipedes and earwigs. They control the remaining populations of other organisms in the soil, especially the microbiota that conducts the decomposing action. Mites are in the group of parasites. Detritivores may include coprophages, which feed on excrement, necrophagous, which consume dead bodies, and microphages, which feed on fungi and other decaying materials. Woodlice, burrowing beetles, millipedes and earthworms are examples of coprophages (PARRON et al., 2015).

Phytophages cause damage to plant roots, they are considered pests from the point of view of agriculture, and mainly include ants, cicadas, earwigs, beetles, mollusks, bedbugs, crickets, and mites, among others. Termites, cockroaches, scorpions, moths, spiders, ants, some beetles and flies stand out as urban pests, whose larvae of the last two are classified as necrophagous (PARRON et al., 2015). Geophages and bioturbators move and transform the soil, both ingesting and transporting it. Some examples are termites, earthworms, enchytraeids, beetles and millipedes (BROWN et al., 2015).

The litter incorporation of waste from biological fragmentation tends to accelerate decomposition processes. Therefore, litter is an adequate indicator, with its nutrient deposition and cycling process related to ecosystem alterations (BAZI, 2019). The structure and diversity of invertebrate communities can be influenced by changes during forest succession (DENG et al., 2022). Saprophagous macroarthropods, for example, are important in the degradation of large amounts of litter (GANAULT et al., 2021).

The period in which interactions between invertebrate species occur in the leaf litter is a factor that increases its structural complexity by offering new niches to be explored. Wide time intervals are important, but little considered in short-term studies and require long-term ecological research (PELD) (FACELLI; PICKETT, 1991).

2.3 Influence of seasonality

The input of plant material occurs throughout the life of plant species, varying the amount of organic material deposited in the soil over different seasons of the year (ARAÚJO et al., 2005). Litter production is influenced by phenology, herbivory, decomposition rates and climatic factors (PINTO et al., 2008). Litter production varies during the year and is also influenced by climatic variables, especially humidity, temperature and precipitation. The seasonal effect can also determine the composition of the plant material (PINTO et al., 2008; YU et al., 2019). Changes in climatic conditions over the year, such as periods of drought or rain, can affect mainly leaf fall, influencing the quantity and quality of litter produced (CHAVE et al., 2010).

Biological activities, such as the decomposition of plant material, can also be affected by seasonality, as temperature and humidity can vary significantly throughout the year. Changes in atmospheric conditions play a significant role in the litter decomposition process. These seasonal variations affect the rate of decomposition and distinct patterns during climatic seasons. Temperature, humidity and precipitation vary throughout the day, seasons and year, influencing the development and behavior of species, on phenology and nutrient cycling, but responses to variations are not immediate (HOLANDA et al., 2015).

The structure of the ecosystem influences the production of litter. There are two basic patterns for annual litter deposition in Brazilian ecosystems. The first refers to greater deposition in the dry season, as occurs in Amazonian ecosystems, mesophilic forests and savannah (Cerrados). The second corresponds to an increase in the intensity of deposition in the wet season, as occurs in the Atlantic forests and restingas (BRASIL et al., 2017).

Given the extension of the Atlantic Forest biome, its predominantly humid tropical climate is diverse, with areas exposed to coastal humidity all year round and marked dry and rainy seasons. In the state of Bahia, the climate can vary from hot and superhumid (Af), hot and subhumid (Am) to hot and dry (Aw) in the coastal-inland direction. In the interior coastal strip, summer is marked by a dry season (December to February) of short duration compensated by high precipitation totals (April to August) and air humidity >80% (BRASIL, 1992; ALVARES et al., 2013). Peak litter production in tropical forests occurs during the dry season in summer. Precipitation, radiation and humidity act as determining factors in this occurrence, mainly due to the diversity of plant species and their different responses to the environmental conditions to which they are submitted (MARTINELLI; LINS; SANTOS-SILVA, 2017).

Climatic variables directly influence the plant community on a larger scale and terrestrial invertebrates act on a local scale for ecosystem productivity. Therefore, this study aims to evaluate the relationship between litter production and the action of functional groups of terrestrial invertebrates, regulated by a possible seasonal effect, as a contribution to reducing the gap in knowledge about efficient methods for restoring ecosystem processes and conservation of native forests.

3. Material and methods

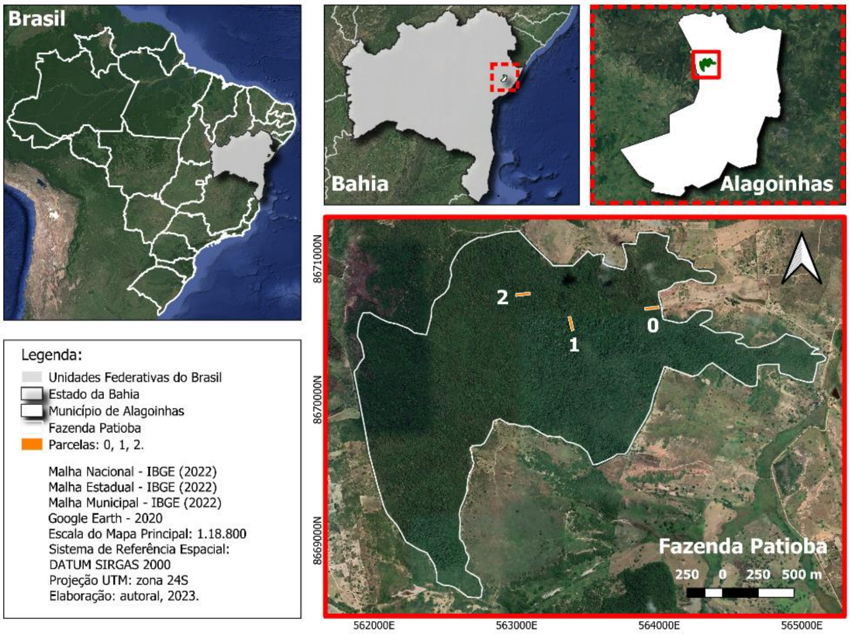
3.1 Study area

The study was performed in the municipality of Alagoinhas, located on the North Coast of Bahia, in a native forest fragment of the Atlantic Forest in the rural area belonging to Fazenda Patioba, with an approximate territorial extension of 343 hectares (Figure 1). Fragments larger than 100 hectares are called forest massifs and are the main habitat for rare species and species with greater carbon reserves (DANTAS, 2021).

Three collection sites were chosen: i) the edge of flat terrain (24 563.956 E; 8.670.645 S) at the entrance adjacent to the main trail that crosses the fragment; ii) an intermediate at the same altitude as the entrance and on a flat ground 522 meters distant from the edge (24 563.388 E; 8.670.530 S) and iii) one further inside the fragment, 804 meters from the edge (24 563.052 E; 8.670.745 S) on high ground at 268 m altitude (Figures 1 and 2).

The edge (T0) has more open vegetation when related to the more closed plant communities observed in both the intermediate (T1) and interior (T2) sites towards the core of the fragment (Figure 2). The Patioba vegetation is described as a Dense Ombrophylous Forest, composed of evergreen trees (medium and large) with dense canopies, shrubs and subshrubs, as well as lianas (DANTAS, 2021; EVANGELISTA; ALMEIDA, 2020).

Figure 1. Study area with the indication of sampling sites on the edge (T0), intermediate (T1) and interior (T2) of the Atlantic Forest fragment at Fazenda Patioba. Alagoinhas, Bahia (Brazil). October/2021 to September/2022.



Source: Proposed by the author, 2023.

Figure 2. Vegetation structure in plots 0, 1 and 2 of the Atlantic Forest fragment at Fazenda Patioba. Alagoinhas, Bahia (Brazil). October/2021 to September/2022.

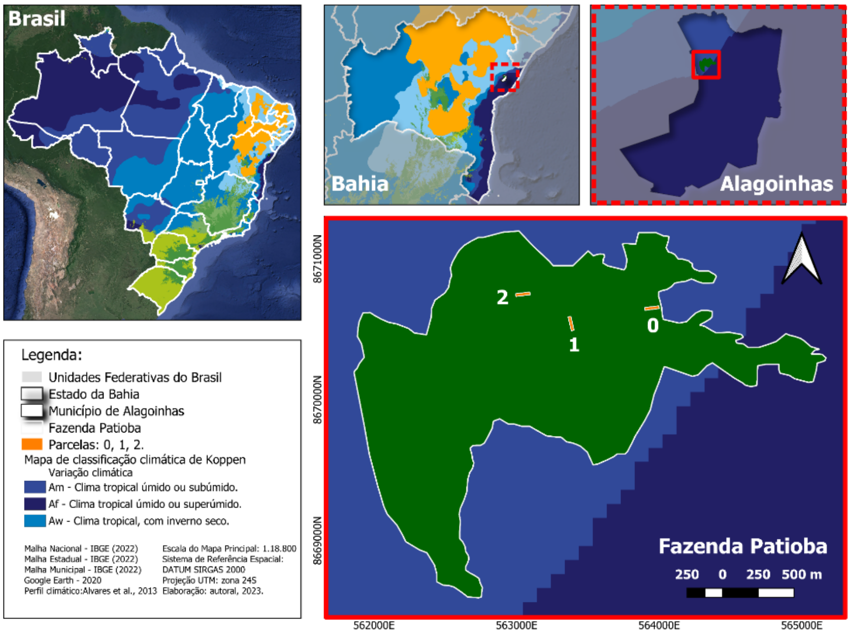
Source: Proposed by the author, 2023.

According to the Köppen-Geiger classification, the study area is under the humid tropical macroclimate, called Am, with a transition between the climatic types Af and Aw. Am is tropical humid or subhumid, a transition between the climate types Af and Aw, characterized by an average temperature of the coldest month always >18ºC with a short dry season compensated by high precipitation totals. This type of climate predominates in the interior coastal strip of Bahia. Type Af is tropical hot and humid, with a dry season in summer (December to February) and a rainy season in autumn-winter (April to August). The driest period occurs between November and January, with

January being the driest month. The rainy season begins in April and lasts until August, with the highest rainfall occurring in May and June (BRASIL, 1992; ALVARES et al.) (Figure 3)

Only the precipitation (mm) and temperature (ºC) parameters for the municipality of Alagoinhas were considered for correlation analysis and obtained from the website Weather Spark (2022) (Table 1). No parameter was measured in the study area, which is why humidity was not considered since the atmosphere in the municipality of Alagoinhas shows saturation records over previous years. Humidity can be provided to the environment through precipitation and maintained by the action of litter covering the soil.

Figure 3. Distribution map of the climatic types occurring in the Atlantic Forest fragment of Fazenda Patioba. Alagoinhas, Bahia (Brazil).



Source: Proposed by the author, 2023.

Table 1. Average monthly precipitation (mm) and temperature (ºC) in Alagoinhas, Bahia (Brazil). October/2021 to September/2022.

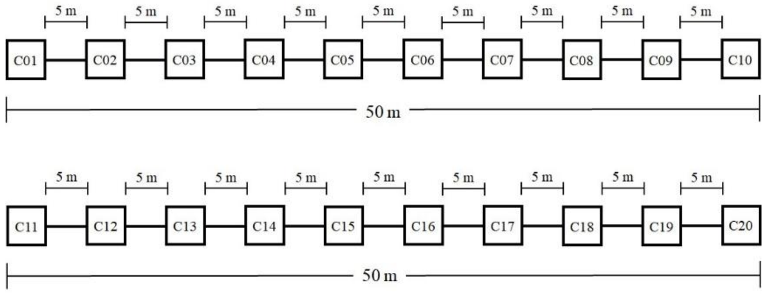
Abiotic factor	Oct/ 2021	Nov	Dec	Jan/ 2022	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Precipitation (mm)	47.3	54.5	53.3	40.8	50.1	53.2	91.7	131.1	122.5	97.4	67.6	47.2
Temperature (ºC)	22.7	27.1	26.9	28.5	28.2	27.8	25.3	25.0	21.4	21.7	24.0	24.4

Source: Adapted from the website *Weather Spark*, 2022.

3.2 Litter production

The study was conducted over a period of 12 months (October/2021 to September/2022). Initially, three plots of 100 m x 20 m were demarcated, and 20 collectors were installed in 5 sets of 1 m^2 subdivided into 4 units of 0.25 m^2 (C1-C4, C5-C8, C9-C12, C13-C16, C17-C20) equidistant every 5 m along the central transect in the plot (Figure 3). This was the method used for a better distribution under trees, generally with a robust trunk and leafy canopy in plots T0, T1 and T2 (Figure 4).

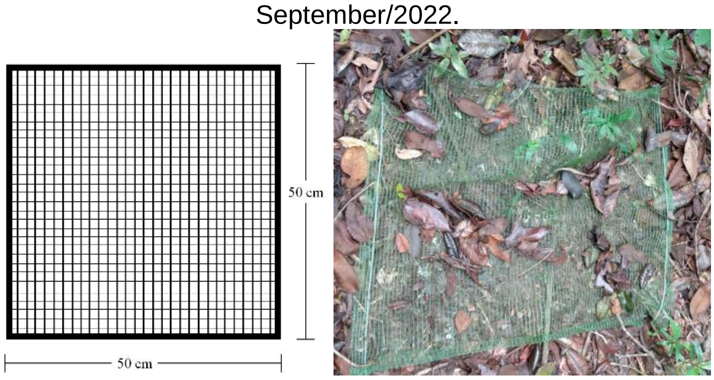
Figure 4. Transect (100 m) installed in the center of each plot in the Atlantic Forest fragment at Fazenda Patioba. Alagoinhas, Bahia (Brazil). October/2021 to September/2022.



Source: Proposed by the author, 2022.

The low-cost collector model was adapted from Fortes et al. (2008) and prepared with nylon mesh (2 mm) of 0.25 m^2 and lateral borders to form 1 cm of depth, having a frame armed with galvanized wire and fixed at the ends with rods (barbecue sticks) to avoid movement by rain or small animal (Figure 5). Samples were collected monthly and taken in identified black bags for proper treatment at the Ecology laboratory of the Center for Research in Ecology and Water Resources (CEPERH) on *Campus* II of the Bahia State University (Universidade do Estado da Bahia - UNEB). The total value of 5 m^2 was added to calculate the estimated monthly litter production.

Figure 5. Litter collector of 0.25 m^2 made of nylon mesh and wireframe, fixed at the ends by rods in the Atlantic Forest fragment at Fazenda Patioba. Alagoinhas, Bahia (Brazil). October/2021 to September/2022.



Source: Proposed by the author, 2022.

Litter samples were sorted manually, separated into the respective fractions of stem, leaf and reproductive part (flower, fruit and seed) in identified paper envelopes, and weighed on semi and analytical scales to record fresh biomass (g). Subsequently, they were dried in an oven at 60°C for 72 hours to record the dry mass (g) (Figure 6).

Figure 6. Manual sorting, recording and drying of litter fractions from collectors in the Atlantic Forest fragment at Fazenda Patioba. Alagoinhas, Bahia (Brazil). October/2021 to September/2022.

Source: Proposed by the author, 2022.

The fresh and dry mass data were used to estimate the monthly biomass production, as well as the humidity content (%), contained in the plant material of each litter fraction and lost after drying in the greenhouse. The humidity content accumulated by each litter fraction was calculated with the formula:

$$M. C. (\%) = 100 - [(Dm*100)/Fm]$$

In which: M.C is the moisture content expressed as a percentage of moisture contained in each litter fraction; Dm is the dry mass of plant material after the greenhouse and Fm is the fresh mass of plant material before the greenhouse.

The analyzes were performed using open-source software Paleontological Statistics (PAST Analyst) 4.10.

3.3 Classification of functional groups

The identification was made by the Specialist of the research group (Ueverton Santos Neves, personal communication) based on the specific literature (PAOLETTI; HASSALL, 1999; BACCARO, 2006; CARDOSO, 2017; BRUSCA; MOORE; SHUSTER, 2018) and comparison with images from virtual collections.

With these taxonomic data in hand, the terrestrial invertebrates captured in the collectors were classified according to their feeding habits and their presumed role in the litter, in: predators, parasites, phytophages, detritivores, saprophages and coprophages, according to Podgaiski, Mendonça Jr. and Pillar (2011) and Parron et al. (2015). To avoid data overlapping of multifunctional species, the animals were recorded only once in each group according to the environmental characteristics observed in the field.

The data were analyzed for the calculation of diversity indices through the Paleontological Statisticscs (PAST Analyst) 4.10 open source and only the monthly data were modeled by the open-use Populus 6.0 (ALSTAD, 2001).

The indices measure diversity (Simpson and Shannon-Wiener), equity (Pielou), wealth and wealth projection (Chao-1, iChao-1 and ACE). Indices of dominance, diversity, wealth and equity were used to estimate the ecological status of the terrestrial invertebrate community associated with litter (Table 2).

Table 2. Parameters, index and reference values for analysis of population data.

Parameters	Indexes	Reference values
Dominance	Simpson	0 - 1
Diversity	Shannon Wiever	1.5 - 3.5
Wealth	Margalef	3.81
	Menhinick	2.05
	Chao	2.5 - 97.5
Equity	Pielou	0.76

Source: Proposed by the author, 2023.

These indices can also be calculated based on the following equations:

$$D = \Sigma\, _{Pi}{}^{2}$$

In which: D, Simpson index (1949); *Pi*, relative abundance (proportion) of species *i* in the sample. Simpson's index indicates the probability that two randomly selected individuals belong to the same species.

$$H = -\Sigma\, _{Pi} * \ln_{Pi} \quad \text{e} \quad Pi = ni/N$$

In which: H, Shannon-Wiener index (1949); Pi, relative abundance; Ln, natural logarithm; N, total number of individuals; *n*i, number of individuals of each order.

The values of the rarefaction curve were obtained through combinatorial analysis, using Hurlbert's equation (1971), to verify how many possible combinations can be made and how many subsets can be obtained:

$$E(S_n) = {}^{S}{}_{i=1} \left[1 - \frac{(N-Ni\ n)}{(N\ n)} \right]$$

In which: N, is the total number of individuals in the community; Ni, is the number of individuals of the species; n is the number of individuals standardized for rarefaction.

The Chao-1 index is an estimator of the abundance of individuals belonging to a given class and estimates the species wealth in a given ecological community based on a sample. The estimator's proposal is based on the frequency of rare species, namely those that occur only once or twice in the samples (CHAO, 1987). This index is useful to compare the biological diversity between habitats or areas and to assess the sufficiency of the sampling effort in capturing most of the species present in the community (SANOS, 2006). The equation can be described as follows:

$$\text{Chao-1} = S_{obs} + F_1^2/2F_2$$

In which: S_{obs}, number of species observed; F_1, number of species that occur only once in the samples; F_2, number of species occurring twice in the samples.

The iChao-1 index assumes that the frequency of unique and duplicated individuals is proportional to the abundance of rare species in the community and that these rare species are the ones that contribute the most to species wealth. The iChao-1 is a robust and simple estimator that can be applied to different types of ecological data and that performs well compared to other estimators of species wealth (BALDRIAN et al., 2022). The iChao-1 can be calculated by the formula:

$$i\text{Chao-1} = S_{obs} + [n_1(n_1\text{-}1)/2(n_2+1)]$$

In which: S_{obs}, number of species observed; n_1, number of unique individuals; n_2, number of duplicated individuals.

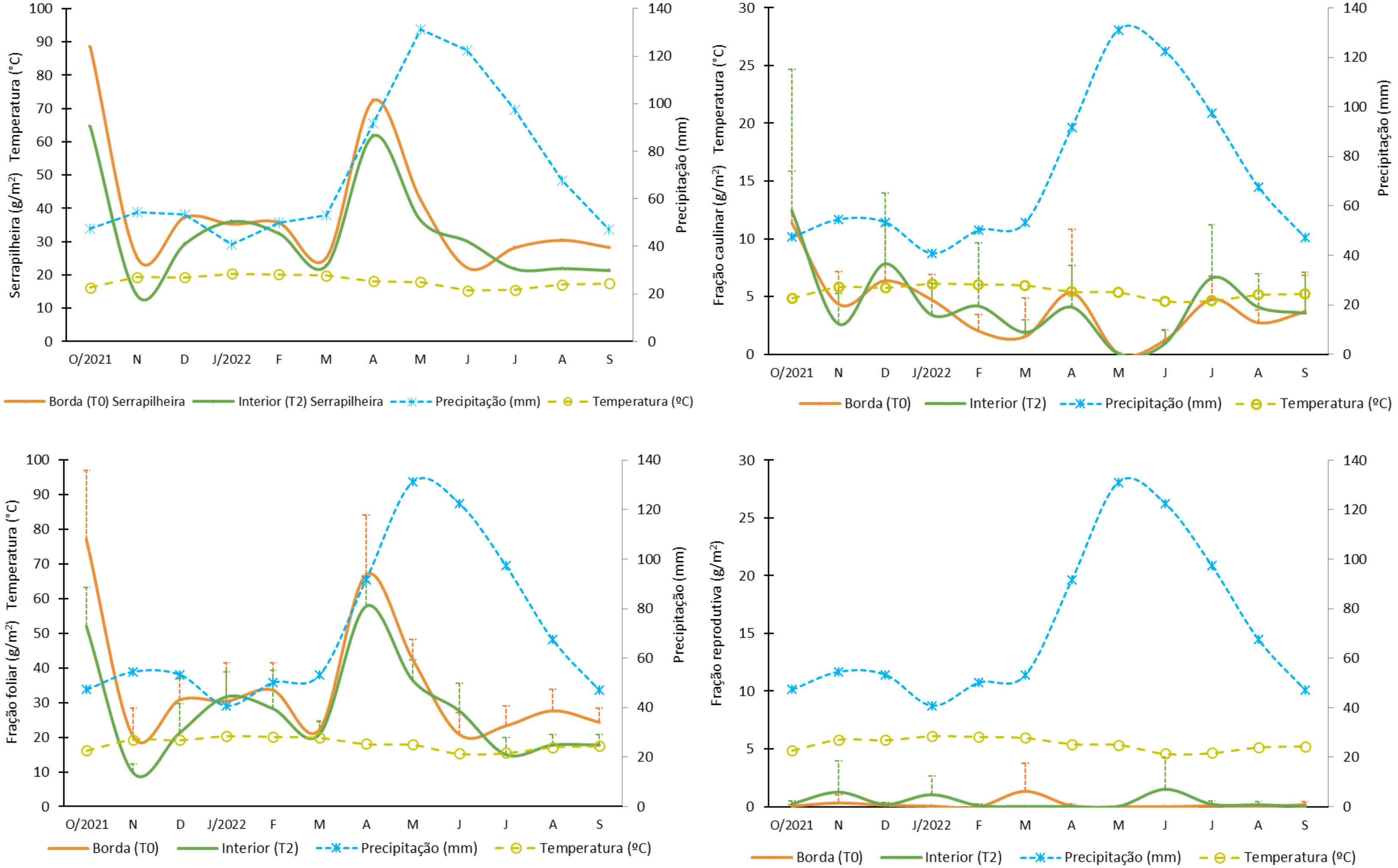
Classical mathematical modeling of ecological systems was performed with the expanded application of the simple Lotka-Volterra model to the case where there is intra-trophic competition between detritivores (prey) and carnivores (predators) (SOUZA, 2017). The dynamics of predator-prey interaction were modeled in continuous flow and dependency of prey (prey-dependent) for the edge (T0) and interior (T2) over 100 days, a period used as a comparative standard for monthly collections over 12 months. Quarterly data were not modeled by incipient or non-existent abundance.

4. Results and discussion

4.1 Litter production and seasonal effect

Litter production was similar ($p<0.05$) between edge (T0) and interior (T2), both in total production and in its stem and leaf fractions, in the 12 monthly collections. Production dropped sharply with increased precipitation in May at the edge and in the interior of the fragment (Figure 7).

Figure 7. Total litter (upper left) and its stem fractions (upper right), leaf (lower left) and reproductive (lower right) collected on the edge (T0) and interior (T2) of the Atlantic Forest fragment at Fazenda Patioba in relation to precipitation (mm) and temperature (ºC). Alagoinhas, Bahia (Brazil). October/2021 to September/2022.

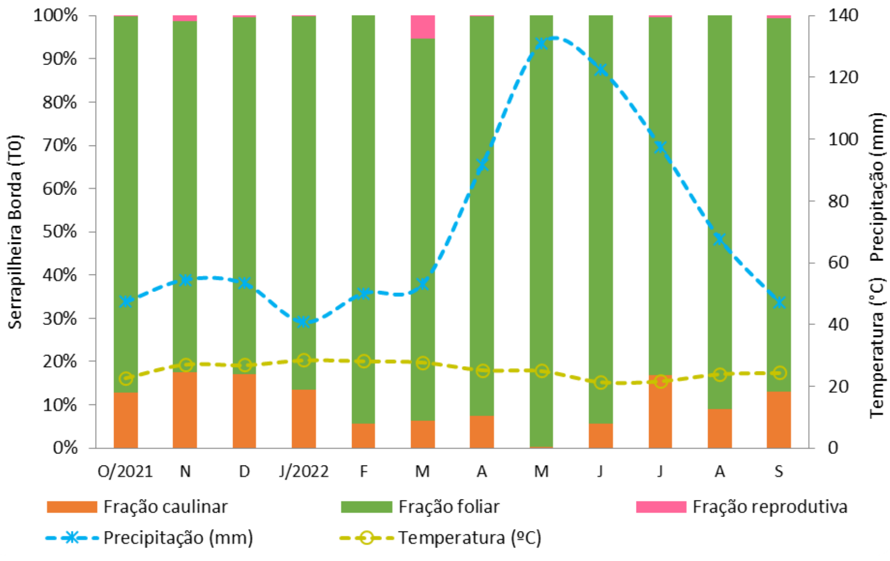


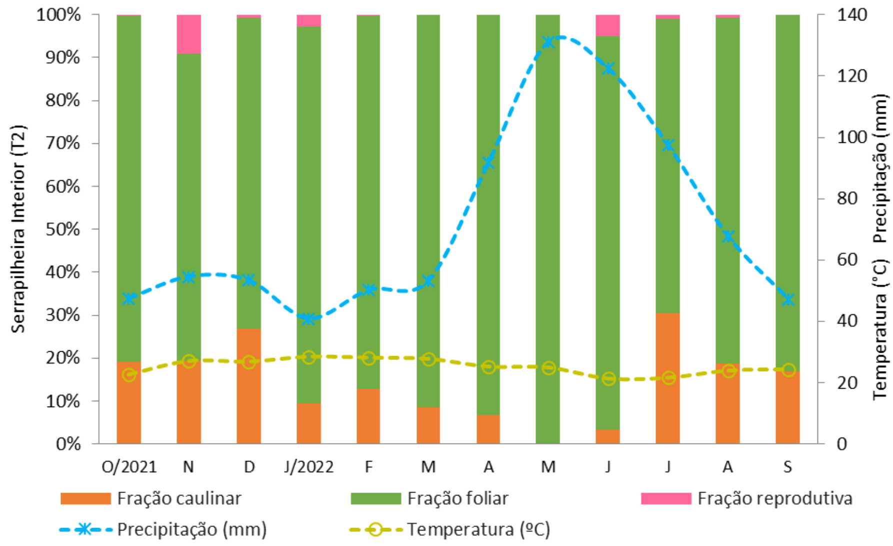
At the edge (T0), the production of the leaf fraction was attributed to the sparse canopy of the tree stratum, which favored the greater fall of leaves from the trees due to the action of rain. At the interior (T2), the structural complexity of the vegetation was reflected by the larger reproductive fraction when related to the edge (T0) (Figure 8).

The seasonal effect of precipitation regulated the production, higher in the dry season and lower in the rainy season, corroborating the studies by Andrade et al. (2020) and Câmara, Holanda and Costa (2021). The edge environment of a native fragment has greater vegetation exposure to the effect of solar radiation, precipitation and temperature. The most open vegetation with sparse canopy is exposed to the impact of rainfall and, consequently, litter production, it is expected to be mainly regulated by precipitation.

The correlation analysis of the total litter and its stem, leaf and reproductive fractions of the collectors between the edge (T0) and the interior (T2) of the fragment showed only a difference in the reproductive fractions between the sampling sites (Figure 9, Table 3).

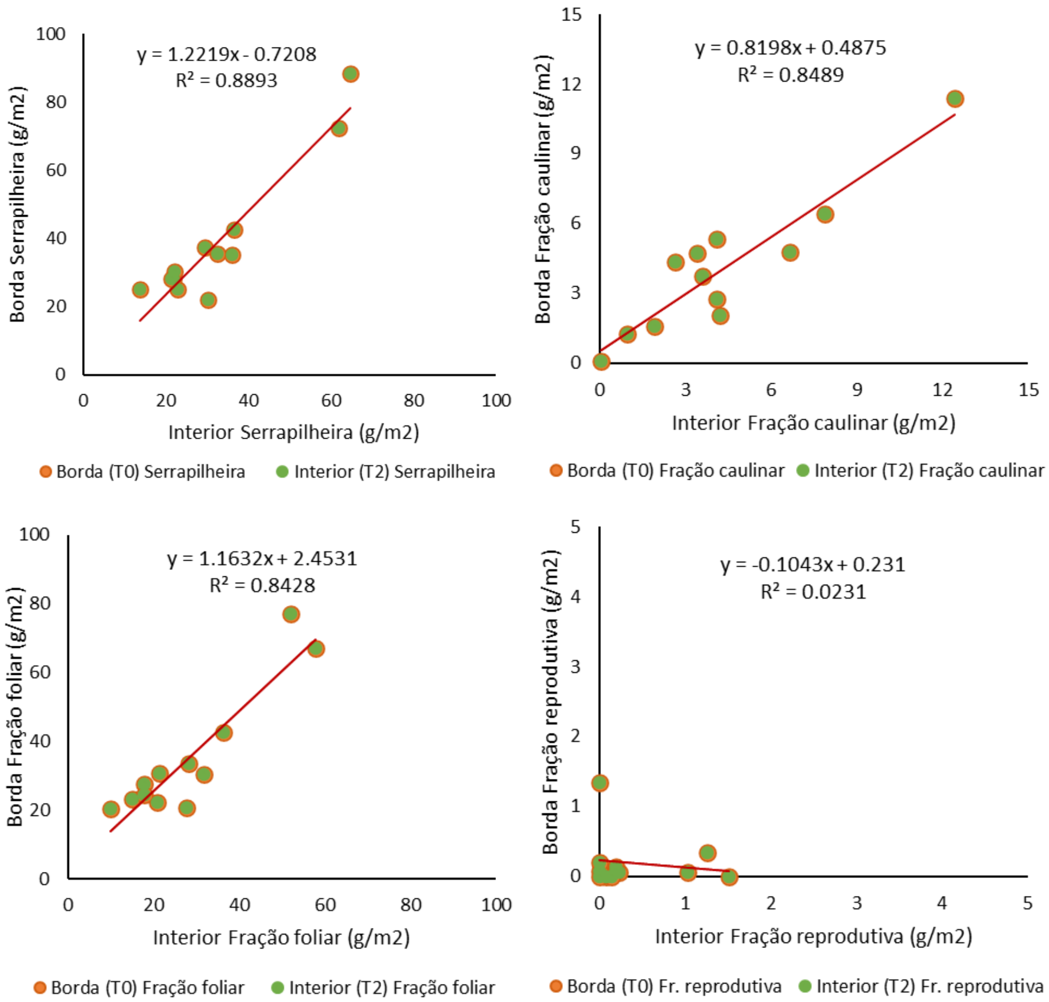
Figure 8. Total litter and stem, leaf and reproductive fractions collected at the edge (T0) the interior (T2) of the Atlantic Forest fragment at Fazenda Patioba. Alagoinhas, Bahia (Brazil). October/2021 to September/2022.





Source: Proposed by the author, 2023.

Figure 9. Correlation of total litter and its stem, leaf and reproductive fractions of collectors between the edge (T0) and the interior (T2) of the Atlantic Forest fragment at Fazenda Patioba. Alagoinhas, Bahia (Brazil). October/2021 to September/2022.



Source: Proposed by the author, 2023.

Table 3. Correlation analysis by Pearson, Spearman and Kendall indices (p<0.05) of total litter and its fractions between plots in the Atlantic Forest fragment at Fazenda Patioba. Alagoinhas, Bahia (Brazil). October/2021 to September/2022.

Edge (T0) x Interior (T2) (p<0.05)			
Correlation	**Pearson**	**Spearman**	**Kendall**
Total Litter	0.94 (p=0.0004)	0.76 (0.004)	0.61 (0.006)
Stem Fraction	0.92 (p=0.002)	0.82 (p=0.001)	0.67 (p=0.003)
Leaf Fraction	0.92 (p=0.003)	0.81 (p=0.001)	0.64 (p=0.004)
Reproductive Fraction	-0.15 (p=0.64)	-0.15 (p=0.65)	0.12 (p=0.59)

Source: Proposed by the author, 2023.

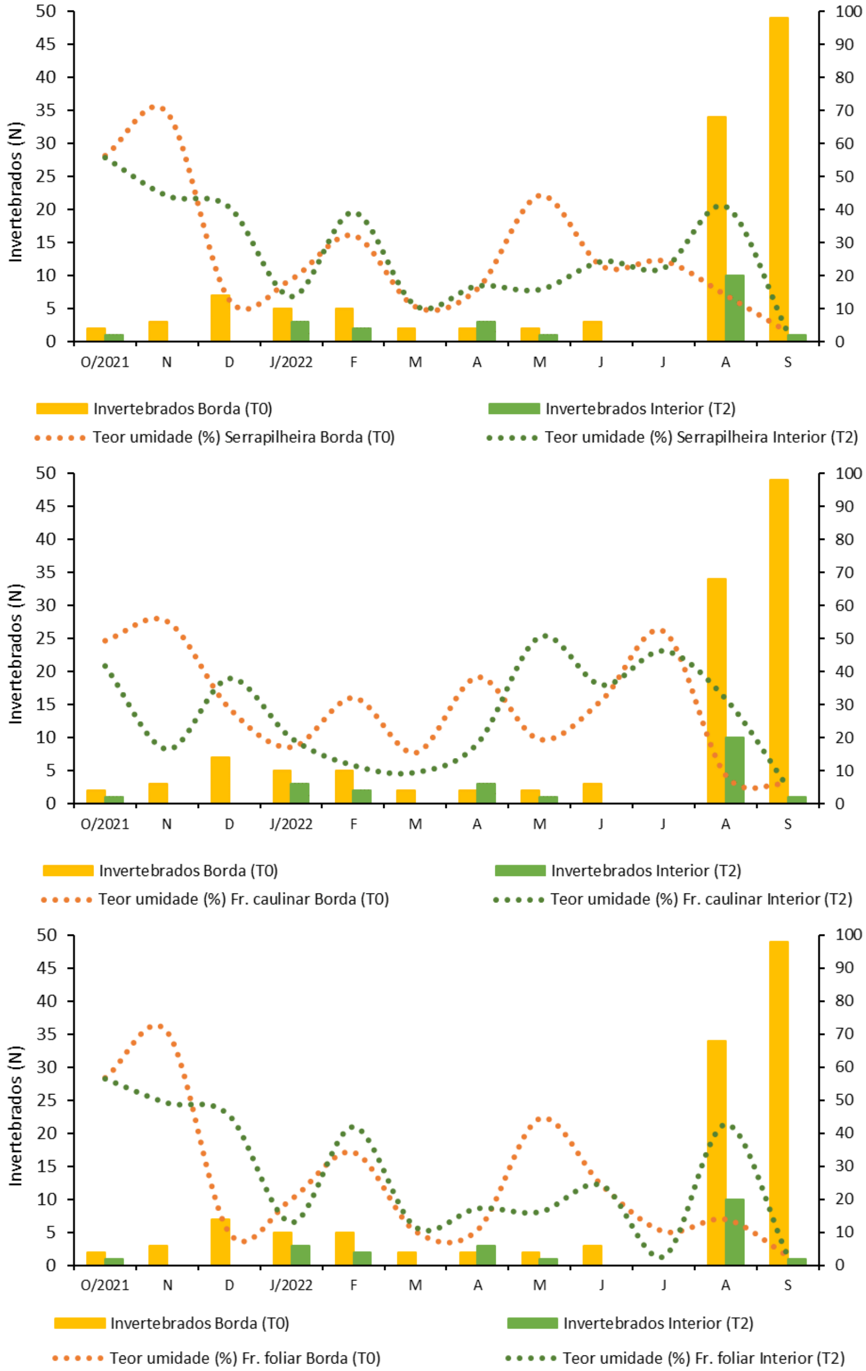
As expected, the humidity content contained in the litter increased with the greater availability of water through the abundant and regular rainfall of the rainy season (autumn and winter). The peak in invertebrate abundance on the edge (T0) was due to isopods in August and ants in September, with the reduction of copious rainfall and the increase in temperature (Figure 10).

Heavy precipitation in the rainy season can drag these organisms out of the collector, to seek shelter in the remaining organic material. A litter is a layer that favors the formation of a humid chamber over the soil. In the rainy season, the stem fraction prevailed over the leaf fraction. Invertebrates seem to prefer movement with less humid litter, either because of the ease of escape in the case of detritivores or predators in the movement to capture their prey (Figure 10).

Humidity is retained by litter, especially by the leaf fraction, after the rainy season, which contributed to the washing (leaching) of toxic polyphenols from the plant material. There is the consequent availability of organic detritus colonized by fungi, which will serve as a nutritious cocktail for detritivores invertebrates (ZIMMER; KAUTZ; TOPP, 2003).

Higher temperature affects the rate of decomposition and nutrient release. A lower value reduces this rate and contributes to litter accumulation. Temperature can also influence the activity of invertebrates, such as ants (Hymenoptera: Formicidae) and beetles (Coleoptera). This integrated effect of climatic factors, humidity and temperature influences the quality of the litter, and depending on the feeding preference of the invertebrate, will affect its composition (PINHEIRO et al., 2002; CARVALHO et al., 2018).

Figure 10. The abundance of invertebrates according to the humidity content in the total litter (first graph) and in the stem fractions (second graph) and leaf fractions (third graph) between the border and the interior of the Atlantic Forest fragment at Fazenda Patioba. Alagoinhas, Bahia (Brazil). October/2021 to September/2022.

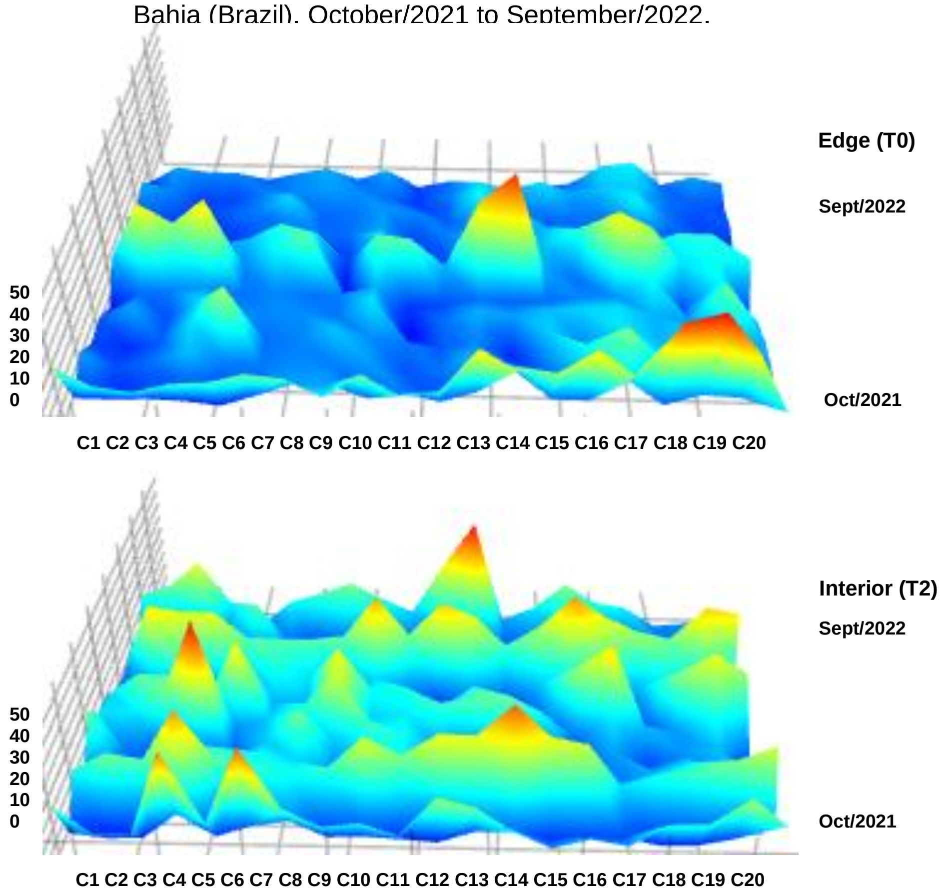


Source: Proposed by the author, 2023.

The monthly deposition of litter was regular with some seasonal peaks in the twenty collectors (C1 to C20) in the interior (T2) when related to the edge of the fragment (Figures 11 and 12).

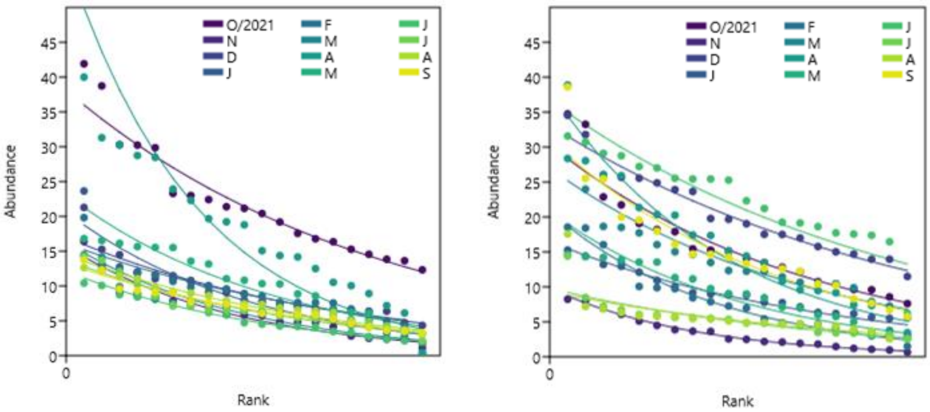
The greater diversity of the arboreal stratum and the large size of the trees contributed to greater support of litter in the interior (T2) when related to the edge (T0) in the native fragment. This result was similar to the records by Santos (2014) and Câmara, Holanda and Costa (2021) for preserved fragments of the Atlantic Forest.

Figure 11. Natural deposition profile of plant material in collectors along the transect in each plot on the edge (T0) and the interior (T2) of the Atlantic Forest fragment at Fazenda Patioba. Alagoinhas, Bahia (Brazil). October/2021 to September/2022.



Source: Proposed by the author, 2023.

Figure 12. Litter abundance distribution model deposited in collectors along the transect in the edge (T0) (left) and interior (T2) (right) plots in the Atlantic Forest fragment of Fazenda Patioba. Alagoinhas, Bahia (Brazil). October/2021 to September/2022.



Source: Proposed by the author, 2023.

The diverse arboreal stratum, consisting mainly of fast-growing evergreen native tree species and deciduous ones, with a variety of leaf consistencies (membranous, chartaceous and coriaceous) guarantees the supply of material to the litter for a long time (DANTAS, 2021). Decomposing leaves represents the first stage of continuous nutrient transfer from plants to the litter-soil system, which represents a carbon sink. The varied leaf consistency among the dominant tree species works as a natural mechanism, which regulates the continuous supply of vegetal material with fast or slow release of nutrients (JESUS, 2020; OLIVEIRA, 2022).

The main factors that form litter are climate and vegetation, due to their genetic characteristics, age, density and diversity. The occurrence of trees with zoochoric dispersion syndrome increases the nutritional richness of litter with fruits and seeds that attract litter fauna, essential for biological fragmentation (PARRON et al., 2015).

4.2 Functional groups captured in collectors

Despite litter collectors being open and the invertebrates free to escape, a total of 192 individuals were captured in 11 orders over 12 months. In total, among the orders, Hymenoptera (34%), Isopoda (22%), Stylommatophora (17%) and Blattaria (13%) had the highest recorded abundance (Table 4, Figure 13).

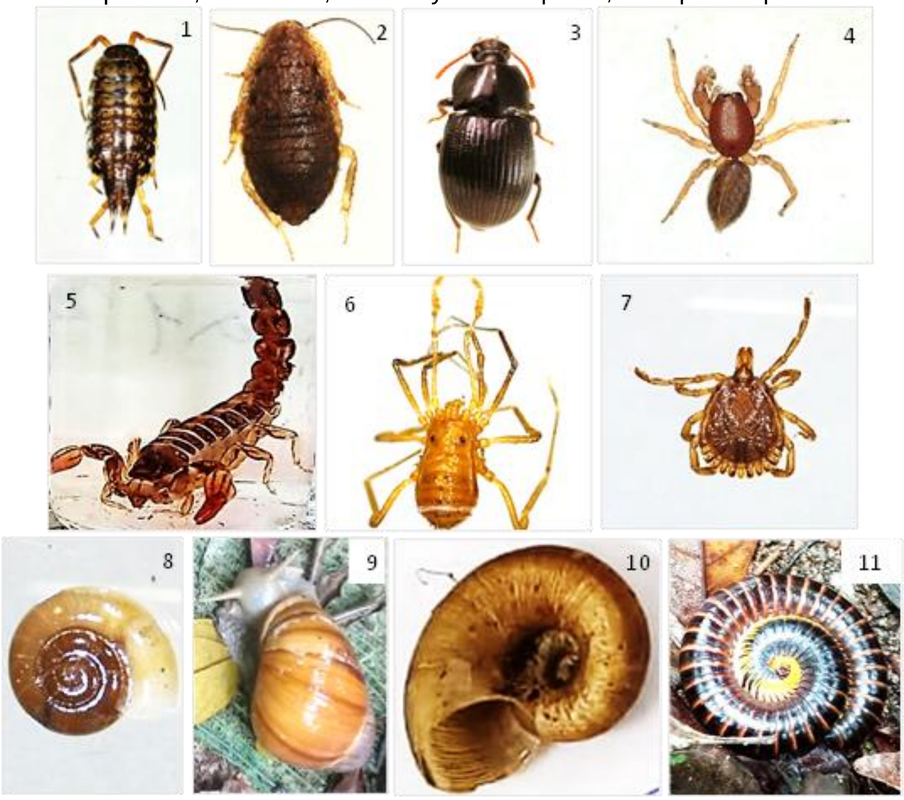
Table 4. Checklist of the taxonomic orders of specimens captured in the litter collectors of the plots in the Atlantic Forest fragment of Fazenda Patioba. Alagoinhas, Bahia (Brazil). October/2021 to September/2022.

Class	Order	Sub/Family	Species	T0	T1	T2
Malacostraca	Isopoda	Philosciidae	*Philoscia muscorum*	24	12	6
Insecta	Blattaria	Blaberidae		4	0	0
		Isoptera		22	0	0
	Hymenoptera	Formicidae	*Atta* sp.	28	32	6
	Coleoptera			4	0	0
	Collembola			1	0	0
Arachnida	Araneae	Ctenidae Dictynidae Lycosidae Salticidae		7	1	1

	Scorpions			0	1	0
	Opiliones			2	0	1
	Ixodida			3	0	0
Gastropoda	Stylommatophora	Achatinidae Bradybaenidae Subulinidae	*Achatina fulica bradybaena similaris Neobeliscus calcareus*	15	11	7
Diplopoda	Spirostreptida			4	0	0
Abundance				114	57	21

Source: Proposed by the author, 2023.

Figure 13. Invertebrates of the taxonomic orders of specimens captured in the litter collectors of the plots in the Atlantic Forest fragment of Fazenda Patioba. Alagoinhas, Bahia (Brazil). October/2021 to September/2022. Label: 1. Isopoda, 2. Blattaria, 3. Coleoptera, 4. Araneae, 5. Scorpiones, 6. Opiliones, 7. Ixodida, 8-10. Stylommatophora, 11. Spirostreptida.

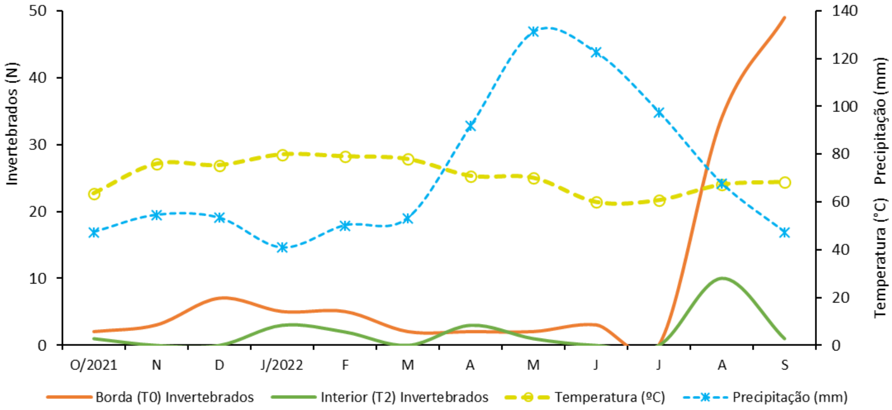


Source: Proposed by the author, 2023.

In the litter of collectors, invertebrates decreased with increasing precipitation and decreasing temperature at the edge and inside the fragment (Figure 14).

The leaf fraction corresponds to the greatest contribution of biomass from the vegetation to the litter and its accumulation allows the action of invertebrates after the rainy season. Abundant and continuous rains solubilize the toxic polyphenols of the deposited vegetal material and alter the structure and quality of the litter that can then be colonized later by microorganisms as a nutritious cocktail for invertebrates, such as isopods (ZIMMER; KAUTZ; TOPP, 2003).

Figure 14. Invertebrates captured in the litter of collectors at the edge (T0) and interior (T2) concerning precipitation and temperature in the Atlantic Forest fragment of Fazenda Patioba. Alagoinhas, Bahia (Brazil). October/2021 to September/2022.



Source: Proposed by the author, 2023.

The monthly collections showed a greater diversity on the edge when related to the interior of the fragment, explained by the artificial habitat that the collector offered, used as a refuge by invertebrates on the edge (T0). Due to its organic composition and physical characteristics, litter plays a key role in sheltering invertebrates, retaining humidity in the soil and regulating temperature, creating a microclimate conducive to the survival of these invertebrates (WOLTERS, 2001). Moreover, the animals in the interior (T2) did not shelter in the collector, but in the litter itself, which is more complex in terms of quantity (production) and quality (different composition) (Table 5). A low sampling with punctual collections can explain the opposite concerning the expected greater diversity in the interior than on the edge of the fragment, according to Tessaro et al. (2020).

Each fragment has particularities, and the edge effect can create habitats and niches that favor the establishment of resilient predatory species or strong competitors that impact the variety of native functional groups in the forest perimeter. Therefore, the increase in species at the edge does not necessarily increase diversity, but it can even cause the opposite effect. Diversity is a ratio between richness and abundance, if richness at the edge is affected by a high number of dominant species, benefiting from less complex conditions, the diversity decreases. Despite this, our results showed that the diversity of terrestrial invertebrates on the edge was larger than on the interior.

The presence of clearing with an exposed surface on the edge allowed colonization by resilient species, which were not found in the interior. However, these conditions were not enough for the species to dominate in the edge community, a fact attributed to the existence of a still satisfactory layer of litter despite environmental degradation and lower tree diversity.

Table 5. Indices of diversity and richness of invertebrates captured in litter collectors on the edge and the interior of the Atlantic Forest fragment at Fazenda Patioba. Alagoinhas, Bahia (Brazil). October/2021 to September/2022.

Indexes	Edge (T0)	Interior (T2)
Rate_S	10	5
Individuals	114	21
Dominance_D	0.1740	0.2429
Simpson_1-D	0.8260	0.7571
Shannon_H	1.9310	1.4670
Evenness_e^H/S	0.6896	0.8675
Brillouin	1.7540	1.1280
Menhinick	0.9366	1.0910
Margalef	1.9000	1.3140
Equitability_J	0.8386	0.9117
Fisher_alpha	2.6400	2.0760
Berger-Parker	0.2456	0.3333
Chao-1	10.50	5.952
iChao-1	10.59	5.952
ACE	10.42	6.283

Source: Proposed by the author, 2023.

Since the work is a pioneer in the study area, the quarterly collections with only 4 months of data proved to be insufficient for the analysis of diversity indices among the three environments. The edge had higher diversity and richness indices than the intermediate environment and the interior of the fragment (Table 6).

Table 6. Indices on diversity and richness of invertebrates captured in litter collectors in the edge, intermediate and interior environments of the Atlantic Forest fragment at Fazenda Patioba. Alagoinhas, Bahia (Brazil). October/2021 to September/2022.

Indexes	Edge (T0)	Intermediate (T1)	Interior (T2)
Rate_S	10	5	1
Individuals	61	57	1
Dominance_D	0.2350	0.3866	-
Simpson_1-D	0.7650	0.6134	-
Shannon_H	1.8600	1.1470	0
Evenness_e^H/S	0.6421	0.6295	1
Brillouin	1.5720	1.0060	0
Menhinick	1.2800	0.6623	1
Margalef	2.1890	0.9894	0
Equitability_J	0.8076	0.7124	-
Fisher_alpha	3.4000	1.3200	0
Berger-Parker	0.4426	0.5614	1
Chao-1	10.49	5.982	1
iChao-1	12.33	5.982	1
ACE	11.30	5.982	1

Source: Proposed by the author, 2023.

Among the terrestrial invertebrates captured in the collectors, the following functional groups were found: predator, phytophage, detritivore, saprophage, coprophage, parasite and bioturbator. The order Isopoda (Philoscidae) showed a characteristic high abundance pattern with only one specie. In this analysis of functional groups, due to their high ecological importance, three orders were also considered at the lowest taxonomic level of family or subfamily, such as Blattaria, with termites (Isoptera) highlighted by their characteristic abundance; Hymenoptera with the families Ponerinae, Formicidae and Myrmicinae; as well as Stylommatophora in the families Achatinidae and Bradybaenidae with a few individuals each. This strategy was chosen to give value to smaller categories, but with equivalence on orders (Table 7).

Table 7. Functional groups of invertebrates collected with leaf litter in Atlantic Forest fragment plots at Fazenda Patioba. Alagoinhas, Bahia (Brazil). October/2021 to September/2022.

Order	Suborder Family Subfamily	Functional group						
		Predator	**Phyto phagous**	**Detritivore**	**Saprophagous**	**Coprophagous**	**Parasite**	**Bioturbator**
Isopoda	Philoscidae			X	X	X		
Blattaria	Blaberidae Isoptera			X X				X X
Collembola				X				X
Stylommatophora	Achatinidae Bradybaenidae			X X				
Coleoptera		X	X	X	X	X		X
Hymenoptera	Ponerinae Formicidae Myrmicinae	 X X	X	X				X
Araneae	Theridiidae	X						
Opiliones		X						
Scorpiones		X						
Spirostreptida			X	X	X			X
Ixodida							X	

Source: Proposed by the author, 2023.

In the monthly collections, they were captured in the collectors of:

- Edge (T0): 37 predators (28 Hymenoptera, 7 Araneae, 2 Opiliones), 73 detritivores (24 Isopoda, 26 Blattaria, 4 Coleoptera, 15 Stylommatophora, 4 Spirostreptida), 1 bioturbator (1 Collembola) and 3 parasites (Ixodida).
- Interior (T2): 8 predators (6 Hymenoptera, 1 Araneae, 1 Opiliones) and 13 detritivores (6 Isopoda, 7 Stylommatophora).

Among the predators, specimens of the orders Hymenoptera (Ponerinae, Formicidae and Myrmicinae; Insecta), Coleoptera (Carabidae, Insecta), Araneae, Opiliones, Pseudoscorpiones (Arachnida) and Scolopendrida (Diplopoda) occurred on the edge (T0) and in the interior (T2) of the Patioba fragment.

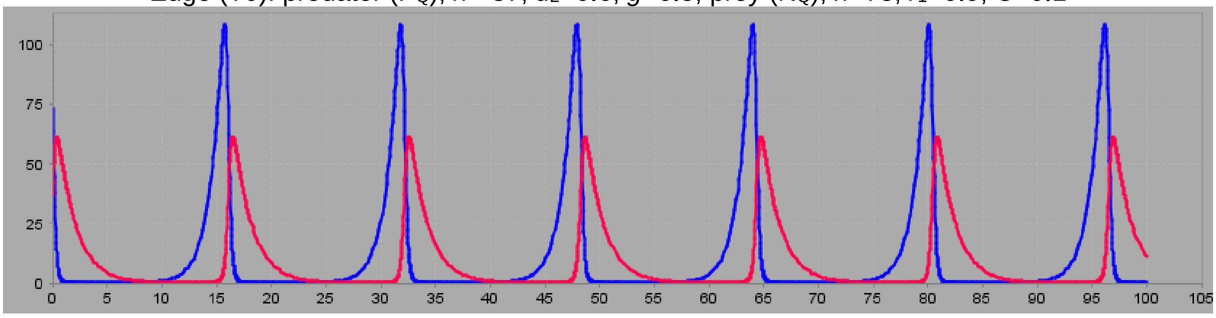
Predator-prey and competition interactions can be represented in models of biological controls for the management of pests in agriculture, as an environmental diagnostic tool in the choice of parameters that demonstrate the balance between species. The population dynamics of predator and prey can follow a continuous flow, without considering the interference of ecological factors, or prey-dependent when predators depend exclusively on prey and their populations are reduced in sequence with prey, which feed on resources in the food web (SOUZA, 2017).

The ponerine ants play a predatory role and can have a wide spectrum of feeding, ranging from generalist to extreme specialist. This results in population regulation of different groups of arthropods, as well as the possibility of being indicators of the diversity of these groups. Nests are made of litter, decaying wood, fallen logs, stones and leaves accumulated on tree branches and epiphytes (LATTKE, 2015).

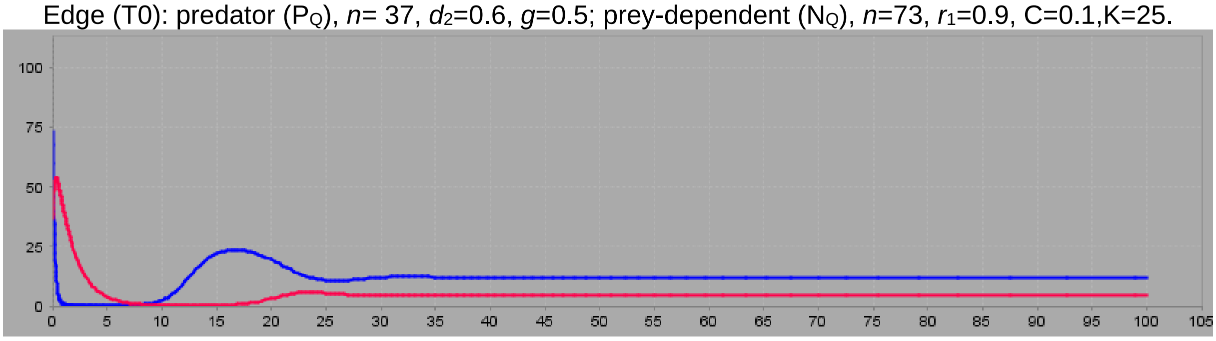
The lower the abundance of predators, the less time is needed for prey population recovery. With the predator-prey interaction, in the continuous flow model, populations of predators (P_Q, n=37) and prey (N_Q, n=73) would take 15 days to start their recovery at the edge (T0); while fewer predators (n=8) would need only 5 days in the interior (T2). In the prey-dependent model, the minimum time required is 15 and 10 days respectively between edge (T0) and interior (T2) (Figure 15).

Figure 15. Simple Lotka-Volterra model of predator (red) prey/prey-dependent (blue) dynamics for the period of t=100 days at the edge (T0) (above) and in the interior (T2) (below) of the Atlantic Forest fragment of Fazenda da Patioba. Alagoinhas, Bahia (Brazil). October/2021 to September/2022.

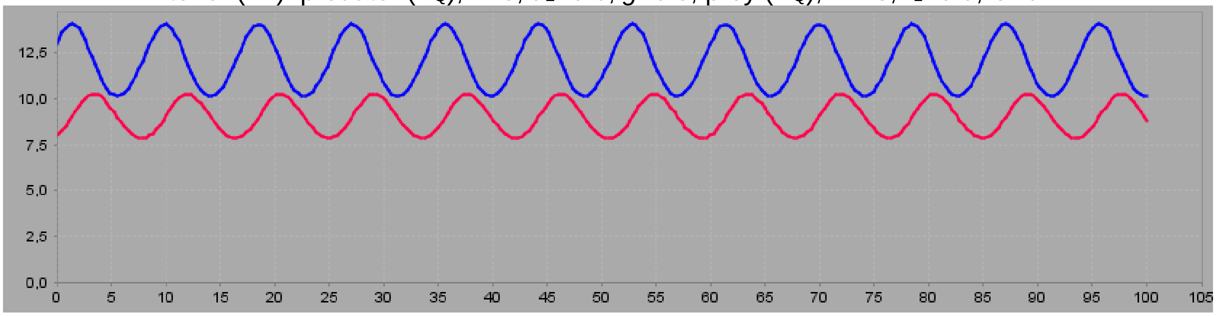
Edge (T0): predator (P_Q), *n*= 37, d_2=0.6, *g*=0.5; prey (N_Q), *n*=73, r_1=0.9, C=0.1



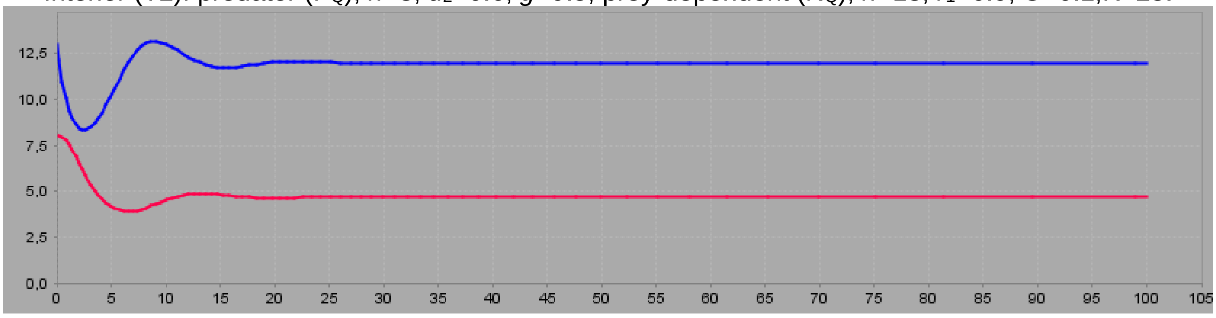
Edge (T0): predator (P_Q), *n*= 37, d_2=0.6, *g*=0.5; prey-dependent (N_Q), *n*=73, r_1=0.9, C=0.1,K=25.



Interior (T2): predator (P_Q), *n*=8, d_2=0.6, *g*=0.5; prey (N_Q), *n*=13, r_1=0.9, C=0.1.



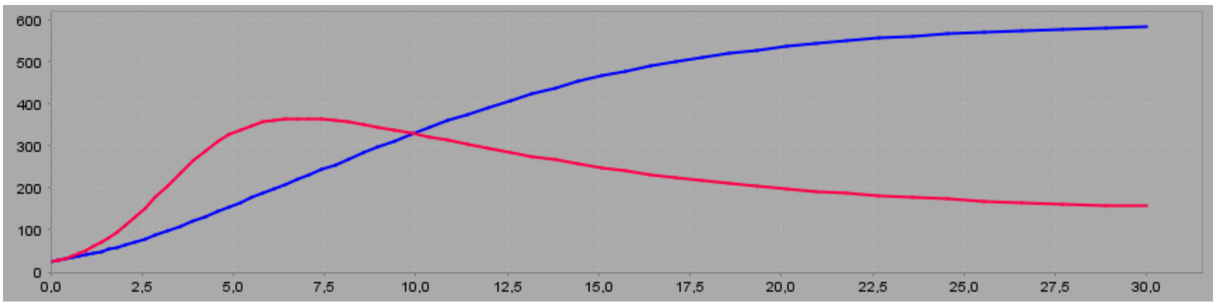
Interior (T2): predator (P_Q), *n*=8, d_2=0.6, *g*=0.5; prey-dependent (N_Q), *n*=13, r_1=0.9, *C*=0.1,K=25.



Source: Proposed by the author, 2023.

If species compete for the same trophic resource then the smaller the difference between the abundances of each order compared, the curves will be closer at the beginning, and then each population will increase as the other decreases. With the interaction of competition between detritivores, populations of Isopoda (*n*=24), Blattaria (*n*=26) and Hymenoptera (*n*=28) would take 15 days to start their recovery at the edge (T0). In the interior (T2), the data for modeling were incipient or non-existent (Figure 16).

Figure 16. Simple Lotka-Volterra model of competition dynamics between detritivores Isopoda (*n**=24), Blattaria (*n**=26) and Hymenoptera (*n**=28) for the period of t=30 days at the edge (T0) of the fragment of Atlantic Forest of Fazenda Patioba. Alagoinhas, Bahia (Brazil). October/2021 to September/2022. Caption: N_1, *n*=*, *r*=0.9, k_1=500, α=0.6 and N_2, *n*=*, *r*=0.5, k_2=700, *β*=0.7.



Source: Proposed by the author, 2023.

Considering only the quarterly records, with a reduced sampling, the edge and the intermediate location were similar in number of predators and detritivores captured in the collectors of the three locations of the fragment:

- Edge (T0): 33 predators (27 Hymenoptera, 4 Araneae, 2 Opiliones), 24 detritivores (10 Isopoda, 4 Blattaria, 3 Coleoptera, 6 Stylommatophora, 1 Spirostreptida), 1 bioturbator (1 Collembola) and 3 parasites (Ixodida).
- Intermediate (T1): 34 predators (32 Hymenoptera, 1 Araneae, 1 Scorpiones), 23 detritivores (12 Isopoda, 11 Stylommatophora).
- Interior (T2): 1 predator (1 Hymenoptera).

The ants present at the edge (28) and at the intermediate location (32) indicated good environmental quality. In the intermediate location, the generalist herbivorous ants of the genus *Atta* (tribe Attini, Hymenoptera, Formicidae) occurred. Leaf-cutting ants take leaves to cultivate fungi in the nest, which they feed on (SANTOS et al., 2020). In addition to cutting plant parts for fungus cultivation, ants can also feed on plant sap, behaving as phytophages. Herbivory is controlled in the fragment by natural predators of ants (DEL-CLARO; OLIVEIRA, 2000).

The woodlice of the species *Philoscia muscorum* (Isopoda, Malacostraca) occurred on the edge (24), in the intermediate environment (12) and in the interior (6) of the fragment. The preference for the edge was attributed to the resilience of the species given its diversified feeding habits. In fact, Isopods colonize sites with material rich in nitrogen, such as ruminant feces (FROUZ et al., 2007). These feces are colonized by fungi, which leads to a preference for food over litter. This behavior attributes to the isopod the coprophagous habit (ZIMMER, 2002; CORREIA et al., 2008).

Among the functional groups, detritivores (herbivores) predominated over predators (carnivores). Detritivores from the orders Isopoda, Blattaria, Collembola, Coleoptera, Hymenoptera, Stylommatophora and Spirostreptida were captured on the edge and interior of the native fragment.

Isopods, ants, spiders and gastropods were found in the collectors of the three plots of the fragment. Individuals of the orders Isopoda (Malacostraca, Philoscidae), Coleoptera and Hymenoptera (Insecta, Formicidae) feed on the remains of dead plants and animals. Populations of detritivores (orders Isopoda, Blattaria, Hymenoptera and Stylommatophora) are controlled by predators in native environments (orders Hymenoptera and Araneae) (ZIMMER, 2002).

The detritivore habit establishes a mutualistic relationship that allows the reproductive development and regeneration of the vegetal community, interfering with the population dynamics of the plants (JORDANO et al., 2003). The isopod's preference for certain plant species, with a low content of tannins, terpenes and alkaloids, guarantees their performance in the decomposition process, contributing fragments and feces to the soil. This material serves for colonization by microorganisms and, consequently, a greater transformation of plant material (ZIMMER, 2002; CORREIA; AQUINO; AGUIAR-MENEZES, 2008).

Due to their detritivorous action and nutrient ingestion for the trophic network, isopods contribute to the restoration of ecosystem processes in degraded environments (FACELLI; PICKETT, 1991; QUADROS, 2010). This ingestion of nutrients into the soil favors the cycle through absorption by plants and ensures the maintenance of the trophic network in the forest system (HÄTTENSCHWILER et al., 2011).

Batistella et al. (2015) found environmental variables influencing the distribution of three species of the order Spirostreptida in a small area of the Amazon in the state of Mato Grosso. *Plusioporus salvadorii* and *Trichogonostreptus mattogrossensis* species were found at the lowest location due to humidity. The small variation in altitude is reflected in the characteristics of the soil, relief and humidity, affecting local humidity and the structure of the habitats (COSTA; MAGNUSSON, 2010).

The functional variety of terrestrial species of the order Isopoda is given by *their habits, in addition to being detritivorous, which allows them to act in the fragmentation and exploration of new niches in the leaf litter.

Three ticks, parasites of the order Ixodida (Arachnida), were collected attached to a millipede (Spirostreptida, Diplopoda) at the edge of the Patioba fragment.

And, finally, the group of bioturbators is also represented by springtails (Collembola), ants (Hymenoptera) and termites (Blattaria: Isoptera). These organisms are important because they revolve and transform the soil, through transport and ingestion, promoting its aeration, recirculation of organic matter, increasing porosity and water entry. Some examples are termites, earthworms, enchytraeids, beetles and millipedes, which are bioindicators of soil quality (BROWN et al., 2015; AMAZONAS et al., 2018).

5. Conclusions

Litter production was similar between the edge and interior. Production dropped sharply with increased precipitation in May at the edge and in the interior of the fragment.

At the edge, the production of the leaf fraction was attributed to the sparse canopy of the tree stratum, which favored the greater fall of leaves from the trees due to the action of rain. In the interior, the structural complexity of the vegetation was reflected by the variable and higher reproductive fraction when compared to the edge.

The monthly deposition of litter was regular with some seasonal peaks in the twenty collectors in the interior of the fragment, attributed to the greater structural complexity with vegetal diversity and the large visible size of the plants in the arboreal stratum when related to the edge.

A total of 192 individuals were captured in 11 orders in monthly collections over 12 months. Among the orders, Hymenoptera, Isopoda, Stylommatophora and Blattaria had the highest abundance.

The quarterly collections in 12 months proved to be insufficient for the analysis of the diversity indices between the three environments, and the edge obtained the diversity and richness indices higher than the two internal environments of the fragment. The ants at the edge and the intermediate site indicated good environmental quality for both.

There was greater diversity ($p<0.05$) of invertebrates on the edge compared to the interior of the fragment, attributed to low sampling with punctual collections, despite the variability observed in the deposition in the twenty collectors in the interior. The edge effect can create microhabitats and niches, favoring the establishment of more species and a variety of functional groups in the forest perimeter.

Among the seven functional groups, detritivores predominated over predators (herbivores and carnivores) and other categories. Detritivores of the orders Isopoda, Blattaria, Collembola, Coleoptera, Hymenoptera, Stylommatophora and Spirostreptida were captured on the edge and the interior of the native fragment.

The lower the abundance of predators, the less time is needed for prey population recovery, 15 and 10 days respectively for the edge and interior.

This study of plant-animal interaction, through litter production and the action of functional groups of terrestrial invertebrates, intends to contribute to knowledge about ecosystem processes and biodiversity conservation in the Atlantic Forest.

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