UNIVERSIDADE DO ESTADO DA BAHIA
POST GRADUATION PROGRAM IN MODELING AND SIMULATION OF BIOSSYSTEMS

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ANTS AND RESTINGA: MODELING RELATING MYRMECOFAUNA, PLANT COVER AND GEOMETRIC MODEL ON THE NORTH COAST OF BAHIA

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Dissertation presented to the Post Graduation Program in Modeling and Simulation of Biosystems at the Universidade do Estado da Bahia as a partial requirement for obtaining the title of Master in Modeling and Simulation of Biosystems, M.Sc .

Area of knowledge: Interdisciplinary
Line of Research: Biosystem Analysis

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Co-advisor : Prof. Dr. Antônio Teófilo Ataíde do Nascimento.

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It was with environmental conservation in mind that I developed this study, which is why I dedicate it to all those who in some way can take advantage of this information for the development of environmental conservation strategies.

THANKS

I thank God for the gift of life and for the opportunity to fulfill another stage of my academic life in good health;

To my family and friends for their ability to push me forward and not give up on my dreams, especially to my husband Josenaldo Souza Cruz, for accompanying me in all stages, especially in collections;

To my advisor, Prof. Dra. Eltamara Souza da Conceição, for the partnership, care and availability in mediating the orientation process with lightness and attention;

To my co-supervisor, Prof. Dr. Antônio Teófilo Ataíde do Nascimento, for conducting this process with lightness, availability and attention;

To Professor Dr. Antônio de Oliveira Costa Neto, for helping me with the statistical analysis of the dissertation;

To Prof. Dra. Raquel Maria de Oliveira, for helping me with the description of the areas where the collections were made;

To my colleague José Linaldo da Paixão Santos Júnior, for contributing to the analysis of the landscape metrics;

To colleague Jivanildo Santana, for effectively participating in the moments of ants collection;

To PRIMA Company, responsible for the property where the studied areas are located, for the total support to the project, mainly for Daiara 's dedication and partnership ;

To UNEB, for granting the scholarship and to PPGMSB for the opportunity to build new learning;

Thanks to everyone who directly or indirectly contributed to this work.

Just as ants are good bioindicators, people can also become aware of the environment and be good conservators. Every effort has its reward, do your part and you will see the difference.

(The author)

SUMMARY

The restinga suffers from environmental degradation and can be found in different conditions in the coastal region. Ants are used to assess environmental impacts and monitor the recovery of environments. An index that has been widely used in this type of analysis and that corroborates the values of the landscape metric is the fractal dimension, FDI, based on the area-perimeter of forest fragments. The present study proposes to verify if there is influence of the geometric model and the vegetation cover of restinga fragments on the diversity of ants in the North Coast of Bahia . Ants were collected in five restinga areas, with *winkler extractors* and baits, both honey and sardines. Correlations were made between the percentage of soil with vegetation cover (PSVC), circularity index (CI) and fractal dimension index (FDI) with indices of diversity and richness of ants. Finally, Kendall's correlation and Theil-Kendall regression lines were performed. The ant diversity index showed no correlation with the PSVC. The CI negatively influenced, while the FDI positively, the diversity and richness of soil ants. Likewise, regarding the tree extract, the CI was inversely proportional, while the FDI was equivalent to the ant diversity index. The similarity dendrogram also showed a similar myrmecofaunistic composition between areas with less fragmentation. It is concluded that the vegetation cover of the soil does not influence the diversity of ants, but the fragmentation of areas and the geometric model measured by the FDI have an influence, and it is possible that the type of soil, in general, prevents the nesting of a larger volume of species and mask the possibility of finding a closer relationship between these variables.

Keywords: Circularity; fractal; ants; restinga.

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LIST OF ABBREVIATIONS AND ACRONYMS

INPE National Institute for Space Research

FDI Fractal Dimension Index

CI Circularity Index

PronaSolos National Soil Program in Brazil

MRRC Mineral Resources Research Company

GSB Geological Survey of Brazil

PSVC Percentage of Soil with Vegetation Coverage

FF Forest Fragmentation

AA Anthropized area

AAA Anthropized area with flooded/flooded area

SUMMARY

1. INTRODUCTION

The Atlantic Forest is one of the richest forests in terms of biodiversity, bringing together various types of ecosystems and phytophysiognomies such as dense rainforest, araucaria forest, highland fields, mangroves and sandbanks (ATLÂNTICA, 2009). The restinga is an ecosystem that encompasses a vegetation that occurs on the sandy deposit along the Brazilian coast (CERQUEIRA; ESTEVES; LACERDA, 2000). It is represented by a mosaic of communities and therefore plays the role of a natural experiment to assess the effects of environmental heterogeneity on animal communities (VARGAS *et al* ., 2007).

Among the Brazilian states, Bahia has the largest coastal strip in extension and, despite so much richness, studies carried out in restinga ecosystems, mainly on the north coast of Bahia, are still recent, starting to occur after the publication of some works scientific studies, such as the one by Britto *et al* . (1993). This refers to the diversity of vegetation on the north coast of Bahia, carried out in the dunes and lakes of Abaeté, in the city of Salvador, Bahia. Despite being a legally protected area, anthropic actions have been causing great environmental degradation, either through the extractive activity of its sands, or by the advance of real estate speculation or simply by the indiscriminate removal of its species, plants and animals for commercialization (SILVA et *al* . ., 2017). Likewise, among the problems that affect the North Coast of Bahia, it can also stand out the disorderly population increase, in addition to large tourist projects and other actions that end up harming the biodiversity of these ecosystems (LIMA et al., 2012 *)* .

According to Viana *et al.* (1992), several standards can be used as indicators of the environmental quality of the landscape; in addition to the edge effect, the shape, the type of surrounding element and the degree of isolation from the landscape contribute to the assessment of the ecological status of each fragment. Therefore, an analysis of the spatial heterogeneity of the landscape, which manages to address important details of its patterns, has gained space in studies that depend on spatial analysis, and one of the indexes widely used in this type of analysis is the fractal dimension index (O'NEILL *et al* ., 1988). In this context, analyzes of landscape metrics collaborate with studies of forest areas, especially those that suffer from anthropic or natural modifications, as they help in the analysis of patterns of alteration of biological communities, including myrmecofauna (COSTA, 2018) .

Prediction models, even if they do not faithfully represent a reality, are important because they make it possible to predict new or future situations (COELI, 2021). Thus, it was included in this study and it was necessary to make predictions that can be used to assess the consequences of the loss of natural resources and biodiversity, as well as to indicate safe strategies for the management of conservation units.

Different ecological states and the landscape metric indicate variations in the result of the fractal index and can help in the evaluation of data linked to the complexity of the forest landscape (SANTOS, 2020). The consequence of the use and management of natural resources requires scientific investigations that are capable of collaborating with the management and conservation of these resources. Thereby, studies addressing landscape metrics have contributed to understanding the dynamics of ecosystems and guided environmental planning, decision-making in environmental licensing, monitoring and implementation of conservation units, among other intervention situations that require greater knowledge about the structural patterns and shapes of the local landscape (FRANÇA, 2019).

Ants are one of the most suitable groups of bioindicators for analyzing the ecological conditions of ecosystems (DELABIE *et al* ., 2006), since there is a correlation between the structure of habitats and the patterns of their communities, such as the richness and composition of species (UNDERWOOD; FISCHER, 2006), among other relationships. Its sampling and identification are relatively easy and are sensitive to environmental changes (RIBAS *et al* ., 2012; SCHMIDT *et al* ., 2013).

As it represents different levels of environmental complexity (ARAÚJO *et al* ., 2004; MENEZES; ARAÚJO, 2005), the restinga presents itself as a favorable environment for carrying out analyzes involving plant complexity, landscape metrics and ant diversity.

Therefore, the evaluation of the landscape metrics, as well as the area-perimeter elements, analyzed from the fractal dimension, serve to verify the influence of the ecological status of different restinga areas on the biodiversity of the myrmecofauna . In this way, it can minimize the level of subjectivity in the evaluation of landscape patterns, increasing the reliability of this relation between the ant diversity indicators.

1.1 RESEARCH PROBLEM

Is there a relationship between vegetal complexity and landscape metrics, with the diversity of ants (Hymenoptera : Formicidae) in restinga ecosystems on the North Coast of Bahia, as it occurs in other ecosystems of different biomes?

1.2 GENERAL OBJECTIVE

- To verify if there is influence of the geometric model and vegetation cover of restinga fragments on the diversity of ants in the North Coast of Bahia.

1.3 SPECIFIC OBJECTIVES

- Identify five different restinga fragments and their conditions in terms of vegetation cover;
- Characterize the ant communities of each evaluated restinga fragment, regarding species, richness and diversity;
- Relate the diversity of ants with the plant complexity, circularity index and fractal dimension index of the restinga areas studied;
- Use predictive models to predict situations related to the myrmecofauna biodiversity and vegetation cover of the studied fragments.

2. STATE OF THE ART

2.1 ATLANTIC FOREST AND RESTINGA

The Atlantic Forest biome is one of the 36 global biodiversity *hotspots (REZENDE et al* ., 2018). *Hotspots* are regions of the planet composed of many endemic species under a high degree of threat (MYERS *et al* ., 2000; HOPPER; SILVEIRA; FIEDLER, 2016) and which have lost more than ¾ of their original vegetation cover (MYERS et al., 2000). Thus, *hotspots* are places that need to be considered as a priority by environmental conservation programs.

Even though it is considered one of the main *hotspots* in the world, the Atlantic Forest has been degraded in several ways, mainly with the process of deforestation, urbanization and agricultural use (FERREIRA, *et al* ., 2019; RIBEIRO *et al.* 2011), due to these and other types of action, today this biome has less than 30% of its original vegetation cover (REZENDE *et al* ., 2018).

According to Fundação SOS Mata Atlântica and INPE (2022), and following some standards established by them with regard to the assessment of deforestation, the total area of the Atlantic Forest deforested, in the period 2020-2021, was 21,642 hectares. For a better understanding of how impactful this number is, this would be equivalent to 59 hectares per day or 2.5 hectares per hour. Through these studies, it was also possible to notice that there was a 66% increase in the deforestation rate compared to the 2019-2020 period. Deforestation between 2020 and 2021 was the highest since 2015 and 90% higher than the lowest value in history, reached in 2018.

According to the third report of the Atlantic Forest Deforestation Alert System – SAD, which gathers deforestation identified and validated until October 2022, the State of Bahia already presented, in that period, a deforestation of 15,814 hectares.

All this degradation has caused the fragmentation of the Atlantic Forest. Due to the high fragmentation rate, the vast majority of forest remnants in this biome have areas smaller than 50 hectares (RIBEIRO *et al* ., 2011).

It is known that forest fragmentation decreases the percentage of soil with vegetation cover and consequently changes the connectivity of landscapes, which may affect the quality of habitats for some species, in addition to intensifying the edge effect, generating several structural impacts on forests and on the richness and diversity of certain species (ARROYO -RODRIGUEZ, *et al.,* 2020).

Despite all the problems mentioned above, the various ecosystems of the Atlantic Forest perform important environmental services, serving as habitat for several species of animals and plants, in addition to being home to 72% of brazilians and concentrating 80% of the national GDP (SOS MATA ATLÂNTICA , 2021). Therefore, the development of strategies aimed at conserving these ecosystems is extremely important for maintaining biodiversity, in addition to contributing to the sustainability of economic activity in the region (JOLY et al., 2014), as well as favoring decision - making , given the growing human pressure (LAURANCE *et al* ., 2012).

The restinga is characterized by the typical vegetation formations of the Brazilian coast and has also been going through the process of alteration to the detriment of anthropic action. This develops in sandy soils and subject to the influence of the tide (CERQUEIRA *et al.,* 2000). Because it presents a great diversity of vegetation types that can vary between herbaceous formations in dry or wetlands, bushes, and small, medium and large forests (LIMA et al., 2015), it is configured as a suitable place for *evaluation* between vegetation diversity and resident or migratory animal communities (VARGAS *et al* ., 2007; GULLAN; CRANSTON, 1996). Therefore, as they represent a field of natural experimentation in this type of evaluation, these are coastal areas that have been attracting great scientific interest (LIMA *et al* ., 2015).

The impacts they have been suffering are great, with various exploratory activities, such as urbanization, tourism, which generate deforestation and loss of its vegetation cover and animal diversity, and also increasing negative impacts on the soil (CORREIA et al., *2020*) .

The ecosystem already faces great environmental stress and its plant and animal species face difficulties generated by excess salinity, soil instability and nutrient availability, high temperatures, oscillation in wind speed, air humidity, among other variables (OLIVEIRA, 2014). Therefore, it needs special attention, because these factors added to anthropic pressure can increasingly reduce its biodiversity.

Bahia is the Brazilian state that has the longest coastline in the country, obviously a wide occurrence of this ecosystem. Despite this, on the North Coast, according to

Gomes and Guedes (2014), little is known about the restinga, which has the potential to harbor many more species than is known.

According to Fahrig (2003), forest fragmentation is a process that involves loss of vegetation, which causes an increase in isolated native areas, in addition to changing the availability and quality of habitats. Depending on the structure and isolation level of the environment that suffers from this process, as well as on the local fauna, it can intensify the edge effect and generate greater habitat loss. Depending on the species involved, the effect can be negative or positive.

Species somehow benefited by fragmentation are generally more abundant in small fragments, as the increase in the edge effect favors the possibility of these species to use attributes of the matrix landscape (OLIVEIRA, 2013). In the case of ants, interference from the edge can benefit some species that take advantage of the increase in litterfall and pioneer plants that tend to appear on the edges of fragments (LAURANCE et al., *2002*)

2.2 ANTS AS BIOINDICATORS IN RESTINGA ENVIRONMENTS

The maintenance of diverse ecosystems increases the chances of survival and increases the number of species. The anthropization of forest areas, including restinga, generates negative impacts on local biodiversity, compromising the balance between fauna and flora on a large scale (WINK, 2005).

Insects, due to their adaptability in different environments, are considered the most successful animals in nature, and because they are sensitive to environmental changes, many of them are considered biological indicators (AZEVEDO et al., 2011 *)* .

Biological indicators, also known as bioindicators, are living beings in which their presence, absence, interaction, diversity, composition or abundance in a given ecosystem can indicate elements about the ecological status of a given environment (WINK, 2005).

Ants are often used as bioindicator organisms (DELABIE *et al* ., 2006) and, according to Wilson (1987), in most terrestrial environments, including restinga ecosystems, they are considered dominant animals. The behavior of the myrmecofauna , such as the ability to adapt to environments that suffer environmental stress, contributes to this dominance. In addition to occupying different ecological niches and being able to nest in different places, species behave differently when faced with a change in the environment; therefore, it is important to understand the interaction of different species, both in anthropized sites and in protected sites and/or in the recovery stage (AZEVEDO, 2011).

The richness and diversity of ants can be influenced by several factors, among them, one can include the characteristics of the habitats, vegetation structure, such as size and shape of the area and edge interference (DANTAS et al., 2016) . It is expected that areas with greater plant complexity offer more resources for ants, which tends to increase the diversity of these insects, whereas anthropized environments, due to lack of nutritional resources and habitat diversity, should present a low diversity of these organisms.

However, it is worth mentioning that the diversity and nesting of ants are not only associated with the attributes of vegetation and climate, but also with those of the soil (SILVA, 2014). The use of ants as bioindicators in the evaluation of an environmental degradation or recovery process must be associated with an understanding of the relationship between the species and the characteristics of the environment as a whole.

2.3 FRACTAL DIMENSION AND LANDSCAPE METRIC INDEX

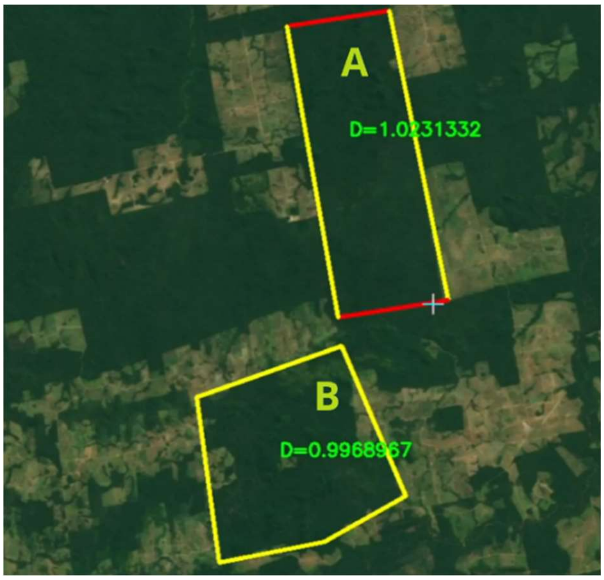
Environmental degradation has generated concern and induced acceleration in the development of strategies for environmental conservation. The loss of vegetation, fragmentation, disordered population growth, which have been destroying forests, including restinga ecosystems, can cause structural alterations in forest fragments, with changes in size and shape, degree of isolation, alteration of the edge effect, among other factors.

This fragmented and degraded form of natural environments results in a geometry that approaches fractal geometry (BATTY, 2008). Therefore, fractal geometry, associated with satellite images, when calculated from the area and perimeter of a forest fragment, can indicate parameters that validate actions to recover degraded areas (BARROS, 2018).

Figure 1 presents two examples of fragments with different area and perimeter, consequently fractal dimension index - FDI as well. It is possible to notice that the fragment represented by the letter A is elongated, as it has more perimeter and less area. Therefore, it is an environment that can suffer more from the edge effect, having a smaller matrix of vegetation in its core. For its recovery, with the aim of increasing the internal area, it would be more viable to expand the area and not the perimeter. The fragment represented by the letter B, on the other hand, presents a good area-perimeter ratio, which may favor the maintenance of habitats for several species.

The FDI identifies the shape pattern of a flat figure, as is the case of a forest fragment (GOMIDE, 2009; HOTT, 2007). With values from 1 to 2, the closer to 1, the shape of the fragment has more rectilinear and simple contours, and the closer it gets to 2, the forest fragment has a shape with a more complex and irregular contour (FERNANDES, 2017) .

Figure 1- Illustration with images of forest fragments and hypothetical flat geometric figures, for calculating the fractal dimension using the Payton Softwere.



Source : Birth (2022).

In addition to the FDI, other data related to landscape metrics, such as the circularity index - CI, fragment size, percentage of soil with vegetation cover, type of vegetation - PSVC, among other aspects, provide a more assertive view of the landscape structure and can collaborate in the development of strategies for recovery and/or preservation of a forest environment.

2.4 THE IMPORTANCE OF ECOLOGICAL MODELING AND PREDICTIVE MODELS FOR ENVIRONMENTAL ASSESSMENT

Modeling is an important tool for understanding different causal phenomena, as well as ecosystem development processes and how they relate to different environmental scenarios (VALENTIN, 2022).

According to Fragoso (2009), an ecological model is one that takes into account the processes and data related to living beings in an ecosystem. Thus, ecological modeling is a tool capable of predicting the distribution of species (ASSIS, 2022). However, this type of modeling is not just a predictability tool, but works as a guide for research and formulation of hypotheses, generating information that allows, among other factors, the organization of future collections and research methods (VALENTIN, 2022).

This type of modeling has been increasingly developed, as environmental problems require immediate responses that should not be analyzed in a simple way, and since modeling is a holistic tool, it is capable of allowing a better understanding of more complex phenomena (ANGELINI, 1989).

That is why, considering the ecological complexity of an environment under reference conditions, it is possible to build a predictive model that is related to the biota and metrics of that space (ASSIS, 2022).

In general, predictive modeling consists of a process of combining species occurrence data under various ecological variables, providing predictions of ideal conditions for certain species (GIANNINI et al., 2012) .

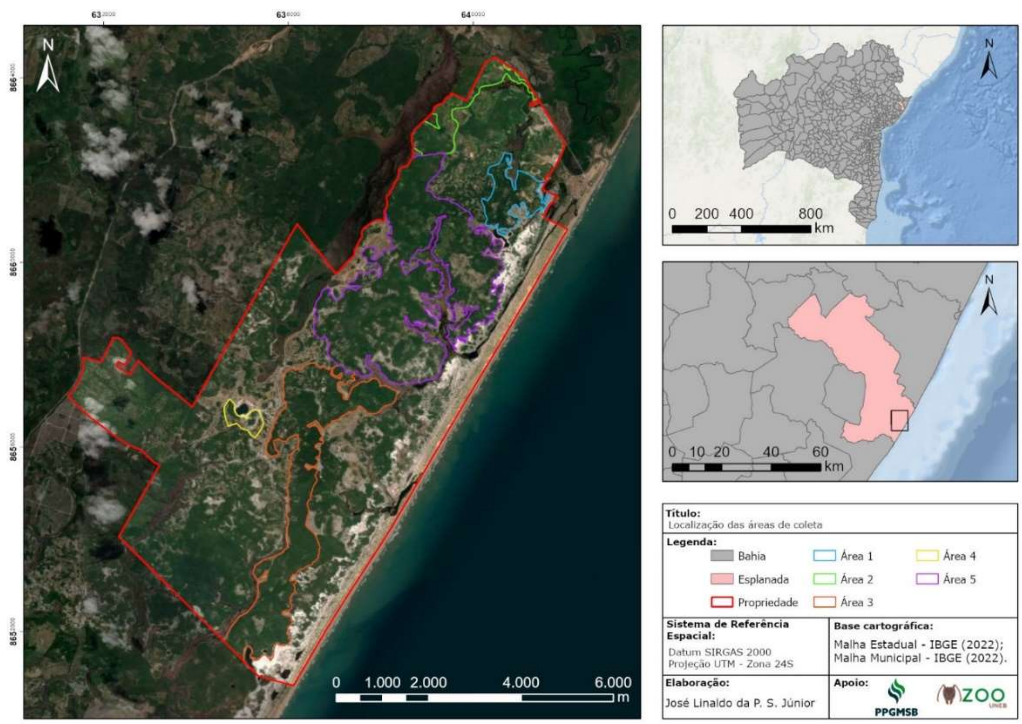
Therefore, the development of predictive models is important because they are configured as a tool that allows the inference about interactions between the analyzed indexes (CRUZ, 2021), in addition to understanding, in a more objective way, real world phenomena (BARI, 2020).

3. MATERIAL AND METHODS

The study was carried out in restinga areas located on the North Coast of Bahia, on the Costa dos Coqueiros, Baixio, Esplanada-BA. The collections took place between September and December 2021, since the colonies are stable, and it is unnecessary, in view of the project objectives, to collect in other seasons of the year. Local annual temperatures vary between 20°C and 32°C (CLIMATEMPO, 2019). According to data provided by the soil map on the platform of the National Soil Program of Brazil (PronaSolos), on a scale of 1:250,000 (CPRM/SGB, 2020), the predominant type of soil in the location of the study areas is neosol quartzarenic . But in some areas it is possible to notice the presence of spodosols ferriluvial and neosol fluvial .

The property where the study was carried out belongs to a private company and has a total area equivalent to 6,204.72 hectares (37°44'10"W 12°8'18"S). Within this and considering different levels of complexity and vegetation structure, five areas were selected. Area 1 – Blue Lagoon (37°42'23"W 12°6'20"S), area 2 – Amadeus Trail (37° 43'9"W 12°5'25"S), area 3 – Mata Verde (37°44'54"W 12°9'39"S), area 4 – Lagoa de Panela (37°45'29"W 12°9'2"S), area 5 – Trilha da Mata (37°43 '43"W 12°7'21"S) (Figure 2).

Figure 2- Property location map, indicating the restinga areas studied. North and Agreste coast of Bahia, Baixio, Esplanada-BA – September to December 2021.



The distances between the fragments were measured and evaluated from the landscape analysis, using Google Earth Pro. Therefore, it was possible to identify that the distance from area 01 to the beach line is approximately 1.5 km, with an altitude of 32 meters, with herbaceous vegetation, with bushes, unprotected soil and influenced by the temperature range. This is the area closest to the beach, therefore it suffers the greatest impacts from salinity and human actions.

Area 02 is approximately 3.6 km away from the beach line, with an altitude of 28 meters. This area has sparse vegetation and exposed soil.

As for area 03, it has a distance to the beach line of 2.4 km, with an altitude of 50 meters at the collection point. The vegetation has a dense physiognomy, less sandy soil and higher organic matter content.

The distance from area 04 to the beach is approximately 3.9 km, with an altitude of 35 meters. This presents a vegetation with sparse bushes, with very sandy soil and the region has been suffering anthropic impacts due to tourism in a lagoon that is in that area.

Finally, area 05 has a distance to the beach of 2.9 km, with an altitude of 51 meters. The vegetation is characterized by dense forest, soil with a dark tone, more protected by vegetation , proving to be less sandy when compared to other areas.

In general, it is possible to identify that the areas present vegetation that varies from herbaceous formations, passing through shrub formations, bushes, reaching the formation of forests. These formations are arranged in dozens of sandy ridges parallel to the coastline, under the influence of flooded or swampy areas . The complexity of restinga vegetation increases from the beach towards the interior of the coastal plain, as detailed by Silva and Somner (1984).

In each chosen area, and evaluating the structure of the landscape through satellite images obtained from the basemap software of the ArcGis Pro program , version 2.9, two transects were delimited, leaving intervals of 25 meters between each sample unit (represented per tree), as well as a distance of 50 meters from the edge. Thus, a total of 25 samples were obtained for each type of trap used, namely Winkler extractors, as well as honey and sardine baits on the plants. The baits were placed in the trees and removed after an interval of one hour in different branches of each tree.

Species were identified by comparison with the reference collection of the Museum of Myrmecology at UNEB, Campus II, and use of taxonomic keys according to Bolton (2003), Bolton et al , (2007), Antcat (Bolton, *2017*) , Bolton (2020), and Antweb v6 13.3.

Richness was estimated from the Chao 2 richness index, using the EstimateS software version 9.1.0 (COLWELL, 2019). The diversity index (Shannon- Winner) and the similarity dendrogram (Jaccard) were obtained using the Past program , version 4.03. Spatial analysis, performed using the ArcGis Pro program, version 2.9, were used to obtain parameters such as fragment size, area, perimeter and percentage of soil vegetation cover.

After the spatial analyzes and using the equations below, the FDI was calculated, as well as the CI, in the GeoGebra program, version 5.0.

$$D_F = 2 * \ln(P/4) / \ln(A).$$

In which:

D_F = Index of fractal dimension
P = Perimeter of the forest fragment
A= Forest fragment area

$$CI = 2 * \frac{\sqrt{\pi * A}}{P}$$

Where:

IC = Circularity Index
P = Perimeter of the forest fragment
A= Forest fragment area

The non-parametric correlation proposed by Kendall was performed using Statistica version 10.0. When the correlations were significant ($p<0.05$), the regression line was made using the Theil-Kendall model ($y=a + bx$) in the R program, version 4.0.4. For the interpretation of the degrees of correlation between the variables, Table 1 was used, replacing the value of r by the value of ŧ (Tau).

Table 1– Reference for interpreting the degrees of correlation between the variables studied in restinga fragments on the North Coast and Agreste of Bahia.

Value of r (+ or -)	Interpretation
0.00 to 0.19	very weak correlation
0.20 to 0.39	weak correlation
0.40 to 0.69	moderate correlation
0.70 to 0.89	strong correlation
0.90 to 1.00	very strong correlation

Source: Silvia and Shimakura (2006), adapted .

4. RESULTS AND DISCUSSION

4.1 MYRMECOFAUNA AND VEGETATIONAL COMPLEXITY IN DIFFERENT RESTINGA AREAS

The most frequently found ant species, considering all sandbank fragments studied here, were *Cephalotes pusillus* (Klug, 1824 *),* *Crematogaster* sp1 and *Ectatomma tuberculatum* (Olivier, 1791) (Table 2). *Cephalotes pusillus* in all areas, *Crematogaster* sp1, in four of the five areas, and *E. tuberculatum* , only in area 5.

Table 2- Relative frequency (%) of arboreal and epigeic ant species in different restinga areas on the North Coast of Bahia. Baixio, Esplanada – BA. September 2021 to December 2021.

Species	**Frequency (%)/Area**				
	01	**02**	**03**	**04**	**05**
Azteca chartifex (Forel , 1912)	0	0	8	0	0
Rectangular Camponotus (Emery, 1890)	0	0	0	0	4
Camponotus crassus (Mayr, 1862)	8	0	0	0	4
Camponotus fastigatus (Roger, 1863)	0	0	0	4	4
Cephalotes clypeatus (Fabricius, 1804)	0	4	0	0	0
Cephalotes minute (Fabricius, 1804)	4	0	0	0	4
C. pusillus **(Klug, 1824** ***)***	**24**	**12**	**32**	**28**	**28**
crematogaster **sp1**	**16**	**0**	**8**	**20**	**20**
Crematogaster sp2	0	0	0	4	4
Dolichoderus imitator (Emery, 1894)	0	0	0	0	4
Ectatomma brunneum (Smith, 1858)	0	4	0	0	0
Ectatomma muticum (Mayr, 1870)	0	0	0	0	8
E. tuberculatum **(Olivier, 1791)**	**0**	**0**	**0**	**0**	**20**
Gnamptogenys *striatula* (Mayr, 1884)	0	0	0	0	4
Hypoponera sp1	0	0	0	0	4
Labidus coecus (Latreille , 1802)	0	0	12	4	0
Odontomachus bauri (Emery, 1892)	4	0	0	0	0
Odontomachus brunneus (Patton, 1894)	0	0	0	0	8
Pachycondyla harpax (Fabricius, 1804)	0	0	0	0	4
Pheidole sp1	0	0	4	0	0
Pheidole sp2	0	0	8	0	8
Pheidole sp3	0	4	0	0	4
Pseudomyrmex gracilis (Fabricius, 1804)	0	4	0	0	0
Solenopsis sp1	0	0	0	0	4
Solenopsis sp2	0	0	4	0	8
Total of species per area	5	5	7	5	18
Grand total of species			25		

The frequency of the most common genus of ants in the present study is justified, since, in general, the areas studied have soils that make it difficult to increase nutrition, as they have a low content of organic matter and are very acidic (SILVA, 2018). That said, they are considered shallow and prone to erosion, because they are very sandy and have low particle aggregation capacity (CUIABANO *et al.* , 2017). They present characteristics that do not allow the nesting of many other genus of ants, but the characteristics of the most frequent species, such as those described below, facilitate their presence.

Species of the genus *Cephalotes* behave, in general, like soldiers, dedicating themselves to the protection of nests and represent a genus with dominant, but non-aggressive species (SILVA, 2018). Even without aggressiveness, they usually surround the food, one next to the other, making it difficult for other ants to access the baits (GOMES, 2012). In an environment with other genera of ants, they access new areas, as numerous colonies can generate more efficient foraging responses, moving to different areas, thus avoiding competition and predation (SILVA, 2018).

Crematogaster is one of the genus with the greatest species richness and also has different adaptations to the environment. Having the ability to attract nestmates to the food source, it is also the only genus of ants with dominant species on all continents with a tropical or subtropical climate (MAJER, 1993).

Ectatomma is a very aggressive genus (HÖLLDOBLER; WILSON, 1990) , which may make it difficult to increase the diversity of other less aggressive genus and/or that do not have many skills to compete for food and habitat (FERNANDES *et al* ., 2000). In addition, it can be found both in environments with diversity and quality of habitats and food, as well as in places that suffer from anthropic actions, such as in agroecosystems, that is, they are tolerant to habitat disturbances and not as demanding as to biotic and abiotic resources. (BARBOSA; FERNANDES, 2003; SOBRINHO; SCHOEREDER, 2007; SUGUITURU *et al* ., 2015).

In this study, there was no tendency in to decrease or increase in diversity and richness indexes between areas with different percentages of soil with vegetation cover - PSVC, as observed in other studies related to the complexity of vegetation and the composition of ant species (CERETO, 2011; CARDOSO, 2009). According to these authors, the complexity of the vegetation determines the composition of the ant assemblage.

Analyzing the table below, it is possible to observe, for example, that area 3, which has the highest percentage of soil with vegetation cover - PSVC, did not present the highest levels of richness and diversity of ants.

Table 3- Indices of diversity (Shannon Winner) and richness (Chao 2) of ant species in restinga areas with different percentages of soil with vegetation cover, on the North Coast and Agreste of Bahia. Baixio, Esplanada-BA. September to December 2021 .

Area	Species	Wealth	Diversity	PSVC*
1	Arboreal	1	0	
	Ground	4.48	1.2	94.79%
	Arboreal	1	0	
2	Ground	10.76	1.47	92.91%
	Arboreal	two	0.56	
3	Ground	10.84	1.56	98.23%
	Arboreal	1	0	
4	Ground	4.96	1.09	71.73%
	Arboreal	17.84	2.25	
5	Ground	27.28	1.98	94.93%

It is known that ants adapt to environments according to conditions that determine there, changes in systems can change the community and influence the diversity and richness of species, but the diversity and richness of ants are not linked only to aspects of vegetation, but can be influenced by various structural factors of the forest fragment (SILVA; BRANDÃO, 2010; ESTRADA, 2019). These factors are important to determine the number of species and the homogeneity in their distribution (MAGURRAN, 1988).

The similarity dendrogram (Figure 3) showed greater similarity between areas 03 and 04, and between this group and area 01. These are precisely the areas with the lowest number of fragments, since the most dissimilar areas are those that presented the greatest fragmentation, that is, greater number of fragments. (Table 04).

Figure 3– Dendrogram of similarity (Jaccard) between the restinga areas of the North Coast and Agreste of Bahia. Baixio, Esplanda-BA, September to December 2021.

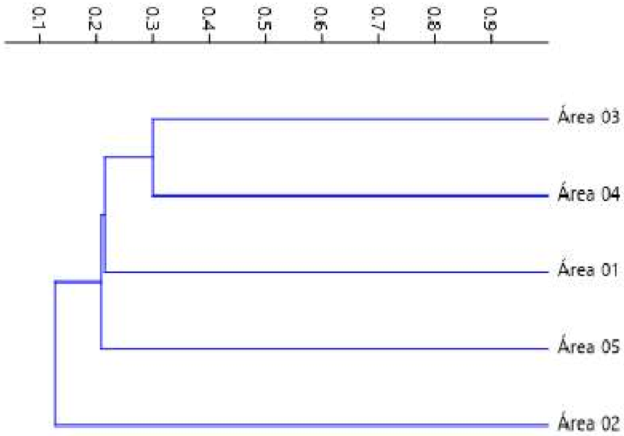


Table 4- Size (ha), number of fragments (FF), Circularity Index (CI), Fractal Dimension Index (FDI), anthropic area - AA, and anthropic area with flooding/flooding - AAA, of each restinga area . North Coast and Agreste of Bahia, September ad

Studied areas	size (ha)	FF	CI	FDI	AA (%)	AAA (%)
01	118.29	two	0.39	1.1184	4.14	5.21
02	125.10	5	0.41	1.11	3.04	7.90
03	601.67	1	0.31	1.1355	0.90	1.77
04	31.96	two	0.66	1.0466	25.21	28.27
05	973.40	3	0.28	1.1454	5.07	5.07

As it was previously seen, the faunal composition does not depend only in the vegetational complexity of the forest fragment, but can also be related to structural, geomorphological, climatic factors, influence of soil type, fragment shape, level of fragmentation, edge effect, among others aspects (CORRÊA, 2006). This justifies the fact that the similarity dendrogram did not follow a regular pattern of grouping in relation to the ecological characteristics of the areas studied, however, the level of fragmentation (SILVERIO NETO, 2015; GUARIZ, 2020) was a relevant aspect that favored this grouping. In addition to fragmentation, another factor that may have influenced the result of the above grouping is the geographic proximity between areas 03 and 04, as only 200 meters separate one area from the other.

Area 04 has a vegetation characterized by sparse bushes, with very sandy soil and the presence of a flooded area, known as Lagoa da Panela, an anthropized place frequented by tourists. Area 03 has a vegetation characterized by forest, with a dense physiognomy and less sandy soil, which favors the increase of humidity and organic matter, however, as it is an area close to Lagoa da Panela, it has places with higher levels of anthropization.

These areas, 03 and 04, have characteristics that influence the impoverishment of the soil, causing it to have a low concentration of nutrients, suffering greater impacts with the effect of wind, a factor that reduces the availability of substrate for nesting and can limit colonization by ant populations (FOWLER *et al* ., 1991).

As seen in Table 4, area 03 has only one fragment, while area 04 has 02 fragments. The different levels of fragmentation, whether caused naturally or anthropically, can have negative consequences on environmental ecosystems, such as loss or reduction of habitats, which is currently one of the main factors for the reduction of global biodiversity (JACOBSON I., 2019) .

According to Lino *et al* . (2019), habitat loss, in conjunction with forest fragmentation, is one of the biggest problems for fauna. However, despite always presenting themselves as a problem for the dynamics of ecosystems, it is suggested to address habitat loss and fragmentation independently (FAHRIG, 2003). Fragmentation can have positive effects for certain species, as they can offer different habitats, less intraspecific and interspecific competition, among other factors (GARMENDIA *et al* ., 2013; FAHRIG, 2017; LAURANCE *et al* ., 2002). Fragments with a total area of less than 50 hectares have a lower capacity to support fauna maintenance (PARDINI *et al* ., 2005). Therefore, the size and fragmentation of area 04 (31 hectares and 2 fragments) is an important factor that may explain the low ant diversity index of this location, when compared with the results of the other areas analyzed here.

The correlations between the PSVC and the ant diversity and richness indexes were not significant, however, it was possible to see (table 3) that, in general, there was a tendency towards an increase in the diversity and richness indexes in the areas with the highest PSVC. The correlations between anthropized areas and the indexes of diversity and richness of ants were also not significant, however, there was a tendency towards a decrease in the indexes of diversity and richness of ants, in areas with the highest percentage of anthropization.

However, this did not happen taking into account all areas. Area 04, with the lowest percentage of soil with vegetation cover, had a higher tree ant richness index than in area 01, which has more than 94% of soil with vegetation cover . However, factors other than PSVC contribute to the characteristics of the ant assemblage, and even though area 01 has a higher PSVC than area 04, it suffers major impacts from salinity and high temperatures, characteristics that limit the local myrmecofauna.

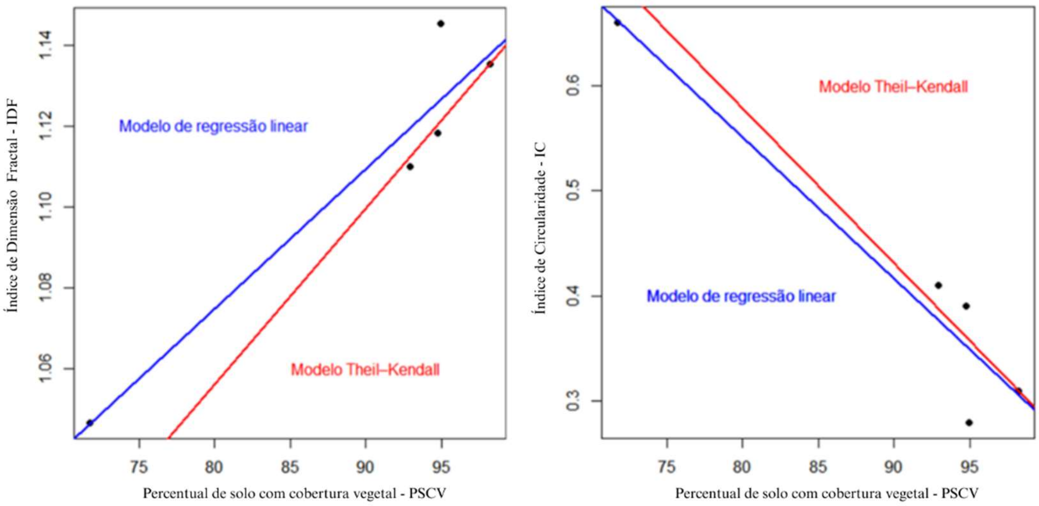
As previously mentioned, the areas where the ant collections were made, present vegetal complexity, among other characteristics that differ from each other. Some of them have the presence of flooding and/or flooding areas, in addition to presenting different percentages of anthropization (Table 4). The percentage of anthropization with flooded area, when correlated with the diversity and richness indexes of ants, presented negative correlations close to significance, therefore, it is possible to identify that the areas that have flooding/flooding areas influence the results of richness and diversity of ants. Anthropized and flooded areas can limit the nesting of ants and hinder the occurrence of species (SILVA, 2014).

4.2 GEOMETRIC ASPECTS OF THE RESTINGA AREAS STUDIED

Observing table 04 above, and taking the geometric aspects of the areas studied as a reference, the one with the largest area (05) also presented the highest FDI, with a positive correlation between these indexes ($r = 0.75$). As for the IC, when correlated with the size of the areas, showed a strong negative correlation ($r = -0.75$). Therefore, the larger the area in hectare, the greater the FDI, which increases due to the complexity and irregularity of the contour of the area. And the smaller the area, the less complex and irregular the edge, getting closer to the figure of a circle, thus presenting a higher CI. Forest fragmentation did not present a significant correlation with the other data shown in the table.

There was a strong positive correlation between FDI and PSVC, as well as a negative correlation between CI and PSVC (Figure 4). This may be due to the size of the area of the fragments, as seen in Table 04, those with the largest area had low roundness indexes. It is noteworthy that the highest CI indices are related to smaller areas, which have low vegetation density in their core area. Therefore, it is important to point out that if the CI is analyzed in isolation, it can hide or mask the degree of vulnerability of the area (SILVA, et al., 2019). On the other hand, the fractal dimension indexes increased when the area had a larger size and PSVC.

Figure 4- Scatter diagrams with correlation indexes and line (Theil-Kendall models and linear regression) between FDI and PSVC (y=0.71 +0.004x; ƚ = 0.80; p<0.05) and CI with PSCV (y=1.76-0.01x; ƚ = -0.80).



The percentage of anthropized area, with flooded area, when correlated with CI, showed a strong positive non-parametric correlation (ƚ = 0.80) (figure 5), however, when correlated with FDI and PSVC, it showed a negative correlation (ƚ = - 0.80 and ƚ = - 1.00) (Figures 6 and 7). Therefore, the closer the geometric shape of the fragment was to a circle, the greater the degree of anthropization and flooded area. The more complex the contour of the fragment, the lower the percentage of anthropization and flooded areas.

Figure 5- Scatter diagram with correlation index and straight line (Theil-Kendall models and linear regression) between CI and Anthropized area with flooded area (%) (y=0.28+ 0.01x; ƚ = 0.80; p <0.05).

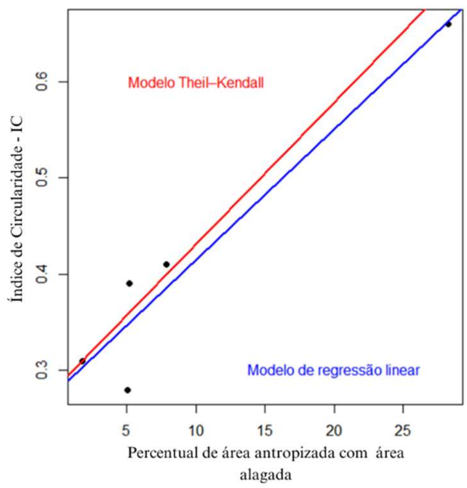


Figure 6- Scatter diagram with correlation index and straight line (Theil-Kendall models and linear regression) between FDI and Anthropized area with flooded area (%) (y=1.14 -0.003x; ƚ = -0.8; p <0.05).

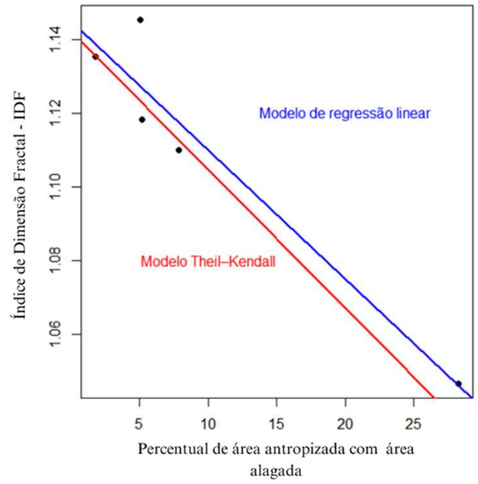
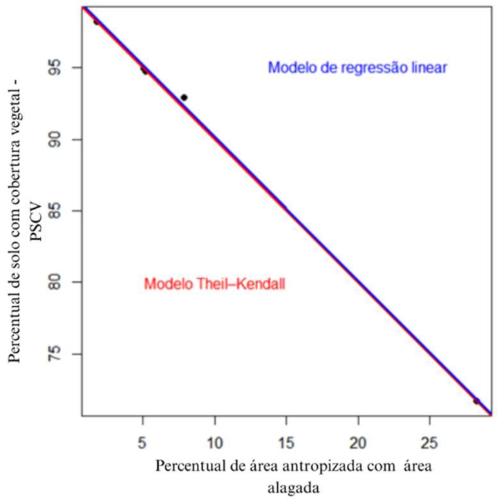
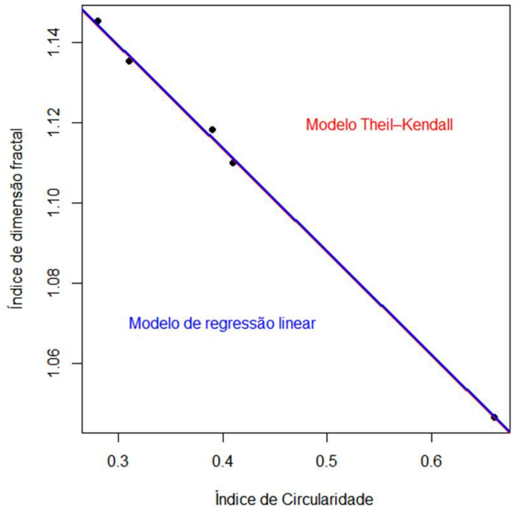


Figure 7- Scatter diagram with correlation index and straight line (Theil-Kendall models and linear regression) between PSVC and Anthropized area with flooded area (%) (y=1.00 -1.0 x; ƚ = -1.00 ;p<0.05).



The correlation between the circularity index - CI and the fractal dimension index - FDI of the analyzed areas were significant and negative (Figure 8).

Figure 8- Scatter diagram with correlation index and line (Theil-Kendall models and linear regression) between FDI and CI (y =1.33 -0.26 x ; ƚ = -1; p<0.05).



The negative correlations between the CI and the FDI must have occurred because of the different approach of each indicator. The CI seeks to identify the compaction level of each forest fragment, considering that it is based on comparing the area of the fragment to a geometric figure/circle (GOMIDE, 2008). Its value ranges from 0 to 1, classified by Viana and Pinheiro (1998) as follows: when the results are less than 0.6, they are considered very elongated; between 0.6 and 0.8, they are elongated; and greater than 0.8, rounded. Thus, the closer to one, the more rounded the polygon is (BORGES *et al* ., 2020). On the other hand, the FDI identifies the shape pattern of each forest fragment (GOMIDE, 2009; HOTT, 2007). With its values from 1 to 2 and, the closer to 1, the shape of the fragment tends to more rectilinear and simple contours (FERNANDES, 2017). This rectilinear shape can make the environment more artificial, since, if the area of the fragment is small, it will be more influenced by the edge, which can affect the microclimatic conditions and change the dynamics of the communities in that place (SILVA, 2013). Therefore, the closer the FDI value is to 2, the forest fragment has a more complex and irregular shape, moving away from more regular shapes (square or circle), which can reduce the possibilities of edge interference. This justifies the difference between the two ways of evaluating the geometry of the areas.

None of the areas were considered rounded, as the CI were not greater than 0.8. But, as for the FDI, the format of the fragments, in the case of these indexes, distances itself from a regular outline, as it presents more complex and less rectilinear perimeters.

4.3 RELATIONSHIP BETWEEN MYRMECOFAUNA AND LANDSCAPE METRICS

The correlation between CI and the tree and soil ant diversity index, and the soil ant richness index were significant and negative (Figures 9, 10 and 11). The correlations between the FDI and the index of diversity of arboreal and soil ants, as well as the index of richness of soil ants were positive (Figures 12, 13 and 14).

Figure 9- Scatter diagram with correlation index and line (Theil-Kendall models and linear regression) between the tree ant diversity index and CI (y=2.26-1.93x; ƚ = -0.8; p <0.05).

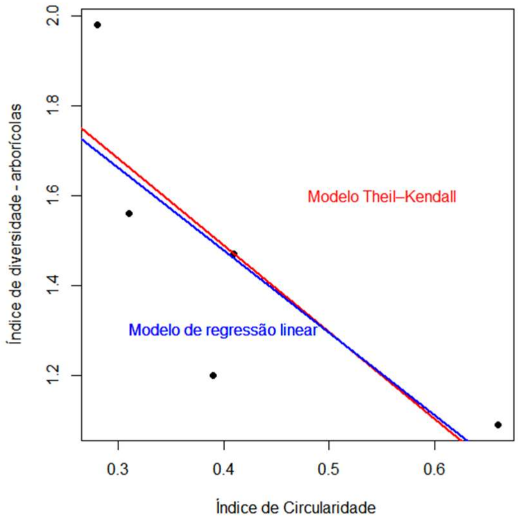


Figure 10- Scatter diagram with correlation index and line (Theil-Kendall models and linear regression) between the epigeic ant diversity index and CI (y=2.37-5.77x; ƚ = -0.84; p <0.05).

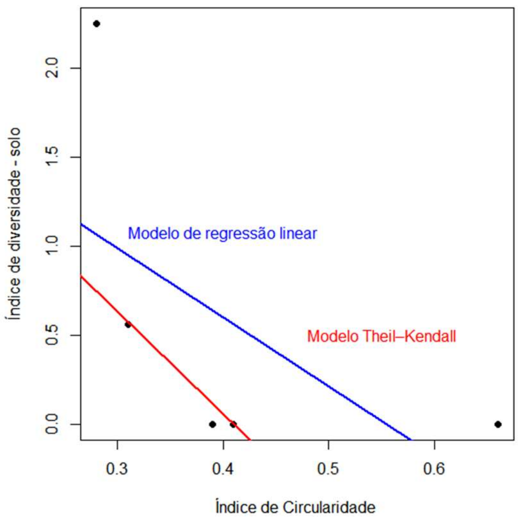


Figure 11- Scatter diagram with correlation index and line (Theil-Kendall models and linear regression) between epigeic ant richness index and CI (y=5.61-11.25x; ƚ = -0.84; p <0.05).

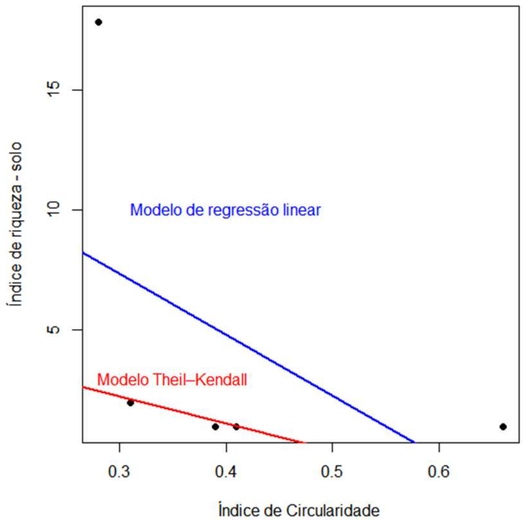


Figure 12- Scatter diagram with correlation index and line (Theil-Kendall models and linear regression) between the tree ant diversity index and FDI (y=-6.86+7.50; ƚ = 0.80; p <0.05).

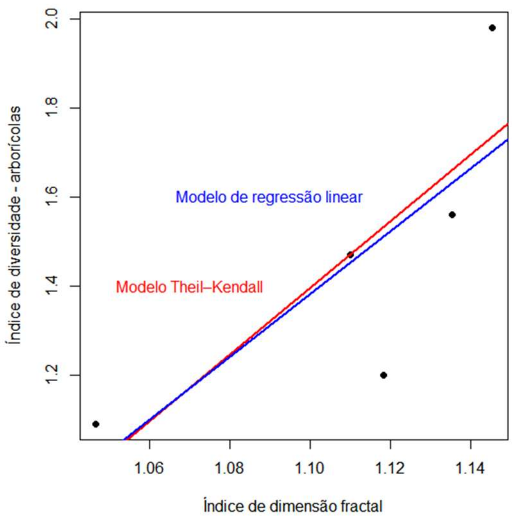


Figure 13- Scatter diagram with correlation index and line (Theil-Kendall models and linear regression) between the epigeic ant diversity index and FDI (y=-24.83 +22.37x; ƚ = 0.84; p <0.05).

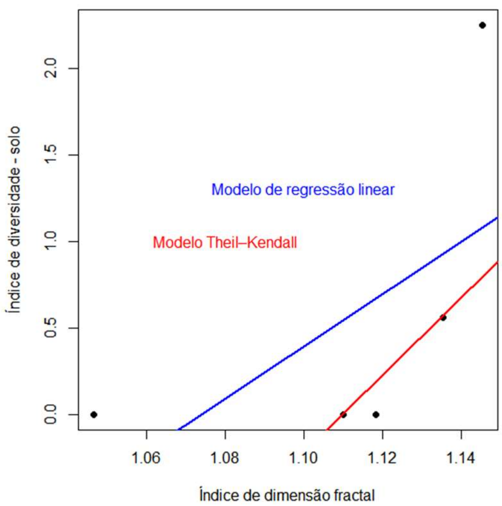
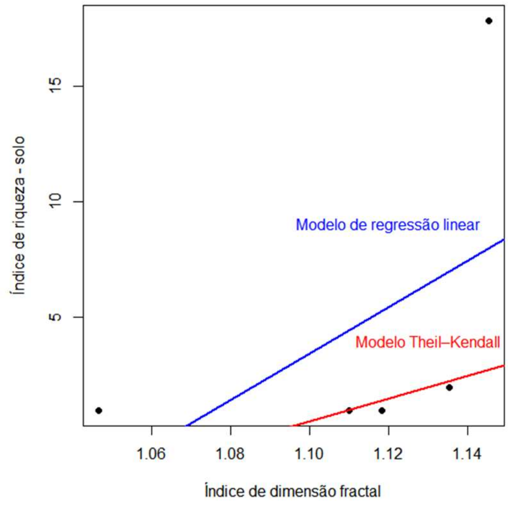


Figure 14- Scatter diagram with correlation index and line (Theil-Kendall models and linear regression) between epigeic ant richness index and FDI (y=-53.22+48.85x; ƚ = 0.84; p <0.05).



The negative correlation between CI and diversity of arboreal and soil ants and between CI and richness of soil ants can be explained by the degree of response of ants to the environment. They need a small area for survival and therefore their response to the metrics of the forest fragment may not be so clear (GOMES *et al* ., 2010).

Less interference from the edge effect makes the fragment more heterogeneous with greater diversity of niches and supply of food resources, thus resulting in greater diversity of species (SILVA, 2013). However, Laurance *et al.* (2002) indicates that interference from the edge can benefit some species of ant, because with the fall of leaves, a common fact on the edge, which increases the availability of litterfall, it can favor some species. In addition, according to the same authors, it is common to have pioneer plant species on the edges of the fragments, which also favors the myrmecofauna .

Furthermore, the predominant soil types in the studied areas, which were neosol quartzarenic , neosol fluvic and spodosols ferriluvians , are considered unstable for the colonization of many ant species (CREPALDI, 2014; SILVA, 2014).

The neosols quartzarenic materials have physical-chemical and mineralogical characteristics with a high degree of porosity and low water adhesion, low organic matter content, low particle aggregation capacity and are very acidic. (SILVA, 2018; ARAÚJO *et al* ., 2013; CUIABANO *et al* ., 2017).

The Spodosols ferriluvials also have a sandy texture, with little capacity to retain water and nutrients and, depending on the relief of the area, may present drainage problems (CARVALHO *et al* ., 2013).

Already the neosols Rivers present fine sediments such as fine sand and low activity clay (SILVA, 2016). Soils with less organic matter influence the nesting of fauna.

Crepaldi *et al* . (2014) found a positive correlation between ant diversity and increasing levels of organic matter in the soil. As the soils of the fragments are dissimilar in this respect, the lack of clarity on the influence between some indicators of the geometric shape of the restinga fragments and the diversity of ants may also be a factor interfering, since the nesting of ants is not only associated with the attributes vegetation and climate, but also those of the soil (SILVA, 2014).

4.4 MODELING, MYRMECOFAUNA AND LANDSCAPE METRICS

From the regression equation by the Theil-Kendall model, it was possible to propose a prediction model. It was the mathematical model that best suited the study, since it is widely used when the number of samples is relatively small and the data have high values in the same distribution (NUNES, 2005). Considering the model adopted, predictions can be made with values higher or lower than those found in the research, but not too far from them. Below is a prediction model proposed from the regression equation by the Theil-Kendall model, based on the FDI and CI data from this study:

Regression equation by theil-kendall model

Y = a + bx
Y = 1.33 - 0.26x
Y = Fractal dimension index
X = circularity index
Substituting in the equation:
Fractal dimension index = 1.33- 0.26 Circularity index

*An example of prediction:

For x = 1.12 (this is a value that was not found)
Fractal dimension index = 1.33 - (0.26 x 1.12)
Fractal Dimension Index = 1.33 – 0.29
Fractal dimension index = 1.04 (this is the expected value if the roundness index was 1.12)

It was also possible to build a prediction model proposed from the regression equation by the Theil-Kendall model, based on CI data and diversity of arboreal ants:

Regression equation by the Theil-Kendall model

Y = a + bx
Y = 2.37 – 5.77x
Y = Soil diversity index
X = circularity index
Substituting in the equation:
Soil Diversity Index = 2.37- 5.77 Circularity Index.

*An example of prediction:
For x = 0.30 (this is a value that was not found)
Diversity index - soil = 2.37 - (5.77 x 0.30)
Diversity index - soil = 2.37 – 1.73
Soil Diversity Index = 0.64 (this is the expected value if the circularity index were 0.30).

The objective of developing models like this one is to obtain the probabilities of modification of the indexes, in case any of them is modified over time. Therefore, this modeling is important because it is a tool that allows inferences about interactions between the analyzed indexes (CRUZ, 2021), in addition to understanding, in a more objective way, real-world phenomena (BARI, 2020).

However, in studies involving ecological data, it is complex to collect fully controlled data, because they depend on variables that are not always constant in the environment. Therefore, in the present study, it was necessary to evaluate the significance of the model adopted through the null model analysis (Table 5).

According to Paes (1995), the null model is based on the construction of a probability distribution by simulation, becoming an important tool for the validation of predictive models.

Table 5- Null model to verify the relationship between ecological variables and diversity of restinga ants on the North Coast of Bahia.

Variables	Coefficient	Error probability	Equation	Residual standard error
Anthropized area (%) x CI	ƚ= 0.40	p=0.33	y=0.31+ 0.01x	0.07
Anthropized area (%) x FDI	ƚ= -0.92	p=0.33	y=1.14-0.03x	0.02
Anthropized area (%) x Diversity index - soil	ƚ= -0.36	p=0.38	y=5.24-0.06x	1.26
Anthropized area (%) x Diversity index - arboreals	ƚ= -0.06	p=0.14	y=-0.19+0.02x	0.33
Anthropized area (%) x Richness index - soil	ƚ= -0.36	p=0.38	Y -0.09+0.11x	9.44

Anthropized area (%) x Richness index - arboreals	ƚ= -0.40	p=0.33	y=-12.82+0.25x	10.23
Anthropized area (%) x PSVC	ƚ= -0.60	p=0.14	y=-0.29-0.01x	1.19
Anthropized area with flooded area (%) x Diversity index - soil	ƚ= -0.60	p=0.14	y=1.58-0.03x	0.38
Anthropized area with flooded area (%) x Diversity index - arboreals	ƚ= -0.60	p=0.14	y=1.52-0.02x	9.49
Anthropized area with flooded area (%) x Richness index - soil	**ƚ= -0.60**	**p=0.14**	**y=11.25-0.22x**	**10.42**
Anthropized area with flooded area (%) x Wealth index - arboreals	ƚ= -0.40	p=0.33	y=99.04-0.90x	2.24
PSVC x Diversity index - soil	ƚ= 0.60	p=0.14	y=0.66-0.06x	1.23
PSVC x Diversity index - arboreals	ƚ= 0.60	p=0.14	y=1.60-0.02x	0.32
PSVC x Richness index - soil	ƚ= 0.60	p=0.14	y=2.18-0.10x	9.4
PSVC x Wealth index - arboreals	ƚ= 0.40	p=0.33	y=12.12-0.25x	0.19
Area (ha) x FF	r=-0.15	p=0.81	y=2.81 – 0.0006x	1.73
Area (ha) x CI	= -0.75	p=0.15	y=0.51 -0.00028x	0.16
Area (ha) x FDI	r = 0.75	p=0.15	y=1.08 + 0.000071x	0.03
FF x CI	r = -0.03	p=0.96	y=-0.42 – 0.0033x	0.18
FF x FDI	**r = 0.03**	**p=0.97**	**y = 1.11 + 0.0007x**	**0.008**

*Bold for the model identified as the worst and best among the nulls.

So, if the residual Standard Error indicates the assertiveness that the regression model can predict as a result from new data, when several models are compared, as in Table 6, it is possible to identify the best and the worst model among the null ones. In the present study, the best model occurred when the variables Forest Fragmentation - FF x Fractal Dimension Index - FDI were correlated, presenting a residual standard error of 0.008. The worst model, on the other hand, was based on the correlation between the percentage of anthropic area with flooded area x soil ant richness index, presenting a residual standard error of 10.42.

The analysis of residuals of the non-null models was also performed, using the Shapiro Wilk W test (Table 6), which seeks to analyze the normality of the data. When p>0.05, it means that the data have a normal distribution, this type of distribution makes it possible to model a variety of causal phenomena and even predict random variables that have other distributions.

Table 6- Analysis of residuals, from the Shapiro Wilk W test, of the non-null models.

Variables	Sum of residuals	Shapiro Wilk's W test for normal distribution of residuals	Residual standard error
Anthropized area with flooded area (%) x CI	-0.081116	0.8951 (P>0.05) normal distribution	0.05426
Anthropized area with flooded area (%) x FDI	0.03126	0.9265 (P>0.05) normal distribution	0.01454
Anthropized area with flooded area (%) x PSVC	0.81	0.5522 (P>0.05) normal distribution	0.4677
PSVC x CI	-0.00044	0.9461 (P>0.05) normal distribution	0.05562
PSVC x FDI	0.0225499	0.7002 (P<0.05) non-normal distribution	0.02093

The sum of residues was close to zero, and for the percentage of anthropized area with flooded area x PSVC, the regression model in which the sum of residues was most distant from zero. On the other hand, between PSVC x CI, it was the model in which the total of residuals was closest to zero.

The regression model for PSVC x FDI did not show an approximately normal distribution for the residuals. All others showed approximately normal distribution by Shapiro Wilk's W test.

The regression model for the percentage of anthropized area with flooded area x FDI, presented the lowest residual standard error, indicating a better adjusted model in relation to the other models. The highest residual standard error was found for the percentage of anthropized area with flooded area x PSVC.

Considering the analysis of the residues, we can infer that the linear regression models for the percentage of anthropized area with flooded area x CI, percentage of anthropic area with flooded area x FDI and PSVC x CI, present more adequate models than the regression models for percentage of anthropized area with flooded area x PSVC and PSVC x FDI. The last one mainly for not obeying the premise of approximately normal distribution of residuals.

5. CONCLUSION

Analyzing in isolation, only the vegetation cover of the fragments does not influence the diversity of ants, but other factors such as vegetation complexity, maritime, fragmentation of areas, influence of salinity and the geometric model, especially measured by the fractal dimension index, have an influence about this diversity. It is possible that the soil, in general, prevents the nesting of a greater volume of species and masks the possibility of finding a closer relationship between these variables. In addition, the degree of response of species to changes in the environment can also contribute to this, as some need a small area for survival and their response to fragment metrics may not be so clear. The most suitable mathematical model in this study was Theil-Kendall and from it a prediction model was proposed to predict new indexes of diversity and richness of ants in relation to metrics and soil vegetation cover.

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