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# Ants and Restingas: the Relationship Between the Geometric Model, Vegetation Cover, and Myrmecofauna in a Dune Habitat in Bahia, Brazil

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**Abstract**

In this study, we propose to investigate whether the geometric model and vegetation cover of restinga remnants influences the diversity of ants on the Northern Coast of Bahia. Using Winkler extractors and baits of honey and sardines, the ants were collected from five restinga remnants. Correlations were made between the percentage of soil with vegetation cover, circularity and fractal dimension index and the diversity and richness of ants. Lastly, Kendall correlations and Theil-Kendall regression were performed. The diversity index of ants was not associated with the percentage of soil with vegetation cover. The diversity and richness of terrestrial ants were negatively influenced by the circularity index and positively by the fractal dimension index. The circularity index was inversely proportional, while the fractal dimension index was equivalent to the ant diversity index. The similarity dendrogram showed that areas with less fragmentation had similar myrmecofauna composition. The vegetation cover of the soil does not influence the diversity of ants, but the fragmentation of the areas and the geometric model measured by the fractal dimension index have an influence, being 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.

## Introduction

Brazil is a country with a large diversity of fauna and flora. As a tropical country, it has many biomes, like the Atlantic Forest, which is notable for its high biodiversity, as it comprises a variety of ecosystems such as dense rainforest, araucaria forest, high-altitude fields (campos de altitude), mangroves (manguezais), and sandbanks (restingas) (Fundação SOS MATA Atlântica, 2009). According to Cerqueira et al. (2000), restingas are ecosystems along the Brazilian coast, including vegetation that grows on sandy deposits. It is represented by a mosaic of communities with different levels of environmental complexity (Araújo et al., 2004; Menezes & Araújo, 2005). Therefore, they are important to assess the effects of environmental heterogeneity on animal communities (Vargas et al., 2007).

Among the Brazilian states, Bahia has the largest coastline in terms of extension, and, despite its wealth, studies in this region are still recent when compared with other ones made in different ecosystems of Brazilian biomes, starting to occur after the publication of some of Britto and colleagues, scientific study in 1993, that refers to the diversity of vegetation in the Northern Coast of Bahia, performed between the dunes and lagoons of Abaeté, in Salvador, Bahia.


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Thereafter, other studies in this region have been developed, however, when the importance of sandbanks in maintaining a high diversity of organisms is considered, it is necessary to expand the research on the biodiversity of invertebrates, including ants in these environments (Lopes & Santos, 2020).

Despite being a legally protected area, anthropic impacts have been causing environmental degradation, such as the extractive activity of its sands, the advance of real estate speculation, or simply the indiscriminate removal of plants and animal species for commercialization. Likewise, the Northern Coast of Bahia confronts several issues, including a disorderly population increase, as well as expansive tourism projects and other activities that negatively affect the biodiversity of these ecosystems.

Regarding the traditional communities that depend on the resources of the restinga, the environment can be characterized as a place that represents a wide range of shapes, colors, and scents (Dias & Freire, 2016). Despite its undeniable importance from both environmental and cultural perspectives, the restinga is one of the coastal ecosystems most severely impacted by the anthropogenic use of its natural resources (Segantini et al., 2015). Therefore, it is crucial to better understand how biological communities react to these impacts, particularly how human-nature interactions endanger the preservation of the restinga and can undermine the ecosystem's functionality by jeopardizing its biodiversity.

Viana et al. (1992) suggest that several patterns can be used as indicators of the environmental quality of the landscape, such as the edge effect, shape, type of surrounding element, and the degree of isolation of the landscape contribute to 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 is the fractal dimension index (O'Neill et al., 1988). In this context, analysis of landscape metrics collaborates with studies of forest areas, especially those that suffer from anthropic or natural modifications, as they help analyze patterns of alteration of biological communities, including myrmecofauna.

Even if they do not represent reality, prediction models are important, as they make it possible to predict new or future situations (Coeli, 2021). Therefore, they are suitable and necessary in this study, to make predictions, avoid significant losses of natural resources and biodiversity, and indicate safe management strategies for conservation units.

Different ecological states and landscape structures show patterns when measured by the fractal dimension. Hence, the variations resulting from the fractal dimension index can help evaluate data linked to the landscape complexity of forest remnants (Santos & Rocha, 2020). The consequence of using and managing natural resources requires scientific investigations that collaborate with the management and conservation of these resources. Thus, studies addressing landscape metrics have contributed to the understanding of environmental dynamics 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 standards of structure and forms of the local landscape (França, 2019).

Ants have been one of the most appropriately selected groups of invertebrates for assessing the ecological conditions of ecosystems (Alonso & Agosti, 2000; Lutinski & Garcia, 2005; Gómez & Abril, 2011). Therefore, they are often used as bioindicator organisms (Delabie et al., 2006) as there is a correlation between the structure of habitats and patterns of their communities, such as species richness and composition (Underwood & Fischer, 2006), among other correlations. Their sampling and identification are relatively easy, and they are sensitive to environmental changes (Ribas & Schroeder, 2012; Schmidt et al., 2013).

Due to its unique characteristics, the restinga is a suitable environment for analyzing plant complexity, landscape metrics, and ant diversity. Therefore, the evaluation of the landscape metrics and the area-perimeter elements, analyzed from the fractal dimension, verify the influence of the ecological status of an ecosystem on biodiversity. In this way, it can minimize subjectivity in evaluating landscape patterns, increasing the reliability of this relationship with the ant diversity indicators. Therefore, the present study aims to verify if the geometric model and vegetation cover of restinga remnants influences the diversity of ants on the Northern Coast of Bahia.

## Materials and Methods

The research was conducted in restinga areas on the Northern Coast of Bahia, in Costa dos Coqueiros-Baixio, Esplanada. The samples were collected between September and December of 2021. Annual temperatures ranged from 20 °C and 32 °C (INMET, 1992). Based on data provided by the soil map of the National Soil Program of Brazil on a scale of 1:250.000 (CPRM/SGB, 2020), the predominant type of soil in the locality of the study areas is quartzite neosol. However, some areas present ferriluvic spodosols and fluvial neosol.

The study area has 6.204,72 hectares (37°44'10"W 12°08'18"S). Considering different levels of complexity and vegetation structure, five areas were selected: area 1 – Lagoa Azul (37°42'23"W 12°06'20"S); area 2 – Trilha de Amadeus (37°43'09"W 12°05'25"S); area 3 – Mata Verde (37°44'54"W 12°09'39"S); area 4 – Lagoa de Panela (37°45'29"W 12°09'2"S); and area 5 – Trilha da Mata (37°43'43"W 12°07'21"S) (Fig 1).

The distance between area 01 to the beach line is approximately 1.5 km, with an altitude of 32 m.a.s.l., presenting herbaceous vegetation, bushy thickets and unprotected soil and it is influenced by the thermal amplitude. This is the closest area to the beach, therefore it suffers greater impacts from salinity and anthropic actions.

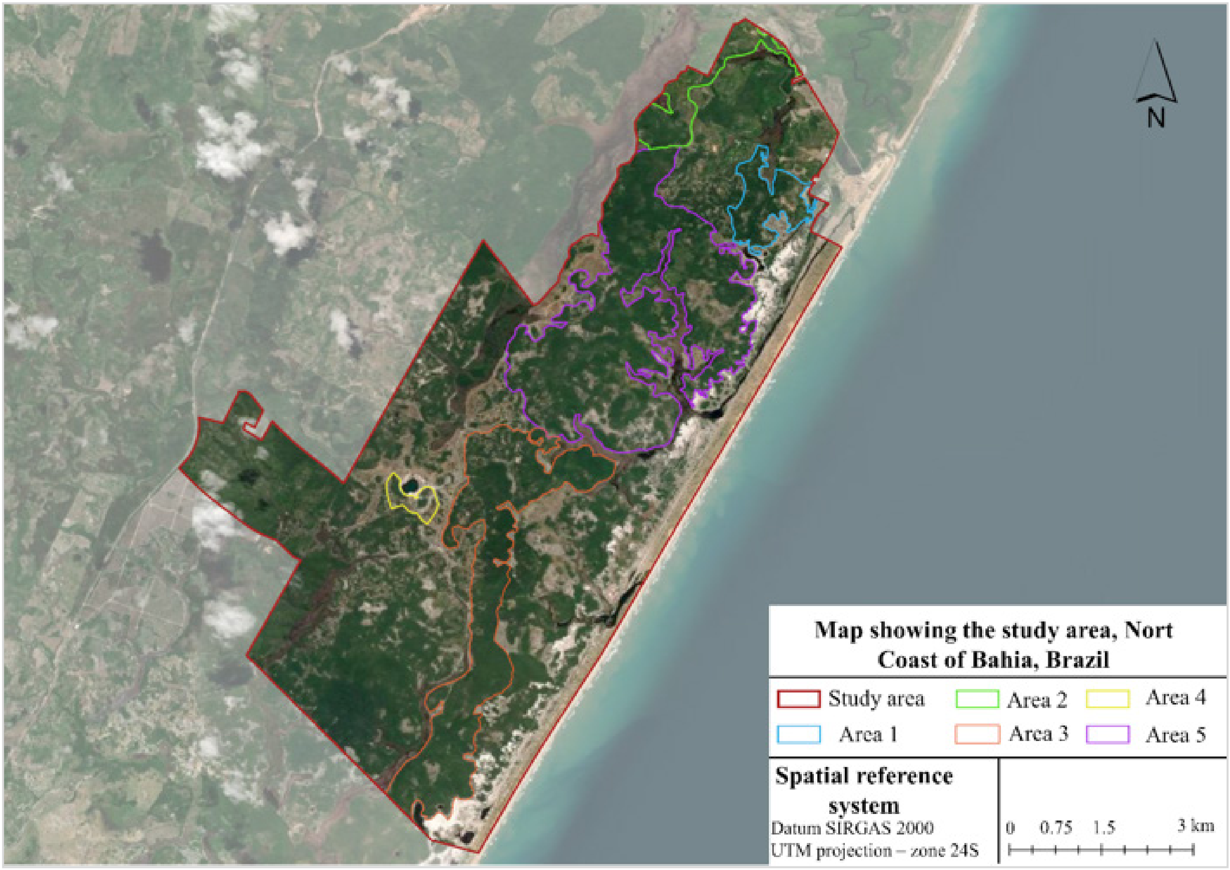


**Fig 1**. Study area, with the five areas studied on the Northern Coast of Bahia, Baixio, Esplanada.

Area 2 is approximately 3.6 km distant from the beach line, with an altitude of 28 meters. Presenting sparse vegetation and exposed soil.

As for area 3, there is a distance of 2.4 from the beach line, with an altitude of 50 meters at the collection point. Its vegetation presents a dense physiognomy, less sandy soil and higher organic matter content.

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

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

Overall, it is possible to identify that the areas present vegetation that varies from herbaceous formations, passing through shrub formations and 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 floodable 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 base map software program ArcGis Pro v.2.9, two transects were delimited, with intervals of 25 m between each sample unit (represented by each tree) and a distance of 50 m from the edge. Therefore, a total of 25 samples were selected for each type of trap: Winkler extractors for epigeic ants, honey baits and sardines for trees and, lastly, each sample unit was a plant. At the base of each plant, samples of epigeic ants were collected with a field sieve and taken to the Zoology laboratory of UNEB at Alagoinhas Campus, located in the state of Bahia, being stored for extraction for an interval of 72 hours in Winkler extractors. In the same plants, honey and sardine baits were also available in different and bilateral branches, being removed after an interval of one hour containing the captured ants. The criterion for choosing the plants was a distance of 25 meters between one and the other and 50 meters from the edge of the fragment, precisely to maintain the independence of the ant samples.

Species were identified using taxonomic keys and by comparison with the reference collection of the Museum of Mirmecologia of UNEB (campus II), according to Bolton (2020). Richness was estimated from the Chao 2 richness index, using the software EstimateS v.9.1.0 (Colwell, 2019). The diversity index (Shannon-Winner) and the similarity dendrogram (Jaccard) were obtained using the software Past v.4.03. Spatial analysis was used to obtain parameters such as fragment size, area, perimeter, and percentage of soil vegetation cover using the software ArcGis Pro v.2.9.

Following the spatial analysis, both the fractal dimension index (FDI) and the circularity index (CI) were calculated using the software Geogebra v. 5.0.

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

In which:

$F_D$ = fractal dimension index

P = perimeter of the forest fragment

A= forest fragment area

CI = 2*π*AP

Where:

CI = circularity index

P = perimeter of the forest

A = forest fragment area

The non-parametric correlation proposed by Kendall was performed using the software Statistica v.10.0. When correlations were significant ($p<0.05$), the regression line was made using the Theil-Kendall model ($y = a + bx$) in the R software v.4.0.4. This mathematical model is widely used when the number of samples is relatively small, and the data have high values in the same distribution (Nunes, 2005). For the interpretation of the correlation between the variables, the values stipulated by Silvia and Shimakura (2006) indicated in Table 1 were used, replacing the *r* value with the value of ƚ (Tau).

## Results

Considering all the restinga remnants studied, the ant species with the highest frequency of occurrence were: *Cephalotes pusillus* (Klug, 1824*), Crematogaster* sp.1, and *Ectatomma tuberculatum* (Olivier, 1791) (Table 2). *Cephalotes pusillus* was found in all areas, while *Crematogaster* sp.1, in almost all areas, and *E. tuberculatum*, was found only in area 5.

Within the parametric correlation, it was verified that among the remnants studied the largest area of the study (area 05) also presented the highest fractal dimension index (FDI), with a significant positive correlation between these indexes with $r = 0.75$. However, the circularity index (CI) when correlated with the size of the areas, showed a strong negative correlation, with a coefficient $r = 0.75$ (Table 3). There was no significant correlation between forest fragmentation and the other data presented in the table.

The similarity dendrogram (Fig 2) revealed a stronger resemblance between areas 03 and 04, and this group shared greater similarity with area 01. These are precisely the areas with the lowest number of fragments. Curiously, the most dissimilar areas of the set of restinga areas evaluated were those that showed the greatest fragmentation, that is, the greatest number of fragments.

**Table 1** - Table adapted (Silvia & Shimakura, 2006) for the interpretation of the degrees of correlation between PVCS, CI, FDI, and indices of diversity and richness of ants in restinga remnants of the Northern Coast and Agreste of Bahia Percentage of vegetation cover and soil (PVCS); Circular index (CI); Fractal dimension index (FDI).

| Value of r (+ or -) | Interpretation |
|---|---|
| 0.00 a 0.19 | Very weak correlation |
| 0.20 a 0.39 | Weak correlation |
| 0.40 a 0.69 | Moderete correlation |
| 0.70 a 0.89 | Strong correlation |
| 0.90 a 1.00 | Very Strong correlation |

**Table 2** - Frequency (%) of arboreal and epigeic ant species in different restinga areas of the Northern Coast of Bahia. Baixio, Esplanada-BA.

| Species | Frequency (%) / Area | | | | |
|---|---|---|---|---|---|
| | **01** | **02** | **03** | **04** | **05** |
| *Azteca chartifex* (Forel, 1912) | 0 | 0 | 8 | 0 | 0 |
| *Camponotus retangulares* (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 minutus* (Fabricius, 1804) | 4 | 0 | 0 | 0 | 4 |
| ***C. pusillus*** **(Klug, 1824*)*** | **24** | **12** | **32** | **28** | **28** |
| ***Crematogaster*** **sp.1** | **16** | **0** | **8** | **20** | **20** |
| *Crematogaster* sp.2 | 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* sp.1 | 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* sp.1 | 0 | 0 | 4 | 0 | 0 |
| *Pheidole* sp.2 | 0 | 0 | 8 | 0 | 8 |
| *Pheidole* sp.3 | 0 | 4 | 0 | 0 | 4 |
| *Pseudomyrmex gracilis* (Fabricius, 1804) | 0 | 4 | 0 | 0 | 0 |
| *Solenopsis* sp.1 | 0 | 0 | 0 | 0 | 4 |
| *Solenopsis* sp.2 | 0 | 0 | 4 | 0 | 8 |
| Total of species of the study area | 5 | 5 | 7 | 5 | 18 |
| Total of species | | | 25 | | |

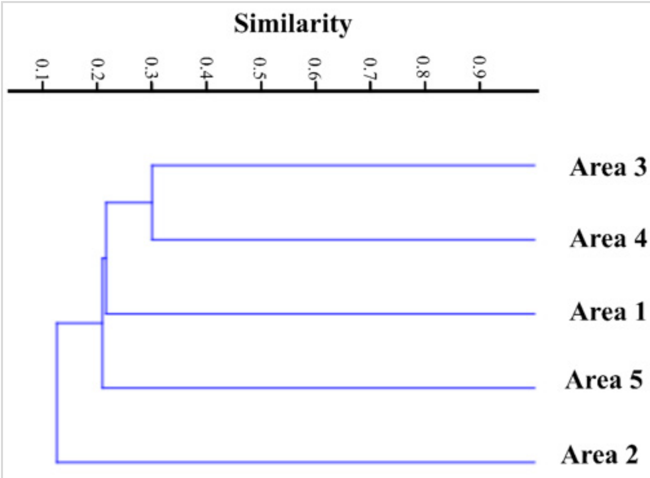


**Fig 2**. Similarity dendrogram (Jaccard) between restinga study areas on the Northern Coast of Bahia, Baixio, Esplanda.

Considering the distance between the areas (Table 4), it was verified that, even though it was not linear, the distance between the remnants influenced the faunistic composition. Correlating the percentage of vegetation cover and soil (PVCS) with CI and FDI (Fig 3) it was noted a strong positive correlation between FDI with PSCV; and a strong negative correlation between CI and PSCV.

**Table 3** - Definition of the size of each area in hectares, on the Northern Coast of Bahia, Baixio, esplanada. Forest fragmentation (FF); Fractal dimension index (FDI); Circularity index (CI).

| Study area | dimension in hectare | FF | CI | FDI |
|---|---|---|---|---|
| **01** | 118.29 | 2 | 0.39 | 1.1184 |
| **02** | 125.10 | 5 | 0.41 | 1.11 |
| **03** | 601.67 | 1 | 0.31 | 1.1355 |
| **04** | 31.96 | 2 | 0.66 | 1.0466 |
| **05** | 973.40 | 3 | 0.28 | 1.1454 |

The correlations between the PVCS and the ant diversity and richness indices were not significant. However, it was possible to perceive that, in general, there was a tendency towards an increase in the diversity and richness indices in the areas with the highest PVCS. This did not happen in all areas, as expected. Area 04, with the lowest percentage of soil with vegetation cover, presented a higher tree ant richness index than area 01, which has more than 94% of soil with vegetation cover (Table 5).

**Table 4 -** Distance between restinga remnants on the Northern Coast of Bahia, Baixio, Esplanada.

| Fragment | Distance (m) | | | |
|---|---|---|---|---|
| | 2 | 3 | 4 | 5 |
| **1** | 872 | 4077.52 | 6353.49 | 18.38 |
| **2** | - | 4877.14 | 6571.91 | 17.15 |
| **3** | - | - | 226.16 | 12.5 |
| **4** | - | - | - | 1.945 |

**Table 5** - Diversity (Shannon Winner) and richness (Chao 2) indices of ant species in restinga areas, with different percentages of vegetation cover, on the Northern Coast of Bahia, Baixio, Esplanada.

| Area | Species | Richness | Diversity | PVCS* |
|---|---|---|---|---|
| **1** | Soil | 1 | 0 | 94.79% |
| | Arboricolous | 4.48 | 1.2 | |
| **2** | Soil | 1 | 0 | 92.91% |
| | Arboricolous | 10.76 | 1.47 | |
| **3** | Soil | 2 | 0.56 | 98.23% |
| | Arboricolous | 10.84 | 1.56 | |
| **4** | Soil | 1 | 0 | 71.73% |
| | Arboricolous | 4.96 | 1.09 | |
| **5** | Soil | 17.84 | 2.25 | 94.93% |
| | Arboricolous | 27.28 | 1.98 | |

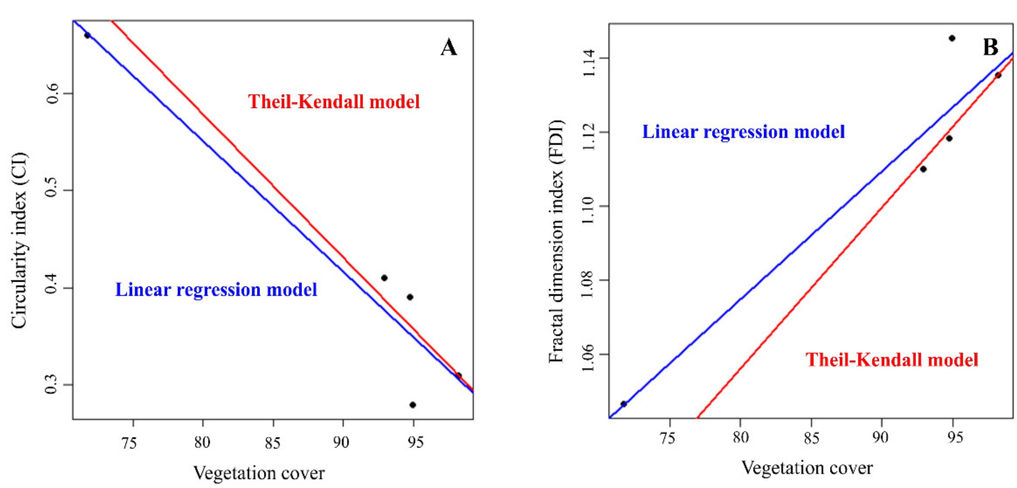


**Fig 3**. Dispersion diagrams with correlation indices (Theil-Kendall models and linear regression) between FDI and PVCS (y=0.71 +0.004x; ƚ = 0.80; p<0.05) and CI with PVCS (y=1.76 - 0.01x; ƚ = -0.80).

The correlation between CI and FDI of the areas was significant and negative (Fig 4a), confirming what was observed in the correlation of Figure 3, as well as between CI and the diversity index of arboreal and epigaeic ants (Fig 4b and 4c) and between the CI and the terrestrial ant richness index (Fig 4d). Therefore, a higher FDI, indicates lower circularity, while a higher CI implies lower diversity and richness of epigaeic ants, as well as lower diversity of arboreal ants.

There were positive correlations between the FDI and the index of the diversity of arboreal and epigaeic ants, as well as the index of richness of epigaeic ants (Fig 4e, 4f, and 4g).

From the regression equation obtained from the Theil-Kendall model, it was possible to propose prediction models. Considering the adopted model, predictions can be made with values higher or lower than those found in the research, but not too far from them. Therefore, based on the prediction model, an area with a circularity index of 1.12 would have a fractal dimension index equal to 1.04.

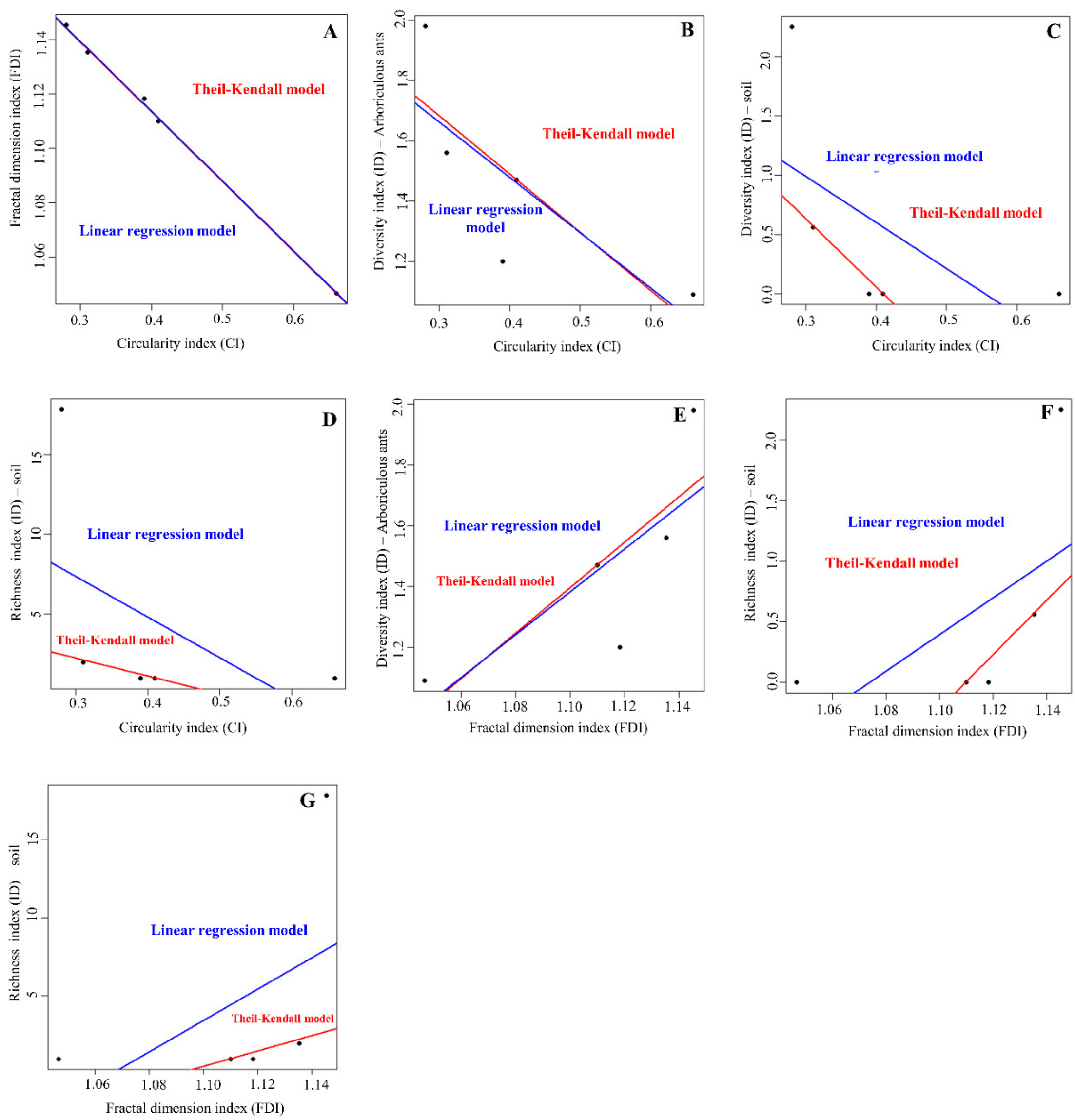


**Fig 4**. Dispersion diagram with correlation and line index (Theil-Kendall models and linear regression). **A.** Between FDI and CI (y =1.33 -0.26 x; ƚ = -1; p<0.05). **B.** Arboriculous ants' diversity index and CI (y=2,26-1.93x; ƚ = -0.8; p<0.05). **C.** Epigeic ants' diversity index and CI (y=2.37-5.77x; ƚ = -0.84; p<0.05). **D.** Epigeic ants' richness index and CI (y=5,61-11.25x; ƚ = -0.84; p<0.05). **E.** Arboriculous ant diversity index and FDI (y=-6.86+7.50; ƚ = 0.80; p<0.05). **F.** Epigeic ants' diversity index and FDI (y=-24.83 +22.37x; ƚ = 0.84; p<0.05). **G.** Epigeic ants' richness index and FDI (y=-53.22+48.85x; ƚ = 0.84; p<0.05). Circularity index (CI); Fractal dimension index (FDI).

## Discussion

In this study, the absence of a linear trend of decrease or increase in diversity and richness indexes between areas with different percentages of soil with vegetation cover was observed. Ants adapt to environments according to conditions that determine them, therefore, changes in systems can change the community and influence the diversity and richness of species (Majer, 1994). However, the diversity and richness of ants are not associated only with aspects of vegetation but can be influenced by the shape of the fragment, amount of litter, extraction of plant specimens, temperature, resource availability and forest fragmentation, among other aspects (Silva & Brandão, 2010; Estrada, 2019). These factors are important to determine the number of species and the homogeneity in their distribution (Magurran, 1988).

As seen in Figure 2 the similarity dendrogram did not follow a regular pattern of grouping concerning the ecological characteristics of the studied areas. However, the level of fragmentation (Silvério Neto et al., 2015; Guariz & Guariz, 2020) was a relevant aspect that justified this result. The different levels of fragmentation, caused by natural or anthropical impacts, can have negative consequences on environmental ecosystems, such as the loss or reduction of habitats, which is currently one of the main factors for the reduction of global biodiversity (Jacobson, et al., 2019). Furthermore, less fragmented areas with greater soil vegetation cover, reduce the impacts of climatic factors such as soil temperature and incidence of light, which can increase the diversity of animal species, including ants (Lopes & Santos, 2020).

According to Lino et al. (2019), habitat loss with forest fragmentation makes up one of the biggest problems for the fauna. However, despite always presenting themselves as a problem for the dynamics of ecosystems, Fahrig (2003) began to question the problems caused by forest fragmentation, suggesting addressing habitat loss and fragmentation independently. Fragmentation can positively affect species, as they can offer different habitats, and less intraspecific and interspecific competition, among other factors (Laurance et al., 2002; Garmendia et al., 2013; Fahrig, 2013).

The size of area 04 evaluated in this study is an important factor that may explain the low ant diversity index when compared with the results of the other areas analyzed here. However, the faunal composition does not depend only on plant complexity but is also linked to structural, geomorphological, weather, the influence of soil type, fragment shape, level of fragmentation, and edge effect (Corrêa et al., 2006). Pardini et al. (2005) indicate that fragments with a total area of less than 50 hectares have a lower capacity to support fauna maintenance.

The negative correlations between the CI and the FDI may have occurred because of the different approaches of each indicator. While the CI identifies the compaction level of each forest fragment, based on comparing the area of the fragment to a geometric figure/circle (Gomide, 2009). Its value ranges from 0 to 1, classified by Viana & Pinheiro (1998), as follows: when results are less than 0.6 they are considered too elongated; between 0.6 and 0.8 are elongated, and greater than 0.8 are rounded. That is, the closer to 1 (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 & Lingnau, 2009). With values from 1 to 2 and closer to 1, the shape of the fragment tends towards a straighter and simpler contour (Fernandes, 2017). The rectilinear format can make the environment more artificial, 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. Thus, the FDI closer 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, which justifies the difference between the two ways of evaluating the geometry of the areas.

None of the areas were considered rounded, as the CI was not bigger than 0.8. But, as for the FDI values, the format of the remnants, distances itself from a regular contour, since it presents more complex, and less rectilinear perimeters, making it difficult to find the contours of a landscape through it (Metzger, 2003). Based on the CI, FDI, and the ant diversity indices, a predictive model was developed, as shown in the results, to obtain the probabilities of indices modification, in case any of them is modified over time. The development of a predictive model is important because models are configured as a tool that allows the inference about interactions between the analyzed indices, in addition to understanding, in a more objective way, real-world phenomena (Bari, 2020).

The negative correlation between the CI and the diversity of arboreal ants can be explained by the degree of ants' response to the environment. They need a small area for survival and therefore their response to the forest fragment metrics may not be so clear (Gomes et al., 2010a). That statement differs from Silva (2019), which says that the larger the CI of a fragment, the smaller its edge/interior ratio, which is desirable, as there is supposedly a greater area in the fragment that will not suffer as many impacts with the edge effect.

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

The types of soils in the studied areas are considered unstable for the colonization of many species of ants (Crepaldi, 2014). Since Quartzarenic neosols have physicochemical 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 (Araújo et al., 2013; Cuiabano et al., 2017; Silva, 2018). Ferriluvic Spodosols 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). Fluvial neosols, on the other hand, have fine sediments such as fine sand and low-activity clay. 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 remnants are similar in this aspect, the lack of clarity on the influence between some indicators of the geometric shape of the Restinga remnants and the diversity of ants may also be a factor interfering, since the nesting of ants is not only associated with the vegetation and climate attribution but also those of the soil (Gomes et al., 2010). The nest structure of *E. tuberculatum*, for example, may vary depending on the soil structure (Poteaux, 2015).

The characteristics of the soil, especially the sandy one, justify the frequency of few species in the present study, since, in general, the areas studied have soils that make it difficult to increase nutrition, because they have a low content of organic matter and are very acidic, therefore they are considered shallow and prone to erosion, since they are very sandy, with low particle aggregation capacity (Cuiabano et al., 2017), and have characteristics that do not allow the nesting of many genera of ants.

However, the characteristics of the studied areas, heterogeneous in their phytophysiognomy, where there is low vegetation, shrubs, and even dense forest characterized as forest, can also justify the presence of some species, for example, *Cephalotes pusillus*. According to Silvestre (2001), species of this genus are strongly associated with the diversity of the vegetation in the environment.

Analyzing in isolation, only the vegetation cover of the soil does not influence the diversity of ants, but other factors such as plant complexity, proximity of the fragment in relation to the sea, altitude and fragmentation of areas, and the geometric model, especially when measured by the fractal dimension index, influence this diversity. 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. However, the response degree of species to changes in the environment can also contribute to it, as some need a small area for survival, and their response to fragment metrics may not be so clear. Therefore, our analysis allows us to identify that the factors that influence the diversity of ants can vary according to the habitat, and understanding these factors can favor future work, in addition to collaborating with the definition of management and conservation strategies for areas such as restinga ecosystems.

## Authors' Contributions

DRF: conceptualization, validation, formal analysis, methodology, investigation, writing - original draft, visualization.

ESC: conceptualization, validation, supervision, formal analysis, methodology, project administration, writing - review & editing.

AOCN: Methodology, software, formal analysis, data curation.

ATAN: software, data curation.

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