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BOTANY

Impacts of the biological invasion by *Ricinus communis* L. on the native biota of the Atlantic Forest, Aracaju, Sergipe State, Brazil

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ABSTRACT. The existence of environmental disturbances is an important facilitating factor to the establishment of biological invasions (BI). Biological invasions are considered the second biggest threat to the planet's biodiversity, behind only anthropic actions such as deforestation and habitat fragmentation. Thus, all environments are subjected to biological invasions, including Conservation Units (CU). The objective of the work was to evaluate the impacts of the exotic invasive *Ricinus communis* L. on the native biota of the Morro do Urubu Environmental Protection Area, Aracaju, Sergipe State, Brazil. Plots were allocated in places invaded by exotic invasive and in non-invaded places. Within the sample units, the number of individuals of each species present was counted. With these data, the statistics of the present study were performed. In the plots plotted on the non-invaded sites, 28 species were found. In the plots plotted on the invaded sites, only three species were sampled, among them the exotic invader studied, which showed to be the most abundant taxon in the area. In total, 75 individuals were counted in the invaded sites, of which 72 were from *R. communis*. In the non-invaded sites, 210 individuals. The average number of species was statistically higher in the plots where the exotic invader was removed, while from the second reading and remained until the eighth reading, the same happened for the average number of individuals. The results of this study showed the impacts caused by invasive exotic *Ricinus communis* on the composition, richness, diversity and resilience of an invaded Atlantic Forest area.

Keywords: invaded environment; environmental impacts; castor bean.

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Introduction

The Atlantic Forest is an extremely important biome for the subsistence of a large portion of the Brazilian population, as it provides various ecosystem services such as regulating the flow of hydric fountains, ensure soil fertility, control climatic balance and protect mountain slopes and slopes (Capobianco & Lima, 1997; Campanili & Schäffer, 2010). This biome also houses a large portion of Brazilian biodiversity and has a high degree of endemism (MMA, 2007), being considered one of the Brazilian Hotspots (Myers, Mittermeier, Mittermeier, Fonseca, & Kent, 2000).

Despiting its species richness and socioeconomic importance, the Atlantic Forest has been degraded by anthropic action since the arrival of Europeans in the Americas. Several reasons have caused the fragmentation and loss of habitats in this biome (see Capobianco & Lima, 1997; Campanili & Schäffer, 2010), leaving only about 7% of its original area (MMA, 2007; Campanili & Schäffer, 2010).

The existence of environmental disturbances is an important facilitating factor for the establishment of biological invasions (BI) (Williamson, 1996). Biological Invasions are considered the second biggest threat to the planet's biodiversity, behind only human actions such as deforestation and habitat fragmentation (Williamson, 1996; Zenni & Ziller, 2011).

All environments are subjected to the impacts generated by biological invasions, including Conservation Units (CU), which is especially worrying since these reserves are created exactly to protect the indigenous genetic heritage. The alien species cause impacts on the native species, physical environment, human health and animal health, thus generating serious environmental, social and economic problems because they also cause negative interference in agriculture and livestock (Parker et al., 1999; Williamson, 1996; Ziller & Zalba, 2007; Fabricante, Araújo, Andrade, & Ferreira, 2012), which reinforces the importance of such studies.

Thus, this study sought to answer the following questions: (i) Does *Ricinnus communis* affect the composition, richness and native diversity from sites invaded of Atlantic Forest? and (ii) Is the presence of the exotic invader capable of preventing the establishment of native species (compromising the process of ecological succession) in sites of the studied biome? Therefore, the objectives of this work were to evaluate the impacts of the exotic invader *Ricinus communis* L. on the native biota of the Morro do Urubu Environmental Protection Area, Aracaju, Sergipe State, Brazil.

Material and methods

Study area

The present work was carried out in the Morro do Urubu Environmental Protection Area. The limits of the APA are defined by Salt River, Sergipe River and the urbanized area of the city (Prefeitura Municipal de Aracaju, 2015). In the area, originally there was a predominance of the Atlantic Forest and its ecosystems, however this vegetation complex suffered from recent urban interferences, being uncharacterized, mainly by the construction and housing of slums that surround the area (Gomes, Santana, & Ribeiro, 2006).

According to the Koppen-Geiger classification, the region's climate is type As, namely, hot tropical climate, with an annual average temperature of 25.6°C and an annual average precipitation of 1,409 mm (Climate-Data.org, 2021). The predominant soils are Podizolic Red Yellow and Vertisols (Embrapa Solos, 2018).

Studied species

The species *Ricinus communis* L., popularly known as castor bean, is a Euphorbiaceae native from the African continent (CABI, 2021), with records of occurrence in all Brazilian biomes (Fabricante, 2013). Extremely toxic to animals and to humans, it is an important weed for several crops (Tokarnia, Döbereiner, & Canella, 1975; Garland & Bailey, 2006; Borges, Cuciara, Silva, & Bobrowski, 2011).

Collection and data analysis

Comparison: sites invaded by *Ricinus communis* x not invaded by the exotic invader

To evaluate the effects of *R. communis* on the native flora, 20 plots of 1 m^2 were allocated, half of which were disposed in invaded sites by the exotic invader and the other half in non-invaded sites with the same biophysical characteristics as the previous ones. Within these sample units, the number of individuals of each species present was counted. At the end of the collection of these data, Shannon-Weaver Diversity (H') (Shannon & Weaver, 1949) and equability using the Pielou index (E) (Pielou, 1977) were calculated. Differences in the diversity between the invaded and non-invaded sites were verified by the t test ($p \leq 0.05$) (Lehmann, 1997).

To evaluate the floristic similarity between the invaded and non-invaded sites, the Jaccard coefficient (Sj) (Müller-Domboi & Ellemberg, 1974) and the dissimilarity by Bray-Curtis (Brower & Zar, 1984) were used. To assess whether there were differences in species composition and abundance between the studied sites, the multivariate NMDS analysis (non-metric multidimensional scaling) and the ANOSIM permutation test (oneway) (Clarke, 1993) were performed. The analyzes were performed using the Past 2.17c © software (Hammer, Harper, & Ryan, 2001).

Samples of these plants within the sampling units were collected, herborized and deposited in the Herbarium of the *Universidade Federal de Sergipe*, São Cristóvão, Sergipe State, Brazil. The taxonomic classification used follows the APG IV System (2016) and the spelling of the names of the species' authors according to the Brasil Flora Species List (2022).

Comparison: plots with the presence of *Ricinus comunnis* x plots that the exotic invader was removed

To evaluate the effect of *Ricinus communis* on the establishment of native plants (beginning of the ecological succession process) were plotted 20 plots in invaded sites by the exotic invasive, and in half of the sampling units, it has been completely removed, while in the other half, were kept, thus serving as witnesses. The plots had dimensions of 1 x 1 m.

Each month it was taken to count the number of subjects recruited by species in both treatments. To compare the number of indigenous species and native between treatments was measured after eight readings, an analysis of variance and t-test was applied ($p \leqslant 0.05$) (Lehmann, 1997). The experiment was carried out in a subdivided plot, with the treatments being the plots and the evaluation times the subplots (Table 1). To test the existence of variation in the composition and abundance of species between treatments at the beginning and end of the experiment, ANOSIM permutation analyzes (oneway) were performed (Clarke, 1993). The analyzes were performed using the Past 2.17c © software (Hammer et al.,2003).

Table 1. Treatments used to assess the impacts of invasive alien species *Ricinus communis* an Atlantic Forest area, Aracaju, Sergipe State, Brazil. Where: T= treatments, t= evaluations times.

Treatments (plots)	Evaluation times (subplots)
T1- without removal of invasive alien species	t0 - initial reading - before removal of species invasive exotic;
	t1 - reading after one month of starting the experiment;
	t2 - reading after two months of starting the experiment;
	t3 - reading after three months of starting the experiment;
	t4 - reading after four months of starting the experiment;
	t5 - reading after five months of starting the experimente;
	t6 - reading after six months of starting the experiment;
	t7 - reading after seven months of starting the experiment;
	t8 - reading after eight months of starting the experimente.
T2- with removal of invasive alien species	t0 - initial reading - before removal of species invasive exotic;
	t1 - reading after one month of starting the experiment;
	t2 - reading after two months of starting the experiment;
	t3 - reading after three months of starting the experiment;
	t4 - reading after four months of starting the experiment;
	t5 - reading after five months of starting the experimente;
	t6 - reading after six months of starting the experiment;
	t7 - reading after seven months of starting the experiment;
	t8 - reading after eight months of starting the experimente.

Results

Comparison: sites invaded by *Ricinus communis* x not invaded by the exotic invader

In the plots plotted on the non-invaded sites, 28 species were found. The family with the highest number of representatives was Fabaceae with three (10.7%) representatives, followed by Asteraceae, Euphorbiaceae and Poaceae with two (7.1%) each species. The other families presented only one (3.5%) taxon each. Already in installments plotted in invaded sites, only three species were sampled, distributed in three families: Amarathaceae, Euphorbiaceae and Malvaceae with a (33.3%) representative each. Among the species found at the invaded site is *Ricinus communis*, which proved to be the most abundant taxon in the area (Table 2).

A total of 75 individuals were sampled in invaded sites, of which 72 were from the exotic invasive studied. In the non-invaded sites, 210 individuals were sampled.

The diversity obtained for non-invaded sites was 2.48 and for those invaded it was 0.19. According to the test performed ($t = 18.42$; $p < 0.01$) there are significant differences between them, being higher in the sites with the absence of *R. communis*.

The equitability value was higher in non-invaded sites (J '= 0.7526) when compared to invaded sites (J' = 0.176). This result shows the dominance of exotic invasive species in relation to other species, causing equitability to be diminished, reflecting on local diversity.

In the similarity analysis, the formation of two groups of plots was evidenced. One formed by the sampling units plotted at the invaded sites and the other at the non-invaded sites. (Figure 1). The same could be observed in the results of the dissimilarity analysis by Bray-Curtis (Figure 2).

Table 2. Species and their respective abundances sampled in an area of Atlantic Forest in APA Morro do Urubu, Aracaju, Sergipe State, Brazil. Where: I = invaded environment; NI = environment not invaded.

Family	Specie	Abundance	
		I	NI
Acantaceae	*Dyschoriste depressa* Nees	0	53
Amarathaceae	*Althernantera tenella* Colla	2	2
Araceae	*Caladium bicolor* (Aiton) Vent.	0	1
Asteraceae	*Centratherum punctatum* Cass.	0	1
	Conocliniopsis prasiifolia (DC.) R. M. King & H. Rob.	0	45
Commelinaceae	*Commelina benghalensis* L.	0	2
Euphorbiaceae	*Cnidoscolus urens* (L.) Arthur	0	2
	Croton campestris A. St.-Hil.	0	1
Euphorbiaceae	*Ricinus communis* L.	72	0
Fabaceae	*Chamaecrista flexuosa* (L.) Greene	0	5
	Desmodium barbatum (L.) Benth.	0	5
	Fabaceae Ind. 1	0	2
Heliconiaceae	*Heliconia psittacorum* L. f.	0	4
Lamiaceae	*Hypenia salzmannii* (Benth.) Harley	0	4
Loganiaceae	*Spigelia anthelmia* L.	0	1
Malvaceae	*Pavonia cancellata* (L.) Cav.	0	3
	Sida sp.	1	0
Melastomataceae	*Clidemia hirta* (L.) D. Don	0	1
Myrtaceae	*Psidium guajava* L.	0	3
Plumbaginaceae	*Plumbago scandens* L.	0	3
Poaceae	*Aristida* sp.	0	21
	Setaria sp.	0	14
Rubiaceae	*Borreria verticillata* (L.) G. Mey.	0	9
Rutaceae	*Ertela trifolia* (L.) Kuntze	0	15
Turneraceae	*Turnera subulata* Sm.	0	7
Verbenaceae	*Latana camara* L.	0	1
Indet.	Ind. 1	0	2
	Ind. 2	0	2
	Ind. 3	0	1

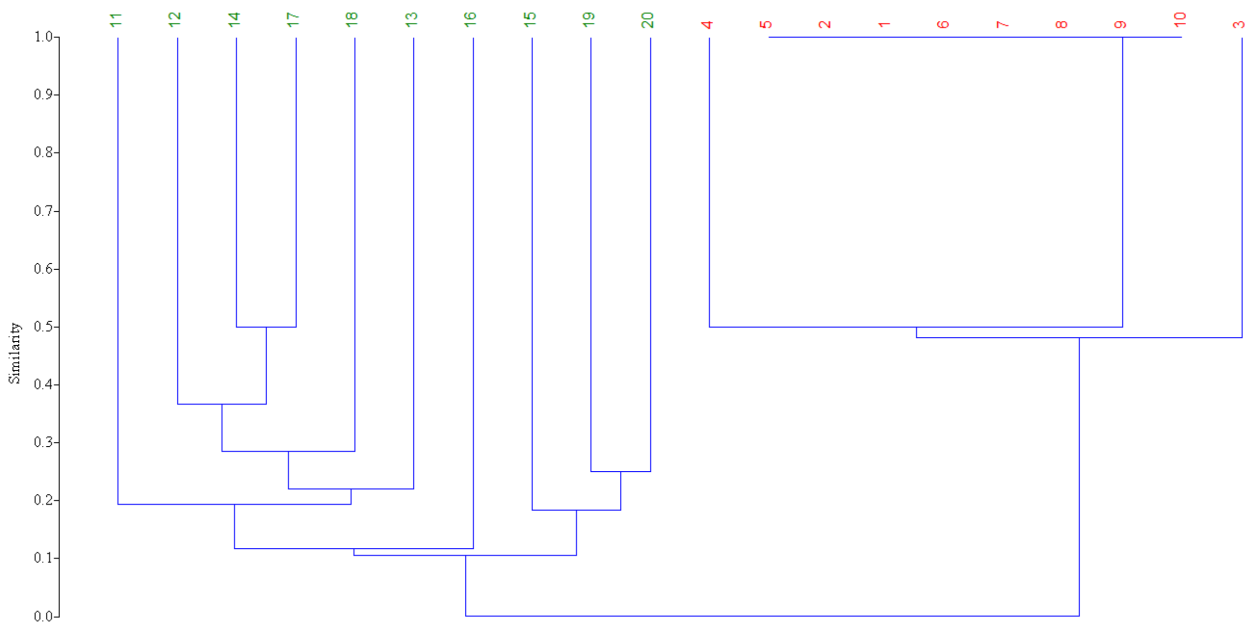

Figure 1. Jaccard similarity analysis for the plots studied in an Atlantic Forest area, Aracaju, Sergipe State, Brazil. Where: numbers in red = portions of the environment invaded by *Ricinus communis*; green numbers = portions of the environment not invaded by the exotic invader.

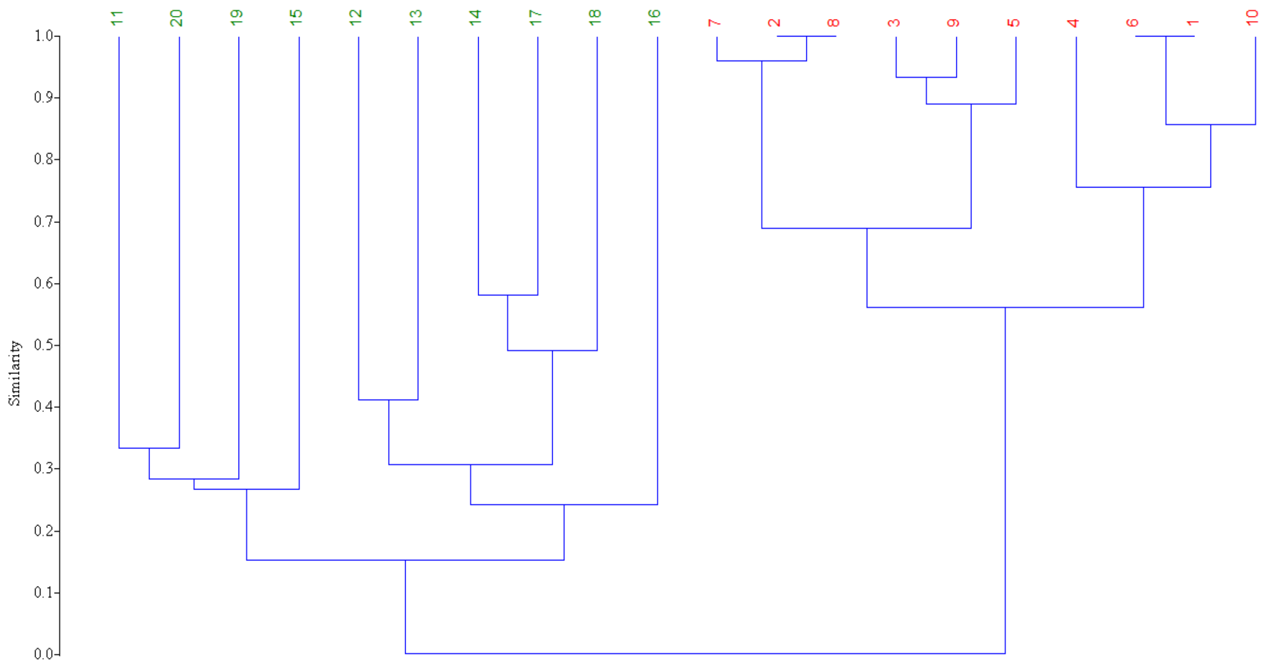

Figure 2. Bray-Curtis dissimilarity analysis for the plots studied in an Atlantic Forest area, Aracaju, Sergipe State, Brazil. Where: numbers in red = portions of the environment invaded by *Ricinus communis*; green numbers = portions of the environment not invaded by the exotic invader.

According to the ANOSIM test, there are significant differences between the environments studied, both by Jaccard (p ≤ 0.01) and by Bray-Curtis (p ≤ 0.01). This fact indicates that the plots in each environment are more similar (or less dissimilar) to each other than to the plots in the other environment and vice versa.

By NMDS graphical analysis it was possible to confirm the formation of two groups of plots reported in previous analysis. The results were similar using Jaccard (Figure 3) and Bray-Curtis (Figure 4).

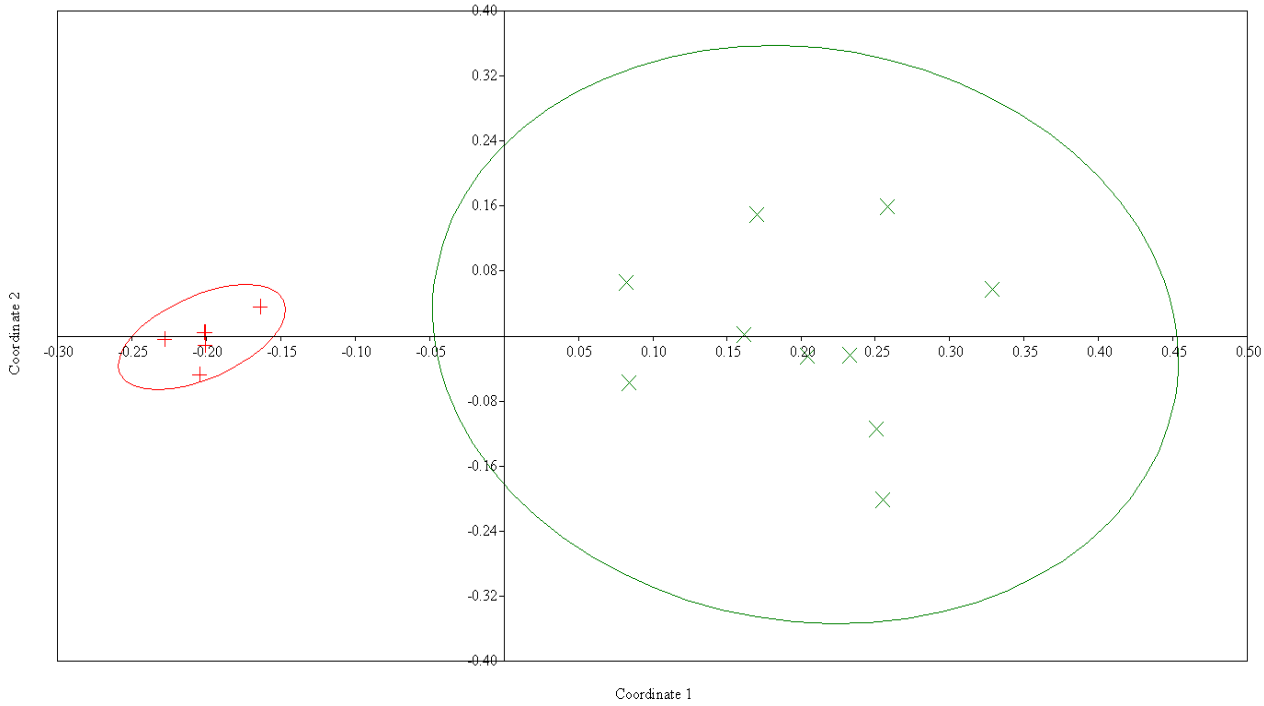

Figure 3. Non-Metric Multidimensional Scaling Analysis (NMDS) by Jaccard for an area of Atlantic Forest, Aracaju, Sergipe State, Brazil. Of which: red crosses = portions of the environment invaded by *Ricinus communis*; green crosses = portions of the environment not invaded by the exotic invader

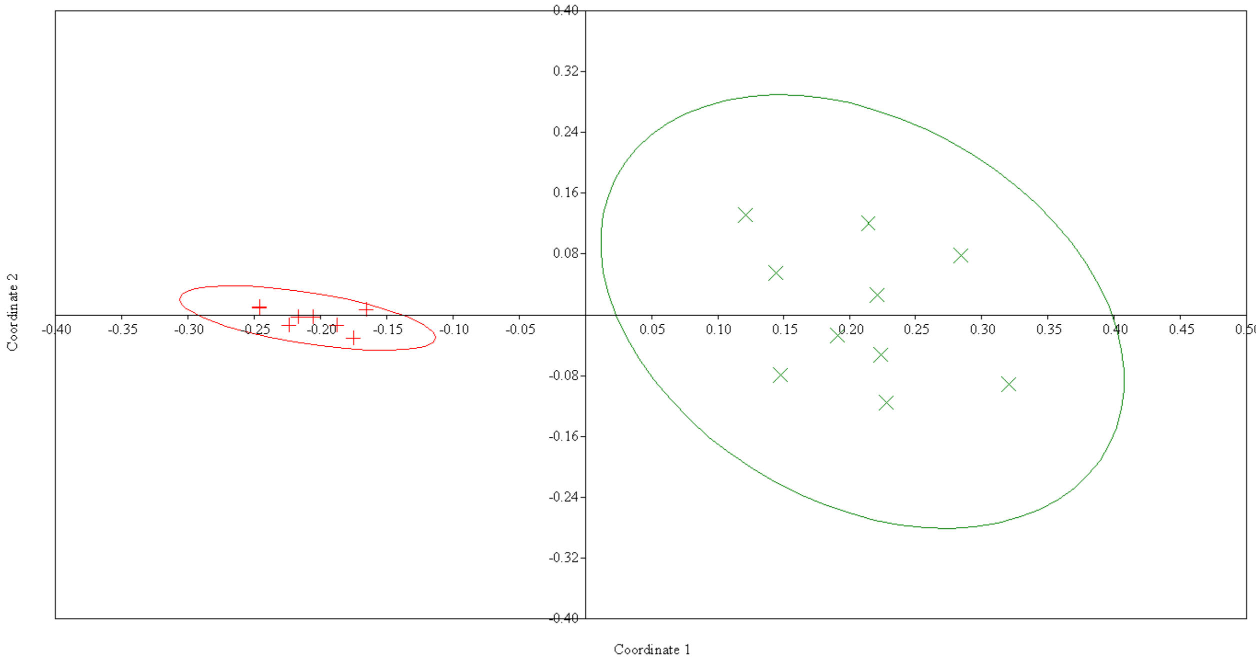

Figure 4. Non-Metric Multidimensional Scaling Analysis (NMDS) by Bray-Curtis for an area of Atlantic Forest, Aracaju, Sergipe State, Brazil. Of which: red crosses = portions of the environment invaded by *Ricinus communis*; green crosses = portions of the environment not invaded by the exotic invader.

Comparison: plots with the presence of *Ricinus communis* x plots that the invasive exotic was removed

The average number of species was statistically greater in the plots where the exotic invasion has been removed from the second reading (1 month after removal of *R. communis*) and remained so until the eighth reading (Table 3).

Table 3. Average number (and standard deviation) of species per treatment in an area of Atlantic Forest invaded by *Ricinus communis* L., Aracaju, Sergipe State, Brazil. Where: CEI = plots with the exotic invader, SEI = plots without the exotic invader.

Time	Treatment	
	CEI	SEI
1	1±0a	0±0a
2	3.1±0.7a	7.9±2.8b
3	4.2±1.9a	7.2±1.3b
4	4.7±1.9a	7±2.2b
5	4.2±1.8a	8.3±1.5b
6	5.4±1.7a	7.4±2.3b
7	5±1.4a	6.9±1.1b
8	5±1.5a	6.7±1.7b

*Average followed by equal letters do not differ statistically according to the t test ($p \leq 0.05$).

For the average number of individuals, the results were similar. From the second reading on, the statistical difference between treatments was already characterized (Table 4).

Table 4. Average number (and standard deviation) of individuals per treatment in an area of Atlantic Forest invaded by *Ricinus communis* L., Aracaju, SE. Where: CEI = plots with the exotic invader, SEI = plots without the exotic invader.

Time	Treatment	
	CEI	SEI
1	7.5±3.6a	0±0a
2	38.9±29.6a	152.5±125.8b
3	27.1±15.7a	84.5±66.6b
4	30.8±21.9a	88.7±86.4b
5	28.3±17.1a	104.8±94.5b
6	28.7±19.2a	59.8±39.1b
7	20.7±10.7a	65.9±58.1b
8	32.8±24.8a	115.9±178b

*Average followed by equal letters do not differ statistically according to the t test ($p \leq 0.05$).

Discussion

All the consulted studies corroborate with the results obtained in the present study, in other words, that invasive exotic species are capable of altering the composition, richness and diversity of the invaded sites. These results were repeated for the species *Artocarpus heterophyllus* Lam. (Fabricante et al., 2012), *Terminalia catappa* L. (Santos & Fabricante, 2018), *Prosopis juliflora* (Sw.) DC. (Pegado, Andrade, Félix, & Ferreira, 2006; Andrade, Fabricante, & Oliveira, 2010) and *Boerhavia diffusa* L. (Santos & Fabricante, 2019). Besides the effects on native biota, invasive exotic species also generate a lot of damage to the physical environment, human health and agriculture and livestock (Parker et al., 1999; Williamson, 1996; Ziller & Zalba, 2007; Fabricante et al., 2012). The studied species, for example, affects several agricultural cultures when competing with them for resources and it has toxic substances in its tissues for animals and for humans (Tokarnia et al., 1975; Garland & Bailey, 2006; Borges et al., 2011).

According to Ricklefs (2016), Humid Tropical Forests, such as the Atlantic Forest, have high resilience power, which is the capacity of an area to return to its original conditions after suffering some disturbance. However, our data refute this statement, indicating that this attribute can be drastically affected by biological invasions. The monitoring of sample units for longer periods is necessary to confirm this event.

These results are extremely worrying since there are also records of the occurrence of *R. communis* in sites under the domains of the Amazon Forest, Caatinga, Cerrado, Pantanal and Pampas (Fabricante, 2013; Lista da Flora do Brasil, 2021). In addition to being important for the livelihood of the Brazilian population (Capobianco & Lima, 1997; Tucci, Hespanhol, & Netto, 2003; Fearnside, 2004; Aquino & Oliveira, 2006; Alves, Silva, & Vasconcelos, 2009; Campanili & Schäffer, 2010; Homma, 2011; MMA, 2021), the Brazilian biomes are home to thousands of species of our flora and fauna, many of them endemic and rare.

The Atlantic Forest, for example, is composed of more than 22 thousand (Franke, Rocha, Klein, & Gomes, 2005; MMA, 2021) species, the Amazon Forest has about 34 thousand (MMA, 2021), the Cerrado, about 12 thousand (Aquino & Oliveira, 2006; MMA, 2021) species, the Caatinga more than 4,400 (Siqueira-Filho et al., 2012), the Pampas around 2,200 (Boldrini et al., 2010) and finally the Pantanal with more than 2,700 species (Embrapa Pantanal, 2021; MMA, 2021).

In addition to being present throughout the Brazilian territory (Lista da Flora do Brasil, 2021), *R. comunnis* has also been registered as an exotic invader in several countries in Asia, America, Europe and Oceania (Jian, Changyi, & O'toole, 2008; Goyal, Pardha-Saradhi, & Sharma, 2014; CABI, 2021; I3N Brazil, 2021). In addition to being present throughout the Brazilian territory (Lista da Flora do Brasil, 2021), *R. comunnis* has also been registered as an exotic invader in several countries in Asia, America, Europe and Oceania (Jian et al., 2008; Goyal et al., 2014; CABI, 2021; I3N Brazil, 2021).

The success of *R. communis* is probably due to a set of intrinsic characteristics of the species, e.g.: (i) production of large quantities of fruits and seeds throughout the year (Melo, Beltrão, & Silva, 2003; CABI, 2021); (ii) efficient dispersion (Seghieri & Simier, 2002; Martins, Guimarões, Silva, & Semmir, 2006; Brighenti & Oliveira, 2011); (iii) tolerance to different edaphic conditions (Matthews, 2005; Santana & Encinas, 2008; Fabricante, 2013) and climatic (CABI, 2021); and (iv) viable propagules for more than one year (CABI, 2021).

The intense degradation characteristics of the study site also contribute to explain the results. Disorders caused by human action, such as the simplification of environments and changes in land use and coverage, act as facilitators of biological invasion processes (Mack et al., 2000). In addition, a plant community becomes more susceptible to invasion when there is an increase in the availability of unused resources (Davis, Grime, & Thompson, 2000) - see hypothesis of vacant niches (Elton, 1958; Mack et al., 2000; Holle, Delcourt, & Simberloff, 2003).

Conclusion

The results obtained in the present study demonstrated the impacts caused by the exotic invader *Ricinus communis* on the composition, richness, diversity and resilience of an area of Atlantic Forest. These findings point to the urgent need to control the species studied in order to conserve the local native flora.

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