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Distribution of invasive exotic species *Artocarpus heterophyllus* Lam. in a forest fragment in the Amazon

Distribuição da espécie exótica invasora *Artocarpus heterophyllus* Lam. em um fragmento florestal da Amazônia

Distribución de la especie exótica invasora *Artocarpus heterophyllus* Lam. en un fragmento de bosque amazónico

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Abstract
Artocarpus heterophyllus is an invasive exotic species known for its negative impacts on Brazilian ecosystems. The aim of this study was to evaluate the distribution and population structure of *A. heterophyllus* in the plant community of a forest fragment in the Amazon. Individuals of this species were subject to active search at Sumaúma State Park, in Manaus, and two plots were delimited, where these individuals were counted. In each plot, the jackfruit tree individual with the largest Diameter at Breast Height (DBH) was centralized, and from it, native species were inventoried. The parameters of relative density, relative dominance and the importance value index were estimated. Jackfruit tree individuals in the plots had grouped distribution and their number in plots 1 and 2 was 308 and 872 individuals, respectively. In quadrant 1, 254 jackfruit trees and 118 native individuals were recorded, and in quadrant 2, 629 jackfruit and 130 native individuals. The jackfruit tree reached indices higher than the sum of the phytosociological indices of all native species. Jackfruit tree distribution was considered similar to that occurring in other already invaded areas of Brazil, which may indicate that the same impacts may occur in Amazonian ecosystems.
Keywords: Phytosociology; Invasive species; Allelopathy; Biological invasions; Jackfruit tree.

Resumo
Artocarpus heterophyllus é uma espécie exótica invasora reconhecida por impactos negativos em ecossistemas brasileiros. Objetivou-se aqui avaliar a distribuição e a estrutura populacional de *A. heterophyllus* na comunidade vegetal de um fragmento florestal amazônico. No Parque Estadual Sumaúma, em Manaus, fez-se uma busca ativa por indivíduos da espécie, sendo delimitadas duas parcelas, onde os indivíduos foram contabilizados. Em cada parcela, o indivíduo de jaqueira com maior Diâmetro à Altura do Peito (DAP) foi centralizado, e a partir dele, inventariaram-se as espécies nativas. Os parâmetros fitossociológicos de densidade relativa, dominância relativa e o índice de valor de importância foram estimados. Os indivíduos de jaqueira nas parcelas apresentaram distribuição agrupada e o número dessas nas parcelas 1 e 2 foi de 308 e 872 indivíduos, respectivamente. No quadrante 1, registraram-se 254 jaqueiras e

118 indivíduos nativos, e no quadrante 2 foram 629 jaqueiras e 130 indivíduos nativos. A jaqueira alcançou índices superiores à soma dos índices fitossociológicos de todas as espécies nativas. Considerou-se que a distribuição da jaqueira é semelhante aquela que ocorrem em outras áreas já invadidas do Nordeste e Sudeste do Brasil, o que pode indicar que os mesmos impactos possam ocorrer nos ecossistemas amazônicos.
Palavras-chave: Fitossociologia; Espécie invasora; Alelopatia; Invasões biológicas; Jaqueira.

Resumen
Artocarpus heterophyllus es una especie exótica invasora conocida por sus impactos negativos en los ecosistemas brasileños. El objetivo de este estudio fue evaluar la distribución y estructura poblacional de *A. heterophyllus* en la comunidad vegetal de un fragmento de bosque en la Amazonía. Individuos de esta especie fueron objeto de búsqueda activa en el Parque Estadual Sumaúma, en Manaus, y fueron delimitadas dos parcelas, donde estos individuos fueron contados. En cada parcela se centralizó el árbol individual con mayor Diámetro a la Altura del Pecho (DAP) y a partir de él se inventariaron las especies nativas. Se estimaron los parámetros de densidad relativa, dominancia relativa y el índice de valor de importancia. Los individuos en las parcelas tuvieron una distribución agrupada y su número en las parcelas 1 y 2 fue de 308 y 872 individuos, respectivamente. En el cuadrante 1 se registraron 254 árboles de jaca y 118 individuos nativos, y en el cuadrante 2 629 árboles de yaca y 130 individuos nativos. El árbol de jaca alcanzó índices superiores a la suma de los índices fitosociológicos de todas las especies nativas. Se consideró que la distribución de los árboles de jaca es similar a la que ocurre en otras áreas ya invadidas de Brasil, lo que puede indicar que los mismos impactos pueden ocurrir en los ecosistemas amazónicos.
Palabras clave: Fitosociología; Especies invasivas; Alelopatía; Invasiones biológicas; Árbol de jaca.

1. Introduction

Changes in land use are increasingly intense in the Amazon region; it is estimated that 20% of the biome has already been devastated and deforestation has continued to rise since the last decade (Rutt et al., 2019). Concurrently, there is a lack of information on the presence of invasive exotic species in the North of Brazil, due to the low number of academic publications in this field (Santos et al., 2021). The scarcity of studies does not mean that invasive species are not present or that the risks and impacts of biological invasions are not a reality.

One of the examples of exotic species commonly cultivated in the Amazon is *Artocarpus heterophyllus* Lam. (Moraceae) (Falcão et al., 2001), popularly known as jackfruit tree, native to the tropical forests of Malaysia and India. It is a large and evergreen tree, with latex in all its organs, reaching up to 20 meters in height, with rapid growth in its early years, attaining a 1.5 m rate per year and decreasing to 0.5 m per year when it reaches maturity (Prakash et al., 2009). Within its genus, *A. heterophyllus* is the most widespread, useful and also the most adaptable species (Elevitch & Manner, 2006).

Due to its food use, the jackfruit tree was introduced in Brazil in the 17th century, and was later used in reforestation projects in the state of Rio de Janeiro (Pereira & Kaplan, 2013). Today, the jackfruit tree is widely distributed throughout the Brazilian territory and is known as an aggressive invasive exotic species in the Atlantic Forest of the Northeast and Southeast of Brazil (Fabricante et al., 2012; Moura et al., 2020). In addition, according to the national database on exotic species, jackfruit trees are present in 12 states (Hórus Institute, 2021). As a result, the environmental impacts arising from the biological invasion of *A. heterophyllus* include negative changes on the richness, diversity and soil of the invaded areas (Fabricante et al., 2012).

Considering *A. heterophyllus* important threat to native vegetation, making management and control actions are necessary (Fabricante et al., 2012). The biological invasion of jackfruit trees can be facilitated on account of its ease of adaptation to a wide range of humid tropical environments (Elevitch & Manner, 2006). Studies involving *A. heterophyllus* and its relationships with native Amazonian species allow for a better understanding of the future scenario of biological invasions in the Amazon and its possible impacts, in addition to promoting adequate management actions to control it. Thus, our aim was to evaluate the distribution and population structure of *A. heterophyllus* in the plant community of a forest fragment in the Amazon region.

2. Methodology

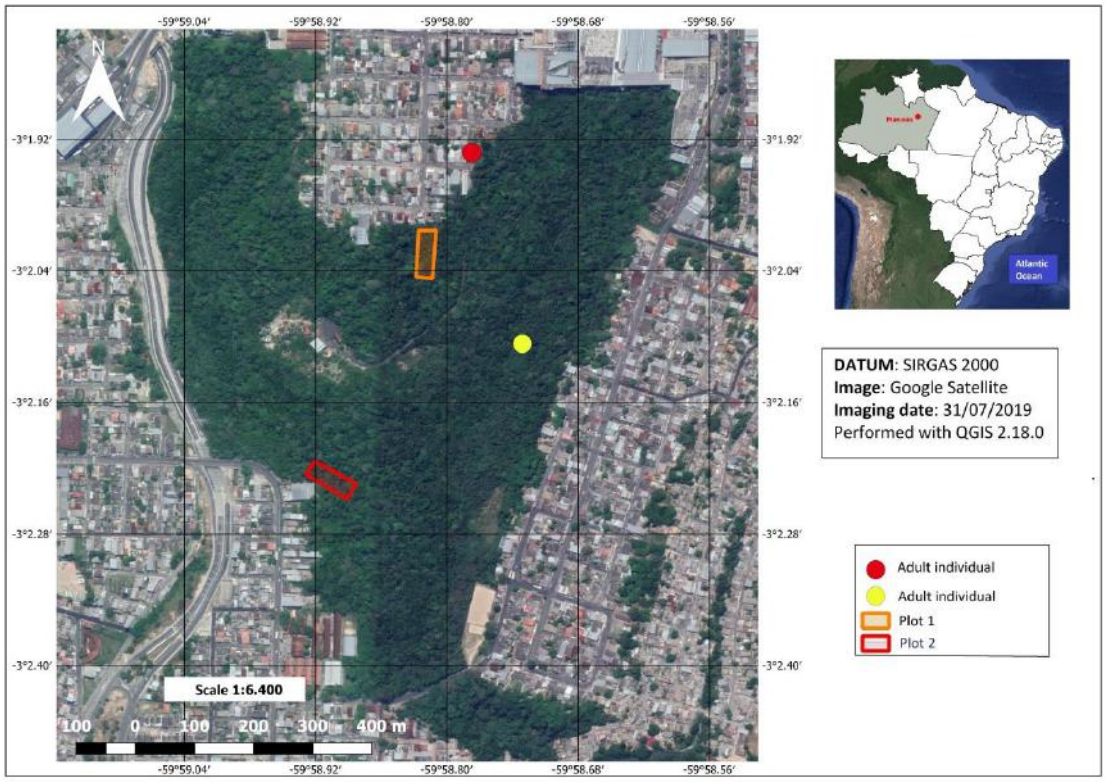
2.1 Study area

The study was carried out in the city of Manaus, Amazonas, Brazil, at Sumaúma State Park (03°01'50" S / 59°58'59" W), a forest fragment with a 52.57 ha area, considered a remnant of lowland tropical rainforest, predominantly in the secondary succession stage and with campinarana patches. The Park does not have a history of controlling and managing the *A. heterophyllus* population or other exotic species, it is a forest edge and an urban park, its boundaries make contact with backyards of homes, some of which have jackfruit trees grown inside them, and which may have an influence on the dispersion of the species into the conservation unit (Magalhães et al., 2020).

2.2 Delimitation of biologically invaded areas by jackfruit trees

From November to December 2018, active searches were carried out for jackfruit tree individuals in the entire perimeter of the Park's forest edges and trails. The occurrence of such species was identified in four areas, two of them only had one adult individual each. The other two areas, plots (P1 and P2) were set up for population sampling, as a greater number of individuals was found (Figure 1). The methodology used in this study was based on the studies by Fabricante et al., (2012).

Figure 1. Distribution of jackfruit trees and plots in the Sumauma Park.



Source: Adapted from Google Earth (2019) and modified by the authors.

Plots were delimited by means of a visual scan of all the jackfruit tree individuals, up to the point where the jackfruit trees were no longer seen (direction from the forest edge to inside the forest). Thus, it was ensured that the jackfruit trees present were included in the two delimited plots, resulting in a 30 x 50 m in P1 and 30 x 80 m in P2. Inside the plots, all individuals were counted and the diameters of each individual of the population structure were obtained for those measuring at least 1.30 m in height, according to the classes defined by Abreu and Rodrigues (2010), based on the DBH (Diameter at Breast

Height), being: Juveniles DBH ≤ 15 cm; Pre-reproductive DBH ≥ 15 and < 25 cm; and Adults DBH ≥ 25 cm.

To verify the distribution of jackfruit trees and native species within each plot, the jackfruit tree individual with the highest DBH was chosen as a matrix. From the centralized matrix jackfruit tree, a quadrant equivalent to the projection of the tree canopy on the ground was delimited, considering that jackfruit trees exert direct influence on the individuals below their canopy (Abreu & Rodrigues, 2010). The two quadrants (Q1 and Q2), referring to plots 1 and 2 respectively, measured 18 x 18 m and 20 x 20 m.

The jackfruit tree individuals and the native species present in the quadrants, whose stems rose above 1.30 m from the ground for DBH measurement, were sampled to calculate the phytosociological variables of relative density, relative dominance and importance value index (Moro & Martins, 2011). The other individuals, including native herbaceous plants and seedlings, were counted and mapped according to their distance from the matrix jackfruit tree.

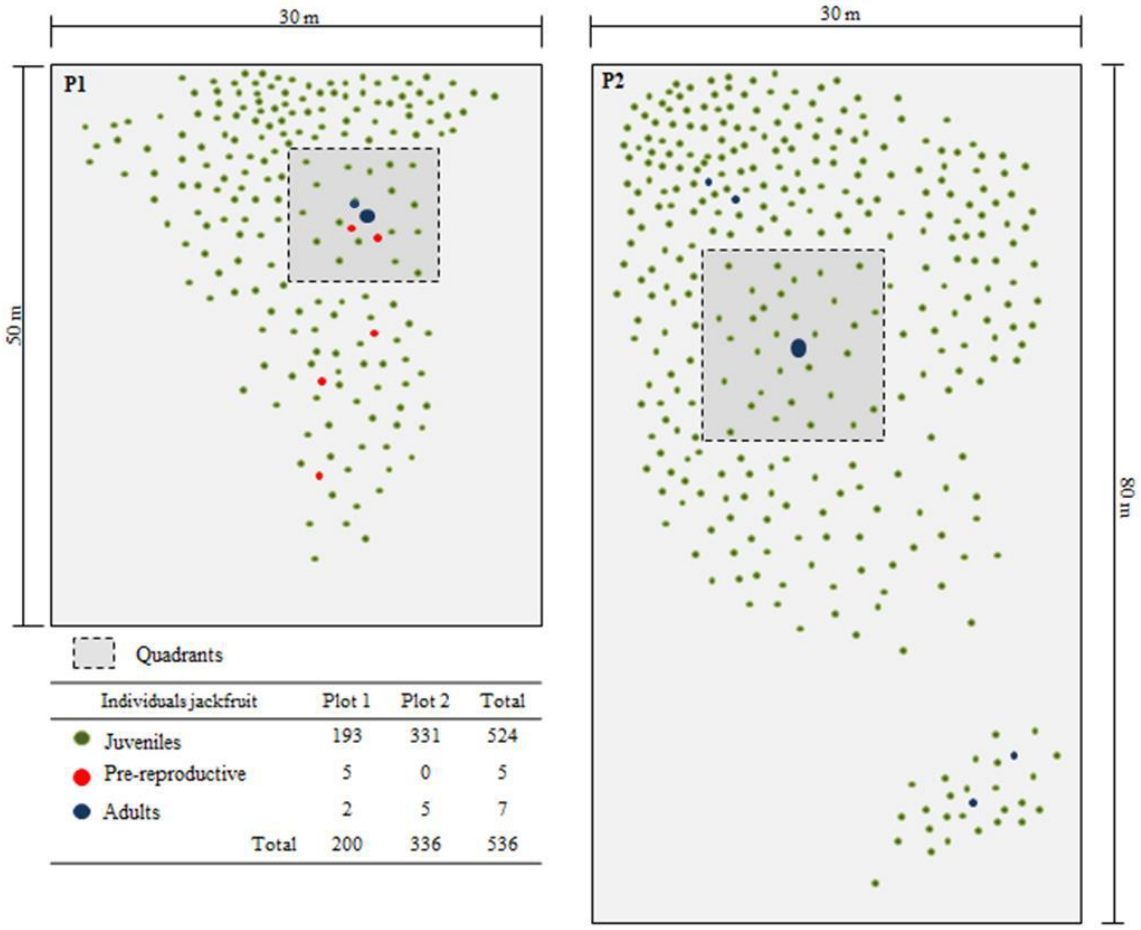
2.3 Identification of native species

The botanical identification of native species was carried out by collecting parts of plant organs, preferably fertile ones. All collected material was oven-dried at 60 °C for 48 to 72 hours. Afterwards, their identification was confirmed with the help of specialists and compared with exsiccates. The origin and area of occurrence of the species were obtained from botanical guides (e.g. Ribeiro et al., 1999; Souza & Lorenzi, 2008) and online databases. All the plant material collected was deposited in the Laboratory of Applied Ecology at Amazonas State University.

3. Results

Jackfruit tree individuals showed predominantly grouped distribution, visually forming a monodominant population in the plots (Figure 2). In plot 1, the total number of jackfruit trees observed was 200, with DBH ranging from 0.7 to 34 cm. In plot 2, a total of 336 jackfruit trees were observed, with DBH ranging from 0.7 to 100.6 cm. The total number of jackfruit accounted for in the two areas was 1.180. Considering the entire population in the plots there were 524 juvenile individuals, 5 pre-reproductive individuals and 7 adult individuals, ages determined by the diameters of each individual of the population. The seedlings totalized 644 individuals, 108 in P1 and 536 in P2.

Figure 2. Distribution and number of individuals the *A. heterophyllus* population in the two invaded areas (P1 and P2).



Individuals jackfruit	Plot 1	Plot 2	Total
Juveniles	193	331	524
Pre-reproductive	5	0	5
Adults	2	5	7
Total	200	336	536

Source: Authors (2022).

Considering only the areas of the quadrants and the inclusion of native species, quadrant 1 (Q1) had 118 individuals in total, distributed in 42 species; in addition to 254 jackfruit (including seedlings). In quadrant 2 (Q2), 130 individuals were observed, distributed in 48 species; with 629 jackfruit (including seedlings). In Q1, the native species with the highest importance value index was *Ficus maxima* (6.5%) and the greatest abundance of native individuals was Lauraceae NI 1, with five individuals, followed by *F. maxima*, with three. In Q2, the highest IVI was that of *Inga edulis* (5.2%), which had seven individuals, being the most abundant among the natives. The estimated phytosociological parameters for jackfruit trees were superior to the set of all native species sampled in the quadrants (Tables 2 and 3).

Table 2. Phytosociological table of species in Q1. (DRe: Relative Density of the species, DoRe: Relative Dominance of the species; IVI: Importance Value Index).

Genus/Species	Dre (%)	DoRe (%)	IVI (%)
Artocarpus heterophyllus	52.9	76.6	64.8
Ficus maxima	4.29	8.72	6.5
Lauraceae NI 1	7.14	0.16	3.65
Pourouma myrmecophila	4.29	2.54	3.41
Annonaceae NI 1	2.86	3.46	3.16
Lauraceae NI 2	4.29	0.17	2.23
Enterolobium schomburgkii	1.43	2.26	1.85
Inga macrophylla	1.43	1.62	1.52
Siparuna guianensis	2.86	0.01	1.44
Protium subserratum	2.86	0.01	1.43
Inga alba	1.43	1.37	1.4
Trattinnickia burserifolia	1.43	1.29	1.36
Lorostemon bombaciflorum	1.43	0.63	1.03
Annonaceae NI 2	1.43	0.4	0.91
Myrcia servata	1.43	0.4	0.91
Swartzia reticulata	1.43	0.13	0.78
Ocotea sp.	1.43	0.08	0.75
Burseraceae NI 1	1.43	0.01	0.72
Helicostylis sp.	1.43	0.01	0.72
Xylopia amazonica	1.43	0.01	0.72
Miconia cf. *egensis*	1.43	0.08	0.71
Total (Species natives)	47.1	23.4	35.2

Source: Authors.

Table 3. Phytosociological table of species in Q2. (DRe: Relative Density of the species, DoRe: Relative Dominance of the species; IVI: Importance Value Index).

Genus/Species	Dre (%)	DoRe (%)	IVI (%)
Artocarpus heterophyllus	38	96	67
Inga edulis	9.86	0.55	5.2
Cupania sp.	5.63	0.46	3.05
Inga cf. *paraenses*	4.23	0.35	2.29
cf. *Spondias* sp.	4.23	0.19	2.21
Handroanthus serratifolius	4.23	0.16	2.19
Aniba canelilla	4.23	0.01	2.12
Swartzia sp.	2.82	0.42	1.62
Theobroma cacao	2.82	0.21	1.51
cf. *Simaba* sp.	1.41	0.49	0.95
Macrosamanea sp.	1.41	0.42	0.91
Sloanea sp.	1.41	0.29	0.85
Eugenia sp.	1.41	0.14	0.77
Annonaceae NI1	1.41	0.1	0.76
cf. *Tovomita* sp.	1.41	0.07	0.74
Iryanthera sp.	1.41	0.06	0.73
Eschweilera cf. *laevicarpa*	1.41	0.03	0.72
Eschweilera sp.	1.41	0.02	0.71
Guatteria sp.	1.41	0.02	0.71
Duroia longiflora	1.41	0.01	0.71
Pouteria cf. *eugeniifolia*	1.41	0.01	0.71
Diospyros sp.	1.41	0.01	0.71
Licaria sp.	1.41	0.01	0.71
Protium subserratum	1.41	0.1	0.71
Inga sp.	1.41	0.1	0.7
Trymatococcus amazonicus	1.41	0.1	0.7
Total (Species natives)	62	4.31	33

Source: Authors.

Regarding the spatial pattern of individuals in the quadrants, it was observed that, in the vicinity of the matrix jackfruit tree, the number of native individuals was smaller, increasing as they distanced themselves from it. For *A. heterophyllus*, the observed pattern was the opposite, as most of its individuals were under the matrix canopy. In Q1, only eight individuals, of five species, were about 5 m away from the matrix jackfruit tree, while in Q2, there were only six, of five species, keeping the same distance as that seen in Q1. As the distance from the matrix jackfruit tree increased, the number of native individuals also increased.

In the case of the species inventoried for phytosociological analyses, in Q1 the most abundant species (*F. maxima*) was approximately 7 m from the matrix jackfruit tree. The species with the closest individuals was *Protium subserratum*, at a distance of 3 m. In Q2, *I. edulis* was 8 m away and *Sloanea* sp. 3 m away, the closest one. Among the herbaceous species identified in Q1 and which remained closest to the matrix jackfruit tree (approximately 3 m), exotic species *Syngonium angustatum*, stood out, in addition to an extensive coverage of fern *Adiantum terminatum* throughout almost all of the

delimitation of the quadrant, and *Phenakospermum guyannense*. In Q2, *Cyathula prostrata* (22) and another exotic species, *Alocasia macrorrhizos* (21) stood out in the 5 m adjacent to the matrix jackfruit tree.

4. Discussion

The main characteristic of the jackfruit tree populations in the invaded areas was their grouped distribution, with the development of monodominant settlements. This distribution pattern, in which younger individuals surround adults, was also observed by Freitas et al., (2017), in the Atlantic Forest. In the same study, the Importance Value Index of *A. heterophyllus* was 35.62% and surpassed the values of all native species in the community (Freitas et al., 2017). The same was true for Sumaúma Park, as the sum of the phytosociological parameters of all natives was inferior to that of the jackfruit trees. This situation shows the dominance of jackfruit trees over the native plant community and one of the negative effects of its biological invasion. This was also made clear by the number of native individuals *versus* jackfruit tree individuals; for example, in Q2, the total number of jackfruit trees was five times that of the natives.

At Sumaúma Park, the plots that cover the jackfruit tree occupation area were located on the forest edge, which may have favored its expansion, since few species are capable of invading advanced succession stages, especially in tropical forests (Fine, 2002). As a result, the jackfruit trees chosen as matrices were located very close to the areas where this species was already cultivated even before the Park was established, which may have acted as a source of propagules for its interior.

Fruit production is also one of the factors that help to understand the establishment and propagation of the species. It is estimated that a jackfruit tree can produce up to 100 fruits per year (Lalmuanpuii et al., 2018), and seed dispersal occurs by barocoria (Novelli et al., 2010), allowing it to reach and colonize more distant areas. Most of the jackfruit tree individuals at Sumaúma Park were juveniles and, probably, the population is booming, considering that many individuals were yet to become reproductive. At Tijuca National Park, the largest proportion of individuals (70%) also belonged to the first diametric classes - Juveniles DBH $\leq$ 15 cm (Abreu & Rodrigues, 2010). This situation shows that the number of areas subject to biological invasion can further increase over time.

The positive interactions with the resident fauna can favor the success of invasive species, through greater reproductive success and colonization of new areas (Taconi & Pires, 2021). Regarding the fruits, jackfruit trees are also associated with small Atlantic Forest mammals, such as the *Didelphis aurita* (opossum), *Trinomys dimidiatus* (bristly mouse), *Cuniculus paca* (paca) (Raíces et al., 2017) and *Leontopithecus chrysomelas* (golden-headed lion tamarin) (Oliveira et al., 2011). All of them were recorded feeding on the mesocarp and carrying the seeds (Oliveira et al., 2011; Raíces et al., 2017), which can influence the dispersion of the species and represent one of the main negative impacts for the protected areas. Sumaúma Park has two populations of the pied tamarin (*Saguinus bicolor*) (Gordo et al., 2019), and recorded jackfruit consumption by these primates, which may further contribute to the dispersal of jackfruit trees (e.g., M Gordo unpubl. res.). Also noteworthy is the occurrence of a species similar to *Didelphis aurita*, the opossum *D. marsupialis* (cf.), potentially also a disperser of jackfruit trees (Amazonas, 2009).

Jackfruit tree invasiveness may also be related to allelopathy, a process capable of suppressing germination and/or the establishment of competing species by means of the production of secondary metabolites (Hierro & Callaway, 2003). Allelopathy may explain the distribution of jackfruit trees in the community, as they showed a grouped pattern and with few individuals of other closely related species, as a possible “zone of chemical inhibition”. Allelopathic plants have the ability to synthesize a wide variety of natural products, which can help plants thrive in their naturally occurring regions and have optimized their establishment in new areas (Ooka & Owens, 2018), since native plants may not show resistance to these metabolites.

The relationship between allelopathy and invasive success was demonstrated in *Centaurea maculosa*, in which allelochemicals exuded by their roots in the invaded area were found to have negative effects on their competitors, with little effect in their native region (Thorpe et al., 2009). This may also explain why some invasive species become more abundant in invaded areas than in their native habitats establishing monodominant settlements (Hierro & Callaway, 2003). In its native environment, jackfruit tree density is low, reaching, on the other hand, high densities in invaded areas (Prakash et al., 2009). The allelopathy of *A. heterophyllus* has already been studied, laboratory tests showed that aqueous extracts of the pulp and dry green leaves of jackfruit trees inhibited the germination of *Lactuca sativa* (lettuce) seeds (Perdomo & Magalhães, 2007). The ethanol extract of *A. heterophyllu*s leaves also reduced the germination speed index of *L. sativa* and *Urochloa brizantha* (Costalonga & Batitucci, 2020).

As for the impacts of the biological invasion of jackfruit trees at Tijuca National Park, in Rio de Janeiro, the species is considered the most aggressive invasive species, causing a reduced native plant biodiversity (Abreu & Rodrigues, 2010). In the Atlantic Forest of the Northeast, the species effectively alters the richness of species, the diversity of vegetation and the soils of the invaded sites (Fabricante et al., 2012).

5. Conclusion

In Sumaúma State Park, we were able to confirm the potential invasive effect of *A. heterophyllus* in Amazonian environments. The distribution patterns similar to those occurring in other densely invaded areas in the Brazil, both in terms of aggregated distribution and distance of some native species individuals from jackfruit trees, which may indicate that the same negative impacts may occur in Amazonian ecosystems. Finally, considering this scenario, we recommend that jackfruit trees have strict management, especially in protected areas and their borders. New studies on their relationships with native plant and animal species, and allelopathy, are necessary developed to increase the understanding of invasions and their impacts on the natural areas. Further research should also investigate the allelopathic potential of jackfruit under field conditions and the influence on native species, in addition to identifying the substances involved in a possible chemical inhibition.

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