Ensaios e Ciência
ISSN 1415-6938 e ISSN 2178-695X

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DOI: https://doi.org/10.17921/1415-6938.2026v30n3p416-432

Spatial Distribution of Tree Species in the Mário Xavier National Forest, Seropédica - RJ

Distribuição Espacial de Espécies Arbóreas na Floresta Nacional Mário Xavier, Seropédica - RJ

Received: 22/02/2026
Accepted: 26/09/2026

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Abstract

The history of anthropogenic interventions directly influences the distribution patterns of tree species. The objective was to evaluate the spatial distribution pattern of tree species in the Mário Xavier National Forest (FLONA MX), Seropédica, RJ. The study area is located in FLONA MX, in the municipality of Seropédica, state of Rio de Janeiro. Data were obtained through a forest inventory carried out in 13 plots (20x40m) randomly distributed (simple random sampling) within each stand. In each sampling unit, the variables diameter at 1.30 m from the ground (DBH) and total height (Ht) of all individuals with DBH ≥ 5 cm were measured. The species found were classified according to ecological group and dispersal syndrome. From the measured data, the pattern and spatial distributionPlot of the species were obtained through six spatial indices: MacGuinnes Index, Fracker and Bischle Index, Payandeh Index, Non-Randomized Index, Hazen Index, and Morisita Index. A total of 1,204 tree individuals were measured, classified into 33 species and 18 families. 54.7% of the evaluated trees were of the species *Erythroxylum pulchrum* A.St.-Hil. (arco-de-pipa). Furthermore, this species was present in all studied sampling units. For all species studied and spatial indices applied, the predominant spatial distribution pattern was aggregated, where individuals live close to each other. This result can be explained by the fact that the FLONA MX area has been reforested.

Keywords: Spatial Pattern. Species Aggregation. Spatial Analysis. Dispersal.

Resumo

O histórico de intervenções antrópicas influencia diretamente os padrões de distribuição das espécies arbóreas. O objetivo foi avaliar o padrão da distribuição espacial das espécies arbóreas na Floresta

Nacional Mário Xavier (FLONA MX), Seropédica, RJ. A área de estudo localiza-se na FLONA MX, no município de Seropédica, estado do Rio de Janeiro. Os dados foram obtidos através de um inventário florestal realizado em 13 parcelas (20x40m) distribuídas de forma aleatória (amostragem casual simples) no interior de cada talhão. Em cada unidade amostral foram mensuradas as variáveis diâmetro a 1,30 m do solo (DAP) e altura total (Ht) de todos os indivíduos com DAP ≥ 5 cm. As espécies encontradas foram classificadas de acordo com o grupo ecológico e síndrome de dispersão. A partir dos dados mensurados, o padrão e a distribuição espacial das espécies foram obtidos através de seis índices espaciais: Índice de MacGuinnes, Índice de Fracker e Bischle, Índice de Payandeh, Índice Não Aleatorizado, Índice de Hazen e Índice de Morisita. Foram mensurados 1.204 indivíduos arbóreos classificados em 33 espécies e 18 famílias. Com 54,7% das árvores avaliadas da espécie *Erythroxylum pulchrum* A.St.-Hil. (arco-de-pipa). Além disso, essa espécie se mostrou presente em todas as unidades amostrais estudadas. Para todas as espécies estudadas e índices espaciais aplicados, predominou-se o padrão de distribuição espacial Aggregated, onde os indivíduos vivem próximos uns dos outros. Esse resultado pode ser explicado pela área da FLONA MX ter sido reflorestada.

Palavras-chave: Padrão Espacial. Agregação de Espécies. Análise Espacial. Dispersão.

1 Introduction

The Mário Xavier National Forest (FLONA MX) is located within the Atlantic Forest biome and encompasses a total area of 496 hectares, of which more than 50% consists of eucalyptus plantations and pastureland. According to IBGE (2023), the area is classified as reforested land. Before being designated as a Sustainable Use Conservation Unit, the site was a forest nursery established during the Getúlio Vargas administration in the 1940s. The location was strategically selected because of its proximity to the National School of Agronomy, now the Federal Rural University of Rio de Janeiro. Its primary objectives were the experimentation, demonstration, and dissemination of silvicultural practices, as well as the production of seedlings of native and exotic species. At that time, it was under the authority of the Silviculture Section of the Forest Service, which was linked to the Ministry of Agriculture (Alves *et al.,* 2017).

Its history has been marked by intense anthropogenic alterations over the years, which have modified the local vegetation characteristics. Consequently, the area no longer exhibits its natural features, instead reflecting the cumulative record of several activities and land uses, including plantations of exotic species (*Eucalyptus robusta* Sm., *Eucalyptus saligna* Sm., *Eucalyptus botryoides* Sm., *Eucalyptus tereticornis* Sm., *Eucalyptus alba* Blume, *Eucalyptus paniculata* Sm., *Eucalyptus citriodora* Hook., and *Eucalyptus rostrata* Cav.), as well as native species (*Lecythis pisonis* Cambess., *Joannesia princeps* Vell., *Mimosa caesalpiniifolia* Benth., *Ceiba pentandra* (L.) Gaertn., among others) (Alves; Vargas, 2019; Vargas; Rodrigues; Oliveira, 2023). In this context, understanding the spatial distribution patterns of tree species is relevant, since few studies have employed spatial indices to investigate population and community ecology in areas that have undergone reforestation or forest restoration.

Understanding the geographic distribution patterns of flora is highly important for elucidating

the dynamics, behavior, and spatial distribution of species within a given area, thereby supporting conservation, management, and forest restoration actions (Almeida *et al*., 2023; Souza; Soares, 2013). Spatial distribution patterns determine how a species occurs within a forest and are influenced by the ecological behavior of the agents involved in gene flow, such as seed-dispersal mechanisms and seedling regeneration (Nascimento *et al.,* 2002; Siminski *et al.,* 2021).

Species distribution patterns can be quantified mathematically through aggregation indices, which have been widely used to characterize biodiversity. In general, these indices can be classified into three groups according to the type of data used in their calculation or the methodology applied: methods based on sampling units, which use individual count data within sampling units; distance-based methods, which require distance or angle measurements; and second-order statistical methods, which require the Cartesian or geographic coordinates of all individuals within the study area (Ledo *et al*., 2012)

Individuals of a species may exhibit three types of spatial distribution: random, regular, and clustered. Each observed spatial pattern reflects a distinct forest context, responds to specific causes, and produces particular consequences (Halpern; Spies, 1995; Legendre, 1993). When a species is regularly distributed, individuals are arranged at approximately equal distances from one another. When it exhibits a clustered pattern, individuals are located very close to each other. In this case, clustering may result from social interactions, resource and environmental-condition aggregation, or limited dispersal capacity, causing individuals to remain close to parent trees.

Conversely, when a species is randomly distributed, each individual has an equal probability of occupying any location within the area; thus, the presence of one individual does not influence the position of another.

Accordingly, this study aimed to evaluate the spatial distribution patterns of tree species in the Mário Xavier National Forest, Seropédica, Rio de Janeiro, Brazil.

2 Material and Methods

2.1 Location and Characterization of the Study Area

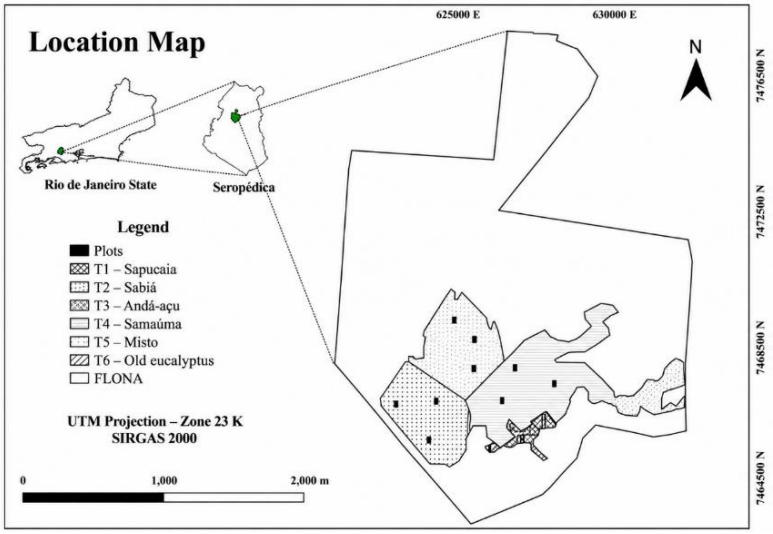
This study was conducted in the Mário Xavier National Forest (FLONA MX), located in the municipality of Seropédica, state of Rio de Janeiro, at the geographic coordinates 22°44'0.62" S and 43°42'33.25" W, SIRGAS 2000 datum, covering an area of 496 hectares. FLONA MX was established by Decree Nº 93,369 of October 8, 1986 (Brasil, 1986), and belongs to the sustainable use category of Conservation Units (SNUC, 2000).

According to the Köppen classification, the region's climate is classified as Aw, tropical with rainy summers and dry winters (Alvares *et al.,* 2014). The mean annual precipitation is 1,143.4 mm. The months with the highest rainfall are April and November, with averages of 201.2 and 207.60 mm,

respectively. The lowest precipitation rates occur in May and July, with averages of 3.6 mm and 0.4 mm, respectively. The mean annual temperature is 22.7 °C, with February (25.7 °C) being the warmest month and June (20.1 °C) the coolest (INMET, 2023). Climate data were obtained from the Automatic Weather Station (EMA), named Ecologia Agrícola at PESAGRO, and from the Automatic Rain Gauge in the center of Seropédica, both belonging to the National Institute of Meteorology (INMET), during the year 2022.

FLONA MX comprises different vegetation strata, in which native and exotic species were planted before the Conservation Unit was officially established. Based on previous studies and historical information, six different stands were considered for this study to ensure representativeness (Figure 1, Table 1).

Figure 1 - Location and distribution of the stands and plots in the Mário Xavier National Forest, municipality of Seropédica, Rio de Janeiro, Brazil



Source: the authors.

Stand 1, named "Sapucaia", is characterized by an old planting of sapucaia (*Lecythis pisonis* Cambess.), but currently has a higher frequency of the species arco-de-pipa (*Erythroxylum pulchrum* A. St. Hil.), lanterneira (*Spachea lactescens* (Ducke) R.F. Almeida & M. Pell.), and eucalyptus (*Eucalyptus* sp.). Stand 2, named "Sabiá," contains an old planting of sabiá (*Mimosa caesalpiniaefolia* Benth.), with the presence of species originating from natural regeneration. Stand 3 (Andá-açú) consists of an old plot of andá-açú (*Joannesia princeps* Vell.), but presents few individuals in the area. Stand 4 (Sumaúma) is characterized as an old plot of sumaúma (*Ceiba pentandra* (L.) Gaertn.). Stand 5 (Misto) is characterized by a line planting of 50 native and exotic species. Stand 6 (Old Eucalyptus) consists of a eucalyptus planting established in the 1940s, with few individuals remaining in an advanced state of senescence and with strong development of natural regeneration (Oliveira, 2022).

2.2 Data collection

Data were obtained through a forest inventory conducted in 13 plots (20×40 m) randomly distributed (simple random sampling) within each stand. One plot was allocated in stands 1, 2, 3, and 4, three plots in stand 6, and six plots in stand 5, ensuring representativeness of the stands (Table 1). In each plot, the variables circumference at 1.30 m above ground (CAP), which was subsequently converted to diameter at 1.30 m above ground (DAP), and total height (Ht) of all individuals with DAP ≥ 5 cm were measured using a measuring tape and hypsometric rod. Each individual was botanically identified at the species, genus, and family levels, following the classification of the Angiosperm Phylogeny Group III (2009).

Table 1 - Division of stands planted species, year of planting, number of sampling units (SUs), area, and percentage of sampled area in the Mário Xavier National Forest, municipality of Seropédica, Rio de Janeiro

Stands	Species	Year	Number of SUs	Area (ha)	Sampled Area (%)
1	Sapucaia	1946-1977	1	0.36	21.86
2	Sabiá	1946-1977	1	1.98	4.03
3	Andá-açú	1946-1977	1	0.55	14.47
4	Sumaúma	1946-1977	1	1.19	6.71
5	Misto	1949-1950	6	82,.9	0.58
6	Eucalipto	1945	3	26.99	0.89

Source: Oliveira (2022).

2.3 Classification of Ecological Groups and Dispersal Syndrome

The classification of ecological groups and dispersal syndromes was based on the works of Lorenzi (1992), Santana *et al*. (2004), Peixoto *et al*. (2004), Souza *et al*. (2007), and Carvalho (2008). For the classification of ecological groups, four groups were adopted: pioneer, early secondary, late secondary, according to Gandolfi *et al.* (1995), and climax (Swaine; Whitmore, 1988).

Pioneer species are those dependent on light, developing in forest gaps or at forest edges. Early secondary species occur under medium shading conditions or not very intense light. Late secondary species develop in the understory under light or dense shade. Finally, climax species are those found in the last stage of succession. For the characterization of species dispersal syndromes, the criteria proposed by Van der Pijl (1982) were followed, employing the following categories: autochorous, anemochorous, and zoochorous.

2.4 Analysis of Species Spatial Distribution

For data analysis, only species with a number of individuals equal to or greater than five were

considered. From the measured data, the pattern and spatial distribution of species were obtained through six spatial indices, which present different interpretation criteria and responses regarding density, frequency, and aggregation of individuals, reducing possible biases associated with the isolated use of a single index: MacGuinnes Index (Equation 1), Fracker and Bischle Index (Equation 2), Payandeh Index (Equation 3), Non-Randomized Index (Equation 4), Hazen Index (Equation 5), and Morisita Index (Equation 6).

$$IGA_i = \frac{n_i}{U_t\left[ln\left(1-\frac{U_i}{U_t}\right)\right]} \quad (1)$$

$$K_i = \frac{|D_i - d_i|}{d_i^2} \quad (2)$$

$$P_i = \frac{S_i^2}{M_i} \quad (3)$$

$$R_i = \frac{S_i^2}{M_i} \quad (4)$$

$$IH_i = \frac{S_i^2}{M_i}(U_t - 1) \quad (5)$$

$$IM_i = \frac{\sum_{j=1}^{U_t} n_{ij(n_{ij}-1)}}{n_i(n_i-1)} \quad (6)$$

Where: IGA_i = MacGuinnes Index; n_i = number of sampled individuals of the i-th species; U_t = total number of sampling units; ln = natural logarithm; U_i = number of sampling units in which the i-th species occurs; K_i = Fracker and Brischle Index; D_i = observed density of the i-th species; d_i = expected density of the i-th species; R_i = Non-Randomized Index; P_i = Payandeh Index; S_i^2 = variance in the number of trees of the i-th species; M_i = mean number of trees of the i-th species; X_i^2 = chi-square test; IH_i = Hazen Index; IM_i = Morisita Index e n_{ij} = number of individuals of the i-th species in the j-th plot.

For the Non-Randomized and Hazen Indices, the chi-square test was applied (X_2), evaluating significance to obtain deviation from randomness. The interpretation of index results was performed according to Table 2.

Table 2 - P Spatial distribution pattern for each spatial index

Index	**Spatial Distribution Pattern**				
	Not Grouped	**Uniform**	**Random**	**Clustering Tendency**	**Aggregated**
MacGuinnes	-	IGA_i<1.0	IGA_i=1.0	1.0<IGA_i≤2.0	IGA_i>2.0
Fracker and Brischle	-	-	K_i≤0.15	0.15<K_i≤1.0	K_i>1.0
Payandeh	-	-	P_i<1.0	1.0≤P_i≤1.5	P_i>1.5
Aleatorizado	-	-	$X^2_{calc.}$≥$X^2_{tab.}$	-	$X^2_{calc.}$<$X^2_{tab.}$
Hazen	IH_i< $X^2_{tab.0.75}$	-	-	$X^2_{tab.0.99}$> IH_i >$X^2_{tab.0.75}$	IH_i >$X^2_{tab.0.99}$
Morisita	-	IM_i >1.0	IM_i=1.0	-	IM_i<1.0

Source: Souza and Soares (2013).

3 Results and Discussion

3.1 Descriptive analysis

In the sampling units, 1,204 tree individuals were measured, classified into 33 species and 18 families. Of the trees evaluated, more than half (54.7%) belong to the species *E. pulchrum* A. St.-Hil. (arco-de-pipa). According to Table 3, regarding the ecological group, 9 species were classified as late secondary, 13 as early secondary, 2 as climax, 8 as pioneer, and one could not be identified. Regarding dispersal syndrome, 16 species were classified as zoochorous, 9 as autochorous, 4 as anemochorous, 2 as autochorous and zoochorous, one as autochorous and anemochorous, and one could not be identified.

Table 3 - List of species with family, scientific name, common name, ecological group (EG), and dispersal syndrome (DS), where ST = Late Secondary; P = Pioneer; ES = Early Secondary; C = Climax; NI = Not Identified; Aut. = Autocoric; Zoo. = Zoochoric; Ane. = Anemochoric

Famíly	**Scientific Name**	**Common Name**	**EG**	**DS**
Anacardiaceae	*Astronium graveolens* Jacq.	Gonçalo-alves	LS	Aut.
Bignoniaceae	*Sparattosperma leucanthum* (Vell.) K. Schum.	Ipê-cinco-chagas	LS	Aut.
	Aegiphila integrifolia (Jacq.) Moldenke	Tamanqueira	P	Zoo.
Cannabaceae	*Celtis iguanaea* (Jacq.) Sarg.	Esporão-de-galo	P	Zoo.
Chrysobalanaceae	*Licania tomentosa* (Benth.) Fritsch	Oiti	ES	Aut./Zoo.
Erythroxylaceae	*Erythroxylum pulchrum* A.St.-Hil.	Arco-de-pipa	ES	Zoo.
	Erythroxylum cuspidifolium Mart.	Cocão	C	Zoo.
Euphorbiaceae	*Joannesia princeps* Vell.	Anda-açu	P	Aut./Zoo.
	Hevea brasiliensis (Willd. ex A. Juss.) Mull. Arg.	Seringueira	C	Zoo.
	Sapium glandulosum (L.) Morong	Leiteiro	P	Zoo.
Fabaceae - Caesalpinioideae	*Pterogyne nitens* Tul.	Amendoim-bravo	ES	Aut.
	Libidibia ferrea (Mart. ex Tul.) L. P. Queiroz	Pau-ferro	ES	Aut.
	Copaifera langsdorfii Desf.	Copaíba	LS	Zoo.
Fabaceae - Mimosoideae	*Mimosa caesalpiniifolia* Benth.	Sabiá	P	Aut.
	Anadenanthera colubrina var. cebil (Griseb.) Altschul	Angico-vermelho	P	Aut.
	Piptadenia gonoacantha (Mart.) J.F. Marcbr	Pau-jacaré	ES	Aut./Ane.
	Anadenanthera colubrina (Vell.) Brenan	Angico-branco	ES	Ane.
	Enterolobium contortisiliquum (Vell.) Morong	Tamboril	ES	Zoo.
Lecythidaceae	*Lecythis pisonis* Cambess.	Sapucaia	ES	Zoo.

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Malpighiaceae	*Spachea lactescens* (Ducke) R.F. Almeida & M.Pell.	Lanterneira	LS	Ane.
Malvaceae	*Ceiba pentandra* (L.) Gaertn	Sumaúma	LS	Ane.
	Basiloxylon brasiliensis (Allemão) K. Schum	Farinha-seca	ES	Aut.
Meliaceae	*Guarea guidonia* (L.) Sleumer	Carrapeta	LS	Zoo.
	Trichilia hirta L.	Catiguá	LS	Zoo.
Myrtaceae	*Corymbia citriodora* (Hook.) K.D.Hill & L.A.S.Johnson	Eucalipto-limão	P	Aut.
	Eucalyptus sp.	Eucalipto	NI	NI
	Eugenia brasiliensis Lam.	Grumixama	ES	Zoo.
Nyctaginaceae	*Guapira opposita* (Vell.) Reitz	Maria-faceira	LS	Zoo.
Phytolaccaceae	*Gallesia integrifolia* (Spreng.) Harms	Pau-d'alho	ES	Ane.
	Seguieria langsdorffii Moq.	Limão-do-mato	ES	Aut.
Rubiaceae	*Genipa americana* L.	Jenipapo	ES	Zoo.
Rutaceae	*Zanthoxylum acuminatum* (Sw.) Sw.	Laranjeira-brava	P	Zoo.
Salicaceae	*Casearia commersoniana* Cambess.	Café-bravo	LS	Zoo.

Source: research data.

3.2 Spatial Distribution Pattern of Species

For the Non-Randomized, Hazen, and Morisita indices, all species presented an aggregated spatial distribution pattern. he Payandeh index showed only the species *E. contortisiliquum* (tamboril) with a tendency toward grouping; the other species presented aggregation of their individuals.

The MacGuinnes index showed a tendency toward grouping for two species, *P. gonoacantha* (Pau-jacaré) and *E. contortisiliquum* (tamboril); for the other species, it presented an aggregated spatial distribution pattern. Through this index, it was not possible to obtain the spatial distribution pattern of the species *E. pulchrum* (arco-de-pipa), because as it appears in all plots, it made the calculation of the expected density of the species unfeasible, since the natural logarithm of zero does not exist.

The same occurred for the Fracker and Brischle index for this species, indicating a limitation in the use of these indices. In addition to this species, the Fracker and Brischle index also showed a tendency toward grouping for the species *P. gonoacantha* (Pau-jacaré) and randomness for the species *E. contortisiliquum* (tamboril); for the other species, it indicated aggregation of their individuals.

Table 4 - Spatial indices of species sampled in the Mário Xavier National Forest, RJ, Where n_i = number of individuals sampled of the *i*-th species; U_i = number of sampling units in which the *i*-th species occurs; d_i = expected density of the *i*-th species; D_i = observed density of the *i*-th species; S_i^2 = variance of the number of trees of the *i*-th species; M_i = mean number of trees of the *i*-th species; IGA_i = MacGuines Index for the *i*-th species; K_i = Fracker and Brischle Index for the *i*-th species; P_i = Payandeh Index for the *i*-th species; R_i = Non-Randomized Index for the *i*-th species; IH_i = Hazen Index for the *i*-th species and IM_i = Morisita Index for the *i*-th species

Species	n_i	U_i	D_i	d_i	S_i^2	M_i	IGA_i	K_i	P_i	R_i	IH_i	IM_i
E. pulchrum	658	13	50.62	-	745.59	50.62	-	-	14.73	14.73	176.77	1.25
G. americana	83	3	6.38	0.26	406.76	6.38	24.33	88.94	63.71	63.71	764.51	10.18
M. caesalpiniifolia	36	5	2.77	0.49	44.19	2.77	5.70	9.69	15.96	15.96	191.50	6.13
G. guidonia	35	6	2.69	0.62	38.40	2.69	4.35	5.41	14.26	14.26	171.14	5.68
E. cuspidifolium	27	4	2.08	0.37	21.41	2.08	5.65	12.64	10.31	10.31	123.70	5.30
S. leucanthum	25	6	1.92	0.62	6.91	1.92	3.11	3.40	3.59	3.59	43.12	2.30
A. integrifólia	24	4	1.85	0.37	21.81	1.85	5.02	10.93	11.81	11.81	141.75	6.64
G. integrifolia	23	3	1.77	0.26	15.36	1.77	6.74	21.89	8.68	8.68	104.17	5.19
L. ferrea	21	1	1.62	0.08	33.92	1.62	20.18	239.64	21.00	21.00	252.00	13.00
C. pentandra	20	1	1.54	0.08	30.77	1.54	19.22	227.63	20.00	20.00	240.00	13.00
B. brasiliensis	19	1	1.46	0.08	27.77	1.46	18.26	215.63	19.00	19.00	228.00	13.00
C. iguanaea	19	4	1.46	0.37	7.27	1.46	3.97	8.09	4.97	4.97	59.68	3.65
Z. acuminatum	19	2	1.46	0.17	24.77	1.46	8.75	46.39	16.95	16.95	203.37	11.63
A. colubrina var. cebil	16	5	1.23	0.49	10.69	1.23	2.54	3.16	8.69	8.69	104.25	7.15
P. nitens	16	1	1.23	0.08	19.69	1.23	15.38	179.61	16.00	16.00	192.00	13.00
A. graveolens	14	4	1.08	0.37	5.08	1.08	2.93	5.24	4.71	4.71	56.57	4.43
C. langsdorfii	13	3	1.00	0.26	9.17	1.00	3.81	10.72	9.17	9.17	110.00	9.17
J. princeps	13	1	1.00	0.08	13.00	1.00	12.49	143.59	13.00	13.00	156.00	13.00
P. gonoacantha	13	6	1.00	0.62	1.67	1.00	1.62	0.99	1.67	1.67	20.00	1.67
T. hirta	13	5	1.00	0.49	2.83	1.00	2.06	2.18	2.83	2.83	34.00	2.83
C. commersoniana	11	4	0.85	0.37	2.97	0.85	2.30	3.54	3.52	3.52	42.18	4.02
H. brasiliensis	11	3	0.85	0.26	6.14	0.85	3.23	8.48	7.26	7.26	87.09	8.51
A. colubrina	10	4	0.77	0.37	1.86	0.77	2.09	2.97	2.42	2.42	29.00	2.89
C. citriodora	8	1	0.62	0.08	4.92	0.62	7.69	83.56	8.00	8.00	96.00	13.00
L. tomentosa	8	3	0.62	0.26	2.09	0.62	2.35	5.13	3.40	3.40	40.75	5.11
S. langsdorffii	8	4	0.62	0.37	1.26	0.62	1.67	1.83	2.04	2.04	24.50	2.79

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L. pisonis	7	3	0.54	0.26	1.44	0.54	2.05	4.01	2.67	2.67	32.00	4.33
S. lactescens	7	1	0.54	0.08	3.77	0.54	6.73	71.55	7.00	7.00	84.00	13.00
Eucalyptus sp.	6	2	0.46	0.17	1.27	0.46	2.76	10.55	2.75	2.75	33.00	5.20
S. glandulosum	6	2	0.46	0.17	1.27	0.46	2.76	10.55	2.75	2.75	33.00	5.20
E. contortisiliquum	5	4	0.38	0.37	0.42	0.38	1.05	0.12	1.10	1.10	13.20	1.30
E. brasiliensis	5	2	0.38	0.17	0.92	0.38	2.30	7.80	2.40	2.40	28.80	5.20
G. opposita	5	2	0.38	0.17	1.26	0.38	2.30	7.80	3.27	3.27	39.20	7.80

Source: research data.

According to the results found, for all studied species and applied spatial indices, the aggregated spatial distribution pattern predominated (Table 5 and Figure 2).

Table 5 - Spatial distribution pattern of the *i*-th species obtained from spatial indices, where IGA_i = MacGuines Index for the *i*-th species; K_i = Fracker and Brischle Index for the i-th species; P_i = Payandeh Index for the i-th species; R_i = Non-Randomized Index for the i-th species; IH_i = Hazen Index for the i-th species and IM_i = Morisita Index for the i-th species

Species	**Spatial Distribution Pattern**					
	IGA_i	K_i	P_i	R_i	IH_i	IM_i
E. pulchrum	-	-	Aggregated	Aggregated	Aggregated	Aggregated
G. americana	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated
M. caesalpiniifolia	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated
G. guidonia	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated
E. cuspidifolium	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated
S. leucanthum	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated
A. integrifólia	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated
G. integrifólia	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated
L. férrea	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated
C. pentandra	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated
B. brasiliensis	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated
C. iguanaea	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated
Z. acuminatum	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated
A. colubrina var. cebil	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated

continue...

...continuation

P. nitens	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated
A. graveolens	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated
C. langsdorfii	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated
J. princeps	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated
P. gonoacantha	Clustering Tendency	Clustering Tendency	Aggregated	Aggregated	Aggregated	Aggregated
T. hirta	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated
C. commersoniana	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated
H. brasiliensis	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated
A. colubrina	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated
C. citriodora	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated
L. tomentosa	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated
S. langsdorffii	Clustering Tendency	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated
L. pisonis	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated
S. lactescens	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated
Eucalyptus sp.	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated
S. glandulosum	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated
E. contortisiliquum	Clustering Tendency	Random	Clustering Tendency	Aggregated	Aggregated	Aggregated
E. brasiliensis	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated
G. opposita	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated	Aggregated

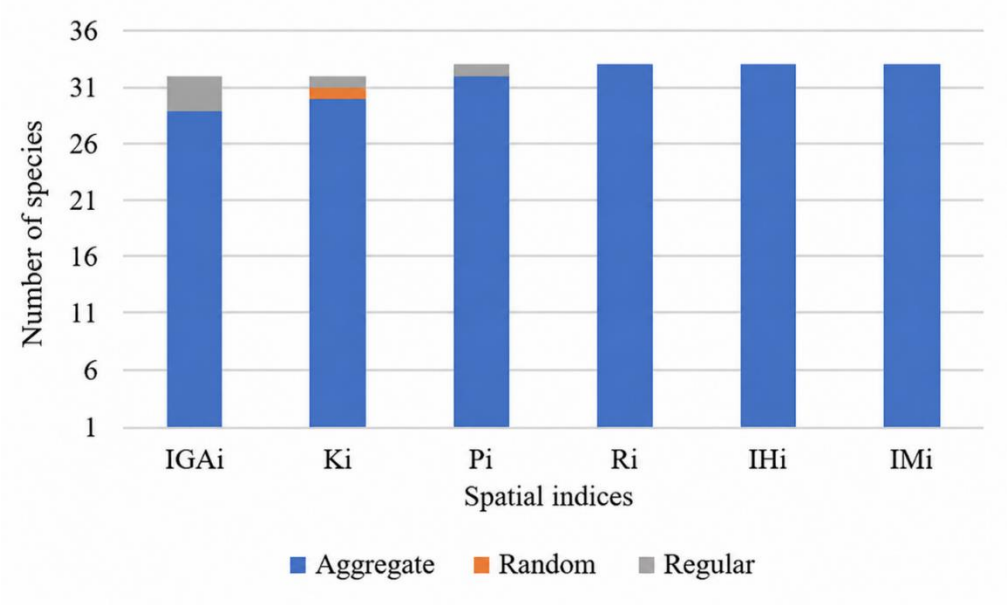
Source: research data.

In the aggregated spatial distribution pattern, individuals live close to each other. This can result from the aggregation of resources and conditions, or from limited dispersal capacity and dispersal type, causing individuals of the same species to remain close to parent trees.

Furthermore, aggregated patterns are strong evidence of limited species dispersal capacity (Lin *et al.,* 2011; Wang *et al.,* 2024).

Thus, the predominance of aggregated spatial patterns may favor ecological dominance processes and reduce forest structural heterogeneity along succession, especially in restored areas, where few species may exhibit high establishment and regeneration capacity (Chazdon *et al.,* 2022; *Poorter et al.,* 2021).

Figure 2 - Relationship between the number of species and the type of spatial distribution according to the spatial index, where IGA_i = MacGuines Index for the *i*-th species; K_i = Fracker and Brischle Index for the i-th species; P_i = Payandeh Index for the i-th species; R_i = Non-Randomized Index for the i-th species; IH_i = Hazen Index for the i-th species and IM_i = Morisita Index for the i-th species



Source: research data.

According to Freitas and Magalhães (2014), the aggregated distribution pattern is common in tropical forests, indicating an attraction force, where the chance of occurrence of an individual is greater with the presence of others of the same taxonomic group or due to the availability of a common resource (Cain *et al*., 2011; Silva *et al*., 2008).

In the case of this study, FLONA MX, even before its creation, received several plantings of exotic and native species, which may influence the spatial distribution of species, given that compared to natural forests, it is still too little time for the implanted species to have a different spatial behavior.

Although the MacGuinnes and Fracker and Brischle indices could not calculate the spatial distribution pattern of the species *E. pulchrum* (arco-de-pipa), Gandra (2008) observed an aggregated spatial distribution pattern for this species using the MacGuinnes Index in the Private Reserve of Natural Heritage Porangaba, located in the municipality of Itaguaí, RJ. Furthermore, the study area of Gandra (2008) presents vegetation in different regeneration stages, a situation similar to FLONA MX.

The species *E. contortisiliquum*, commonly known as tamboril, was the only one that presented a random spatial distribution pattern for the Fracker and Brischle Index. This result can be explained by this species presenting five individuals distributed in four sampling units, and as this index estimates the degree of aggregation through observed and expected density, it tended toward

randomness. However, according to Polli *et al.* (2021), this species has a zoochorous dispersal syndrome, meaning an aggregated spatial distribution is expected, as seeds are deposited in animal feeding micro-sites (Bernasol; Lima-Ribeiro, 2010).

The tree species *P. gonoacantha* (pau-jacaré), *A. colubrina* (angico-branco), *S. lactescens* (lanterneira), *C. pentandra* (sumaúma), and *G. integrifolia* (pau-d'alho) were classified as anemochorous, meaning their seeds are dispersed by wind, and presented aggregation and tendency toward grouping of their individuals. However, Bernasol and Lima-Ribeiro (2010) associate anemochory with a random spatial distribution pattern, given that adult plants disseminate their seeds randomly, without intentional deposition in specific environments. A similar result was found by Almeida and Cortines (2008) in the Private Reserve of Natural Heritage Rio das Pedras in Mangaratiba, Rio de Janeiro, where the species *P. gonoacantha*, using the Morisita Index, presented an aggregated spatial distribution pattern. As for the species *C. pentandra*, Belem (1997) found a random distribution, but for this study, it may have presented an aggregated spatial distribution pattern due to the planting of this species carried out more than 55 years ago in the studied area (Alves; Vargas, 2019) and also because it is of Amazonian origin, hindering its natural regeneration in other biomes.

For species that have autochorous dispersal syndrome (27.3% of the studied species) and presented an aggregated spatial distribution pattern, Bernasol and Lima-Ribeiro (2010) state that an aggregated spatial distribution is expected, as seeds are deposited in specific locations, that is, around the parent plant.

Through knowledge of the spatial distribution pattern of species, it is possible to have a better understanding of forest dynamics, contributing to the definition of management and conservation strategies, such as the choice of enrichment measures or species control. In addition to the possibility of being one of the parameters to evaluate a reforested area over the years.

3.3 Aspects Related to Species Management

The species *E. pulchrum* (arco-de-pipa) presented the highest number of individuals of its species (54.7%), a similar result was found by Domiciano (2010) in a forest fragment in Seropédica, where this species presented higher relative density, representing 17.4% of the individuals found in the sampled area.

According to the Management Plan of the Mário Xavier National Forest (ICMBIO, 2022), in the stand named "old eucalyptus", fast-growing species predominate together with eucalyptus plantings, in an advanced state of senescence with few specimens in good condition, allowing light penetration and, therefore, accelerating the natural regeneration process, which is giving way to more adapted native species, mainly arco-de-pipa.

Furthermore, according to Alves and Vargas (2019), trees of species such as arco-de-pipa (*E. pulchrum*) and pau-brasil (*Paubrasilia echinata* (Lam.) Gagnon, H.C. Lima & G.P. Lewis) were planted in areas composed of mixed species plots, with the aim of enriching the vegetation component of the area and regenerating areas affected by fires, one of the major problems affecting FLONA MX, which aids in the aggregation of the species.

According to Carvalho *et al.* (2006), this species has a zoochorous dispersal syndrome. However, when observing the conditions presented by the species in the study area, it also appears to have an autochorous dispersal syndrome, given that during field visits to collect forest inventory data, it was noticed that *E. pulchrum* seeds that fell to the ground germinated in a few days, which evidences that the species is well adapted to the edaphoclimatic conditions of the site.

The aggregated spatial patterns observed for most species have important implications for the ecological restoration of FLONA MX. Although aggregation is common in tropical forests and may reflect natural dispersal limitations, as discussed earlier, in addition to planting history and regeneration around parent trees, the predominance of this pattern may also indicate a risk of excessive concentration of certain species along the successional process.

In the case of the species *E. pulchrum*, which represented more than half of the sampled individuals and occurred in all sampling units, a potential tendency toward ecological dominance is observed, which may negatively influence floristic diversity and future structural heterogeneity of the forest. In view of this, for the referred species, dominant characteristics can be observed, due to its concentrated and continuous distribution, requiring more in-depth research on its behavior, its dispersal form in FLONA MX, and its advantage in natural regeneration compared to other species. From this, it will be possible to define management strategies for this species, aiming at its control, in a way that favors the regeneration and propagation of the others.

Concomitantly, it should be observed that the high spatial concentration of few species may limit the establishment of less competitive species and compromise the ecological resilience of the restored ecosystem. In this context, management and restoration strategies should prioritize floristic enrichment, favoring greater functional diversity, different ecological groups, and a less concentrated spatial distribution of tree species.

4 Conclusions

For 90.9% of the studied species and applied spatial indices, the aggregated spatial distribution pattern predominates. This result is explained by the fact that the FLONA MX area is reforested. Thus, for future forest management and restoration projects, it is important to adopt techniques that ensure greater diversity and a broader spatial distribution of species in FLONA MX, considering their respective ecological groups and dispersal types.

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