



SIZE, DENSITY, ECOLOGICAL GROUPS, AND DISPERSAL SYNDROMES OF THE SEED RAIN IN URBAN ATLANTIC FOREST FRAGMENTS IN NORTHEASTERN BRAZIL

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Abstract: Urban expansion has been one of the main factors contributing to the reduction and fragmentation of tropical forests, and such urban green areas are crucial for conserving and maintaining local and regional biodiversity. This study assessed different aspects of the seed rain (seed size, seed density, dispersal syndromes, ecological groups) in two urban Atlantic Forest fragments (Jardim Botânico – 11 ha / Mata do Curado – 106 ha) in Recife, northeastern Brazil. We expected that i) the connectivity and large size would reduce the floristic homogenization in Mata do Curado, ii) the continuous human presence would increase the abundance of non-shaded tolerant species, and iii) in the Jardim Botânico the absence of connectivity and small size would reduce the abundance of shade-tolerant species (large seeds). A total of 50 fruit traps were maintained for 12 months at each site, and visits were performed fortnightly to collect seeds. The collected seeds were quantified, measured (length and width), and categorized into dispersal syndromes (zoochoric, anemochoric, autochoric) and ecological groups (shade and non-shade tolerant). 4,621 seeds were collected in the traps across the study period (Jardim Botânico: 1,778; 7 spp. / Mata do Curado: 2,843; 8 spp. plus 18 morphotypes). Overall, large seeds (15.1 mm - 30 mm) were more abundant in the Jardim Botânico. Zoochoric seeds were longer in length and width in the Mata do Curado. As expected, connectivity and size appeared to contribute to the decrease of floristic homogenization, and human presence increased the abundance of non-shade tolerant seeds in the Mata do Curado. In contrast, albeit small and isolated, the Jardim Botânico demonstrated a higher abundance of shade-tolerant seeds. Our results reinforce the urgency of preserving urban forests to conserve regional biodiversity.

Keywords: Dispersal syndromes, forest homogenization, forest connectivity, seed size, shade-tolerant species.

INTRODUCTION

The Atlantic Forest is the second-largest tropical rainforest in the Americas (Oliveira-Filho & Fontes 2000). In the past, it covered more than 1.5 million km², with approximately 92% of this area in Brazil and the rest distributed across northeastern Paraguay and eastern Argentina, at its southern frontier (SOS Mata Atlântica & INPE 2001, Galindo-Leal & Câmara 2003). Although it is among the 25 global hotspots for biodiversity conservation (Myers *et al.* 2000, Mittermeier *et al.* 2004), it has suffered dramatically from the deleterious effects caused by anthropogenic disturbances since the colonial period (Dean 1996). Among anthropogenic actions, deforestation and habitat fragmentation divide continuous habitats into small and isolated fragments and reduce the coverage of forested areas (FAO 2005). Intense modifications occur in these forests as human activity and occupation increase, mainly due to the alteration of the local ecosystem by cultivable areas (Ramankutty & Foley 1998) and by urban expansion (Wittemyer *et al.* 2008). These threats lead to irreversible losses in the biodiversity of tropical ecosystems (Gardner *et al.* 2009) and result in mainly negative ecological consequences (Poulsen *et al.* 2013, Malhi *et al.* 2014).

Forest fragments embedded in an urban matrix are primarily small and isolated (Grimm *et al.* 2008, Parris 2016). However, they can host high levels of biodiversity (Brunbjerg *et al.* 2018) and provide essential ecosystem services to promote human well-being and maintain the environment (Mullaney *et al.* 2015). These forest fragments often face abiotic stresses, diseases, or pests (Frankie & Ehler 1978, Raupp *et al.* 2010), reducing the benefits of these services (Meineke *et al.* 2016). The effects of human activity, for example, predation caused by domestic animals, urban lighting, and implantation of exotic plants, can be very harmful to forest fragments, increasing the reduction of native species and the actions caused by edge effects (Godefroid & Koedam 2003). Forest fragments surrounded by an urban matrix mostly shelter species of the regional arboreal flora and reveal the importance of their conservation, thus increasing the educational potential of urbanized fragments (Cielo Filho & Santin 2002). Furthermore, some of these forest fragments are essential for mitigating problems caused by over-urbanization, such as air

pollution, soil impermeability, climate warming, and other factors, in addition to attracting dispersal fauna, especially birds, to vegetation (Dislich & Pivello 2002).

On the other hand, urban fragments are less prone to the arrival of seeds from terrestrial and arboreal dispersal fauna due to anthropogenic barriers (*e.g.*, highways and cities). Besides avoiding the arrival of new propagules, these barriers can increase the mortality rate of those animals trying to cross highways (Fahrig & Rytwinski 2009). In a forested and permeable matrix, the probability to arrive new seeds is higher because of the connectivity of the forest fragments (Metzger & Décamps 1997) and the facility for arboreal and terrestrial fauna, mainly mammals, to move between areas (Cramer *et al.* 2007a). Also, when small and disturbed areas are connected to large forest fragments – areas with a high abundance of tree species with large seeds (Melo *et al.* 2006, Melo *et al.* 2010) – the dispersal fauna can act by carrying large seeds among sites (Cramer *et al.* 2007b). Therefore, the number and quality of seed rain are affected not solely by the local conditions (*e.g.*, floristic composition) but also by composition and landscape configuration (*e.g.*, size, connectivity, and isolation of the forest fragments).

Seed rain is represented by the number of seeds that reach the ground in a given period (Hardesty & Parker 2003). This process strongly influences forests' subsequent dynamics and plant composition (Nathan & Muller-Landau 2000). The entry of seeds is achieved by diverse forms of dispersal, either by animals (zoochory), wind (anemochory), or propagation from the mother tree (Piña-Rodrigues & Aoki 2014). Seed dissemination in the forest consists of seeds generated on-site and in nearby areas. The seeds that arrive from the site itself promote the natural regeneration of the forest, and those brought by dispersing agents from neighboring areas represent the increase of floristic and genetic diversity (Martinez-Ramos & Soto-Castro 1993).

The lack of seed sources due to low dispersal agent activity (zoochory) and environments with limited access to propagules results in low seed flow in plant communities (Battilani 2010). In addition to isolated forest fragments may act as a limiting factor for the arrival of seeds due to unable of dispersal

animals – especially terrestrial and arboreal species – to deposit the seeds, and small-sized habitats also reduce seed abundance (Terborgh 1986). This disability to arriving new propagules becomes more pronounced for isolated forest fragments and large seeds. For small seeds, birds would be able to deposit them between different forest fragments with the presence of potential barriers (Hewitt & Kellmann 2002). In contrast, the arrival of large seeds in isolated forest fragments is strongly influenced by the difficulty of terrestrial or arboreal mammals to either move long distances on open areas (*e.g.*, non-forested landscapes) or cross physical barriers (*e.g.*, highways or rivers) (Hewitt & Kellmann 2002, Vistnes *et al.* 2004, Jesus *et al.* 2012). Moreover, anthropogenic disturbances increase the floristic and structural homogenization of these habitats (Lôbo *et al.* 2011), thus decreasing the presence of shade-tolerant species (Laurance *et al.* 2006). The knowledge of the predominant dispersal syndrome in a plant community allows inferences to be made about the vegetation structure, the degree of conservation, and the successional stage (Pivello *et al.* 2006).

Several studies have focused on understanding the structure and composition of plant communities based only on the standing vegetation (Bakker *et al.* 1996, Savadogo *et al.* 2017). However, as seed availability is the first ecological filter for plant regeneration (Terborgh *et al.* 2011), understanding the local structure and composition of plant communities requires joint consideration of the standing vegetation, the spatial extent achieved by dispersal (seed rain), and the temporal exploration obtained through the existence of soil seed banks (Bakker *et al.* 1996, Nathan & Muller-Landau 2000, Vandvik *et al.* 2016, Savadogo *et al.* 2017).

Thus, the present study aimed to evaluate the seed rain in two urban Atlantic Forest fragments in Pernambuco. Additionally, we characterized the plant community's dispersal syndromes and ecological groups using seeds. Although the forest fragments are protected areas, they present different sizes, forms, degrees of connectivity, and disturbance histories. For instance, the Mata do Curado Wildlife Refuge has suffered from intense anthropogenic disturbance over the years due to the construction of numerous residences within the area, the introduction of many exotic species, and intense military training (Campêlo

et al. 2018). However, this area is connected to a large forest fragment and houses a considerable number of potential dispersal fauna species (J.P. Souza-Alves, *personal observation*). Contrarily, the Jardim Botânico do Recife is smaller and isolated, but does not experience direct human interference (*e.g.*, logging, trash, exotic plants), and presents a better-structured forest (Souza-Alves *et al.* 2020). In this sense, we expected that i) a reduction of floristic homogenization in the Mata do Curado can occur due to their size and connectivity, resulting in a decreased non-shade tolerant species and small seeds. However, we also could expect that ii) the human pressure can act inversely, thus increasing the abundance of non-shade tolerant species. On the other hand, we expected that iii) the absence of connectivity of Jardim Botânico can avoid the arrival of new propagules, mainly large seeds dispersed by terrestrial and arboreal mammals, thus decreasing the number of shade-tolerant species.

MATERIAL AND METHODS

Study area

The study was conducted in two urban Atlantic Forest fragments located in the Metropolitan Region of Recife, northeastern Brazil (Figure 1). The first study area is located in the Jardim Botânico do Recife (hereafter Jardim Botânico) (08° 04' 36" S, 34° 57' 32" W, *datum* WGS84; Figure 1). This is a small Atlantic Forest fragment (11 ha) composed of secondary forest vegetation in various successional stages of recovery (Velooso *et al.* 1991). The area presents trees with a basal area of 18.5 m²/ha, a density of 203 trees/ha, and diversity of 3.6 nats/individuals (Sousa Júnior 2006, Souza-Alves *et al.* 2020). The vegetation is predominantly composed of *Helicostylis tomentosa* (Rosales, Moraceae), *Parkia pendula* (Fabales, Fabaceae), *Dialium guianense* (Fabales, Fabaceae), and *Didymopanax morototoni* (Apiales, Araliaceae) (Sousa Júnior 2006). With regards to dispersers, the fauna recorded in this area includes common marmosets (*Callithrix jacchus*, Primates, Callithrichidae), agouti (*Dasyprocta iacki*, Rodentia, Dasyproctidae), birds, and bats (J.P. Souza-Alves, *personal observation*). This area is incredibly isolated in the urban matrix by the BR-232 federal highway and local communities.

The second area was a fragment of Atlantic



Figure 1. Map showing the location of two urban Atlantic Forest fragments in the urban region of Recife, northeastern Brazil. The orange polygon represents the Mata do Curado and the red polygon represents the Jardim Botânico.

Forest located in the Mata do Curado Wildlife Refuge (hereafter Mata do Curado) ($8^{\circ} 04' 50''$ S, $34^{\circ} 58' 21''$ W, datum WGS84; Figure 1). The fragment comprises approximately 106 ha within the spatial limits of the Northeast Military Command (CMNE). This fragment is characterized by the high prevalence of Monimiaceae and Melastomataceae plant species, with a tree density of 780 individuals/ha, a basal area of $24.7 \text{ m}^2/\text{ha}$, and a low canopy height (11.2 m) (Lins-e-Silva & Rodal 2008). Although the site presents high species richness of the families Moraceae, Mimosaceae, Anacardiaceae, Euphorbiaceae, and Araliaceae, there is also a high abundance of exotic species such as jackfruit (*Artocarpus heterophyllus*, Rosales, Moraceae), mango (*Mangifera indica*, Sapindales, Anacardiaceae), oil palm (*Elaeis guineensis*, Arecales, Arecaeae) and java plum (*Syzygium cumini*, Myrtales, Myrtaceae) (Campêlo *et al.* 2018). Both areas are located to the right (Jardim Botânico) and to the left (Mata do Curado) of the BR-232 federal highway, in the direction of Recife (Figure 1). This area is connected to a large forest fragment, and it is possible to record a variety of dispersal animals such as *C. jacchus*, *D. iacki*, an exotic squirrel monkey (*Saimiri* spp., Primates,

Cebidae), paca (*Cuniculus paca*, Rodentia, Cuniculidae), coatis (*Nasua nasua*, Carnivora, Procyonidae) and crab-eating foxes (*Cerdocyon thous*, Carnivora, Canidae) (A. Campêlo, *personal observation*, Oliveira-Silva *et al.* 2018, Campêlo *et al.* 2019).

The climate in the region is type *As'* (Tropical climate, hot and humid or Savanna) according to the Köppen classification (Alvares *et al.* 2013). Over the last ten years (2006 - 2016), the average monthly rainfall from December to May was $188.6 \pm 110 \text{ mm}$ (67.7 mm - 335.2 mm). During the study period (December/2016 to May/2017), rainfall ranged from 67.8 mm (December) to 397.7 mm (May), with an average of $157.7 \pm 154.5 \text{ mm}$ (APAC 2017).

Evaluation of seed rain

We collected data for 12 months in both areas during different periods. In the Jardim Botânico, we collected seeds from January to December 2018 and the Mata do Curado from May 2016 to April 2017. We installed 50 traps distributed across five transects throughout each study area. Each transect was composed of 10-traps with 2 m between each trap. Each trap was made with polyester mesh ($1 \text{ mm} \times 1$

mm) cut into squares with an area of 1 m² (Oliveira-Silva *et al.* 2018). They were tied with string to native trees present at the site, 1 ½ meters above the ground. We took care to avoid the predation of the fruits/seeds by invertebrate and vertebrate animals (Bocchese *et al.* 2008). Furthermore, in order to estimate the possible loss of fruit, we deposited pieces of fruit such as bananas and mango inside the traps. Every 15 days, the presence of these fruits was verified. As a result, during the entire study period, no predation event was found in bananas and mango in traps. We collected fruits and seeds fortnightly to obtain a more accurate pattern regarding the potential variation in the availability of these resources in the study areas (see Bencke & Morellato 2002).

All fruits and seeds from trees and lianas collected in the traps were placed in plastic bags identified with the day/month of collection and forwarded to the Ecology, Behavior, and Conservation Lab of the Federal University of Pernambuco (LECC - UFPE). The seeds were sorted, quantified, and measured (length and width) with the aid of a 150 mm digital pachymeter (LEE TOOLS-684132). Before measuring length and width, all seeds were dried. We identified all the material to the highest possible level with the help of fruits and seeds collected from trees near the traps, as well as using the germplasm bank of the Jardim Botânico do Recife. We determined the samples' morphotypes from their morphological characteristics (size, color, texture) if identification was not possible. We classified the seeds into five size classes: very small: 1-3 mm long, small: 3.1-6 mm, medium: 6.1-15 mm, large: 15.1-30 mm, and very large: > 30 mm (see Tabarelli & Peres 2002).

Dispersal syndromes and ecological groups

After identifying the seeds, we classified them according to the corresponding dispersal syndrome, such as anemochoric, autochoric, and zoochoric (Van der Pijl 1982). Zoochoric seeds can be included with seeds that have a high potential of dispersal by vertebrates due to the production of diaspores adhered to the pulps. The other syndromes can be categorized as seeds dispersed by abiotic means (winged seeds, seeds with plumes, dispersed by wind or by the explosion of the fruits). We performed this characterization based on our

knowledge about the previously described local plant community in the study areas (Sousa Júnior 2006, Lins-e-Silva & Rodal 2008, Campêlo *et al.* 2018, Oliveira-Silva *et al.* 2018), and from details about life-history traits of the species from the literature (Souza & Lorenzi 2008).

Additionally, we also classified the seeds according to different ecological groups: non-shade tolerant (occur in large and small clearings or forest edges and are light-dependent) and shade tolerant (develop in the understory under light or dense shade conditions) species (following Gandolfi *et al.* 1995).

Data analysis

We organized the data into monthly samples to obtain a yearly overview. We treated each forest fragment as a sampling unit, thus the data provided in fruit traps were summed. Although the data for both study sites were not collected during the same period, since they are in close proximity to one another - less than 1 km apart - the abiotic effect suffered (*e.g.*, rainfall level) by both areas is similar (Student t test: $t = -0.447$, $df = 21.656$, $p = 0.658$) (Supplemental Material I). As such, it is possible to apply comparative tests between the areas. We extracted descriptive statistics (mean \pm standard deviation) of seed abundance and size for both sites. We performed a Non-Metric Multidimensional Scaling (NMDS) based on the Bray-Curtis dissimilarity index to verify the floristic composition of both study areas across the study period. For this analysis, the total number of species and their respective abundances recorded in each plot were considered. The stress value represents the distortion of the distance, where values close to 0 mean that the distances presented in the bi-plot are more accurate (Clarke & Warwick 2001). We carried out NMDS with two dimensions, which resulted in a stress of 0.17. This analysis was performed in the software PAST 2.16 (Hammer *et al.* 2001). The seed density (seeds/m²/month), width, length, and abundance of zoochoric seeds were compared between areas using a Student t-test. We worked only with zoochoric seeds to understand the influence of dispersal fauna (terrestrial and arboreal mammals) on seeds and the potential role of highway (BR-232) as a barrier (Lesbarrères & Fahrig 2012) to the arrival of seeds. We used a Chi-

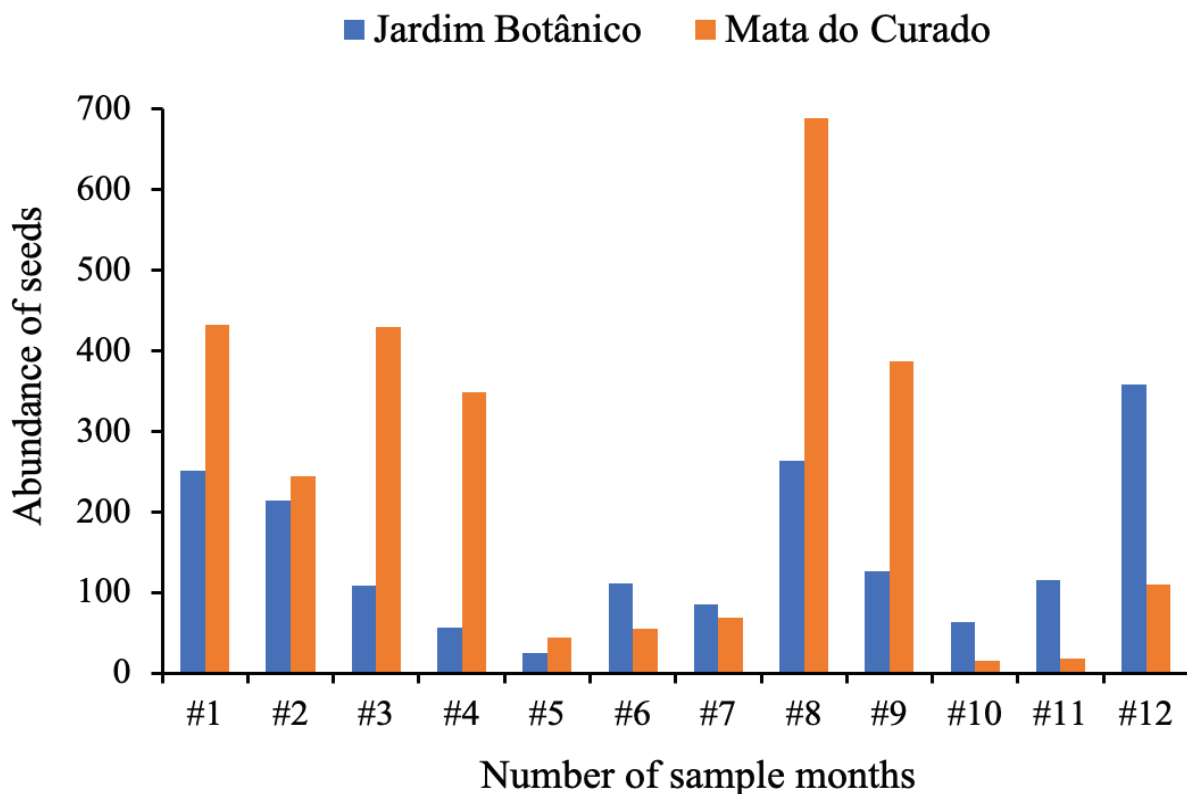


Figure 2. The monthly abundance of seeds recorded in the traps in two urban Atlantic Forest fragments in Recife, northeastern Brazil.

square test to compare the abundance of shade-tolerant and non-shade tolerant seeds between sites. All the statistical analyses were performed in RStudio version 1.2.5 (RStudio Team 2019) with a significance p -value at 0.05.

RESULTS

Seed composition, abundance, and density

A total of 4,621 seeds from trees ($N=3,943$) and lianas ($N=678$) were collected in the traps throughout the study period. In particular, 1,778 were collected in the Jardim Botânico and 2,843 in the Mata do Curado. Annually, the Jardim Botânico presented 148 (± 100) seeds (mean/month), and the Mata do Curado 237 (± 219). The Jardim Botânico presented a higher abundance of seeds in the months of January to February ($N=465$: 232 ± 26 seeds), and between August and December, while higher abundances in the Mata do Curado occurred between January and April ($N=1455$: 363 ± 88 seeds) and August and September ($N=1076$: 538 ± 213 seeds) (Figure 2). In

accordance with the NMDS analysis, the floristic composition varied between study areas (Figure 3).

In the Jardim Botânico, seeds were grouped into five botanical families and seven species (Table 1). Araliaceae, Fabaceae, and Sapindaceae were the most abundant families (Table 1). The seeds of *D. morotoni* and *Serjania lethalis* were the most abundant (Table 1). In the Mata do Curado, we recorded eight species encompassing six families, and 18 morphospecies (Table 1). The most abundant families were Anacardiaceae, Araliaceae, and Fabaceae (Table 1). Among the species, *Tapirira guianensis* produced the most significant quantity of seeds during the study period (Table 1).

Within the seed size classes recorded in the study areas, a variation was only observed in class #4 (large seed: 15.1 mm - 30 mm), with the Jardim Botânico showing an abundance of seeds in this category which was almost tenfold the values recorded in the Mata do Curado (10.2 vs. 1.5: $t = -2.111$; $df = 11.4$; $p = 0.05$). There was not

variation in the other classes (class #1: 24.8 vs. 15.8 - $t= 0.474$; $df= 21.8$; $p= 0.64$; class #2: 68.5 vs. 139 - $t= 0.808$; $df= 12.1$; $p= 0.434$; class #3: 44.1 vs. 70.5 - $t= 0.753$; $df= 15.7$; $p= 0.462$; class #5: 10.2 vs. 1.5 - $t= 1.052$; $df= 15.5$; $p= 0.307$). Mean seed density in the Jardim Botânico (3 ± 2 seeds/m²: 0.6 - 7.2) was similar to that recorded for the Mata do Curado (4.7 ± 4.4 seeds/m²: 0.3 - 13.8) ($t= 1.254$; $df= 15.48$; $p= 0.228$).

Dispersal syndromes and ecological groups

Throughout the study in the Jardim Botânico, zoochoric, autochoric, and anemochoric seeds were identified. For the Mata do Curado, anemochoric seeds were not recorded. In the Jardim Botânico, 1,246 seeds (89 ± 59 seeds: 49%) were recorded with zoochoric dispersal, followed by anemochoric (total: 972; 49 ± 81 : 38%) and autochoric (total: 314; 11 ± 19 : 12%). For the Mata do Curado, the plants with zoochoric dispersal counted 2,172 seeds (74.6%), followed by the unidentified dispersal syndrome with 668 seeds (22.9%), and the autochoric dispersal

syndrome with 72 seeds (2.5%). Unidentified seeds represented 24% ($N= 668$) of the samples.

When comparing only the zoochoric seeds, there was not variation in abundance between two areas (113 vs. 65: $t= 1.687$; $gl= 13.68$; $p= 0.114$). On the other hand, the length ($t= 2.756$; $gl= 21.7$; $p= 0.01$) and width ($t= 2.627$; $gl= 21.9$; $p= 0.03$) of zoochoric seeds was greater, in general, in the Mata do Curado (length: 9.5 ± 2.6 mm / width: 6.8 ± 1.5 mm) when compared to the Jardim Botânico (6.6 ± 2.4 / 5.4 ± 1.4) (Table 2). Overall, we were able to identify the ecological groups of 13 species. Of the seven species sampled in the Jardim Botânico, five (71%) were classified as shade tolerant, and two species were classified as non-shade tolerant. In the Mata do Curado, 26 species were recorded, but only six were classified into ecological groups. Two were classified as shade tolerant, and four as non-shade tolerant (Table 1). Two non-shade tolerant species were more abundant in both sites (Mata do Curado: *T. guianenses*= 1,096 seeds; Jardim Botânico: *S. morototoni*= 922 seeds) (Table 1). When compared to the abundance of non-shade tolerant seeds, Mata do Curado presented a higher abundance

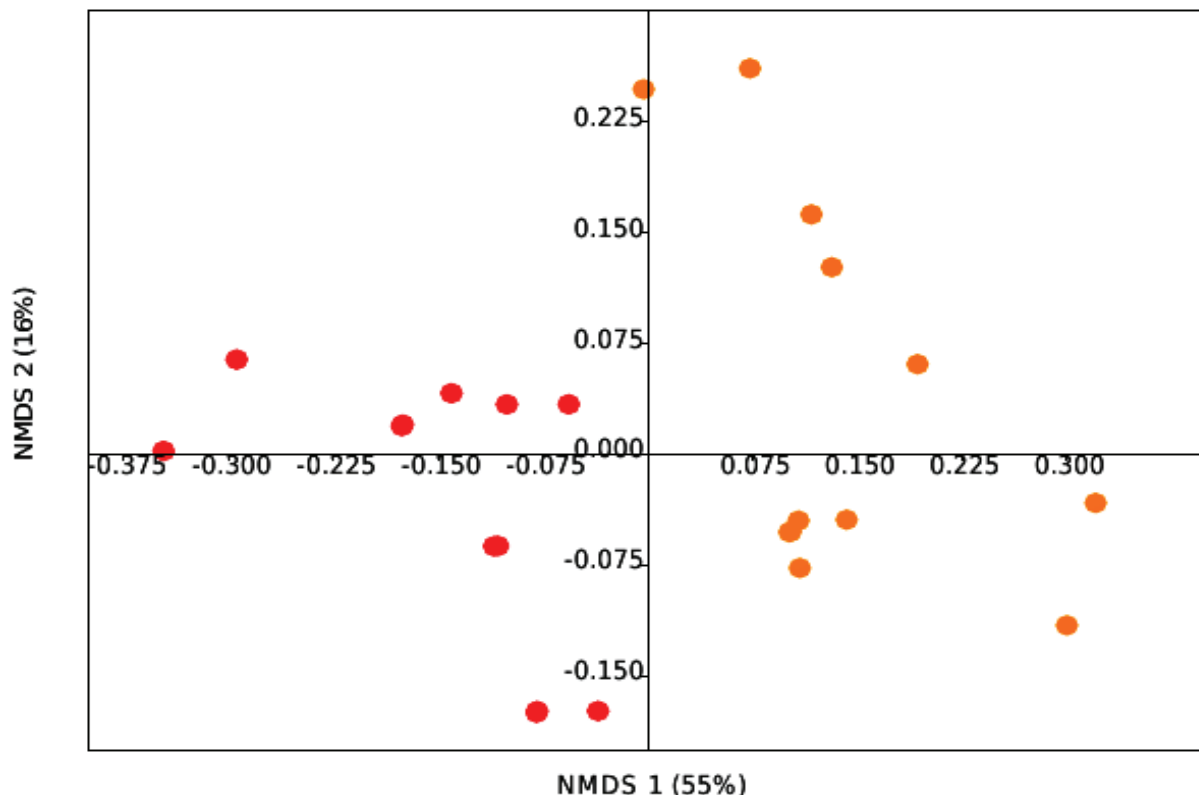


Figure 3. Two-dimensional Non-metric Multidimensional Scaling (NMDS) for the floristic composition of the Mata do Curado Wildlife Refuge and Jardim Botânico in Pernambuco, northeast Brazil. The red dots represent the Jardim Botânico, and orange dots represent the Mata do Curado.

Table 1. Composition, ecological group, and dispersal syndromes of seeds recorded in the two urban Atlantic Forest fragments in the Recife, northeastern Brazil. Ecological groups: ST – shade tolerant, NST – non-shaded tolerant.

Family	Species	Jardim	Mata do	Ecological group	Dispersal syndrome
		Botânico	Curado		
		Abundance			
Anacardiaceae	<i>Spondias mombin</i> L.	16		ST	Zoochoric
	<i>Tapirira guianensis</i> Aubl.		1096	NST	Zoochoric
Annonaceae	<i>Xylopia frutescens</i> Aubl.	131		NST	Zoochoric
Araliaceae	<i>Didymopanax morototoni</i> (Aubl.) Decne. Planch.	922	912	NST	Zoochoric
Fabaceae	<i>Bowdichia virgilioides</i> Kunth	330		ST	Anemochoric
	<i>Dialium guianense</i> (Aubl.) Sandwith	177		ST	Zoochoric
	<i>Dioclea virgata</i> (Rich.) Amshoff		36	-	Autochoric
	<i>Inga ingoides</i> (Rich.) Willd.		34	NST	Zoochoric
	<i>Parkia pendula</i> (Willd.) Benth. ex Walp.	314	36	ST	Autochoric
Meliaceae	<i>Guarea guidonia</i> (L.) Sleumer		28	ST	Zoochoric
Moraceae	<i>Artocarpus heterophyllus</i> Lam.		11	NST	Zoochoric
Rubiaceae	<i>Palicourea deflexa</i> (DC.) Borhidi		35	-	Zoochoric
Sapindaceae	<i>Serjania lethalis</i> A.Sit.-Hil	642		ST	Anemochoric
Unidentified	Morphospecies 1		4		
	Morphospecies 2		191		
	Morphospecies 3		316		
	Morphospecies 4		57		
	Morphospecies 5		20		
	Morphospecies 6		8		
	Morphospecies 7		4		
	Morphospecies 8		8		
	Morphospecies 9		5		
	Morphospecies 10		4		
	Morphospecies 11		14		
	Morphospecies 12		1		
	Morphospecies 13		18		
	Morphospecies 14		1		

Family	Species	Jardim Botânico	Mata do Curado	Ecological group	Dispersal syndrome
		Abundance			
	Morphospecies 15		1		
	Morphospecies 16		3		
	Morphospecies 17		6		
	Morphospecies 18		7		

($\chi^2=1705.1$, $df=3$, $p<0.0001$). In contrast, the Jardim Botânico obtained a higher abundance of shade-tolerant seeds ($\chi^2=234.0$, $df=4$, $p<0.0001$).

DISCUSSION

Our results demonstrate that a higher richness (species + morphotypes) and abundance of seeds found in the traps were recorded in the Mata do Curado. However, for both study areas, two non-shade tolerant species with small seeds were the most abundant. The increased floristic homogenization in the Jardim Botânico can be

linked with the absence of connectivity and the small size; conversely, the connectivity with a large forest fragment appeared to reduce the floristic homogenization in the Mata do Curado, and the continuous human presence increased the frequency of small and non-shade tolerant seeds. All the dispersal syndromes were recorded, except in the Mata do Curado, where anemochoric seeds were not found. There are three potential factors to explain this absence of anemochoric seeds in Mata do Curado. First, anemochoric seeds are more prone to occur in small and isolated forest fragments and are common in early-successional

Table 2. Abundance and size of zoochoric seeds recorded in two urban Atlantic Forest fragments in Recife, northeastern Brazil.

Months	Abundance (length \pm SD / width \pm SD) of the zoochoric seeds in:	
	Jardim Botânico	Mata do Curado
#1	110 (5.6 \pm 1.7 / 4.8 \pm 1.2)	116 (12.4 \pm 5.4 / 8.9 \pm 4.1)
#2	134 (5.1 \pm 0.8 / 4.6 \pm 0.8)	124 (5.1 \pm 0.8 / 4.6 \pm 0.8)
#3	109 (6.4 \pm 2.4 / 5.6 \pm 2.0)	409 (7.8 \pm 8.7 / 5.6 \pm 5.1)
#4	56 (6.8 \pm 4.9 / 5.9 \pm 4.6)	310 (11.9 \pm 2.9 / 8.0 \pm 1.9)
#5	25 (13.8 \pm 11.4 / 9.7 \pm 7.1)	29 (9.4 \pm 8.1 / 7.1 \pm 6.0)
#6	45 (6.9 \pm 6.9 / 6.3 \pm 6.1)	55 (9.3 \pm 3.5 / 6.1 \pm 2.4)
#7	45 (5.7 \pm 4.8 / 4.5 \pm 3.1)	69 (9.8 \pm 3.5 / 7.5 \pm 2.6)
#8	241 (4.6 \pm 0.5 / 4.6 \pm 0.3)	469 (5.1 \pm 1.9 / 4.3 \pm 1.0)
#9	117 (5.4 \pm 1.0 / 4.4 \pm 0.7)	379 (4.9 \pm 0.9 / 4.2 \pm 0.7)
#10	60 (5.5 \pm 0.7 / 4.7 \pm 0.6)	15 (12.6 \pm 1.1 / 8.7 \pm 1.3)
#11	50 (7.5 \pm 1.8 / 5.7 \pm 1.8)	18 (13.1 \pm 1.3 / 7.7 \pm 1.6)
#12	70 (7.1 \pm 1.0 / 4.8 \pm 1.2)	110 (11.0 \pm 2.4 / 7.6 \pm 2.4)

stages of the Atlantic Forest (Tabarelli & Peres 2002, Tabarelli *et al.* 2008, Jesus *et al.* 2012). These features – isolation and connection – contradict at least one of the characteristics (connection) presented by Mata do Curado. Thus, connected forest fragments tend to present a high abundance of anemochoric seeds. Second, the proximity of another forest fragment appears does not influence the arrival of wind-dispersed seed. Unfortunately, we do not know the floristic composition and vegetation structure of this other forest fragment to infer with robustness on this relationship. And third, several species (N= 18) were classified as morphotypes in Mata do Curado, which probably made it impossible to identify their dispersal syndromes. Additionally, seed density was similar between study areas. Although both study areas are inserted into an urban matrix and are influenced by identical weather conditions, the reduced or lack of anthropogenic disturbance (logging, trash, constant human presence) in the forest fragment located in the Jardim Botânico appears to be promoting the maintenance and growth of the larger shade-tolerant species.

The most representative families in this study also are those with a higher number of records in the study areas (Sousa Júnior 2006, Lins-e-Silva & Rodal 2008). The abundance of Fabaceae and Araliaceae seeds was occasioned by the presence of two species, *T. guianensis*, and *D. morototoni*, respectively. The seeds found in these species are smaller, listed as non-shade tolerant, and have zoochoric dispersal syndrome (Kimmel *et al.* 2010, Silva *et al.* 2010). High levels of disturbance have generated an increased number of non-shade tolerant seeds, which are generally small and employ a zoochoric dispersal syndrome (Turner 2001, Laurance *et al.* 2006, Freitas *et al.* 2013). Furthermore, the number of seeds available in a given area is directly associated with their size, with smaller forest fragments possessing decreased seed rain composition (Terborgh 1986). Although this relationship was not tested here due to the absence of a suitable number of replicates (number of fragments), the Mata do Curado forest fragment is connected to another fragment. Moreover, it is almost ten times more extensive than the Jardim Botânico, suggesting that this factor – size – occasioned the elevated difference in species richness.

Larger seeds recorded in this study varied between 15.1 mm and 30 mm and were recorded in the forest fragment inserted into the Jardim Botânico. The isolation level of fragmented forests is expected to correlate positively with seed size. For instance, the abundance of seeds is negatively related to the degree of isolation of an area (Freitas *et al.* 2013). Associated factors, such as the presence of potential dispersers and the ability of these species to cross open and highly disturbed regions, can strongly and positively influence these results (Freitas *et al.* 2013). Contrarily, the forest fragment in the Jardim Botânico demonstrates opposite features. The area is very small (11 ha) and is highly isolated due to the presence of a highway and local neighboring communities.

Nevertheless, this is a less-disturbed area with large trees and a restoration program that was implemented almost ten years ago (Oliveira *et al.* 2015, Souza-Alves *et al.* 2020). Any affirmative statements must be made with caution; however, we could suggest that these aspects may favor the high abundance of large seeds in the Jardim Botânico. Additionally, this high abundance of large seeds may, in the long-term, contribute to this forest fragment reaching older successional stages (Costa *et al.* 2012).

The reasons for the similarity in zoochoric seed abundance between study areas are unclear. Small and isolated forest fragments are prone to present a lower diversity of dispersal fauna due to their size and absence of functional connectivity, thereby decreasing the likelihood of seed deposition on the forest floor. In contrast, large and connected forest fragments facilitate dispersal fauna move between different sites, increasing the diversity of zoochoric species (Freitas *et al.* 2013). High levels of disturbance can also act on the prevalence of zoochoric seeds in fragmented forests (Turner 2001). When combining these factors, we could expect a higher abundance of zoochoric seeds in the Mata do Curado; however, the observed lack of variation appears to be associated with strictly local elements, such as the density of zoochoric species with large canopies in both areas. These trees would have the ability to deposit many seeds on the ground. On the other hand, the Mata do Curado presented larger zoochoric seeds compared to the Jardim Botânico. It is possible that this is linked to the occurrence and diversity of dispersal fauna and

the connectivity of the study area to a large forest fragment. Due to the difficulty faced by dispersal fauna in moving between isolated forest fragments inserted into the human-modified matrix, larger and heavier seeds are less abundant (Freitas *et al.* 2013). In addition to the previously mentioned factors (isolation and small size), ecological drift in small fragments can increase extinction rates (Pimm *et al.* 1995). Thus, the presence of coatis, agoutis, paca, crab-eating foxes, and exotic squirrel monkeys can facilitate the arrival of large zoochoric seeds in the Mata do Curado.

Urban forest fragments are essential for maintaining local biodiversity (Brunbjerg *et al.* 2018). In our study, the Jardim Botânico is a small and isolated forest fragment that appears to support an essential component of tropical forests: large and shade-tolerant seeds. The reduced human pressure on the habitat and the functioning restoration program may be potential drivers of the conservation of these species. Furthermore, the increased ability of the Mata do Curado to receive large zoochoric seeds seems to be associated with its connectivity to a large Atlantic Forest fragment and diverse species of dispersal fauna. An important limitation of the study was the low number of identified seeds, mainly for the Mata do Curado. Nevertheless, this issue does not make our study unviable or less significant in light of the valuable data collected. Furthermore, we recommend future studies to evaluate the viability of seeds deposited by arboreal and terrestrial mammals in both study areas. This procedure should elucidate the role of the animals in the floristic composition and consequently in the seed rain of these forest fragments. Therefore, our study reinforces the importance of urban forests in conserving local and regional biodiversity.

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