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Short Communication

Future trends for biodiversity in urban afforestation of São Paulo, Brazil: insights for the restoration decade

Tendências futuras para a biodiversidade na florestação urbana de São Paulo, Brasil: *insights* para a década da restauração

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ABSTRACT

São Paulo city has three municipal nurseries for the distribution of urban tree specimens that meet the demand for its public landscape projects and increase in tree covering. One of them (Manequinho Lopes) receives tree seedlings from the environmental compensation processes contracted with the Municipal Secretariat for Green and Environment (MSGE). This paper aimed to evaluate the scenario of tree biodiversity received between July 2013 and July 2018 by the Manequinho Lopes nursery, as a measure of environmental compensation. The results indicated that 144,727 tree seedlings were received by the nursery, with approximately 80% of the total belonging to only 30 species, half of them belonging to only 10 different groups. We found just two predominated families: *Myrtaceae* and *Bignoniaceae*, highlighting a biotic homogenization risk. Regarding ecological attributes, it was found that 33% of the species were zoochoric, 16% autochorous and 22% anemochoric. Most of them were non-endangered specimens.

Keywords: Green areas; Native species; Green infrastructure; Environment; Nurseries

RESUMO

A cidade de São Paulo possui três viveiros municipais de distribuição de exemplares de plantas que atendem à demanda de seus projetos paisagísticos e o aumento da cobertura arbórea. Um deles (Manequinho Lopes) recebe mudas de árvores pelos processos de compensação ambiental contratados pela Secretaria Municipal do Verde e Meio Ambiente (SVMA). Este trabalho teve como objetivo avaliar o cenário da biodiversidade arbórea recebida entre julho de 2013 e julho de 2018 pelo viveiro Manequinho Lopes, como medida de compensação ambiental. Os resultados indicaram que 144.727 mudas de árvores foram recebidas pelo viveiro, com aproximadamente 80% do total pertencendo a apenas 30 espécies, sendo que metade delas pertencem a apenas 10 grupos diferentes. Encontramos apenas duas famílias predominantes: *Myrtaceae* e *Bignoniaceae*, evidenciando o futuro risco de homogeneização biótica. Em relação aos atributos ecológicos, constatou-se que 33% das espécies eram zoocóricas, 16% autocóricas e 22% anemocóricas. A maioria deles eram espécimes não ameaçados de extinção.

Palavras-chave: Áreas verdes; Espécies nativas; Infraestrutura verde; Meio Ambiente; Viveiros

1 INTRODUCTION

The efforts to preserve the biodiversity in big cities are focused on the promotion of ecological corridors and the maintenance of urban green spaces, such as parks and forest fragments. In turn, the afforestation has become decisive in the maintenance or management of biodiversity, playing a crucial ecological role for the urban biological community (Arratia *et al*., 2020; Oliveira *et al*., 2020). In fact, these green spaces promote the mitigation of urban heat islands, air pollution and contribute to a favorable microclimate in urban environments (Ferreira *et al*., 2017; Nakazato *et al*., 2021; Ribeiro *et al*., 2023).

The exposure to extreme heat has already been associated with an increase in health problems, hospitalizations and deaths, once cities are particularly vulnerable to extreme heat events, due to high population densities and large numbers of elderly and vulnerable people (Petri; Wilson; Koeser, 2019). If properly designed and managed, urban vegetation can be turned into a natural "biotechnology", aiming at reducing some adverse effects to the environment and to public health that are associ-ated with urbanization (Martins *et al*., 2021; Theophilo *et al*., 2021).

Moreover, the United Nations declared in the June of 2021 the beginning of the "Decade of Restoration". Its agencies, PNUMA and FAO, promoted several meetings and programs aiming to propagate guidelines for reforestation actions in urban and natural systems. Such initiatives might assist cities to reach the Sustainable Development Goals and the accomplishment of the Agenda 2030 (Dubey *et al*., 2021).

A means to encourage urban biodiversity is the afforestation of the road system and green areas. In the city of São Paulo, this may occur by means of environmental compensation, which is ensured by Environmental Commitment Terms (ECT), TCA – in Portuguese, Termo de Compromisso Ambiental –, compromised between the environmental agent and the entrepreneur (Almeida *et al*., 2018). In the city of São Paulo, ECTs are established by the Municipal Secretariat of the Green and Environment (MSGE) and the interested party, founded on the Environmental Compensation Project prepared by the party that is planning to execute works or renovations involving cutting or transplanting of trees.

Not only can the interested party execute the compensatory planting of arboreal items in the area of interference, but there is also the alternative of converting the compensatory planting into donation of seedlings to the municipality (PMSP, 2019). This donation must comply with the quantity of seedlings stipulated after the conversion and with minimum requirements based on a standard document, as predicted in MSGE Ordinance No. 130.

This document establishes specifications that consider ideal technical characteristics for urban afforestation involving native species of the forest formation where the city of São Paulo is inserted. Some of the characteristics are: minimum height of 2.50 m; minimum diameter at breast height (DBH) of 3 cm; first bifurcation at 1.80 m; root system consolidated in the substrate, and potting (12-liter flexible pots).

The definition of species is a step that directly guides the activities of the Afforestation Technical Sections of the municipal plant nurseries. These sections set the guidelines for the receipt of seedlings coming from compensatory terms and

destined to the improvement of the urban green infrastructure with the necessary quality and standard.

In this context, São Paulo city hall, by means of the Production Division and Municipal Herbarium (PDMH) produces and supplies seedlings to municipal green public areas. It is then understood that PDMH is also responsible for the municipal green infrastructure, because it not only organizes the planting, but also carries out research and experiments aiming at the improvement of seedling production.

PDMH involves three nurseries responsible for the production of seedlings, namely: i) Viveiro Manequinho Lopes (VML) ii) Viveiro Arthur Etzel (VAE), and iii) Viveiro Harry Blossfeld (VHB), in the city of Cotia (PMSP, 2019).

Besides producing ornamental plants, VML receives tree seedlings coming from environmental compensation processes inherent to MSGE, that is, seedlings produced by private nurseries, provided that legal requirements are complied (Ordinance No. 85/2010/SVMA). A critical factor concerning private nurseries is that financial rather than ecological interests interfere in the seedling production, so large-scale production of species that belong to a few taxonomic groups can be economically more attractive. Therefore, environmental compensation via private nurseries can be a threat to the future of urban biodiversity.

Considering the specificity of VML in receiving seedlings from tree specimens via environmental compensation measures, the following question was raised, in order to guide this research: Is there a biotic homogenization threat behind the supply of seedlings coming from environmental compensation actions, as they come primary from private nurseries, which usually aim at economical rather than ecological interests?

Among the contributions of this research, there are those linked to the socioenvironmental scope, engaged in supporting the strategic planning of São Paulo Municipality afforestation. The research was focused on the possible need of adjustments in the production of tree seedlings by municipal plant nurseries and on the

efficiency in choosing species to be received via environmental compensation terms. The research is also a theoretical contribution regarding the operation of municipal plant nurseries.

2 MATERIALS AND METHODS

2.1 Characteristics of the Manequinho Lopes Municipal Nursery

The object of this research is the Manequinho Lopes Nursery. VML is a 48,000 m² area annexed to the Ibirapuera Park (São Paulo, SP) and is equipped with 10 greenhouses, ready to supply municipal public agencies (PMSP, 2019).

All the procedures for the seedling supply to this municipal nursery are controlled by technical criteria and must meet public interests, as well as respect the necessities related to the existing stocks and the strategies elected by MSGE for the development of urban afforestation. Nevertheless, and expectedly, the nurseries count on restricted varieties and quantities of species. It is then possible to understand that there are certain limitations for the composition of the tree seedlings stocks coming from this type of supply, this fact may influence the promotion of biodiversity (Galhardo, 2018).

2.2 Research protocol

This is a quantitative exploratory research based on bibliographic and documentary surveys. The bibliographical survey involved two major themes – urban afforestation and biodiversity.

The documentary survey was based on the historical series of tree seedling receipts by MSGE, specifically by VML, including monthly internal reports from July 2013 to July 2018, which has entries of tree seedlings resulted exclusively from environmental compensation terms contracted with MSGE.

The worksheets contained data from each delivery to VML and records of the respective species and abundance, as well as information that identified the environmental compensation process, seedling characteristics, and internal procedures.

In order to standardize and update the taxonomic information, a thorough review of nomenclature was carried out. Comparisons and analyses were made using digital data made available by the Reflora/CNPq Program – Projeto Flora do Brasil 2020 (REFLORA, 2019).

It is worth mentioning that the mischaracterization of pre-existing information was kept to a minimum, maintaining its relational structure, but updating the taxonomic information with accepted and correct names (REFLORA, 2019). Duplicities were removed, synonymies were consolidated, and pertinent information, such as botanical families, were included.

Vernacular names were substituted by the scientific ones, considering whenever possible, nomenclatures already consolidated or even those defined by Normative Instruction 29 of the Ministry of Agriculture, Livestock and Supply, dated 21st May 2008, according to popular names suggested for registration in the National Register of Cultivars, and the MSGE Urban Afforestation Technical Manual (PMSP, 2019).

The classification of ecological attributes of the species received by VML followed the proposal of Barbosa *et al*. (2017), which guided the suggestions of plants to be used in reforestation programs in the State of São Paulo.

3 RESULTS

From July 2013 to July 2018, VML received a total of 144,727 tree seedlings coming from environmental compensation terms contracted with MSGE. These seedlings were distributed in 150 species. From July to December 2013, VML received 15,601 seedlings; in 2014 it received 15,961 seedlings. In 2015, this number almost tripled, totaling 44,689 seedlings. In the following three years (2016-2018), this number decreased to, respectively 29,063; 21,808; and 17,605 seedlings.

Table 1 presents the 30 most representative species received during the period of the study, which represent the exorbitant value of 80.8% of the total (n=116,954 seedlings). Solely two species, *Handroanthus chrysotrichus* (Ipê amarelo) and *Plinia*

cauliflora (jaboticaba), add up to 23,624 seedlings, representing 16.4% of the total received by VML.

Table 1 – Quantities of tree seedlings of the 30 main species received by VML

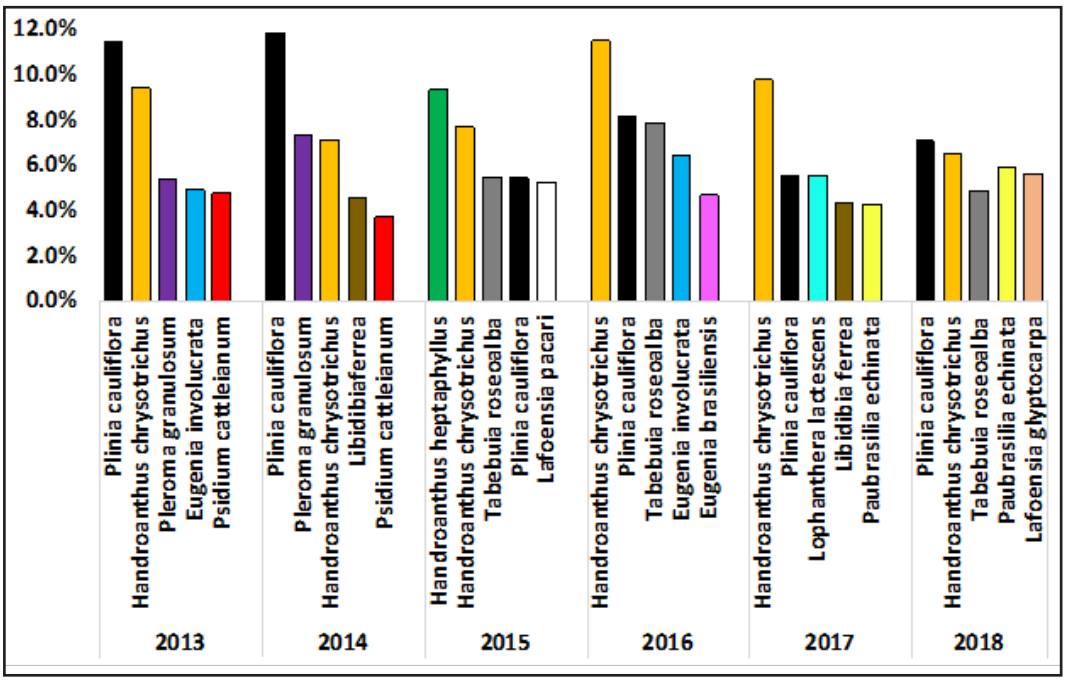
Species	Vernacular Name	Qtty	%
Handroanthus chrys-otrichus	Ipê-amarelo	12,682	8.8
Plinia cauliflora	Jabuticaba	10,942	7.6
Tabebuia roseoalba	Ipê-branco	7,527	5.2
Eugenia involucrata	Cereja-do-rio-grande	6,065	4.2
Handroanthus heptaphyllus	Ipê-roxo-7-folhas	6,005	4.1
Pleroma granulosum	Quaresmeira	5,715	3.9
Psidium cattleianum	Araçá-comum	5,588	3.9
Eugenia brasiliensis	Grumixama	5,308	3.7
Lafoensia glyptocarpa	Mirindiba	5,195	3.6
Lafoensia pacari	Dedaleiro	4,645	3.2
Libidibia ferrea	Pau-ferro	4,614	3.2
Poincianella pluviosa	Sibipiruna	3,753	2.6
Lophanthera lactescens	Lofântera-da-amazônia	3,752	2.6
Paubrasilia echinata	Pau-brasil	3,327	2.3
Jacaranda cuspidifolia	Caroba	3,278	2.3
Eugenia uniflora	Pitanga	3,114	2.2
Calophyllum brasiliense	Guanandi	2,804	1.9
Jacaranda puberula	Carobinha	2,733	1.9
Syagrus romanzoffiana	Jerivá	2,367	1.6
Pterocarpus rohrii	Aldrago	2,307	1.6
Handroanthus impetiginosus	Ipê-roxo-de-bola	2,197	1.5
Myrciaria glazioviana	Cabeludinha	1,946	1.3
Pleroma mutabile	Manacá-da-serra	1,922	1.3
Lecythis pisonis	Sapucaia-vermelha	1,572	1.1
Schinus terebinthifolia	Aroeira-pimenteira (Aroeira-mansa)	1,443	1.0
Cassia ferruginea	Chuva-de-ouro	1,404	1.0
Calycophyllum spruceanum	Pau-mulato	1,387	1.0
Nectandra megapotamica	Canelinha	1,216	0.8
Genipa americana	Jenipapo	1,091	0.8
Aspidosperma cylindrocar-pon	Peroba-poca	1,055	0.7
TOTAL		116,954	80.8

Source: Authors (2021)

The ten most abundant received species represented approximately 50% of the total throughout the period, limited to the following groups: *Handroanthus chrysotrichus*, *Plinia cauliflora*, *Tabebuia roseoalba*, *Eugenia involucrata*, *Handroanthus heptaphyllus*, *Pleroma granulosum*, *Psidium cattleianum*, *Eugenia brasiliensis*, *Lafoensia glyptocarpa*, *Lafoensia pacari*. Regarding the ten most received species throughout the period; only *Handroanthus chrysotrichus* and *Plinia cauliflora* represent 34%, highlighting the low floristic diversity incompatible with the composition of the flora existing in the forest formation where the city of São Paulo is inserted.

Figure 1 shows the five most representative species of tree seedlings coming from environmental compensation terms for each year of the 2013-2018 period. The relative abundance varied among the main species over the years, so, out of 13 different species delivered to VML, *Handroanthus chrysotrichus* and *Plinia cauliflora* appeared among the five most representative species throughout the study period.

Figure 1 – Receivement and relative abundance (%) of tree species by Manequinho Lopes Nursery from 2013 to 2018 period



Source: Authors (2021)

Regarding the higher taxonomic levels, species from 35 different families were received, as shown in Table 2. *Myrtaceae* and *Bignoniaceae* stand out among them, representing half of all seedlings received (50.1%). On the other hand, the 20 least representative families corresponded to only 5.2% of the total.

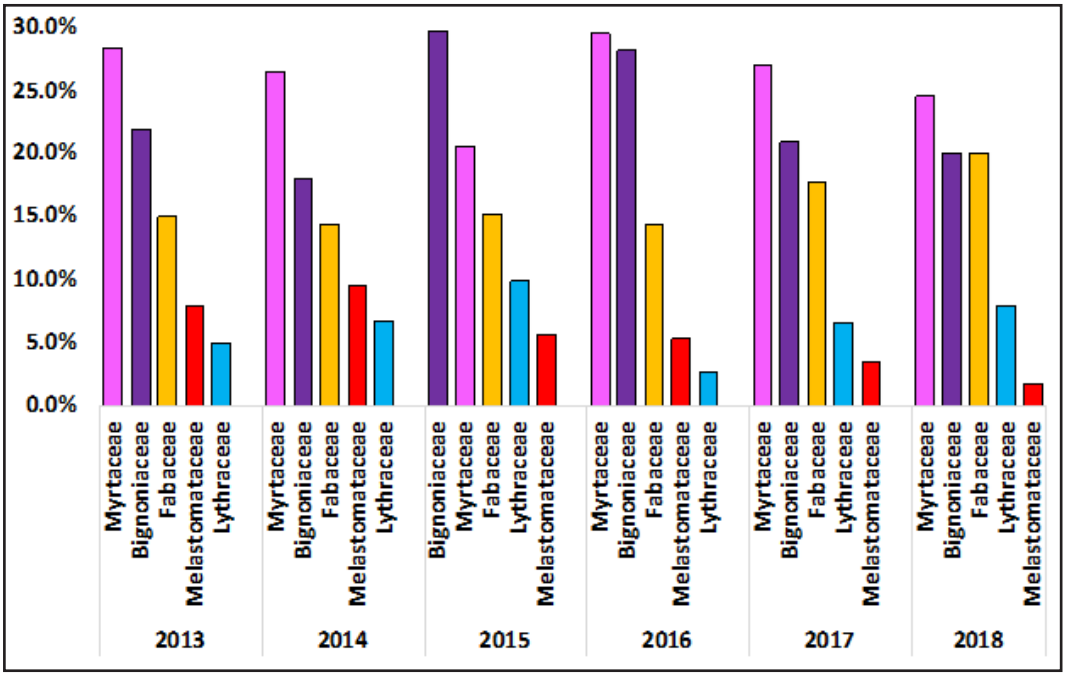
Table 2 – Distribution of botanical families received by VML

Family	Qtty	%	Family	Qtty	%
Myrtaceae	36,648	25.3	*Rutaceae*	789	0.5
Bignoniaceae	35,874	24.8	*Meliaceae*	701	0.5
Fabaceae	23,021	15.9	*Polygonaceae*	682	0.5
Lythraceae	9,840	6.8	*Chrysobalanaceae*	578	0.4
Melastomataceae	7,823	5.4	*Annonaceae*	376	0.3
Arecaceae	3,991	2.8	*Sapotaceae*	357	0.2
Malpighiaceae	3,752	2.6	*Verbenaceae*	295	0.2
Lecythidaceae	3,628	2.5	*Urticaceae*	270	0.2
Calophyllaceae	2,804	1.9	*Euphorbiaceae*	159	0.1
Rubiaceae	2,478	1.7	*Phytolaccaceae*	145	0.1
Anacardiaceae	2,154	1.5	*Araucariaceae*	141	0.1
Apocynaceae	1,672	1.2	*Caricaceae*	98	0.1
Sapindaceae	1,554	1.1	*Lamiaceae*	83	0.1
Lauraceae	1,551	1.1	*Moraceae*	22	0.02
Malvaceae	1,369	0.9	*Primulaceae*	20	0.01
Clusiaceae	925	0.6	*Peraceae*	10	0.01
Boraginaceae	916	0.6	*Proteaceae*	1	0.001

Source: Authors (2021)

Over the 5-year period, individuals from different families were received by the nursery, indicating a limited floristic diversity. In 2013, approximately 65% of the seedlings belonged to only three families (*Myrtaceae*, 28.4%; *Biognoniaceae*, 21.9%; and *Fabaceae* 15%). The same trend occurred from 2014 onwards, always with these same three representative families ranging around 70% of the total received each year (Figure 2). Little alternance of ranking is observed with no change occurring in the sequence of the first three ranks (*Myrtaceae*, *Bignoniaceae* and *Fabaceae*).

Figure 2 – Receivement and relative abundance (%) of tree families by Manequinho Lopes Nursery from 2013 to 2018 period highlighting the limited floristic diversity



Source: Authors (2021)

Regarding the ecological attributes, the species received by VML were an-alyzed in terms of dispersion syndrome, resulting in 33% zoochoric, 24% anemochoric, and 16% autochoric species. Regarding the classification as endangered species, 67% were non-endangered, 4% were “almost endangered”, and 2% were “vulnerable”, as shown in Table 3. More than half of the species were native (56%) and 15% had come from other ecologic regions of the State of São Paulo.

It was also observed that 41 tree species received by VML in the 2013-2018 period (representing 27% of the total), hade neither been catalogued in Barbosa *et al*. (2017) list of native species, nor in the list of relevant synonyms associated with these species, published by Reflora (2019).

Table 3 – Ecological attributes (Dispersion syndrome, threat category and geographical distribution) of tree species received by environmental compensation actions in the VML

Ecological Attributes	%
Dispersion syndrome	
No data	27
Zoochoric	33
Authocoric	16
Anemochoric	24
Extinction risk	
No data	27
Non-endangered	67
Almost endangered	2
Vulnerable	4
Biogeographic distribution	
No data	27
Native SP (State)	15
Native (Region)	58

Source: Authors (2021)

4 DISCUSSIONS

Biodiversity is a component that must be present in the revaluation processes of urban afforestation (Isernhagen; Le Bourlegat; Carboni, 2009). In this sense, data gathered in this research do not reflect the biodiversity framework expected for the forest formation of where the city of São Paulo is inserted. Some species by far predominate, and almost half of all received seedlings (48.1%) come from only 10 species.

These data are even more concerning when compared to the total of 939 tree species that compose the flora of the State of São Paulo (Barbosa *et al*., 2017). There is a taxonomic limitation that has been distributed in the city of São Paulo, not contributing to the framework of biotic heterogenization that is expected (Table 1).

Phytosociological studies report that certain species of the Atlantic Forest have significant Importance Value Indexes (IVI), among which *Euterpe edulis*, *Chrysophyllum viride*, *Bathysa mendoncaei*, *Eriotheca pentaphylla*, *Ecclinusa ramiflora*, *Licania hoehnei*,

Guapira opposita (Padgurschi *et al*., 2011; Rochelle; Cielo-Filho; Martins, 2011). The genus *Eugenia* is ranked in position 50 by Padgurschi *et al*. (2011) and is among those of high IVI. However, Rochelle, Cielo-Filho and Martins (2011) ranked *Eugenia* as the richest genus, with almost 10% of the total species studied in a preserved area of the SE region of Brazil, precisely in the Atlantic Forest biome. Only in 2013 and 2016, this genus was received by the nursery and was not the most abundant. This data contrasts the ecological planning for the biodiversity restoration in the city of São Paulo.

The abundance of species most received by VML as environmental compensation actions from 2013 to 2018 do not necessarily reflect the phytophysiognomy conditions of the city of São Paulo, thus failing to promote a scenario as close as possible to the one devastated over the last centuries by the urbanization process.

Likewise, the predominance of a few botanical families within the species delivered to VML indicates the restriction of biological diversity, once we found in this study that only two families totalized 50.1% of the seedlings received by the nursery.

Part of the city of São Paulo can be considered an ecotone between the Atlantic and Cerrado domains, which characterizes the natural occurrence of species belonging to both biomes. It is then acceptable that street afforestation should use species recurrent in different forest formations, both Atlantic Forest and Cerrado. In Cerrado forest formations, the most comum families are *Vochysiaceae*, *Sapotaceae*, *Ochnaceae*, *Lauraceae*, *Asteraceae* and *Erythroxylaceae* (Carvalho; Bernacci; Coelho, 2013). Despite Bignoniaceae does not reflect the highest IVI in phytosociological studies in the State of São Paulo, it is a family with representatives of symbolic (e.g. H*androanthus albus*, the tree symbol of Brazil) and ornamental value, facts that justify the ample distribution along the urban green areas of São Paulo.

Our results show the limited variety of botanical families to be distributed and planted in the city of São Paulo. The biodiversity limitation might lead the urban biodiversity scenario to a critical level of biotic homogenization (Bergeron *et al*., 2019). This homogenization scenario is associated with the loss of urban ecosystem services,

such as the maintenance of pollinators (Langellotto *et al*., 2018), which can structurally compromise the urban ecological system. Therefore, it is necessary to review the instructions that guide the receipt of seedlings coming from private nurseries as environmental compensation actions.

Besides, the biogeographic aspect is fundamental to the choice of the correct species to be planted in urban areas. The city of São Paulo is facing a serious environmental and economic problem with the removal of the alien palm tree in many places, with special attention to the Trianon Park, located at Paulista Avenue, central area of the city. Public managers have spent more than R$2 million to remove this species from this central park, highlighting the concern with the removal of invasive species from the city's parks, even if this requires investing large volumes of resources. In this sense, the choice of species that belong to the same bio-geographical forest formation in which the city of São Paulo is inserted is a priority when it comes to environmental compensation mechanisms, independently of the private nurseries supply.

Under the view that native species are solely those coming from a limited territorial area with ecological similarities (Bechara; Topanotti; Silva, 2016), municipal public administration must assure that afforestation does not favor exotic species. Somehow, the results of this study may serve as satisfactory guidelines for the contracts of environmental compensation involving seedlings. However, based on the results herein, MSGE can establish more audacious goals regarding the receipt of seedlings (and their abundance) that would biogeographically correspond to the forest formation in which the city is inserted, and should also attend the diversity evenness in its distribution. It is worth highlighting that this biogeographical aspect is aligned with municipal norms (Decree No. 53889, dated 13th September 2002; SVMA Ordinance No. 85, dated 14th October 2010; SVMA Urban Arborization Technical Manual, 2013).

A pertinent guideline concerning the receipt of seedlings from private nurseries should be the use of endangered species. Cities are composed of empty spaces,

landscaped areas, parks, and forest fragments. These areas would be adequate to receiving specimens prone to be extinct, according to endangered species lists. On the contrary, we observed that VML received only 4% of specimens considered "vulnerable" and 2% of "almost endangered" species (Table 3), a fact that seems to be more convenient from an economic and productive point of view than from an ecological one. Most of the taxonomic groups received by VML belonged to the non-endangered category, which little contributes to the maintenance of the ecological structure.

Besides the already mentioned biotic homogenization, authors have reported that the planet is probably entering its sixth mass extinction (Ceballos *et al*., 2015). Grimm *et al*. (2008) referred to urban systems as the main drivers of environmental changes. Thus, endangered species must be seen as a priority in programs of urban reforestation, including afforestation of streets and public areas, and in ECT guidelines and other regulations in the municipal environmental sector.

The biodiversity tree richeness is associated with a better offer of ecological niches to the urban fauna, mainly pollinators and seed dispersers. Thus, species with distinct dispersion syndromes can play functional roles in the offer of food to birds. We observed that a third of the species received by VML were zoochoric (Table 3), which is in accordance with the premise of "food-niche".

It is worth mentioning that biodiversity richeness is not the sole attribute to be elected when choosing species for urban afforestation. Some authors observed that it is necessary to know each species and the planting site, because not all of them are recommendable in specific situations of urban afforestation (Benchimol *et al*., 2017). This condition is widely approached by the MSGE Urban Afforestation Technical Manual, which contains definitions to guide the choice of species according to public equipment, measures, and other details that can significantly interact with plants during their life cycle, besides not recommending species, which attributes are inappropriate to the road system (PMSP, 2019). Although biotechnological and market aspects can be considered in seedling production by private nurseries, public agencies must prioritize only ecological aspects.

The last MSGE report on São Paulo tree covering showed that more than 48% of the city is green (PMSP, 2020). This document also revealed that the city has a heterogeneous distribution of the green covering. Although São Paulo has finished one of the most important environmental policies regarding the conservation of the Atlantic Forest (Atlantic Forest Municipal Plan), the biggest challenge is to implement some strategic plans derived from this policy. Data from this study come in a timely moment to encourage stakeholders to promote the appropriate afforestation of the city.

As urban populations continue to grow and to increase the necessity and pressure for green spaces, these sites should be understood as multifunctional landscapes that can improve air quality, mitigate rainfall runoff, sequester carbon, improve native biodiversity, and promote recreation. Land available for urban forests is limited in big cities and therefore afforestation initiatives are under intense pressure to succeed.

5 CONCLUSIONS

The analysis of VML seedling entries from July 2013 to July 2018 indicates the predominance of a few taxonomic groups in the municipal supply, so that the contribution of ECTs has been little for the maintenance of the natural biodiversity richness of the city of São Paulo.

Should this trend be maintained for many years, the environmental scenario related to the afforestation of the city of São Paulo will be compromised and may cause critical problems for future environment managers. This research also stresses out that ecological criteria can be better applied to the selection of tree specimens, such as the prioritization of endangered or high-risk species to be planted in parks and urban forest fragments. The dispersion syndrome of the tree species was not at risk in this study, and should be properly monitored to promote the maintenance of the urban fauna.

Luckily enough, VML has satisfactorily received regional native species, that is, from the forest formation in which the city of São Paulo is inserted. This practice should continue in the program of environmental compensation involving seedling and, if

possible, until the values obtained for the 2013-2018 period are improved. It is relevant that further studies that involve new technologies of seed and seedling production are developed, so that market aspects can be aligned with ecological attributes inherent to the urban environment.

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