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ORIGINAL ARTICLE – Conservation of Nature

Forest Seedlings Supply for Restoration of the Atlantic Forest in Rio de Janeiro, Brazil

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Abstract

Half of the territory in Rio de Janeiro (RJ) state is composed of degraded areas. This work evaluated the profile, distribution, and production capacity of plant nurseries in RJ which produce forest seedlings, as well as their species' richness. The potential to meet the increased demand arising from environmental commitments in different hydrographic regions was also analyzed. We identified 81 active forest seedling nurseries and 73 of them participated in our interview, by adopting a regional survey. Nearly one-third of the nurseries closed down in this region in the last decade. A high richness of species in the nurseries (977 species, 99 native species/nursery) was found, representing 22% of the regional flora. Most of this species' richness is exclusively produced by small nurseries. The current production of the nurseries is capable of supplying less than 1% of the potential demand for seedlings for restoring priority watershed areas in the state.

Keywords: Seedling production, Ecological restoration, Nurseries, Biodiversity.

1. INTRODUCTION AND OBJECTIVES

The UN Decade on Ecosystem Restoration started in 2021 and intends to restore 350 million hectares by 2030 (UNEP, 2019). A goal to restore 15 million hectares of degraded lands in the Atlantic Forest region in Brazil by 2050 was established in international and national agreements (Crouzeilles et al., 2019). Restoring forests increases carbon storage and prevents greenhouse gas emissions, playing an important role in mitigating climate change (Griscom et al., 2017). Planting seedlings is undoubtedly the most widespread method among those used to ecologically restore tropical forests, although it is more expensive than other restoration techniques (Uriarte & Chazdon, 2016; Pérez et al., 2019; Raupp et al., 2020). It is essential that projects strike a balance between ecological and social objectives to maximize the benefits of tree planting (Holl & Brancalion, 2020). Otherwise, the social factors that originally caused deforestation will not mitigate climate change because those same factors will destroy planted forests or shift ecosystem destruction elsewhere (Fleischman et al., 2020).

The availability of seeds and seedlings is an important bottleneck and not only a great challenge for the forest restoration supply chain in Brazil, but also in other countries (Smith et al., 2007; Dedefo et al., 2017; Silva et al., 2017; Urzedo et al., 2020; León-Lobos et al., 2020; Atkinson et al., 2021). It is recommended that the propagation material used to restore degraded areas is of good quality, using locally collected seeds with some genetic diversity (Vander Mijnsbrugge et al., 2010; Bischoff et al., 2010; St. Clair et al., 2020). However, restoration projects cover a limited diversity of native species, which added to the lack of genetic diversity of propagation material constitute critical aspects for the resilience of restoration plantations (Jalonen et al., 2018; León-Lobos et al., 2020; Atkinson et al., 2021).

Not all biomes in Brazil have enough nurseries to meet the demands of restoration, with the risk of using native species from few biogeographic regions in a much broader and ecologically diverse area (Silva et al., 2017). Although nurseries in the Atlantic Forest region can meet a growing demand for seedlings in relation to other biomes in Brazil, the problem is that the lack of seed supply and qualified labor can hamper market growth (Silva et al., 2017). The availability of seeds and seedlings is particularly challenging in Rio de Janeiro state, which has half of its territory transformed into pastures and needs to restore 1/5 of the territory to protect the water supply networks (INEA, 2018). Thus, it established the subnational goal of restoring 440 thousand hectares of degraded lands by 2050 at COP26 meeting (O Fluminense, 2021).

The present work aims to evaluate the productive potential of the seedling nurseries in Rio de Janeiro state in order to meet the demands of forest restoration, verifying the nurseries' profiles (size, administrative category), the regional distribution, the diversity of species produced, the production systems, and the origin of seeds. We compared the results of this diagnosis with the last diagnosis carried out in 2010 (SEA, 2010; Alonso et al., 2014), and then we evaluated the evolution of the productive sector in the last 10 years. The study will make it possible to identify the main bottlenecks and challenges to form a well-structured production chain which represents the inherent diversity of natural ecosystems typical of tropical regions.

2. MATERIALS AND METHODS

The study was developed from diagnosing nurseries that produce forest seedlings in Rio de Janeiro (RJ) state in Brasil, carried out from July 2018 to July 2020. Forest nurseries were considered to be those that produce with a focus for environmental restoration projects. In this survey, ornamental plant nurseries were excluded when their production was concentrated on some native seedlings for afforestation and landscaping projects. We started from an initial list of 70 forest nurseries surveyed in the 2010 diagnosis (SEA, 2010). Nurseries which started their activities after 2010 were added to this list using the snowball methodology (Etikan et al., 2015), as were the nurseries registered on the website of the Ministry of Agriculture, Livestock and Supply (MAPA).

Once the nurseries were listed, contact was made by email, telephone or technical visit for evaluation and to apply a standard, semi-structured questionnaire containing 69 topics (Appendix 1). The nursery mapping was based on the geographical coordinates provided by each producer or by searching Google maps for the informed addresses. The number of nurseries by municipality and by hydrographic region (CERHI, 2013) of the State of RJ were tallied.

The nurseries were classified by their administrative category (private, public or NGO) and size: small nurseries (<10,000 seedlings.year-1), medium-small nurseries (10,001-50,000 seedlings.year-1), medium nurseries (50,001-100,000 seedlings.year-1), medium-large nurseries (100,001-300,000 seedlings.year-1), and large nurseries (above 300,001 seedlings. year-1), using the methodology adapted from SEA (2010) and Vidal & Rodrigues (2019).

The productive capacity of the nurseries was evaluated through the actual production (total amount of seedlings produced per year, considering the average of seedlings produced in the last 3 years) and potential seedling production (total amount of seedlings that the nursery would be able to produce per year). These parameters considered native and exotic forest species seedlings. The annual production of seedlings for the nurseries which did not answer this question was estimated based on the average of the other nurseries. We evaluated the total productive capacity of nurseries for RJ state and for each hydrografic region, size and administrative category of nursery.

The species' richness of produced in each nursery was analyzed from the list of species provided by them. Only the shrub or tree species from the species list in each nursery were selected, excluding the climbing plants (vines), pteridophytes, vines, epiphytes and herbs. The selection of the size of the species took into account the initiatives in the state territory of active restoration in which only shrub and arboreal species are almost entirely used. A database with information on each tree or shrub species was created, including: a) scientific name, synonyms and family; b) plant habit, natural distribution (biomes, states and forest typologies) (both obtained from Flora do Brasil (Brasil, 2020), status conservation (threatened, near threatened, least concern, not available, deficient in data) from Flora do Brasil (Brasil, 2020) and Brasil (2022); c) endemic degree (to the country, the biome or the State) (Martinelli et al., 2018); d) sucessional stage (pioneer, early secondary or late secondary) from Gandolfi (1995); and the seed dispersal syndrome (anemochory, zoochory, autochory), based on published papers for each species.

Then, the following parameters were calculated considering native and exotic forest species, separately and together: total number of species, average species richness (average number of different species produced) and the total number of unique species. These parameters were analyzed for each Hydrographic Region, size class and administrative categories of nurseries.

Next, we used the Generalized Linear Model (GLM) with negative binomial distribution, with the log link function significantly adjusted to the average richness data to compare the average species richness of the nurseries in the different hydrographic regions. The significances between the regions were verified by the Chi-Squared test (X^2) using the deviance analysis (ANODEV). The means estimated by the negative binomial model were compared by pair-by-pair contrast at 5% probability. We used analysis of variance (ANOVA) and the means were compared by the Scott Knott method to compare mean species richness between different sizes and administrative categories of nurseries, with a significance level of 5%. All statistical analyzes were performed using the R software program (R CORE TEAM, 2021).

We considered the Areas of Interest for the Protection and Recovery of Hydrographic Basins (AIPMs) with high and very high priorities, as presented by the INEA study (2018), to estimate the amount of seedlings required for restoration in the State of RJ and for hydrographic region. For these areas, we considered planting 50% by active restoration, using 2,500 seedlings per hectare (2m x 2m spacing), based on the methodology proposed by Urzedo (2020).

3. RESULTS AND DISCUSSION

The analysis of the forest tree seedlings production in f RJ state revealed that important changes have occurred in the last decade. A total of 35 nurseries from the 120 identified in the present study are deactivated, most of them private ones (27), representing a 29% retraction of the sector. Moreover, 81 are active, with 31 (38%) belonging to the private sector, 48 (59%) to public agencies and 2 (3%) to the tertiary sector. No information was obtained for 4 of them (3%). Of the 81 active nurseries, 73 (90%) responded to the interview (Appendix 2).

This retraction in the productive sector of seedlings in RJ in the last 10 years is associated with a sequence of opening and closing private nurseries while the public sector remained more stable. As a result, the present work reveals an increase in public nurseries compared to the last diagnosis when 51% of the nurseries were public, 43% private and 7% belonged to NGOs (SEA, 2010). Considering that private nurseries rely on a constant demand for seedlings, this fluctuation in the proportion of public and private nurseries may reflect a lack of specific public policies which make the supply chain of forest restoration feasible. This condition weakens the private productive system of seedlings of native species and the restoration itself due to the inconsistency of local and national political processes (Urzedo et al., 2019).

Half of the municipalities do not have seedling supply infrastructure. The Guandu and Baía de Guanabara Hydrographic Regions (HRs) have the largest number of nurseries in the different HRs of the State with 15 and 20 nurseries, respectively, concentrating 43% of the nurseries and more than half of the quantity of seedlings produced in RJ state (Figure 1; Table 1).

The third region with the highest number of nurseries was the Baixo Paraíba do Sul - Itabapoana HR (n=13). This HR has the largest territorial extension and the smallest vegetation cover (16%) (Figure 1; Table 1), so this region continues to be proportionally poorly served even considering the high number of nurseries, and has the lowest density of nurseries per total area (9.63 nurseries.mHa^{-1}).

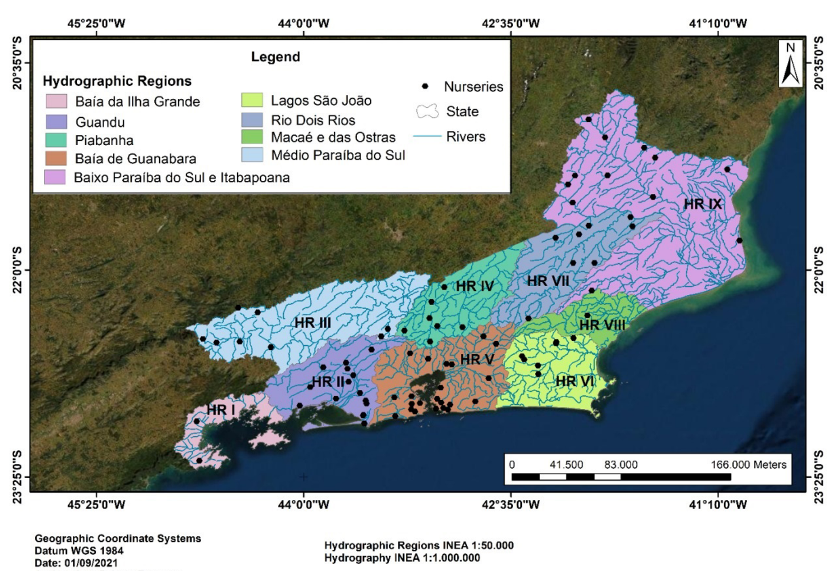

Figure 1. Distribution of active nurseries of forest species in the Hydrographic Regions of Rio de Janeiro state.

Table 1. Number of active nurseries by hydrographic region (HR) in two periods (2010 and 2020), percentage of vegetation cover, area (hectares) and density of nurseries (in number of nurseries per million hectares) in Rio de Janeiro state.

HR ID	HR Name	HR Total area (ha)[1]	HR vegetation cover(%)	Priority areas for restoration (ha)[1]	Number of nurseries 2010*	Number of nurseries 2020**	Number nurseries/ area (Mha)	Amount of seedlings produced. year^{-1}	Total production capacity.year^{-1}	Demand for seedlings for restoration[1]
HR - I	Baía da Ilha Grande	175,731	86.2	162	2	2	11.38	15,000 (n=1)***	100,000 (n=1)	202,500
HR - II	Guandu	371,374	41.7	81,008	17	15	40.42	898,038 (n=13)	1,944,000 (n=19)	101,260,000
HR - III	Médio Paraíba do Sul	642,827	29.9	145,326	12	8	12.45	440,802 (n=8)	888,000 (n=10)	181,657,500
HR - IV	Piabanha	345,932	49.9	111,345	2	7	20.23	162,500 (n=7)	360,500 (n=6)	139,181,250
HR - V	Baía de Guanabara	481,377	39.1	38,855	13	20	41.54	1,399,648 (n=16)	2,083,000 (n=9)	48,568,750
HR - VI	Lagos São João	365,080	29.4	46,137	4	7	19.15	522,085 (n=7)	1,580,000 (n=7)	57,671,250
HR - VII	Rio Dois Rios	446,211	39.3	142,605	5	7	15.67	242,500 (n=6)	291,000 (n=5)	178,256,250
HR - VIII	Macaé e Rio das Ostras	201,299	41.9	21,983	4	2	9.92	1,000 (n=1)	50,000 (n=2)	27,478,750
HR - IX	Baixo Paraíba do Sul e Itabapoana	1,346,689	16.2	209,069	11	13	9.63	571,250 (n=12)	2,333,000 (n=12)	261,336,250
	Total	**4,376,663**	**32.9**	**796,490**	**70**	**81**	**18.49**	**4,252,824 (71)**	**9,629,500**	**995,612,541**
	CV	-	-	-	-	**66.43**	**69.85**	**96.22**	**89.73**	**77.63**

Sources: [1] Areas of Interest for Watershed Protection and Recovery (AIPMs), considering high and very high priorities (INEA, 2018); * SEA (2010); ** this work; Mha – million hectares; *** in parentheses the number of sampled nurseries.

3.1. Productive capacity

The average annual quantity of forest seedlings produced per nursery is 59,899 ± 89,344 seedlings. Although small nurseries are numerous (n=24; 30%), they only contribute to 3% of the seedlings produced in the state (Figure 2). Most of them are public (n=17), but some are private (n=6) or run by NGOs (n=1) - Table 2. Small nurseries also predominate (<10,000 seedlings/year) in Amazonas state and make up 36% of the total number of sampled nurseries (Marques et al., 2022). The authors suggest that this is related to low demand for native species, which is caused by socioeconomic, technical-scientific and political bottlenecks. The predominance of nurseries (60%) with small-scale production (<50,000 seedlings per year) in RJ (Figure 2) and in Amazonas states (Marques et al., 2022) contrast what was observed in São Paulo, where large (> 500,000 seedlings) and medium-large nurseries are the majority (100,000 to 499,000 seedlings.year-1) across all categories from public to private nurseries (Vidal et al., 2019).

The different forest seedling production systems between Brazilian states result from social and political factors that influence the restoration economy in a particular region. In São Paulo state, a robust forestry industry was historically established by significant multi-sector investiments and substantial scientific and technological developmetns (Mora & Garcia, 2000). In addition and more recently, a regional coalition between multiple stakeholders mobilized the Pact for the Restoration of the Atlantic Forest that influence the wide adoption of tree seedling planting techniques aligned with the economic interests of large private nurseries (Urzedo et al., 2020).

The seedlings production was estimated at 4,851,814 seedlings.year^{-1} in RJ state, corresponding to 44% of the annual installed capacity, estimated at 10,955,770 seedlings per year. These values have not changed much in 10 years, since the installed production capacity of approximately 10,655,000 seedlings per year was observed in the previous diagnosis (SEA, 2010). The annual number of seedlings produced by RJ state corresponds to 0.5% of the estimated demand for seedlings for active restoration of 50% of priority areas for the protection of public water sources, estimated at 796,490 hectares or 995,612,500 seedlings (Table 1).

Table 2. The average number of seedlings produced per year per nursery according to their size category and administrative category considering the interviewed active nurseries that produce forest species in Rio de Janeiro state. *Estimation based on the average number of seedlings per nursery.

	ADMINISTRATIVE CATEGORY (SECTOR)							
	PRIVATE		PUBLIC		NGO		TOTAL	
SIZE CATEGORY	no.	Production	no.	Production	no.	Production	no.	Production
Large nurseries	1	323,717	1	508,140	-	-	2	831,857
Medium-large nurseries	3	670,000	7	1,140,175	0	-	10	1,810,175
Medium nurseries	4	318,831	6	440,428	1	63,667	11	822,926
Medium-small nurseries	13	371,798	11	256,612	0	-	24	628,410
Small nurseries	6	43,500	17	111,956	1	4,000	24	159,456
SUB TOTAL	27	1,727,846	42	2,457,311	2	67,667	71	4,252,824
Not informed	4	-	6	-	-	-	10	598,990*
TOTAL	**31**		**48**		**2**		**81**	**4,851,814**

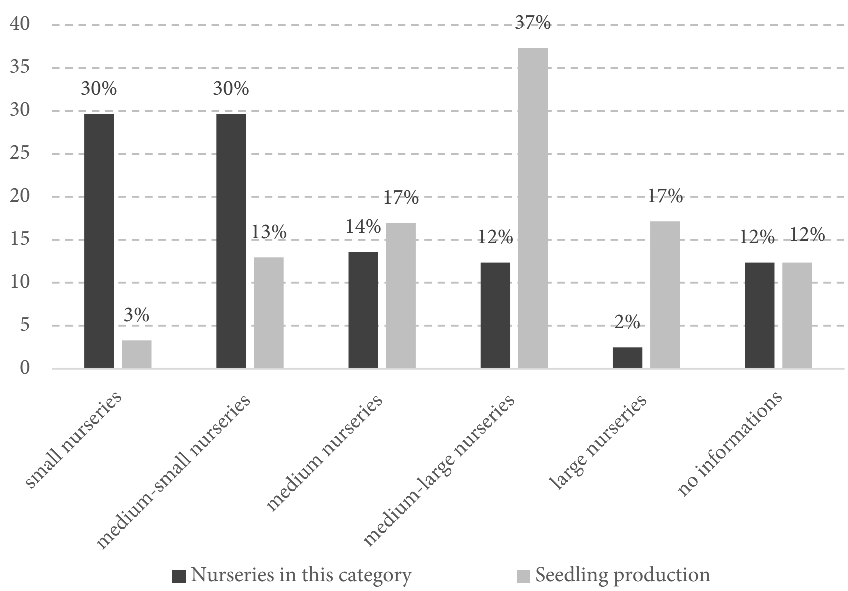

Figure 2. Percentage of active nurseries (n = 81) in Rio de Janeiro state according to their size category and their contribution to the total quantity of seedlings produced. No info: production estimated based on the annual average of all the nurseries.

The reason for the low production in the nurseries could be the same as the closing of private nurseries: the poor economic return, since only 14% of the nurseries interviewed affirm that the nursery achieved the expected profit. The main bottlenecks pointed out in seedling production were low profitability, high production costs, and the difficulty of selling seedlings. Marques et al (2022) also observed annual production of all nurseries below maximum capacity in Amazonas state. The authors estimated the native seedlings production of 1,258,600 seedlings in 2018, which could be increased by up to seven times (9.7 million seedlings year^{-1}). The most significant business and trade difficulty for all producers was the generally low demand for their products, and specifically for native tree species. Other complaints were volatile demand, as the preference for species changes over time; and the informality of business, as consumer requests are often spontaneous and not linked to contracts, which makes planning difficult and generates financial insecurity.

The role of the environmental policies and legislation in the restoration supply chain must be addressed in order to understand what problems may be affecting this demand. The approval of the Native Vegetation Protection Law (Law no. 12.651/2012), despite made the georeferenced registration of all rural properties in the country mandatory through the Rural Environmental Registry (CAR), created legal uncertainty and reduced the demand for restoration at the national level (Guidotti et al., 2020; Magano et al., 2021). Moreover, there was no law enforcement 10 years after its approval (Pacheco et al., 2021). Successive postponements, and finally the Law 13,887/2019, which made enrollment in the CAR mandatory for an indefinite period for all rural properties and possessions, frustrated the expectations of the productive sector of seeds and seedlings, causing its retraction (Brasil, 2019; Chiavari & Lopes, 2019; Vidal et al., 2019). In this study, we identified that, in practice, this represents a reduced potential demand of at least 353,980,000 seedlings to actively restore half of the 283,184 hectares of environmental liabilities in 55,421 rural properties registered in the Rural Environmental Registry System (*SISCAR*) in RJ state. This liability corresponds to 6.5% of the state's territory, most of which is for legal reserve restoration (60.1%), followed by riparian forests and springs (22.3%) and slope areas (17.5%), according to *SISCAR* data in September/2021.

If, on the one hand, there were no significant progress with the implementation of National Plan for the Recovery of Native Vegetation ("PLANAVEG") at the federal level (MMA, 2017), on the other hand, important advances can be observed in the state's environmental policy. Among these political instruments, there were the consolidation of the domestic forest restoration legislations (Law no. 8.538/2019), the realization of the Forest Inventory (SFB, 2018), and the pioneering survey of endemic species (Martinelli et al., 2018). Finally, success in the application and execution of the environmental compensation resource model developed by the Secretary of Environment and Sustainability of RJ, called *Fundo Mata Atlantica* (Teixeira, 2018).

3.2. Origin of seeds

Most nurseries (96%) collect their own seeds, and it is the only source of seeds for 52% of them. Other ways of acquiring the seeds are by purchasing (17%), from donations (32%) or by exchange (14%). Most nurseries mark mother trees for seed collection (61%). The seeds can be collected from remnants of the region (82%), in urban arborization (62%), in Protected Areas (60%), in trees outside the forest (pastures) (51%) or isolated trees (22%). However, seed collection from isolated trees and from urban arborization is not technically recommended (Vander Mijnsbrugge et al., 2010; Bischoff et al., 2010; St. Clair et al., 2020). The genetic diversity of the species used in restoration projects is essential to promote the stability of environmental services and allow its adaptation and resistance over time (Reynolds et al., 2012). The use of seeds from isolated trees or populations of restricted size tends to reduce genetic diversity (Sebbenn et al., 2011) and does not meet one of the main rules for collecting seeds for restoration (Vander Mijnsbrugge et al., 2010; Kashimshetty et al., 2017), indicating potential genetic quality problems in a significant portion of the material produced.

The lack of seeds was the second most cited problem by nurseries (18%), second only to labor difficulties (24%), being considered an important bottleneck in seedling production. Forest restoration projects and nurseries around the world face similar challenges related to the difficulty of acquiring seeds (Nyoka et al, 2015; Dedefo et al., 2017; Jalonen et al, 2018). The scarcity of seeds in Brazil can be explained by the lack of public investment (Urzedo et al., 2020). Although Brazil has more than 50,000 species recognized by the Flora of Brazil (Brasil, 2020), national forestry programs have actively invested in a few exotic species for the production of wood, paper and cellulose. Two decades ago, the federal government financed the creation of seed networks in Brazilian biomes. However, most of these networks fragmented after the end of national investments because these initiatives were not able to develop commercial schemes (Urzedo et al., 2020).

3.3. Species richness

A total of 977 forest species were identified (shrubs and trees) being produced in 46 nurseries that shared their species list, which corresponds to 63% of the active nurseries interviewed. This value is higher than that found in São Paulo (n=687 in 54 nurseries) (Vidal et al., 2019), and for that found in the last diagnosis carried out in RJ state (n=277 in 9 nurseries) (Alonso et al., 2014). In performing an analysis for the native forest species produced, we observed that 539 (55%) of the total species are native to the Atlantic Forest in RJ state. If native species of the Atlantic Forest are considered, regardless of their natural occurrence in RJ state, 673 (69%) species were found. About 107 (11%) species were native to other biomes and 197 (20%) were exotic, meaning that they are originally from other countries.

The number of species found in the nurseries represents 22% of the total number of trees and shrub species native to the Atlantic Forest of the state, estimated at 2,485 forest species (Brasil, 2020). From the 248 endemic tree/shrub species of the Atlantic Forest in RJ state (Martinelli et al., 2018), only ten (4%) are produced by the nurseries in the state. Furthermore, 34 of the threatened species of the Atlantic Forest are produced in the nurseries, which represents 1% of the 3,209 threatened species of Brasil, considering all growth habits (Brasil, 2022). Limitations in native tree seedling supply could lead to a homogenization of restored areas with few widespread species dominating (Silva et al., 2017), and loss of local biodiversity, including endemic and threatened species. Although the species richness produced by the nurseries have increased in the past years, and represents one of the greatest in Brazil, it is still very low compared to the diversity found in the Atlantic forest, considered one of the World's hotspots (Myers et al., 2000).

Of the 539 native forest species produced in RJ state, 34 species (6%) are considered threatened (vulnerable or endangered), 6 species (1%) are near threatened, 2 species (0.4%) are deficient in data and the vast majority of 395 species (73%) were not evaluated. Considering the high number of unassessed species, the number of threatened species should increase significantly. Most of the native forest species produced are late secondary and zoochoric regarding the successional stage and the seed dispersal syndrome (Figure 3).

An average number of native florest species produced per nursery was estimated at 99 ± 54 species. This value is much higher than that observed 10 years ago (n = 56) (SEA, 2010), or even compared to the national average (n = 64) (Silva et al., 2017), or found in nurseries in other countries (Nyoka et al., 2014). This average rises to 136 ± 82 species per nursery if the total number of species is included, not just the native ones.

This richness significantly varies when nursery size categories are considered. Medium and medium-large nurseries produce a larger number of species on average than the small, medium-small and large nurseries. The average species' richness of seedlings produced practically did not vary among the different sectors of nurseries or among HR (Table 3).

However, the average species' richness may not reflect the contribution of each nursery size category to the total species richness. This is because nurseries can produce a great number of similar species, thus not representing regional diversity. We can observe that the small nurseries produce 577 of the 977 species produced by all nurseries. Therefore, despite having a low average species' richness individually, together the small nurseries contribute more to the total diversity of species produced than the other size categories (Table 3). Of the 577 species produced by small nurseries, almost half of them (n = 271) are exclusive to this category, meaning they are not produced by any other nursery belonging to another category (Table 3).

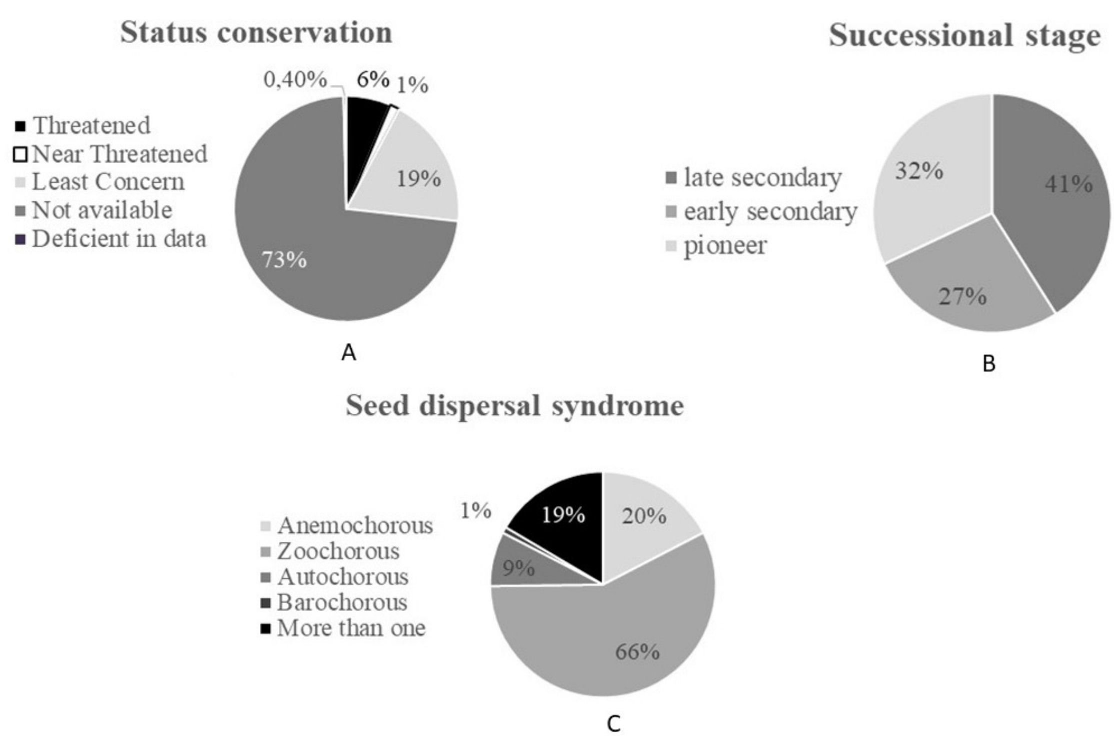

Figure 3. Profile of the 539 native forest species, considering only those, produced by nurseries in Rio de Janeiro state, according to status conservation (A), sucessional stage (B) and seed dispersal syndrome (C).

Table 3. Contribution of each hydrographical region, size category and sector of the nursery to the species' richness of seedlings produced in the State of Rio de Janeiro.

	ID	No. of sampled nurseries	Total Richness		Average richness		Exclusive Species	
			Total Spp	Native Spp	Total Spp	Native Spp	Total Spp	Native Spp
HYDROGRAPHIC REGION	I	0	-		-	-		-
	II	11	595	275	128^{ab}	90^{ab}	46	35
	III	3	258	213	117^{ab}	100^{ab}	46	49
	IV	4	508	261	156^{ab}	90^{ab}	214	150
	V	12	781	359	171^{a}	128^{a}	87	97
	VI	5	190	176	125^{ab}	120^{ab}	14	19
	VII	4	329	204	170^{ab}	108^{b}	17	27
	VIII	0	-	-	-	-	-	-
	IX	7	342	220	72^{b}	48^{b}	21	29
SIZE CATEGORY	Large	2	273	202	174^{ab}	135^{a}	8	7
	Medium-large	9	415	288	190^{a}	128^{a}	46	28
	Medium	9	493	339	186^{a}	140^{a}	43	40
	Medium-small	12	544	366	128^{ab}	106^{a}	64	52
	Small	14	577	277	70^{b}	41^{b}	271	59
SECTOR	Public	25	641	376	160^{a}	109^{a}	239	103
	Private	19	695	402	108^{a}	92^{a}	313	127
	NGO	2	190	167	103^{a}	86^{a}	24	22

Averages followed by the same letter do not differ according to the Scott Knott Test at a 5% significance level to size category and sector. For HR the significances between the regions were verified by the Chi-Squared test (X^2) using the deviance analysis (ANODEV).

4. CONCLUSIONS

A great richness of species produced in the nurseries was observed in the study of the forest seedling production for restoration in Rio de Janeiro state, with a large contribution of small nurseries (<10,000 seedlings) in this biodiversity. Although this richness has increased in the last decade and is the highest ever recorded in other nursery diagnoses carried out in Brazil, it still includes little diversity of the Atlantic Forest of RJ state (22%), with low incorporation of endemic and threatened plant species (<5%). Nurseries reported mostly difficulties in availability of seeds (18%) and labor (24%) to operate their supply systems. Another important bottleneck is the sale of seedlings, due to low demands, high production costs and low profitability. The sector suffered a retraction of 30% in the last ten years, mainly experienced by private nurseries. The nurseries produce less than 50% of the state's potential capacity, estimated at almost 11 million seedlings. The number of seedlings produced by the nurseries does not meet 1% of the potential demand for restoration of only priority areas in the state, which is insufficient to meet current environmental legislation. In order for nurseries to support the expected growth in demand for forest restoration projects with a diverse range of suitable species adapted to local conditions and able to persist in a changing climate, it is essential that government effectively implements environmental legislation, especially Protection of Native Vegetation Law (Law No. 12,651/2012), thereby generating permanent incentives for the sector.

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AUTHORS' CONTRIBUTIONS

Juliana Müller Freire: Conceptualization (Lead), Data curation (Lead), Formal analysis (Lead), Funding acquisition (Lead), Investigation (Lead), Methodology (Lead), Project administration (Lead), Resources (Lead), Supervision (Lead), Validation (Lead), Writing – original draft (Lead), Writing – review & editing (Lead).

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SUPPLEMENTARY MATERIAL

The following online material is available for this article:

Annex 1 - Questionnaire.

Appendix 2 - List and contact of the nurseries interviewed in the survey.

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