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PRACTICAL ARTICLE

Can current native tree seedling production and infrastructure meet an increasing forest restoration demand in Brazil?

Ana P. Moreira da Silva[1], Daniella Schweizer[2,3], Henrique Rodrigues Marques[1], Ana M. Cordeiro Teixeira[1], Thaiane V. M. Nascente dos Santos[1], Regina H. R. Sambuichi[1], Carolina G. Badari[2], Ulysse Gaudare[2], Pedro H. S. Brancalion[2]

Recent global commitments have placed forest and landscape restoration at the forefront of countries' efforts to recover ecosystem services, conserve biodiversity, and mitigate the effects of climate change. However, it needs to be asked if current native tree seedling supply meets an increase in demand for forest restoration? This study assessed the current configuration, distribution, and production capacity of forest nurseries producing native trees in Brazil. Brazil provides an interesting example of how global agreements aligned with national policies can lead to the proliferation of native seedling nurseries, and the challenges faced to restore species-rich native forest ecosystems. We found that the nurseries in the Atlantic Forest region can still meet an increase in demand—both in terms of seedling quantity and diversity—because most of their production capacity is not currently used. However, not all Brazilian biomes have sufficient nurseries to meet restoration demands, thus there is a risk of using native species from a few biogeographical regions in a much spatially wider and ecologically diverse area. In addition, lack of seed supply and qualified labor can hamper the growth of the market. Barriers to seed supply may also lead to low levels of genetic variability and floristic representation in the populations and ecosystems to be restored. We conclude that restoration of high-diversity forest ecosystems requires policies and supportive programs, with emphasis on private nurseries, to guarantee adequate supply of native tree seedlings and provide the necessary incentives to develop the emergent economy of forest restoration.

Key words: **active restoration, native seedling stock, restoration plantations, restoration policy, restoration supply chain, tropical forest restoration**

Implications for Practice

- Brazil's case study shows it is viable to provide sufficient native tree seedlings to landscape forest restoration programs, but coordination is needed to align supply and demand.
- When adequate legal frameworks and incentives exist, restoration can be a vibrant economic activity that generates important job opportunities.
- When market incentives and regulations to promote the establishment of forest nurseries in different biogeographical regions are lacking, restoration efforts may have a limited potential to match the floristic composition and genetic diversity of reference ecosystems and populations.
- Developing a knowledge base for producing native tree seeds and seedlings, and disseminating this learning through capacity building initiatives, are key steps toward successfully achieving a stable seedling supply for forest restoration.

Introduction

Increasing awareness of the multiple benefits to society of forest and landscape restoration (FLR) has fostered an unprecedented engagement of many developing countries in ambitious restoration commitments (Suding et al. 2015; Chazdon et al. 2016). From Latin America to Southeast Asia, countries have declared interest in implementing restoration programs in significant expanses of their territory in order to conserve biodiversity, mitigate climate change, reinforce the provision of locally demanded ecosystem services, and generate green jobs and income derived from a better use of degraded lands (Laestadius et al. 2015; Sabogal et al. 2015). Because restoration is now a global priority, it is time to transform commitments into actual hectares of restored landscapes and ecosystems (Aronson & Alexander 2013). However, restoration is an emergent market

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[1]Instituto de Pesquisa Econômica Aplicada (IPEA), Edifício Rodolpho de Paoli. - Av. Nilo Peçanha, 50 - Centro, Rio de Janeiro - RJ 20020-100, Brazil
[2]Department of Forest Sciences, "Luiz de Queiroz" College of Agriculture, University of São Paulo, Avenida Pádua Dias 11, Piracicaba, SP 13418-260, Brazil
[3]Address correspondence to D. Schweizer, email daniellaschweizer@gmail.com

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and its supply chain may not yet be consolidated enough to adequately support large-scale restoration programs, especially when it comes to hyper-diverse tropical forests (Murcia et al. 2016).

Pioneer FLR programs, such as those implemented in South Korea (Xu 2011) and China (Temperton et al. 2014), have relied heavily on the use of exotic tree species to increase tree cover in deforested landscapes. The production of seedlings of some exotic tree species is much easier, faster, and cheaper than investing in the production of a vast diversity of native tree species, for which information on seed collection and seedling production is scarce (Brancalion et al. 2012; Nunes et al. 2016). Imbalances in the supply and demand of native tree seedlings may promote the use of exotics to meet a growing demand for seedling stock to increase tree cover on degraded lands. However, the use of native tree seedlings must be an integral part of FLR, as a means to safeguard biodiversity conservation in human-dominated landscapes (Janishevski et al. 2015; Possingham et al. 2015). The use of exotic species in FLR may increase the risk of biological invasion (Richardson 1998; Simberloff et al. 2011), prevent the recovery of pollination and seed dispersal networks (Dixon 2009; Ribeiro da Silva et al. 2015), and, ultimately, oversimplify the structure and functioning of restored ecosystems, reducing their potential provision of ecosystem services to society (Dodds et al. 2008; Isbell et al. 2011). Apart from the growing debate about embracing other types of interventions as part of a broader approach to ecological restoration (Murcia et al. 2014; Stanturf et al. 2014; Hobbs 2016), limitations in native tree seedling supply could lead to a homogenization of restored areas with few, widespread species dominating. We believe native seedling supply for restoration has been overlooked in academic discussions about FLR programs.

Seeds and seedlings for forest restoration are generally purchased from private nurseries, which turn forest restoration into an emergent economic activity. As such, restoration not only requires technical knowledge on tree species propagation and maintenance, but also a well-structured production and sales market chain and clear public policies and incentives to support its development and growth (BenDor et al. 2015). Therefore, it becomes pertinent to assess the status of native tree seedling production to see if it can support an expected growth in demand as a result of public policies that promote FLR.

Global restoration commitments, such as the New York Declaration on Forests for the restoration of 350 million hectares by 2030 (UN 2014), must be linked with national policies to turn large-scale forest restoration into a reality. Brazil represents an example of how global agreements, aligned with national policies, have led to the emergence of forest restoration as a vibrant economic activity (Mesquita et al. 2010), and may provide lessons on the challenges and solutions to support the inclusion of a high diversity of native tree seedlings in restoration projects (Aronson et al. 2011). Since the 1960s, the Brazilian Forest Code mandates the restoration of riparian buffers and other environmentally fragile habitats, such as mountaintops and steep slopes. In the 2000s, compliance with the Forest Code was fostered by environmental certification of agricultural enterprises to obtain market advantages in commodities exportation, and high-diversity native tree seedling plantations were employed as a prominent approach (Rodrigues et al. 2011). In order to support the establishment of restored forests with similar tree species levels as reference ecosystems, legal instruments were drafted (Aronson et al. 2011) and further modified (Chaves et al. 2015) to define a minimum number of native tree species to be employed in restoration plantings. From 2003 to 2010, seedling production of shrub and tree species in São Paulo state, southeastern Brazil, increased from 13 million to 42 million per year, and the average number of species produced jumped from 30 to over 80 (Brancalion et al. 2010).

A new phase for scaling-up restoration in Brazil started in 2012, after the revision of the 1965 Forest Code. In spite of setbacks in environmental protection and reduction of restoration requirements (Soares-Filho et al. 2014), the new law established innovative mechanisms to support legal compliance and improve the governance of ecosystem restoration (Brancalion et al. 2016). The new law created the Rural Environmental Registry (CAR, in Portuguese), a web-based system for self-declaration of the environmental status of rural landholdings. This registry will be used by legal enforcement agents to monitor restoration interventions conducted to mitigate the deficit of native vegetation in predetermined land portions as described by the law (Brancalion et al. 2016). Restrictions to obtaining environmental licenses or rural bank financing will be applied to nonregistered farms. At the time of writing, 3.74 million rural properties, encompassing approximately 397 million hectares (97.3% of the total land required to be registered), had already been incorporated in the CAR (Servicio Florestal Brasileiro 2010–2016). The next step is to start implementing restoration interventions in more than 20 million hectares to comply with this legislation, which includes the reforestation commitment of 12 million hectares set by Brazil's Intended Nationally Determined Contributions (iNDCs), agreed to at the 21st Conference of the Parties on Climate Change held in Paris in 2015 (Brazil 2016).

In addition to national-level policies, Brazil has committed to biome-scale restoration initiatives. The Atlantic Forest Restoration Pact, a coalition of over 250 organizations including private companies, governments, nongovernmental organizations (NGOs), and research institutions, has demanded high numbers and diversity of native tree seedlings to meet its ambitious restoration goal: 15 million hectares of Atlantic Forest—a top five global biodiversity hotspot—to be restored by 2050 (Melo et al. 2013). The implementation of these restoration programs will require an unprecedented number of native tree seedlings from many different species, and thus the production capacity and quality of the national seedling supply chain needs to be better assessed.

This study provides a current assessment of the distribution, quantity, size, and production capacity of nurseries that sell native tree seedlings in Brazil. This information can give a current perspective on the organization of the seedling production sector and evaluate whether the seedling supply could meet an increase in the demand for seedlings for forest restoration to meet both national and international commitments. This assessment will help identify the challenges to setting up a well-structured supply chain, representing the inherent diversity of natural ecosystems typical of tropical countries, and shed light on the programs and policies needed to meet an emerging demand for a high diversity of native species.

Methods

We collected nursery data across Brazil between November 2012 and March 2013 with support from the Applied Economics Research Institute (IPEA) and the Ministry of the Environment (MMA). We included data from all six major biomes of the country, which have, overall, remarkable levels of tree species diversity: Amazon (4,720 species), Atlantic Forest (3,325 species), Cerrado (1,796 species), Caatinga (882 species), Pantanal (177 species), and Pampa (59 species) (Flora do Brasil 2020). Many of these tree species are shared between and among biomes (e.g. 44% of tree species are shared between Cerrado and Atlantic Forest, and 15% between Cerrado and Amazon; Françoso et al. 2016), but a large portion of them are endemic and require a biome-specific approach to be employed in restoration programs.

To obtain information on the forest nurseries producing native tree species in Brazil, we contacted 83 forestry professionals and researchers, 71 staff from state and regional government environmental offices and agriculture secretariats, and 27 staff members from regional offices of the Ministry of Agriculture (MAPA). In addition to direct inquiries, we searched the national nursery registry system (RENASEM): a website in which Brazilian nurseries can register and advertise their services (http://sistemasweb.agricultura.gov.br/pages/RENASEM.html). We also searched previous reports on nursery distribution. Nursery sites that sold only exotic species were excluded from the analysis. We also deleted nurseries for which we could not identify whether they sold only exotics or also natives. We conducted structured phone interviews between July 2013 and March 2014 geared toward characterizing the nurseries. The questionnaire contained 34 questions divided in seven parts: (1) basic information; (2) consent to conduct the interview; (3) nursery identification; (4) characterization; (5) socioeconomic information; (6) impact of the new forest code; and (7) other nursery contacts (Appendix S1, Supporting Information). With the initial data collection and the additional contacts provided by the interviewees, we obtained a list of 1,276 nurseries.

We tried to reach all nurseries, but only 246 either answered our questionnaire or were eligible for the study, as nurseries that only produced exotic species were excluded (205). For those that did not reply, this was either because the telephone number listed was incorrect (311), the call was not answered, the nursery manager could not be contacted (136), they declined to participate in the research (102), or they were not active at the time of the research (54). We lacked detail contact information for 222 nurseries whose names were given by the interviewees. The high number of incorrect phone numbers highlights the degree of informality that stills exists in the sector of native tree seedling sales. The data were organized using the software Epidata 3.1 (The EpiData Association, Odense M, Denmark; Lauritsen 2000–2008). The survey was not structured to separate the quantity of native seedlings produced by nurseries working with both exotic and native species. Therefore, for estimating native seedlings produced annually we employed only data from nurseries that strictly produce native species.

Results

Most nurseries (71%) were private, followed by public (19%) and NGO/other holder category nurseries (10%). Surveyed nurseries collected native tree seeds mainly in native forests on private lands (80%), but 35% of them also collect seeds in urban areas. Most of them do not hire a third party for seed harvesting and use the collected seeds exclusively for seedling production in their nursery and not for selling in the market. Ninety percent of nurseries have more than 10 permanent staff members, while 4 nurseries have over 50 permanent employees. Twenty-eight percent of the nurseries employ temporary staff members, but the majority (80%) employ less than 10 people in this condition.

The total maximum production capacity informed by the surveyed nurseries reaches 142 million seedlings per year. Twenty-nine percent of the 246 surveyed nurseries produced only native species with a combined maximum production of 37 million seedlings per year, but only 43.2% of that maximum capacity is in use (~16 million seedlings per year). Close to 60% of the nurseries produce between 1,000 and 100,000 native seedlings per year, with seven nurseries producing over 500,000 seedlings per year (Fig. 1). Forty of the nurseries sampled (16.2%) can produce over 100 native tree species; however, most nurseries (57%) produce <50 species (Fig. 2). Most nurseries sell their production to private landowners, NGOs, or restoration companies (60%).

We found a highly clustered distribution of nurseries across Brazil (Fig. 3). The Atlantic Forest had the largest number of nurseries as well as the biggest nurseries, especially in the southeast, where the main Brazilian urban centers are located. The other biomes where trees may be required for restoration programs—Caatinga (mostly dry forests), Amazon (mostly rainforests), Pantanal (mosaic of wetlands with dry and evergreen riparian forests), and Cerrado (tropical savannas, which also has dry and seasonal forests and gallery forests in riparian buffers)—were poorly represented by the forest nurseries network. As expected, the nonforest biome Pampa (southern grasslands) showed very few and small nurseries, concentrated in the contact zone with the Atlantic Forest, where native trees occupy riparian zones and are thus required for restoration.

The main hurdles in native seedling production indicated by our respondents relate to a lack of seed supply (80% of the cases), difficulties in seedling commercialization (75%), and lack of trained labor (65%). When asked about the impacts of the new Forest Code (Law #12.652/2012) on the native seedling market, 59% of the respondents stated they did not experience changes in sales, 19.3% declared having experienced sale increases, and 18% felt a decrease in sales.

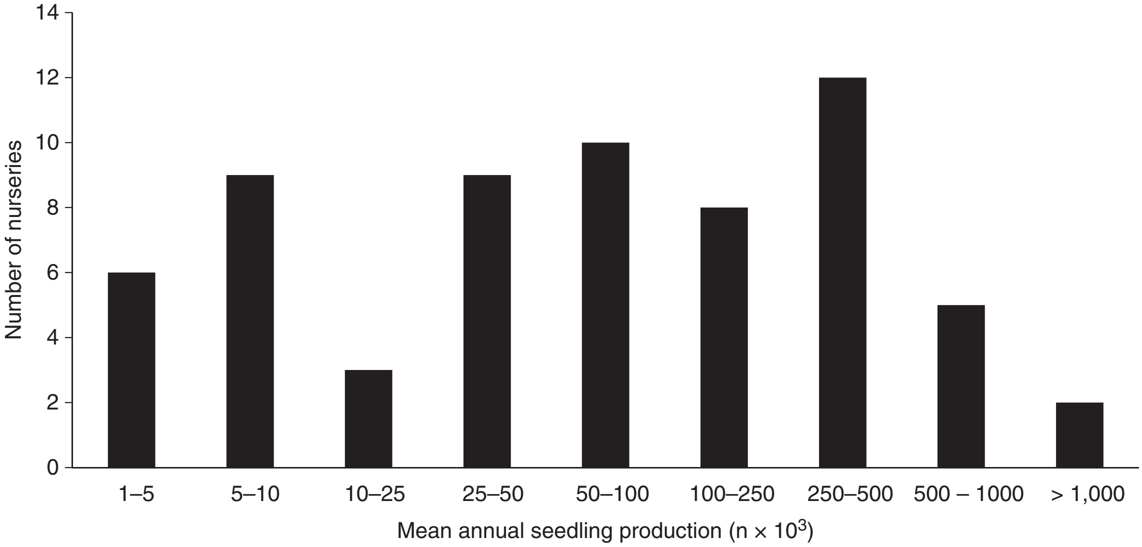

Figure 1. Frequency distribution of the number of forest nurseries according to their mean annual production of native seedlings in Brazil. Only nurseries producing exclusively native species were reported.

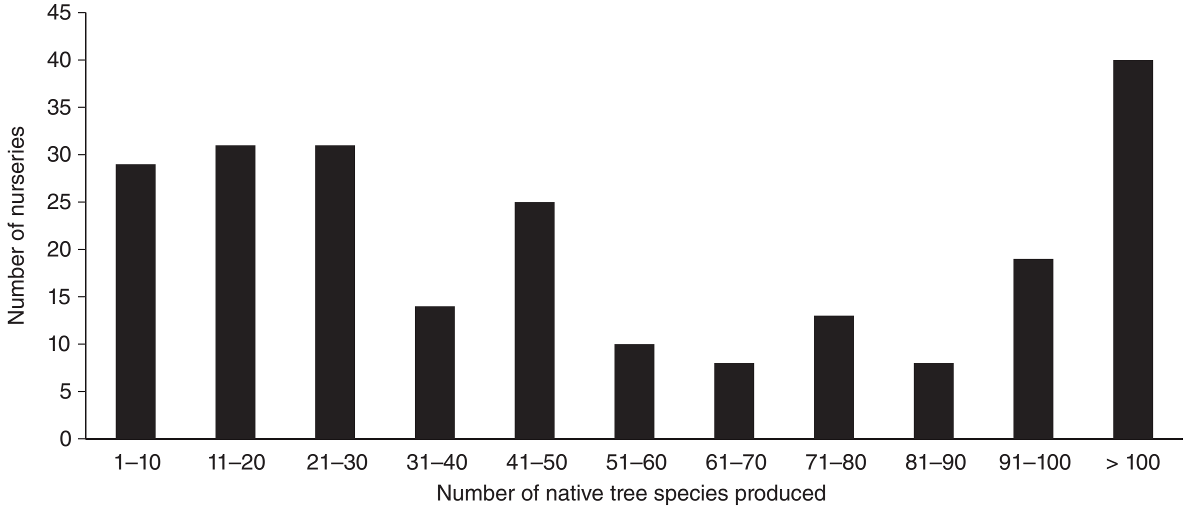

Figure 2. Frequency distribution of the number of native species produced by forest nurseries in Brazil.

Discussion

The analysis of native tree seedling production in Brazil revealed that in the southern part of Brazil, in the Atlantic Forest biome, a well-structured supply chain of nurseries exists. These nurseries produce a large number of seedlings for forest restoration projects, some of them from a high diversity of native tree species (over 100 species). However, other biomes, such as the Caatinga, lack the seedling supply needed to embrace large landscape restoration projects. The number of jobs generated and the predominance of private nurseries in our survey highlight the promising potential of this activity to contribute to the socioeconomic development of the country. However, the current use of a limited fraction of the production capacity provides evidence that this potential has yet to be fully realized, but that, at least in the region where most nurseries are concentrated, the capacity exists for a rapid response to an increasing demand for seedlings. The joint production of native and exotic tree species in most of the nurseries is also a consequence of the lack of supportive policies for this sector. It is difficult to maintain the production of strictly native species because demand can abruptly decline as a consequence of changes in environmental legislation and production can be hampered by the lack of seeds and trained labor. In this context, producing exotics can be a smart solution to increase the economic resilience of forest nursery operations in the face of uncertainties and technical constraints.

Seedling production is the basis for a more complex restoration supply chain that involves project development, implementation, maintenance, and monitoring of restoration interventions. As such, restoration has great potential to

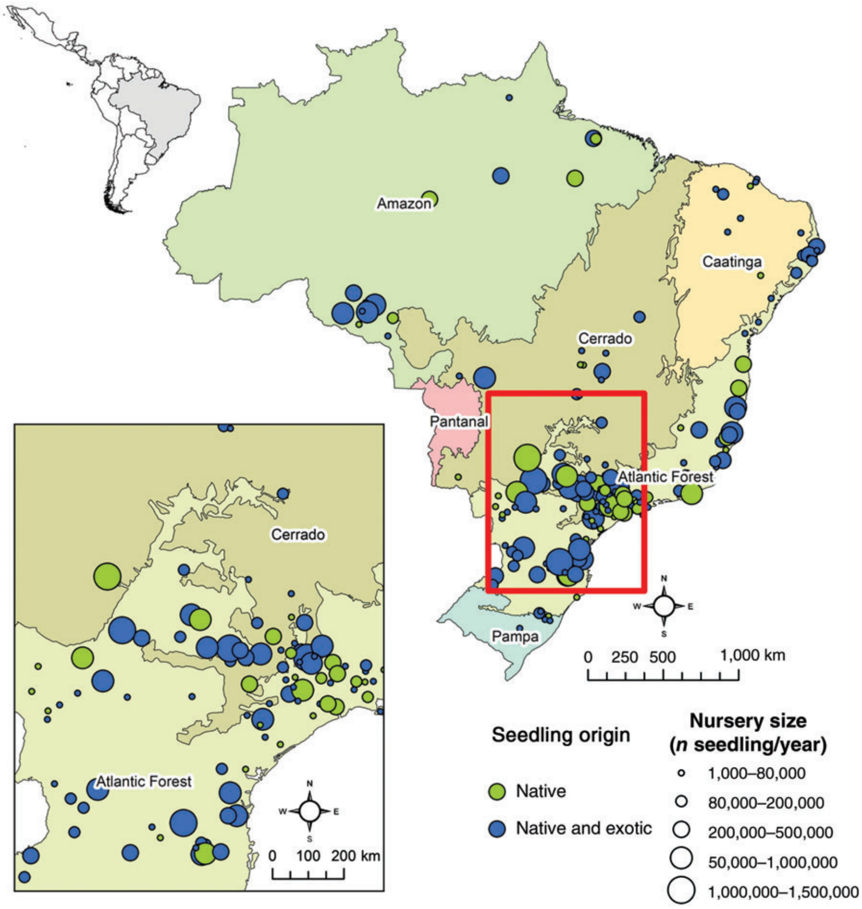

Figure 3. Spatial distribution and size of nurseries that sell native tree seedlings across the different Brazilian biomes.

scale-up the generation of green jobs and income, especially in marginalized rural communities distant from urban centers (Mesquita et al. 2010). To illustrate this potential, the Atlantic Forest Restoration Pact estimates that 6 million jobs will be generated through the accomplishment of the goal to restore 15 million hectares of Atlantic Forest by 2050 (Melo et al. 2013). However, problems in native tree seedling supply may represent a bottleneck to advance this plan. We identified two main barriers to the production of sufficient native tree seedlings for restoration programs: the lack of seed supply and trained labor.

In the case of seed supply, one alternative could be the development of seed collection as an independent commercial activity. A previous study describing strategies to improve seedling stocks in a private nursery in the Atlantic Forest has already demonstrated this potential (Brancalion et al. 2012). Hiring independent seed collectors and contracting seed harvesting cooperatives provided 78 new native tree species for the nursery, while seed collecting conducted exclusively by the seed harvesting team from the nursery provided only nine species. At the time of the study, freelance professional seed collectors earned U.S.$ 1,400 per month, over four times the minimum wage of Brazil (Brancalion et al. 2012).

Lack of supportive environmental laws also hampers seed supply. Currently native seed collection is forbidden in Protected Areas in Brazil, which constrains the inclusion of species with higher conservation value in restoration projects, especially in biomes with very low forest cover remaining such as the Atlantic Forest. In addition, a recent Instructive Norm from the Ministry of Agriculture (IN #56) has several aspects that hinder seed production. One aspect is that it does not discriminate between exotic and native seed production, even though the production of native seeds is generally at a lower scale and with a conservation aim rather than a purely economic aim as is the case with the production of exotics. The norm requires nurseries to follow detailed and strict rules in order to safeguard the sanitary and physiological quality of native seedlings, traceability of seed origins, and to minimize the risks of impacts of seed harvesting in native vegetation. Unfortunately, such strict rules are difficult to follow by small-scale seed collectors who generally are not well organized or lack the necessary education level to follow these norms (Moreira da Silva et al. 2014).

The lack of trained labor, identified as the second barrier for the development of the nursery sector, can be overcome through increased capacity building workshops that may be delivered either by private programs or by local government agencies. Capacity building courses have already been performed throughout the Atlantic Forest biome to train nursery operations to work with native trees species of their region, as well as to improve their management skills (Pinto et al. 2014), but are lacking in other biomes.

The concentration of forest nurseries in the Atlantic Forest and, more prominently, in São Paulo state, reflects the higher demand for native tree seedlings in this region as a consequence of its historical degradation, engagement of agricultural activities in markets requiring environmental certification, and more effective pressure for legal compliance (Rodrigues et al. 2009). For instance, in an assessment of restoration requirements in over 500,000 ha of sugarcane farms in São Paulo state, native vegetation cover in riparian buffers, where restoration is mandatory by law, was only 36.9% (Rodrigues et al. 2011). Due to reduced site resilience and low native vegetation cover across the landscape (<8%), high-diversity native tree plantations were indicated for 76% of the area targeted for restoration (Rodrigues et al. 2011). Future demand for native tree seedlings is also expected to be high in the region, where most of the deficit of native vegetation cover, according to the 2012 Forest Code, is concentrated (Soares-Filho et al. 2014).

However, such concentration of seedling production in large nursery operations brings two main threats to ecological restoration in Brazil. First, the fast expansion of restoration projects in other Brazilian regions not adequately covered by forest nurseries may foster the use of exotics, including non-Brazilian species and endemic species to the Atlantic Forest. The same threat applies within the Atlantic Forest, a complex biome with eight major biogeographical zones and one of the highest percentages of endemic species in the world (Ribeiro et al. 2009). For example, the Northeast region of the Atlantic Forest is not well represented in the forest nurseries network, meaning that a restoration program in that zone may need to buy seedlings from another biogeographical zone. Second, the economic barriers faced by small- and medium-sized nurseries, especially those exclusively producing native species, may amplify the concentration of production in a few large forest nurseries with better conditions to deliver cheaper seedlings to the market.

The concentration of seedling production in a few large nurseries may, in turn, bring additional problems to ecological restoration. First, it may aggravate the floristic composition mismatch between nursery-grown seedlings and reference ecosystems, and reduce the total number of species being used in restoration projects, because it would be difficult for these few nurseries to cover an area big enough to sample all potential native tree species occurring in the hyper-diverse ecoregions typically found in Brazil. Although some individual nurseries produced a high diversity of native trees (over 100 species), we believe that most of them concentrate production on a narrow group of species that are easier to produce, with negligible representation of the total species pool. However, our dataset does not allow us to explore the composition of seedling stocks, because we did not have access to the species list produced by nurseries, although this issue warrants further study. Another potential problem is the use of nonlocal genotypes for species with wide ecological distributions, which may compromise their fitness when planted in ecological conditions different than those in which they have evolved and developed local adaptations (Thomas et al. 2014).

It is thus evident there is a need for supportive policies and programs to subsidize the regionalization of seedling production in smaller-scale nursery operations, especially in regions poorly served by nurseries specializing in native species production. Developing certification and verification schemes for controlling nursery operations is worth considering as a strategy to safeguard the quality of native tree seedlings for restoring native ecosystems. However, the establishment of mandatory rules to be followed by nurseries supplying seedling stocks for restoration has to be well balanced with appropriate incentives for producing native species; on the contrary, mandatory rules may constitute an additional disincentive for these forest nurseries and further compromise the supply of native tree seedlings for restoration programs.

We conclude that the production of a high diversity of native tree species can be a viable approach for FLR programs, but coordination is needed. The use of exotics is not needed, but can be a direct consequence of the lack of planning to organize the supply chain of native tree seedling production to meet market demands. Therefore, the use of native tree species in FLR programs, which support the restoration of high-diversity forest ecosystems, requires policies and supportive programs that: (1) create favorable conditions for the economic development of this activity, (2) decentralize seedling production, (3) embrace the different target ecosystems of restoration programs, (4) develop a knowledge base to support the production of native species, and (5) promote the capacitation of stakeholders to apply this knowledge. The consequence of these actions will be the recovery of forest ecosystems with higher diversity and potential to generate ecosystem services to society, aligned with the generation of jobs and income in marginalized rural communities.

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LITERATURE CITED

Aronson J, Alexander S (2013) Ecosystem restoration is now a global priority: time to roll up our sleeves. Restoration Ecology 21:293–296

Aronson J, Brancalion PHS, Durigan PHS, Rodrigues RR, Enge VS, Tabarelli M, et al. (2011) What role should government regulation play in ecological restoration? Ongoing debate in Sao Paulo State, Brazil. Restoration Ecology 19:690–695

BenDor T, Lester TW, Livengood A, Davis A, Yonavjak L (2015) Estimating the size and impact of the ecological restoration economy. PLoS One 10:1–15

Brancalion PHS, Rodrigues RR, Gandolfi S, Kageyama PY, Nave AG, Gandara FB, Barbosa LM, Tabarelli M (2010) Instrumentos legais podem contribuir para a restauração de florestas tropicais biodiversas. Revista Árvore 34:455–470

Brancalion PHS, Viani R, Aronson J, Rodrigues RR, Nave AG (2012) Improving planting stocks for the Brazilian Atlantic Forest restoration through community-based seed harvesting strategies. Restoration Ecology 20:704–711

Brancalion PHS, Garcia LG, Loyola R, Rodrigues RR, Pillar VD, Lewinsohn TM (2016) A critical analysis of the native vegetation protection law of Brazil: updates and ongoing initiatives. Brazilian Journal of Nature and Conservation I4S:1–15

Brazil (2016) Intended nationally determined contribution: towards achieving the objective of the UNFCCC. http://www4.unfccc.int/submissions/INDC/Published%20Documents/Brazil/1/BRAZIL%20iNDC%20english%20FINAL.pdf (accessed 13 Sep 2016)

Chaves RB, Durigan G, Brancalion PHS, Aronson J (2015) On the need of legal frameworks for assessing restoration projects success: new perspectives from Sao Paulo state (Brazil). Restoration Ecology 23:753–759

Chazdon RL, Brancalion PHS, Laestadius L, Bennett-Curry A, Buckingham K, Kumar C, Moll-Rocek J, Vieira ICG, Wilson SJ (2016) When is a forest a forest? Forest concepts and definitions in the era of forest and landscape restoration. Ambio 45:538–550

Dixon KW (2009) Pollination and restoration. Science 325:571–572

Dodds WK, Wilson KC, Rehmeier RL, Knight GL, Wiggam S, Falke JA, Dalgleish HJ, Bertrand KN (2008) Comparing ecosystem goods and services provided by restored and native lands. Bioscience 58:837–845

Flora do Brasil (2020) Jardim Botânico do Rio de Janeiro. http://floradobrasil.jbrj.gov.br/ (accessed 13 Sep 2016)

Françoso RD, Haidar RF, Machado RB (2016) Tree species of South America central savanna: endemism, marginal areas and the relationship with other biomes. Acta Botânica Brasílica 30:78–86

Hobbs RJ (2016) Degraded or just different? Perceptions and value judgements in restoration decisions. Restoration Ecology 24:153–158

Isbell F, Calcagno V, Hector A, Connolly J, Harpole WS, Reich PB, et al. (2011) High plant diversity is needed to maintain ecosystem services. Nature 477:199–202

Janishevski L, Santamaria C, Gidda SB, Cooper HD, Brancalion PHS (2015) Ecosystem restoration, protected areas and biodiversity conservation. Unasylva 245:19–28

Laestadius L, Buckingham K, Maginnis S, Saint-Laurent C (2015) Before Bonn and beyond: a history of forest landscape restoration and an outlook for the future. Unasylva 245(66):11

Lauritsen JM (ed) (2000–2008. http://www.epidata.dk) EpiData Data Entry, data management and basic statistical analysis system. EpiData Association, Odense, Denmark

Melo FPL, Pinto SRR, Brancalion PHS, Castro PS, Rodrigues RR, Aronson J, Tabarelli M (2013) Priority setting for scaling-up tropical forest restoration projects: early lessons from the Atlantic Forest Restoration Pact. Environmental Science and Policy 33:395–404

Mesquita CB, Holvorcem CGD, Lyrio CH, Dimas De Menezes P (2010) COOPLANTAR: a Brazilian initiative to integrate forest restoration with job and income generation in rural areas. Ecological Restoration 28:199–207

Moreira da Silva A, Rodrigues Marques H, Ferreira Luciano M, Nascente dos Santos TV, Cordeiro Teixeira A, Sambuichi R (2014) Gargalos da regulamentação da produção e comercialização de sementes e mudas florestais nativas no Brasil. Contribuições para revisão da normativa. IPEA Boletim Regional, Urbano e Ambiental 12:71–80

Murcia C, Aronson J, Kattan GH, Moreno-Mateos D, Dixon K, Simberloff D (2014) A critique of the 'novel ecosystem' concept. Trends in Ecology & Evolution 29:548–553

Murcia C, Guariguata MR, Andrade A, Andrade GM, Aronson J, Escobar EM, Etter A, Moreno FH, Ramirez W, Montes E (2016) Challenges and prospects for scaling-up ecological restoration to meet international commitments: Colombia as a case study. Conservation Letters 9:213–220

Nunes A, Oliveira G, Mexia T, Valdecantos A, Zucca C, Costantini EAC, et al. (2016) Ecological restoration across the Mediterranean Basin as viewed by practitioners. Science of the Total Environment 566–567: 722–732. DOI:10.1016/j.scitotenv.2016.05.136

Pinto S, Melo F, Tabarelli M, Padovesi A, Mesquita A, Scaramuzza CA, et al. (2014) Governing and delivering a biome-wide restoration initiative: the case of Atlantic Forest Restoration Pact in Brazil. Forests 5:2212–2229

Possingham HP, Bode M, Klein CJ (2015) Optimal conservation outcomes require both restoration and protection. PLoS Biology 13:1–15

Ribeiro da Silva F, Montoya D, Furtado R, Memmott J, Pizo MA, Rodrigues RR (2015) The restoration of tropical seed dispersal networks. Restoration Ecology 23:852–860

Ribeiro MC, Metzger JP, Martensen AC, Ponzoni FJ, Hirota MM (2009) The Brazilian Atlantic Forest: how much is left, and how is the remaining forest distributed? Implications for conservation. Biological Conservation 142:1141–1153

Richardson DM (1998) Forestry trees as invasive aliens. Conservation Biology 12:18–26

Rodrigues RR, Lima R, Gandolfi S, Nave AG (2009) On the restoration of high diversity forests: 30 years of experience in the Brazilian Atlantic Forest. Biological Conservation 142:1242–1251

Rodrigues RR, Gandolfi S, Nave AG, Aronson J, Barreto TE, Vidal CY, Brancalion PHS (2011) Large-scale ecological restoration of high-diversity tropical forests in SE Brazil. Forest Ecology and Management 261:1605–1613

Sabogal C, Besacier C, Mcguire D (2015) Forest and landscape restoration: concepts, approaches and challenges for implementation. Unasylva 245:3–10

Servicio Florestal Brasileiro (2010–2016) http://www.florestal.gov.br/cadastro-ambiental-rural/numeros-do-cadastro-ambiental-rural (accessed 5 May 2016)

Simberloff D, Alexander J, Allendorf F, Aronson J, Antunes PM, Bacher S, et al. (2011) Non-natives: 141 scientists object. Nature 475:36

Soares-Filho B, Rajão R, Macedo M, Carneiro A, Costa W, Coe M, Rodrigues H, Alencar A (2014) Cracking Brazil's Forest Code. Science 344: 363–364

Stanturf JA, Palik BJ, Dumroese RK (2014) Contemporary forest restoration: a review emphasizing function. Forest Ecology and Management Forest Ecology and Management 331:292–323

Suding K, Higgs E, Palmer M, Callicott JB, Anderson CB, Baker M, et al. (2015) Committing to ecological restoration. Science 348:638–640

Temperton VM, Higgs E, Choi YD, Allen E, Lamb D, Lee CS, Harris J, Hobbs RJ, Zedler JB (2014) Flexible and adaptable restoration: an example from South Korea. Restoration Ecology 22:271–278

Thomas E, Jalonen R, Loo J, Boshiera D, Gallo L, Cavers S, Bordács S, Smith P, Bozzano M (2014) Genetic considerations in ecosystem restoration using native tree species. Forest Ecology and Management 333:66–75

United Nations (2014) Forests: action statements and action plans. Climate Summit 2014: 17 pp

Xu J (2011) China's new forests aren't as green as they seem. Nature 477:371

Supporting Information

The following information may be found in the online version of this article:

Appendix S1. Semi-structured interview.

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