Restoration Ecology
THE JOURNAL OF THE SOCIETY FOR ECOLOGICAL RESTORATION INTERNATIONAL

RESEARCH ARTICLE

Improving Planting Stocks for the Brazilian Atlantic Forest Restoration through Community-Based Seed Harvesting Strategies

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Abstract

High-diversity reforestation can help jumpstart tropical forest restoration, but obtaining viable seedlings is a major constraint: if nurseries do not offer them, it is hard to plant all the species one would like. From 2007 to 2009, we investigated five different seed acquisition strategies employed by a well-established tree nursery in southeastern Brazil, namely (1) in-house seed harvesters; (2) hiring a professional harvester; (3) amateur seed harvesters; or (4) a seed production cooperative, as well as (5) participating in a seed exchange program. In addition, we evaluated two strategies not dependent on seeds: harvesting seedlings from native tree species found regenerating under *Eucalyptus* plantations, and in a native forest remnant. A total of 344 native tree and shrub species were collected as seeds or seedlings, including 2,465 seed lots. Among these, a subset of 120 species was obtained through seed harvesting in each year. Overall, combining several strategies for obtaining planting stocks was an effective way to increase species richness, representation of some functional groups (dispersal syndromes, planting group, and shade tolerance), and genetic diversity of seedlings produced in forest tree nurseries. Such outcomes are greatly desirable to support high-diversity reforestation as part of tropical forest restoration. In addition, community-based seed harvesting strategies fostered greater socioeconomic integration of traditional communities in restoration projects and programs, which is an important bottleneck for the advance of ecological restoration, especially in developing countries. Finally, we discuss some of the limitations of the various strategies for obtaining planting stocks and the way forward for their improvement.

Key words: forest nurseries, functional groups, high-diversity reforestation, restoration genetics, seedling production, tropical forest restoration.

Introduction

One of the nine attributes of restored ecosystems proposed in the Society for Ecological Restoration (SER) Primer is the presence of "a characteristic assemblage of the species that occurs in the reference ecosystem and that provides appropriate community structure" (SER 2004). However, historical degradation of some natural ecosystems has compromised their resilience, so that active restoration is frequently needed to reintroduce a large pool of typical native species from tropical rainforests (Chazdon 2008; Holl & Aide 2011; Rodrigues et al. 2011).

In the Brazilian Atlantic Forest region, low forest cover and fragmentation (Ribeiro et al. 2009), extirpation of avian frugivores (Silva & Tabarelli 2000), and on-going degradation of forest remnants (Tabarelli et al. 2010) have reduced seed dispersal, which in turn hinders enrichment of restoration areas through natural processes (Souza & Batista 2004; Bertoncini & Rodrigues 2008). Indeed, poor seed dispersal is one of the main factors limiting restoration success in tropical areas worldwide (Holl et al. 2000; Donath et al. 2003; White et al. 2004). Hence, to reestablish a significant proportion of the plant diversity of a tropical forest restoration site in human-dominated landscapes, a significant pool of native species should be intentionally reintroduced. To face these challenges, high-diversity reforestation can be an effective restoration methodology in the early stages of a project or program (Larvajaara 2008; Rodrigues et al. 2009, 2011).

In this context, nurseries assume an important role by providing desirable and—ideally—well-identified planting stock

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doi: 10.1111/j.1526-100X.2011.00839.x

and provenances for tropical forest restoration. However, there are as yet several obstacles elsewhere to obtaining nursery-grown seedlings from a large pool of native species and genotypes, which constitutes an important bottleneck for the advance of ecological restoration (Smith et al. 2007; Merritt & Dixon 2011; Tepe & Meretsky 2011). Paradoxically, just as reduced forest cover and forest fragmentation amplify the need for using higher plant diversity in restoration efforts, they also make it very difficult to harvest viable seeds of most tree species. In the Brazilian Atlantic Forest in particular, many tree species are represented by only a few individuals at any given site (Caiafa & Martins 2010), while others have low density due to overexploitation for timber production (Oliveira et al. 2008), and several others have been lost altogether or at least are not commonly found in the isolated forest remnants occurring fragmented and largely transformed landscapes (Liebsch et al. 2008; Santos et al. 2008). Seed collecting is further hindered by the fact that fruiting time is highly variable among trees, these trees are often very tall with the result that seeds are inaccessible and, finally, as soon as they fall to the ground, ripe seeds are predated by a wide range of rodents and insects.

After the recent enactment of a São Paulo state resolution that obliges mandatory restoration projects to reach at least 80 native woody species in high-diversity forest ecosystem areas (Aronson et al. in press), the quantity and diversity of Atlantic Forest native species produced in São Paulo state nurseries, southeastern Brazil, have greatly improved. From 2003 to 2008, seedling production of shrubs and tree species increased from 13,000,000 to 33,000,000 per year, and the average number of plant species produced jumped from 30 to over 80 (Barbosa et al. 2009). In 2010, a total of 208 forest nurseries distributed throughout the state produced no less than 42 million tree seedlings, and 89% of them depended mainly on in-house seed harvesting as source of seeds (Martins 2011). However, as seedling production in nurseries increases, the more difficult it becomes for seed collectors to obtain commercially important seeds from the various species of interest, especially in the hyper-fragmented landscapes of the Atlantic Forest. In this context, the diversification of strategies to obtaining planting stocks, rather than depending solely on a nursery's own seed harvesting team, can be highly worthwhile.

In this context, we hypothesized that using different strategies of obtaining planting stocks improves species richness, representation of some functional groups, and genetic diversity of tree seedlings in nurseries, which in turn supports the use of high-diversity plantings for tropical forest restoration.

Methods

Field work was carried out in collaboration with the private forest nursery BioFlora, in Piracicaba, São Paulo state (hereafter SP), in southeastern Brazil. This nursery produces approximately 3 million seedlings of native tree and shrub species per year. These young trees are sold primarily for use in various kinds of forest restoration efforts. In addition, BioFlora sells seeds to other forest nurseries engaged in this same range of business activities. BioFlora adopts a system of production that divides seedlings in two main functional groups, named "filling group" (fast growing and wide canopy species) and "diversity group" (slow growing and/or narrow canopy species), adopted from Rodrigues et al. (2009). Half of the seedlings produced by this nursery are from each of the two planting groups, aiming at favoring reforestation (to jumpstart restoration) using equal proportions of individual trees from these two functional groups. Because the "filling group" is composed of relatively few species (circa 20 species) and the "diversity group" of more than 80 species, a higher number of seedlings have to be produced for each filling group species to achieve the desired balance. As a result, seed harvesters are required to collect larger amounts of seeds from "filling group" species.

We investigated five different strategies used by BioFlora to improve and diversify their planting stocks, based on seed harvesting in the Atlantic Forest domain (Table 1). In addition, we evaluated two strategies not dependent on seeds: collecting live seedlings from desirable native tree species found regenerating under *Eucalyptus* plantations, and in a native forest remnant (Table 1).

Seed production was monitored in 2007, 2008, and 2009, while seedling composition of the understory of the forest plantations and the forest remnant were evaluated in May and April 2003. Seedlings were identified in the ESA Herbarium (the herbarium of the Department of Biology, University of São Paulo, Campus Luiz de Queiroz), as well as the mother trees that produced the seeds, based on an herbarium voucher specimens that were collected and delivered with each seed lot.

We created a database for the seedlings obtained from natural regeneration and for each seed lot that entered the nursery, with the following information: (1) species name; (2) date of harvesting; (3) strategies for obtaining planting stock, according to the seven strategies described above; (4) physical mass of the seed lot; (5) seed dispersal syndrome, following by Almeida Neto et al. (2008); (6) planting group versus filling or diversity group—according to Rodrigues et al. (2009); and (7) shade tolerance, according to specialized publications on São Paulo state native trees and the personal experience of the authors. This dataset, including 2,465 seed lots and 100 seedling sampling plots, was used to address the following questions.

How Do the Studied Strategies Differ in Their Ability to Obtain "Exclusive" Species and Species with Different Functional Attributes?

We grouped the number of "exclusive" species (i.e. not supplied by any other strategy) and total number of species obtained per strategy in each year. To estimate the potential contribution of seedling stock of the understory of the forest plantations and forest remnant as a source of plant diversity to nurseries, their species lists were compared with the results obtained in 2009 by the five described strategies of seed acquisition. Next, we compared the strategies of obtaining planting stocks in relation to dispersal syndrome, planting group, and shade tolerance of the target species.

Table 1. Strategies for obtaining planting stocks of Atlantic Forest species in a commercial forest nursery in Piracicaba, southeastern Brazil.

Strategies for Obtaining Planting Stocks	*Description of the Strategy*	*Harvesting Region*
Seed harvesting		
(1) Own team of seed harvesting	A team composed of the BioFlora nursery by two employees (one technician and one field worker)	Piracicaba-SP, which has 9% of its area of 1,369 km^2 covered by natural forest
(2) Hiring a freelance professional seed harvester	A seed harvester who collected seeds exclusively for BioFlora during the period of this study and obtained most of his income from this activity	Laranjal Paulista-SP, which has 6.5% of its area of 386 km^2 covered by natural forest
(3) Hiring several independent, amateur seed harvesters	Seed harvesters who take on occasional contracts to obtain a supplementary income	Piracicaba-SP, which has 9% of its area of 1,369 km^2 covered by natural forest
(4) Contracting a seed production cooperative	An organized group of seed harvesters with training and coordination for native seed production and selling	Ribeirão Grande-SP, which has 62% of its area of 332 km^2 covered by natural forest
(5) Participating in a seed exchange program	A program set up and run by BioFlora nursery and eight other forest tree nurseries of sugarcane companies. The goal of the program is to mutually exchange seeds to improve plant richness and genetic diversity of their native seedling stocks. Seed exchange was accomplished every month during the period of this study	Central region of São Paulo state, including several municipalities
Collecting live seedlings from the natural regeneration under forest stands		
(6) *Eucalyptus* plantations	Species found by Viani et al. (2007), who transplanted to forest nurseries seedlings up to 30 cm in height found in 80 randomly installed 2 × 2 m plots in the understory of six *Eucalyptus* plantations	Bofete-SP, which has 21.7% of its area of 653 km^2 covered by natural forest
(7) Forest remnant	Species found by Viani and Rodrigues (2009), who transplanted to nurseries the seedlings up to 30 cm in height found in 20 randomly installed 4 × 4 m plots in the understory of a 150 ha forest remnant of seasonally dry forest	Bofete-SP, which has 21.7% of its area of 653 km^2 covered by natural forest

Which Strategies of Seed Acquisition Were More Cost-Effective for Improving Plant Diversity?

We evaluated the annual income earned from sales of seed obtained by the professional seed harvester, the several amateur seed harvesters, and the seed production cooperative, both in 2008 and 2009. The first two strategies were based on the same price list, whereas payments for the seed production cooperative were based on a list with prices that were approximately 30% more expensive. Higher seed prices were established in this case for the maintenance of seed handling and selling structure, as well as to pay for taxes necessary to keep the cooperative working legally. The monetary values obtained were converted to US$ for the evaluation using the interbank exchange rate of Brazilian R$ 1,00 = US$ 0.66, as published on 1 March 2011.

How Many Seed Lots Were Incorporated Per Species in the Nursery by the Strategies of Obtaining Plant Diversity?

The number of seed lots per species used to produce nursery-grown seedlings can be considered as an estimator of genetic diversity, because different seed lots represent different seed provenances and/or mother trees (in the case that seed harvesting occurs in different periods at the same seed provenance). Needless to say, each seed lot can be harvested from several mother trees. For each of the 3 years of this study, we calculated the mean number of seed lots per species. In addition, we elaborated a histogram of species distribution according to number of seed lots, considering four arbitrarily established classes: less than 4, 4–8, 8–12, and greater than 12 seed lots per year.

Is There a Most Favorable Period in the Year for Obtaining Plant Diversity Through Seed Harvesting?

We separately evaluated the total number of species, as well as the number of animal-dispersed, wind-dispersed, and gravity-dispersed tree species with data obtained monthly in each year of this study, simultaneously considering all the strategies of seed acquisition. If seed lots of the same species were harvested and supplied to the nursery in different periods of the year, we considered these months as the natural dispersal period of the species.

Results

The different strategies considered for obtaining planting stocks in the nursery resulted in a total of 344 native tree and shrub species from 63 families, over the 3-year period of 2007–2009 (see complete species list including dispersal syndrome, planting group, shade tolerance, source—seed or seedling, and year of harvesting, provided in Table S1, Supporting Information). Among these, a subset of 120 species was obtained repeatedly through seed harvesting in each year. The most important plant families, numerically, were Fabaceae, Myrtaceae, Rubiaceae, and Bignoniaceae, with 80, 35, 17, and 13 species, respectively (Table S1).

The amount of seeds obtained by each seed production strategy was highly variable among years (Table 2). Interestingly, each strategy had unusually high success rate in certain years, but not others, as providers of large amounts of seeds. However, hiring a freelance professional seed harvester yielded the highest number of species overall. Combining all the seed-collecting strategies provided more than 100 species to the nursery, as well as the two seedling-collecting strategies together, which provided to nursery 102 species. Furthermore, harvesting seedlings from exotic tree plantations and the forest remnant provided 50 exclusive species, yet only two of the 36 species found in the seedling stage in *Eucalyptus* plantations were exclusive, as compared to 37 of the 95 species found in the seedling stage in the forest remnant (Table 2). Indeed, harvesting seedlings in a forest remnant, and contracting a seed production cooperative provided the highest number of exclusive species, while in-house seed harvesting, and hiring several amateur seed harvesters, resulted in the lowest number

Table 2. Seed harvest, number of species, and number of exclusive species (i.e. not supplied by any other strategy) obtained by five different seed acquisition strategies and two strategies not dependent on seeds (i.e. collecting live seedlings from understory) in a private forest nursery in Piracicaba-SP, southeastern Brazil.

Strategies to Increase Plant Stock Diversity in Forest Nurseries	*Seed Harvest (kg)*				*Number of Species*				*Number of Exclusive Species*			
	2007	*2008*	*2009*	*Total*[a]	*2007*	*2008*	*2009*	*Total*[b]	*2007*	*2008*	*2009*	*Total*[c]
Own team of seed harvesting	104.0	246.2	488.6	838.8	43	41	79	121	9	6	22	9
Hiring a freelance professional seed harvester	194.6	590.8	372.5	1157.9	73	83	105	146	9	10	6	22
Hiring several independent, amateur seed harvesters	434.9	389.2	377.0	1201.1	55	63	61	112	31	43	18	8
Contracting a seed production cooperative	106.8	498.1	175.6	780.5	51	89	46	131	24	26	33	44
Participating in a seed exchange program	195.1	332.4	229.7	757.2	88	105	79	141	34	31	21	23
Seedlings from natural regeneration under *Eucalyptus* plantations[d]	—	—	—	—	—	—	36	36	—	—	2	2
Seedlings from natural regeneration under a forest remnant[d]	—	—	—	—	—	—	95	95	—	—	40	37

[a] Sum of the seed harvests of each year.
[b] Number of species of each considering the 3 years, without recounting species supplied in more than 1 year.
[c] Number of exclusive species of each strategy among all the species supplied for the nursery during 3 years.
[d] These strategies were evaluated in 2003, but their results were included in 2009 to allow comparison with seed acquisition strategies.

Table 3. Cost-effectiveness of seed harvesting strategies used to supply seeds to a private forest nursery in Piracicaba-SP, southeastern Brazil.

	Total Expenditure Per Year (US$)		*Value Per Species (US$)[a]*		*Value Per Exclusive Species (US$)[b]*	
Strategies for Obtaining Planting Stocks	*2008*	*2009*	*2008*	*2009*	*2008*	*2009*
Freelance professional seed harvester	16,569	10,837	226	131	1,841	1,806
Several independent, amateur seed harvesters	14,930	7,241	271	115	1,658	724
Seed production cooperative	19,034	7,919	373	89	793	305

All monetary values expressed as US$, as of official exchange rate of 1 March 2011.
[a] Represents the total expenditure per year divided by the total number of species obtained in the year.
[b] Represents the total expenditure per year divided by the total number of exclusive species obtained in the year.

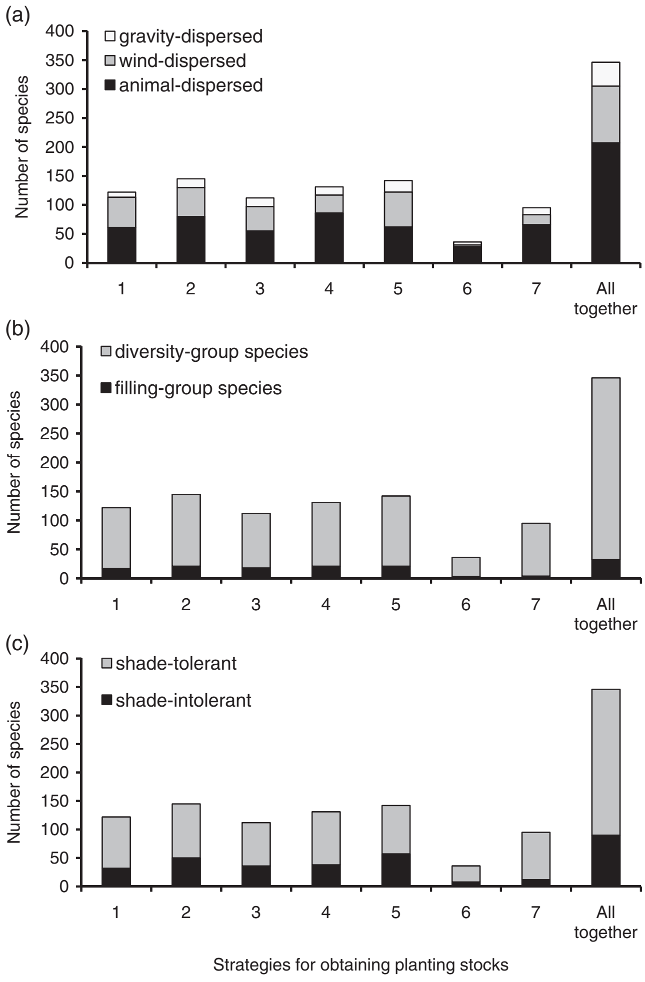

Figure 1. Comparison among strategies of obtaining planting stocks in relation to (a) dispersal syndrome, (b) planting group (filling group, i.e. fast growing and wide canopy species, versus diversity group, i.e. slow growing and/or narrow canopy species), and (c) shade tolerance (1) own team of seed harvesting; (2) hiring a freelance professional seed harvester; (3) hiring several amateur seed harvesters; (4) contracting a seed production cooperative; (5) participating in a seed exchange program; (6) collecting live seedlings from the natural regeneration under *Eucalyptus* plantations; and (7) collecting live seedlings from the natural regeneration under a forest remnant. Strategies 1–5 represent the total assemblage of species harvested in 2007, 2008, and 2009, whereas strategies 6 and 7 represent the species harvested in 2003.

of exclusive species (Table 2). Contracting a seed production cooperative was the least cost-effective strategy of seed harvesting for obtaining different species in 2008, while in 2009 this was the most cost-effective one for this purpose (Table 3). However, this strategy was the most cost-effective in both years for supplying exclusive species (Table 3).

Most species collected were animal-dispersed, shade-tolerant, and part of the diversity planting group (Fig. 1). Notably, almost all species harvested at the seedling stage under *Eucalyptus* plantations were dispersed by animals. The proportions of animal-dispersed, wind-dispersed, and gravity-dispersed species, filling group and diversity-group species, and shade-tolerant and shade-intolerant species were similar among strategies of seed harvesting (Fig. 1). Overall, collecting seedlings from the natural regeneration under *Eucalyptus* plantations and forest remnants resulted in a lower number and proportion of filling group and shade-intolerant species compared to seed harvesting strategies (Fig. 1).

The mean number of seed lots per species was 3.0 in 2007, 5.5 in 2008, and 3.5 in 2009. In all 3 years, there was high variation in the number of seed lots per species, with numbers ranging from 1 to 14 in 2007, 1 to 41 in 2008, and 1 to 26 in 2009. Overall, most species were represented by less than four seed lots per year (Fig. 2).

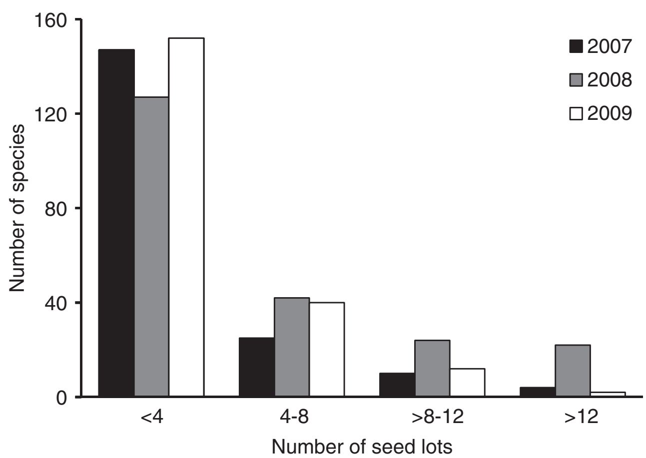

Figure 2. Distribution of species according to the number of seed lots obtained by the forest nursery.

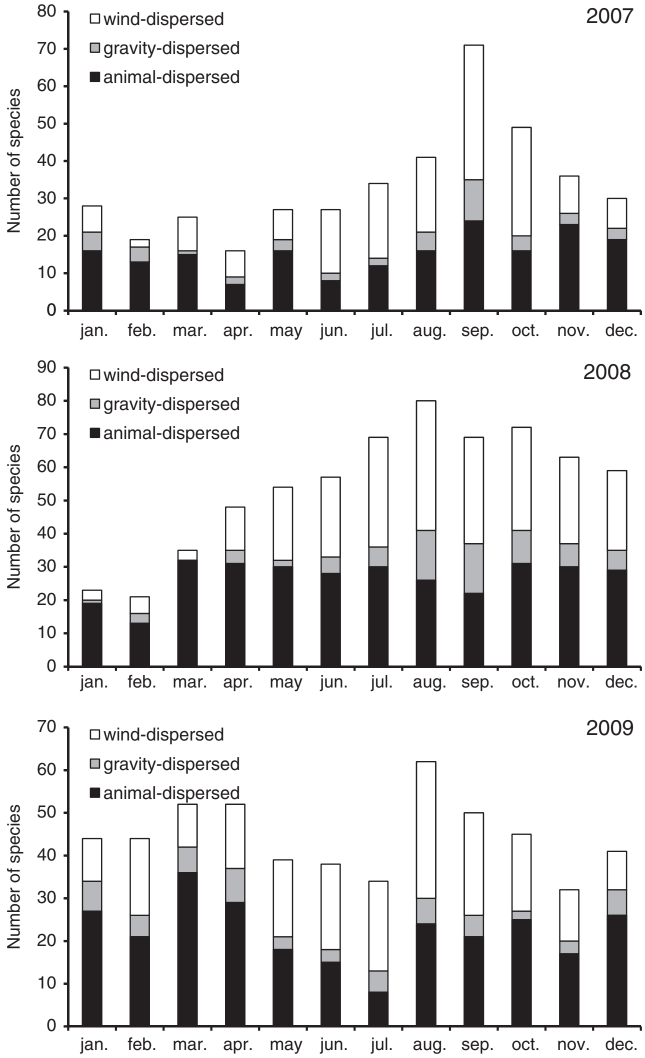

Figure 3. Wind-dispersed, gravity-dispersed, and animal-dispersed species obtained per month in each year, considering different strategies of native seed production used by a private forest nursery at Piracicaba-SP, southeastern Brazil.

There was a peak of plant species richness obtained through seed harvesting from July to October in the 3 years of this study, which essentially resulted from an increase of seed harvesting of wind-dispersed species (Fig. 3). The availability of gravity-dispersed and animal-dispersed species tended to remain stable throughout the year, but some particularities were observed. In 2007 and 2008, for example, there was an increase of gravity-dispersed plant species richness coincident with the increase of wind-dispersed species, while in 2009, an increase in the harvesting of animal-dispersed species in May and April resulted in a second peak of plant species richness (Fig. 3). Considering the total richness obtained in the 3 years of this study, the majority of species harvested were animal-dispersed (93, 120, and 117 species, respectively, in 2007, 2008, and 2009), followed by wind-dispersed (70, 73, and 69 species), and gravity-dispersed (22, 24, and 20 species).

Discussion

Combining several strategies for obtaining planting stocks is an effective way to increase species richness, representation of some functional groups, and genetic diversity of seedlings produced in tropical forest tree nurseries. Such characteristics are greatly desirable to support high-diversity reforestation as an integral part of tropical forest restoration. In addition, community-based seed harvesting strategies can foster greater socioeconomic integration of traditional communities in restoration programs, which is an important bottleneck for the advance of ecological restoration, especially in developing countries (Aronson et al. 2010).

Although each strategy studied can individually result in the production of a large number of native tree/shrub species (circa 70 species per year), this level of richness is insufficient to represent most of the tree species found in reference sites of Brazilian Atlantic Forest. This biome has at least 20,000 plant species (Myers et al. 2000), while the number of tree and shrub species found in large and conserved remnants of São Paulo state, where this study was conducted, vary from 150 to 200 species (Rodrigues et al. 2011). However, if several strategies are combined, a highly satisfactory number of native woody plant species can be attained because each strategy contributes a different group of exclusive species. In addition, the strategy of collecting live seedlings seems useful for increasing forest nursery diversity and should be used in conjunction with all available strategies for obtaining seeds. Tropical forests usually have a high spatial and temporal heterogeneity in the composition of the seedling cohort or community at any given time (Lieberman 1996). Therefore, this strategy could contribute even more to increasing forest nursery diversity if considered for other locations and years, as we have done with strategies for obtaining seeds. Diversification of strategies for obtaining planting stocks is thus an effective way to bring higher levels of tree and shrub diversity into forest nurseries. To obtain even better results, a concentrated harvesting effort in the period from July to October may be needed in seasonal forests of the southern hemisphere, to maximize plant richness through the collection of wind-dispersed species.

When analyzing the differentiation of the harvested species into functional groups, some important patterns have emerged. The higher proportion of animal-dispersed species, corresponding to 50.2, 55.3, and 56.8% of the species in 2007, 2008, and 2009, respectively, was a very favorable result in view of the special usefulness of this functional group in accelerating autogenic restoration processes (Wunderle 1997). However, this high proportion is nonetheless lower than that reported for this functional group in large and conserved Atlantic Forest remnants, in which animal-dispersed woody species usually represent over 70% of plant species richness (Almeida Neto et al. 2008). Hence, animal-dispersed species deserve higher attention in future programs of seed production for tropical forest restoration.

As the high mobility of animal-dispersed species in fragmented landscapes allows them to dominate the understory of *Eucalyptus* plantations, the lower mobility of wind- and gravity-dispersed species, and their lower contribution to the understory of these plantations, may limit their inclusion in restoration efforts if the technique of obtaining planting stock from this source is used alone. In addition, although harvesting seedlings from the understory of commercial tree plantations and forest remnants provided many exclusive and shade-tolerant species to the nursery, those strategies may not supply as many shade-intolerant species for restoration projects as harvesting seeds does. Recall that pioneer and early succession phase species are considered to be important for reestablishing secondary succession in degraded areas and, consequently, should be used in large quantities in restoration plantings (Lamb et al. 2005). The type of reforestation used in southeastern Brazil indicated by Rodrigues et al. (2009), based on the use of "filling" and "diversity" planting groups, would also be heavily limited if the planting stock of the nursery was based only on the species present in seedling banks. This reinforces the need to combine different strategies to obtain desired planting stocks for restoration efforts. Another advantage of using such different strategies is the improvement of genetic diversity of nursery-grown seedlings.

As shown by this study, the use of different strategies for obtaining plant diversity is an effective way to get several seed lots per species, which in turn should favor the use of appropriate genotype mixtures. However, the advantages and risks of using a mix of genotypes, instead of strictly local genotypes, have not been evaluated experimentally to date, so that more research is needed to clarify to what extent we should continue mixing seed lots rather than separate them on the basis of specific, narrowly defined seed transfer zones (Lesica & Allendorf 1999).

Although combining all seed harvesting strategies is desirable for numerous reasons, buying seeds from a cooperative was the most cost-effective strategy in this study for the purpose of bringing to the tree nursery a large pool of exclusive species. This holds true because a lower investment was needed to obtain species not supplied by any other strategy, and a higher number of species was attained per year. The higher forest cover of the region where this seed production cooperative is located was certainly conducive to harvesting several native species, including those locally extinct in highly degraded landscapes, where the other strategies of seed harvesting were based. However, merging different actors in seed acquisition schemes is still the best way to increase the inclusion of traditional indigenous communities or individuals in the restoration process.

Indeed, traditional populations generally live nearby or even inside the forest and are intimately familiar with the distribution and phenology of many native plant species. Unfortunately, as elsewhere in the world, such peoples are continuously moving to the cities in search of jobs and higher income. As our results show, the ecological restoration production chain in Brazil can offer valuable job and income-generating opportunities (cf. Mesquita et al. 2010), including seed harvesting. Considering that most seed harvesters are non-qualified workers (at least for regular jobs), and that most of them earn a minimum wage (circa 340 US$ per month in Brazil) when they get a job in the city, our data show that seed harvesting offers a highly favorable alternative of income generation. When conducted as a full-time job, as in the case of the freelance professional seed harvester, monthly wages could be approximately US$ 1,400. When the intention is to obtain seasonal or complementary income for rural workers, or even to small-scale farmers and landowners, as exemplified by the amateur seed harvesters, one could earn US$ 130 per month.

Hence, the use of different strategies for obtaining seeds and seedlings appears to be an effective way to increase species richness, genetic diversity, and functional groups representation in forest nurseries, as well as to increase income generation and job opportunities in traditional communities. In this way, it should be possible to support the kind of high-diversity reforestation that is planned as the main strategy for initiating and accelerating the ecological restoration of 15% of the Brazilian Atlantic Forest biome (Calmon et al. 2011). As this approach is widely recommended as a means of jumpstarting ecological restoration in human-dominated tropical forest landscapes around the world, the results of this study may be of interest elsewhere.

Implications for Practice

- Combining several strategies for obtaining planting stocks is an effective way to increase species richness, representation of some functional groups, and genetic diversity of seedlings produced in forest tree nurseries, and consequently to support high-diversity reforestation as part of tropical forest restoration.
- Although collecting seedlings arising from natural regeneration under *Eucalyptus* plantations, and native forest remnants, provided many exclusive species to the nursery, those strategies have the limitation of not supplying early sucessional species; species-specific seed harvesting may satisfactory provide this group of species for restoration plantings.
- Organizing seed production cooperatives in regions with high forest cover provides the most cost-effective strategy for obtaining high-diversity planting stocks for tropical forest restoration.
- Seed harvesting of animal-dispersed plant species, especially those more affected by degradation, deserves more attention from nursery operators.
- There is clear potential to foster greater community participation in restoration programs through seed and seedling harvesting, and thereby to achieve better ecological, socioeconomic, and cultural integration.

Acknowledgments

We thank the forest nursery BioFlora for collaboration and the several seed harvesters involved in this work. R.R.R. thanks the National Council for Scientific and Technological Development (CNPq) for financial support.

LITERATURE CITED

Almeida Neto, M., F. Campassi, M. Galetti, P. Jordano, and A. Oliveira-Filho. 2008. Vertebrate dispersal syndromes along the Atlantic Forest: broad scale patterns and macroecological correlates. Global Ecology and Biogeography **17:**503–513.

Aronson, J., J. N. Blignaut, S. J. Milton, D. Le Maitre, K. J. Esler, A. Limouzin, et al. 2010. Are socioeconomic benefits of restoration adequately quantified? A meta-analysis of recent papers (2000–2008) in restoration ecology and 12 other scientific journals. Restoration Ecology **18:**143–154.

Aronson, J., P. H. S. Brancalion, G. Durigan, R. R. Rodrigues, V. L. Engel, M. Tabarelli, et al. What role should government regulation play in ecological restoration? On-going debate in São Paulo State, Brazil. Restoration Ecology **19**:690–695.

Barbosa, L. M., F. C. Parajara, E. E. Teixeira, T. C. Barbosa, K. C. Barbosa, N. A. Santos Júnior, and J. M. Barbosa. 2009. Diagnóstico sobre produção de sementes e mudas de espécies florestais nativas do Estado de São Paulo. Informativo ABRATES **12:**527.

Bertoncini, A. P., and R. R. Rodrigues. 2008. Forest restoration in an indigenous land considering a forest remnant influence (Avaí, São Paulo State, Brazil). Forest Ecology and Management **255:**513–521.

Caiafa, A. N., and F. R. Martins. 2010. Forms of rarity of tree species in the southern Brazilian Atlantic rainforest. Biodiversity and Conservation **19:**2597–2618.

Calmon, M., P. H. S. Brancalion, A. Paese, J. Aronson, P. Castro, S. C. Silva, and R. R. Rodrigues. 2011. Emerging threats and opportunities for large-scale ecological restoration in the Atlantic Forest of Brazil. Restoration Ecology **19:**154–158.

Chazdon, R. L. 2008. Beyond deforestation: restoring forests and ecosystem services on degraded lands. Science **320:**1458–1460.

Donath, T., N. Holzel, and A. Otte. 2003. The impact of site conditions and seed dispersal on restoration success in alluvial meadows. Applied Vegetation Science **6:**13–22.

Holl, K. D., and T. M. Aide. 2011. When and where to actively restore ecosystems? Forest Ecology and Management **261:**1558–1563.

Holl, K. D., M. E. Loik, E. H. V. Lin, and I. A. Samuels. 2000. Tropical montane forest restoration in Costa Rica: overcoming barriers to dispersal and establishment. Restoration Ecology **8:**339–349.

Lamb, D., P. D. Erskine, and J. A. Parrotta. 2005. Restoration of degraded tropical forest landscapes. Science **310:**1628–1632.

Larvajaara, M. 2008. A review on benefits and disadvantages of tree diversity. The Open Forest Science Journal **1:**24–26.

Lesica, P., and F. W. Allendorf. 1999. Ecological genetics and the restoration of plant communities: mix or match? Restoration Ecology **7:**42–50.

Lieberman, D. 1996. Demography of tropical tree seedlings: a review. Pages 131–138 in M. D. Swaine, editor. The ecology of tropical forest tree seedlings. UNESCO and Parthenon Publishing Group, Paris.

Liebsch, D., M. C. M. Marques, and R. Goldenberg. 2008. How long does the Atlantic Rainforest take to recover after a disturbance? Changes in species composition and ecological features during secondary succession. Biological Conservation **141:**1717–1725.

Martins, R. B. 2011. Diagnóstico dos produtores de mudas florestais nativas do Estado de São Paulo. Programa Mata Ciliar, Secretaria de Meio Ambiente do Estado de São Paulo, São Paulo.

Merritt, D. J., and K. W. Dixon. 2011. Restoration seed banks—a matter of scale. Science **332:**424–425.

Mesquita, C. A. B., C. G. D. Holvorcem, C. H. Lyrio, P. D. Menezes, J. D. S. Dias, and J. F. Azevedo Jr. 2010. Cooplantar: a Brazilian initiative to integrate forest restoration with job and income generation in rural areas. Ecological Restoration **28:**199–207.

Myers, N., R. A. Mittermeier, C. G. Mittermeier, G. A. B. Fonseca, and J. Kent. 2000. Biodiversity hotspots for conservation priorities. Nature **403:**853–858.

Oliveira, M., A. Santos, and M. Tabarelli. 2008. Profound impoverishment of the large-tree stand in a hyper-fragmented landscape of the Atlantic Forest. Forest Ecology and Management **256:**1910–1917.

Ribeiro, M. C., J. P. Metzger, A. C. Martensen, F. J. Ponzoni, and M. M. Hirota. 2009. The Brazilian Atlantic Forest: how much is left, and how is the remaining forest distributed? Implications for conservation. Biological Conservation **142:**1141–1153.

Rodrigues, R. R., S. Gandolfi, A. G. Nave, J. Aronson, T. E. Barreto, C. Y. Vidal, and P. H. S. Brancalion. 2011. Large-scale ecological restoration of high-diversity tropical forests in SE Brazil. Forest Ecology and Management **261:**1605–1613.

Rodrigues, R. R., R. A. F. Lima, S. Gandolfi, and A. G. Nave. 2009. On the restoration of high diversity forests: 30 years of experience in the Brazilian Atlantic Forest. Biological Conservation **142:**1242–1251.

Santos, B., C. Peres, M. Oliveira, A. Grillo, C. Alves-Costa, and M. Tabarelli. 2008. Drastic erosion in functional attributes of tree assemblages in Atlantic Forest fragments of northeastern Brazil. Biological Conservation **141:**249–260.

SER (Society for Ecological Restoration). 2004. Society for ecological restoration international's primer of ecological restoration (available from http://www.ser.org/Primer). Accessed 13 October 2010.

Silva, J. M. C., and M. Tabarelli. 2000. Tree species impoverishment and the future flora of the Atlantic Forest of northeast Brazil. Nature **404:**72–74.

Smith, S. L., A. A. Sher, and T. A. Grant III. 2007. Genetic diversity in restoration materials and the impacts of seed collection in Colorado's restoration plant production industry. Restoration Ecology **15:**369–374.

Souza, F. M., and J. L. F. Batista. 2004. Restoration of seasonal semideciduous forests in Brazil: influence of age and restoration design on forest structure. Forest Ecology and Management **191:**185–200.

Tabarelli, M., A. V. Aguiar, M. C. Ribeiro, J. P. Metzger, and C. A. Peres. 2010. Prospects for biodiversity conservation in the Atlantic Forest: lessons from aging human-modified landscapes. Biological Conservation **143:**2328–2340.

Tepe, T. L., and V. J. Meretsky. 2011. Forward-looking forest restoration under climate change - are U.S. nurseries ready? Restoration Ecology **19:**295–298.

Viani, R. A. G., A. G. Nave, and R. R. Rodrigues. 2007. Transference of seedlings and aloctone young individuals as ecological restoration methodology. Pages 145–170 in R. R. Rodrigues, S. V. Martins and S. Gandolfi, editors. High diversity forest restoration in degraded areas: methods and projects in Brazil. Nova Science Publishers, New York.

Viani, R. A. G., and R. R. Rodrigues. 2009. Potential of the seedling community of a forest fragment for tropical forest restoration. Scientia Agricola **66:**772–779.

White, E., N. Tucker, N. Meyers, and J. Wilson. 2004. Seed dispersal to revegetated isolated rainforest patches in North Queensland. Forest Ecology and Managemen **192:**409–426.

Wunderle, J. M. Jr. 1997. The role of animal seed dispersal in accelerating native forest regeneration on degraded tropical lands. Forest Ecology and Management **99:**223–235.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1. List of all species obtained by the seven different strategies of collecting seeds or seedlings evaluated and their classification into some functional groups. In the planting group category, "filling" species represent fast growing and wide canopy species, whereas "diversity" species represent slow growing and/or narrow canopy species.