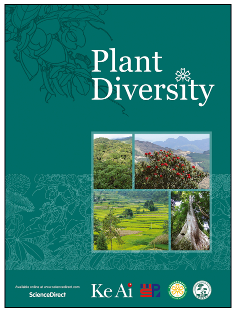

Species diversity in restoration plantings: important factors for increasing the diversity of threatened tree species in the restoration of the Araucaria forest ecosystem

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Title Page

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Species diversity in restoration plantings: important factors for increasing the diversity of threatened tree species in the restoration of the Araucaria forest ecosystem.

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Abstract:

The Araucaria forest ecosystem in southern Brazil is highly threatened: less than one percent of the original forest remains, and what is left is a fragmented agro-mosaic of mostly early-to-late secondary forest patches among high-yield agriculture and timber monocultures. Forest restoration initiatives in this region aim to restore degraded areas, however the limited number of species used in restoration projects represents a missed opportunity for species-rich plantings. High diversity plantings represent a larger number of functional groups and provide a targeted conservation strategy for the high number of threatened species within this ecosystem. This study interviewed nurseries (Ns) and restoration practitioners (RPs) in Paraná and Santa Catarina states to identify what species are being cultivated and planted, and what factors are driving the species selection process. An average of 20 species were reportedly used in restoration plantings, most of which are common, widespread species. Baseline data confirms that Ns and RPs have disproportionately low occurrences of threatened species in their inventories and plantings, supporting findings from pre-vious research. Questionnaire responses reveal that opportunities for seed acquisition are an important factor in order for nurseries to increase their diversity of cultivated species. Results also suggest that facilitating species-rich plantings for restoration practitioners would only be feasible if it did not increase the time required to complete planting projects, as it would impinge on their ability to minimize costs. This study proposes solutions for increasing the number of species used in restoration practice—such as developing a comprehensive regional species list, foster knowledge-sharing between actors, create seed sharing programs, and increase coordination of planting projects. Long-term strategies involve complimenting traditional ex-situ approaches with emerging *inter-situ* and quasi *in-situ* conservation strategies which simultaneously provide long-term preservation of genetic diversity and increase seed production of target species.

Keywords
restoration, Araucaria forest, threatened species, nurseries, restoration practitioners, decision-making

1. Introduction

1.1 Restoration of Degraded Land and Fragmented Forests

Over 20% of forest and agricultural lands in Latin America are degraded: 300 million hectares of the region's forests are considered degraded, and about 350 million hectares are classified as deforested, leaving many remaining forests fragmented (Vergara et al. 2016). Small forest fragments tend to retain a degraded structure (Tabanez & Viana 2000) as fragmentation promotes a decrease in species richness, a shift in the relative abundance of tree reproductive traits, and a reduction in the functional diversity of tree assemblages in fragmented landscapes (Girão et al. 2007). These effects drive fragments toward early-successional states (Pütz et al. 2011), leading to tree species impoverishment.

Governments in Latin America and the Caribbean have committed to bringing 20 million hectares of degraded land into restoration by 2020 (WRI 2017). In Brazil targets have been set to restore twelve million hectares of deforested and degraded forest land by 2030 through forest restoration initiatives (WRI 2016), and forest restoration is mandatory under the Native Vegetation Protection Law of Brazil (Law #12,651/2012). As a result there are a number of state, NGO, and corporate land restoration initiatives underway throughout the country (IUCN 2016; AFRP 2016). This level of restoration can provide myriad benefits to degraded land, such as restored biodiversity (including recovery of threatened species), increased ecological functioning, the supply of goods and ecological services, and the amelioration of rural poverty (Lamb et al. 2005).

Land can be restored passively or actively. Passive restoration is the spontaneous recovery of native tree species and active restoration requires planting nursery-grown seedlings, direct seeding, or mimicking disturbance regimes to speed up recovery processes. Although passive regeneration has been demonstrated to promote richer regeneration than active restoration at a fraction of the cost, it is not more effective in highly fragmented areas where population levels are low and species rich communities cannot be naturally recruited (Crouzeilles et al. 2017). Active restoration is most appropriate for fragmented forests, thus this paper is limited to the role of nursery-grown seedlings in restoration plantings.

1.2 Species Selection in Restoration Interventions

There are differing recommendations for the ideal number of native species to be included in restoration plantings, each which depend on particular restoration objectives. The “Framework Species Approach” recommends 20-30 species (Goosem & Tucker 1995). However, high-diversity plantings, defined by 80-90 species per hectare, are preferable to lower-diversity plantings as this number of species represents multiple functional groups that a smaller number of common and fast-growing species lacks (Rodrigues et al. 2009). When restoration includes a limited set of 20-30 taxa, the “restored” area cannot achieve maximal functionality; it cannot recruit threatened species under pressures such as lack of seed flow from neighboring locations, small population sizes, competition, and encroachment (Volis 2016b). Conversely, the more threatened species included, the more representation for taxa with narrow regeneration niches and limited dispersal abilities (Volis 2016b).

The delivery of high-diversity plantings are a challenge within the restoration industry, as the instability of native species markets and problems with the commercialization of native seedlings usually result in species bottlenecks (Bozzano et al. 2014; Silva et al. 2014). In Mexico 60-80 species have been demonstrated to be a financially feasible target number, but due to constraints within the market only 20-30 are typically used (Arroyo-Rodríguez et al. 2009).

It is valuable to include threatened species in high-diversity plantings, as they are exceedingly vulnerable in fragmented landscapes. Threatened populations are expected to continue decreasing due to time-lag biological responses even if no further degradation occurs (Metzger et al. 2009), compounded with bottlenecks in genetic diversity (Sork & Smouse 2006). Furthermore, permanent distortions of species composition in favor of abundant dominant or dispersal-efficient subdominant species in fragmented landscapes makes rare and threatened species disproportionately vulnerable to extinction due to their limited immigration and colonization abilities (Maina & Howe 2000; Tabarelli et al. 2005). Given their increased vulnerability in fragmented landscapes, therefore, inclusion of threatened species is an essential strategy to support their *in-situ* conservation, which is a key goal in ongoing restoration projects in the Latin America region (Gill et al. 2017).

1.3 Constraints on Species Selection

Although high-diversity plantings are demonstrably more successful in terms of maximizing representation of functional groups and therefore ecosystem function, there are various practicalities imposing restraints on the ability of restoration actors to use a large number of species—including threatened species—in their plantings. Restoration actors attempting to balance species richness goals with their available resources must consider a multitude of factors in their species selection processes. The scope of this paper focuses on two primary actors in the restoration supply chain: nurseries who grow seedlings for restoration projects, and restoration practitioners who purchase seedlings from nurseries in order to carry out restoration plantings.

Nurseries encounter seed sourcing, collection, production, and storage of species as significant challenges to their use (Jalonen et al. 2017; Ladouceur et al. 2017), as well as adequate information on a wide range of species, preventing their ubiquity in plantings (Hoffmann et al. 2015). Nurseries are restricted by their ability to travel to seed sources and the technical feasibilities of wild seed collection in adequate quantities. Specific barriers include limited number of individuals and populations, difficulty and cost to access these populations, in addition to narrow collection windows, seed crops of mixed maturity, and atypical germination patterns (Broadhurst et al. 2016; Hoffmann et al. 2015). Currently native seed collection is forbidden in Protected Areas, which limits 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 (Silva et a. 2016). Further restraints include low market prices for seedlings which result in lack of motivation for nurseries to diversify their stock, and relationships with restoration practitioners who request a limited set of species (Jalonen et al. 2017; Volis 2016a).

Restoration practitioners—those who purchase seedlings from nurseries—must choose species with ecological properties advantageous to plantings, such as high survival and growth rates in degraded sites, dense crowns that shade out herbaceous weeds, provision of resources that attract seed dispersers at early restoration stages, and natural regeneration capacity (Blakesley et al. 2002; Lindell et al. 2013; dos Santos et al. 2008). Restoration practitioners tend to use common and widespread species because they are ubiquitous in nurseries and have high success rates once planted (Aronson et al. 2011). Although the selection of a limited set of species produces successful plantings, it can lead to the homogenization of restored areas with few, widespread species dominating the landscape (Silva et al. 2016).

Given these competing considerations, diversity is seldom prioritized and typically only common or commercially important species are cultivated in large numbers and used for plantings (Jalonen et al. 2017). This leads to a species bias (Broadhurst et al. 2016), where a few core species that can be reliably and readily sourced, easily stored and germinated are selected by nurseries, and these same reliable species are then purchased by practitioners. Biased selections deliver cost-effective outcomes with low risk to both nurseries and practitioners, but they represent only a fraction of species required to reconstruct diverse and resilient restoration outcomes (Volis 2016b).

1.4 Restoration of the Araucaria Forest

The subtropical Araucaria forest ecosystem in Brazil is a unique case for restoration as so little remains: less than 0.8% of the original forest is extant in advanced successional stages, none of which is considered primary forest (Castella & Britez 2004). It is a subregion of the Atlantic Forest biome—a global biodiversity hotspot (Myers et al. 2000)—and hosts 352 known tree species (Leite

& Klein 1990). There are currently 71 taxa classified as threatened (39) and rare (32) (Appendix A)[1], which comprises 20% of all taxa in this ecosystem.

The original extent of the Araucaria forest is an estimated 25,379,300 ha (Ribeiro et al. 2009), yet historic timber exploitation and intensive agriculture has led to large-scale loss of forest habitat. Today the landscape is an environmental agro-mosaic with small patches of edge-affected Araucaria forest remnants <50 ha (Ranta et al. 1998; Gascon et al. 2000; Ribeiro et al. 2009), early-to-late secondary forest patches recovering from cropland or pasture abandonment (Tabarelli et al. 2010), high-yield agriculture (Fonseca et al. 2009), and ecologically-managed monocultures of *Pinus* and *Eucalyptus* timber plantations (Carlos et al. 2009) which have been steadily expanding in the last three decades (Fundação 2001; Baptista & Rudel 2006).

As the Araucaria forest is comprised of highly fragmented populations, actors must employ active restoration projects with a diverse species composition that promotes successful recruitment and establishment. Evidence of successful legislative high-diversity minimum requirements in Brazil exist: São Paolo state has the exemplary minimum requirement of 80 native species per hectare (Wuethrich, 2007). Unfortunately, the Brazilian states where the Araucaria forest ecosystem is located do not have such requirements. Although restoration projects in this region must legally be comprised of native species, there is no law specifying which or how many species should be used, and consequently a limited selection of approximately 10-20 common species are typically found in plantings (Pablo Hoffmann 2016, pers.comm., 17 December). Silva et al. (2016) reports that most nurseries do not meet their production capacities, which represents a practical and currently missed opportunity to increase the native seed quantity and diversity within inventories.

[1] This list is adapted from Hoffmann et al. (2015), but this paper advocates for many of the species' threat statuses to be updated, given their observed rarity in the field. It is likely that in actuality their threaten statuses are more severe.

1.5 Research Objectives

In support of the *in-situ* conservation of the Araucaria forest generally and threatened species specifically, targeted high-diversity restoration is essential. Given that commitments to restoration are presently underway, optimal strategies may be identified in order to use available resources for the deliberate protection of a wider number of species. To identify logistical opportunities for less species-biased choices, the present study examines drivers of the species-selection process for nurseries and restoration practitioners.

This study interviewed nurseries and restoration practitioner organizations working in the Araucaria forest to (1) identify a baseline sample of what species are produced and planted in restoration projects; and (2) identify which factors are most important in governing species selection. Nurseries and restoration practitioners will hereafter be referred to as Ns and RPs, respectively.

2. Methods

2.1 Study Area

The original extent of the Araucaria forest ranges from 53.95613ºW to 48.22327ºW (west to east), and from 23.56218ºS to 29.74095ºS (north to south) throughout Paraná, Santa Catarina, and Rio Grande du Sol states in southern Brazil. Interviews were conducted within the original Araucaria forest extent in Paraná and Santa Catarina (Figure 1), however due to resource limitations inter-views were not conducted in Rio Grande do Sul. According to the AFRP identified land suitable for restoration (Calmon et al. 2011), Paraná is suitable for the largest area of restoration (2,455,537 ha), followed by Santa Catarina (1,402,183 ha) and Rio Grande du Sol (891,716 ha). Paraná state nurseries are also the main producers for restoration efforts in the Araucaria forest region (Martins et al. 2004), so interviews were prioritized for Paraná and subsequently Santa Catarina.

2.2 Interviews

Ns and RPs were identified from a combination of sources: Diagnosis of the Production of Native Forest Seedlings in Brazil (Silva et al. 2015); Embrapa, an agricultural research institution's nursery list (Embrapa 2017); the Brazilian Institute of Forestry nursery list (IBF 2017); Environmental Institute of Paraná registered nursery list (IAP 2017); contacts from previous nursery research from The Nature Conservancy; and Internet searches. Participants were selected by stratified random sampling method: nurseries were grouped according to municipality and participants within each group were randomly selected and asked via telephone to participate in the study. Those who agreed were scheduled for an in-person interview. The sample represented a gradient of demographic variables such as size and public/private nurseries, and were relatively evenly distributed throughout the study area. RPs were not stratified by location because most had centrally located offices in Curitiba, Paraná's capital city, although they coordinate plantings throughout the entire study area.

2.3 Data Collection

2.3.1 Baseline Data

Structured interviews (Neuman 2014) were conducted in Portuguese from April to June 2017. The 36 interviews comprised of 20 Ns (9 public, 11 private) and 16 RPs (11 private consultants, 4 NGOs, 1 government agency). N participants were nursery managers and RP participants were company owners, managers, or high level staff involved in planning and coordinating restoration projects.

During each N interview, annual inventory lists were collected to ascertain species occurrence, as defined by which species were present/absent in any given nursery. Abundance, defined by the quantity of present species produced annually, was also recorded. The RP interviews collected similar data, although occurrence is defined by which species were present/absent in any plantings of the past year, and abundance is defined by the quantity of each species planted annually. Species which were only present on one nursery or planting list were noted but excluded from further analysis, as the majority of species were singly occurring and would have skewed the results to disproportionately represent rarely occurring species as commonly present.

2.3.2 Questionnaires

Separate structured questionnaires were given to Ns (Appendix B) and RPs (Appendix C) to assess the economic, technical, and institutional constraints on species selection. Questionnaires were composed of open-ended, multiple-choice, and Likert-scale response (Likert 1932) questions. The N questionnaire was composed of 62 questions in the following categories: infrastructure, business objectives, seedling sale, technical knowledge, market and client needs, seed acquisition methods, fluctuations in nursery operational activity, regulations, inventory decision-making processes, and incentives for using threatened species. The RP questionnaire was composed of 64 questions in the following categories: project planning, business objectives, nursery selection, species selection, staffing, and the planting process.

3. Results

3.1 Baseline Sample

Participant responses provided baseline data on how many species are present in N and RP inventories (Table 1). In total 139 native species were found to occur in two nurseries or more (Appendix D). Only 25 tree species were occurred in nine (median occurrence) or more nurseries. In RP lists, 63 tree species occurred in two or more plantings (Appendix E), although only 18 species occur in six plantings (median occurrence) or more. The mean number of occurring species (richness) is 34 in nurseries and 21.8 in RP planting lists.

Although 20% of Araucaria forest taxa are threatened, less than 20% of recorded occurrence and abundance are comprised of threatened species. Of the Ns and RPs which had high occurrences of threatened species (defined as >median occurrence), their inventories showed a significantly lower proportion of threatened species which one would expect to occur by chance (N: $t(138)=4.19$, $p < 0.001$; RP: $t(61) = 2.92$, $p < 0.005$). Of the taxa commonly occurring in N and RP lists (>median frequency), only 4.6% (N) and 4.7% (RP) are threatened.

3.2 Questionnaire Responses

3.2.1 Factors Governing Species Selection in Nurseries

N responses indicated that although 40% of nurseries purchase seeds and 15% farm seeds, 100% of nurseries participate in wild seed collection. This practice enables nurseries to acquire seeds for free and they are only limited by the resources (fuel, time, and staff labor) required for travel and seed collection. One hundred percent of Ns reported that on seed collection trips they do not target certain species but rather collect any seeds they happen across. Ninety percent of nurseries reported adding additional species to their inventory in the last year, the primary reason (55% of responses) being opportunistic: they simply found a new species' seeds in sufficient quantity.

Seedlings most commonly occurring in N inventories were common species easily available for seed collection. When asked which species were most easy and inexpensive to acquire, common species were most frequently reported, with the exception of *Araucaria angustifolia,* which is a flagship species and despite its threatened status is found in every nursery (and therefore is also easy and cheap to acquire). Conversely, when asked what are the most difficult and expensive species to acquire, mostly threatened species were cited (Table 2). "Sporadic seed availability", "technically advanced seed collection requirements" and "difficult to access" were cited as primary reasons for difficulties collecting these species.

Nursery participants were asked to score a list of barriers that prevented them from increasing the number of threatened species in their inventory. The highest mean scores were "seeds too far away" (8/10), "difficult to find seeds" (8/10), and "not enough resources to acquire seeds" (7/10) (Figure 2a). Customers wanting or not wanting the seeds was not highly scored (5.5/10). When N respondents were asked their reasons for the addition of a new species to their inventory, only 35% cite "customer request" as a reason. Seventy percent of nurseries would be willing to add threatened species to their inventory if clients would pay more, but only 25% believe they would. These scores indicate that nurseries do not consider customer demand as a high priority, and that it is not driving their species selection decision-making process.

3.2.2 Factors Governing Species Selection for Restoration Practitioners

When RPs were asked to cite the greatest barriers to increasing the use of threatened species in their plantings, nurseries simply not carrying those species was the most cited reason (Figure 2b). When asked to select only one driving reason that would limit their use of threatened species, the majority (62.5% of responses) cited an absence of those species in nursery inventories; the next most cited reason was price (18.75%). Nurseries, regardless of customer demand, are simply not carrying these species, thus eliminating the option for RPs to include them in their plantings.

Another factor which proved important to the decision-making process was willingness of RPs to be flexible with their planting list. Respondents were more likely to adapt their planting list to match what a nursery had on hand than search for another nursery with a more species-diverse stock of seedlings. Of RPs, 81.25% reportedly come to nurseries with pre-defined lists of species, although 75% of RPs were willing to shorten their list if the nurseries do not carry all the species on it. N responses substantiate the RP claims: when a client discusses a species list with a nursery, 30% of Ns report that the clients request specific species, while 70% say their clients are willing to purchase whatever the nursery has in its inventory. Taken together, most RPs are more likely to change their lists than spend time contacting and liaising with multiple nurseries.

Rather than receiving an order with adequate time to grow the requested amount of seedlings, nurseries are expected to have large quantities of seedlings in stock at all times, with little or no notice before making a potential sale. The mean advance notice a typical RP gives a nursery prior to transaction is 1.5 days. The mean time RPs plan a planting is 4.1 weeks. As plantings happen relatively quickly, the time it takes participants to find a suitable nursery carrying all the species on their original planting list would consume a considerable amount of their overall planning time, impacting their profit margin.

When asked to rate on a 1-10 scale the different considerations involved in selecting which nursery to purchase seedlings from, “timely delivery” and “price” were rated the most important reasons. When asked to choose one primary reason driving nursery selection, the majority of RPs selected price as the primary factor (43.75%). On average RPs rated 9.77/10 level of interest in increasing their use of threatened species, however because price and time are limiting factors, one can infer that despite a strong reported interest their decisions are ultimately governed by minimizing costs.

The mean number of species RPs used in plantings was 20.73, which is notable given in another question RPs reported a mean number of 30.1 species as “sufficient for a quality planting”, and 73.5 species as an “ideal number for any quality planting”. RPs, given their priorities of price and time, are on average knowingly planting fewer species than they consider sufficient or ideal for a quality planting (which supports the difficulties outlined by other authors (Rodrigues et al. 2009)).

4. Discussion

4.1 Seed Availability

The Southeast region of Brazil has the greatest amount of nurseries and produces the largest quantities of seedlings compared to other regions in Brazil, yet has the smallest *variation* in the number of species produced between nurseries (Silva et al. 2015). While nurseries across the region vary greatly in their capacity to produce a diverse range of native seedlings (Silva et a. 2016), the present study demonstrates that N inventories in the Araucaria forest region focus on a disproportionally low number of threatened species in occurrence (17.9% occurring in two nurseries, 5% occurring in 7 or more) and abundance (comprising 13.8% of total abundance). RPs have lower species occurrences in their plantings than the ideal recommended amount (80-90), instead planting on average 21 species, supporting previous findings which draw the same conclusions (Volis 2016b; Aronson et al. 2011).

Although consumer demand did not emerge as a crucial driver of species selection for Ns, opportunities for seed acquisition were found to be extremely important. Ns cannot acquire more species without expending considerably more of their resources on accessing new seeds and cultivating them in large enough quantities for an RP to immediately purchase. RPs are unwilling to spend additional back-and-forth time with nurseries in order to request and secure a more species-rich planting, which in turn makes nurseries less likely to carry a wider variety of species in the future.

In both public and private nurseries, the two most highly reported factors impeding the increased use of threatened species are lack of resources and opportunity for seed acquisition. This is a common difficulty in other regions of Brazil (Brancalion et al. 2011) and countries in Europe (Bischoff et al. 2008). If nurseries, therefore, could acquire additional species' seeds at no or minimal extra cost, which would not then be passed on to practitioners, one of the substantial hurdles would be eliminated which could spur increased adoption of threatened species for both N and RP actors.

4.2 Short-term Actionable Recommendations

As the existing restoration framework currently does not provide incentives to increase the number of species for Ns and RPs, actionable steps must be outlined to preferentially improve access to currently under-represented and threatened taxa. Results suggest that increasing seed availability is a most crucial factor governing the species selection decision-making process, and is therefore the first step toward increasing diversity in nurseries and subsequent restoration plantings. The following recommendations mirror similar recommendations put forth by other researchers in this field (Silva et al. 2016; Jalonen et al. 2017), and are geared toward increasing seed availability and improving the conditions which would enable actors to broaden the focus of seed collection and restoration efforts to include more (including threatened) species.

4.2.1 Comprehensive Species List

The creation of a comprehensive list of species is crucial if restoration actors are to know what variety of species are available to them and appropriate for their site. Paraná-based NGO Sociedade Chauá provides such lists, grouped by region (http://www.sociedadechaua.org/floraparana). They include identifying photos and cultivation information for public use. Comprehensive lists such as these could also provide assessments of the state of wild seed supply for collection, information which would be useful to all nurseries who participate in wild seed collection.

4.2.2 Foster Knowledge-Sharing

Adequate information about each species on a comprehensive list is necessary for actors to successfully use these species. Insufficient knowledge of threatened species' reproductive biology, and lack of efficient propagation and planting methods are primary barriers for their use in restoration projects (Volis 2016a). Some Araucaria forest species exhibit seasonal fluctuations in phenology, have low levels of fruit production, or produce a high proportion of non-viable seeds (due to maturation and predation complications), hence the timing and ease of seed collection remains a constant challenge (Hoffmann et al. 2015).

In addition to further empirical research on less-studied species, expanding and strengthening a network of stakeholders in public and private forums can provide opportunities for exchange of cultivation and planting knowledge. Policy regulations alone are not sufficient to meet restoration goals (Silva et al. 2016); they must be simultaneously approached from the stakeholder perspective as a sustainable and feasible economic activity (Brancalion et al. 2012). When stakeholders can develop their knowledge base and exchange success stories, confidence and perceived feasibility of adopting a wider variety of species increases. The stronger the network and exchange of knowledge, the more these networks can produce flexible approaches, increased competency of practitioners, and less risk in implementing new strategies (Nyoka et al. 2015).

4.2.3 Seed Sharing Program

A seed exchange program is an organized group of seed harvesters with training and coordination for native seed production which could distribute seeds throughout a network of nurseries interested in growing a wider range of threatened species. This solution has been piloted elsewhere in the Atlantic forest (São Paolo state), has proven to be an effective support of high-diversity reforestation initiatives (Brancalion et al. 2011), and such decentralization of seedling production has been recommended by leaders in community- and industry-based restoration communities (Merritt & Dixon 2011; Nevill et al. 2016; Silva et al. 2016). Programs with collaborative participation between independent seed collectors, community-based organizations, and local seed exchange programs have shown to yield increased restoration diversity—measured by number of species and seed lots—than relying on any one strategy alone (Brancalion et al. 2011).

Seed sharing programs which span over 100km (long-distance germplasm exchange) are particularly advantageous, given that distance still falls within a species' native range. Although local germplasm sourcing is important to maximize local adaptations in plant traits and avoid outbreeding depression (Mijnsbrugge et al. 2010; Edmands 2006), doing so in highly fragmented landscapes produces poor restoration outcomes, so on balance actors should prioritize high quality and highly diverse seeds (Broadhurst et al. 2008, Bischoff et al. 2008). Mixing provenances of germplasm increases the genetic diversity of seed in addition to enhancing taxonomic diversity. Seeds of mixed provenances within a participating network result in enhanced seed quality (Brancalion et al. 2011) which is critical to successful restoration efforts. Enhanced seed quality reduces germination and cultivation risk for Ns, and reduces risk for RPs who have a vested interest in a high survival rate in their plantings. High seed quality also provides resilience of restored areas to climate change, now an important consideration in any restoration project (Jalonen et al. 2017). Moreover, seed sharing networks will positively feed back on comprehensive species lists, associated collective knowledge, and seed sources of local tree species.

4.2.4 Increased Coordination of Plantings

Increasingly linked stakeholder networks can also produce more coordinated plantings within the RP community. As Ns are encouraged to increase the variety of species available in their nurseries, RPs can likewise improve the degree to which they link their plantings to other plantings in the region. Three quarters of RPs reported mean planting areas of 5 ha or less, while three RPs reported plantings of 115, 200, and 300 ha, raising the mean planting area to 41.87 ha. Even the largest reported plantings (mean 268.9 ha) are still considered small in terms of forest fragments in the Atlantic forest, which are defined by Oliveira et al. (2008) as < 300 ha and Ribeiro et al. (2009) as <100 ha. Given that restoration plantings in this region are at best restoring fragments, it is crucial to maximize restoration impact by coordinating plantings occurring in neighboring areas, ideally serving to link and bolster populations of newly added species.

Coordinated restoration efforts across the entire North American Great Lakes region have demonstrated to be nine times more cost-effective than individual local-scale planning (Neeson et al. 2015). Coordinated efforts also work in direct opposition to habitat fragmentation, one of the leading causes of declining biodiversity and ecosystem services (Fahrig 2004). Although coordinated plantings at a landscape level have historically been a major challenge for this region (Rodriguez et al. 2009), they are critical to restoring land on a large enough scale to promote a diverse, healthy, ecologically functional ecosystem (Lopes et al. 2009).

Currently RP projects act in isolation of one another and are planting mostly common species which have reliable establishment success rates. Instead than asking individual RPs to add a large quantity of new species (high risk), RPs can coordinate their planting lists to each add a small quantity of new species (low risk), which cumulatively expand the richness of planted species in a given region. Coordination between RPs will serve as a decision-support tool for species selection (Beier et al. 2011), and will help actors identify linkage opportunities which is currently not possible.

4.3 Long-term Strategies

Wild seed collection requires ethical and genetic considerations, particularly when collecting threatened and rare species (Broadhurst et al. 2016). Seed collection of threatened species should be targeted and limited, where the fewest sufficient number of seeds should be collected under strict ecological criteria, in order to prevent decimating any given population’s ability to sustain itself naturally. Extremely rare species or those having small isolated populations require expert and targeted intervention organized by appropriate conservation organizations, meeting minimum collection requirements before removing any seeds from the wild (Jalonen et al. 2017). The global assessment of forest genetic resources adopted by the FAO (2013) calls for policymakers to reinforce national seed programs to provide sufficient quantities of genetically appropriate seeds for restoration so as not to exhaust wild populations. Hence *ex-situ* seed farming programs are an essential long-term component to the conservation of threatened species, as current and future demand for seeds exceed the volume that can be practically and economically sourced from the wild (Nevill et al. 2016).

Intermediate approaches which combine and bridge *in*- and *ex-situ* strategies exist as long-term methods that can be used for increasing species richness in restoration efforts (Volis 2017). While botanical gardens and arboreta host small *ex-situ* living collections, opportunities for *inter-situ* collections exist in areas such as abandoned agricultural lands. These designated areas can exist outside of the current species range but within the past range of a species (Burney & Burney 2007), and can host a wider range of species in larger numbers than are typically possible in strictly *ex-situ* operations (Volis 2017). *Inter-situ* collections can be planted to simultaneously reintroduce a large number of threatened species and restore degraded lands, an ideal conservation solution for highly fragmented regions.

Quasi *in-situ* (Volis & Blecher 2010) collections are another solution appropriate for a highly fragmented region such as the Araucaria forest, defined as “living collections in protected areas under natural or semi-natural conditions, where site selection accounts for local adaptation, and focuses on preservation and production of plant material”. Planting threatened species outside their current natural range can be advantageous in light of anticipated range shifts due to climate change (Vitt et al.2016; Butterfield et al., 2016), particularly when there are few alternatives as extant populations are so rare and isolated. This method would produce a large quantity of plant material, relieving pressure on nurseries to access and collect rare and threatened samples from the wilds.

Complementing the inter-situ method, the quasi in-situ method focuses on preserving locally-adapted genetic variation and producing large quantities of seeds of species that present the greatest challenge in regional restoration projects. In Belgium, seed orchards propagating locally sourced planting stock have successfully demonstrated the ability to preserve local adaptations and a diverse range of native plants in highly fragmented areas (Vander Mijnsbrugge 2014). Even in extreme cases of critically endangered species of as few as 30 remaining individuals, seed orchards outside a species' current natural range have been demonstrated to increase genetic diversity of future generations, while also creating more planting material *ex-situ* without detracting from the existing population (Ducci 2014). These newly emerging, adaptive methods are recommended as long-term strategies to increase the use of threatened species in restoration plantings in the Araucaria forest region.

4.4 Conclusion

Although this study is not exhaustive in sample size or potential decision-making factors to investigate, it provides a baseline sample of what species are commonly used in the restoration industry, and baseline information on N and RP attitudes over a large study area in the Araucaria forest. It provides evidence that some factors such as seed acquisition and financial risk are more important drivers of species selection than others, such as customer demand.

Overcoming limitations at various stages of the restoration process will improve the likelihood of increased species use, including threatened species. A multifaceted approached would maximize the ability for restoration actors to increase species richness: (1) seed acquisition support enabling nurseries to carry more species in adequate quantities on hand; (2) increase knowledge of threatened species so restoration practitioners can make informed decisions on which species they can confidently add without depressing status quo survival rates; (3) increasing opportunities for Ns and RPs to create stakeholder networks where knowledge, seeds, and landscape-level plans can be shared between actors; and (4) employ long-term *inter-situ* and quasi *in-situ* conservation strategies which simultaneously provide long-term preservation of genetic diversity and increase seed production of target species. With a balance of practical considerations, it is possible for restoration plantings in the Araucaria forest region to be species-rich, representing an increased number of functional groups and targeted for the conservation of threatened species at risk of extinction.

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Tables

Table 1. Summary of native species occuring in Nursery (N) annual inventories and Restoration Practitioner

N/RP	Total No. Species Present* (Occurence)	Total Native Species Present, Single Occurrence Removed	No. Species Occurring > Median Freq. (over half the lists)	Total Abundance	Threatened Taxa Present (% of Total Occurrence)	No. Threatened Species Occurring >Median Freq. (% of Total Occurrence)	Combined Abundance Threatened Species (% of Total Abundance)
$N_{(n=20)}$	354	139	25	12,554,600	25 (17.9%)	7 (5.0%)	1,732,535 (13.8%)
$RP_{(n=16)}$	154	62	18	870,122**	17 (27.4%)	3 (4.8%)	147,050 (16.9%)

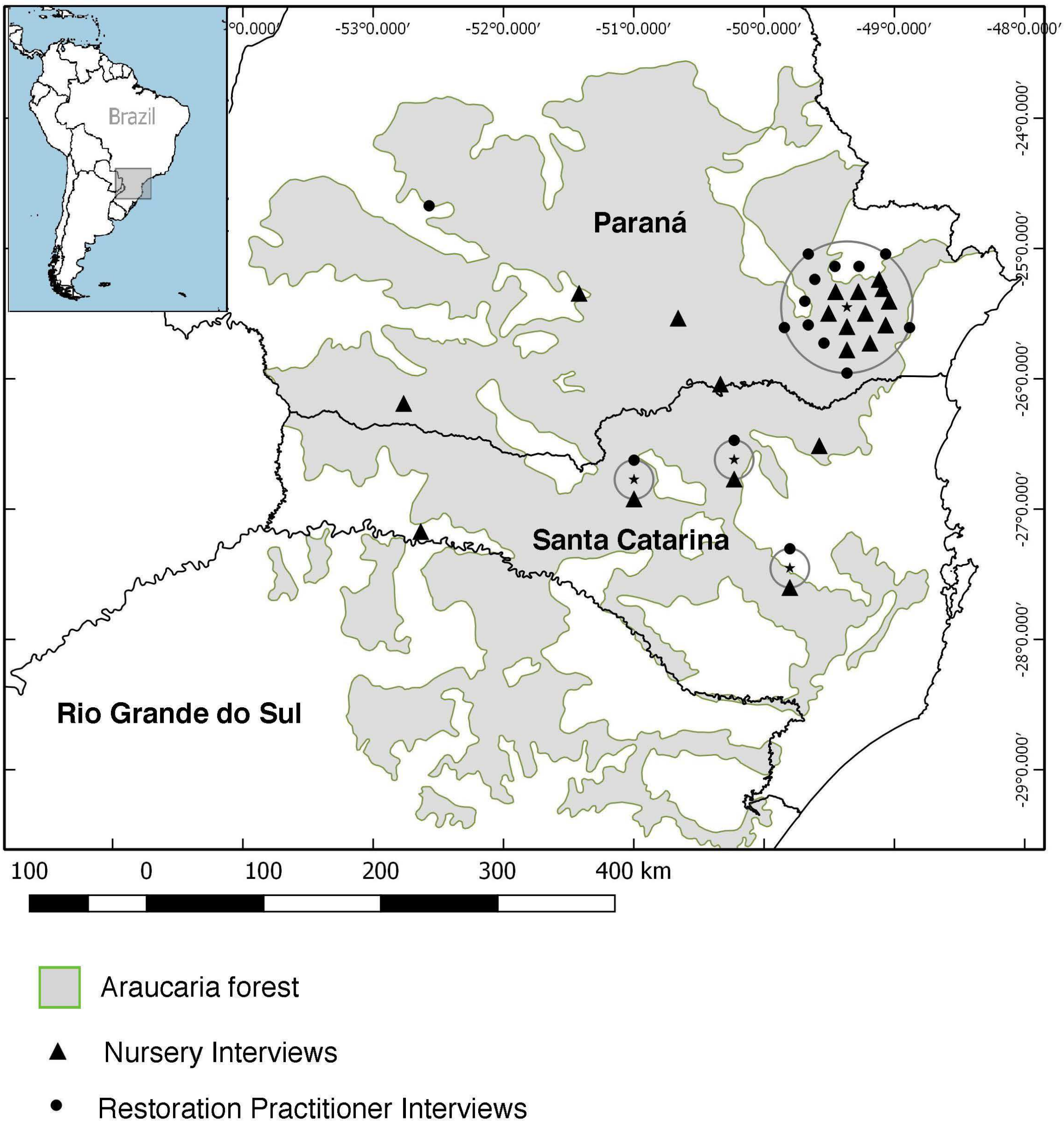
*Including non-tree and exotic species
**n=9 (not 16); RP participants were able to tell us which species they used but were unable to provide quantities.

(RP) annual planting lists. Data collected April-June 2017 in Paraná and Santa Catarina, Brazil.

Table 2. Species most often cited for open-ended seed acquisition questions in Nursery Questionnaire. Highest ranking three species for each question are listed; ties for a ranking are also included (ranking 1 = mentioned most, 2 = mentioned second most, 3 = mentioned third most).

Category	Species	Ranking	Threat Status
Easy to Acquire	Araucaria angustifolia	1	Near Threatened[1], Endangered[2], Critically Endangered[4]
	Psidium cattleianum	2	-
	Eugenia uniflora	3	-
Inexpensive to Acquire	Araucaria angustifolia	1	Near Threatened[1], Endangered[2]
	Eugenia uniflora	1	-
	Eugenia involucrata	2	Rare[3]
	Psidium cattleianum	2	-
Difficult to Acquire	Ocotea odorifa	1	Near Threatened[1], Endangered[2], Vulnerable[4]
	Ocotea porosa	2	Near Threatened[1], Endangered[2], Vulnerable[4]
	Caesalpinia echinata	3	Endangered[4]
	Cedrella fissillis	3	Endangered[4]
Expensive to Acquire	Ocotea odorifa	1	Near Threatened[1], Endangered[2], Vulnerable[4]
	Ocotea porosa	2	Near Threatened[1], Endangered[2], Vulnerable[4]
	Cedrella fissillis	3	Endangered[4]
	Jacaranda puberal	3	-
	Caesalpinia echinata	3	Endangered[4]

[1] SEMA (1995); [2] MMA (2008); [3] Hoffmann (2015); [4] IUCN (2013)



Figures

Figure 1. Original distribution of the Araucaria forest in southern Brazil. Interviews are demarcated by triangles (nurseries) and circles (restoration practitioners) and were conducted from April 25th to June 9th, 2017.

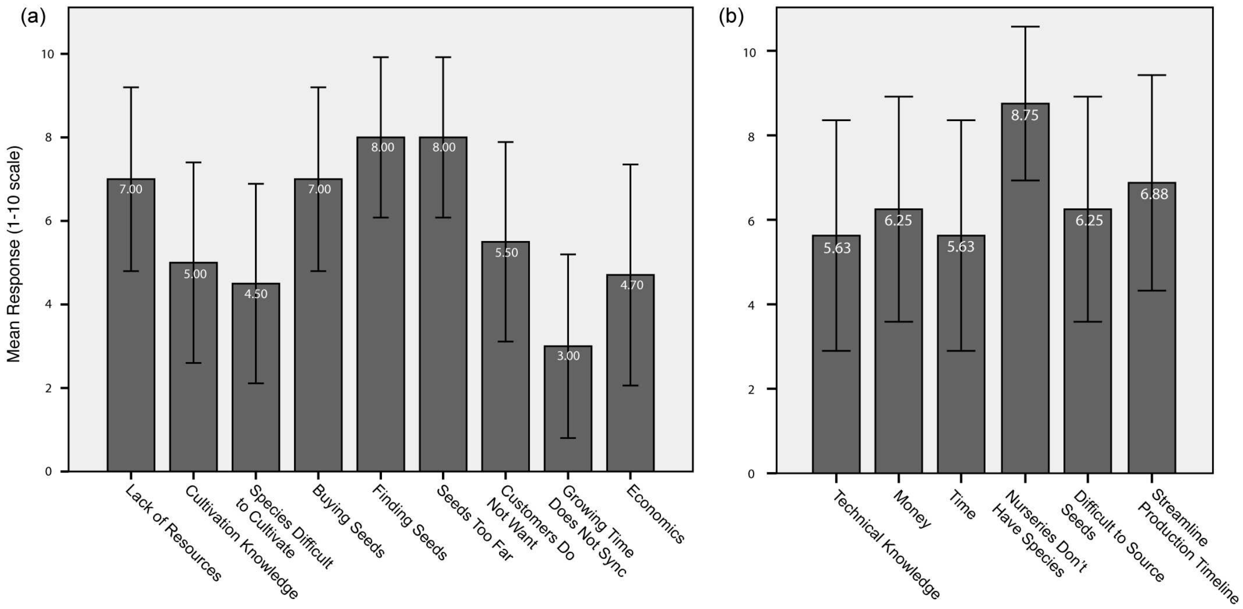


Figure 2. Mean responses of (a) Nurseries and (b) Restoration Practitioners in Paraná and Santa Catarina states, Brazil (2017) when asked to rate a 1-10 scale (1 = not important, 10 = very important) on various potential barriers to adding threatened species to their inventories. Means are listed in white. Error bars represent 95% CI.

Appendices

See attached PDF. These appendices need not accompany the published articles (they are very long), but can be made available electronically should anyone wish to see them.

Appendix A.1. List of threatened and rare tree species native to the Araucaria forest ecosystem (39 threatened, 32 rare), adapted from Hoffman et al. (2015). Of the threatened species, 14 were listed only in the Paraná state Red List (SEMA 1995), one was listed only in the national Red List (MMA 2008) and 17 were categorized as globally threatened (IUCN 2013).

	Species	Threat Status
1	*Acca sellowiana*	Rare
2	*Agarista pulchella*	Rare
3	*Agonandra excelsa*	Rare
4	*Albizia burkartiana*	Vulnerable[3]
5	*Albizia edwallii*	Vulnerable (3)
6	*Aloysia hatschbachii*	Endangered[1]
7	*Araucaria angustifolia*	Near Threatened[1]; Endangered[2]; Critically Endangered[3]
8	*Azara uruguayensis*	Endangered[1]
9	*Bunchosia pallescens*	Rare
10	*Butia eriospatha*	Endangered[2]; Vulnerable[3]
11	*Casearia lasiophylla*	Data Deficient[3]; Rare
12	*Cassia leptophylla*	Rare
13	*Castela tweedii*	Rare
14	*Cedrela fissilis*	Endangered[3]
15	*Cedrela lilloi*	Data Deficient[2]; Endangered[3]
16	*Chionanthus filiformis*	Near Threatened[3]
17	*Colletia paradoxa*	Rare
18	*Cunila incana*	Endangered[1]
19	*Curitiba prismatica*	Rare
20	*Cybistax antisiphylitica*	Rare
21	*Cyphomandra diploconos*	Near Threatened[3]
22	*Eugenia involucrata*	Rare
23	*Eugenia pyriformis*	Rare
24	*Gleditsia amorphoides*	Endangered[1]; Data Deficient[2]
25	*Handroanthus albus*	Rare
26	*Ilex paraguariensis*	Near Threatened[3]
27	*Inga lenticifolia*	Endangered[1]; Vulnerable[3]
28	*Inga sellowiana*	Endangered[3]
29	*Lafoensia pacari*	Rare
30	*Lonchocarpus muehlbergianus*	Near Threatened[1]
31	*Machaerium brasiliense*	Rare
32	*Machaerium paraguariense*	Near Threatened[1]
33	*Maytenus aquifolia*	Rare
34	*Maytenus boaria*	Rare
35	*Maytenus dasyclada*	Rare
36	*Maytenus ilicifolia*	Near Threatened[1]
37	*Mimosa urticaria*	Endangered[1]

Appendix A.2

	Species	Threat Status
38	*Myrceugenia bracteosa*	Vulnerable[3]
39	*Myrceugenia gertii*	Endangered[1]
40	*Myrceugenia hatschbachii*	Data Deficient[2]; Rare
41	*Myrceugenia miersiana*	Near Threatened[3]
42	*Myrceugenia scutellata*	Near Threatened[1]; Vulnerable[3]
43	*Myrcia selloi*	Rare
44	*Myrcianthes gigantea*	Rare
45	*Myrcianthes pungens*	Endangered[3]
46	*Myrciaria cuspidata*	Vulnerable[3]
47	*Myrocarpus frondosus*	Near Threatened[1]; Data Deficient[3]
48	*Ocotea catharinensis*	Near Threatened[1]; Endangered[2]; Vulnerable[3]
49	*Ocotea nutans*	Rare
50	*Ocotea odorifera*	Near Threatened[1]; Endangered[2]; Vulnerable[3]
51	*Ocotea porosa*	Near Threatened[1]; Endangered[2]; Vulnerable[3]
52	*Oreopanax fulvus*	Near Threatened[1]
53	*Ouratea sellowii*	Rare
54	*Picramnia excelsa*	Rare
55	*Picrasma crenata*	Rare
56	*Podocarpus lambertii*	Near Threatened[3]
57	*Quillaja brasiliensis*	Vulnerable[1]
58	*Rollinia salicifolia*	Endangered[1]
59	*Ruprechtia laxiflora*	Rare
60	*Sambucus australis*	Rare
61	*Schinus engleri*	Data Deficient[3]; Rare
62	*Scutia buxifolia*	Rare
63	*Sloanea lasiocoma*	Rare
64	*Solanum melissarum*	Near Threatened[3]
65	*Solanum pinetorum*	Near Threatened[1]; Near Threatened[3]
66	*Solanum reitzii*	Vulnerable[1]
67	*Symplocos glandulosomarginata*	Rare
68	*Tetrorchidium rubrivenium*	Near Threatened[1]
69	*Tibouchina kleinii*	Endangered[1]
70	*Trithrinax brasiliensis*	Vulnerable[1]; Data Deficient[2]; Data Deficient[3]
71	*Zanthoxylum kleinii*	Rare

[1]SEMA (1995)
[2]MMA (2008)
[3]IUCN (2013)

Appendix B.1. Nursery Questionnaire

1. Nursery Name____________________________
2. Date ___________________________________
3. Interviewers ____
4. Number of Staff participating ________________

Infrastructure

5. How many hectares does this nursery occupy? ____________________________________

6. Is this land rented (1) or owned (2)? _______________________

7. How many staff work here full-time? ______________________

8. How many staff work part-time (if any)? ____________________

9. How many volunteers (if any)? ___________________________

10. What is your main water source used for nursery operations (*select only one*):
    1. Piped Water
    2. Tank
    3. River
    4. Spring
    5. Stream
    6. Pond
    7. Well
    8. Rain

11. (a) What is your full annual operating budget? _______________________________

11. (b) What tax category are you in? _______________________________
(1) Micro (2) Small (3) Medium (4) Large

Primary Objectives:

12. What is your organization's primary objective/target goal? (s*elect only one*)
    (1) Satisfy customer requests
    (2) Grow business
    (3) Meet timelines for clients
    (4) Break even/stay in business
    (5) Reforestation
    (6) Restoration
    (7) Biodiversity conservation
    (8) Meet government targets
    (9) Meet urban reforestation targets

13. How important are the following objectives to your business?
    (a) Satisfy customer requests 1-10 scale: ____________
    (b) Grow business 1-10 scale: ____________
    (c) Meet timelines for clients 1-10 scale: ____________
    (d) Break even/stay in business 1-10 scale: ____________
    (e) Reforestation 1-10 scale: ____________
    (f) Restoration 1-10 scale: ____________
    (g) Biodiversity conservation 1-10 scale: ____________
    (h) Meet government targets 1-10 scale: ____________
    (i) Meet urban reforestation targets 1-10 scale: ____________

Appendix B.2

Sale

14. Price
(a) What is the average price a seedling is sold for? ____________
(b) What is the minimum price a seedling is sold for? ___________
(c) What is the maximum price a seedling is sold for? ___________

15. (a) Order Size
(a) What is the average order size? ____________
(b) What is the minimum order size? ___________
(c) What is the maximum order size? ___________

15. (b) What level of quality are your seedlings? 1-10 scale ________________________

Technical Requirements
16. Indicate any methods you employ for seedling care:
- ☐ root pruning
- ☐ weeding - chemical
- ☐ weeding - manual
- ☐ removal of duplicates/competitors
- ☐ check and removal of unhealthy individuals

16. (b) List the top 3 species that are difficult to cultivate in your nursery and why. _________________
____

Market/Client Needs
17. Which kind of clients do you supply most seedlings to? (*select one)*
1. NGOs
2. Individuals/landowners
3. Corporations
4. Government departments
5. Urban tree-planters

18. Do clients request specific species (1), do they obtain whatever you have available in your nursery (2), or both (3)? ______________

19. If clients make requests, what are top three species are normally requested?___________________
____

20. Do you advertise for new clients (1), do new clients find you (2), or both (3)? ___________

21. How early in advance are you first contacted by a client to provide for a job? ___________ months

22. Do you deliver seedlings (1), is your client expected to arrange collection (2), or both (3)? _________

23. If you deliver, what is your delivery radius? ________________ km

24. Do you have repeat clientele? Y/N

25. How many times does a client usually return? (please select one)
- ☐ 1
- ☐ 2-5
- ☐ once every year
- ☐ multiple times every year

Appendix B.3

26. Do you have or need any kind of official or certified authorization for the operation or commercialization of the seedlings? Y/N ___________

27. (a) Are there any approval processes, regulations, or specifications you need to meet in order to take a job with a client? Y/N ____________________

27. (b) Please elaborate:____
____
____

Seed Acquisition Difficulty

28. Which methods do you employ for seed acquisition?

☐ (a) Purchase seeds: If so, from whom? ____

☐ (b) Wild Collection: If so, from where? ____

☐ (c) Donation: If so, from whom? ____

☐ (d) Farm seeds

29. (a) What is the average distance you travel to acquire seeds? ____________________________

(b) Shortest? ____________________________ (c) Longest? ____________________________

30. Which species are easiest to acquire? (*list top 3*) ______________________________________

31. Which species are most difficult to acquire? (*list top 3*) _________________________________

32. Which species are cheapest to acquire? (*list top 3*) ____________________________________

33. Which species are most expensive to acquire? (*list top 3*) _______________________________

34. (a) When collecting seeds do you target particular species? (Y/N) _________________________

34 (b) If so, which ones? ____

35. When collecting seeds, which methods do you employ? (select all that apply)

☐ (a) tree climbing
☐ (b) stand on ground, remove from tree via hand-held tools
☐ (c) collect fallen seeds on ground

36. If no, why not? (0=N/A, 1 = don't need, 2 = don't know how) ___________

Fluctuations in Nursery Activity

37. Do you operate year-round? Y/N ________________

38. If yes, does production vary throughout the year? Y/N_____________________

39. If yes, which season has highest productivity? (0=no, 1= spring, 2=summer, 3=autumn, 4=winter)

40. If yes, which season has highest productivity? (0=no, 1= spring, 2=summer, 3=autumn, 4=winter)

41. If no, list reasons why operation is intermittent (ex: irregular cash flow, water availability, staff only available when not doing other jobs, etc.) ____
____

Appendix B.4

Regulations
42. Does your state require a minimum number of species in a planting? Y/N ________________

43. If yes, how many? _____________

44. If yes, are you penalized if you deliver below that minimum requirement? Y/N ______________

45. If yes, are you incentivized for providing at or above that minimum requirement? Y/N ________

46. Do you participate in incentivization? Y/N ______________

Inventory Decisions
47. How is the species inventory determined? (*check all that apply*)
- ☐ (a) Follow external regulation/protocol
- ☐ (b) Management decides
- ☐ (c) Customer request

48. Have new species been added to the inventory since you have worked here? Y/N ______________

49. If yes, what was the reason?
- ☐ (a) Customer request
- ☐ (b) Management decided
- ☐ (c) Found new seeds (opportunistic)
- ☐ (d) Obligation to meet new standard

50. (a) How important is it to you personally to produce threatened species? 1-10 scale ____________

50. (b) How important is it to your company to produce threatened species? 1-10 scale ____________

51. (a) How interested are you personally in increasing the number of threatened trees you produce (3 more species)? 1-10 scale _______________

51. (b) How interested is your organization in increasing the number of threatened trees you produce (3 more species)? 1-10 scale _______________

52. How difficult would it be to do this? 1-10 scale _____________

53. What do you think are the major barriers to including more threatened trees in production? (*select all that apply*)
- ☐ Lack of resources
- ☐ Don't know how to cultivate
- ☐ Difficult to cultivate
- ☐ Difficult to buy seeds
- ☐ Don't know where to collect seeds
- ☐ Know where to collect seeds but too far
- ☐ Customer does not request
- ☐ Time to cultivate does not match production schedule
- ☐ Difficult economically
- ☐ Other________________________________

Appendix B.5

Incentives
54. Would you be willing to add more threatened species to your nursery if clients were willing to pay a higher price for them? Y/N ___________________

55. Do you think your clients would be willing to pay a higher price for threatened species? Y/N _______

56. How willing would you be to add threatened species to your nursery if you can market a conservation aspect of your business? 1-10 scale _________________

57. Do ecosystem services best provided by certain species (e.g. carbon sequestration rates) play a role in which species you would add to your inventory? Y/N ___________________

58. Are you aware of any Payment for Ecosystem Services schemes available to you? Y/N __________

59. If so, how inclined are you to participate? 1-10 scale _____________________

60. What do you think is a *sufficient* number of species for a quality planting? ___________________

61. What do you think is the *ideal* number species for a quality planting project? ________________

62. Nurseries grow (1) small seedlings; (2) large seedlings; or (3) both? ________________________

Appendix B.6

Please list each species cultivated on site, and approximately how many per year are sold:

Common Name	Scientific Name	Cultivated Continuously or On Demand?	Number Sold per Year	Number Donated per Year	Primary Purpose (1=garden, 2=urban planting, 3=reforestation, 4=restoration)

What percentage of seedlings do not get sold/donated (if any)? _______________

Appendix C.1. Restoration Practitioner Questionnaire

1. Organization Name______________________________

2. Date ______________________________________

3. Number of Staff participating _________________

4. Interviewers __________________

5. How would you categorize your organization (*choose one*):

(1) Government organization
(2) Consultant
(3) NGO
(4) Corporation
(5) Private landowner
(6) Community Forestry

6. Are you a (1) planting contractor (carrying out another organization's project), or (2) are the plantings your own project? _______________

Insights Into Planning Process

7. Please select the best land category that your plantings occur on:

(1) Private protected land
(2) Public protected land - state
(3) Public protected land - municipal
(4) Public protected land - federal
(5) Agricultural areas
(6) Pastureland
(7) Private-owned
(8) Community-owned
(9) Owned by you
(10) Buffer zones
(11) Other ____________________

8. On average, how many plantings do you do a year? _________________

9. On average, how much time is spent developing project plans? ______________ weeks

10. Do you (1) hire restoration experts to consult on project, or (2) are the plans developed in-house, or (3) both? _____________________

11. Please check any external collaborators you have partnered with in the past two years? (*Select any that apply.*)

☐ local residents
☐ farmers
☐ land management authorities (ex. National Park staff)
☐ government officials
☐ area NGOs
☐ local businesses
☐ biologists/forestry professionals
☐ any other stakeholders: ____________

What are your aims/objectives for plantings?

12. What are your main objectives for your plantings (list three):______________________
____

13. Of the options listed above, which is your most important? __________________________

14. Is restoration (1) the only focus of your organization, or (2) just one facet? ____________

15. If there are other facets to the organization's mission, what are they? ________________
(List below is used for interviewer reference to categorize open-ended answer)

- governance/policy
- social welfare
- education
- livelihood creation
- wildlife rescue/conservation
- infrastructure development
- research

Funding

16. How do you fund your restoration projects? (select all that apply)

☐ Trust/Foundation grant
☐ Local Donor
☐ Foreign Donor
☐ Local fundraising

Appendix C.2

- ☐ Contract/Employer
- ☐ Government Funding
- ☐ NGO partners / co-funding
- ☐ Local business participation
- ☐ Corporate responsibility funding

Nursery Selection

17. How do you source seedlings?
(1) Grow your own
(2) Purchase from nursery
(3) Obtain from nursery (as donation)
(4) Hire third party to liaise with nursery and organize logistics

If you purchase from nursery, ask the boxed questions. If they do not use nurseries, go to Q32.

18. If you source seedlings from a nursery, which nursery(ies) do you source from?
____

19. If you use nursery, do you require a tender process when selecting which nursery to purchase from? (0=no, 1=yes) ____________________

20. How important is it that a nursery delivers seedlings on time? 1-10 scale ___________

21. How important is it that the seedlings are a reasonable price? 1-10 scale __________

22. How important is it that your nursery is located close to your project? 1-10 scale _____

23. How important is it that your nursery carries a wide variety of species? 1-10 scale ____

24. How important is the quality of seedlings when selecting a nursery? 1-10 scale ______

25. Select **primary** reason for nursery selection:
(1) proximity to planting site
(2) proximity to your organization
(3) price
(4) timeline delivery
(5) species variety
(6) pre-existing relationship
(7) seedling quality

26. When you place an order with a nursery, do you pre-arrange a production number in advance? 0=N, 1=Y ______________

27. If yes, how often do nurseries meet the production number?
(1) Never (2) Rarely (3) Half of the time (4) Most of the time (5) Always

28. If yes, how often have nurseries met production timeline?
(1) Never (2) Rarely (3) Half of the time (4) Most of the time (5) Always

29. If a nursery doesn't have the species you want, do you ask if they can acquire them?
0=N, 1=Y _____________

30. If a nursery doesn't have the species you want, do you…
(1) find a different nursery or (2) use the inventory they have?

31. If a nursery suggested adding a threatened species that they cultivate to your order, how open would you be to adding that species to your plans? 1-10 scale

Appendix C.3

32. If you don't source seedlings from a nursery, why not? (*select all that apply*)

☐ More affordable to grow on our own
☐ Nurseries don't have quantity we require
☐ Nurseries don't have species we require
☐ We grow better quality ourselves
☐ Other ___________________________

Species Selection

33. Do you have a pre-defined species list you aim to use for planting? 0=N, 1=Y _______

☐ **IF YES, PLEASE PROVIDE COPY.**

34. How is this list developed? ____

____

____

35. Select any factors limiting the amount of species you include in your planting:

☐ lack of technical knowledge
☐ money
☐ time
☐ lack of availability in nurseries
☐ difficult to source seeds
☐ varying species requirements - need to streamline process/timing
☐ other ___________________________

36. Of the factors you selected, which is the primary factor? _______________________

37. (a) How interested are you personally in including threatened species? 1-10 scale _____

37. (b) How interested is your company in including threatened species? 1-10 scale _______

38. (a) How difficult would it be to incorporate more threatened species into your plans?

1-10 scale ____________________ (b) Why? _____________________________________

39. Do you feel you need specialist knowledge to work with threatened species? N/Y _____

40. Do you feel you have the technical knowledge to work with threatened species? N/Y ___

41. What is the sufficient number of species for a quality planting? _________________

42. What is the ideal number species for a quality planting project? ________________

43. How likely would you be to include threatened species in your plantings if it allowed you to market biodiversity conservation (in addition to reforestation)? 1-10 _____________

44. Do you test the site's soil in planning phase? 0=N, 1=Y _______

45. If so, how important is matching soil quality to species selection? 1-10 scale __________

46. Do you assess water availability in planning phase? 0=N, 1=Y _______

47. If so, how important a consideration is water availability to species selection? 1-10_____

48. Are additional considerations for certain species (such as soil or water requirements) a deterrent to using them in your plantings? 0=N, 1=Y __________

Appendix C.4

Staffing

49. Who participates in the restoration planning stage? (*select all that apply*)

- ☐ Full-time employees
- ☐ Part-time employees
- ☐ Contractors
- ☐ Volunteers

50. How confident are you are in the technical knowledge required to manage a restoration project? 1-10 scale ___________________

51. How skilled is the team tasked with planning the planting project? 1-10 scale __________

52. How experienced is the team tasked with planning the planting project? 1-10 scale ____

Planting

53. Who participates in the planting stage? (select all that apply)

- ☐ Full-time employees
- ☐ Part-time employees
- ☐ Contractors
- ☐ Volunteers
- ☐ Hired labor

54. What is the average size of plantings (in hectares)? ___________________

55. Smallest? ______________

56. Largest? _______________

57. What is the average number of trees planted per project? __________________

58. Smallest? ______________

59. Largest? _______________

60. What is more important to you, (1) hitting target densities or (2) planting target proportion of species? __________________

61. Do you prepare your site before planting?

62. If so, select any site preparation methods you employ:

- ☐ Weeding
- ☐ Livestock exclusion (fence building)
- ☐ Pruning site edges
- ☐ Ripping planting lines
- ☐ Fertilizing
- ☐ Other: ________________________

63. What is the average time for a planting (including follow-up monitoring/maintenance)?

- ☐ 1 year or less
- ☐ 2-3 years
- ☐ 4-5 years
- ☐ >5 years

64. On average, how many species do you use in a planting? ______________________

Appendix C.5

Please list the species you routinely use in plantings.

Common Name	Scientific Name	Number Sold per Year	Primary Purpose (1=garden, 2=urban planting, 3=reforestation, 4=restoration)

Appendix D. List of species found occurring in more than one nursery's annual inventory. Species are listed by occurrence (low to high), then alphabetically, then by abundance.**

Species	Frequency of Occurrence	Abundance
Acacia mangium	2	25000
Albizia edwalli	2	1070
Alchornea Triplinervia	2	2549
Anacardium occidentale	2	3000
Annona coriacea	2	1500
Aristolochia elegans	2	550
Ateleia glazioviana	2	5125
Bixa orellana	2	2800
Brunfelsia uniflora	2	4979
Buxus sempervirens	2	17392
Calophyllum brasiliense	2	5020
Campomanesia adamantium	2	3100
Campomanesia Reitziana	2	10196
Carya illinoinensis	2	3000
Cassia fistula	2	2690
Centrolobium tomentosum	2	3315
Chrysophyllum gonocarpum	2	309
Cinnamodendron dinisii	2	807
Coffea arabica	2	76
Cryptocaria aschersoniana	2	403
Curitiba prismatica	2	520
Cydonia oblonga	2	1500
Dahlstedtia muehlbergiana	2	1910
Dalbergia brasiliensis	2	1100
Eugenia brasiliensis	2	24163
Eugenia multicostata	2	5877
Eugenia myrcianthes	2	150
Euterpe oleracea	2	2000
Gingko biloba	2	5215
Handroanthus umbellatus	2	14607
Ilex dumosa	2	5200
inga lenticifolia	2	5500
Inga vera	2	2510
Inga virescens	2	5200
Jacaranda micrantha	2	30662
Jasminum mesnyi	2	12909
Koelreuteria paniculata	2	6540
magnolia ovata	2	4106
Malpighia Emarginata	2	1000
Malpighia glabra	2	14
Mauritia flexuosa	2	3600
Myrcia hatschbachii	2	1050
Myrocarpus frondosus	2	517
Nectandra megapotamica	2	530
Ocotea catharinensis	2	3004
Persea americana	2	190
piptadenia gonoacantha	2	3915
Pleroma mutabilis	2	106
Prunus Myrtifolia	2	5887
Pseudobombax grandiflorum	2	1610
Rhapis excelsa	2	280
Rhododendron indicum	2	150
Rhododendrum sp.	2	9861
Schizolobium parahyba	2	10005
Tabebuia Roseo-alba	2	5050
Zanthoxylum rhoifolium	2	20
Abutilon megapotamicum	3	800
Annona cacans	3	11780
Annona dolabripetala	3	4000
Annona sylvatica	3	923
Balfourodendron	3	2335
Casearia decandra	3	10140
Cinnamomum amoenum	3	6740
Cupressus semprevirens	3	4200
Cybistax antisyphilitica	3	5163
Duranta erecta	3	4498
Enterolobium	3	10533
Fuchsia regia	3	2410
Hydrangea macrophylla	3	33651
Lagerstroemia indica	3	7628
Macherium stipitatum	3	1375

(continued)

Species	Frequency of Occurrence	Abundance
Magnolia grandiflora	3	345
Maytenus aquifolia	3	15891
Mimosa bimucronata	3	18339
Moquiniastrum	3	1534
Myrcia splendens	3	3150
Myrsine umbellata	3	18000
Nectandra lanceolata	3	2666
Pimenta pseudocaryophillus	3	364
Pleroma granulosa	3	2200
Punica granatum	3	4302
Roupala montana	3	290
Senna multijuga	3	850
Tibouchina sellowiana	3	10266
Acca sellowiana	4	5600
Annona Rugolosa	4	7831
Calliandra brevipens	4	6610
Cordia americana	4	38083
Jacaranda mimosifolia	4	20904
Jacaranda puberula	4	2150
Paubrasilia echinata	4	5025
Persea willdenovii	4	10546
Poincianella pluviosa	4	15671
Euterpe edulis	5	59082
Libidibia ferrea	5	5175
Lithraea brasiliensis	5	17460
Myrsine coriacea	5	15446
Anadenanthera colubrina	6	16861
Bauhinia variegata	6	17300
Casearia sylvestris	6	4024
Cupania vernalis	6	15371
Matayba elaeagnoides	6	9205
Peltophorum dubium	6	86484
Annona emarginata	7	15180
Bauhinia forficata	7	17918
Lafoensia pacari	7	19390
Maytenus ilicifolia	7	55473
Prunus brasiliensis	7	20216
Schinus molle	7	42747
Cabralea canjerana	8	45609
Campomanesia	8	15635
Ceiba speciosa	8	32165
Handroanthus chrysotrichus	8	22989
inga marginata	8	40350
Luehea divaricata	8	34724
median line		
Allophylus edullis	9	57382
Cassia leptopylla	9	11710
Mimosa scabrella	9	92326
Myrcianthes pungens	9	27925
Ocotea odorifera	9	22811
Ocotea puberula	9	32994
Butia eriospatha	10	7055
Parapiptadenia rigida	10	44018
Syagrus romanzoffiana	10	19774
Gymnanthes klotzschiana	11	41733
Handroanthus heptaphyllus	11	47839
Podocarpus lambertii	12	28431
Cedrela fissilis	13	48403
Eugenia piryformis	13	78902
Ilex paraguariensis	13	943099
Vitex megapotamica	13	45310
Handroanthus albus	14	67759
Ocotea porosa	14	33423
Schinus terebinthifolius	14	56728
Campomanesia xanthocarpa	15	107839
Plinia peruviana	15	104780
Psidium cattleianum	15	106964
Araucaria angustifolia	16	204991
Eugenia involucrata	17	105963
Eugenia uniflora	18	105351

* Threatened or Rare species above the median (see Appendix A for full list)
**Species abundance is the cumulative number of seedlings found in all nurseries, however this number is only an aggregate of abundance when the number could be attained. Some participants could tell us they carry/use a species, but not in what quantity.

Appendix E. List of species found occurring in more than one nurser's annual inventory. Species are listed by occurrence (low to high), then alphabetically, then by abundance.**

Species	Frequency of Occurrence	Abundance
Acca sellowiana	2	2079
Bixa orellana	2	28
Campomanesia Guazumifolia	2	1674
Colubrina glandulosa	2	196
Cordia trichotoma	2	1709
Cupania vernalis	2	1081
Enterolobium contortisiliquun	2	4698
Euterpe edulis	2	33509
Handroanthus heptaphyllus	2	252
Inga sessilis	2	932
Jacaranda puberula	2	1147
Moquiniastrum polymorphum	2	610
Myrcia splendens	2	1300
Ocotea catharinensis	2	30
Poincianella pluviosa	2	2772
Schinus molle	2	699
Alchornea Triplinervia	3	3074
Anadenanthera colubrina	3	250
Annona Rugolosa	3	6371
Annona sylvatica	3	1284
Butia eriospatha	3	2578
Ceiba speciosa	3	18201
Citharexylum myrianthum	3	8103
Jacaranda micrantha	3	23525
Lithraea brasiliensis	3	500
Maytenus ilicifolia	3	4506
Myrsine coriacea	3	7543
Nectandra lanceolata	3	2241
Peltophorum dubium	3	5301
Prunus brasiliensis	3	n/a
Bauhinia forficata	4	7048
Cabralea canjerana	4	10113
Cassia leptopylla	4	2317
Handroanthus albus	4	5628
inga marginata	4	19084
Inga vera	4	1632
Lafoensia pacari	4	8250
Matayba elaeagnoides	4	3678
Mimosa bimucronata	4	3279
Myrcianthes pungens	4	6864
Podocarpus lambertii	4	10898
Vitex megapotamica	4	5531
Casearia sylvestris	5	2572
Ocotea odorifera	5	2187
Ocotea puberula	5	1965
———— median line ————		
Handroanthus chrysotrichus	6	11870
Luehea divaricata	6	11499
Mimosa scabrella	6	7357
Parapiptadenia rigida	6	549
*Eugenia piryformis**	7	11313
Plinia peruviana	7	11431
Syagrus romanzoffiana	7	9817
Allophylus edullis	8	16739
*Eugenia involucrata**	8	21123
Gymnanthes klotzschiana	8	19327
*Ilex paraguariensis**	8	30361
Cedrela fissilis	9	17043
*Ocotea porosa**	9	7455
Psidium cattleianum	9	31889
*Araucaria angustifolia**	10	13225
Eugenia uniflora	10	22204
Campomanesia xanthocarpa	11	43128
Schinus terebinthifolius	11	29222

* Threatened or Rare species above the median (see Appendix A for full list)
**Species abundance is the cumulative number of seedlings found in all nurseries, however this number is only an aggregate of abundance when the number could be attained. Some participants could tell us they carry/use a species, but not in what quantity.

Table 1. Summary of native species occuring in Nursery (N) annual inventories and Restoration Practitioner (RP) annual planting lists. Data collected April-June 2017 in Paraná and Santa Catarina, Brazil.

N/RP	Total No. Species Present* (Occurence)	Total Native Species Present, Single Occurrence Removed	No. Species Occurring > Mean Freq. (over half the lists)	Total Abundance	Threatened Taxa Present (% of Total Occurrence)	No. Threatened Species Occurring > Median Freq. (% of Total Occurrence)	Combined Abundance of Threatened Species (% of Total Abundance)
$N_{(n=20)}$	354	139	25	12,554,600	25 (17.9%)	7 (5.0%)	1,732,535 (13.8%)
$RP_{(n=16)}$	154	62	18	870,122**	17 (27.4%)	3 (4.8%)	147,050 (16.9%)

*Including non-tree and exotic species
**n=9 (not 16); RP participants were able to tell us which species they used but were unable to provide quantities.

Table 2. Species most often cited for open-ended seed acquisition questions in Nursery Questionnaire. Highest ranking three species for each question are listed; ties for a ranking are also included (ranking 1 = mentioned most, 2 = mentioned second most, 3 = mentioned third most).

Category	Species	Ranking	Threat Status
Easy to Acquire	*Araucaria angustifolia* *Psidium cattleianum* *Eugenia uniflora*	1 2 3	Near Threatened[1], Endangered[2], Critically Endangered[4] - -
Inexpensive to Acquire	*Araucaria angustifolia* *Eugenia uniflora* *Eugenia involucrata* *Psidium cattleianum*	1 1 2 2	Near Threatened[1], Endangered[2], Critically Endangered[4] - Rare[3] -
Difficult to Acquire	*Ocotea odorifa* *Ocotea porosa* *Caesalpinia echinata* *Cedrella fissillis*	1 2 3 3	Near Threatened[1], Endangered[2], Vulnerable[4] Near Threatened[1], Endangered[2], Vulnerable[4] Endangered[4] Endangered[4]
Expensive to Acquire	*Ocotea odorifa* *Ocotea porosa* *Cedrella fissillis* *Jacaranda puberal* *Caesalpinia echinata*	1 2 3 3 3	Near Threatened[1], Endangered[2], Vulnerable[4] Near Threatened[1], Endangered[2], Vulnerable[4] Endangered[4] - Endangered[4]

[1] SEMA (1995); [2] MMA (2008); [3] Hoffmann (2015); [4] IUCN (2013)