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ORIGINAL ARTICLE

Behind the forest restoration scene: a socio-economic, technical-scientific and political snapshot in Amazonas, Brazil

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ABSTRACT

Conservation of the Amazon rainforest is a global concern and is supported by the Brazilian government's ratification of the Bonn Challenge and Paris Agreement and the introduction of national regulations on vegetation protection and restoration. Amazonas is the largest and least deforested of the states occupied by the Brazilian Amazon (< 3%). We carried out a survey on the current state and growth potential of seed and seedling production in Amazonas state, pointing out constraints where future investment can promote the achievement of large-scale restoration commitments. We visited the 35 officially registered seed producers or nurseries working with native seeds and interviewed their owners or managers using open and closed questions. Enterprises were mainly privately-owned family businesses with small production (10,001 – 100,000 seedlings per year) and concentrated in the metropolitan area of the state capital Manaus. We uncovered a further 54 non-officially registered nurseries. Annual production (2018) was almost four tons of seeds and nearly ten million seedlings. According to the owners, production could be increased five to seven times with existing infrastructure. Production is focused foremost on species for food production (48% seeds, 74% seedlings), while ecological restoration only makes up 35% of seed and 8% of seedling use. Major bottlenecks cited by the producers were low demand for native tree species, high transportation costs and excessive bureaucracy. To achieve large-scale restoration, we recommend enforcement of national policies for vegetation protection and restoration, and a restructuring of the seed and seedling sector with a bottom-up approach.

KEYWORDS: Amazon rainforest, public policy, seed and seedling production, native tree species, nursery, plant propagation

Por trás do cenário da restauração florestal: um panorama socioeconômico, técnico-científico e político no Amazonas, Brasil

RESUMO

A conservação da Amazônia é uma preocupação global, apoiada pela ratificação do *Bonn Challenge* e do Acordo de Paris pelo governo brasileiro e pelas regulamentações nacionais de proteção e restauração da vegetação. O Amazonas é o maior e menos desmatado estado da Amazônia brasileira (<3%). Realizamos um levantamento do estado atual e potencial da produção de sementes e mudas no Amazonas, indicando os principais obstáculos e gargalos onde investimentos futuros podem ajudar a alcançar o compromisso da restauração ecológica em larga escala. Visitamos os 35 produtores de sementes ou mudas de espécies nativas oficialmente registrados, e entrevistamos seus proprietários ou responsáveis técnicos, utilizando um questionário com perguntas abertas e fechadas. Os empreendimentos eram predominantemente privados, familiares, com pequena produção (10.001 - 100.000 mudas por ano) e concentrados na região metropolitana de Manaus. Detectamos outros 54 viveiros não oficialmente registrados. A produção anual (2018) foi de quase quatro toneladas de sementes e quase dez milhões de mudas. Segundo os proprietários, esta produção poderia aumentar de cinco a sete vezes com a infraestrutura existente. A produção foi focada principalmente em espécies para produção alimentar (48% sementes, 74% mudas), enquanto apenas 35% de sementes e 8% de mudas foram destinadas para restauração ecológica. Os principais gargalos citados pelos produtores foram baixa demanda por espécies nativas, alto custo de transporte e excessiva burocracia. Para alcançar restauração em larga escala, recomendamos o cumprimento de políticas de proteção e restauração da vegetação e uma reestruturação do setor de sementes e mudas em uma abordagem ascendente (*bottom-up*).

PALAVRAS-CHAVE: floresta amazônica, políticas públicas, produção de sementes e mudas, espécies florestais nativas, viveiro, propagação de plantas

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INTRODUCTION

Ecological restoration is "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed" (SER 2004), and is part of the 2030 Agenda for Sustainable Development (UNO 2021a). Examples of recent international agreements for this purpose include the Bonn Challenge in 2014 (IUCN 2021) and the 2021-2030 UN Decade on Ecosystem Restoration (UNO 2021b). Brazil ratified these agreements, which led to the publication of the National Policy of Native Vegetation Restoration (*Plano Nacional de Recuperação da Vegetação Nativa* – PLANAVEG (Brasil 2017a). The fulfillment of PLANAVEG goals to restore native vegetation will occur in conjunction with Brazil's Law for Protection of Native Vegetation (*Lei de Proteção da Vegetação Nativa* – LPVN) (Brasil 2012). Additionally, the Rural Environmental Registry (*Cadastro Ambiental Rural* – CAR) created by LPVN supports regulation enforcement on private properties. However, within LPVN, the government granted an amnesty to all rural producers who deforested their property before August 2008. In practice, this means impunity for violation of environmental regulations and is a major cause of inefficiency of LPVN (Brancalion *et al.* 2016), evidencing the leniency of Brazilian political leaders in the execution of LPVN and the prosecution of illegal deforestation on private lands (Ferrante and Fearnside 2019).

The Environmental Reserve Quota (*Cota de Reserva Ambiental* – CRA) is a LPVN mechanism that enables allocation of deforestation quotas of properties that still have cutting allowance to properties in debt for excess deforestation. In 2014, an estimated 5.8 million ha of such private areas with environmental debt could be compensated through CRA, and would not require restoration efforts (Soterroni *et al*. 2018). Even with CRA, the Brazilian commitment to the global target for the restoration of degraded land until 2030 is 12.5 million ha, of which 4.8 million ha will be in the Amazon region.

Most restoration techniques require seeds or seedlings. Quantity, quality and species diversity of planting material have to be guaranteed, and the capability of seed and seedling provision has to be known for each region (Brasil 2017a). An ideal seed/seedling supply system should have applicable laws, requiring minimum guidelines and quality control, along with a tight connection between practitioners and researchers working on seed/seedling technology (Schmidt 2007). Depending on the restoration technique, demand for native seeds in Brazil until 2030 will vary from ≈ 10,000 to 40,000 tons of seeds to restore 12.5 million ha (Freire *et al*. 2017).

In Brazil, the Ministry of Agriculture, Livestock and Food Supply (MAPA in Portuguese) is the political and administrative organ for seed and seedling production. In 2003, a national system for production of seeds and seedlings was established, including a database for the accreditation of private, corporate and public seed producers, the National Registry of Seeds and Seedlings (*Registro Nacional de Sementes e Mudas* – RENASEM (https://sistemasweb.agricultura.gov.br/renasem/). This registry includes information about seed and seedling producers, entails production reports and seed sources. In 2017, MAPA exempted nurseries with production capacity below 10,000 seedlings per year from registration (Brasil 2017b,c).

In 2012/2013, most Brazilian nurseries were private and governmental enterprises, and only a small number was owned by associations or cooperatives (Moreira da Silva *et al*. 2017). The latter authors pointed out 26 nurseries in the Brazilian Amazon region, but did not report their specific location. According to our personal work experience with seed and seedling production, there are more than 26 producers in Amazonas state alone, one of nine Brazilian states occupied by the Amazon biome. This underrepresentation encouraged us to survey seed and seedling production in more detail, including both officially and non-officially registered enterprises, of which the latter form a vast network of informal "invisible" producers of native seed/seedling supply in Brazil (Urzedo *et al*. 2019). We focused on the state of Amazonas, which is Brazil's largest state in terms of area, with approximately 1.6 million km^2, comprising 62 municipalities and about 4.2 million inhabitants (IBGE 2021). We visited seed and seedling producers and interviewed owners to characterize their current and potential production capacity, and discuss socio-economic, technical-scientific and political constraints on current production and actions needed to achieve large-scale restoration commitments.

MATERIAL AND METHODS

Survey of seed and seedling producers

We based our survey on the list of producers accredited in the RENASEM database on November 2018. At this point, 83 producers (74 nurseries and nine seed producers) were registered for Amazonas state (MAPA 2018). During the planning stage of the on-site visits, we detected that 32% of the nurseries had stopped production and, among the active ones, only 30 mentioned native tree species in their production list. Three of the nine seed suppliers had also closed and one was registered twice, resulting in five active seed suppliers, all working with native species. Therefore, this study was based on 35 producers.

We visited all production sites or their respective points of sale, including locations accessible by road in the municipalities of Manaus, Iranduba (40 km from Manaus), Rio Preto da Eva (80 km), Presidente Figueiredo (119 km), Careiro (124 km), and Itacoatiara (282 km), or only by boat or plane in Maués (280 km), Parintins (445 km), Apuí (454 km), Humaitá (592 km), and Manicoré (611 km).

We interviewed the owner of each production facility and, for the governmental institutions, the manager in charge. To each interviewee, we applied an oral questionnaire with open and closed questions (Supplementary Material, Appendix S1). We asked for the annual production and compared this information with the official MAPA production reports. The interviewees were also asked to estimate their maximum production potencial with the existing infrastructure. We established four categories of nursery size based on seedling production: i) very small: up to 10,000 seedlings year^{-1} (for these RENASEM registration is voluntary); ii) small: 10,001 - 100,000 seedlings year^{-1}; iii) medium: 100,001 – 1,000,000 seedlings year^{-1}; and iv); large: above 1,000,000 seedlings year^{-1}. Bottlenecks in seed and seedling production were assessed with specific questions to identify technical-scientific, economic and political constraints. All replies were self-declared and not systematically verified.

We assessed enterprises without registration in RENASEM through the snowball method (Goodman 1961). We asked the interviewees if they could indicate other producers until no "new" indication was obtained. However, non-registered producers were not interviewed nor included in formal analysis of this study, as our aim was to estimate the current and potential production capacity for large-scale restoration by legally accredited producers.

Data analyses

All replies to closed questions were analyzed with descriptive statistics. The variables extracted from the questionnaire answers were cross-tabulated. Qualitative data were analyzed with content analysis (Bardin 2011). Producers could cite more than one difficulty, and replies were categorized. Within categories, answers were arranged according to citation frequency of specific topics (bottlenecks).

Ethical aspects

To assure anonymity, producers received a number in decreasing order of self-declared maximum production capacity. This study was approved by the Human Research Ethics Committee (CEP) of Instituto Nacional de Pesquisas da Amazônia (INPA), accredited by the National Commission of Ethics in Research, (Certificado de Apresentação de Apreciação de Ética no. 80225317.6.0000.0006, December 2017).

RESULTS

Seed and seedling producer characterization

Of the 35 native plant species producers, 69% were located in the metropolitan area of Manaus, which includes all municipalities that were reachable by road, while 10 producers were visited by boat or airplane (Figure 1a). Production sites were located in 11 of the 62 municipalities of Amazonas

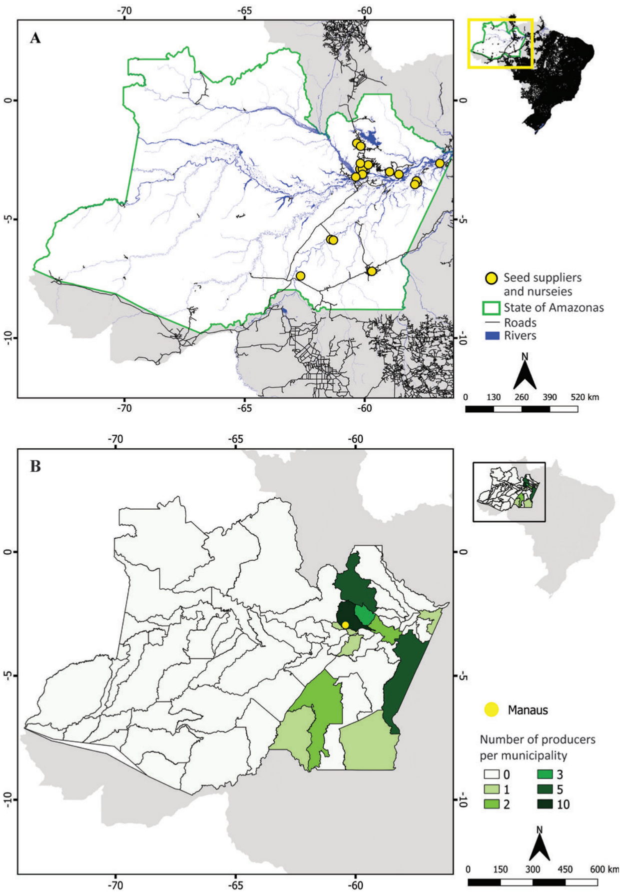

Figure 1. A – Location of seed suppliers and nurseries in Amazonas state (Brazil) that are registered with the Brazilian Ministry of Agriculture, Livestock and Food Supply (MAPA). B – Number of producers per municipality in Amazonas state. This figure is in color in the electronic version.

(Figure 1b). The municipality of Manaus concentrated the highest number of producers (10), with one to five in other municipalities (Figure 1b). The snowball method revealed a further 54 nurseries that were not officially listed in RENASEM, implying that nearly two times more seedling producers than the 30 active regsitered in Amazonas are invisible to MAPA. Seed suppliers and nurseries were primarily private businesses (88.5%). Two seed suppliers and one nursery were located in governmental institutions (Table 1). Four nurseries and one seed supplier collaborated to acquire supplies and maintain a common sales point.

Owners of private business and managers of the governmental institutions were predominantly male (71.4%) and aged between 41 and 65 years (57.1%), and 48.5% had a university or even a post-graduate degree in agronomy (4), business and administration (5) and forestry (2), among others (6) (Table 1). Seed supplier businesses were active between four and 25 years and the nurseries between one and 37 years.

The 35 seed and seedling suppliers generated permanent jobs for 201 persons in 2018, but most employees (56%)

Table 1. Socio-economic profile of officially registered seed suppliers and nursery owners (n = 35) in Amazonas state in 2018.

Parameter	N	Relative frequency (%)
Type of ownership		
Private	31	88.5
Association	1	2.9
Governmental	3	8.6
Gender		
Male	25	71.4
Female	10	28.6
Age (years)		
18-30	3	8.6
31-40	8	22.9
41-50	6	17.1
51-65	14	40.0
> 65	4	11.4
Education		
None	2	5.7
Primary	7	20.0
Secondary	3	8.6
Technical	6	17.1
Graduate	12	34.3
Postgraduate	5	14.3

were concentrated in four businesses. Additional part-time or temporary workers were hired by 60% of the seed suppliers and 80% of the nurseries. Many nurseries (43%) were family businesses, and another 27% counted on additional external help. Thus, the family workforce was necessary for 70% of the nurseries and 20% of seed suppliers.

Ecological restoration was the final destination of 35% of the seed production and 8% of the seedlings (Figure 2). Far more important was the demand for food-producing species, mainly citrus trees (*Citrus* spp., Rutaceae), Brazil-nut (*Bertholletia excelsa* Bonpl., Lecythidaceae), açaí (*Euterpe oleraceae* Mart., Arecaceae) and guaraná (*Paullinia cupana* Kunth, Sapindaceae). Food plantations made up 48% of seed and 74% of seedling production. Seeds were also produced for scientific research (15%), and urban arborization (2%). Seedlings were also destined to landscaping (5%) and urban arborization (8%) (Figure 2).

According to the producers' self-declared information, the annual production of all seed suppliers was below maximum capacity (Figure 3). In 2018, almost 4 tons of seeds (3,964 kg) were collected, which could have been 5.5 times higher (21.8 tons) with the existing infrastructure (Figure 3). Most nurseries (90%) also worked below maximum production capacity (Figure 4). Total seedling production in 2018 was of 1,258,600 seedlings and could still be increased up to seven times (9.7 million seedlings year^{-1}). According to official reports at MAPA, annual seedling production in Amazonas in 2018 was 413,600 seedlings, about a third of the producers' self-declared information during the on-site visits. When questioned about strategies to increase demand, none of the producers showed interest in promoting their business.

Based on current seedling production, there were 11 very small, 16 small, three medium and no large nursery (Figure 4). However, based on maximum production capacity, there would be five very small, 14 small, nine medium and two large nurseries (Figure 4). When questioned about profit margins, apparently the producers did not register their incomes and expenses. Production costs and profits were roughly calculated by the producers themselves, with profit margins ranging from 25 to 90%. Many of the private nurseries (13 of 27) could not give even a crude estimate, emphasizing the informality in this sector.

Bottlenecks in seed and seedling production

Difficulties in seed supply and seedling production cited by the interviewees could be grouped into ten categories and,

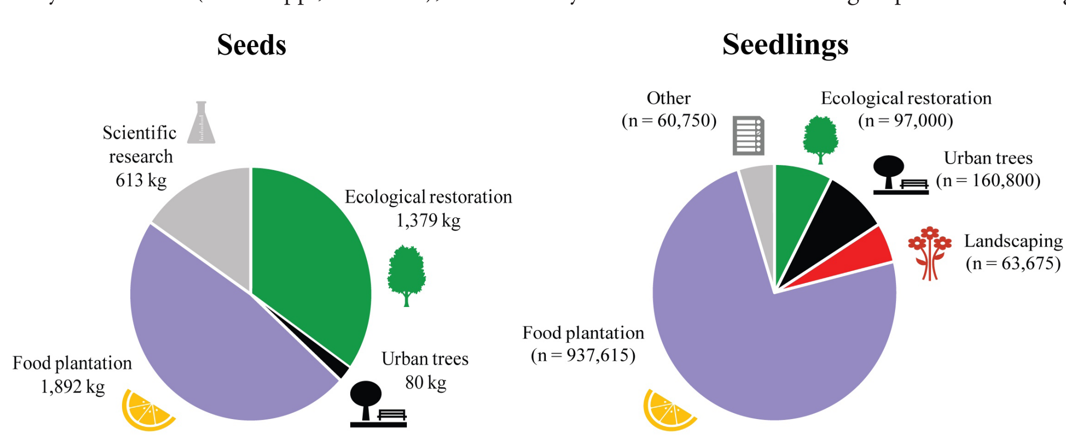

Figure 2. Final destination of seeds and seedlings produced in Amazonas state in 2018. This figure is in color in the electronic version.

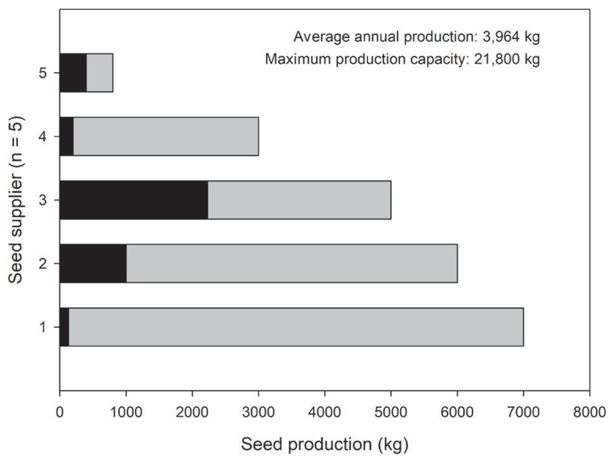

Figure 3. Annual seed production (black) and maximum production capacity (grey) of five seed suppliers in Amazonas state (Brazil) in 2018. Seed supplier nr. 1 is a producer association.

within each category, bottlenecks were ordered according to citation frequency (Figure 5).

Socio-economic bottlenecks – These involved business and trade, logistics and human resources. The most significant difficulty regarding business and trade for all producers was low demand in general for their products, and specifically for native tree species. Fruit trees and ornamental plants, often of exotic origin, were easier to sell (Figure 2), reinforcing the self-declarations that actual production is below maximum capacity and could easily be increased (Figure 3 and 4).

Other complaints were volatile demand, as preference for species changes over time; and the informality of the business, as consumer requests are frequently spontaneous and not bound to contracts, which makes planning difficult and creates financial insecurity. Limited access to consumers was considered a barrier to economic growth, as in rural areas, contact with consumers by mobile phone is not always guaranteed. Irregular internet access was mentioned several times as a barrier to business.

Many producers recognised that business management and marketing strategies should be improved. In general, high seed prices were a problem, furthmore, according to the producers, the improvement in seed and seedling quality did not result in higher economic return ("quality vs price" in Figure 5). Non-registered or non-local production was said to have often more competitive prices ("trade competition" in Figure 5). Further bottlenecks were the lack of financial resources to start, and later to improve business, together with non-professional and non-collaborative behaviour when working in associations or cooperatives (Figure 5).

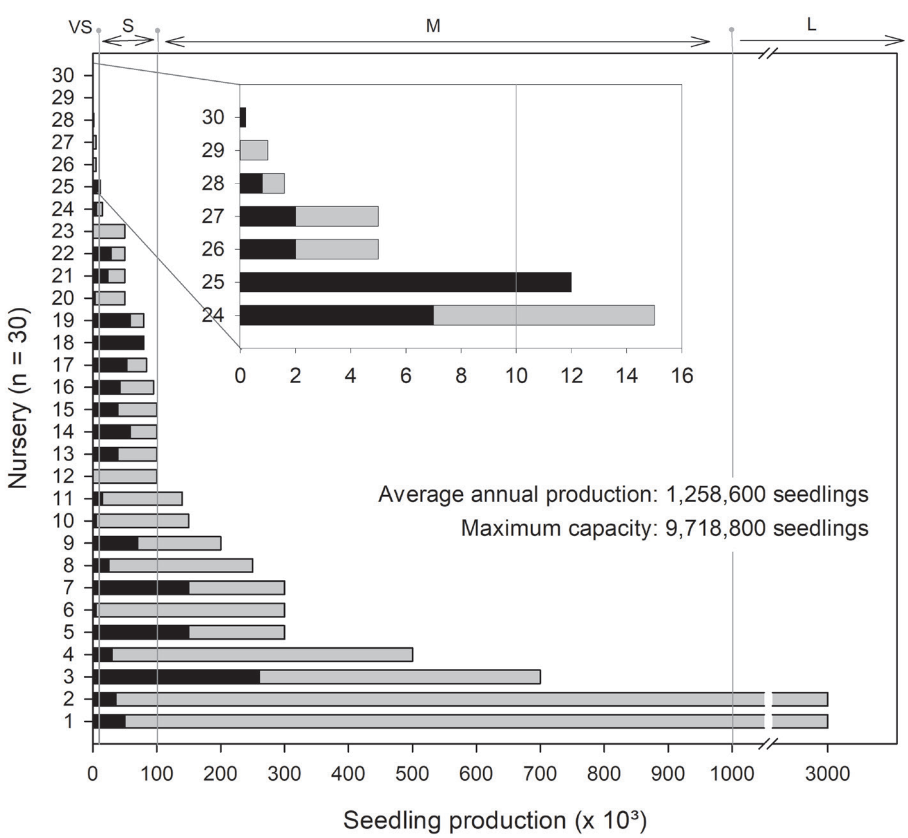

Figure 4. Annual seedling production (black) and maximum production capacity (grey) of 30 seedling nurseries in Amazonas state (Brazil) in 2018. Nurserys were classified in very small (VS), small (S), medium (M) and large (L).

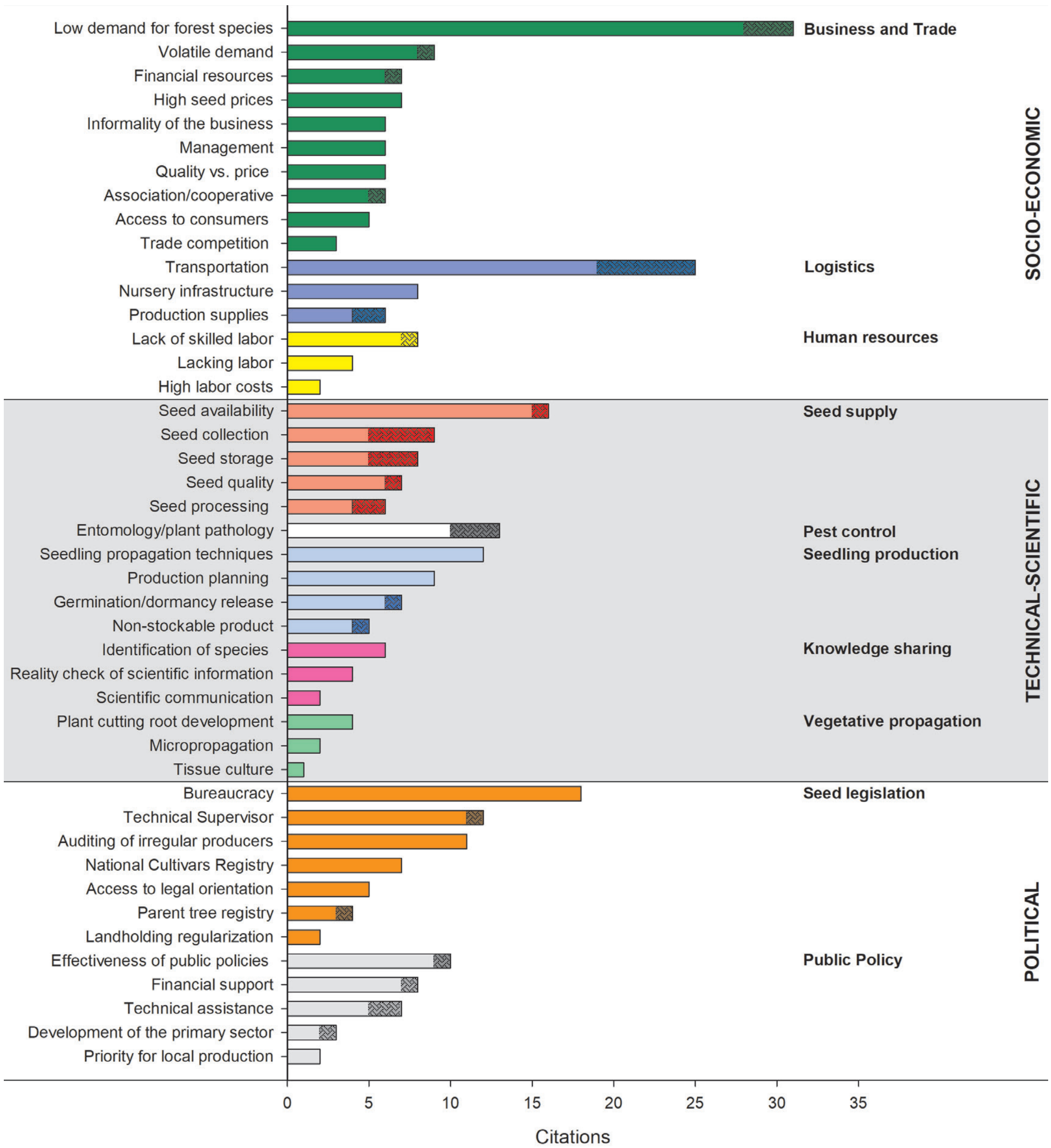

Figure 5. Socio-economic, technical-scientific and political bottlenecks in seed/seedling production as indicated by producers in Amazonas state (Brazil) in 2018 arranged by number of citations in categories and sub-categories. Shaded segments represent citations by seed suppliers, and unshaded segments citations by nurseries. Each producer could cite more than one bottleneck. This figure is in color in the electronic version.

Logistics bottlenecks included planning and executing transport and storage of goods from the point of origin to consumers. Transportation was the second most cited bottleneck. High transportation costs and difficulty of access to potential consumers are also closely related to business and trade. Transportation is difficult in areas with low population density, where distances are long. In Amazonas, many roads are unpaved, or there is no road at all, and transport depends on river transport. Transport is specifically a problem for seedlings and recalcitrant (desiccation sensitive) seeds, which need special care due to quick viability loss. Transport difficulties also influence the acquisition of good quality products for the business ("production supplies" in Figure 5). Some supplies may have to be bought in other states or countries, and thus transport costs may hinder maintenance and improvement of nursery infrastructure.

Regarding human resources, cited bottlenecks were finding skilled labour and manual workers who agree to the low remuneration in the sector and the physical hardships of the labour ("lacking labour" in Figure 5) and high labour costs of specific jobs, such as tree climbing.

Technical-scientific bottlenecks – These involved technical aspects of production (seed supply, seedling production and vegetative propagation), pest control and knowledge sharing.

Regarding seed supply, nursery owners cited seed availability (17%) as the primary bottleneck, while seed suppliers indicated seed collection (80%) and seed storage (60%) as a difficulty. Producers recognised that reduced seed availability in high diversity forests is an inevitable problem. The whole seed collection process is labour-intensive, and is a high-cost activity as it needs skilled workers and security equipment. Good quality seeds have to be collected in tree crowns of several mother trees to form a high-quality seed lot. Another difficulty mentioned was seed storage and the need for dry- and wet-storage facilities for species with desiccation-tolerant or desiccation-sensitive seeds, respectively. Difficulties in seed processing were cited by 17% of the producers. Knowledge of seed morphology was desired for proper processing.

Regarding seedling production, major bottlenecks were related to the lack of species-specific knowledge due to the high diversity of Amazonian trees. This was mentioned for seed germination, dormancy release and seedling propagation. The planting season in the Amazon corresponds to the five to six months with higher precipitation, and producers claimed that orders take place only in the rainy season, leaving no time for seedlings production within the same season. Production in advance is risky due to the already mentioned informality in ordering behavior of clients. Unsold seedlings have to be discarded, as they are a non-storable product. Thus, production planning is a significant difficulty for seedling producers.

Vegetative propagation by micropropagation and tissue culture was cited as a problem by few producers, as it is an investment with high fixed costs and requires a steady demand. Lack of knowledge in plant-cutting techniques was also cited. Pest and disease control was the fifth most cited bottleneck (37% of producers) ("entomology/plant pathology" in Figure 5).

Lack of knowledge sharing between the academy and the producers was seen as a problem. Amazon flora is not fully described, and field guides are rare, thus, botanical species identification is the primary difficulty. Producers asked for a reality check of scientific information as they fear differences between scientific results and field practice. They expressed reservations about scientific communication, considering that academic texts are not understandable by the lay public.

Political bottlenecks – These included seed legislation and public policy. Regarding the former, excessive requirements to comply with legislation ("bureaucracy" in Figure 5) was the most cited difficulty and was the third in overall citations (n = 18). For example, besides the registration of the business, the nursery or seed supplier (including the intended species for production) have to be registered at MAPA with many details and registration taxes. Producers can only commercialise species listed in the National Cultivars Registry (*Registro Nacional de Cultivares* – RNC) with the scientific and corresponding popular name. The RNC may hinder production, as it fails to include all native species and does not consider regional variations of popular names. Seed collection areas or individual parent trees ("parent tree registry" in Figure 5) have to be georeferenced (four producers mentioned not to have GPS equipment). In the Amazon region, people frequently do not have the legal title to the land where they live or have their business, which was the case of two nurseries ("landholding regularisation" in Figure 5).

A critical bottleneck cited by 12 producers regarding seed legislation was the legal requirement to have a technical supervisor with a university degree. Besides additional costs, the assistance was not always provided as expected. Lack of auditing of irregular producers was cited by 31% of the interviewees, who claimed that non-registered producers might be more competitive, as their operational costs are lower.

Access to legal orientation on seed legislation was also considered a bottleneck, as 49% of the interviewees claimed not to understand the Brazilian seed and seedling legislation due to the technical language and excessive details. Legislation updates were not followed by 54% of producers, who cited lack of interest, or reliance on the technical supervisor for updates.

The most outstanding bottleneck regarding public policies could be simplified as a general lack of public policy effectiveness. Deficiency of public support to promote business, e.g., through funding and/or credit programs ("financial support" in Figure 5), and to improve production, e.g., through training and knowledge transfer ("technical assistance" in Figure 5) were also mentioned. Amazonas producers recognised the limitations of forest resources, and they cited the need for public policies to increase plantations of native species. Furthermore, they claimed that governmental initiatives should prioritise local production and stimulate the primary sector's development.

DISCUSSION

Socio-economic bottlenecks

This is the first comprehensive survey of all registered seed and seedling producers of native tree species in Amazonas state. On-site visits were the only way to obtain reliable information and get insights into the socio-economic aspects of businesses, as many producers could not be reached by phone, e-mail or other internet contact. Our sample size (35 seed suppliers and nurseries) was 50% larger than that of a recent phone-based survey of 26 producers over the whole Brazilian Amazon (an area 2.6 times larger than Amazonas state) (Moreira da Silva *et al*. 2015; 2017), which only reached a part of the officially registered businesses in the inference area.

A majority of private businesses (88% in our survey) was also recorded for the national level in Brazil (71%; Moreira da Silva *et al*. 2017). The organization of producers in associations may increase success for large-scale demands, especially for small-scale nurseries, as it allows access to broader seed provision sources (Frost and Muriuki 2006). Associations could also encourage public engagement, promote training, and collectively negotiate legislation that addresses the native seed markets (Abbandonato *et al*. 2018). On the other hand, associations may have difficulties in management, human relations, and economic sustainability (Mesquita *et al*. 2010). In our interviews, producers were hesitant to work in cooperatives or associations, due to negative social and economic issues in the past. The only current association reported here was in seed supply. A few nurseries (with the lowest production capacity) mentioned an informal collaboration to sell ornamental plants, showing the importance of collaboration to gain visibility in the market. However, the producers' primary difficulty in this study was demand below their production capacity, which may have further discouraged association.

Every three years, each producer has to renew the registration at MAPA. However, we found that the information in MAPA´s database did not match with the current addresses and phone contacts of producers, and even 25 closed enterprises were still listed, which may indicate a high turnover of enterprises in this sector. The advanced age (above 51 years for the majority of producers) indicates that most had reached retirement age or were close to it, according to Brazilian legislation. During the interviews, we got the impression that, in several cases, the business had more social/recreational than economic objectives. We infer that nursery activities for these producers may be a pastime with some monetary return, and financial management would not be a priority. This may explain why many producers, even those with a graduate degree, did not track costs in detail per species, or had no interest in promoting their business. Our observations suggest that a combination of several factors is causing the high turnover of enterprises in the seed and seedling sector of native species: a) the advanced age of business managers is linked to risk aversion and disregard for new opportunities (Gielnik *et al*. 2017); b) the operating deficit may be a consequence of not calculating gross margin per seedling (Frost and Muriuki 2006); and c) the long delay in the enforcement of the federal restoration plan, which did not give the expected return and discouraged investors.

The producers cited that their production capacity could be increased five to seven times with the current infrastructure, however, it is questionable whether some producers would be prepared to manage significant upgrades in financial resources and labour force. Good quality technical assistance and training in financial and administrative management would be a necessary improvement, as well as the creation of catalogues (printed and online) with basic information on traded plant species to improve sales (Schmidt 2007).

Likely for logistical reasons, most producers were concentrated in the Manaus metropolitan area, yet a wider distribution of producers could improve seed and seedling availability across the state and reduce transportation costs, the second most cited bottleneck. A well-distributed seed and seedling network is desirable to accomplish ecologically sound restoration by matching local species composition with planting material provenance (Brasil 2017a). Community-based networks could be a key factor for success, as shown in the Brazilian Cerrado, and in the southeastern and western Amazon (Schmidt *et al*. 2018). In 2020, Amazonas had 43,369 km^2 of deforested and degraded areas, which corresponds to 2.7% of the area of the state (INPE 2021). Considering a standard spacing of 3 × 2 m among seedlings, 1,667 seedlings per hectare would be required for restoration projects. Based on the current annual production of seedlings in Amazonas, an area of 755 ha could be restored each year. This area could be increased to 5,830 ha (58.3 km^2) if maximum production capacity of registered nurseries would be used, and it would still correspond to only 0.14% of the deforested area.

Transport in Brazil is generally road-dependent, contrasting with Amazonas, where year-round terrestrial access is limited and five of 11 visited municipalities were accessible only by air or river. The lack of roads explains the relative conservation of forests in Amazonas, as road access is a driver of deforestation and subsequent land degradation (Barber *et al*. 2014). At the same time, lack of road access also conditiones the distribution of nurseries in the state. Relatively more nurseries are located in southeastern Amazonas, where they have access to three highways (BR-317, BR-319 and the BR-230 Transamazonica; see Figure 1a). In this region, deforestation is higher and represents 47.9% of all deforested areas in Amazonas (INPE 2021). The municipality of Maués is a singular case. It is situated south of the Amazonas River, at 280 km southeast of Manaus, and has no road access, but hosts five nurseries. This owes to that the municipality is the production centre of guaraná (*Paullinia cupana* Kunth) and there is high demand for seedlings of this species, illustrating how demand drives seedling production increase.

Technical-scientific bottlenecks

According to the Amazon Seed Network (*Rede de Sementes da Amazônia* – RSA) the three most critical technical-scientific challenges for seed and seedling producers are seed collection, seed storage and botanical identification of species (Gonçalves *et al*. 2004). In our interviews, technical-scientific bottleneck citations may be conditioned by the unawareness of the importance of scientific information. A good example is the botanical identification of species. The same popular name may be given to several species, and popular names vary depending on the region and even within municipalities. Yet many producers use only popular names to refer to species and consider the scientific botanical identification irrelevant, unaware that an incorrectly identified species may result in financial losses or even adverse environmental implications (see details in Martins da Silva *et al.* 2003).

Seed collection is the first step in the seed production chain and is critical to all other courses of action, as it will determine quality (Schmidt 2007; Pedrini *et al.* 2020), and, consequently, was a common problem for producers. In tropical climates, fruiting may not be synchronised, even within the same species (Alencar *et al.* 1979). In highly diverse forests, species density is low, large-seeded species produce small amounts of seeds, and consumption by animals in the forest is high. Collection recommendations are scarce and need to be aligned with the final use: forest products (timber or non-timber), ecological restoration or species threatened by extinction. Ideally, large-scale restoration should maximise genetic diversity (Higa and Silva 2006; Broadhurst *et al*. 2008). In contrast with highly developed restoration markets, where producers are highly qualified and able to analyse genetic sources of plant material (e.g., Smith *et al*. 2007), producers in Amazonas have restricted access to simple quality control. Moreover, seed and seedling production is such an underdeveloped practice that producers are not yet concerned with seed quality, and this aspect was not a prominent bottleneck among interviewees.

Storage depends on seed physiology, and just under half of the rainforest tree species are estimated to have desiccation-sensitive seeds (Tweddle *et al*. 2003). In the central Amazon, 63% of timber species (Ferraz *et al*. 2004) and 75% of fruit-tree species (Carvalho *et al*. 2001) are estimated to have desiccation-sensitive seeds. This is a challenge for producers as most seed and seedling production is destined for food, especially fruit plantations. Even for desiccation-tolerant seeds, storage requires infrastructure such as drying equipment or areas for natural drying, which is economically unfeasible for most producers in Amazonas. Drying under natural conditions may also be unfeasible due to the high humidity and the risk of fungal attack. Seed storage capability allows year-round seed provision and reduction of seed collection costs (Schmidt 2007). Despite these advantages, seed storage was not a primary concern for producers, again reflecting the lack of demand and the specific socio-economic constraints that have hindered investments.

The higher demand for seeds than for seedlings for restoration detected in this study is explained by higher seed transport ease. Besides, in southeastern Amazonas, seeds can be sold to bordering states with higher deforestation rates. Seedling trade is preferred for short-distance destinations, including urban arborization, landscaping and small scale food production.

Our results show that, for an adequate native seed supply, a multidisciplinary approach is needed, including regular and productive dialogue among academics, producers and decision-makers, as already noted by Elzenga *et al.* (2019). The lack of knowledge sharing mentioned by interviewees included the absence of inteligible communication of scientific information to producers and insufficient dissemination of empirical knowledge to the academy. Similar challenges are reported from other countries, where practitioners sometimes cannot apply the technical solutions proposed by the academy and disagree regarding technical problems (Smith *et al.* 2007). The US National Seed Strategy is an example of an approach based on a coalition of government agencies, non-governmental organisations, and the scientific academy to improve public policy effectiveness and support for seed and seedling production (Oldfield and Olwell 2015). In 2001, there has been a similar endeavour with national edicts for the organisation of seed networks in Brazil (Piña-Rodrigues *et al*. 2015). At the time, eight seed networks were created, but very few of them remain active due to discontinuation of funding (Freire *et al*. 2017), including the Amazon Seed Network (*Rede de Sementes da Amazônia* – RSA). It promoted scientific research, technical training, and advice on formal laws and regulations and had a crucial role in generating and sharing knowledge. Today, the RSA works with low impact as all contributions are voluntary. Renewed investment into the seed networks, with governmental support for the different biomes in Brazil, could ally interdisciplinary actors in the seed market and improve the efficiency of large-scale restoration.

Political bottlenecks

We expected that the producers would refer problems that require scientific solutions along the seed production chain (collection, processing, storage, germination, testing) and nursery techniques (plant emergence, growth). However, they strongly indicated bottlenecks in economic and political aspects hampering seed production, which, in their opinion, must be resolved through changes in public policy.

MAPA requires registered producers to provide reports on seed and seedling production every six months, however, many producers do not adhere to this requirement and MAPA's staff is too reduced to assure enforcement (M. M. Pereira, MAPA-Manaus, pers. comm.). Staff shortage in Amazonas' delegation of MAPA is illustrated by the fact that, in 2019, each technical agent was responsible for an area of roughly 800,000 km^2.

The production-capacity threshold for registration exemption with RENASEM should be above 10,000 seedlings per year, to exempt more producers from the bureaucratic load of registration obligations, especially those that produce environmentally valuable species. It has been proposed that registration exemption should also cover seed suppliers, up to a seed-weight threshold of less than 500 kg per year (Urzedo *et al.* 2019). The seed-supplier threshold would be a welcome improvement, but we consider that number of seeds would be a more suitable measure, as seed size variation in native trees is very large (e.g., one seed of *Scleronema micrantha*, Malvaceae, may weigh up to 220 g; Ferraz *et al.* 2019).

It is symptomatic that 60% of seedling producers complained of excessive bureaucracy of Brazilian seed and seedling legislation as a disadvantage relative to non-registered businesses. This corroborated our findings, as the snowball method revealed that 61% of all producers were not registered. However, we cannot estimate their degree of competitiveness, as they were not included in our interviews.

Complete digitalization of registration and monitoring processes would be a significant improvement and would facilitate contact over long distances for producers. However, MAPA is still struggling to enforce guidelines and registration, and data sharing is still dependent on analog processes. Seed documentation should provide minimum quality criteria to safeguard consumers and, as proposed by Schmidt (2007), could additionally provide a database for decision-makers in restoration, tree farming, and urban forestry.

Testing of forest seeds is only done in 16 of the 225 accredited laboratories in Brazil (Urzedo *et al*. 2019). Among these, only one is in the Legal Amazon, an area greater than half of Brazil's territory, and 1,295 km away from Manaus. MAPA has granted a three-year reprieve for non-accredited laboratories to perform seed analyses (Brasil 2017b,c) which can potentially improve the situation.

Low demand for native species was an unexpected bottleneck in our survey. Demand can only be improved by public policies that enforce restoration. Governmental agencies can be the leading consumers of native seeds and seedlings for habitat restoration, as is the case in the USA (Oldfield and Olwell 2015). Adequate policies can also promote the establishment of a market for restoration (Brancalion *et al*. 2017). With the implementation of LPVN (Brasil 2012) and PLANAVEG (Brasil 2017a) and the country's commitment to the Bonn Challenge (IUCN 2021), a boost in seed and seedling production was expected in Brazil. However, 59% of Brazilian seedling producers have not noticed any improvement since 2012 or even have noticed a decrease in seed or seedling demand (Moreira da Silva *et al*. 2017), indicating a lack of commitment of all stakeholders. In this context, the link between public policy and forest species demand needs to be improved drastically.

Alternative restoration techniques and strategies can reduce the demand for seedlings, for example, direct seeding reduces costs by 36%, compared to planting seedlings (Campos-Filho *et al.* 2013), a practice successfully implemented by the community-based Xingu Seed Network, which has restored more than 5,000 hectares since 2007 (Schmidt *et al.* 2018). According to the interviews, the same area could be restored yearly with seed and seedlings produced in the Amazonas state. This emphasises the importance of establishing seed networks as already discussed in the technical-scientific bottlenecks.

CONCLUSIONS

Prior to our survey of seed and seedling producers in Amazonas state, we had expected that most reported difficulties would be related to technical-scientific issues, however the major difficulties were related to low demand, transportation logistics and seed legislation. We have identified key areas that need strengthening if the Brazilian government's commitment to the Bonn Challenge and the Paris Agreement is to be met in the next decade. The effective application of LPVN and PLANAVEG and the stimulation of demand through legislation enforcement are crucially necessary actions. Higher demand will give structure to the seed and seedling sector to achieve the goal of large-scale restoration. Public incentives for production or donation programs of planting material can prioritize and favor demand for native species. Furthermore, the legal framework regulating seed and seedling production could be improved by a shift from command and control measures to economic incentive mechanisms to assure restoration performance and the commitment of all involved actors. A bottom-up approach might reduce the need for governmental law enforcement, and facilitate adjustments to local/regional specificities and adherence to good practices.

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SUPPLEMENTARY MATERIAL (only available in the electronic version)

Marques *et al*. Behind the forest restoration scene: a socio-economic, technical-scientific and political snapshot in Amazonas, Brazil

Appendix S1. Questionnaire applied to owners or managers of 35 officially registered seed suppliers and nurseries of nativer tree species of interest for forest restoration in Amazonas state (Brazil).

Interviewers:____

Date: ___/___/_____ **Hour:** ____:____

Producer: ( ) Seed ( ) Seedling

Municipality:______________________ **Geographical coordinates:** ________________________

Name of interviewee: ____ **Gender:** ( ) M ( ) F

Owner classification: ( ) Private ( ) NGO, Association, Co-op ( ) Governmental

RENASEM Registry: ____

Address:____

Tel: ( ) _______________________________ **E-mail:** __________________________________

Nursery production: ( ) Tree species ___% ( ) Fruit trees ____% ( ) Ornamental plants _____ %

Estimated annual production: ____

Which are the most produced and their selling price? (Ask for species and price list)

Among the species listed, which are the most produced/commercialized? ____________________________________

How long have you been working as a seedling/seed supplier? ____

Are other family members involved? __________________________

How many full-time employees? __________________________

Is there temporary workers recruitment? ( ) Yes, When? ____________________ ( ) No

Material produced is allocated to: ( ) Forest restoration ____% ( ) Urban forestation ____% ( ) Landscaping ____% ( ) Food plantations ____% ( ) Others ____% Which? ______________________________________

Does the business have a spreadsheet with costs for production of seeds/seedlings? ( ) Yes ( ) No

Estimated average production cost R$ ____________ **Estimated average marketing price** R$ _____________

Current demand is: ( ) Smaller ( ) Equal ( ) Higher than maximum production capacity

Maximum production capacity _____________________________

Advertisement? ______________________________________

Intention to advertise? ____________________________________

Does the nursery have a spreadsheet with seed/seedling production costs? ( ) Y ( ) N

Average cost of production R$ __________

Average selling price R$ __________

What are the main technical, scientific, logistical and commercial difficulties faced? (List in order of importance)

Are you aware of the changes in the seed and seedling legislation? ( ) Yes ( ) No

Do you have difficulty understanding the laws of seeds and seedlings regarding? ( )Yes ( ) No