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RESEARCH PAPER

Community-based native seed production for restoration in Brazil – the role of science and policy

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ABSTRACT

- Large-scale restoration programmes in the tropics require large volumes of high quality, genetically diverse and locally adapted seeds from a large number of species. However, scarcity of native seeds is a critical restriction to achieve restoration targets.
- In this paper, we analyse three successful community-based networks that supply native seeds and seedlings for Brazilian Amazon and Cerrado restoration projects. In addition, we propose directions to promote local participation, legal, technical and commercialisation issues for up-scaling the market of native seeds for restoration with high quality and social justice.
- We argue that effective community-based restoration arrangements should follow some principles: (i) seed production must be based on real market demand; (ii) non-governmental and governmental organisations have a key role in supporting local organisation, legal requirements and selling processes; (iii) local ecological knowledge and labour should be valued, enabling local communities to promote large-scale seed production; (iv) applied research can help develop appropriate techniques and solve technical issues.
- The case studies from Brazil and principles presented here can be useful for the up-scaling restoration ecology efforts in many other parts of the world and especially in tropical countries where improving rural community income is a strategy for biodiversity conservation and restoration.

INTRODUCTION

Several public and private efforts have promoted the restoration of native vegetation in recent decades. International agreements (*e.g.* The Bonn Challenge) established the auspicious goal of restoring 350 Mha (million hectares) by 2030. In Brazil, between 21 and 44 Mha should be restored, according to the national environmental legislation (Gouvello 2010; Soares-Filho *et al.* 2014). To fulfil international commitments, the Brazilian government pledged to support the restoration of 12 Mha by 2030 through the National Restoration Policy (Decree 8972/2017). Consequently, seed demand to restore such an area will increase drastically, while the current installed capacity for native seed production is around 17–29 t year^{-1} (Freire *et al.* 2017).

To achieve the goals of large-scale restoration programmes, several improvements in the restoration productive chain are needed (Brancalion *et al.* 2016). To date, restoration efforts in tropical countries are mainly based on large nursery enterprises and tend to be very limited by seed and seedling supply (Brancalion *et al.* 2012; Moreira da Silva *et al.* 2017). Such a market-driven restoration industry is highly technical, generates limited employment and is mostly centred on specialised technology and staff. Commonly, large nurseries also concentrate efforts on a few pioneer or short-lived species from which seeds are easy to collect, store, germinate and convert into seedlings (Fernandes *et al.* 2017). The most commonly applied restoration techniques (tree seedling planting) are expensive and mostly unknown to small farmers and local rural communities. These stakeholders are commonly responsible for conservation and restoration in their lands and may supply seeds and seedlings to ecological restoration production chains (Scherr 2000; Frayer *et al.* 2014).

Large-scale restoration programmes may also contribute to the conservation of areas used to collect native seeds, as well as improve local livelihoods. For that, there is a clear need for flexible legislation, local community participation, technical assistance and environmental awareness (Guariguata & Brancalion 2014; Meli & Brancalion 2017). However, we did not find in these documents examples of community-based restoration initiatives. Although these guidelines appear in articles and policy reports (Mansourian *et al.* 2005; Chazdon 2008; Brancalion & Chazdon 2017; Chazdon *et al.* 2017), in Brazil, the existing large-scale restoration projects tend to strictly follow the legally required actions, ignoring local ecological knowledge from rural communities and most technical innovations (Durigan *et al.* 2010). Planting nursery-raised tree seedlings is the main restoration technique applied in Brazil (Moreira da Silva *et al.* 2017), as in other tropical regions (Lamb *et al.* 2005; Chazdon 2008); even if this technique might not be the cheapest or most appropriate to the original vegetation, disturbance and conditions of the site to be restored (Brancalion & van Melis 2017). For example, planting seedlings of riparian forest species from central Brazil is extremely common in operations trying to restore savanna and grassland vegetation within the same region (Cerrado biome; Sousa & Vieira, unpublished data), when such plantings are able to establish the trees, this can lead to inadequate afforestation (Veldman *et al.* 2015).

This happens due to the higher attention forest environments and tree species receive in conservation and restoration contexts (Veldman *et al.* 2015); but also because the seeds of these riparian forest species are easily available and their seedlings have faster initial growth rates (Freire & Piña-Rodrigues 2006). Ignoring the original vegetation structure and composition in restoration operations leads to high rates of failure in restoration projects (Suding 2011). This highlights the need to consider site-appropriate ecological theory and conditions to promote successful restoration. Incorporating local ecological knowledge and involving local communities are also key elements to promote sustainable restoration economic chains. This improves local livelihoods with economic activities based on natural resource conservation and sustainable use. In this context, public policies need to foster community-based seed networks to foment ecological restoration, focusing on the organisational and structural aspects of the production chain. Seed production efforts to accomplish Brazilian international agreements will represent only 1% of the US$ 19.2 billion planned investments and has the potential to generate about US$ 36.9 million per year of income for seed producers (Freire *et al.* 2017).

In this paper, we analyse three successful community-based networks that supply native seeds and seedlings for Brazilian Amazon and Cerrado restoration projects. In addition, we propose directions to promote local participation, legal, technical and commercialisation issues for up-scaling, with quality and social justice, the native seeds market for restoration. The guidelines we derive from these three case studies are useful and applicable for the up-scaling of restoration ecology efforts in many other parts of the world and especially in tropical countries.

THREE COMMUNITY-BASED LARGE-SCALE ECOLOGICAL RESTORATION INITIATIVES IN BRAZIL

Native seed production and restoration in Upper Xingu region, southeast Amazon

The colonisation process in the southeast Amazon has promoted profound land-use transformations, mainly since the 1970s, with the execution of government development programmes. Livestock farming, logging, and more recently, soybean cultivation for the international market became the economic basis of the Xingu Basin. The agribusiness production model turned this into one of the highest deforestation regions of the Amazon, totalling 6.5 million deforested hectares, which represents 37% of the Upper Xingu area (INPE 2017). Thus, the existing indigenous lands and protected areas lie across agriculture frontiers (Schwartzman *et al.* 2013). In this region, forest degradation has clearly caused regional climate change (Nobre *et al.* 2016).

A shared responsibility campaign, named 'Y Ikatu Xingu' (save the good water of Xingu), was launched in 2004 to articulate and implement a development plan compatible with conservation of the Xingu river headwaters. This campaign promoted collective action based on collaboration among landowners, indigenous and rural communities, government and non-governmental organisations (NGOs) and political representatives. These efforts, associated with the increased environmental law enforcement in the region, have promoted the restoration of different types of vegetation, especially riparian forests, semi-deciduous forest and forest–savanna transition areas.

Considering the regional restrictions for producing and planting seedlings and successful use of direct manual seeding by other Brazilian initiatives, mechanised direct seeding was adopted as the main restoration technique (Durigan *et al.* 2013). The mixture of seeds ('muvuca de sementes') is composed of different native species and green manure species. These direct seeding techniques allow use of agricultural machinery, available at the farms that are required by law to perform restoration in the areas that were illegally deforested. On average, this mechanical seeding technique applies around 200,000 native seeds and 150,000 seeds of annual and sub-perennial legumes, plus 50–150 kg of sand for each hectare to be restored (Campos-Filho *et al.* 2013).

This technical approach up-scaled regional demand for native seeds, and civil society organisations started encouraging local communities and households from several sociocultural contexts to become seed collectors. In 2007, the Xingu Seed Network (Rede de Sementes do Xingu) was created as a partnership between indigenous communities, landowners, local governments and NGOs. In this first year, ten seed collectors harvested 5 t seed, from 120 native species. This experience motivated other communities to start collecting and selling native seeds for restoration. The social diversity of Xingu's seed collectors represents realities, identities and cultures, which creates a unique symbol for this production system in the forest restoration value chain.

The marketing process in Xingu Seed Network involves several organisation levels. Seed collector groups plan their seed production annually, considering ecosystem observations (how much and which species will produce seeds) and interested seed collectors, thus defining the potential for seed supply. Meanwhile, the management office establishes partnerships with landowners who need to restore degraded lands. Combining the seed collectors' potential for supplying native seeds to market demand, the goal for annual seed production is established.

Following the Brazilian legislation for seed commercialisation (see below), the quality of the seeds (germination and purity rates) is checked by partner universities and research institutes. The restored areas are periodically monitored by NGO staff, practitioners, landowners and researchers to evaluate field outcomes. With this operating system, it was possible to obtain the National Register of Seeds and Seedlings (RENASEM), which represents the formal requirement for seed production and commercialisation, following the national regulations.

Over a decade, the Xingu Seed Network has facilitated production of a substantial volume of seeds (175 t) of 220 native species (Table 1). It has engaged 450 seed collectors in 16 municipalities in the Upper Xingu region, covering 14 rural settlements, one extractive reserve and four indigenous territories with the participation of indigenous peoples from six ethnicities. The price of seed from each species is decided collaboratively among seed collector groups under the direction of Xingu Seed Network technical staff. Seed production has positive impacts on seed collector livelihoods, in such dimensions as health and nutrition level, home and shelter, local knowledge, cash income and empowerment of women (Urzedo *et al.* 2016). Over this period, this network has been responsible for the restoration of more than 5000 ha within the Xingu River basin. In general, these restored areas present higher tree densities (2500–32,250 trees ha^{-1}) and more vegetation layers than a mature forest, resembling areas under natural early forest succession (Campos-Filho *et al.* 2013). The Xingu Seed Network operating system and institutional model have inspired and spread into different regions of Brazil.

Grassland and savanna restoration at Chapada dos Veadeiros region

The Chapada dos Veadeiros National Park (CVNP) is one of the essential zones of a UNESCO World Heritage Area, in the state of Goiás, in central Brazil. The park encompasses 240,000 ha of Brazilian savanna (Cerrado) where there are approximately 600 ha of degraded area that had been converted into African grass species pastures before the Park creation. Since 2012, a partnership between the Brazilian Protected Areas agency (ICMBio), the University of Brasília and Embrapa (Brazilian Agriculture and Animal Husbandry Research Enterprise) has performed restoration experiments within the park. The experiments aim to develop low-cost, efficient techniques for restoring grasslands and savannas at a landscape scale (Sampaio *et al.* 2015). Such ecosystems are rarely properly restored in Brazil. This is because grasslands and savannas are commonly neglected in conservation and restoration initiatives (Veldman *et al.* 2015). When these areas become restoration targeted, they are commonly 'restored' by the planting of tree species seedlings, which in fact represents inadequate afforestation and has several negative consequences, leading to degradation instead of restoration (Veldman *et al.* 2015).

The direct seeding experiments developed in CVNP were inspired by the success of the large-scale restoration efforts of the Y Ikatu Xingu initiative, especially considering the involvement of local communities and the use of agricultural machinery to reduce restoration costs. In addition to tree species seed, we tested a variety of methods for direct seeding of native grasses, shrubs and forbs, which are important structural and diversity components of savanna and grassland ecosystems in the region (Rezende *et al.* 2008).

The initial funds for this restoration experiments came from ICMBio and helped to raise additional funding, which guaranteed the restoration of 3 ha in 2012 and 3 ha in 2013. In 2014, a partnership with the Cerrado Seeds Network allowed the restoration of a further 7 ha. Seed collection, preparation and storage techniques were adapted or developed considering local ecological knowledge and available scientific information. Local dwellers, living in small cities and local communities around the CVNP were trained and performed all the steps of restoration, from seed collection to seed sowing.

With these 13 ha under restoration and the identification of species with higher establishment potential (Pellizaro *et al.*

Table 2. Prices, production and revenue from seed commercialisation for the Xingu Seed Network by 2017 in the Southeast Amazon.

seed price (US$ kg^{-1})	species (n)	seed production (kg)	revenue (US$)
1 to 15	57	21,382	108,240
15 to 35	34	2992	64,214
35 to 60	22	1340	66,205
60 to 110	17	724	56,179
Total	130	26,438	294,839

Table 1. Main characteristics and achievements of three community-based ecological restoration initiatives until 2017 in the Brazilian Amazon and Brazilian savanna (Cerrado).

	community-based restoration initiatives		
parameters	Xingu seeds network	Chapada dos Veadeiros National Park	Jirau hydroelectric dam
Biome	Amazon	Cerrado	Amazon
Starting year	2007	2012	2011
Main proposal/driver	Securing water quality with community participation	Restore degraded areas inside a National Park	Restore degraded areas around a large artificial dam
Organisation model	Association	Association	Cooperative
Community members (n)	450	60	81
Total production	175 tons of seeds	22.4 tons of seeds	1.7 tons of seeds 406,000 seedlings
Number of native Species (n)	220	80	80
Restoration area (ha)	5000	108	291
Approximate income generated (USD)	750,000	85,000	300,000

2017), this consisted in the largest grassland and savanna restoration initiative in the Cerrado. In 2015, a power line company (Norte Brasil) was searching for degraded areas that they could restore, as offset for vegetation suppression required by law. The power line company established a pioneer agreement with ICMBio and local seed collectors to restore 95 ha inside the park through mechanised direct seeding (Table 1, Fig. 1).

The power line company restoration request significantly increased the demand for native seeds and generated more than US$ 60,000 of income for seed collectors from more than 60 families within local rural communities in 2 years (2015–2016). Understanding that seed collection for restoration can result in income generation and livelihood improvement, seed collectors funded a community association, named Cerrado de Pé (Standing Cerrado) that, in partnership with the Cerrado Seeds Network, is selling native seed for restoration projects in Chapada dos Veadeiros and other regions of central Brazil. Within a short time period, this cooperative has become self-sustaining and is now generating revenue to improve local livelihoods. In addition, the seed market for restoration helps decrease the threat of vegetation conversion, because the conserved areas outside the park became important seed sources, generating income for local dwellers through seed collection and sale.

The direct seeding restoration methods developed within this initiative cost less than US$ 3500 ha^{-1} compared to US$ 7000 ha^{-1} for tree seedling planting (around R$ 11,000 *versus* R$ 22,000, respectively). In addition, the higher demand for seeds allows for involvement of a larger number of local dwellers, better distributing the income generated by restoration projects. Seeding shrub and herbaceous native species that can compete with invasive grasses increases the restoration success of grassland and savanna ecosystems and decreases the need to control weeds. These grassland and savanna restoration activities were performed within a national park, where legal restrictions on the use of herbicides and on exotic species were followed.

Since 2017, the whole seed marketing process occurs through Cerrado Seeds Network, which contacts the institutions that need to restore degraded areas to organise the seed demand and potential supply by seed collectors. As in the Xingu River basin experience, seed price is established per each species collaboratively among collectors (Table S1). Seed prices consider species density in natural areas and the labour/time/equipment required for seed collection and seed processing. Cerrado Seeds Network holds a National Register of Seeds and Seedlings (RENASEN) and, in partnership with research institutions and universities tests for seed quality, according to legal requirements. Since the use of native grass, forb and shrub species is still rare in restoration projects in Brazil there are no established seed quality parameters for these species. In this context, the Cerrado Seeds Network and partner institutions are proposing the parameters for seed quality tests for several species. In addition to legal parameters, there is also very little published information on Cerrado herbaceous species, especially grasses, regarding seed production, germination and establishment in natural conditions. All the species selected for restoration purposes, collection techniques and storage protocols are under development, based on local ecological knowledge and practical experience. The registration of ongoing

Fig. 1. A: Collector processing *Magonia pubescens* seeds in the Upper Xingu region, Amazon; B: adapted machine for processing native seeds in the Upper Xingu region, Amazon; C: seed mixture preparation for mechanised direct seeding; D: mechanised direct seeding of Brazilian savanna (Cerrado); E: family nursery producing seedlings to restore areas around the Jirau Hydroeletric dam; F: Xingu Seeds Network meetings for community organisation. Photos: Tui Anandi/ISA (A, B, F); Fernando Tatagiba/ICMBio (C, D); Daniel Vieira (E).

practices and information on seed quality related to this seed market will likely help to improve available information on these areas. Applied research and monitoring has been performed in the restored areas and have led to several improvements in direct seeding techniques related to seed sowing and especially exotic grass species control (Sampaio *et al.* 2015; Pellizaro *et al.* 2017), however much more information is needed.

Restoring areas around a large hydroelectric dam in the western Amazon

The Jirau hydroelectric dam, built on the Madeira River, Rondônia state, western Brazilian Amazon created an artificial 258-km^2 reservoir, which is more than 100 km^2 larger than the original riverbed (Fearnside 2014). According to Brazilian law, the companies that build artificial dams are required to buy and conserve (or restore) the area immediately around the dam (30 to 100 m), which are determined as areas for permanent preservation (Áreas de Preservação Permanente, APP). As a result, the companies owning medium and large artificial dams need to restore thousands of hectares. In the case of to the Jirau hydroelectric dam, the hydroelectric company is now responsible for the conservation and/or restoration of an area of approximately 14,000 ha around the artificial lake. Of these, around 3000 ha need some level of intervention for restoration, which varies from passive restoration mostly consisting of fencing to isolate the area and allow natural regeneration, to active exotic species control and but also includes the need for active restoration by planting native species (Rocha *et al.* 2016).

To restore these areas, the hydroelectric company (Energia Sustentável do Brasil – ESBR) hired a local cooperative (COOPPROJIRAU – Cooperativa de Produtores Rurais do Observatório Ambiental Jirau). Rural families from the cooperative that are interested in providing native seedlings for the restoration areas are trained and receive support to build a small nursery to produce and maintain the seedlings for the planting operations. Each family produces and sells between 1000 and 2000 seedlings per year in these nurseries (Fig. 1).

The restored areas are monitored by the cooperative and by researchers from Embrapa (Brazilian Agriculture and Animal Husbandry Research Enterprise). The monitoring by local dwellers and researchers led to changes in planting practices. One of the main innovations is associated with the use of direct seeding, especially to introduce early successional tree species. The seeds are collected by families who cooperate through COOPPROJIRAU, generating direct income for local communities. The demand for seeds and seedlings is established each year by the company and communicated to the cooperative and the producers. Since 2012, more than 291 ha have been actively restored through a combination of direct seeding and tree seedling planting, involving more than 81 local dwellers, who produced and sold more than 406,000 seedlings and 1.7 t of seed (Table 1).

The local arrangement established to restore the areas around Jirau hydroelectric dam represents income generation that benefits local communities in the region impacted by the dam. By becoming seed collectors and seedling producers, local families benefit from the environmental legal requirements imposed on energy companies. Such an arrangement contributes to local livelihoods, decreases social-economic conflicts related to the construction of a large dam, improves logistics and reduces the cost of restoration efforts in remote areas.

COMMUNITY-BASED NATIVE SEED PRODUCTION ARRANGEMENTS

Native seed production for large-scale restoration projects requires strong social arrangements to connect multiple stakeholders in a long-term partnership and with participatory instruments. Initiatives and organisations have engaged in the seed production to connect stakeholders and exchange knowledge and technologies at different levels (Görg *et al.* 2016). Key stakeholders encompass businesses, investors, governments, researchers, NGOs and local communities (Nevill *et al.* 2016). In Brazil, native seed production is essentially a household and community-based activity. According to National Plan for Native Vegetation Recovery, the promotion of native seed quality and availability are national strategies for achieving Brazil's restoration target. It is estimated that 190,000 job positions can be related to the restoration value chain activities in Brazil, mainly from native seed collection and seedling production, which can help poverty reduction and alleviation (M.M.A., Brazil 2017).

The community-based approach has been considered a key strategy for natural resource management (Rout 2010). However, a clear impasse characterises the ecological restoration value chain in Brazil. On the one hand the restoration programmes, practitioners and nurseries report a shortage of native seed in the market to supply the demand for large quantities of high-quality and genetically diverse seed. On the other hand, seed producers constantly state that the instability and fragility of the restoration demands have resulted in production prevention. The restoration market in Brazil is mainly driven by legal requirements for environmental liability on private property (Soares-Filho *et al.* 2014). Moreover, legally required offsets for infrastructure and facilities construction, nurseries and environmental campaigns also represent niches of seed demand. Large individual buyers, as well as adequate and reliable funding are important to help structure the seed market; for instance, in the USA federal agencies are major buyers of native seed for land rehabilitation and restoration (Oldfield & Olwell 2015). In contrast, in Brazil, seed and seedling sales occur on a much smaller scale, since most buyers are individual landowners, small companies and research institutes; this poses challenges for up-scaling seed and seedling production.

Seed networks, environmental campaigns and community restoration programmes have improved the relationship between native seeds supply and local restoration demands (Durigan *et al.* 2013). For local organisation and market access, community groups in Brazil have been structured through associations and cooperatives. Different aspects of the value chain must be quantified in terms of costs to established native seed prices. The first aspect is to consider the costs of seed collection, which involves collectors' labour to collect, transport, process and store seeds, as well as the costs of tools and equipment required for these activities. Second, the organisational and administrative costs of seed production and sale must be added to seed costs. For example, in the case of Xingu Seeds Network, a participatory approach defined a rate of 50% for the seed market. This amount is applied to pay for costs related to the network administration, accounting, taxes and seed storage facilities. These two costs comprise the seed price, considering also the ecological restoration viability. In Chapada dos Veadeiros region, during the first year of large seed selling

(2017), the Cerrado Seeds Network considered an administrative cost of 11% over the price of the seeds, which was decided collectively by seed collectors. This percentage helped to promote the seed market for restoration; however it did not completely cover the administrative costs of the operation, which were covered by conservation projects run by the network. The seed prices were therefore revised to allow for long-term sustainability of the seed marketing.

Even when all administrative costs of seed production and sale can be covered by the prices of the seed, such as in the Xingu Seeds Network, the social work, community workshops and training courses are not covered in the price of seed. Therefore, these initiatives must access external funding to support such activities. The support of NGOs, research institutions and/or governmental institution that can fund or raise funds for social engagement and training activities are essential for the success and long-term sustainability of community-based restoration initiatives. It is possible that after some years of experience, community-based initiatives may be able to sustain seed and seedling production activities independently. However, the socio-economic benefits arising from such community-based arrangements certainly justify outside investment to help establish and even maintain such restoration arrangements. Community participation in seed markets must acknowledge the participatory approach for price development, the capacity to sustainably produce native seeds, the sharing of social benefits and the economic viability of ecological restoration large-scale efforts.

Market supplies can shape very different pricing of native seeds (Allison 2005). Seed prices from community-based production in these three case studies are smaller than values applied for the same species in business production models. For example, seeds of *Hymenaea stigonocarpa* have a sale price between US\$ 4.66 and 7.45 kg^{-1} in the Seed Network cases, while the price of seeds of the same species can reach US\$ 25.00 when sold by private companies. The most accessible prices allow financial viability of the restoration, especially using the direct seeding technique that requires high seed volumes (Campos-Filho *et al.* 2013). In the case of the Xingu Seed Network, of 130 native species sold in 2017, almost half of the species prices were less than US\$ 15 kg^{-1}. This species group represented more than 80% of the total production and one-third of total revenue from the native seed trade (Table 2). It demonstrates that seed collectors produce a high number of species at affordable prices, generating a community-based market with transparent profit sharing. These community-based groups are organised according to models and production strategies, following the household economy systems and local sociocultural realities. Therefore, the seed is a component of other productive activities, promoting community autonomy, diversifying income generation and improving local livelihoods. In some instances, the seed production for restoration may also be associated with fruit pulp production, especially within the Amazon and Cerrado region in Brazil. Public programmes that buy fruit pulp and other related products (sweets, cookies, ice creams) from small farmers to provide student meals in primary and middle schools in Brazil generate more than US\$ 10 million $year^{-1}$ directly to small farmers (IBGE 2015). For the three community-based experiences, there is no research focused specifically on measuring the impact of native seed harvesting on native plant populations. Seed harvesting from perennial plants tend to have little impact on plant population dynamics (Franco & Silvertown 2004; Schmidt *et al.* 2011), although it can result in impacts on frugivores (Galetti & Aleixo 1998). However, all seed collector groups have established agreements for good seed collection practices that aim to minimise impacts. These agreements establish that fruits can only be harvested when mature, only reproductive parts can be harvested (*i.e.* no branches should be cut) and no more than 30% of the fruits should be collected. In Chapada dos Veadeiros herbaceous species seed collection is performed preferably from several plant individuals in large populations. In addition, collectors from the Xingu Seed Network are responsible for restoring 0.5 ha each year in or around their own land to improve local natural resource availability.

LEGAL REQUIREMENTS FOR NATIVE SEED PRODUCTION

The legal requirements are the main factors inducing and shaping restoration in many countries (Ruiz-Jaén & Aide 2005; Durigan *et al.* 2010; Aronson *et al.* 2011), fostering the use of native seeds in the restoration programmes (Freire *et al.* 2017). The Brazilian legislation, since the 1930s, requires that at least 20% (and up to 80%) of all rural properties should conserve the original vegetation in a 'legal reserve area' and that land converted irregularly should be restored. Despite some criticism (Aronson *et al.* 2011; Chaves *et al.* 2015), legal policies established in the 2000s in São Palo state promoted an increase in native seed and seedling production and species diversity in nurseries (Brancalion *et al.* 2010; Martins 2011; Fernandes *et al.* 2017). At this time, eight seed networks were formed supported by the Brazilian Government and these foster wider social participation in public policies (Piña-Rodrigues *et al.* 2015).

In the meantime, the Law 10.711/2003 and Decree 5153/2004 established obligatory National Registers of Seeds and Seedlings (RENASEM) and the Register of Cultivars (RNC), supervised by the Ministry of Agriculture, Livestock and Food Supply (MAPA). As Brazil is a mega-diverse country (Harding *et al.* 2013), these legal requirements, together with the requirement for a responsible technician (RT), made illegal the activities of thousands of small producers and seed collectors, who accounted for about 60% of the seed supply chain (Freire *et al.* 2017). Just recently, in 2017, a normative (IN 17/2017, MAPA) simplified the RENASEM and RNC and excluded the need for a RT for small seedling nurseries, but not for seed producers. In addition, it included a 3-year moratorium for the requirement for seed analysis in accredited laboratories, allowing for seedling emergence tests in uncertified nurseries and laboratories.

The Brazilian Government has established seed quality protocols (MAPA 2009) based on the International Rules of Seed Testing. There are species-specific protocols for pre-treatment (seed cleaning, dormancy breaking) and germination tests (substrate, temperature and number of days for germination evaluation) for 300 forest species, mostly exotic. Whereas there are less than 50 native species for which seed quality protocols are validated and published in legal documents (MAPA, IN 44/2010, 35/2011, 26/2012). In addition, there are about 300 native species with recommended (but not validated and published) protocols (Brazil 2013). These regulations highlight the need for the development of fast seed quality tests, such as the tetrazolium test for seed viability, techniques for seed dormancy breaking and simplified storage methods that could be applied in community-based seed production, including local knowledge for seed management.

The native seed legislation has brought positive aspects to improving seed quality, such as the requirement for credentials of seed producers and collectors, the need for proper species identification, the registration of seed sources and the co-responsibility of producer and responsible technician. Besides, legal procedures can turn the online registration system into a public collaborative network that allows the identification of producers, the species produced and their origin or provenance. This is a strategy to rationalise and facilitate the process of providing seeds and seedlings for restoration. Nevertheless, to include the community-based seed production networks, legal requirements need to be simplified. For example, the simple adoption of the 'Label Principle' from Consumer Protection Code (Law 8078/1990), which assumes that the product label provides all information consumers need, could replace legal requirements and transfer liability to seed sellers/producers. This would decrease the need for law enforcement and allow governments to produce guidelines to be followed by seed producers and buyers.

Another legal improvement to benefit community-based seed production would be distinguishing small (<500 kg seed year^{-1}, <50,000 seedlings year^{-1}) from large producers, fitting obligations to producer capacity. With the increasing demand for land restoration, it becomes difficult for nurseries to obtain a variety of species only from their own seed collectors (Brancalion *et al.* 2012). By relying on community-based seed production systems, restoration programmes would include adapted seeds; thus improving species richness and genetic diversity in a range of species localities, since seeds can be collected across the species occurrence range by hundreds of seed collectors, using different skills and diverse local knowledge (Freire *et al.* 2017).

DIRECTIONS TO IMPROVE COMMUNITY-BASED NATIVE SEED PRODUCTION

Ecological restoration in a large and diverse country requires seed with high species diversity, adapted to different ecosystems. To overcome this bottleneck, spreading seed collection in many sites throughout the whole territory is desirable for individuals and species adaptation, evolution and to reduce inbreeding depression (Broadhurst *et al.* 2008). For that, it is necessary to diversify the sources of seed collection. Several mechanisms can help to achieve this goal, such as: (i) increasing the number and cultural diversity of the seed collectors; (ii) establishing different prices for different seed species; (iii) ensuring long-term contracts so the collector can spread seed harvesting over the different months of the year, which would also foster the use of recalcitrant seeds for seedling production or for direct seeding immediately after seed dispersal.

In order to ensure genetic and species diversity, local community-based seed production requires social technologies that are relatively cheap and regionally adapted. Among the seed production operations, collection can represent the most expensive activity, due mainly to the specific security procedure and distance of transport, followed by the seed extraction and processing (Schmidt 2000). Hence, the local knowledge of species occurrence and seed sources, together with plant population mapping and expertise in maturation indicators (colour, dehiscence, opening) will contribute to decrease the costs of this time-consuming operation. This also increases the potential for seed/fruit collection, reducing its 'storage' in the field under inadequate conditions. In addition, unlike large-scale

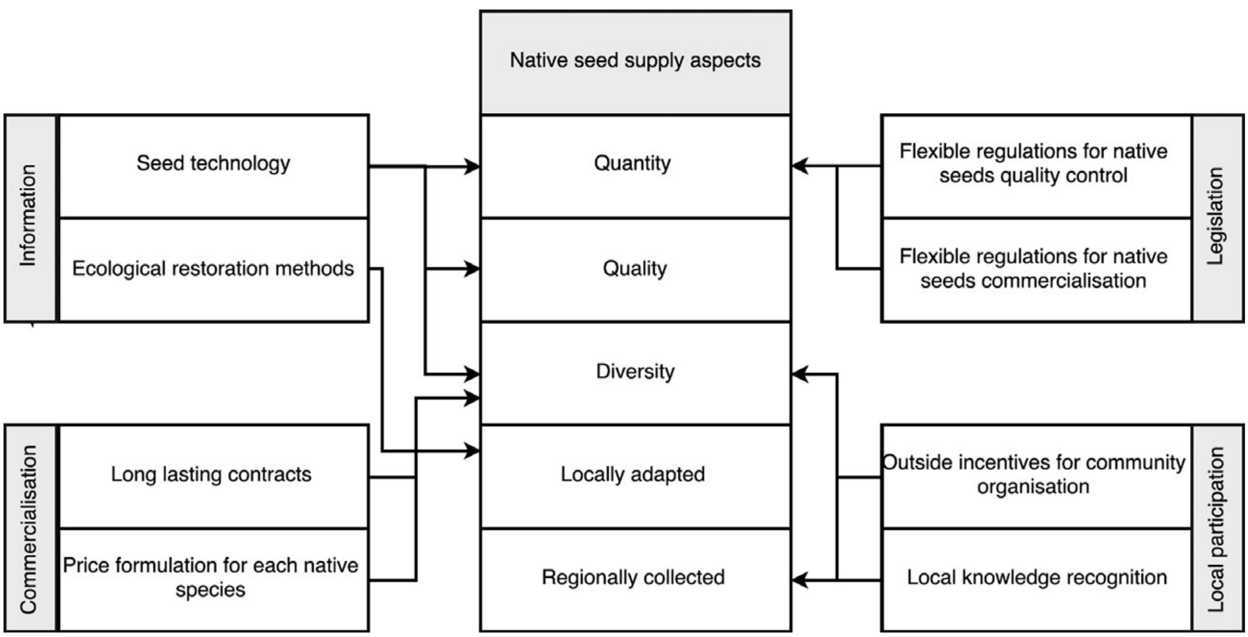

Fig. 2. Conceptual diagram linking the types of information, legislation and local engagement necessary to improve community-based native seed and seedling production for large-scale restoration efforts, allowing for seed collection of a high diversity of species, from a large regional species pool that have a higher chance of being adapted to restoration areas.

seed production for agriculture, the processing of native seeds does not yet have specific equipment and depends on the creativity of local seed collectors to adapt existing tools to the diversity of propagule forms and sizes, frequently creating new uses for unusual equipment or apparatus. For example, seed collectors from Xingu River Basin use laundry machines to extract *Hymenaea courbaril* L. (Fabaceae) and other seeds from fleshy fruits. Grass grinders can be used to extract seeds from hard legumes or to separate grass foliage from seeds. Local ecological knowledge on plant propagation, plant establishment and growth is prolific among local rural communities. Considering this knowledge and fostering the ability to innovate may improve several steps of the ecological restoration process.

There are several research gaps that must be filled to improve restoration practices. Since 2007, research on native seed has increased; however, 43% was concentrated on genetic and biochemical issues, while basic essentials, such as germination requirements, maturation, dormancy, diseases and native seed technology were clearly overlooked (Piña-Rodrigues *et al.*, in press). In fact, research focused on ecological niche germination, seed traits and species establishment (Vargas *et al.* 2015) needs to be translated and applied to restoration practitioners, helping in evaluating field emergence and establishment, for example. To improve community-based seed production, we still need research on practical methodologies to define germination techniques, maturation indicators, seed processing and storage conditions. Seed technology and management information for native species linking scientific research and local knowledge are flourishing (*e.g.* Mori *et al.* 2012; Piña-Rodrigues *et al.* 2015). At the same time, legal requirements need to be simplified, mainly to accept simple seed quality tests, such as emergence tests in seedling beds, which can be easily incorporated into the community-based production.

CONCLUSIONS

Local restoration networks can emerge from and significantly contribute to the establishment of effective restoration actions as long as technical training is provided to local communities (Fig. 2). Establishing inclusive, fair-trade seed and seedling markets, as well as decreasing bureaucracy associated with this market may foster ecological restoration associated with income generation for local communities. The three case studies presented here show that community-based organisations can be capable of providing resources to large-scale programmes with positive participation and livelihood outcomes.

Non-governmental and governmental organisations in Brazil have an essential role to support local communities in supplying native seeds. Such inclusive networks help increase the diversity of techniques and species available for restoration, being more cost-effective since they consider local solutions and resources, which tend to be more appropriate to restoration reality. This is possible because communities have local knowledge and working capacity to promote large-scale native seed production. For the long-term success of these community-based initiatives, seed production must be based on real market demand, to avoid seed losses or local community engagement. In addition, simplified legal requirements are necessary, and should acknowledge how a community-based system can promote a seed trade organisation in association with local social, cultural and economic values.

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SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article:

Table S1. List of species of seed, prices per kilogram and quantity traded in 2017 by the three community-based seed production organisations in the Upper Xingu region, Chapada dos Veadeiros and Jirau region in Brazil.

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