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Essays and Perspectives

How can Brazilian legislation on native seeds advance based on good practices of restoration in other countries?

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HIGHLIGHTS

- The Brazilian legislation on native seeds has bottlenecks and gaps that can be addressed based on international best practices.
- Seed collection from nature should be discussed and standardized by environmental agencies to ensure it becomes a sustainable practice.
- Seed quality is crucial for the success of ecological restoration, but it should not adhere to the standardization required for agricultural cultivars.
- The commercialization of species mixtures for restoration, including directly harvested ones, should be facilitated to promote biodiversity.
- The implementation of seed transfer zones is highly recommended to guarantee the resilience of restored ecosystems in the long term.

GRAPHICAL ABSTRACT

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ABSTRACT

In the decade of global ecological restoration efforts, Brazil intends to restore 12 million hectares of degraded areas. This will require an ample offer of seeds of native species, unavailable on the current market, which is partly due to inadequate legislation. We reviewed the literature on native seed production and the specific legislation in Brazil, and compared with rules of other countries to identify good examples to be followed. We first verified a lack of regulation concerning the seed collection in natural environments in Brazil, which contrasts with the Society of Ecological Restoration (SER) recommendations. Best practices for seed collection should be developed by environmental agencies. Second, the scarcity of accredited laboratories for native seed quality analysis is a limitation in Brazil. The development of strategies for streamlined accreditation that align with SER's quality standards for native seeds meant for restoration purposes is an important step. Furthermore, the regulation of the trade of seed mixtures in Brazil is currently restrictive and requires a revision of norms to facilitate their use, as the case in the European Union. The mixtures directly harvested from remnants are promising to promote restoration, especially of grassy ecosystems. Another aspect is the establishment of Seed Transfer Zones (STZs) to promote

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the use of locally adapted ecotypes and to ensure the conservation of genetic diversity in restoration. Our study indicates how examples from other countries and the SER guidelines can guide advances in Brazilian legislation and streamline the development of a seed supply chain for ecological restoration.

Introduction

The UN Decade on Ecosystem Restoration (2021–2030) is to contribute significantly to crucial objectives of sustainable development, such as improving people's livelihoods, fighting climate change, and halting biodiversity collapse (UN, 2019). The Bonn Challenge, the largest global restoration initiative, aims to restore/recover 350 million hectares of degraded areas by 2030 (Gann et al., 2019). However, the supply of native seeds for restoration to meet such ambitious goals poses a tremendous challenge (Merritt and Dixon, 2011; Nevill et al., 2018; Pedrini and Dixon, 2020).

In Brazil, 21 million hectares need to comply with legal obligations for restoration (Soares-Filho et al., 2014). The National Policy for Native Vegetation Recovery, PLANAVEG (MMA, 2017), aims to restore 12 million hectares of degraded land by 2030 and is to improve the quantity, quality, and accessibility of native seeds and seedlings. However, this endeavor faces challenges, particularly due to the lack of a well-structured seed and seedling production chain (Moreira da Silva et al., 2016). On the other hand, Brazil has, in some regions, experience with community-based seed networks, which, with proper incentives, could significantly increase their capacity (De Urzedo et al., 2020). However, the existing national seed legislation is considered impeditive to increasing seed production (Daldegan Sobrinho, 2016; Freire et al., 2017). Problems include control regulations for native and exotic species seeds, the difficulty in accreditation of seed laboratories, and the lack of genetic quality control of seeds (Moreira da Silva et al., 2016; Freire et al., 2017; De Urzedo et al., 2019).

Brazilian legislation (Box 1) is predominantly based on standards typically used for agricultural species, neglecting the need for native genetic diversity in ecological restoration. It does not consider the socioecological context of production and/or commercialization of native seeds locally (De Urzedo et al., 2020). Several legal requirements have hindered thousands of small native seed producers who are crucial for this production chain to comply with legislation (Schmidt et al., 2019). Consequently, informality is widespread in the sector (Piña-Rodrigues et al., 2020), and progress is challenging due to limited knowledge of native species, scarcity of accredited laboratories, and fluctuating demand (De Urzedo et al.,

Table 1
Summary of information gathered from the review of 75 articles, legislation analysis, and consultation with 39 experts from 7 countries concerning the four topics discussed in this article. The complete list of consulted legislation is included in Supplementary Material - Appendix I and the information confirmed by experts and institutions are cited throughout this article.

Countries	Permit for collection in nature	Seed quality	Mixtures	Zones (STZ)
Brazil[1]	Overall not mandatory. The regulations provide some guidelines, but there is a need for further development in terms of standardization and training.	Required, with an agricultural and forest bias. Lab accreditation is complex and not compatible with the reality of the supply chain.	Allowed with restrictions. The commercialization of directly harvested mixtures is not regulated.	There is mention of bioclimatic regions in the legislation, but they are not regulated.
Germany[2]	Yes, mandatory prior to collection. No records of problems related to this.	Required, with certification. No records of difficulties with laboratory accreditation, which seems to be linked to a strong market for native seeds.	Permitted, with specific rules for directly collected mixtures. This type of mixture is widely used, with few quality requirements.	Yes, mandatory. There are 08 regions where seeds can be commercialized within their boundaries. It was necessary to group ecoregions (8 out of 22) to make the market viable.
United States of America	Only required on public lands and protected areas.	Required. No records of difficulties with laboratory accreditation, which seems to be linked to a thriving market for native seeds.	Permitted and widely used. Mixtures are generally made from purchases of individual species' seeds.	There are suggested zones, generally observed in government purchases or projects with high-quality standards, which represent a large part of the production chain.
Australia[4]	Yes, mandatory prior to collection, according to State requirements. There are records of difficulties for collectors in this stage.	Not mandatory. There are guidelines for good practices. Guidelines alone are not enough to ensure quality seeds in the country.	Permitted, without restrictions, as quality control is not mandatory.	Only as guidelines for good practices. Not mandatory.
Chile[5]	Not required.	Not mandatory. The absence of regulation did not result in a developed production chain.	No control.	No defined STZ. There is technical material discussing the need for and proposing the definition of STZ.
Argentina[6]	Yes, but focused on collection for access to genetic heritage. Not clear regarding collection for ecological restoration.	Required, but not clear in the specific regulation for native seeds.	Permitted, but focused on the use of forage plant cultivars. No records of mixtures for restoration.	There are defined zones for some species, but they are not mandatory. There is technical material proposing the definition of STZ.
Uruguay[7]	Yes, but focused on collection for access to genetic heritage. Not clear regarding collection for ecological restoration.	Required, but focused on agricultural cultivars. Voluntary guidelines for forest seedlings.	Permitted, but focused on the use of forage plant cultivars.	No regulation or technical discussion found about STZ in the country.

[1]Law No. 10.711/2003; Decree No. 10.586/2020; Normative Instruction MAPA No. 17/2017; Law No. 12.651/2012; [2]BNatSchG/2009; ErMiV/2011; Directive No. 62/2008; Directive No. 60/2010; [3]Federal Seed Act/1940; Federal Land Policy and Management Act/1976; [4]Act No. 91/1999; [5]Decree Law No. 1.764/1977; [6]Law No. 20.247/1973; Law No. 25.675/2002; Resolution INASE No. 318/2018; [7]Law No. 16.811/1997; Law No. 17.283/2000; Standard INASE No. 786/2018.

Box 1
Main norms in Brazilian seed legislation.

Law No. 10.711/2003 (Brazil, 2003), recently altered by Decree No. 10.586/2020 (Brazil, 2020), establishes the National Register of Seeds and Seedlings, primarily focusing on agricultural cultivars. The responsibility for regulating the production and trade of forest species seeds, whether native, exotic, or of medicinal and environmental interest, is with the Ministry of Agriculture, Livestock, and Supply (MAPA) (Article 47). A In administrative terms, the Normative Instruction (NI) MAPA No. 17/2017 (Brazil, 2017) regulates the production of native seeds and seedlings in practice, aiming to ensure the seeds' origin, identity, and quality.

This legislation introduces requirements such as the National Registry of Seeds and Seedlings – RENASEM (https://sistemasweb.agricultura.gov.br/pages/renasem.html), where individuals or legal entities engaged in seed production, processing, storage, repackaging, and commercialization must be registered. Moreover, those involved in activities related to technical responsibility, sampling, collection, certification, and laboratory analysis of seeds and seedlings are also required to register under RENASEM. Small producers selling up to 10,000 seedlings a year are exempt from registering.

Furthermore, the National Register of Cultivars – RNC (https://sistemas.agricultura.gov.br/snpc/cultivarweb) serves as a platform for registering both cultivated varieties and wild native species that are commercially traded - Regulation No. MAPA 502/2022 (Brazil, 2022).

More relevant legislation is listed in the Supplementary Material - Appendix I.

2019). Additional challenges are regulatory gaps, including insufficient control of genetic quality and variability of seeds, jeopardizing long-term restoration success (Gann et al., 2019), and lack of control over wild seed collection, which may lead to overexploitation of seeds in remnants (Nevill et al., 2018). While addressed in international recommendations (ENSCONET, 2009; Pedrini and Dixon, 2020), these issues remain poorly considered in Brazil. In addition to the strong agricultural bias in Brazilian seed legislation, the terminology associated with native species heavily focuses on forests, leaving professionals dealing with species from grassy ecosystems, which originally represent 27% of the country's territory (Overbeck et al., 2022), at the discretion of authorities to be recognized.

Here, we present a synthesis on seed legislation for restoration in Brazil, based on literature and legal norms. To be able to discuss the legal framework in Brazil, we selected neighboring countries and others that are recognized for their native seed production or commercialization for restoration. We analyzed the literature and legislation (Table 1; see also Supplementary Material) and consulted experts from these countries on regulations and recommendations for using and commercializing native species seeds for restoration purposes, for comparison. We focused on four aspects: (i) regulation of native species seed collection from natural remnants; (ii) quality standards for seed commercialization; (iii) production and commercialization of seed mixtures; (iv) establishment and delineation of seed transfer zones.

Seed collection in the wild

The Society for Ecological Restoration (SER) has developed standards for collecting and producing native seeds for ecological restoration. The maximum recommended amount of mature seeds collected from a natural remnant to maintain healthy collection sources is 20% (10% for annuals; Pedrini and Dixon, 2020). Particular attention should be given to populations that are threatened, endemic, or rare (Nevill et al., 2018). European guidelines follow a similar approach, with collection licenses mandatory in many countries (ENSCONET, 2009). In Germany, a collection license is mandatory for collection of all native species (BNatschG, 2010). In Australia, licenses must be obtained from state authorities (Cuneo et al., 2021). In the United States, government permits are required

Box 2
Seed collection in nature versus access to the genetic bank/heritage.

Seed collection from natural habitats, whether for extraction purposes or seed and seedling production, is regulated by environmental legislation at both the federal and state levels. Particularly noteworthy is the Federal Law No. 12.651/2012 (Brazil, 2012), which states:

Art.21. The collection of non-timber forest products, such as fruits, vines, leaves, and seeds, is allowed under certain conditions, and it is subject to the following considerations:

I - The periods of collection and volumes defined in specific regulations, if applicable;

II - The fruit and seed maturation period;

III - Techniques that do not jeopardize the survival of individuals and the collected species when harvesting flowers, leaves, barks, oils, resins, vines, bulbs, bamboos, and roots.

The collection for access to genetic heritage must adhere to the specific law - Law No. 13.123/2015 (Brazil, 2015), in which we emphasize the concepts established in Article 2, VIII, X, and XI:

Access to genetic heritage - research or technological development carried out on samples of genetic heritage;

Research - experimental or theoretical activity conducted on genetic heritage or associated traditional knowledge to produce new knowledge through a systematic process of building knowledge that generates and tests hypotheses and theories and describes and interprets the underlying principles of observable phenomena and facts.

Technological development - a systematic effort on genetic heritage or associated traditional knowledge, based on existing procedures obtained through research or practical experience, aimed at developing new materials, products, or devices, as well as improving or creating new processes for economic exploitation.

for collecting on public lands (USDI/BLM, 2018). Regarding Latin American countries, no specific seed collection regulations exist in Chile and Peru (Atkinson et al., 2018). In Argentina, collection permits are regulated by provincial environmental agencies (e.g., Buenos Aires, 2019), and the collection area must be registered producer (APSEN; Argentina, 2018). However, environmental control is focused on access to genetic resources. Similar control measures exist in Uruguay (Article 22 of Law No. 17.283/2000, Uruguay, 2000), without specific legislation on collection for restoration purposes. In Brazil, collection for extraction and reproduction of species for seed and seedling production only constitutes access to genetic resources when it involves research and technological development of new products, the case when the objective is genetic improvement, typical of cultivar development, and it must follow the provisions of Law No. 13.123/2015 (Brazil, 2015) and Decree No. 8.772/2016 (Brazil, 2016) (see Box 2).

Normative Instruction No. 17/2017 (Brazil, 2017) from the Brazilian Ministry of Agriculture, Livestock, and Supply (MAPA) stipulates compliance with environmental legislation on seed collection from nature (Article 5, III). The Native Vegetation Protection Law (Brazil, 2012) allows seed collection from nature, except when specific regulations restrict periods of the year and maximum volumes (Article 21). Collection techniques must ensure the survival of individuals and species conservation in the case of endangered species, while complying with recommendations and restrictions outlined in action plans or specific norms (Brazil, 2014). For instance, the collection of seeds from Brazilian pine (*Araucaria angustifolia*) is subject to strict control to safeguard reproduction (Brazil, 1976). A normative regulation (Brazil, 2022b) on the collection of seeds and other propagules of native species in federal protected areas for restoration or population recovery of threatened species has been recently published, with guidelines on collection methods that ensure genetic diversity and monitor post-collection impacts.

Regulating seed collection from nature is important, but overly restrictive regulations could adversely impact the supply chain. For instance, in Australia, excessive bureaucracy for obtaining collection licenses has led many producers to operate informally (Gibson-Roy et al., 2021). Finding a balance between effective regulation and practicality is crucial to meet the growing demand for seeds to fulfill restoration goals. Additionally, cultivating native species in designated Seed Production Areas (SPAs) has been recommended, mostly for herbaceous species (Zinnen et al., 2021). Similarly, the Brazilian legislation considers "seed orchards", although further refinement in complementary regulations is necessary. These native seed orchards will be essential as restoration demand increases, safeguarding the natural seed supply for populations in their habitat, especially for less abundant species and in regions with substantial degradation. However, even when establishing SPAs, proper management practices, such as renewing herbaceous species beds with seed from wild individuals every five years, are required to prevent unintentional genetic selection (Basey et al., 2015).

Considering international experiences and recommendations for ecological restoration, there is a clear need to update the guidelines provided by Brazilian environmental agencies for the sustainable collection of seeds and other propagules from natural habitats. Manuals for good collection practices, including specific rules for rare or threatened species, alongside professional training for collectors, are necessary to potentialize the native seed production chain. Overly restrictive rules may lead to the creation of bottlenecks in the production chain.

Seed quality: standards for restoration and laboratory access

The concept of seed quality in commercial markets has been heavily influenced by a focus on standardization and productivity, a trend that originated from the Green Revolution in the 1960s and has been reinforced by legislation on plant variety protection. The shift towards industrialized agriculture led to favoring selected, uniform, and high-yielding varieties, which resulted in the undervaluation of genetic diversity and the gradual loss of agricultural varieties over time (Prip and Fauchald, 2016). Ecological restoration, on the other hand, requires a diverse gene pool to enhance the resilience of restored ecosystems (Gann et al., 2019): standardization is inadequate.

This bias toward agricultural standardization is observed in Brazilian legislation and in other countries, which mostly lack specific legal instruments to regulate the production of native seeds for restoration (Mainz and Wieden, 2018; Prip and Fauchald, 2016). The mere absence of control regulations did not lead to the development of a robust supply chain of native seeds, as seen in Chile (Bannister et al., 2018; León-Lobos et al., 2020) and Peru (Atkinson et al., 2018). On the other hand, guidelines without explicit regulations may prove ineffective in ensuring adequate seed quality, as observed in Australia, where guidelines with quality standards (https://florabank.org.au/guidelines) exist, but are not widely followed in the market due to voluntary adherence, difficulties in accessing accredited laboratories, and costs (Gibson-Roy et al., 2021). Conversely, Argentina and Uruguay have specific national institutes for seed control (INASE), but the regulations mainly focus on agricultural cultivars. Uruguay offers voluntary certification for the production of exotic and native forest seedlings (Uruguay, 2018), while Argentina has its own standard for production and trade of native seeds and seedlings (Argentina, 2018) without explicitly describing quality requirements.

For ecological restoration, the SER recommends practical and accessible quality standards for wild native species seeds to produce a reliable final product with the highest possible quality (Pedrini and Dixon, 2020). Seed quality refers to measurable attributes like purity, viability, germination, and dormancy (Frischie et al., 2020). However, the standards in restoration should not be as strict as those used for agricultural purposes, and the main focus should be on genetic quality (Abbandonato et al., 2018). Even so, testing is recommended to inform consumers about the expected product quality (Pedrini and Dixon, 2020). Investing in the quality of seeds intended for ecological restoration is important and aspects of the dependability of the commercialized product (e.g., attributes of purity, germination, or viability) and ecological considerations (e.g., seed source) must be considered. For instance, purity attributes should focus - as in the United States (Elias et al., 2006) - on the absence of invasive species in the seed lot, as biological invasion in restoration areas is a major risk (Funk et al., 2008). Purity, combined with viability - the percentage of seeds capable of germination - determines the percentage of 'pure live seeds', which is essential for defining the lot's price and seeding density (Pedrini and Dixon, 2020). Tetrazolium is recommended for testing seed viability, but interpretation standards (ISTA - https://www.seedtest.org/) are unavailable for most native species (Frischie et al., 2020). Seed dormancy does not influence this test, making it indicated for native species with this characteristic (Elias et al., 2006). Brazilian regulations (NI No. 17/2017) allow flexibility in choosing which information to present on the commercial labels (viability or germination).

Accurate botanical identification of species and their origin is crucial for seed quality. This process is handled by certifying agencies in some countries. In Brazil, this falls on a specialized technical supervisor (RT – '*responsável técnico*'), who ensures seed identity and origin throughout production (Article 51 of NI No. 17/2017). However, hiring an RT can be financially challenging for small-scale producers (De Urzedo et al., 2019). In Germany, seed certification is mandatory (Mainz and Wieden, 2018), and private certifying agencies like VWW-Regiosaaten (https://www.natur-im-vww.de/wildpflanzen/vww-regiosaaten/) assess identity, origin, quality, packaging, and labeling of seed lots. In contrast, the United States offers voluntary seed certification, with third-party certifying agencies verifying origin and identity based on AOSCA (https://www.aosca.org/) defined processes. Quality tests, with varying mandatory requirements depending on state legislation, are conducted in laboratories following AOSA (https://analyzeseeds.com/) guidelines (NASEM, 2020). For Brazil, it still must be seen how to solve this; capacitation of RTs is a key step, alongside collaboration with research institutions that, however, need adequate resources to be involved. Accurate botanical identification of seeds intended for commercialization may be challenging, but this issue must be addressed, and improvements can be achieved through an ongoing process of demand and use, as in adaptive management of restoration programs.

In Brazil, existing current native seed production chain are mostly community-based (Schmidt et al., 2019; De Urzedo et al., 2020; Piña-Rodrigues et al., 2020), which is important to observe when formulating public policies and regulations (Kuhlmann and Dey, 2021). Today, accessing accredited seed testing facilities approved by MAPA is challenging, mainly due to the economic and social particularities of the sector, the fluctuating demand (Moreira da Silva et al., 2016), and the complexity of accrediting laboratories. Despite 188 accredited laboratories in the country (MAPA, 2022), most are dedicated to the agricultural market. Only eleven laboratories are known to work with forest species (native and exotic), ten of which are in the south and southeast of Brazil (Redário and CTSF, 2023). This is a critical bottleneck for the development of the native species production sector, and was addressed with a three-year exemption from accreditation in NI No. 17/2017 (Article 30, §1 - the exemption has already expired). This issue deserves a reevaluation during the normative revision as difficulties in accreditation persist.

The limited access to accredited laboratories and the suitability of testing and methodologies for native seeds clearly pose challenges to the production chain. No such difficulties are reported in countries like Germany and the USA, likely due to their larger and more financially robust production chains. In contrast, in Brazil, small producers involved in the native species production chain often struggle to meet all necessary requirements (Urzedo et al., 2019), making it even more challenging to supply native seeds for restoration projects. One potential solution that has already been explored is exempting small-scale seedling production (up to 10,000 seedlings per year) from registering. It would be beneficial to reevaluate the production scale for exemption during this regulation revision, considering the production chain's specific needs, and extend it to small seed producers (i.e., not only to seedlings producers). The exemption of community-based associations and networks non-profit organization of mandatory analyzes in accredited laboratories, for the purpose of ecological restoration, may be another solution (Redário and CTSF, 2023). Simplifying the laboratory accreditation process is essential, as the current requirements appear excessively burdensome. Possibly, focusing more on the origin of seed material, and not so much on testing requirements, would be helpful. Moreover, multiple solutions should be considered in large and diverse countries like Brazil. One example is the participatory certification for the commercialization of agroecological and organic products, a modality that links the Union's official regulatory procedures with the civil society through a Participatory Conformity Assessment Body (OPAC) (MAPA, 2008; Moura et al., 2022).

Seed mixtures for restoration: regulation of production and trade

Ecological restoration aims at promoting species diversity and ensuring long-term functionality (Gann et al., 2019). Maximizing diversity in plantings through seed mixtures is considered highly beneficial (Di Sacco et al., 2021). Seed mixtures offer a practical way to introduce a high species richness through direct seeding (Erickson and Halford, 2020; Kaulfuß et al., 2022). In the United States, which leads in germplasm production for restoration purposes, the Bureau of Land Management acquires an impressive average of 907,000 kg of native seeds annually (McCormick et al., 2021), with seed mixtures being extensively utilized (Shaw et al., 2020).

The production of directly harvested seed mixtures for ecological restoration purposes is a common practice in Europe (Scotton and Ševčíková, 2017; Mainz and Wieden, 2018) and has shown promising experimental results in the South American Pampa (Porta-Siota et al., 2021; Pañella, 2022) (Fig. 1). In Brazil, there is a clear need to advance the regulation of the production and commercialization of directly harvested seed mixtures. Seeds can be mechanically harvested and mixed directly from their source, especially in the case of herbaceous plants from grassy ecosystems, utilizing conserved remnant areas as seed source (Scotton and Ševčíková, 2017). Harvesting machines with mechanical brushes have proven effective in collecting substantial seed quantities (Pedrini et al., 2020). These machines harvest only mature seeds that readily detach from the inflorescences, without cutting biomass (Pañella, 2022), ensuring a sustainable and efficient seed collection process.

In Europe, the marketing of native species seeds mixtures received a boost with the introduction of Directive No. 60 (EU, 2010), which aimed to regulate the production and commercialization of mixtures for conservation purposes (De Vitis et al., 2017; Mainz and Wieden, 2018; Abbandonato et al., 2018). The trade of conservation mixtures is restricted to only 5% (art. 8 of Directive EU No. 60/2010) of the forage mixture market as to not compete with commercial native forage cultivars (De Vitis et al., 2017; Abbandonato et al., 2018). The mixtures directly harvested from nature are commercialized with or without cleaning (art. 1, c), and are intended for restoration. Some specific requirements for mixtures directly collected from nature include: well-conserved source areas, species listed on the label, along with their respective percentage, and absence of undesirable in the batch (art. 5). Considering the successful results achieved by European countries in restoring grasslands (De Vitis et al., 2017), this Directive serves as a good example for the regulation of commercializing mixtures to restore grassy ecosystems, like in Brazil.

In Brazil, the regulations for commercializing native species mixtures (art. 37 of NI No. 17/2017) are limited as they require differentiating between similar seeds in the batch (e.g., using coloration). Such a requirement is not found in Directive No. 60 (EU, 2010) in Germany and the USA for native seed mixtures. Moreover, the commercialization of directly harvested mixtures is not allowed in Brazil; at the moment, the seeds are mixed only at the moment of planting (Campos-Filho et al., 2013). Allowing the commercialization of directly harvested mixtures at the example of other countries could be crucial for advancing the country's large-scale restoration of grassy ecosystems. The Brazilian standard allows seed production for personal use (art. 61 of NI No. 17/2017), which we understand as applicable for the use of these mixtures in restoration projects, without commercialization, with a declaration of production to the MAPA (Annex XIII of NI No. 17/2017).

Additional challenges arise when dealing with directly harvested mixtures, such as ensuring the correct identification of species in the mix, particularly when several species of the same genus, possibly with similar seeds, are fruiting simultaneously. Further, selecting source areas free from invasive exotic species is crucial. Other purity and germination information may be unfeasible since mixtures often contain a significant percentage of inert material. Instead, the focus should be on identifying the source area, region of origin, habitat, harvesting method, and species composition, as in Europe (art. 11, EU Directive No. 60/2010). Quality standards can be higher for mixtures developed by cultivation, produced in beds with individual species, and later blended for sale according to demand. The EU Directive No. 60/2010 is a valuable example to guide the discussion in Brazil, based on the European experience (Abbandonato et al., 2018).

Seed origin and seed transfer zones

The assurance of seed origin and the establishment of seed or seedling transfer zones for native species reflect the concern for quality and genetic identity of the materials used in restoration and for long-term ecosystem functioning (Gann et al., 2019). The lack of genetic quality control for native seeds and seedlings remains an issue in Brazil (Freire et al., 2017), despite the regulatory requirement to provide information on the origin of commercialized propagules (art. 5, I of the NI No. 17/2017). Native seeds and seedlings production in Brazil is concentrated in the southeastern region (Moreira da Silva et al., 2016), with material then sold to other regions. Although some species have broad geographical distributions, this practice can potentially jeopardize restored ecosystems by introducing non-adapted ecotypes (McKay et al., 2005). It is well-established that using regional seeds is the most suitable in ecological restoration, as regional or local seeds are better adapted to a specific site, resulting in higher restoration success (Vander Mijnsbrugge et al., 2010). Additionally, introducing non-local genotypes can adversely impact the genetic structure of local remaining populations, reducing adaptation in following generations due to the introduction of poorly adapted genes, compromising ecosystem restoration's long-term success (McKay et al., 2005). However, careful consideration is crucial to ensure an adequate number of distinct populations, avoiding using seeds from

Fig. 1. Images illustrating the harvest of seed mixtures (1a, b) and directly harvested mixtures (1c) in Germany; the harvest of seed mixtures in Italy (2a, b); experimental harvests of seed mixtures in the South American Pampa region, in Argentina (3), Uruguay (4), and Brazil (5a, b, c). Pictures: 1 (a,b,c): Anita Kirmer, Phillip Seeligmann; 2 (a,b): Davide Barberis; 3: Fernando Porta Siota; 4: Anaclara Guido; 5 (a, b, c): Ana Porto, Davi Morales, Antonela Seelig.

populations too close by, small, or fragmented to prevent inbreeding issues (Gann et al., 2019). SER recommends providing clear guidance to seed collectors by defining Seed Transfer Zones (STZ) based on geological, climatic, soil, hydrological, and vegetation data where genetic distribution data is lacking (Pedrini and Dixon, 2020). Definitions based on soil and climate data have been shown to capture a significant portion of genetic variability within species (Durka et al., 2017); within these zones, seeds can be transferred without negatively affecting plant performance (Gann et al., 2019). Importantly, environmental differences hold more significance in defining STZ than geographic distance (Cevallos et al., 2020). However, considering global climate change scenarios, addressing the spatial context of a changing environment as much as possible is crucial, as even local provenancing can entail inherent risks for long-term success (Jordan et al., 2024).

STZs have been extensively discussed and adopted in the USA and Europe, primarily for tree species and, more recently, for herbaceous plants (Erickson and Halford, 2020). In the USA, STZs are considered provisional and are based on climate parameters like aridity and temperature rather than genetic data, often complemented by geographical distribution maps and ecoregions (Bower et al., 2014). In Europe, several countries have also implemented specific STZs, including Austria, Germany, Switzerland, France, United Kingdom, Czech Republic, Norway, and Hungary (De Vitis et al., 2017; Cevallos et al., 2020). For example, Germany has designated 22 regions of origin, but commercialization is allowed within eight grouped production areas to facilitate the native seed industry (Mainz and Wieden, 2018). Currently, Brazil has no designated STZs. The existing seed legislation (art. 82, XIX of Decree No. 10.586/2020) (Brazil, 2020) includes the concept of bioclimatic regions based on edaphoclimatic conditions that influence species growth and development. This can be a starting point for future STZs, but these regions have not yet been officially delimited.

A STZ can transcend national borders (De Vitis et al., 2017; Cevallos et al., 2020). Exploring the possibility of creating an international STZ for ecological restoration within the Southern Common Market (Mercosur) framework seems promising, considering the presence of shared ecoregions for grassland and forest ecosystems among its member countries. In the Latin American context, Mexico has implemented mandatory and well-defined STZs, while Argentina has taken a technically-oriented approach by delineating zones for specific tree species (Atkinson et al., 2018). Chile lacks established STZs, even for species of considerable commercial or conservation significance (León-Lobos et al., 2020).

In Brazil, a potential start for definition of STZs could be already defined ecoregions such as in the Pampa (Hasenack et al., 2023) and Cerrado (Françoso et al., 2020), complemented by studies on genetic diversity (e.g. Segatto et al., 2024). It may be feasible to group similar ecoregions, as done in Germany, to enhance the economic viability of seed production. It is worth noting that technical recommendations without a specific obligation for implementation may not be as effective (Gibson-Roy et al., 2021). To strengthen the genetic quality of plants used in ecological restoration, environmental agencies could mandate using locally or regionally sourced seeds and seedlings in restoration, recovery, and licensing projects. Similar requirements could be integrated into public funding or government procurement initiatives (Jalonen et al., 2018).

Conclusions

Our synthesis presented a comprehensive examination of Brazilian regulations governing the native species seeds and seedlings trade, and we discussed measures to ensure seed provenance and distribution for ecological restoration (see summary in Table 1). The regulation of native seeds in Brazil has the potential for improvement by learning from the experiences and practices of other countries and international organizations involved in ecological restoration, as evident in SER protocols or national legislation. It is crucial to shift the focus towards diversity attributes for native seed commercialization rather than adhering to standardizations commonly applied to agricultural seeds. Specific and targeted norms should be established for native seeds with ecological significance. Currently, most purchased seeds and seedlings in Brazil lack genetic quality assurance, which poses a significant risk to restoration, as this may compromise resilience and long-term ecological functionality: Brazilian environmental agencies should actively engage in discussions about regulating native seed collection and production. The challenges of laboratory accreditation can be addressed by streamlining procedures and establishing working groups, such as reactivation of the Technical Committee on Seeds and Seedlings of Native and Exotic Forest Species (Redário and CTSF, 2023).

As seen in other countries, these groups would bring together various stakeholders, including collectors, producers, seed networks, restorers, authorities, and seed technology experts. Through collaborative efforts, these stakeholders can identify their respective needs and common concerns, leading to suggestions for improvements and the development of suitable quality tests for native seeds used in ecological restoration. Moreover, local and regional alternative solutions can be achieved through participatory initiatives that link civil societies and official regulatory procedures, with a focus on regional restoration markets.

Furthermore, when updating seed control regulations, evaluating the specific audience they serve is crucial, considering factors such as the market size, its limited and intermittent nature, and other particularities warrant regulatory flexibility (Kuhlmann and Dey, 2021). Lastly, it is essential to acknowledge that, in countries with well-established seed production chains, improvements in regulations have often been driven by public policies that stimulated a consistent demand (Jalonen et al., 2018). In this regard, it is urgent to implement public policies, such as the Environmental Regularization Program (Brazil, 2012), as this will create the necessary demand to bolster the native seed production chain.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.pecon.2024.08.002.

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