Lack of adequate seed supply is a major bottleneck for effective ecosystem restoration in Chile: Friendly amendment to Bannister et al. (2018).

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RESPONSE ARTICLE

Lack of adequate seed supply is a major bottleneck for effective ecosystem restoration in Chile: friendly amendment to Bannister et al. (2018)

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We argue that the need for a quality seed supply chain is a major bottleneck for the restoration of Chile's native ecosystems, thus supplementing the list of bottlenecks proposed by Bannister et al. in 2018. Specifically, there is a need for defining seed transfer zones, developing standards and capacities for properly collecting and storing seeds, reducing information gaps on seed physiology and longevity, and implementing an efficient seed supply chain with certification of seed origin and quality. Without such capacities, countries are unlikely to meet their restoration commitments. Although we focus on bottlenecks in Chile, the issues we raise are relevant to other countries and thus the global agenda for ecological restoration.

Key words: native seed markets, nurseries, seed banks, seed production, seed supply, seed transfer zones

Implications for Practice

- There is an immediate need to model genetic and phenotypic variation across landscapes under contemporary and future climates and define seed transfer zones.
- The issue of insufficient capacities for storing large volumes of seeds should be resolved by creating restoration seed banks.
- Research investments are urgently needed to fill information gaps about seed storage response, seed longevity, tolerance to desiccation, cryopreservation, large-scale seed farming, dormancy release, and germination requirements.
- Native seed regulations need to focus on certification of quality assurance of commercial native seeds and seedlings used for ecological restoration, under an integrative seed supply chain.
- Local communities and, in particular, indigenous communities can play a strategic role in the seed supply chain.

Introduction

Bannister et al. (2018) identified three major bottlenecks for successful ecological restoration of Chilean forests, including "lack of a national plan for forest landscape restoration, poor quality and low supply of native plant species, and poor results in the establishment phase." We agree with these three crucial barriers and offer a fourth, equally important bottleneck: lack of an adequate seed supply chain (Merritt et al. 2016). The success of restoration plantings pivots on the entire set of practices along the chain of seed use, from seed collection to the point at which seedlings are delivered to field sites for outplanting (Merritt et al. 2016). The steps within the chain are interdependent and, therefore, early steps affect the success of the ones that follow (Fig. 1). Despite the awareness of substantive issues associated with procuring quality seeds for restoration (Jalonen et al. 2017), a missing link in the discussion is the adequacy of the seed supply chain. Here, we discuss the main constraints (Fig. 1) that limit the supply of materials for restoration of native ecosystems in Chile and discuss strategies for overcoming such hurdles. Although we focus on restoration of Chilean ecosystems, the issues raised are not just limited to Chile but exist to a greater or lesser extent across the globe (Jalonen et al. 2017).

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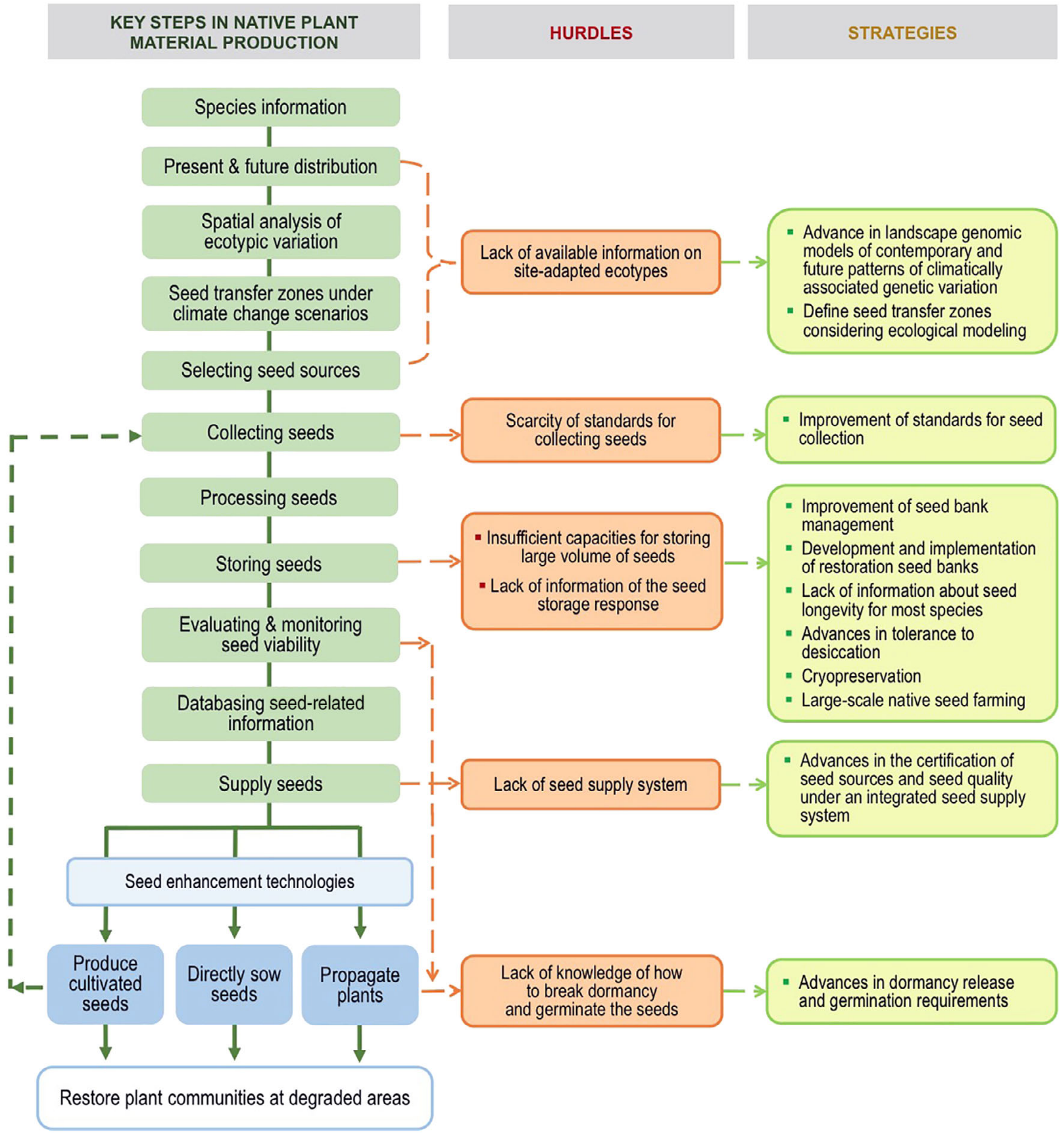

Figure 1. Key steps in the production of native plant material for seed-based ecological restoration projects, as well as the main hurdles associated with each and strategies to overcome them (based on Basey et al. 2015).

Lack of Information on Site-Adapted Ecotypes

One of the most important factors in seed selection is identifying site-adapted seed sources. Understanding local adaptation (Gibson & Nelson 2017) is a critical first step in the process of selecting site-adapted seeds. In the United States and Europe, maps of seed transfer zones (STZs) have been used since the 1950s for commercial tree species (e.g. Randall & Berrang 2002) and recently, in the United States, STZs have been created for a limited number of restoration-relevant grasses, forbs, and shrubs (e.g. Gibson et al. 2019).

In Chile, however, STZs have not yet been created even for native trees with high commercial and conservation value. There have been a limited number of studies in which variation in genetic diversity and differentiation have been mapped (e.g. Vergara et al. 2014; Hasbún et al. 2016), although STZs were not identified. In addition, there is growing awareness of the need to assess potential ecotypic variation in response to future climate change, so that seed sources are not just matched to historical conditions but to current or future conditions (Gann et al. 2019). Advances have been made in identifying zones with high climate-change vulnerability for Chilean species (e.g. Alarcón & Cavieres 2018). However, further research including climate-change projections and spatial analysis of ecotypic variation (ideally based on both traits and genetic variation) is necessary to define STZs for ecological restoration.

Lack of Standards for Seed Collection

Using adequate seed collection methods and protocols is imperative to maximize the quality and genetic diversity of plant materials. Collectors should consider the extent and variation of genetic diversity among and within populations (Brown & Hardner 2000) to collect representative genetic diversity. Given high among-species variability in factors that drive genetic variation (e.g. life history, landscape distribution, and gene flow), there is no single recommended number of populations required for collecting representative seed samples (Gibson & Nelson 2018). Assessments of ecotypic variation, however, can provide information on necessary sample sizes for individual species. For instance, studies from western United States suggest that graminoids require larger number of populations for seed collection than do forbs or woody species (Gibson & Nelson 2018).

Seed harvesting of native species is not regulated in Chile (Atkinson et al. 2018) and generally seeds are used without information about where and how they were collected. Precautions should be taken to avoid overharvesting and ensure that the reproductive capability of source populations is preserved. Towards that end, specific direction to avoid overharvesting should be included in seed collection standards and protocols (Nevill et al. 2018).

Insufficient Capacities for Storing Required Volumes of Seeds

Seed storage is equally important as seed collection (Hay & Probert 2013). Ex situ seed banks can play a crucial role in supplying seeds for ecological restoration (Merritt & Dixon 2011; León-Lobos et al. 2012). Successful ex situ preservation, however, requires storing seeds in a controlled environment that conforms to international standards and management procedures (FAO 2014; MSBP 2018; CPC 2019).

Although some seed banks are available in Chile, the majority do not comply with minimum standards (León-Lobos et al. 2020) and do not have the capacity for storing and managing seed volumes required to meet the long-term goals of ecological restoration. Thus, there is an urgent need to improve storage capacities of existing seed banks or to develop new ones.

Limited Information About Seed Storage Response

For seeds to be conserved through ex situ strategies, they must tolerate desiccation (orthodox seeds, Roberts 1973) at low moisture content and survive storage at low temperatures (FAO 2014). Therefore, prior to initiating a storage program, information on seed response to storage is needed (Daws et al. 2006). Around 80% of Chilean tree species are predicted to have orthodox seeds (León-Lobos et al. 2014). If the Chilean flora follow global trends (Wyse & Dickie 2017), the percentage of native shrubs and herbs with high desiccation tolerance should be even higher, particularly in herbs (over 99%). So, conservation in seed banks could be feasible for most native Chilean herbs. For desiccation-intolerant seeds (recalcitrant seeds, Roberts 1973), cryo-preservation may be a feasible option (Li & Pritchard 2009).

Poor Knowledge About Breaking Seed Dormancy and Germinating Seeds

One of the major impediments to the potential use of wild species germplasm for habitat restoration is the lack of knowledge about techniques for breaking seed dormancy and caring for germinating seeds (Hay & Probert 2013). Thus, improving understanding of seed biology is crucial, if we are to restore a broader and more representative range of species (Broadhurst et al. 2016).

Germination requirements for many Chilean native trees are relatively well known (Donoso 2006), but seed germination requirements for most shrubs, herbs, climbers, and epiphytes remain poorly known (e.g. Figueroa et al. 2004). This asymmetry in knowledge is astonishing because trees represent only 2.1% of the Chilean vascular flora (Rodríguez et al. 2018). Thus, to use a wide diversity of species in ecological restoration there is a need for studies of seed dormancy and germination in a large number of non-tree species.

Lack of Seed Supply Chain

If ecological restoration in both the private and public sectors increases according to the Chilean target (CONAF 2015) and global targets (Gann et al. 2019), seed supply will be not able to meet the demands, as has been noted before (Merritt & Dixon 2011). Consequently, it is essential to secure the seed supply chain within the next few years (Broadhurst et al. 2015), developing a market-driven restoration industry (Brancalion et al. 2016). Under an integrative approach, local communities, and in particular indigenous communities, can play a strategic role in the seed supply chain, not only by collecting native seeds, but also by storing seeds in community seed banks, multiplying germplasm in seed production areas and taking an active role in participatory restoration (Schmidt et al. 2019). Given the large volume of seeds needed to meet Chile's restoration targets, seed-based restoration could be a significant factor in revitalizing local communities, especially if coupled with strategic investments, capacity building, and trainings (Broadhurst et al. 2017).

Lack of Appropriate Policies to Regulate and Support the Development of a Viable Native Seed Market

There is increasing concern about the importance of adopting and enforcing standards for the seed supply chain (Atkinson et al. 2018) to ensure the provision and delivery of high-quality seed batches that are appropriately documented in terms of both collection site information and seed information. Because provision of quality seed is a relatively recent issue, few countries have developed quality standards for native seed supply, such as certification (Mainz & Wieden 2019) or accreditation. Two exceptions are Australia (RIAWA 2019) and the United States (PCA 2015), which have developed standards.

Currently, in Chile, the business of supplying seeds of native species is an informal activity without quality standards or regulations. There is an immediate need to develop effective policies for regulation and support of the development of a viable native seed market (Abbandonato et al. 2018). Also, it is essential to adopt a seed certification program that accounts for genetic diversity and requires seed providers to include standard information on all seed lots, including species identity, number of source plants and source locations, year of collection, seed collecting methods, storage conditions, seed purity, viability, and germination conditions. Although the seed viability and percent germination needs to be reported so that the seed user can make an informed decision for planting/propagation, minimum thresholds should not be enforced, given high variability in viability and germination, even within batches of the same species (Abbandonato et al. 2018).

Concluding Remarks

The bottlenecks identified by Bannister et al. (2018) are real threats to restoration programs for forest and non-forest ecosystems in Chile, as well as elsewhere. However, issues related to seed sourcing, seed quality/availability, processing and storing seeds, dormancy-breaking, and germination also severely limit the efficacy of active ecological restoration. To date, investment in research on genetic diversity, seed physiology, plant physiology, and horticulture remains insufficient. National plans for ecological restoration in Chilean and other countries must include resources to address these essential research and technology needs. The provision of enough quality seed must be a key component of the plan.

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