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SHORT COMMUNICATION

Foreword: International Standards for Native Seeds in Ecological Restoration

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Restoration practitioners must increasingly incorporate seed procurement models and seed use planning early in project development, despite insufficient guidance about what are reasonable expectations for the sourcing and use of native seeds. This special issue presents a series of articles examining each key step in the native seed supply chain, and provides a framework for the "standards" that need to be applied to native seed batches if the native seed supply chain is to achieve the levels of reliability and transparency required. These Standards provide seed buyers, end users, and funding bodies with a level of confidence and reliability in the sourcing of quality native seeds, and a pathway toward global best practice in native seed use.

Key words: ecological restoration, seed biology, seed collection, seed dormancy, seed storage, rehabilitation

Global initiatives in ecological restoration and forest landscape restoration (as defined in the International Standards for the Practice of Ecological Restoration; Gann et al. 2019) are increasing in both number and scale. Native seeds are the foundation of many ecological restoration projects (Nevill et al. 2018), and as the scale of restoration projects continue to increase, so too the demand for large quantities of native seeds is expected to grow. While the specific seed requirements of individual projects and initiatives will vary depending upon geographic location and land use context, the efficient and effective use of native seeds is a cornerstone of ecological restoration (Kirmer et al. 2012; Erickson et al. 2017). However, the success of restoration projects continues to be constrained by seed-related factors including limited seed availability, highly variable and often poor seed quality, inappropriate seed storage conditions, and low rates of seedling establishment in the field (e.g. Turner et al. 2006; James et al. 2013).

It is clear that the sustainable collection or procurement of native seeds in the required volumes and diversity for ecological restoration projects represents a significant constraint for restoration practitioners around the world (Merritt & Dixon 2011; Menz et al. 2013; Nevill et al. 2018). Additionally, the high rates of seed wastage associated with suboptimal native seed use are a major economic constraint, as the cost of native seeds can be considerable (Merritt & Dixon 2011; Nevill et al. 2018; Masarei et al. 2019). It is becoming evident that successful restoration requires practitioners incorporate seed procurement models and seed use planning into restoration projects at the earliest stages to ensure that seed demands can be matched by seed supply. Such planning may be extremely complex, accounting for many factors including seasonal variability in local climate and plant phenology, and may need to be undertaken on a case-by-case basis as the required seed volumes and species diversity of seed mixes will be dependent upon the scale and requirements of each project site.

To meet the demand for native seeds there is a push to develop native seed supply chains that are reliable, sustainable, and transparent. We need standardized expectations and terminology and consistent methodologies to ensure that different restoration projects can source adequate quantities of native seeds. Such seeds need to reflect appropriate origin and diversity with native seed batches processed, stored, and treated (dormancy release, seed enhancement technologies) to make every seed count, and to ensure that seeds are delivered to the right location at the most appropriate time. These factors are often unclear or poorly defined: What constitutes "native" for a given ecological restoration project? What is the right source of seeds for the requirements of a particular site? How can native seeds be collected and produced in a sustainable manner? What are the most reliable methods for testing the quality of native seed batches and how should "quality" be defined for native seeds? Which seed enhancement options are available, and what is the most appropriate or effective for the needs of a particular project? When is the most appropriate time to sow native seeds?

Seed use in the agricultural and forestry sectors is governed by regulatory seed standards. These standards offer internationally recognized seed testing practices (e.g. AOSA 2019; ISTA 2019),

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and provide buyers with confidence of the quality (purity, viability, germinability, and genotype) of purchased seeds. However, comparable standards guiding the collection, production, quality testing, storage, and sale of native seeds are lacking in most countries. This leaves little by way of guidance for seed users about what are reasonable expectations for the quality of native seed batches. This extends to the supply of information by seed suppliers about the type and alleviation of seed dormancy, methods to promote seed germination, and seed enhancements to optimize seed sowing and seedling establishment.

There is a clear need for unambiguous guidance around the supply and use of native seeds destined for global restoration programs (Fig. 1). This special issue addresses that need, by presenting a series of overview articles on topics relevant to industry, restoration practitioners, and regulators. The overview articles examine each key step in the native seed supply chain: (1) seed sourcing and procurement models (Erickson et al. 2020); (2) the fundamentals of native seed collection from natural populations and the establishment of seed production systems (Pedrini et al. 2020); (3) established practices and protocols for cleaning, processing, and assessing the quality of native seeds (Frischie et al. 2020); (4) methodologies for short- and long-term seed storage, and for determining the longevity and quality of stored seed collections (De Vitis et al. 2020); (5) an overview of seed dormancy classification, with examples of how dormancy alleviation techniques can be applied at scale for restoration projects (Kildisheva et al. 2020); (6) how seed enhancement technologies can improve the efficiency of native seed use (Pedrini et al. 2020); and (7) strategies, considerations, and current technologies in delivering seeds to site at field scales (Shaw et al. 2020). The information presented in each of the overview articles then builds the framework of the final synthesis article that details the "standards" that need to be applied to native seed batches if the native seed supply chain is to achieve a level of reliability and transparency (see "Principles and Standards for Native Seed in Ecological Restoration"; Pedrini & Dixon 2020). This synthesis document provides seed users with practical tools to develop and structure seed supply systems, and aims to provide restoration practitioners with standard operating procedures for testing and reporting the quality of native seed batches. This synthesis document is a companion to and draws upon the International Standards for the Practice of Ecological Restoration (Gann et al. 2019), a foundational document that guides ecological restoration practice globally.

The underpinning principle for the International Standards for Native Seeds in Ecological Restoration (the Standards) is to provide buyers, end users and funding bodies with a level of confidence and reliability in the sourcing of quality native seeds similar to that enjoyed for crop and forestry species. Both suppliers and consumers of native seeds need assurance of the expectations surrounding seed use. By providing a common nomenclature and testing protocols and guidance in the

Figure 1. Schematic diagram of the interaction between restorative activities and key steps in the native seed supply chain. Seed needs and seed procurement strategies should be identified and assessed in the early phases of restoration planning. The native seed supply chain is then activated, with seeds sourced either from sustainable collection from natural populations or from seed production systems. Sourced seeds should then ideally undergo seed processing and quality testing, and be stored under appropriate conditions to maintain viability if required. Seed dormancy may need to be alleviated prior to the delivery of seeds to site, and appropriate seed enhancement techniques may improve seed delivery and the success of seedling establishment. Seeding should follow site preparation activities, and be conducted in the appropriate season. Monitoring activities should be undertaken following seeding, to facilitate adaptive management if required and provide evidence of ecosystem trajectory at the site. Graphic by S. Pedrini.

deployment of native seeds, producers will be able to efficiently tailor their production methods to meet the specific requirements of end users. Similarly, restoration practitioners require certainty about the origin, quality, and value of seed batches they are purchasing which is now possible with these native seed standards. While the Standards are not intended to be mandatory, they aim to guide industry, regulatory authorities, and governments to adopt standards in native seed use.

This first edition of the Standards is intended to be a living document that will be updated and improved over time in consultation with native seed scientists, restoration practitioners, and native seed suppliers. The International Network for Seed-based Restoration (INSR 2020), a thematic section of the Society for Ecological Restoration, would be the ideal platform for future discussion, implementation, and sharing of these updates with the global native seed community.

If we as a society are to achieve the lofty aspirations of ecological recovery anticipated in the coming decades (Cross et al. 2019; Aronson et al. 2020), while avoiding the environmental harm likely to result from unethical sourcing of native seeds (Nevill et al. 2018), we must develop seed use efficiencies, reduce seed procurement costs, and improve the environmental outcomes of seed-based restoration. These Standards provide a pathway forward for the global native seed industry to adopt, adapt, and transition practices to align with global best practice in native seed.

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