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TECHNICAL ARTICLE

Should I pick that? A scoring tool to prioritize and valuate native wild seed for restoration

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Commercial sources of native seed are often unavailable for ecological restoration projects or do not have a suitable provenance. Local collection of wild seed is an option, but it can be challenging to collect seed for a variety of species and set fair seed prices. Our aim was to quantify the relative effort to collect, clean, store, and propagate seed to better prioritize species and assess the value of their seed. For 57 species native to the Canadian subarctic and typical of upland habitats, we evaluated 13 poorly correlated attributes in the field and lab or using the literature. For collection attributes, regional occurrence, local abundance, seed collection rate, and collection window were normally or log-normally distributed. Most species were easy to identify and posed few collection obstacles. Cleaning effort was evenly distributed across species and the majority could be cleaned to more than 95% purity. We only encountered orthodox seed and most species had seed longevity exceeding a year. Seed viability mostly exceeded 80%, pre-treatment requirements were evenly distributed and the majority of species could be germinated under standard conditions. We propose a standard worksheet, in which we assign relative effort scores to the distribution of each attribute. We illustrate this approach for the revegetation planning of a remote mine site. We also propose a seed lot certificate to ensure high seed quality. This tool can be applied to various restoration applications to assess relative effort, to plan and prioritize species for restoration projects and to help set fair seed pricing.

Key words: revegetation planning, seed collection, seed value, subarctic, wild native seed

Implications for Practice

- This tool allows for users to score the relative effort required to collect, clean, store, and propagate local wild seed across a regional species pool.
- Users can use this tool to prioritize target species and to help set objective, fair seed prices.

Introduction

Natural resource managers sow seed or plant seedlings to revegetate severely disturbed lands, and they select plant species based on several considerations (Graff & McIntyre 2014; Giannini et al. 2017). Managers are increasingly mandated to revegetate sites toward native vegetation, so they prioritize native species and minimize the use of non-native species (Macdonald et al. 2015; De Vitis et al. 2017). They may consider representative species from nearby reference ecosystems (Shinneman et al. 2008). In early successional situations, managers choose species that can tolerate specific conditions of a substrate and stabilize the soil surface (Haan et al. 2012). They also consider species that contribute to ecosystem succession and function, through biomass production, nutrient fixation and sequestration, soil development, the production of shade and suitable microclimates for later successional species or pollinator attraction (Walker et al. 2007). Managers may even consider species with conservation or cultural or economic value (Giannini et al. 2017). Lastly and most practically, managers select species whose seed or plant material is both available and cost-effective. This study focuses on this last consideration.

In remote regions, seed is commercially available for only a few common native species, and that seed is often sourced from distant provenances, which is less suitable for land restoration (Vander Mijnsbrugge et al. 2010; Basey et al. 2015). An alternative is to collect local wild seed. But collecting wild seed can be expensive (De Vitis et al. 2017). Some species are favored simply because their seed is easy to collect, store, and germinate. Other species may be desirable for restoration but are not favored because they are uncommon, require specialized collection equipment, have poor longevity, or have complex germination needs. Put simply, species differ in the effort (and cost) required to produce seed or seedlings. It is critical to consider

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these differences to ensure the success and efficiency of local seed collection programs and fair seed pricing.

Few studies have looked at an economic valuation of seed collected from the wild. Espirito Santo et al. (2010) attempted to give a relative value to seed from 22 tree species of conservation interest in the Caatinga region of southeastern Brazil. Past approaches to local seed pricing had been arbitrary, so they examined several attributes across target plant species, including their distribution, native status, risk of extinction, successional class, processing and collection efforts, seed behavior, and number of seeds per unit mass, in order to score the seed of each species. Their results were used by local seed collectors to determine seed prices for ecological restoration. We know of no such valuation system for wild seed in North America.

In the current study, we built from the work of Espirito Santo et al. (2010) and present a methodological approach to score the effort to collect, clean, store, and propagate wild-collected seed. Our intent was to support seed collection by local communities, so we emphasize simple, inexpensive techniques. We propose a standard effort scoring worksheet as a general tool. The calculated seed effort scores can be paired with a plant's restoration value to prioritize species for restoration and help set prices of wild-collected seed or their seedlings. This approach is intended for managers of large restoration projects and seed collectors, but it should also be useful to nurseries, government agencies, and industry groups involved in ecological restoration. We demonstrate this approach with an example of restoration planning from a mine site in subarctic north-central Canada.

Methods

We conducted field studies in 2016 near the De Beers Canada Victor Mine (52°49′N, 83°53′W, 83 m elevation) and Attawapiskat First Nation (52°55′N, 82°26′W, 5 m elevation), both within the Attawapiskat River drainage of the Hudson Bay Lowland (HBL), Canada. The HBL is a vast peatland plain covering 325,000 km^2 with a subarctic climate (Martini 1989; Riley 2003). The open pit mine has created approximately 900 ha of upland from its waste deposits. Upland habitats only cover less than 5% of the HBL (Riley 2003). They occur, in part, on raised beach ridges, eskers, palsas, and limestone outcrops within the peatland matrix (Martini 1989), with low diversity coniferous forest vegetation. Paradoxically, upland habitats also occur along large rivers, which have cut through the peatland plain over millennia, producing drained conditions along valley walls, upper floodplains and river islands, favoring upland vegetation (Riley 2003). Large ice blocks seasonally gouge the floodplain, forming a patchwork of species-rich herb and shrub-dominated vegetation, with diverse mixed or coniferous upland forests further upslope.

We targeted 57 species of vascular plants (Appendix S1, Supporting Information). Species had to be indigenous, abundant to occasional in the region (Riley 2003), typical of upland habitats as determined by botanical texts, and representative of life forms in local upland vegetation (Garrah 2013). If common upland species were not producing seed during our field study year (e.g. *Populus tremuloides*), we excluded them. Botanical nomenclature follows the integrated taxonomic information system (ITIS) (www.itis.gov). For each species, we gathered data on 13 poorly correlated attributes that affect the effort associated with (1) collecting, (2) cleaning, (3) storing, and (4) propagating their seed. We include a general score card, with attributes and instructions, along with data forms for seed collection information (Appendix S2).

We measured six attributes related to seed collection: (1) regional occurrence; (2) local abundance; (3) seed collection rate; (4) collection window; (5) identification effort; and (6) number of collection obstacles. To determine the regional occurrence of the species, we conducted field surveys from June to July 2016, and returned later to confirm the identity of some species. We sampled 56 upland plots using a stratified sampling strategy. We selected sites with easy access, different successional stages, higher overall species diversity or the presence of unique species, as seed collectors would. Our primary focus was along a 30 km stretch of the Attawapiskat River valley (31 plots), because collection sites are accessible by small boat, support a high diversity of upland plants from early to late successional stages, and represent a natural reference chronosequence for mine site restoration. Plots along the river were spaced at least 500 m apart. We also surveyed along the smaller Nayshkootayaow River shoreline (3 plots), upland areas regenerating from human disturbances (10 plots), other upland forests (6 plots), a disturbed esker (2 plots), limestone outcrops (2 plots), and coastal shorelines (2 plots). Each plot was 100 m by 15 m. We oriented plots in the river valleys so their length paralleled the river and the width extended from the shore up into mature forest. We surveyed the plots as seed collectors; three observers walked in a meandering pattern for 45 minutes through the plot, or until we were confident that we encountered most species. We determined the regional occurrence of each target species as the proportion of plots where it was present.

For local abundance, three observers visually estimated the cover of species in each plot following a modified Braun-Blanquet scale, with intervals of roughly 0.5 $\log_{10}$ cover percentage units: 1, <0.1; 2, >0.1 to 0.3; 3, >0.3 to 1; 4, >1 to 3; 5, >3 to 10; 6, >10 to 30; and 7, >30%. These log-scale classes allowed the discrimination of species across three orders of magnitude. We determined the local abundance from the median cover for a species, only using data from sites where it was present.

We quantified seed collection rates by conducting three collection trials per species. We first determined the best collection method for each species (Rantala-Sykes & Campbell 2017*a*), and then, for each trial, we collected seeds actively for 15 minutes, then air-dried collections at 25 to 30°C for 5 days and cleaned and weighed them. We determined final seed lot purity (below) and calculated the seed collection rate as the mass of the seed lot collected per unit time corrected by the final seed lot purity divided by the seed mass. We log-transformed this attribute to discriminate species across five orders of magnitude.

The seed collection window was based on the persistence of the seed or fruit on the plant following maturity. We assessed this attribute based on field notes from all plots, in 1-week intervals, up to more than 4 weeks.

For identification effort, we asked seven lay seed collectors to answer two questions. (1) Is the species distinct? (2) Can you identify the species in the field? Species for which both answers were affirmative received a low identification effort, and those with both negative answers received a high identification effort. We used the mode of the distribution to determine the score for each species. We asked the same participants to quantify the number of seed collection obstacles (Appendix S2). We used the mode of the number of obstacles to assess a species' collection obstacle score.

We measured two attributes related to seed cleaning: (1) seed cleaning effort and (2) final seed lot purity. We first determined the simplest, most inexpensive seed cleaning technique for each species (Rantala-Sykes & Campbell 2017*a*). We assessed the seed cleaning effort based on the amount of equipment and the number of steps required. We ranked seed cleaning effort as (1) easy if it involved 1–2 steps and 1–2 types of equipment; (2) moderate if it required 3 steps and 2–3 types of equipment; or (3) high if it required ≥3 types of equipment or specialized equipment costing greater than \$500 CAN.

We determined final seed lot purity by subsampling each cleaned seed lot, using approximately 5–15 mL for small- (<10 mg) to large-seeded (>10 mg) species. We separated seeds from impurities and calculated the mass ratio of pure seed to seed plus impurities (International Seed Testing Association 1985).

We determined two attributes related to seed storage: (1) storage behavior; and (2) seed longevity. For storage behavior, we classified the species as having orthodox, intermediate, or recalcitrant seeds using online databases (Royal Botanical Gardens Kew 2016). This classification describes the sensitivity of seeds to decreasing moisture content following harvesting (Hong & Ellis 1996). If species-specific storage behavior was unavailable, we used the most common storage behavior for that genus in nearby biomes.

For seed longevity, we classified species into three categories based on dried seed stored at 1–5°C, using botanical literature (Smreciu et al. 2013; Royal Botanical Gardens Kew 2016; Native Plant Network 2017; Rantala-Sykes & Campbell 2017*a*). Category limits were: (1) less than 1 year, (2) 1–5 years; and (3) more than 5 years. If reports were conflicting or unavailable, we classified a species as having intermediate longevity.

Finally, we measured three attributes related to seed propagation, namely (1) seed viability; (2) pre-treatment requirements; and (3) germination requirements. To measure seed viability, we subsampled 35 seeds from each of three cleaned seed lots, for a total of 105 seeds per species. We did not use a tetrazolium stain because the test requires species-specific experience for accurate interpretation. Instead, we sectioned each seed longitudinally and judged the embryo to be viable if it appeared undamaged, plump, and consistent in color. In some species, the embryo was poorly differentiated at seed maturity or the seed was too small, so we considered the seed viable if the seed was plump and firm and if the endosperm was consistent in color, not desiccated (International Seed Testing Association 1985). For two Salicaceae species, we assessed their viability by germinating fresh seeds on moistened paper towel at room temperature for 7 days.

We classified the pre-treatment requirements of species into three groups based on their seed dormancy requirements prior to germination, as determined from the literature (Young & Young 1992; Baskin & Baskin 1998; Native Plant Network 2017). We classified species that require less than 90 days of cold stratification to break dormancy as needing a simple pre-treatment. We considered species requiring more than 90 days of cold stratification, or with physical, chemical, and/or morphological dormancies, as needing complex pre-treatments.

We categorized germination requirements based on a species' need for typical versus special germination conditions, based on the literature (Young & Young 1992; Smreciu et al. 2013; Royal Botanical Gardens Kew 2016; Rantala-Sykes & Campbell 2017*a*). We considered typical conditions to be a temperature regime of 25–15°C on a 12–16 hours light–dark cycle, and a non-specific substrate. We gave species a high germination score if they require temperatures outside the standard range, specific light conditions, or specific substrates.

We examined the frequency distributions of quantitative attributes on linear or log scales, and scored them in three to five intervals, with those species requiring more effort for that attribute receiving the highest score. For categorical attributes, those species requiring the lowest effort received the lowest score.

Results

We have published the raw data (Rantala-Sykes & Campbell 2017*b*) and present data summaries here (Appendix S1). For collection attributes (Fig. 1A), the regional occurrence of target species followed a roughly normal distribution, with half of the 57 species present in 30–50% of the plots surveyed. In contrast, we found 11 species in less than 20% of our plots, and most of these had specific habitat preferences. Local abundance was also approximately log-normally distributed, but slightly skewed toward less abundant species. Trees usually had the highest local abundance, while small herbaceous species with a vertical growth habit had the lowest. Seed collection rates also followed a roughly log-normal distribution, spanning five orders of magnitude, ranging from 250 seeds/hour for the large-seeded legume *Lathyrus palustris* to approximately 23 million seeds/hour for the dust-seeded *Juncus dudleyi*. The collection window was normally distributed, although slightly skewed toward species whose seed was available for less than 2 weeks. Lay seed collectors considered three quarters of the species to be easy to identify in the field, and moderate to difficult species were typically graminoids, legumes, *Salix*, and some Asteraceae. The seed collectors found two-thirds of the species to have no collection obstacles.

For seed cleaning attributes (Fig. 1B), species were almost evenly distributed in the effort required to clean their seed. However, final seed lot purity was heavily skewed; we could clean three quarters of target species to over 90% purity, but we

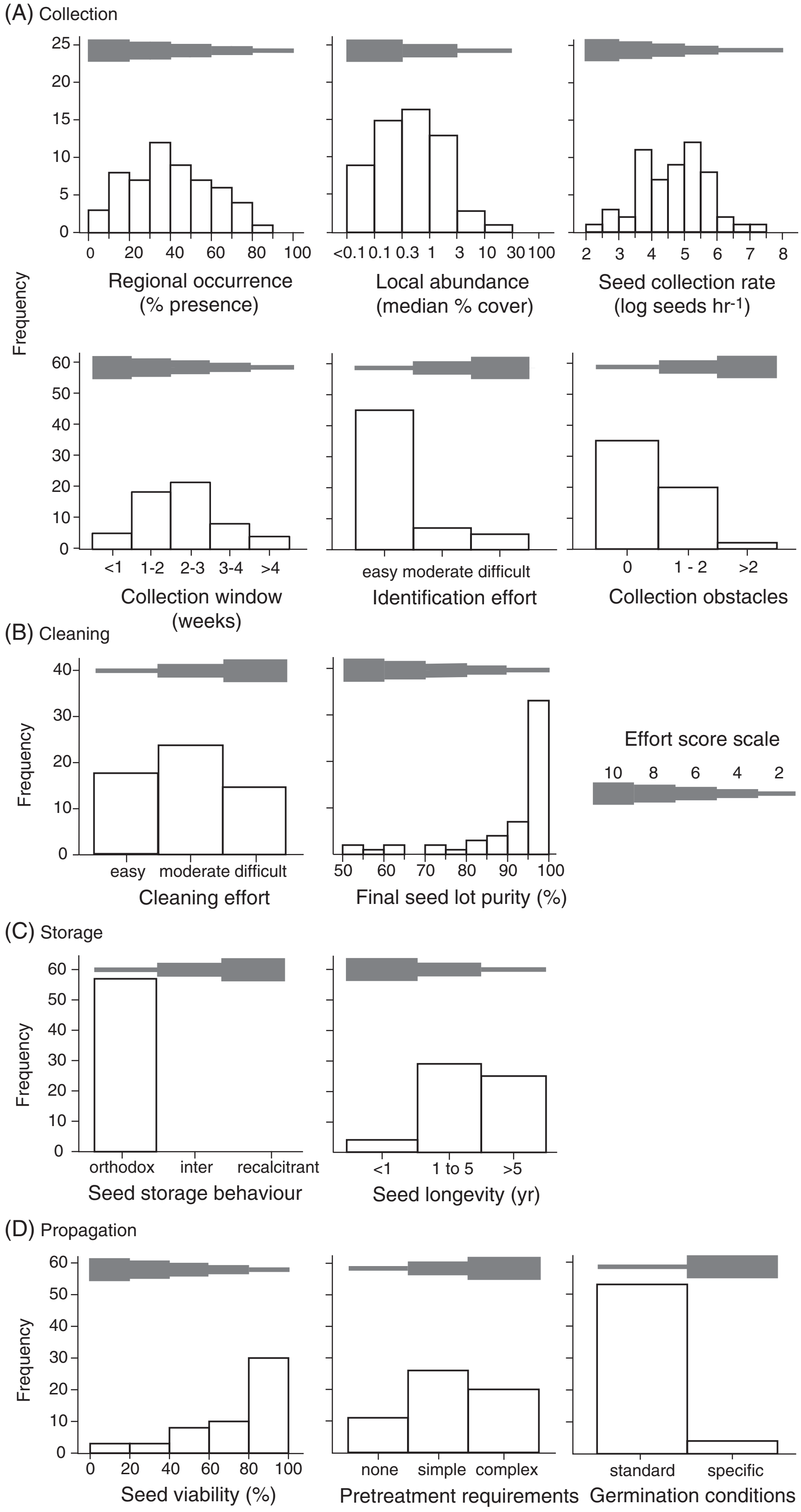

Figure 1. Frequency distributions for the attributes related to seed (A) collection, (B) cleaning, (C) storage, and (D) propagation of upland species in this study ($n = 57$). The gray bars above each panel show the effort scores we assigned across the distribution each attribute on a 10-point scale, with 10 requiring the highest effort.

could only clean some species to 50–60% purity, despite our best efforts.

For seed storage (Fig. 1C), all 57 target species have orthodox storage behavior. Over 40% of the species had long-term seed longevity, including all evergreen species and members of Fabaceae, while only three species had poor seed longevity.

For seed propagation (Fig. 1D), seed viability was strongly skewed; over half the species had viabilities exceeding 80%. Only 20% of our target species do not require pre-treatment to germinate. Half require at least a simple pre-treatment, while the remaining third require complex pre-treatment. Finally, 53 out of our 57 species can germinate under standard conditions after pre-treatment.

Discussion

The purpose of our study was to build a tool to assess the relative effort to collect, clean, store, and propagate local native seed. We broke our valuation system down into its stages of collection, cleaning, storage, and propagation. In this way, a user may consider all four stages together, or separately, depending on the need for seed or seedlings. We argue that all of these attributes contribute to determining the relative effort, although we acknowledge that they may not contribute evenly. A user has the flexibility to assign different a priori weights in different contexts. For instance, in remote regions, a user may upweight seed collection attributes, because of the increased effort to collect seed in remote regions. Or if the goal is to collect seed from a challenging genus (e.g. *Solidago*), and its individual species are not important, a user may upweight the seed collection rate and ignore identification effort. For the number of seed collecting obstacles, a user may even weight the obstacles differently. Users also have the potential to modify or to add attributes. For instance, our qualitative seed cleaning attribute could be assessed quantitatively as the mass of seed cleaned per hour; we could not complete this extra step because of our small batches of seed to clean.

Several attributes apply across a species, but some will vary among sites and seed lots, including the local abundance, the seed collection rate, the seed lot purity, and the seed viability, and would have to be assessed again when the approach is applied to other regions. They may change with time and need to be assessed across multiple years, due to the annual variation in seed output for many species. Also, seed viability will only diminish with time. A seed lot certificate, which describes the collection locality and dates and cleaning and storage protocols (Appendix S2), will be essential to accompany seed lots.

In our study, we focused on seed collection by lay persons using simple inexpensive techniques. If the process were scaled up, with experienced collectors and more efficient (and expensive) collection and cleaning equipment, the scoring of some attributes would differ, such as seed collection rates or seed cleaning effort, but we argue that a modified scoring system would still be useful to describe the required effort.

Our breakdown of effort into many attributes allows for a better, more objective understanding of the relative value of seed and seedlings from different species. Managers can use this tool, alongside their other criteria for selecting species, to most economically prioritize species when planning restoration projects. For example, the Victor Mine in the HBL must revegetate approximately 900 ha of barren uplands at the mine site. Managers are constrained by provincial regulations (Ontario Regulation 240/00) and agreements with local First Nations to use native species to restore them toward regionally representative upland vegetation. They will select (1) one main tree species, given the forested reference conditions; (2) nitrogen-fixing plants to build soil fertility, and (3) a variety of other trees, shrubs, and herbs to promote ecosystem resilience. *Picea glauca* is suitable for their main tree species, because it is regionally dominant on alkaline reference sites, similar to the barren mine site uplands (Garrah 2013), but it has higher collection and processing seed effort scores, so managers may pay a premium for its seed. For N-fixers, the candidates are two native legumes (*Lathyrus palustris* and *Vicia americana*), and several actinorhizal shrubs (*Alnus* spp., *Shepherdia canadensis* and *Elaeagnus commutata*). Both legumes have high seed collection effort scores, because of their low local abundances and seed collection rates, so the shrubs would be favored. Managers could prioritize the lowest scoring N-fixing species, *Alnus crispa ssp. viridis* and *E. commutata*. For the remaining variety of species, managers could target 10 species with the lowest effort scores, including the shrubs *Cornus sericea* ssp. *sericea*, *Rubus ideaus* ssp. *ideaus*, *Viburnum edule*, and *Physocarpus opulifolius*, the forbs *Chamerion angustifolium* ssp. *angustifolium*, *Achillea millefollium*, and *Fragaria virginiana,* and the grasses *Poa palustris*, *Calamagrostis canadensis*, and *Agrostis scabra*. The tree *Populus balsamifera* scored relatively low and could also be added, but its seed would have to be sown immediately or frozen, given its poor storage. Managers would still need to conduct trials of these species in amended mine substrates to verify their success.

Managers and seed collectors can use this tool to help set actual seed pricing when no pricing structures exist. Espirito Santo et al. (2010) estimated actual costs of collecting and cleaning seeds across 22 tree species in Brazil by calculating a correction factor based on one species for which the fair market value was well known and then comparing the relative value of its seed to other species. No local pricing exists for any of our species in this subarctic region. If the actual costs of a few species were assessed here, fair seed pricing could similarly be calculated for other species. Alternatively, managers could use the pricing in populated regions and then factor in the additional costs for remote regions. However, this translation from an effort score to a seed price may not be straightforward. Seed pricing could also reflect a species' desirability for restoration, in which case a premium may be added. Or if extensive travel is required to seed collection sites, such as for this mine site example, which can require long trips in freighter canoe from local communities, these extra costs would have to be considered in the actual seed price.

Buyers of wild seed of native species will also insist on quality seed. The onus is on collectors to follow best practices and complete seed lot certificates with full provenance and handling details (Appendix S2), indicating that proper protocols were followed at all stages (Basey et al. 2015). In return, buyers must anticipate paying a premium for purchasing high quality seed, suitable for ecological restoration.

The demand for native seed is increasing in multiple biomes. This tool provides a strong foundation on which to assess the relative effort required to collect, clean, store, and propagate seed. This approach has a place in revegetation planning. It will also facilitate seed pricing in a developing market.

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Supporting Information

The following information may be found in the online version of this article:

Appendix S1. Relative effort scores for seed collection, cleaning, storage, and propagation of 57 upland species from subarctic north-central Canada.
Appendix S2. Seed effort scoring worksheet.

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