CONSERVATION

Restoration Seed Banks—A Matter of Scale

Seed banks must shift from being "stamp-collections" of species to collections that can provide tons of seeds and the expertise to improve restoration efforts.

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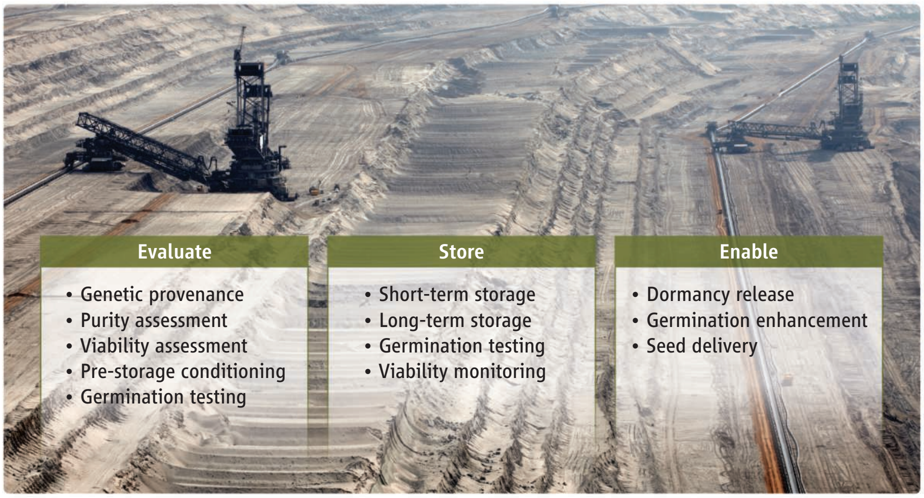
With nearly two-thirds of the world's ecosystems degraded (*1*), the October 2010 meeting of the Conference of the Parties to the Convention on Biological Diversity (COP-10) highlighted ecological restoration as a significant opportunity for achieving global conservation goals (*2*). The restoration of nature, natural assets, and biodiversity is now a global business worth at least $1.6 trillion annually and likely to grow substantially (*3*). Although seed banks have emerged as a tool to protect wild plant species (*4*), off-site (ex situ) conservation measures at seed banks must be complementary to "on the ground" management at the conservation site. For example, whereas global targets are for restoration or management of at least 15% of each ecological region or vegetation type (*1*, *5*), recognition of the mechanisms required to achieve these goals is largely absent from policies.

How are large-scale (100- to 1000-km^2) plant reintroductions that recreate biodiverse communities to be achieved? We argue that use of native seeds underpins achievement of these restoration targets and that seed banks need to shift from being "stamp-collections" of species to collections that can deliver restoration-ready seeds at the scale of a metric ton and larger. We propose the concept of the restoration seed bank as a facility that looks beyond the core skills of collection and storage of germplasm (*6*) to rigorous science-based restoration-use of germplasm, seed farming, training, and information dissemination. These functions must be linked to community- and industry-based restoration initiatives. Connecting science to the community is particularly important (*7*), with opportunities at a local scale to develop traditional foods and medicines into the restoration palette through traditional ecological knowledge (*8*, *9*).



Integrated seed curation and research functions of a restoration seedbank.

Scale in Restoration

Seeds are the primary tool for reintroducing plant species (*10*–*14*). But effectively using seeds of wild species in contemporary restoration is facing a crisis of scale. The majority of the world's seed banks dedicated to wild species have seed holdings that are barely sufficient to provide seed for but a few percent of the areas in need. The Millennium Seed Bank, for example, stores, as of March 2011, 1.8 billion seeds of 30,402 species (*15*). This translates on average to around 60,000 seeds per species, well short of the amount required to restore at the landscape-scale.

It is common for restoration programs to tackle thousands, or tens of thousands, of hectares, often in poorly studied ecosystems. The Gondwana Link project (*16*) in southwestern Australia is the world's largest integrated wild species restoration program in a biodiversity hotspot. It aims to repatriate with local indigenous species many thousands of hectares of former farmland to create a biological corridor spanning 1000 km.

Ambitious restoration programs require large volumes of seed, in the order of tens to hundreds of metric tons. For example, through the United Nations Compensation Commission, Kuwait proposes to revegetate 720 km^2 of land damaged during the 1990–91 Gulf War (*17*). Applying even a modest seeding rate of 2 to 4 kg of seed per hectare will require 140 to 280 tons of native seed. At present, there is no seed bank in Kuwait to address this need, outside of the kilogram-scale seed storage facility at the Kuwait Institute for Scientific Research (*18*).

Current levels of seed wastage compound the problem. Typical establishment rates in biodiverse restoration result in seed losses of >90% (*19*) through substandard storage, lack of seed pretreatments for "on-demand" dormancy release, and lack of precision in delivering seeds to sites at the appropriate time and into a suitable soil environment for seedling establishment (*12*, *14*).

Technology Shifts, Infrastructure Capacity

A key issue is whether seed banks have the infrastructure and scientific and technological capacity to deploy seeds wisely for landscape-scale restoration. At present, the storage of seeds for restoration is undertaken largely by end users (e.g., seed suppliers, mining companies, NGOs, and community-based groups). These facilities often have limited access to knowledge and training, and as a result, most seed banks are missing the technological resources and capacity to deliver landscape-scale restoration. Restoration seed banks must adapt the scientific principles of germplasm storage developed by seed banks conserving wild species (e.g., strict control over seed moisture content and storage temperature) that have proven effective vehicles for the protection of biodiversity (*5*, *20*, *21*). Unlike current technologically advanced seed banks conserving germplasm, restoration seed banks need to be stor-

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ing tens to hundreds of tons of seeds. Some seed banks on this scale are emerging, such as the Seed Warehouse of the Utah Division of Wildlife Resources, with a storage capacity of 340 tons (*22*).

For policy-makers, the science to deliver effective seed for restoration does not rely on an expectation of open-ended funding, as solutions found for one plant species may apply across many other species. For example, the discovery of smoke-stimulated germination in 1990 (*23*) revolutionized propagation for thousands of wild plant species (*24*).

Integrating Science with Practice

Although seeds are recognized as a viable means for accelerating plant establishment, rarely is the source, availability, or effective management and use of the seeds considered (*10*, *13*). Commonly encountered shortfalls in seed knowledge and handling practices that hamper restoration outcomes include a lack of research data on the phenology of seed development and maturation for most wild species and the spatial and temporal variation for these factors (*10*, *25*) that can lead to inappropriate timing of seed collection; the failure to document or understand the quality and viability of collected seeds at input into the seed bank resulting in no knowledge of the potential of the seed resource to produce plants (*25*); an inability to break seed dormancy for many plant families preventing germination at the time seeds are sown (*26*); the use of poor storage procedures such as seed stored in uncontrolled environments where humidity and temperature fluctuations occur (*26*); and low seedling establishment rates from broadcast seed (<10% of delivered seeds establish) for biodiverse ecosystems such as in Mediterranean environments (*19*, *25*). Seed farming of wild species is a critical area in need of broader recognition and rapid development to address shortfalls in seed supply to restoration seed banks.

Achieving effective landscape-scale restoration will need seed banks to scale-up capacity in a number of key areas: seed technology for effective seed use and site delivery, large-scale native seed farming enterprises to generate the seed needed to reduce the impact of seed collection on wild sources, and genetic analysis tools to ensure provenance issues are addressed in seed farming. Critically, it is the integration of these research areas that is necessary to improve wild seed use in restoration (see the chart).

Examples of research-driven improvements in seed-use efficiency for restoration are not available. However, as an example, land areas disturbed by mining in the biodiverse semiarid region of the Pilbara in Western Australia exceed 20,000 ha. Current seeding rates for restoration in this region are 5 to 7kg/ha (*27*), and an average seed price is $749 ± 65 per kg, based on the available seed prices from commercial suppliers for 88 dominant Pilbara plant species (*28*) [supporting online material (SOM)]. If restoration research reduced the number of seeds required to achieve plant establishment targets by 30%, this research effort would represent a reduction in seed use of ~30 to 42 tons and a saving of $20 to $34 million in seed purchase costs (SOM).

A Role for Botanic Gardens

Botanic gardens have the potential to contribute to global restoration outcomes through their infrastructure, the knowledge generated by their scientifically curated plant collections, and their seed bank technological capacity (*29*). With 2700 botanic gardens in 100 countries, including representation in all of the world's biodiversity hotspots (*21*), botanic gardens have the geographical reach and networking capability to retool for delivery of a global restoration capability (*20*, *30*). Whereas botanic gardens promote their seed bank collections as a viable restoration resource (*20*), most fall well short of the capacity for delivering large-scale restoration.

To move botanic garden seed banks from single-species conservation to landscape-scale restoration will require major refocusing on collection strategies, seed utilization, and funding. For example, Kew's Millennium Seed Bank Project achieved its seed collection target of 10% of the world's flora in 2009 (*20*, *30*). But the effort is now refocusing to expand its mandate from germplasm conservation to restoration and is planning a global seed-based initiative through the Breathing Planet Program for botanic gardens and local communities to begin developing and delivering in-country restoration capacity through worldwide partnerships (*31*).

Globally, communities need knowledge on using seeds and restoring landscapes. In the last session of COP-10, a village cattleman from Sudan "talked about how his fields are drying up, his cattle are dying, his family is suffering, and he is witnessing a continuing and accelerating loss of plants and animals that provide subsistence to his community" (*32*). He pleaded for answers, technical guidance, and support that he could take back to his community so he and his family could cope with the impending changes to his livelihood (*32*). Delivering effective and timely restoration and technology sets that build healthy environments and sustainable livelihoods is therefore a global issue for wild seed banks—and none too soon if we are to stem the tide of extinction and environmental degradation.

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