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25

Strategies for Enhancing and Restoring Rare Plants and Their Habitats in the Face of Climate Change and Habitat Destruction in the Intermountain West

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Ecological restoration is a practice that seeks to heal degraded ecosystems by reestablishing native species, structural characteristics, and ecological processes. The Society for Ecological Restoration International defines ecological restoration as "an intentional activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity and sustainability.…Restoration attempts to return an ecosystem to its historic trajectory" (Society for Ecological Restoration International Science & Policy Working Group 2004).

Most frequent-fire forests throughout the Intermountain West have been degraded during the last 150 years. Many of these forests are now dominated by unnaturally dense thickets of small trees, and lack their once diverse understory of grasses, sedges, and forbs. Forests in this condition are highly susceptible to damaging, stand-replacing fires and increased insect and disease epidemics. Restoration of these forests centers on reintroducing frequent, low-severity surface fires—often after thinning dense stands—and reestablishing productive understory plant communities.

The Ecological Restoration Institute at Northern Arizona University is a pioneer in researching, implementing, and monitoring ecological restoration of frequent-fire forests of the Intermountain West. By allowing natural processes, such as low-severity fire, to resume self-sustaining patterns, we hope to reestablish healthy forests that provide ecosystem services, wildlife habitat, and recreational opportunities.

The ERI Working Papers series presents findings and management recommendations from research and observations by the ERI and its partner organizations. While the ERI staff recognizes that every restoration project needs to be site specific, we feel that the information provided in the Working Papers may help restoration practitioners elsewhere.

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Cover Photo: *Pediocactus knowltonii* (Knowlton's cactus). A case study outlining reintroduction efforts for this species is described in Falk et al. 1996. *Photo by Robert Sivinski.*

Photo 1. Reintroduction efforts for the federally endangered *Astragalus cremnophylax* var. *cremnophylax* (sentry milkvetch) are underway at the South Rim of the Grand Canyon in Arizona. *Photo by Janice Busco.*

Introduction

"If the land mechanism as a whole is good, then every part is good, whether we understand it or not. If the biota, in the course of aeons, has built something we like but do not understand, then who but a fool would discard seemingly useless parts? To keep every cog and wheel is the first precaution of intelligent tinkering." – Aldo Leopold (*A Sand County Almanac*, p. 190)

Adopting Leopold's sage advice to "keep every cog and wheel," the International Union for Conservation of Nature and Natural Resources regards "the maintenance of existing genetic diversity and viable populations of all taxa in the wild in order to maintain biological interactions, ecological processes and function" (IUCN 2002, p. 1) as a fundamental conservation goal. Such an outlook is shared by many conservation-oriented organizations, including federal land management agencies in the United States. This Ecological Restoration Institute working paper will review various strategies land managers can use to maintain one segment of the plant world—rare plants—as we experience the current period of changing climate. Rare plants may be seen as the "seemingly useless parts," but they deserve attention. "Intelligent tinkering" through innovative biological conservation and ecological restoration strategies will be necessary to provide them with the kinds of habitat they will need for their continued survival and growth.

Rare Plants and Climate Change

Climate change is the latest in a long list of threats to plant diversity, in general, and rare plants, in particular. A study by Kew Gardens (2011) indicates that human activities, such as agriculture, harvesting, development, logging, and livestock grazing, account for nearly 70 percent of the global threats to plant diversity. However, given its potential to affect plant habitats both regionally and globally, even in protected areas where typical human disturbances are less likely, the effects of climate change on rare and endangered plants cannot be ignored (Society for Ecological Restoration 2009).

Foden and colleagues (2008) outline five basic traits that influence a rare plant species' susceptibility to climate change: 1) need for specialized habitat and/or microhabitat that may be lost or reduced due to climate change, 2) narrow environmental tolerances or thresholds that are likely to be exceeded due to climate change at any stage in the species' life cycle, 3) dependence on specific environmental triggers or cues that are likely to be disrupted by climate change, 4) dependence on interspecific interactions that are likely to be disrupted by climate change, and 5) poor ability or limited opportunity to disperse to, or colonize, a new or more suitable range. In addition to these, a sixth trait to consider is genetic variability. Each of these traits, which in large part have to do with site suitability and dispersal potential, may be dramatically affected by changes in climate that are likely to alter the geographic location and extent of habitable sites for many plant species and create what some are describing as no-analog communities or novel ecosystems (Williams and Jackson 2007, Hobbs et al. 2009). Perhaps not surprising then, simulated climate change research indicates that some rare plants will have a difficult time adapting to a new climate in their existing location and will have an equally difficult time migrating as climate changes (Jump and Peñuelas 2005).

Rare, endemic species in the West will probably be heavily affected by such change. For example, the Colorado Plateau contains more than 300 species of endemic vascular plants (10 percent of the flora) (Krause 2010), with many of them restricted to specialized habitats, such as specific soil types, hanging gardens (i.e., seeps along canyon walls), and alpine zones. Modeling of this region predicts that 40-65 percent of endemic species may experience range reductions as early as 2040, and 2-11 percent may be faced with extinction. Some specialized groups, such as succulents, may face even greater chances of extinction (Krause 2010).

Planning for Climate Change

While policymakers, supported by the general public, continue to move forward with incentives and strategies designed to forestall or reverse changes in climate, land managers will need to develop strategies to address the various possibilities that a changing climate could bring to natural resources, including rare plant species.

At this point, managers have three basic options for managing climate-affected rare plants—*in situ* ("on site") conservation, *ex situ* ("off site") conservation, or doing nothing—depending on the species and situation in question. If the primary goal is conservation of biodiversity, this points to the need for greater human intervention in the form of *in situ* and/or *ex situ* strategies. The do-nothing option may be preferred in some situations, particularly for non-listed species or for those rare plant populations that appear demographically viable, contain enough heritable variation in necessary adaptive traits, and/or are not limited by barriers to migration. Monitoring, whether short-term or long-term, can be used to determine what type of action would be best suited for attaining management goals.

In situ conservation involves protection and/or restoration of habitats and ecosystems along with their associated species, and remains the highest priority among conservationists. *Ex situ* approaches involve the long-term, off-site maintenance and protection of living genetic samples of species (Morse 1996). Both approaches have a place in the field of conservation and are natural complements of each other. They are not always mutually exclusive of one another, however. For example, some actions, such as augmentation, reintroduction and assisted migration, may bring *ex situ* plant materials into an *in situ* management situation.

In addition, there are several other approaches worthy of exploration that will not be detailed in this working paper, such as modifying existing laws and providing incentives for landowners to participate in preservation and rare plant efforts, including agreements between cooperating non-federal property owners and the U.S. Fish and Wildlife Service (USFWS 2012).

In Situ Approaches to Rare Plant Habitat Enhancement

Currently, there are five basic *in situ* strategies for enhancing or conserving rare plant habitat. They include: 1) addressing habitat fragmentation, 2) identifying refugia, 3) augmenting existing plant populations, 4) managing habitat or genetic diversity to increase resiliency, and 5) restoring of degraded habitat. Reintroduction, which may be considered to be *in situ* if within the historical range of a species, will be discussed in the section on *ex situ* conservation practices.

Addressing Habitat Fragmentation

Habitat fragmentation, due to road building, construction, and other land uses, is a well-known barrier to seed dispersal. A number of methods have been proposed to increase landscape permeability and to "soften" intensively managed landscapes. These fairly traditional methods promote habitat for pollinators and seed dispersers. They include hedgerow planting, ditch management, pond creation, water level management, grass strip creation, and reduced pesticide and fertilizer applications (Donald and Evans 2006).

Creating corridors to improve landscape connectivity has long been proposed as a restoration/conservation method to allow gene flow and increased intra-species genetic diversity, facilitate seed dispersal, and as an aid in range shifts (Loss et al. 2011). Experimental creation of corridors is a fairly new area of research, so results have been mixed. However, a study by Kirchner and colleagues (2003) in France indicated that flooding events along natural channels increased gene flow and allowed for colonization of new habitat by a rare freshwater species, *Ranunculus nodiflorus*. In a study in South Carolina, Damschen and colleagues (2006) found that 100-m^2 patches of thinned longleaf pine (*Pinus palustris*) forests that were connected by 150-m by 25-m wooded corridors contained more species than the surrounding, unthinned forest. With time, the thinned, connected patches developed a 20-percent higher level of plant species richness than unconnected, thinned patches. Higher species richness of animal-dispersed plants in corridors and near patch edges may be driven by seed-dispersing birds (Brudvig et al. 2009). Wind dispersal of seeds may also be aided within patches and corridors.

One untested, but widely accepted, assumption is that thinned patches used as corridors within forests will promote weedy or invasive species. While this may be a concern, there are a small number of studies that indicate corridors have no detectable effect on the number of exotic species (e.g., Damschen et al. 2006, Brudvig et al. 2009). An advantage of such corridors is increased movement of butterflies and other pollinators between connected patches, but little similar movement to unconnected patches (Tewksbury et al. 2002).

Whether these same general patterns of movement and dispersal will be observed in other ecosystems remains to be seen. Regardless, migration by standard dispersal mechanisms may still be insufficient for species to stay ahead of projected climate change (Pearson and Dawson 2005). Gravity- and ant-dispersed plant species are particularly vulnerable due to dispersal limitations. Gravity-dispersed seeds fall to the ground below the plant while ants are known to disperse individual seeds a few meters, at most (Cain et al. 1998). Those species whose seeds are ingested or adhesive have the most potential for migratory success (Cain et al. 2000, Takahashi and Kamitani 2004).

Identifying Refugia

Refugia are defined by Keppel and colleagues (2011, p. 1) as "habitats that components of biodiversity retreat to, persist in and can potentially expand from under changing environmental conditions." Land managers and planners need to understand where potential future refugia may exist in order to protect the character and physical environment of these areas, which may serve as valuable habitat for rare plants and other species. Keppel and colleagues (2011) suggest two approaches for identifying potential refugia to protect species from climate change. One approach relies on determining biogeographic patterns and paleoecological evidence for refugia. The other approach involves identifying environmental and physical geographic processes, such as high-intensity fire or glaciation, that define the environmental conditions which can or might support the formation of refugia. Both require a multi-disciplinary approach with multiple lines of evidence to identify future potential areas that might act as refugia (Figure 1).

Augmenting Existing Plant Populations

Augmentation (often referred to as "restocking") involves reintroduction of plants or seeds into pre-existing habitat or populations. In about half of seed augmentation studies, in which seeds were applied to existing populations, there was evidence of seed limitation (Turnbull et. al 2000). Seed limitation is demonstrated by an increase in population size following the addition of seed. Seed sowing experiments can be used to determine if limitation is present for a given species and may also be used to increase existing population numbers (Turnbull et al. 2000). Another strategy to increase population size involves management efforts, such as protecting plants from herbivores, pathogens, and seed predators that may theoretically lead to increased vigor of the population overall and to increases in population numbers (Bevill et al. 1999).

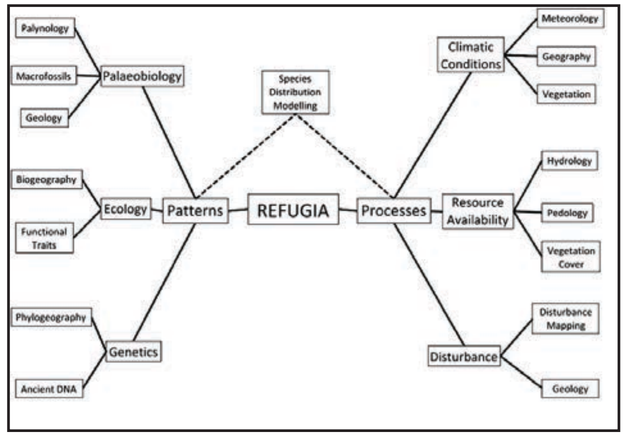

Figure 1. Two synthetic methods for identifying rare plant refugia. The left branch is based on gathering evidence from the past while the right branch relies on knowledge of current conditions for predicting future habitats (Adopted from Keppel et al. 2011).

Managing Habitat or Genetic Diversity to Increase Resilience

Ecosystem resilience has been defined as "the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks" (Walker et al. 2004). Increasing ecosystem resiliency at the habitat level, although potentially risky, can be fostered by returning natural processes (e.g., fire regime, hydrology) to the ecosystem, or by protecting and restoring quality habitat and creating robust plant communities. This, in effect, provides a potential buffer to the short-term effects of climate change (Rice and Emery 2003, Fulé 2008).

A plant species' resilience also depends on the genetic variations found within populations. Such genetic variations allow species to adapt and evolve to meet changing conditions like those that could occur with changes in climate (Srgò et al. 2011). Population sizes of hundreds or even thousands of individuals may be necessary for maintaining this level of resilience. Augmentation is a plausible *in situ* conservation tool for helping to increase genetic diversity in a rare plant population. However, land managers need to consider the consequences of such a strategy in order to avoid genetic swamping and the loss of uniquely adapted alleles in the recipient population (Weeks et al. 2011). Srgò and colleagues (2011) list two situations in which augmentation might warrant consideration: 1) when populations have experienced reductions in genetic diversity and their dispersal processes have been hampered by fragmented habitats, and 2) populations with strong local adaptation, which may lessen their ability to adapt to environmental changes.

Ecological Restoration of Degraded Habitats

Restoration ecology and conservation biology share many of the same basic goals, although they have some fundamental differences that can lead to conflicts in practice, based mainly on their historical foundations (Seddon et al. 2007). The core of restoration ecology is that some measures of habitat loss and population decline are temporary and reversible whereas conservation biology seeks to minimize permanent losses (Young 2000).

These two fields can come together to work toward preventing further habitat degradation and restoring the remnants that remain (Noss et al. 2006). Passive restoration of degraded habitats may take significant periods of time, and ecological restoration is one way to speed up natural processes in order to enhance habitat for conservation of various species (Dobson et al. 1997).

Ex Situ Approaches to Rare Plant Habitat Enhancement

Conservationists generally argue that *in situ* approaches should be used wherever feasible because they involve less risk of accidentally altering ecosystems by introducing a species that may have invasive tendencies outside of its native habitat. With the exception of seed banking, *ex situ* management strategies should be considered as an alternative only in exceptional circumstances (IUCN 2002) and after much deliberation among affected entities. In the following section, four *ex situ* strategies are discussed in some detail: 1) seed banking, 2) reintroduction, 3) assisted migration, and 4) seed transfer zones (along with information about reciprocal transplant studies and common gardens).

Seed Banking

Seed banking (i.e., the systematic saving of seeds and other propagules) is another way to provide a safety net for rare species and hopefully ward off extinction of individual species. It may be useful in both *in situ* and *ex situ* conservation and restoration approaches. One example of such an effort is the Seeds of Success (SOS) Program, which is an initiative that partners the Bureau of Land Management (BLM) with botanic gardens and other organizations to "increase the number of species and the amount of native seed that is available for use to stabilize, rehabilitate, and restore lands in the United States by partnering with the seed producing industry" (BLM 2011). While SOS currently supports *ex situ* collection of seeds of more common species (G3-G5—ranked globally as vulnerable, apparently secure, and secure, respectively), rare plant *ex situ* conservation is the specialty of the Center for Plant Conservation (CPC) in St. Louis, Missouri. The mission of the CPC is to "conserve and restore the imperiled native plants of the United States to secure them from extinction" (CPC 2012). Along with SOS and CPC, there are other organizations, such as the Dixon National Tallgrass Prairie Seed Bank (located at the Chicago Botanic Garden), that are also involved in seed banking efforts for research and restoration purposes (Vitt et al. 2010). The seed collection protocols of one of these organizations are outlined in Box 1. Improving overall ecosystem health by ensuring that plant communities contain a full and healthy complement of common species is important—which is why the collaboration and restoration efforts of the seed-banking organization are so critical to plant species conservation.

Box 1. Seed collection protocols for common (G3-G5) plant species from Vitt et al. 2010 (originally a synthesis of protocols developed for the Millennium Seed Bank; Brown and Briggs 1991; Vitt and Havens 2004; Guerrant et al. 2004b.

- Collect from a minimum of 50 maternal plants to capture 95 percent of the genetic diversity
- Collect no more than 10–20 percent of the available seed on any given day to ensure that collection efforts do not affect vital (reproductive) rates of the target populations
- Collect across any obvious environmental gradients
- Collect both from within the center of population density and from the periphery to ensure the greatest genetic diversity, and to ensure collection from individuals that may perform better in marginal portions of the habitat
- Search out and collect even the smallest plants because they may contain trait variation that would pre-adapt them to an alternate site
- In general, collections are bulked within a population, but maternal lines may be stored separately in some target species:
    - to facilitate research efforts
    - when a species has naturally low reproduction
    - to ensure equalization of the plants used as foundation stock so that no one line has more weight than another
    - when collecting from small or marginal populations
    - when collecting species known to be self-incompatible
- Collect a minimum of 3,000 seeds of common or abundant species, with an optimal target of 30,000 (adjusting amounts accordingly for rare or uncommon species). It may be necessary to collect across years in the same populations. If so:
    - collect no more than 10 percent of the seeds
    - consider maternal-line collections (where seeds from individual plants are maintained separately in order to facilitate better tracking and control for future seeding projects) rather than bulked collections
    - annual collections should be accessioned individually
- Collect at peak seed maturity, recognizing that some phenotypes (and sires) will be excluded, or collect on multiple days
- Collect from within the entire inflorescence, recognizing that proximal patterns of maternal plant development as well as patterns of embryo development might be influenced by genetic makeup of the embryos and, therefore, skew genetic contributions
- Collect voucher specimens for confirmation of species identification. Leaf tissue samples can ultimately become DNA vouchers. Collection information is critical to establish provenance of each accession. Standard collection protocols that include the collector's name, locality information (particularly GPS coordinates with the correct datum noted), property ownership, terms of the collecting permit if it limits the use of the seeds, etc., are essential. Information about the habitat that might be critical for habitat matching includes basic soil type, description of the terrain and hydrologic qualities of the site as well as community dominants and other associated plant species. Additional information about the status of the target population should include an estimate of population size, percentage of reproductive plants, and the number of plants from which the seeds were collected, which is particularly important when the seeds are not separated by maternal line.

Different approaches can be taken when choosing the appropriate genotypes to conserve through seed banking. High-latitude and high-elevation populations presumably contain the necessary genotypes to expand populations after the last ice age and may still have the advantage in colonizing these areas (McLachlan et al. 2007, Loss et al. 2011). There are also advantages to increasing genetic diversity by collecting genotypes from 1) the low-latitude and low-elevation edges of a species range (i.e., those plants most likely to colonize)) 2) the interior of the range (i.e., those plants most likely to be adversely affected by climate change) or 3) poor or harsh sites, where populations may have developed traits that allow them to tolerate more extreme conditions (McLachlan et al. 2007, SER 2009, Loss et al. 2011).

Reintroduction

Reintroduction is an attempt to establish a species in an area that was once part of its historical range, but from which it has been extirpated or become extinct (Note: the term "reestablishment" is sometimes used interchangeably but it implies that the reintroduction has been successful). Any reintroduction or translocation project (note that both terms are used interchangeably and are defined as the intentional movement of species across landscapes to maintain or enhance biodiversity (Weeks et al. 2011)) should begin with a well-researched plan (see reintroduction guidelines in Maschinski and Haskins (2012)). Methods for obtaining plant stock for reintroduction and translocation include collecting seed, preparing cuttings, separating clumps, micropropagation techniques, direct seeding at the translocation site, and salvage of mature plants (Vallee et al. 2004). One little used but promising technique is the transfer of soil containing seeds of the target species in the soil seed bank (Vallee et al. 2004).

Photo 2. A National Park Service employee tends endangered *Astragalus cremnophylax* var. *cremnophylax* (sentry milkvetch) plants in the greenhouse in preparation for reintroduction into the field. *Photo by Janice Busco.*

There are many examples of reintroduction projects in the literature. Seeds and soil from donor vernal pools have been successfully translocated, leading to the successful establishment of threatened and endangered plant species (Dodero and Hanson 2000). "Living mats" cut from a bog have been transferred to other degraded sections of the bog to aid in plant community establishment (Wilcox and Ray 1989). Large "off-the-shelf" landscaping equipment can be used to move salvaged plants, entire pieces of sod, and even small trees, such as ponderosa and pinyon pine, to new locations (Munro 1994, Heim 1994, Ross and Travis 1997). Indeed, Curtis Prairie (in Madison, Wisconsin), one of the earliest restorations (1936-1941), was accomplished using plants dug from a prairie remnant about 35 miles away as well as seeds and sod obtained from roadsides and railway rights-of-way (Jordan 1983, Sperry 1994).

Salvaged plants should be relocated to sites with similar aspect, soil type, elevation, hydrology, precipitation, and community associations in order to increase chances of success (Bowler and Hager 2000), which, in terms of plant reintroduction, is generally measured by the successful reproduction of reintroduced individuals. Research indicates that the current rates of survival, flowering, and fruiting are low on average in reintroduction projects worldwide (Albrecht et al. 2011, Godefroid et al. 2011, Maschinski et al. 2012).

In the southwestern United States, a survey of land managers tasked with conserving rare species revealed that herbivory and trampling, invasive plant species encroachment, off-road vehicle use, and fire suppression or fire regime disruption present the greatest threats to rare species (Springer et al. 2011). Respondents focused their conservation efforts mainly on occupied habitat, with only 11 percent reporting attempts to establish species on unoccupied, but seemingly suitable, habitat. Survey responses indicated that attempts to introduce species to new habitat have had a fairly low success rate, with two species showing indications of successful establishment—Kearney's bluestar (*Amsonia kearneyana*) and Chiricahua Mountain dock (*Rumex orthoneurus*)—and the other three attempts unsuccessful: Charleston Mountain angelica (*Angelica scabrida*), Charleston Mountain goldenbush (*Ericameria compacta*), and Siler's pincushion cactus (*Sclerocactus sileri*). Reasons given for the failed attempts include mortality of transplants at the relocation sites, failure of seeds to germinate, and death of seedlings shortly after germination (Springer et al. 2011).

In their study of reintroduction programs, Godefroid and colleagues (2011) identified several programmatic failings including: 1) insufficient monitoring (most projects collect monitoring data for four years or less), 2) inadequate documentation, particularly for failed projects, 3) lack of understanding of species biology and the reasons for population declines, 4) overly optimistic evaluation of success based on short-term results, and 5) poorly defined success criteria. Similarly, to some of the findings in the Springer et al. (2011) survey, Vallee and colleagues (2004) found that unsuccessful, single species translocations were due to the following: 1) failure to adequately control or manage the threats affecting the species or its new habitat, 2) lack of adequate consideration of the biological and ecological requirements of the species (including mycorrhizal associations, pollinators, and seed/fruit dispersers), 3) use of inappropriate translocation methods, 4) failure to use an experimental approach to determine variables that might affect success, 5) absence of ongoing commitment of resources to monitoring, evaluation and follow-up maintenance, and 6) failure to consider genetic variability.

Moving the plants is not the only concern, because some rare species, such as orchids, rely on mycorrhizal fungi for seed germination, and even seedling development in some species. They may also require specialized pollinators (Keel 2007). Attempts have been made to restore plant-pollinator mutualisms, but increasing flowering plants to draw in pollinators has the potential to backfire if pollinators concentrate on the more common planted species, rather than the inconspicuous targeted species in need of pollinators (Menz et al. 2011). In addition, rare species may already be hampered by constraints to reproduction, dispersal, or other factors, making range shifts particularly difficult (Marsico and Hellmann 2009). To complicate matters, flowering and reproduction may be curtailed in years of below average precipitation, further impeding unassisted plant migration efforts if the climate in a given area becomes warmer and drier over a long time period.

With these problems in mind, the CPC has developed a checklist of actions needed to advance successful rare plant reintroduction projects (Maschinski et al. 2012). This list (Box 2) is generally supported by the findings of other plant reintroduction researchers (e.g., Vallee et al. 2004, Godefroid et al. 2011).

Box 2. The Center for Plant Conservation's proposed best management practices guidelines for rare plant reintroduction (Maschinski et al. 2012).

- ✓ Secure adequate funding to support the project.
- ✓ Keep detailed records throughout the process and store documentation in multiple locations. Document the species status and distribution.
- ✓ Ascertain the threats to a particular rare species and, when possible, take action to remove, control or manage these threats, such as removal of invasive species or thinning tree canopy. Engage land managers in discussion about options for conservation of the species. Consider whether the proposed reintroduction will do any harm to the recipient community or to existing wild populations. If so, consider alternative conservation strategies.
- ✓ Determine whether the reintroduction is feasible legally, logistically, and socially.
- ✓ If a reintroduction effort cannot be justified, do not proceed.
- ✓ Examine other conservation options.
- ✓ Develop a reintroduction plan. Whenever possible design the reintroduction as an experiment and seek peer review.
- ✓ Obtain legal permission to conduct the reintroduction.
- ✓ Ensure that land owners and managers are supportive of the project and can account for possible changes in the future.
- ✓ Know the species biology and ecology.
- ✓ Ascertain whether genetic studies are needed before conducting the reintroduction and, if possible, conduct studies to measure genetic structure of the focal species. At a minimum, gather information about life history traits.

✓ Select appropriate source material that has been collected from a location with similar climatic and environmental conditions to the restoration/reintroduction site.

✓ Where possible, use *ex situ* source material before collecting new material from wild populations.

✓ Confirm that the species can be successfully propagated and that adequate numbers of high-quality healthy, genetically diverse founder plants are available. Allow enough time to generate adequate numbers of plants for reintroduction efforts.

✓ Choose a suitable recipient site, preferably one that has connectivity to additional suitable habitat to allow for dispersal opportunities. Seek or develop growing conditions with the intention of improving germination, establishment, and survival of next generation seedlings.

✓ Determine the necessary timing, materials, personnel, and logistics to implement the reintroduction.

✓ Reintroduce at least 50 plants of varying size and life-stage to account for variable success of life stages in different microsites, using whole plants rather than seeds, where possible.

✓ Plant in a spatial pattern and at a density that will promote effective pollination, seed production and recruitment and minimize competition. Pattern and density can often be determined from observations of natural populations or by conducting a spatial point pattern analysis. Label plants and plots with color coded, long-lasting tags.

✓ Provide additional care following planting to ensure establishment, including watering and weeding.

✓ Develop a monitoring plan and determine how success will be measured. Collect demographic or life history data about the reintroduced population and, if possible, about wild reference populations for comparison purposes.

✓ Monitor for a minimum of three years. Additional years of monitoring are necessary to legitimately define success, so ten years or more is ideal. As short-term goals are achieved, monitoring intensity may change from experimental to observational.

✓ Analyze data in a timely fashion and publish results in several forms of media, including newsletters, websites, and popular news media in addition to scientific journals.

Photo 3. Transplanting the rare *Phemeranthus validulus* (Tusayan flameflower) from a construction site to a more protected site. *Photo by Janice Busco.*

Assisted Migration

Assisted migration (AM), also known as managed translocation, managed relocation or assisted colonization, is a more recent, and controversial, *ex situ* strategy (Holmes 2007, Camacho 2010, Hewitt et al. 2011). The Managed Relocation Working Group, a collaboration of researchers, land managers and conservationists, has defined this strategy as the "purposeful translocation of species adversely affected by global change, particularly climate change (2008)." A small number of assisted migration projects involving plant species are already under way around the world (McLachlan et al. 2007, Marris 2009). At least one experiment was initiated to examine the effects of climate change and to test assisted migration approaches by translocating an intact piece of meadow soil and vegetation to a site at higher elevation (see Bruelheide 2003). Thus far, these experiments and projects have been on a very small scale and may or may not be a part of well-researched scientific studies. As a result, there is little published scientific literature available to document long-term success or failure. For the conservation of rare species in a changing climate, there are risks with both action and inaction, particularly in relation to biodiversity (Schwartz et al. 2009, Lawler and Olden 2011). The main potential benefits of AM are the possibility of preventing the extinction of species vulnerable to climate change and protecting species that are confined to fragmented or specialized habitats (Hewitt et al. 2011). On the other hand, researchers have identified numerous risks, including:

- Introduced species may become invasive (Ricciardi and Simberloff 2009) and/or undesirable pathogens may be introduced (Hoegh-Guldberg et al. 2008)
- Funds may be diverted away from critical conservation projects, including restoration or reversal of habitat fragmentation
- Single species may be valued more highly than communities or ecosystems
- Climate modeling may be incorrect for future bioclimatic envelopes (Hewitt et al. 2011, Haskins and Keel 2012)
- Success rates may be even lower than typical due to uncertainty of climatic conditions (Haskins and Keel 2012)
- Introduced and native populations may hybridize and cause genetic swamping of native populations in the recipient community (Minteer and Collins 2010)
- Socioeconomic risks involve financial and cultural harm to the recipient community with AM (Richardson et al. 2009)
- Unresolved legal issues (Camacho 2010)

Despite these acknowledged risks, increasing numbers of scientists and conservation organizations are beginning to explore how AM might be most effectively implemented, should a conservation need arise (Swarts and Dixon 2009, Liu et al. 2010). Haskins and Keel (2012) suggest that to make AM an acceptable option would require research that would include ecology, climate research, and ethics. Planning, conducting weed risk assessments for the species being moved, and following the reintroduction guidelines outlined in Maschinski and Haskins (2012), or similar guidelines, will also likely be essential to ensure that any AM project is implemented successfully. Hoegh-Guldberg and colleagues (2008) provide an excellent flow chart for making decisions about whether to proceed with AM or take some other course of action (see Fig. 2). Likewise, Gordon (1994) compiled a very useful dichotomous key in the early 1990s to assist with decision-making in situations involving translocation. Although this key was created prior to our present concern over climate change, it remains an invaluable tool for land managers needing to make decisions about whether or not to take the AM approach. Key decision elements include: 1) degree of threat to the species that is being considered for translocation, 2) dispersal from site of introduction, 3) interspecific genetic risks, 4) cause of threat, 5) propagule source, 6) competitive interactions, 7) consumptive interactions, 8) contamination risks, and 9) site management.

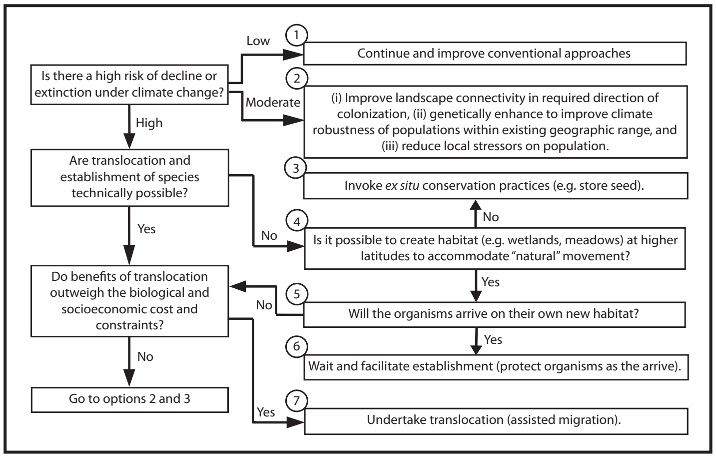

Figure 2. Decision framework for assessing possible species translocation (Adapted from Hoegh-Guldberg et al. 2008)

Determining Rare Plant Translocation Suitability

Whatever type of rare plant translocation is chosen (i.e., reintroduction or assisted migration), the land manager will have to determine the suitability of a species for the proposed project. Fortunately, there are some existing tools to use for this purpose—seed transfer zone maps, reciprocal transplant studies, and common garden studies—as will be explained in the following section. These tools may help identify whether a plant species might survive translocation to a given site as well as provide important information about its genotype.

Seed transfer zones are "geographic areas within which plant materials can be moved freely with little disruption of genetic patterns or loss of local adaptation" (Miller et al. 2011, see also U.S. Forest Service 2012). Researchers at the U.S. Forest Service Pacific Northwest Research Station and at the Western Wildland Environmental Threat Assessment Center have put together several useful tools, including the Wildland Threat Mapper: Seed Zones for Native Plants (USFS 2012). While these tools are helpful, the researchers caution that, at this point in time, the maps are not species specific and are only intended as guidelines or a starting point for more detailed, site-specific study. In addition, seed transfer zones may change over time as climate shifts occur.

Johnson and colleagues (2004) conducted long-term trials of tree seed zones and found that poorly adapted tree seed sources were generally able to tolerate average conditions, but were unable to tolerate rare climatic events that occurred every ten or more years. A similar pattern may be observable in herbaceous species. This is cause for concern as weather events become more extreme, and it points to the need for longer term studies that will be able to capture responses to these extreme events.

If populations are tested in various environments through reciprocal transplant studies (i.e., in experiments where species from two or more habitats are introduced into each other's habitats), and local sources of plant material outperform more distant sources, then using material from appropriate seed zones may be necessary to protect the adaptive patterns within populations from those zones (Kitzmiller 2009). Using only local sources of plant material to augment populations may lead to genetically depauperate populations, with insufficient evolutionary potential to meet new environmental challenges across a highly degraded landscape (Broadhurst et al. 2008, Srgò et al. 2011). In addition, distant populations may be more able to adapt to these changes than local sources (Srgò et al. 2011). "Composite provenancing" is a strategy that uses local seed sources, along with sources from areas farther away with matching soil type, aspect, elevation and community type, with the hope that new genetic combinations able to adapt and to withstand climate changes will be produced (Broadurst et al. 2008). These approaches are somewhat novel and, like assisted migration, require additional research and discussion among scientists and practitioners prior to implementation.

Common garden experiments involve bringing species from various habitats into one locale to determine genetic differences within and among populations. They can also be helpful for matching seed sources of individual species to restoration sites that have suitable ecological conditions. Low-stress environments may mask genetic variation in certain traits such as survival, germination, and flowering (Kitzmiller 2009). When seeds of various populations are brought together to grow in common environmental conditions, phenological differences that are observed among the different sources may be assumed to be due to genetic differences. Caution is warranted, however, with the use of these techniques in terms of AM programs. Species that experience vigorous growth or adaptations to a wide variety of environments in common garden experiments may have the potential to displace other species and reduce diversity both within species and within the plant community as a whole (Johnson et al. 2010).

Photo 4. An NPS employee displays an *Astragalus cremnophylax* var. *cremnophylax* (sentry milkvetch) reintroduced into the field. This plant will be monitored for several years to gauge the success of the project. *Photo by Janice Busco.*

Conclusions

In this working paper, we have described several strategies that land managers may find useful in their efforts to conserve and/or restore rare plant species. To summarize, these include:

- *In situ* strategies (on-site protection and/or restoration of habitats and ecosystems along with their associated species)
    - Manage or restore habitat to increase resiliency (e.g., restore disturbances such as fire to reduce competition, move threatened plants to a safer locale within their current range)
    - Reduce habitat fragmentation to increase dispersal (e.g., habitat corridors)
    - Identify and protect potential plant refugia
    - Augment existing plant populations (e.g., reintroduce plants/seeds into existing habitat or populations, protect existing plants from disturbance, herbivory)
- *Ex situ* strategies (off-site maintenance and protection of living genetic material of species)
    - Seed banking (collection and storage of rare plant seed

for use as needed in both *ex situ* or *in situ* situations; collaborative efforts are under way between federal agencies and botanic gardens/arboreta)

- Reintroduction (establish a species in an area that was once part of its historical range, but from which it has been extirpated or become extinct; also known as translocation)

- Assisted migration (controversial, experimental strategy that involves moving species specifically to overcome the expectations/predictions of climate change occurring within the species' current habitat/range)

We have also discussed the potential of seed transfer zone maps, reciprocal transplant studies, and common garden studies to help the land manager determine the likelihood of success in reintroduction, translocation, and assisted migration projects.

There are a number of excellent resources for land managers and others about *in situ* and *ex situ* approaches to rare plant conservation and restoration. These include *Genetics and Conservation of Rare Plants* (Falk and Holsinger 1991), *Restoration of Endangered Species: Conceptual Issues, Planning, and Implementation* (Bowles and Whelan 1995), *Restoring Diversity: Strategies for the Reintroduction of Endangered Plants* (Falk et al. 1996), *Ex Situ Plant Conservation: Supporting Species Survival in the Wild* (Guerrant et al. 2004a), and *Plant Reintroduction in a Changing Climate: Promises and Perils* (Maschinski and Haskins 2012).

While saving all the "pieces" is probably unlikely, a logical first step for any land manager is to conserve as many species as possible through seed banking while at the same time protecting and restoring as much critical habitat as possible. Other strategies include increasing the permeability of the landscape by creating corridors, working with policymakers and the public to modify existing laws, such as the Endangered Species Act (under which many translocated species would be considered non-native outside of their historic range (Camacho 2010)), and providing incentives for landowners to participate in rare plant conservation efforts.

Land managers and others concerned about or mandated to conserve rare plants will face unprecedented challenges as the climate changes. Planning for these changes should begin now, so that decisions will be made that follow existing, well-planned frameworks. Fortunately, steps are now being taken to lay the groundwork for solutions and guidelines for conserving the most imperiled species. This paper and the references it cites provide helpful information and promote an active, engaged dialogue among natural resource professionals for planning to meet these challenges.

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