Growing Assisted Migration: Synthesis of a Climate Change Adaptation Strategy

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Abstract: Assisted migration may be necessary as a climate change adaptation strategy for native plant species that are less adaptive or mobile. Moving plants has been practiced a long time in human history, but movement of species in response to climate change is a new context. First proposed in 1985, assisted migration has gained attention since 2007 as a strategy to prevent species extinction, minimize economic loss, and sustain ecosystem services. We present a synthesis of proposed assisted migration guidelines and provide resources for nurseries, landowners, and researchers.

Keywords: climate change, decision framework, implementation, managed relocation, native plant transfer guidelines, seed transfer zones

Introduction

Climate change adaptation strategies may not be at the forefront of everyone's mind, but within the context of seed technology for forest and conservation nurseries they have significant merit. If temperature and precipitation predictions are correct, plant populations in their native settings will have to adapt or move to avoid maladaptation and/or extinction (Peters and Darling 1985). Current climate predictions would require plants to migrate 3000 to 5000 m (9842 to 16404 ft) per year far exceeds their observed maximum rates of less than 500 m (1640 ft) per year (Davis and Shaw 2001; Aitken and others 2008; Lempriere and others 2008).

Assisted migration of plants, that is, human-assisted movement, may be necessary for species that are less mobile or adaptive (Peters and Darling 1985; Hoegh-Guldberg and others 2008; Vitt and others 2010). Short-lived and annual species will likely adapt faster to changes in climate than long-lived species (Jump and Penuelas 2005; Vitt and others 2010). Despite disparity in rates between climate change and observed plant migration, survival may be more determined by available geophysical connections among landscapes needed for plants to move (Hannah 2008) and whether or not suitable recipient ecosystems exist (Aubin and others 2011). Furthermore, impacts from climate change can be so abrupt, for example, the mountain pine beetle outbreak on populations of lodgepole pine (*Pinus contorta*) (Regniere and Bentz 2008) that management options will be limited.

Moving plants has been practiced for a long time in human history, but the movement of species in response to climate change is a relatively new concept (Aubin and others 2011). First proposed in 1985 (Peters and Darling), assisted migration has gained attention since 2007 as a climate-change adaptation strategy (Hewitt and others 2011). Preventing species extinction, minimizing economic loss (for example timber production), and sustaining ecosystem services (for example wildlife habitat, recreation, and water and air quality) are three reasons for assisted migration (Aubin and others 2011). The only known assisted migration program in the U.S. is a grassroots effort to save Torreya taxifolia (*Florida torreya*), a southeastern evergreen conifer, from extinction (McLachlan and others 2007; Barlow 2011). Since 2008, Florida torreya has been planted on private lands in five southern states (Torreya Guardians 2012). To prevent economic loss in the timber industry, some Canadian provinces have adjusted their planting guidelines. (Pedlar and others 2011). Using assisted migration to sustain ecosystem services has been addressed, but is not well-studied (Jones and Monaco 2009; Aubin and others 2011). If ecosystem function and structure become a main focus in assisted migration plans, it will prompt ecologists to consider moving assemblages of species rather than moving a single species (Harris and others 2006; Park and Talbot 2012).

Risks such as establishment failure and negative effects on the recipient and donor ecosystem are associated with assisted migration (Aubin and others 2011). Establishment failure can result from moving the species before the donor site is suitable and from any number of factors familiar to traditional planting efforts (Vitt and others 2010). The species could have negative effects on the recipient ecosystem, such as genetic pollution, hybridization, function/structure impairment, pathogens, and invasion. The risk of invasion, however, is subject to debate in regards to assisted migration and climate change because the definition itself depends upon human perception (Mueller and Hellman 2008). Some degree of "invasiveness" in an assisted-migratory might be necessary for establishment. Effects on the donor ecosystem are less definitive. Over-harvesting a population at risk of decline or extinction is a concern (Pedlar and others 2011). Removing seeds or plant materials from a donor ecosystem could hinder natural adaptation and migration (Vitt and others 2010; Aubin and others 2011).

Whether or not assisted migration is implemented or even possible, management and conservation plans need to incorporate climate change research as soon as it becomes available (Peters and Darling 1985). Unfortunately, since 1985, only a handful of assisted migration guidelines have been proposed (Hoegh-Guldberg and others 2008; Vitt and others 2010; Lawler and Olden 2011; Pedlar and others 2011; Schwartz and others 2012), largely born out of conservation biology, restoration ecology, and forestry. We present a synthesis of these guidelines and include examples of current efforts and available resources for nursery managers, land managers, and restorationists.

Informed Decisions

An overwhelming conundrum for assisted migration lies in the matching of existing plant materials (that is, seed, nursery stock, or genetic material) with ecosystems of the future that have different climate conditions (Potter and Hargrove 2012). To alleviate the challenge, a few tools are available to make informed decisions about assisted migration (Lawler and Olden 2011; Schwartz and others 2012). Bioclimatic models coupled with species genetic information in a GIS can be used to identify current and projected distribution (for example Rehfeldt and Jaquish 2010, McLane and Aitken 2012, and Notaro and others 2012). These forecasts can assist land managers in their long-term management plans, such as, where to collect seeds and plants. In Rehfeldt and Jaquish (2010), western larch (*Larix occidentalis*) distribution and seed zones are mapped under a combination of climate change scenarios for 2030 and 2060. Although the modeled projections have some uncertainty, they provide some indication of how seed zones will change over time.

We can gain much information from past reintroductions given our long history of moving and re-establishing species, not only from forestry, agriculture, and horticulture, but from restoration ecology (for example coal mine reclamation). Experiments such as the Assisted Migration Adaptation Trial (Marris 2009) in Canada and the Florida torreya project in the southeastern U.S. can inform us of how species respond to migration and warming. Further, we can use pollen and fossil records to understand how species responded to past climate changes.

Of the published frameworks, Hoegh-Guldberg and others (2008) present a decision matrix to help identify species risk and feasibility of migration under climate change (Figure 1). Addressing ethical, legal and policy, and ecological questions such as "What are the priority taxa, ecosystem functions, and human benefits for which to consider assisted migration?" and "Do existing laws and policies enable assisted migration actions?" (Aubin and others 2011; Schwarz and others 2012) are central to species selection and navigating through the matrix. Maintaining or improving conservation plans would be sufficient for species at low risk, whereas species at moderate or high risk require more involved actions (Figure 1).

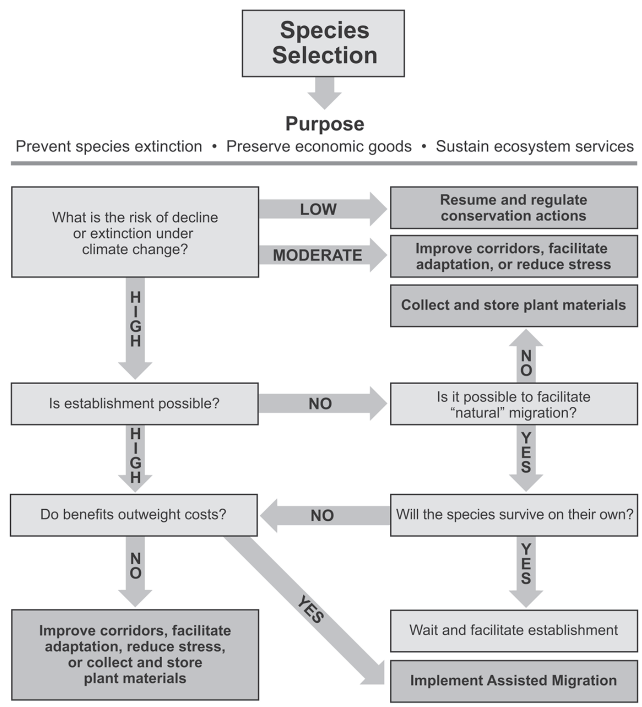

Figure 1. An assisted migration decision matrix can be used to determine adaption strategies for a plant species that has conservation, economic, or social value. Genetic information, bioclimatic models, historical records, and current assisted migration experiments should be consulted in navigating through the matrix. In order to implement assisted migration the species must be at high risk of decline or extinction, establish well, and provide more biological, economic, and social benefits than costs. (From Hoegh-Guldberg and others 2008).

Assisted migration may be warranted if: 1) a species is at high risk of extinction or if loss of the species would create economic or ecosystem loss, 2) can be established, and 3) provides more benefit than cost. In the event that establishment is not possible or costs constrain assisted migration, alternative options to facilitate migration or conservation would be considered. For example, reducing fragmentation, increasing landscape connections, collecting and storing seed, and creating suitable habitats could facilitate "natural" migration. Risk status will change over time. Existing programs (see Beardmore and Winder 2011) such as the Forest Tree Genetic Risk Assessment System (ForGRAS, Devine et al. 2012), NatureServe Climate Change Vulnerability Index (NatureServe 2011), System for Assessing Species Vulnerability (SAVS, Bagne and others 2011), and Seeds of Success program (Byrne and Olwell 2008) are available to determine a species' risk to climate change. Species most vulnerable to climate change are rare, long-lived, locally adapted, geographic and genetically isolated, and threatened by fragmentation and pathogens (Erickson and others 2012). Suitable candidates are those that may decline in growth and productivity under climate change. Listing species as candidates for assisted migration is a practical first step (Vitt and others 2010; Pedlar and others 2011), but requires a substantial amount of knowledge about the species and their current and projected habitat conditions. Provenance data exist for several commercial tree species and should be used to estimate their response to climate scenarios (for example Rehfeldt and Jaquish 2010). In the U.S. we know a lot about conservation and commercial species because of their social and economic value. Regardless, the decision matrix is a proactive starting point that can be tailored over time, and not just to plants.

Implementation

In the following sections, we outline guidelines, including issues to consider, in an assisted migration plan (Figure 2). Largely from Pedlar and others (2011) and Vitt and others (2010), the guidelines are not unlike conventional reforestation and restoration approaches. We illustrate each component from an assisted migration and climate change perspective. We do not detail conventional guidelines. The Nursery Manual for Native Plants (Dumroese and others 2009), Raising Native Plants in Nurseries: Basic Concepts (Dumroese and others 2012), Seedling Nutrition and Irrigation (Landis and others 1989), Seedling Processing, Storage, and Outplanting (Landis and others 2010), Seedling Propagation (Landis and others 1998), The Society for Ecological Restoration International Primer on Ecological Restoration (SER 2004) and the Woody Plant Seed Manual (Bonner and others 2008) are appropriate resources to consult for seed and plant collection, propagating, site selection and preparation, outplanting, and maintenance.

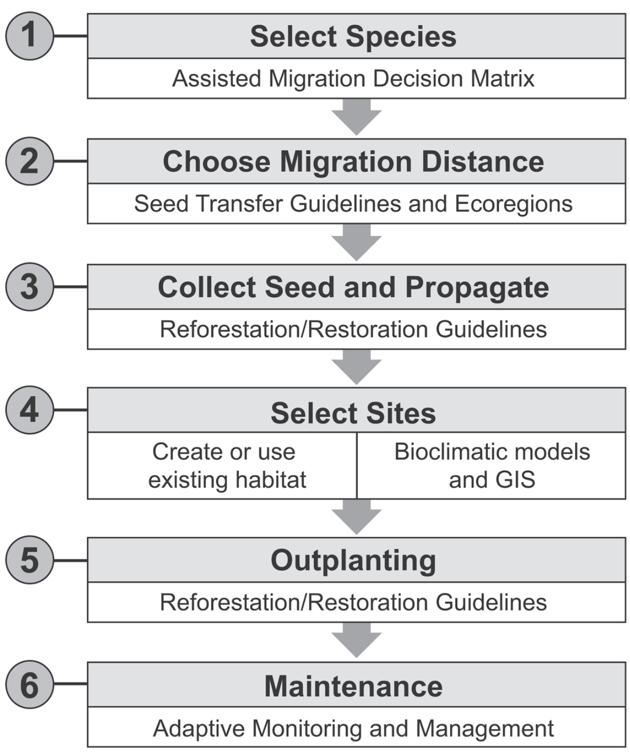

Figure 2. A guide for implementing assisted migration which can be adapted to address a single species or an assemblage of species. Although species selection (1) and migration distance (2) are principle components in an assisted migration program, cost, location, and public support will determine implementation. (From Pedlar and others 2011; Vitt and others 2011).

Select Species

Whether the species is of commercial and/or conservation value, the decision matrix (Figure 1) can help identify a candidate species for assisted migration. Species selection will dictate migration distance, collection, propagation, planting site, outplanting method, and maintenance. Species may be selected on the basis of their risk of decline or extinction, importance to economic services, or contribution to ecosystem sustainability. For example, assisted migration could target commercial tree species that are predicted to decline in productivity under climate change (O'Neill and others 2008). Suitability of assisted migration for conservation species could be determined by a number of indicators such as available habitat, endangered status, and migration potential (Vitt and others 2010).

Determine Suitable Migration Distance

Distance is the safest geographic and/or climatic distance that populations can be moved to avoid maladaptation (reduction in fitness, health, or productivity as a result of growing in an unsuitable environment). Seed transfer zones and guidelines developed using species-specific genetic and climatic information can be used to determine distances. Guidelines and zones are available for many commercial tree species and some conservation species (Table 1). Empirical guidelines and zones created from common garden studies are available for a few grasses and shrubs, such as blue wildrye (*Elymus glaucus*) (Kitzmiller and Hanson 2011) and sagebrush (*Artemisia* spp.) (Mahalovich and McArthur 2004).

The paucity of transfer zones and guidelines established for shrubs, grasses, and forbs is a major limitation in making informed decisions about assisted migration. At best, we can rely on provisional seed zones (for example Seed Zone Mapper - Table 1) developed from temperature and precipitation data and Omernick level III and IV ecoregion boundaries (Omernik 1987) to evaluate candidates for assisted migration where species provenance data and bioclimatic data are lacking. Another option is to match the seed source climate with projected climate at the outplanting site with the assumption that the intended site is within the projected habitat of the species. This option requires knowing when the migration or outplanting will occur (Pedlar and others 2011).

Seed transfer functions can be used to calculate migration distances under climate change (Thomson and others 2010; Ukrainetz and others 2011). These functions relate performance of provenances at given test sites to climatic distance between the test site and outplanting site (Raymond and Lindgren 1990). Online tools are available to assist forest managers and researchers in making decisions about matching seedlots with outplanting sites and seed transfer (Table 1). The Seedlot Selection Tool (Howe and others 2009) is a mapping tool that matches seedlots with planting sites based on current or future climates and Seedwhere (McKenney and others 1999) can map out potential seed collection or outplanting sites based on climatic similarity of chosen sites to a region of interest. Rehfeldt and Jaquish (2010) employed bioclimatic models to map current and projected seed transfer zones for western larch. Others have performed similar assessments for aspen (*Populus tremuloides*) (Gray and others 2011), longleaf pine (*Pinus palustris*) and dogwood (*Cornus florida*) (Potter and Hargrove 2012), and whitebark pine (*Pinus albicaulis*) (McLane and Aitken 2012).

Identify Collection Sites, Collect Seeds, and Propagate Plants

Seed collection sites and collection and propagation methods will depend on the target species and purpose of assisted migration (that

Table 1. Resources related to native plant transfer guidelines, climate change, and assisted migration for the U.S. and Canada. Most programs are easily located by searching their names in common web browsers. All URLs were valid as of 15 October 2012.

Resource or Program	Description	Authorship
Center for Forest Provenance Data http://cenforgen.forestry.oregonstate.edu/index.php	Database for tree provenance and genecological data that allows public access. Users are able to submit and retrieve data.	USDA Forest Service and Oregon State University
Centre for Forest Conservation Genetics http://www.genetics.forestry.ubc.ca/cfcg/	Portal for forest genetics and climate change research conducted in British Columbia, Canada.	Ministry of Forest and Range, BC
Climate Change Resource Center http://www.fs.fed.us/ccrc/	Information and tools about climate change for land managers and decision-makers.	USDA Forest Service
Climate Change Tree Atlas http://www.nrs.fs.fed.us/atlas/tree/tree_atlas.html	An interactive database that maps current (2000) and potential status (2100) of eastern US tree species under different climate change scenarios.	USDA Forest Service
Forest Seedling Network http://www.forestseedlingnetwork.com	Interactive website connecting forest landowners with seedling providers and forest management services and contractors	Forest Seedling Network
MaxEnt (Maximum Entropy) http://www.cs.cmu.edu/~aberger/maxent.html	Software that uses species occurrences and environmental and climate data to map potential habitat. It can be used to develop seed collection areas.	Carnegie Mellon University
Native Seed Network http://www.nativeseednetwork.org/	Interactive database of native plant and seed information and planting guidelines for restoration, native plant propagation, and native seed procurement by ecoregion.	Institute for Applied Ecology
Seed Zone Mapper http://www.fs.fed.us/wwetac/threat_map/SeedZones_Intro.html	An interactive seed zone map of western North America. User selects areas to identify provisional and empirical seed zones for grasses, forbs, shrubs, and conifers. Map displays political and agency boundaries, topography, relief, streets, threats, and resource layers.	USDA Forest Service
Seedlot Selection Tool http://sst.forestry.oregonstate.edu/index.html	An interactive mapping tool to help forest managers match seedlots with planting sites based on current climate or future climate change scenarios. Can also be used to map present or future climates defined by temperature and precipitation.	USDA Forest Service and Oregon State University
Seedwhere https://glfc.cfsnet.nfis.org/mapserver/seedwhere/seedwhere-about.php?lang=e	GIS tool to assist nursery stock and seed transfer decisions for forest restoration projects in Canada and the Great Lakes region. It can identify geographic similarities between seed sources and planting sites.	Natural Resources Canada, Canadian Forest Service
System for Assessing Species Vulnerability (SAVS) http://www.fs.fed.us/rm/grassland-shrubland-desert/products/species-vulnerability/savs-climate-change-tool/	Software that identifies the relative vulnerability or resilience of vertebrate species to climate change. It provides a framework for integrating new information into climate change assessments.	USDA Forest Service

is, commercial or conservation). Seed collection areas, zones, and orchards exist for most commercial tree species. Species of concern are not regularly collected or propagated at the same scale as commercial species making assisted migration a challenge, but provisional seed zones can be used to select collection areas (Table 1).

Guidelines that maximize genetic diversity within outplanted materials provide some long-term insurance that would counter against uncertainty in climate predictions and species reactions to climate change (Ledig and Kitzmiller 1992; Vitt and others 2010). Seed collection guidelines to increase genetic diversity with assisted migration in mind are synthesized by Vitt and others (2010). Selecting a few extreme variants within seed collections or allowing for physiological or morphological variation in nursery stock might serve to facilitate migration (Pedlar and others 2011). For example, drought tolerance in nursery stock would be a desirable trait for planting sites projected to experience warmer and drier conditions. Establishing seed orchards and collecting seed from low elevations or southern latitudes so that the resulting material is adapted to these conditions are other options (Pedlar and others 2011).

Select Outplanting Sites

Creating suitable outplanting sites might be necessary for species at moderate or high risk of decline or extinction (Hoegh-Guldberg and others 2008; Aubin and others 2011). The target species and its habitat requirements will dictate outplanting site selection. Some species have well-defined habitat conditions that can help with site selection. Soil surveys and ecological site descriptions provide additional support for site selection (Herrick and others 2006) as well as current and projected seed transfer zones and guidelines (Table 1). Site selection for commercial tree species, which have a long history of human-assisted propagation, is largely determined by harvest and reforestation operations, which by their very nature produce planting sites (Pedlar and others 2011). Conversely, species of conservation value have a short history of human-assisted propagation and outplanting sites are not routinely created through commercial activities. However, using disturbed areas as outplanting sites to test assisted migration has been suggested (Jones and Monaco 2009; Aubin and others 2011).

Outplanting

Volume 7 of the Container Tree Nursery Manual - Seedling Processing, Storage and Outplanting - provides thorough outplanting guidelines for trees including outplanting window, or, best time to plant (Landis and others 2010). Outplanting window can vary year to year even within current climate conditions, therefore the "window" will be difficult to determine for assisted migration. In other words, when and where do you plant a long-lived species in a rapidly changing climate? Maladaptation may occur if a species is introduced too soon to its "new" environment or it may competitively interact with other species causing loss of ecosystem function or structure (Aubin and others 2011). Assisted migration experiments coupled with projected climate change may help determine the best time to deploy plant materials (Lawler and Olden 2011).

Monitoring and Maintenance

Adaptive monitoring and management is imperative to any natural resource program, especially in an assisted migration program given the uncertainty in climate change projections and adaptation to changes in climate. Programs need to encourage feedback and learning which can be used to change and/or create management actions. Short-(months to years) and long-term (several years) monitoring of survival and growth will provide valuable feedback about plant performance and measures of success to nursery and land managers (Landis et al. 2010). Post-establishment maintenance such as watering, herbicide application, and pest/predation control can be employed post-planting to help the species establish (Pedlar and others 2011). Questions such as "Which reference ecosystem should be used to evaluate an assisted migration effort?" and "What measures do we use to determine success?" will help determine what characteristics to monitor in the species and receiving ecosystem (Aubin and others 2011). Growth measurements, reproduction, ecosystem health (structure and function), and degree of invasiveness are indicators to consider (Herrick and others 2006; Pedlar and others 2011).

Assisted Migration Examples

Other than the Florida torreya assisted migration project in the southeastern U.S., only a few assisted migration efforts are underway in North America, and all of them are in Canada. In response to a changing climate, seed transfer guidelines for Alberta have been revised to extend current zones northward by 2° latitude and upslope by 200 m (656 ft). Alberta is also considering the evaluation of ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*) as replacements for lodgepole pine because it is predicted to decline in productivity or suffer from extinction under climate change (Pedlar and others 2011). In British Columbia, a large, long-term experiment called the Assisted Migration Adaptation Trial (AMAT), a collaborative effort between B.C. Ministry of Forests and several agencies and stakeholders, tests both assisted migration and climate warming (Marris 2009). The program evaluates the adaptive performance of 16 tree species collected from a range of sources in B.C., Washington, Oregon, and Idaho and planted in several sites in the same areas. Two components of the trial are to test how sources planted in northern latitudes perform as the climate changes and evaluate endurance of northern latitude sources to warmer conditions in southern latitudes.

Limitations

We cannot reliably predict future climates so it is difficult to know which or how ecosystems will be affected. We have a long history of moving plants, but limited knowledge about establishing native plant materials outside their range in anticipation of different climate conditions. To further complicate matters, we know little about the long-term ecological effects of assisted migration, such as, invasiveness, maladaptation, and site stability (Aubin and others 2011). One way to address uncertainty is to maximize genetic and geographic diversity in plant materials (Ledig and Kitzmiller 1992), but seed collection efforts will need to factor this into their budgets (Vitt and others 2010).

Research Needs

To make informed decisions about implementation, we need a central, standardized database of species-specific genetic, ecological, and geographic information. Databases listed in Table 1 can serve as templates for non-commercial species, but we need to solicit and organize existing data in order to identify gaps. Discussion and evaluation of complementary actions, such as ecosystem engineering (for example using drastically disturbed areas as sites to test assisted migration) and increasing landscape connectivity (for example reduce fragmentation) are also warranted (Jones and Monaco 2009; Lawler and Olden 2011).

Dynamic seed transfer zones and guidelines are also needed. Transfer guidelines based on geographic boundaries and provisional zones may not be suitable, especially in regions without supporting genetic and climatic information (Mahalovich 1995). This was demonstrated, for example, by blue wildrye, where supporting common garden information showed that seed zones based solely on ecoregions mapped the species' adaptive variation poorly (Erickson and others 2004). Climate-based seed transfer guidelines should overcome these restrictions (Rehfeldt 2004), but the guidelines need to factor in future climate conditions – a major challenge for nursery and land managers given uncertainty about which climate to prepare for (Park and Talbot 2012; Potter and Hargrove 2012). This is especially true for long-lived species and populations that take several decades to reach reproductive maturity and become adapted through evolution to a new climate (Potter and Hargrove 2012). Park and Talbot (2012) suggest that managers prepare for all future climate scenarios. This might entail small-scale experiments, such as, planting fast-growing trees adapted to projected climate in the next 15 to 30 years (Park and Talbot 2012) or randomly planting a variety of seed sources in one area and monitoring their adaptive response (similar to provenance testing) (Pedlar and others 2011).

Not only must one factor in performance of delineating seed zones and transfer guidelines but also cost. Cost increases with an increase in the number of seed zones in terms of seed and nursery productions (stock, storage, and delivery), administrative regulations, and record keeping (Lindgren and Ying 2000). The biological, operational, and administrative tradeoffs are vital considerations in transfer guideline development for future climate scenarios.

Conclusion

Regardless of the debate on assisted migration, we have little time to act given current climate change predictions and restricted ability of plants to adapt or migrate rapidly on their own. Framing the discussion to identify objectives and produce frameworks that lead to strategies is pertinent (McLachlan and others 2007; Lawler and Olden 2011; Park and Talbot 2012). Ultimately our capacity to implement projects will be limited by cost, location, and time (Park and Talbot 2012), but recognizing and synthesizing what we already know about plant adaptation and climate change is a necessary start.

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