

Planning the Future's Forests with Assisted Migration

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***Abstract:** Studies show that changes in climate may exceed plant adaptation and migration. The mismatch in rates between climate change and plant adaptation and migration will pose significant challenges for practitioners that select, grow, and outplant native tree species. Native tree species and populations that are planted today must meet the climatic challenges that they will face during this century. Anticipated shifts in climate call for the revision of ethical, legal, political, and economical paradigms, as well as changes in the guidelines for growing and outplanting trees to maximize survival and curtail maladaptation. Growing trees that survive may be more important than growing perfectly shaped trees and may require selection of adapted genetic material and/or movement of plant populations (for example, assisted migration). We review and explore assisted migration as an adaptation strategy, present some working examples, and provide resources for consultation.*

INTRODUCTION

If the climate changes faster than the adaptation or migration capability of plants (Zhu and others 2012; Gray and Hamann 2013), foresters and other land managers will face an overwhelming challenge. Growing trees that survive may become more important than growing perfectly formed trees (Hebda 2008) and may require selection of adapted plant materials and/or assisting the migration of plant populations (Peters and Darling 1985). Agencies, land managers, and foresters are being advised to acknowledge climate change in their operations, but current client demands, policies, and uncertainty about climate change predictions and impacts constrain active measures (Tepe and Meretsky 2011). For example, the practice of restricting native plant movement to environments similar to their source has a long history in forest management (Langlet 1971), however, transfers must now factor in climate change because plant materials guided by current guidelines and zones will likely face unfavorable climate conditions by the end of this century.



To facilitate adaptation and migration, we will need to rethink the selection, nursery production, and outplanting of native trees in a dynamic context, such as modifying seed transfer guidelines in the direction of climatic change to suit target species and populations. A challenge 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, strategies such as assisted migration (also referenced as assisted colonization and managed relocation) have been proposed in adaptive management plans (for example, USDA Forest Service 2008), but without specific guidance. In this article, we summarize the main mechanics of assisted migration, discuss the societal issues, and present some working examples with resources to help generate dynamic guidelines.

MECHANICS OF ASSISTED MIGRATION

Foresters have been moving tree species and populations for a very long time. Usually, these movements are small and properly implemented by using seed transfer guidelines. Occasionally, these movements are drastic and intercontinental to support commercial forestry (for example, exporting Monterey pine [*Pinus radiata*] from the United States to New Zealand). The concept of assisted migration, first proposed by Peters and Darling (1985), builds on this forestry legacy of moving species and populations, but deliberately includes management actions to mitigate changes in climate (figure 1) (Vitt and others 2010). This does not necessarily mean moving plants far distances, but rather moving genotypes, seed sources, and tree populations to areas with predicted suitable climatic conditions with the goal of avoiding maladaptation (Williams and Dumroese 2013). How far we move plant materials to facilitate migration will depend on the target species and populations, location, projected climatic conditions, and time. For a species or population, this may require target distances across current seed-zone boundaries or beyond transfer guidelines (Ledig and Kitzmiller 1992). Target migration distance is the distance that populations could be moved to address future climate change and foster adaptation throughout a tree's lifetime (O'Neill and others 2008). Target migration distance can be geographic (for example, distance along an elevation gradient), climatic (for example, change in number of frost-free days along the same elevation gradient), and/or temporal (for example, date when the current climate of the migrated population equals the future climate of the outplanting site). Instead, evaluating species that might naturally migrate is an option. For example, Alberta, Canada is considering ponderosa pine (*P. ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*), now absent in the province but occurring proximate to the province, as replacements for lodgepole pine (*P. contorta*) because it is predicted to decline in productivity or become extirpated under climate change (Pedlar and others 2011).

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). As an adaptation strategy, assisted migration could be used to prevent species extinction, minimize economic loss (for example, timber production), and sustain ecosystem services (for example, wildlife habitat, recreation, and water and air quality) (figure 1) (Aubin and others 2011). Assisted migration may be warranted if a species is at high risk of extinction or if loss of the species would create economic or ecosystem loss, establishes easily, and provides more benefits than costs (Hoegh-Guldberg and others 2008). Reducing fragmentation, increasing landscape connections, collecting and storing seed, and creating suitable habitats are all viable options (depending on

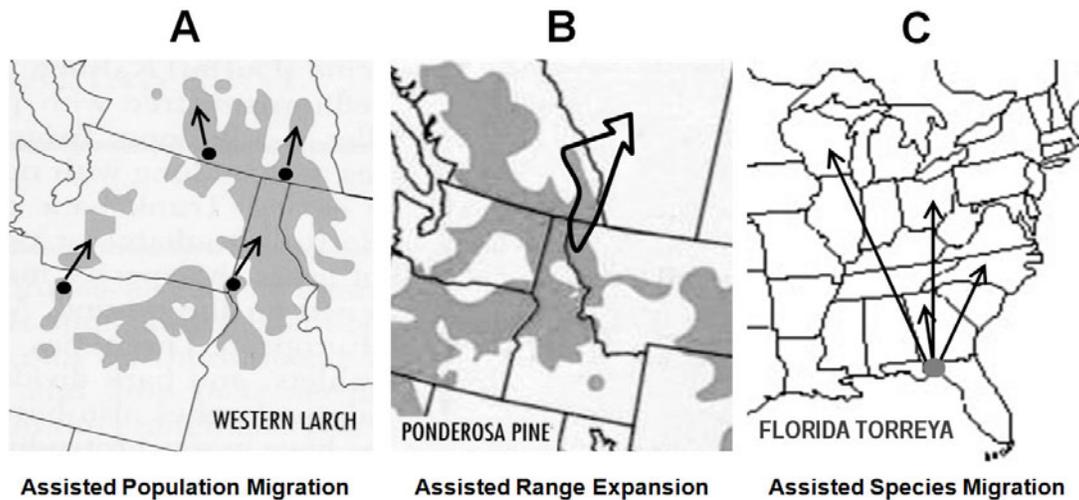


Figure 1. Assisted migration can occur as assisted population migration where seed sources are moved climatically or geographically within their current ranges, even across seed transfer zones (A). For example, moving western larch (*Larix occidentalis*) 200 km north within its current range. Seed sources can also be moved climatically or geographically from current ranges to suitable areas just outside to facilitate range expansion (B), such as moving seed sources of ponderosa pine (*Pinus ponderosa*) into Alberta, Canada, hypothetically. In an assisted species migration (or assisted long-distance migration) effort (C), species are moved far outside current ranges to prevent extinction, such as planting Florida torreya (*Torreya taxifolia*) in states north of Florida. Distribution ranges are shaded gray; terms from Ste-Marie and others 2011; Winder and others 2011; Williams and Dumroese 2013 and distribution maps from Petrides and Petrides 1998; Torreya Guardians 2008.

the species and population) to facilitate adaptation and migration. Some species may migrate in concert with climate change, thus conserving and increasing landscape connections should take precedence over other management actions. Other species may adapt to changes in climate, while other species may have limited adaptation and migration capacities. Assisted migration needs to be implemented within an adaptive management framework, one that assesses species vulnerability to climate change, sets priorities, selects options and management targets, and emphasizes long-term monitoring and management adjustments as needed.

Frameworks, tools, and guidelines on implementation (table 1) (Beardmore and Winder 2011; Pedlar and others 2011; Williams and Dumroese 2013) have been introduced to make informed decisions about climate change adaptation strategies. Programs such as the Climate Change Tree Atlas (Prasad and others 2007), Forest Tree Genetic Risk Assessment System (ForGRAS; Devine and others 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). Listing species as suitable candidates—those with limited adaptation and migration capacity—is a practical first step, 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. The Center for Forest Provenance Data provides an online database of tree provenance data (St. Clair and others 2013).

Table 1. Resources related to forest management, 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 2013.

Resource or Program	Description	Authorship
Assisted Migration Adaptation Trial http://www.for.gov.bc.ca/hre/for/gen/interior/AMAT.htm	Large, long-term project to evaluate the response of 15 tree species to climate change and assisted migration	Ministry of Forest and Range, BC
Center for Forest Provenance Data http://cenfor.gen.forestry.oregonstate.edu/index.php	Public users are able to submit and retrieve tree provenance and genealogical data	Oregon State University and USDA Forest Service
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	The University of British Columbia
Climate Change Response Framework http://climateframework.org/	Collaborative framework among scientists, managers, and landowners to incorporate climate change into management	Northern Institute of Applied Climate Science
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; includes seed zone maps	Forest Seedling Network
Forest Tree Genetic Risk Assessment System (ForGRAS) http://www.forestthreats.org/research/projects/project-summaries/assessing-forest-tree-risk	Tool to identify tree species risk of genetic degradation in the Pacific Northwest and Southeast	North Carolina State University and USDA Forest Service
MaxEnt (Maximum Entropy) www.cs.princeton.edu/~schapire/maxent/	Software that uses species occurrences and environmental and climate data to map potential habitat; can be used to develop seed collection areas	Phillips and others (2006)
Native Seed Network http://www.nativeseednetwork.org/	Interactive database of native plant and seed information and 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 outplanting sites based on current climate or future climate change scenarios; maps current or future climates defined by temperature and precipitation	Oregon State University and USDA Forest Service
SeedWhere https://gfc.cfsnet.nfis.org/mapserver/seedwhere/seedwhere-about.php?lang=en	GIS tool to assist nursery stock and seed transfer decisions for forest restoration projects in Canada and the Great Lakes region; can identify geographic similarities between seed sources and outplanting sites	Natural Resources Canada, Canadian Forest Service
System for Assessing Species Vulnerability (SAVS) www.fs.fed.us/rm/grassland-shrubland-desert/products/species-vulnerability/	Software that identifies the relative vulnerability or resilience of vertebrate species to climate change; provides a framework for integrating new information into climate change assessments	USDA Forest Service

Bioclimatic models coupled with genetic information from provenance tests and common garden studies in a GIS can be used to identify current and projected distributions (for example, Rehfeldt and Jaquish 2010; McLane and Aitken 2012; Notaro and others 2012). These forecasts can assist land managers in their long-term management plans, such as, where to collect seeds and plants. Although modeled projections have some uncertainty in future climate predictions and tree responses (Park and Talbot 2012), they provide an indication of how climatic conditions will change for a particular site.

ECOLOGICAL, ETHICAL, AND LOGISTICAL ISSUES

The movement of species in response to climate change does not come without economical, ecological, ethical, and political issues (Schwartz and others 2012). Assisted migration is a sensitive strategy because it disrupts widely held conservation objectives and paradigms (McLachlan and others 2007). Adoption requires us to balance conservation of species against risks posed by introduced species (Schwartz 1994). Current natural resource management plans were not written within the context of climate change, let alone rapid changes in climate. The U.S. Forest Service anticipates using assisted migration of species to suitable habitats to facilitate adaptation to climate change (USDA Forest Service 2008). But, these management statements imply that assisted migration should only be implemented in cases where past research supports success (Erickson and others 2012; Johnson and others 2013). Assisted migration is essentially incompatible with existing U.S. state and federal land management frameworks (Camacho 2013). For example, in current tree-improvement programs in the United States, seed transfer guidelines and zones are used to determine the safest distance that a population can be moved to avoid maladaptation (Johnson and others 2004). For most jurisdictions in the United States, the guidelines and zones prohibit the movement of seed sources between and among zones. As they currently stand, seed transfer policies do not account for changes in climate, even though research has identified that suitable habitat for some important commercial tree species will shift north and to higher elevations during this century (Aitken and others 2008; Rehfeldt and Jaquish 2010). The existing policies hamper any formal actions and may encourage more privately-funded operations, such as the Florida torreyia (*Torreya taxifolia*) project in southeastern United States. Since 2008, it has been planted on private lands in five southern states in an effort to curtail extinction (Torreyia Guardians 2012).

Even so, the debate about its implementation is largely focused on an ecological assessment of risks and benefits (see Ricciardi and Simberloff 2009; Aubin and others 2011; Hewitt and others 2011; Lawler and Olden 2011). We cannot reliably predict future climates so it is difficult to know which or how ecosystems will be affected. We have limited knowledge about establishing native plants outside their range in anticipation of different climate conditions let alone the impact of climate change on ecosystem properties important to the survival and growth of trees (for example, photoperiod, soil conditions, and pollinators). 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). Uncertainty about future climate conditions and risks, such as genetic pollution, hybridization, impairment of ecological function and structure, introduction of pathogens, and bringing on invasive species are major constraints to consensus and implementation (Gunn and others 2009; Aubin and others 2011).

Economic costs and ecological risks will vary across assisted migration efforts (figure 1) and likely increase with migration distance (Mueller and Hellmann 2008; Vitt and others 2010; Pedlar and others 2012). Establishment failure could occur if the species or population is moved before the outplanting site is climatically suitable or if the seed source is incorrectly matched with the outplanting site in a projected area (Vitt and others 2010). Assisted migration to areas far outside a species current range would carry greater costs, management responsibilities, and ecological risks than assisted population migration and assisted range expansion (Winder and others 2011). Principle to reforestation success is using locally adapted plant materials, so the greater the difference between seed origin and outplanting site the greater the risk in maladaptation. An increase in distance (either geographic or climatic) is usually, but not always, associated with loss in productivity, decrease in fitness, or mortality (Rehfeldt 1983; Campbell 1986; Lindgren and Ying 2000).

Forest tree species are highlighted most often in the assisted migration literature because of their economic value and focus in climate change research, however, assisted migration conducted for economic rather than conservation reasons is cited as another major barrier to implementation, meaning that economic benefit may be an insufficient justification (Hewitt et al. 2011). On the contrary, the forestry profession is well suited to evaluate, test, and employ an assisted migration strategy given its long tradition of research, development, and application of moving genetic resources through silvicultural operations (Beaulieu and Rainville 2005; Anderson and Chmura 2009; McKenney and others 2009; Winder and others 2011). For commercial forestry, assisted migration could address health and productivity in the coming decades (Gray and others 2011) because operational frameworks already exist.

ASSISTED MIGRATION IN ACTION

Forest management policy drafts to allow assisted migration and trials of assisted migration are currently underway in North America. The Assisted Migration Adaptation Trial (AMAT) is a large collection of long-term experiments undertaken by the British Columbia (BC) Ministry of Forests (Canada) and several collaborators, including the U.S. Forest Service and timber companies, that tests assisted migration and climate warming (Marris 2009). The program evaluates the adaptive performance of 15 tree species collected from a range of sources in BC, Washington, Oregon, and Idaho and planted on a variety of sites in BC. Important components of the trial 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. For decades in the southeastern United States, some southern pine seed sources have been moved one seed zone north to increase growth (Schmidting 2001). Similarly, Douglas-fir has been planted around the Pacific Northwest to evaluate their growth response to climatic variation (Erickson and others 2012). The only known assisted species migration project in the United States is a grassroots initiative to save the Florida torreyia, a southeastern evergreen conifer, from extinction by planting it outside its current and historic range (McLachlan and others 2007; Barlow 2011). The project has prompted the U.S. Fish and Wildlife Service to consider assisted migration as a management option for this species (Torreyia Guardians 2012).

Assisted migration will be best implemented where seed transfer guidelines and zones are currently in place and most successful if based on climate conditions (McKenney and others 2009). Provenance data, seed transfer guidelines, and seed zones can be used to facilitate the adaptation

of trees being established today to future climates of tomorrow (Pedlar and others 2012). In Canada, several provinces have modified policies or developed tools to enable assisted migration. Seed transfer guidelines for Alberta were revised to extend current guidelines northward by 2° latitude and upslope by 656 ft (200 m) (NRC 2013) and guidelines for some species were revised upslope by 656 ft (200 m) in BC (O'Neill and others 2008). Policy in BC also allows the movement of western larch (*Larix occidentalis*) to suitable climatic locations just outside its current range (NRC 2013). To test species range limits in Quebec some sites are being planted with a mixture of seed sources from the southern portion of the province. Canada and the United States have tools to assist forest managers and researchers in making decisions about seed transfer and matching seedlots with outplanting sites (for example, Optisource [Beaulieu 2009] and BioSim [Regniere and Saint-Amant 2008] in Quebec, Seedwhere in Ontario [McKenney and others 1999], and the Seedlot Selection Tool in the United States [Howe and others 2009]). Seedwhere can map out potential seed collection or outplanting sites based on climatic similarity of chosen sites to a region of interest. The Seedlot Selection Tool is a mapping tool that matches seedlots with outplanting sites based on current or future climates for tree species such as Douglas-fir and ponderosa pine.

Target migration distances must be short enough to allow survival, but long enough to foster adaptation toward the end of a rotation, or lifespan of a tree plantation (McKenney and others 2009). Preliminary work in Canada on most commercial tree species demonstrates that target migration distances for populations would be short, occurring within current ranges (O'Neill and others 2008; Gray and others 2011). For some tree species, target migration distances are < 125 miles (< 200 km) north or < 328 ft (< 100 m) up in elevation during the next 20 to 50 y (Beaulieu and Rainville 2005; O'Neill and others 2008; Pedlar and others 2012; Gray and Hamann 2013). Target migration distances are needed for short and long-term planning efforts and will require adjustments as new climate change information comes to light. Methods using transfer functions and provenance data have been developed to guide seed movement under climate change (for example, Beaulieu and Rainville 2005; Wang and others 2006; Crowe and Parker 2008, Thomson and others 2010; and Ukrainetz and others 2011). Bioclimatic models mapping current and projected seed zones have been assessed for aspen (*Populus tremuloides*) (Gray and others 2011); lodgepole (Wang and others 2006), longleaf (*P. palustris*) (Potter and Hargrove 2012) and whitebark (McLane and Aitken 2012) pines; dogwood (*Cornus florida*) (Potter and Hargrove 2012); and western larch (Rehfeldt and Jaquish 2010).

The lack of genetic, provenance, and performance data on which seed transfer guidelines and zones are based impede making informed decisions about assisted migration for non-commercial species. At best we can consult provisional seed zones (for example, Seed Zone Mapper - table 1) developed from temperature and precipitation data and Omernik level III and IV ecoregion boundaries (Omernik 1987). Furthermore, we can shift the focus to producing plant materials that grow and survive by modifying past and current projects and implementing studies and strategies. Many existing projects, such as provenance and common garden studies can be transformed with little modification to look at adaptation and response to climatic conditions (Matyas 1994). Information such as where the plant comes from, where it is planted on the site, and how it performs (growth, survival, reproduction, and so on) can guide forestry practices to increase the proportion of species that survive and grow well (McKay and others 2005; Millar and others 2007; Hebda 2008).

CLOSING REMARKS

Climate change poses a significant challenge for foresters and other land managers, but given its long history of selecting and growing trees, the forestry profession has the knowledge and tools to test and instigate assisted migration; we need dynamic policies that allow action. The frameworks and techniques for production and outplanting already exist, therefore researchers and practitioners can work with nurseries to design and implement adaptive measures that consider assisted migration and hopefully curtail significant social, economic, and ecological losses associated with impacts from a rapidly changing climate. The science and practice of growing trees to sustain ecosystems will greatly benefit with collaboration (McKay and others 2005). The Adaptive Silviculture for Climate Change (Linda Nagel, project lead) is one such collaborative effort in the United States that focuses on the understanding of long-term ecosystem response to adaptation options and to help forest managers integrate climate change into silviculture planning (Northern Institute of Applied Climate Science, table 1). Framing the discussion to identify objectives and produce frameworks, such as the Climate Change Response Framework, that lead to practical and dynamic strategies is pertinent. Changing policies will require collaboration and discussion of how predicted conditions will affect forests, how managers can plan for the future, and how landowners can be encouraged to plant trees adapted to future conditions, such as warmer conditions and variable precipitation patterns (Tepe and Meretsky 2011).

Assisted migration may not be appropriate for every species or population. Whatever the chosen adaptive strategies, foresters need to be included in the dialogue with scientists and land managers in climate change planning. We have little time to act given current climate change predictions and uncertainty regarding the adaptation and migration capacities of species and populations. Establishment of healthy stands is vital now to prepare forests as changes occur. 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). Planting the standard species or stocks in regions highly sensitive to climate change will be unwarranted (Hebda 2008), given that reductions in fire frequency from 100 to 300 y to 30 y have the potential to quickly shift some forest systems to grasslands and woodlands (Westerling and others 2011). Instead, we need to shift our focus to plant species adapted to the novel conditions and/or those anticipated to migrate into these areas. Implementation of complementary actions, such as ecosystem engineering (for example, using drastically disturbed areas as sites to test assisted migration), increasing landscape connectivity, emphasizing genetic diversity in seed source collections, targeting adaptive traits, and focusing on ecosystem function and resilience rather than a historical reference are also necessary considerations for any climate change strategy (Jones and Monaco 2009; Lawler and Olden 2011; Stanturf and others, in press).

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