Assisted Migration Best Management Practices for Pacific Northwest Habitat Restoration Projects

Brenda C. Clifton
Skagit River System Cooperative
bclifton@skagitcoop.org

Dee Dee Korsikas-Fogg
Pierce County Parks
deidre.korsikas-fogg@piercecountywa.gov

Kathleen Farley Wolf
King County
kfarleywolf@kingcounty.gov

Michael Yadrick
City of Tacoma
myadrick@cityoftacoma.org

Rachel Gregg
Environmental Service Associates
rgregg@esassoc.com

Rolf Gersonde
City of Seattle
rolfgersonde@gmail.com

Rowan Braybrook
Northwest Natural Resource Group
rowan@nnrg.org

October 11, 2024

Produced by a subcommittee of the
Forest Adaptation Network
Northwest Natural Resource Group
2701 1st Ave, Seattle, WA 98121

Introduction

In the last century, average temperatures have risen in the Pacific Northwest and models predict additional increases over the next decades. The Office of the Washington State Climatologist (2024) recorded a 3.3 °F increase in Washington and a 3.6 °F increase in Oregon since 1924. The University of California MERCED Climatology Lab's Multivariate Adapted Constructed Analog Future Time Series Tool (2024) modeled an average summer temperature increase of 2.4 °F for a low greenhouse gas scenario and 3.7°F for a high greenhouse gas scenario in Washington by 2040 and 2.3 °F for a low greenhouse gas scenario and 2.9°F for a high greenhouse gas scenario in Oregon. Precipitation is predicted to increase overall but decrease during the summer. Reduced snowpacks that melt earlier will reduce summer stream flows and increase the frequency and severity of floods and droughts. The soil moisture available on July 1 will decline throughout the North Cascades by up to 35 percent by the 2040s (Elsner et al. 2010). Increased evaporation and transpiration, with decreased soil moisture, will reduce forest species' growth, vigor, and survivorship (Raymond et al. 2022). Increased wildfires and insect outbreaks will alter forest structure and composition (Halofsky 2020; Agne 2018; Flannigan et al. 2000).

If climate change proceeds as predicted, plants will suffer negative consequences to biological processes (V´azquez et al. 2017). Extreme temperatures and droughts are already harming Pacific Northwest species such as bigleaf maple (*Acer macrophyllum*), western red cedar (*Thuja plicata*), and Douglas-fir (*Pseudotsuga menziesii)* (Betzen et al. 2021; Goodrich et al. 2023). The severity of climate change, the ability of individual plants to acclimate, the ability of plant populations to respond to new conditions, and the ability of plants to migrate to better conditions will determine how these stressors affect restoration plantings. Plants have adapted genetic variations in response to climate, which shape phenology, morphology, and growth (Anderson and Song 2020). Plants can migrate in response to changing climate, but models suggest that many species will be unable to migrate fast enough to keep up with future climate change (Williams and Dumroese 2013).

We developed this document to provide guidance on the use of assisted migration to the Northwest Natural Resource Group's Forest Adaptation Network, whose members share information on forest adaptation in the Pacific Northwest. Forest Adaptation Network members restore habitat in uplands, floodplains, wetlands, riparian areas, and groundwater-dependent systems, both inside and outside of urban areas. This document focuses on Pacific Northwest trees and shrub species, which are the species most used by the members of the Forest Adaptation Network (NRGG 2022). For information on nonwoody species see Rogers et al. (2024), Bucharova et al. (2019), Bower et al. (2014), Breed et al. (2012), Saltonstall (2002), and Keller et al. (2000), among others.

A recent Forest Adaptation Network survey identified that 95 percent of the members are open to using plant materials of non-local origin (NNRG 2022). Forest Adaptation Network members are moving populations of species within their existing range (e.g. planting Willamette Valley Oregon Douglas-fir in the Washington Puget Sound), moving species just outside of their natural range (planting Washington Coast seaside juniper [*Juniperus scopulorum*] in the Cascade Mountain foothills), and moving species far outside of their natural range (planting Eastern Washington Ponderosa pine [*Pinus ponderosa*], Oregon incense cedar [*Calocedrus decurrens*], and California giant sequoia [*Sequoiadendron giganteum*] in Western Washington). Many practitioners have reservations about the consequences of this practice, yet there are few clear guidelines. The Forest Adaptation Network convened a subcommittee to develop best management practices for assisted migration to support practitioners and address concerns.

Types of Assisted Migration

Handler et al. (2018) defines assisted migration as the "human-assisted movement of species in response to climate change". Within the broader category there are several actions (Figure 1).

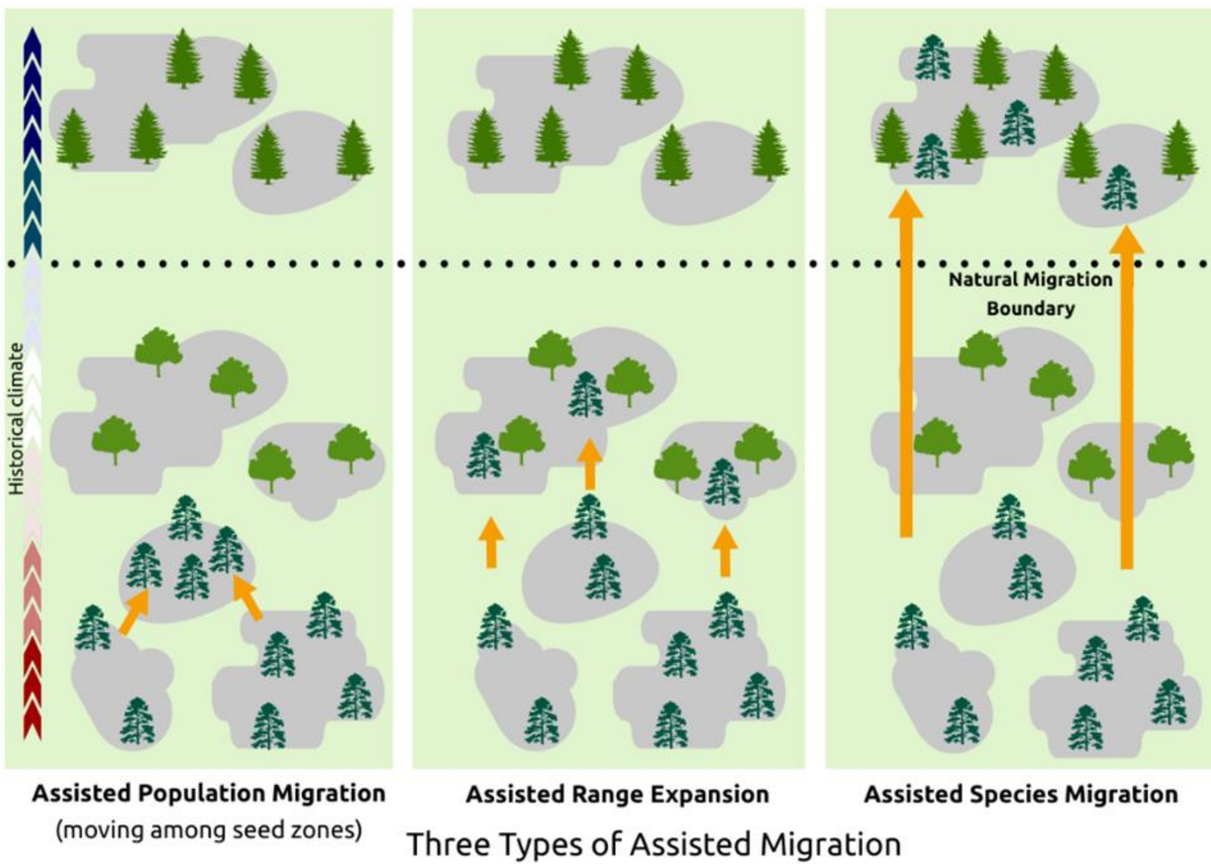

Figure 1. Graphic representation of the three types of assisted migration. The gray areas are different seed zones, and orange arrows represent movement of plants from one seed zone or population to a new location. The historical climate shows the movement of plant material from warmer climates to historically cooler climates. Graphic from USDA Northwest Climate Hub 2024.

Assisted population migration

Assisted population migration involves moving seed sources or populations to new locations that represent a different seed zone within the current natural species range. As indicated in Figure 1, movement occurs within distinct seed zones (gray areas). For example, planting Douglas-fir and western red cedar seedlings grown from northwest Oregon seed in a post-wildfire forest regeneration project on the Gifford Pinchot National Forest outside of Randle, Washington.

Assisted range expansion

Assisted range expansion involves moving seed sources or populations from their current natural species range to suitable areas just outside the current natural species range, aiding autonomous dispersal. For example, planting ponderosa pine from Willamette Valley, Oregon at a restoration site on Clark County land in southwestern Washington.

Assisted species migration

Assisted species migration involves moving seed sources or populations to a location far outside the current natural species range to locations that would otherwise be unattainable by autonomous dispersal. This intentional movement by humans overcomes the natural migration boundary that is indicated in Figure 1. For example, planting coast redwood (*Sequoia sempervirens*) in a park in King County, Washington.

There are also climate adaptation strategies that avoid assisted migration.

No assisted migration, self-adaptation

Self-adaptation allows an ecosystem to change without intervention. For example, taking no action in a high severity burned area in the Stephen Mather Wilderness Area, North Cascades National Park, Washington.

Increased species diversity

Erickson et al. (2012) suggest placing an increased emphasis on genetic diversity as a “no regrets” approach. This involves using locally sourced native species and current seed zones with propagules collected throughout the zone to facilitate climate adaptation. For example, planting drought tolerant black cottonwood (*Populus trichocarpa*) sourced from alluvial soils throughout the watershed on The Nature Conservancy lands in southwest Washington.

Assisted Migration Approaches

Species Rescue Perspective

One approach is Species Rescue Assisted Migration, the migration of a target population at risk of extinction from climate change to a more suitable habitat (Iverson et al. 2013). Species Rescue is appropriate when the target species lacks invasive life history traits, has little potential to migrate across natural or man-made barriers, has little ability to adapt, an/or possesses a small population size.

Ecosystem Services Perspective

Ecosystem Service Assisted Migration aims to maintain or restore the ecosystem function at a target site or landscape (Iverson et al. 2013). The approach adds to or replaces species or genotypes at risk from climate change with others that are better adapted to future climates. This type of assisted migration aims to sustain the parts and functions of the existing ecosystem.

Risks Associated with Assisted Migration

Assisted migration without a science-based approach may result in unexpected impacts, but there are few published empirical studies. Support for assisted migration is based on ample evidence that plants are adapted to local environmental conditions (Bowman et al. 2008; Leimu and Fischer 2008; Jakobsson and Dinnetz 2005; Kawecki and Ebert 2004; Gandon and Michalakis 2002; among others), evidence of decline in local species in response to changing environmental conditions (Betzen et al. 2021; Goodrich et al. 2023), and models of future climates and species migration (MACA 2024; Mote and Salanthé 2010; Elsner et al. 2010; Littell et al. 2011). But we have little data on the performance of translocated plants under climate change conditions across different species and life history types and on the biotic interactions with, for example, existing flora, pests, pollinators, fauna, and below ground organisms (Benomar et al. 2022). Two published studies that show physiological differences between coastal and interior populations of western red cedar to experimental climate change conditions are Grossnickle and Russell (2010) and Grossnickle et al. (2005). The Stossel Creek project is also monitoring several species of plants translocated from Oregon and California to the Cedar Creek watershed in Washington, but the experiment is still young. Practitioners will need to determine if there is sufficient information available to decide whether the benefits associated with assisted migration outweigh the risks.

Incorporating species or populations from outside of the planting region could result in poor survival and reduce the success of a restoration project. Traditionally, restoration practitioners used locally adapted seed to ensure better survival and growth and reduce the risk of maladaptation to site conditions (Broadhurst et al. 2008). The forestry community in the Pacific Northwest defined seed zones in the 1960’s because of large differences noticed in growth and survival of various seed sources within the range of native species, such as Douglas-fir (Randall and Berrang 2002). Provenance tests within species showed a large amount of genetic variation in traits that impact fitness, such as leaf morphology, cold hardiness, frost tolerance, and phenology.

Assisted migration may also result in the introduction of invasive plant genotypes, plant species, and pests or pathogens, causing high economic and ecological costs. These may result from the invasion potential of translocated species and/or hitchhiker organisms (moving seeds, seedlings, or associated soils that transport microbiomes). Introduced genotypes may also have low resistance to local insects and pathogens. Numerous novel diseases have emerged through other translocation activities because of an introduced pathogen, an altered or new host, and/or altered climatic conditions, for example chestnut blight (*Cryphonectria parasitica*), sudden oak death (*Phytopthora ramorum*), Swiss needle cast of Douglas fir (*Nothophaeocryptopus gaeumannii*), Eucalypt rust (*Puccinia psidii*), and Dothistroma needle blight of lodgepole pine (*D. septosporumi*) (Simler et al. 2019).

There is a risk of altering genetics when genotypes are introduced into an area where the species already exists (Ste-Marie et al. 2011; Saltonstall 2002). The relocated genotype may have low diversity if the seeds are collected from a limited number of sources and the translocated individuals represent a small portion of the source populations (Keller et al. 2000). Hybridization with the local genotype could reduce the diversity of the local population. But it could also improve the gene pool and increase genetic diversity if practitioners use diverse populations with genes that are well-adapted to future conditions.

A restoration site may lack community structure after translocating species without matching understory species. Similarly, a migrated species may be unable to fill the ecological niche of local species by serving the native wildlife population and pollinators (Keith 2017). The action may also have a socio-economic impact if there are negative effects on commercial or cultural species.

The above risks must be weighed against the risk of doing nothing (Dumroese et al. 2015). Higher temperatures, changing rain patterns, and extreme weather events are threatening habitats, and native plants may be unable to adapt to changing conditions or migrate quickly enough, putting species and ecosystems at risk of extirpation. Climate change favors some insects and diseases by increasing pest abundance and plant stress, while decreasing defense mechanisms. It also increases natural disturbances, such as fires and floods, and extreme weather events, such as heat domes and droughts, leaving some landscapes stressed and at risk of high mortality. Physical barriers may also limit migration. Some vulnerable species reproduce slowly and/or require specific habitats (Handler et al. 2018).

The types of assisted migration differ in levels of risk, ecological impacts, and ethical considerations (Table 1). We assigned risk levels to each action based on their geographical scale as risk is directly proportional to the distance plants are transported from their historical ranges (Sansilvestri et al. 2015). Practitioners should weigh the risks and benefits for themselves based on the scientific knowledge of individual species and restoration sites. Climate adaptation strategies without assisted migration appear to present no risk since there is no movement of species or genotypes. However, climate change is outpacing many species' autonomous dispersal rates, presenting a risk in taking no action.

Table 1. Levels of risk associated with climate adaptation strategies with and without assisted migration.

Strategy	Risk Level
Assisted population migration	Low risk
Assisted range expansion	Medium to high risk
Assisted species migration	High risk
No assisted migration, self-adaptation	Medium to high risk
Increased species diversity	Low risk

Assisted Migration Decision Framework

We developed a decision framework to help restoration practitioners determine whether to use assisted migration, and in what form, by reviewing existing resources (Figure 2). Practitioners should use the framework as a guideline and follow it to completion even if some information is unavailable. We divided the framework into Species Rescue and Ecosystem Services Assisted Migration but most of the steps are the same. If at any step assisted migration is deemed inappropriate, the practitioner should opt for one of the no assisted migration options presented above.

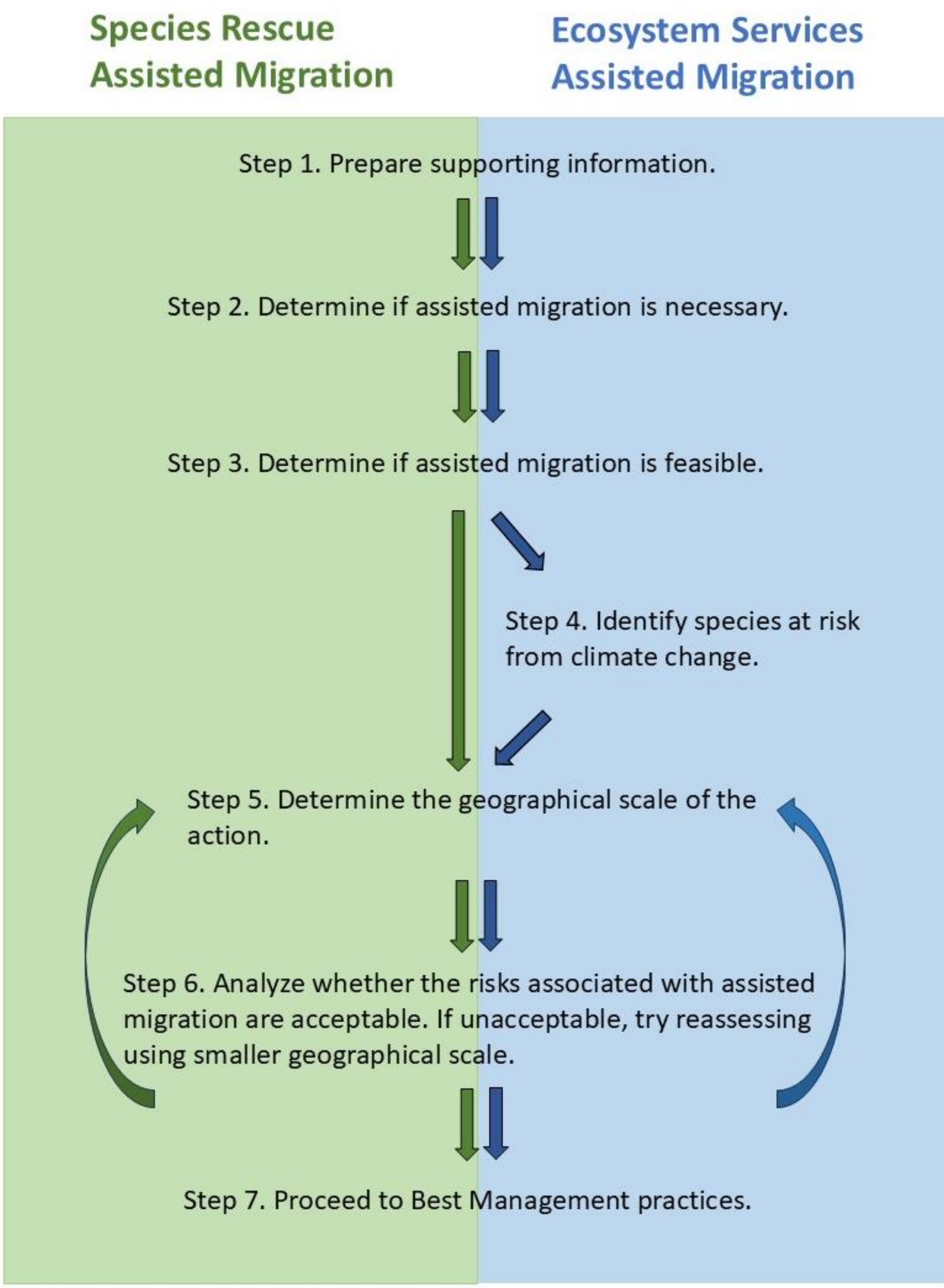

Figure 2. Assisted migration decision tree for restoration practitioners.

Defining the intent for assisted migration is the first step in preparing for the decision framework. Practitioners should identify if project goals are based on Ecosystem Services or Species Rescue Assisted Migration (Iverson et al. 2013). Ecosystem Services Assisted Migration tends to move plants within or just beyond the current natural species range, whereas Species Rescue may move plants far outside the historical species range. Other assisted migration goals may include increasing the productivity of a commercial species, managing urban forests, or creating resilience to change in degraded or fragmented landscapes. Assisted migration goals are unique to each land manager and must be addressed within the context of the restoration goal.

Any decision about assisted migration will depend on the goals of the organization or agency leading the work. These decisions evaluate ethical, ecological, legal, policy, and institutional questions. Key considerations can be found in Iverson et al. (2013), Karasov-Olson et al. (2021), and Turner et al. (2021).

Step 1. Prepare supporting information.

Ethical considerations for any assisted migration proposal should articulate why restoration goals are valued and evaluate how they compare to other goals set forth by the organization or agency. This should include a clear understanding of how the goals of assisted migration fit within this broader context, including that of cultural resources. Practitioners have the ethical responsibility to prevent irreversible effects from assisted migration (Schwartz et al. 2012). We recommend that any project begin by collecting input from within the organization or agency and from external stakeholders, including local tribes, regarding:

- Whether target ecosystems should be actively managed so that the current condition persists, or whether they should be managed to attempt to increase their resilience under future conditions (Iverson et al. 2013).
- What constitutes an acceptable risk of harm.
- Which species are culturally important and the risks or benefits that could arise from assisted migration. Practitioners can draw information from published resources (see Gunther 1945 for Western Washington) and local tribes.
- Whether to introduce species from outside the region that could have potential cultural value. Turner et al. (2021) noted the "widespread and long-standing extent of plant translocation practices among Indigenous Peoples of northwestern North America," and documented many of the food, material, medicinal, spiritual, and other uses of translocated plants.

In addition to the broad questions above, there are more specific ecological issues that should be considered prior to making any decision about assisted migration. We recommend collecting information on:

- Priority species and ecosystem functions for which assisted migration could be considered.
- Low risk alternatives to assisted migration (e.g. improving habitat connectivity).
- The probability of assisted migration success for the priority species.
- The negative impacts of relocated species on local species or ecosystem functions.

Finally, there are considerations that vary from one organization to another that determine whether assisted migration is advisable and feasible. Based on Schwartz et al. (2012), we recommend collecting information on:

- Organizational policies on how climate change adaptation should be approached.
- Organizational or governmental policies, if any, that indicate whether assisted migration is permitted or what factors should be considered in making assisted migration decisions.
- Who has the authority, staff, and funding to initiate assisted migration.
- Who has the authority, staff, and funding to monitor outcomes of assisted migration.

Climate and species migration models can aid in decision making. Several studies model potential changes to the existing habitat (see Peterson 2021; Hudec et al. 2019; Littell et al. 2011; Littell et al. 2014; Raymond et al. 2014; Rybczyk et al. 2019). Others model future suitable habitat for key species in the ecosystem (see Coops et al. 2011; Coops et al. 2016; Weiskittel 2012) allowing land managers to identify impediments to natural migration.

Step 2. Determine if assisted migration is necessary.

Determine whether the target species or ecosystem has experienced a decrease in plant health and survival, has exhibited changes in composition, has moved geographically, or has any other known negative effects from climate change. There may be certainty on damages to species, clear evidence of environmental risk (environmental degradation, population reduction, habitat fragmentation, etc.), or ecological modeling that suggests negative future climate impacts.

Step 3. Determine if assisted migration is feasible.

There are numerous considerations to weigh when determining if assisted migration is feasible for your project. Unfortunately, there are no clear guidelines within most organizations and few consistent guidelines across organizations regarding assisted migration.

Policy and Laws

Search existing laws, codes, policies, and procedures within your entity to determine if there is any mention of assisted migration or barriers, such as endangered species lists (Iverson et al. 2013). For Species Rescue, target species are often endangered, complicating the steps for assisted migration (Sansilvestri 2015). Endangered species are regulated and the longer the migration distance the more complicated the process. Check if laws and policies permit, prevent, or provide guidance on assisted migration. Collaborate with restoration practitioners, stakeholders, and scientists to make assisted migration decisions.

Logistic feasibility

Determine the timeframe of your project and if you have the resources to find the desired seed or plant materials. For example, finding nurseries with desired seed zones for different species may be challenging. Species from specific elevation bands can be hard to obtain. Coordinating sales and shipping of plant materials may be a challenge and may cross state and/or country lines. Growing plant materials from seed is an option but there are minimal standards for seed collection, testing, and storage, and there is a shortage of seed collectors. Make sure to ask questions to ensure adequate collection and good quality seed. Ensure that vegetation control and monitoring is logistically feasible for the first few years after planting and consider your project's potential as a research project.

Financial feasibility

Analyze the potential costs of assisted migration in the project budget. Programs or organizations may require local species or genotypes, and grant timelines may limit advanced planning, monitoring, and long-term stewardship. Consider the costs of climate adapted seed or plants and the cost to grow seedlings; transporting, cleaning, and storing seeds or plant materials; and seedling failure in the nursery or after transplanting. Be sure to include the costs of vegetation maintenance and monitoring.

Social feasibility

Determine whether assisted migration is feasible given the views of the stakeholders. Social feasibility depends on the landscape (a federal wilderness area will have less support for assisted migration than a city park). Identify your social license to complete assisted migration plantings and any opposition to assisted migration in the past. Address concerns that assisted migration degrades the integrity of an environment, promotes invasive species, or that nature should "figure it out". Peterson St-Laurent et al. (2018) found that public opposition to assisted migration is stronger with strategies that involve the movement of species outside of their historical range in a survey of British Columbia's population at large.

Ecological feasibility

Practitioners need to understand which ecological functions may be lost with a given species or genotype and if climate-adapted species or genotypes would fill those ecological functions and roles. Things to consider include the likelihood that:

- A species with important ecological function will lose viability in the target location (phenotypic plasticity).
- Ecological function will be lost and cannot be replaced by another species (functional redundancy).
- The declining population will adapt, or natural migration will replace the population.
- The new species or genotype can sustain itself in the recipient community.

Most ecosystems are expected to change in structure, composition, and function and individual species will respond differently with climate change. The extent of climate induced changes depends on climate exposure (an abiotic factor) and ecosystem sensitivity (a biotic factor). When deciding if assisted migration is appropriate for a recipient ecosystem, practitioners should consider landscape connectivity and understand the interaction of climate and landscape to gauge the scale and pattern of climate impacts. Climate change may require active intervention on ecosystems with high exposure and sensitivity, while having no impact on less exposed ecosystems. Things to consider include whether:

- Climate impacts on comparable ecosystems are isolated or widespread.
- Climate impacts on target species or ecosystems are severe compared to other species or ecosystems.
- Climate impacts are indirect through changes in disturbance regime.
- Ecosystems are resilient with the ability to adapt to disturbances.

Step 4. Identify species at risk from climate change (for Ecosystem Services Assisted Migration only).

Restoration practitioners should identify the keystone species in the target ecosystem and research peer reviewed literature to determine the potential effects of climate change (Iverson et al. 2013). Species at risk from climate change due to their geographical location, life history, or anthropogenic pressures should be prioritized for assisted migration. Backus and Basket (2021) listed species at risk of extinction from climate change as those with limited dispersal, limited occurrence, narrow climate tolerance, and low population sizes. Hudec et al. (2019) showed a decrease in western hemlock abundance and an increase in Douglas-fir and grand fir abundance using vegetation modeling with climate change scenarios through 2100.

Step 5. Determine the geographical scale of the action.

Determine if the project should relocate species of concern within, to the margin of, or beyond their current range. Practitioners should base this on the risk that climate change poses to each target species, compared to the risks associated with assisted migration. Greater climate risks to target species may justify a greater geographic scale, which will correspond to the type of assisted migration appropriate for the project.

Step 6. Analyze whether the risks associated with assisted migration are acceptable.

Restoration practitioners can assess the ecological risk of the type of assisted migration selected for each of the species of concern using Karasov-Olson et al. (2021). They may also consider a combination of species on a given site to diversify the risk level accomplished by different combinations and strategize an action plan. This step can be repeated to evaluate different scenarios and different species.

Karasov-Olson et al. (2021) identified six areas of risk with seventeen subsections and provided a scoring guidance for each area of risk with both the risk rank (low, moderate, high, or very high-risk) and the confidence level (low, medium, or high). The practitioner should take notes on their responses to the questions in each sub-category to remember why each rank was selected. Karasov-Olson et al. (2021) provides a spreadsheet and matrix to assess the risks and suggest "that users could find risks posed by a proposed action to be acceptable if:

- Confidence scores are sufficient that managers feel confident that the risk assessment is informative;
- There is no single risk category that is so high and so important as to make the project unacceptably risky; and
- The general distribution of risk is not so high as to exceed some level of expectation that one of many potential problems could arise and lead to decision regret."

Best Management Practices

Regardless of which assisted migration (or no assisted migration) action the practitioner chooses; the project should incorporate the following best management practices:

- Avoid generic, ad hoc, and non-science-based management decisions.
- Track survivorship, growth, and health of plants to determine the success of prescriptions and allow for adaptive management of species and seed source prescriptions over the long term. Consider monitoring additional characteristics, such as system productivity, plant ecophysiology, and soil properties. Monitoring is essential to assess how well the plants respond to climate change and to design future actions.
- Build nursery relationships to communicate stock needs with growers. This may be local stock with high genetic diversity or migrated stock from a different region.
- Consider public outreach and education to improve the social feasibility of the project.
- Use a system-wide approach to assess the risk of disease translocation and take actions to reduce the risk, such as investigating the sanitation practices of the source nursery or sanitizing material upon arrival (see Simler et al. 2019).

Assisted population migration

Restoration practitioners should select source populations using scientific methods and models. Base actions on reliable data such as common garden studies and reciprocal transplant experiments, climate model projections, remote sensing, dendroclimatology, and other empirical research and forest health and productivity monitoring approaches. Consider that some plants may do poorly in their new range and carefully monitor the action.

- Focus on species most at risk from climate change.
- Choose to transport propagules (e.g. seed) over larger stock (bareroot, potted stock, etc.), as the movement of seeds will require less sanitary controls for pests than adult plants (Sansilvestri 2015).
- Use the Seedlot Selection Tool to inform seed sources for the planting area. The Department of Forest Ecosystems and Society at Oregon State University and the U.S. Forest Service Pacific

Northwest Research Station partnered to develop this tool and used available climate-interpolation models to define seed zones.

- Include multiple genotypes with different climatic tolerances: the most suitable genotype for the site will remain uncertain until tested.
- Plan for difficulties in acquiring stock and identify back-up seed sources.
- Create a protocol to detect, isolate, and eliminate pests in transported plants.
- Plan for the possibility of poor performance of migrated stock. Include local stock in the plantings and increase planting densities to compensate for losses.
- Design a monitoring plan before the planting occurs. This includes labeling the plants, documenting source information, and documenting the plant's placement in the field. Be sure to include local plants as controls.

Assisted range expansion

Practitioners should incorporate all the Best Management Practices for assisted population migration for assisted range expansion and place an emphasis on whether the migrated species will negatively affect the recipient ecosystem and/or affect species within ecosystems that occupy the same niche.

- Project managers can use the Seedlot Selection Tool to determine the seed source by setting the zone to "generic as a transfer limit method.
- Restoration practitioners should solicit and incorporate feedback from local tribes if a cultural species in the recipient ecosystem may be negatively affected by the project.

Assisted species migration

Practitioners should justify the use of assisted species migration with a specific plant population that is at risk of extirpation or a planting environment that contains that species or provides migration barriers (e.g. urban environments). All the Best Management Practices for assisted population migration should be incorporated into the project with an emphasis placed on avoiding migrating species with invasive traits.

- Practitioners should have a back-up plan in case plants don't survive, such as planting at a higher density.
- Redundancy approaches could minimize risks of failure (Sansilvestri et al. 2015). One way of dealing with uncertainty is to place translocated populations on multiple sites across a climatic gradient instead of concentrating them in one habitat.

Increased species diversity (no assisted migration)

To include a large diversity of long-lived woody species, pay attention to the populations' ranges, reproductive traits, and seed distribution methods to ensure that future forests possess the tools to survive changing environmental conditions. Choose plants propagated using small quantities of propagules (i.e. live stakes and seeds) from many plants over large areas and varying microclimates. Pay special attention to isolated, disjunct, or marginal populations, which contain rare gene pools.

- Purchase plants from several vendors that collect seed in different areas.
- Consider hiring contractors or paying staff to collect seed locally. Establish partnerships with conservation landowners that allow seed collection on their land.
- Stress the value of genetic diversity to seed collectors and nurseries and offer to pay more to collect from numerous sources.
- Harvest seed throughout the season to capture varying phenology. Variety in bud set, flowering, and fruiting timing may be important to cope with changing seasons.
- Collect seed from parent plants that exhibit adaptive traits associated with climate change like flood and drought tolerance.
- Collect seed from survivors of events, for example heat domes.
- Form seed partnerships to collaborate on seed purchase, collection, and swapping.

Case Study: Riparian Restoration along the South Fork of the Skagit River, Washington

The Skagit River System Cooperative analyzed the use of assisted migration in a habitat restoration planting on Milltown Island, a Washington Department of Fish and Wildlife property in the South Fork distributary of the Skagit River. The restoration site was diked and maintained for farming until the late 1970s when dikes breached in a flood. Once abandoned for agricultural uses, it sat fallow and became dominated by invasive reed canarygrass (*Phalaris arundinacea*).

The planting will use the ecosystem services approach to rehabilitate ecological function by overcoming long-term disturbance regimes that inhibit the natural process of vegetation succession. Reference marshes and historical data indicated that higher elevations of the site were well suited for forested wetlands (Clifton and Hood 2023).

Western red cedar is a keystone species of this ecosystem. Trees provide food, shelter from predation, and lodging for many wildlife species. Western red cedars improve fish habitat by reducing water temperatures and providing stable in-channel wood. It is also a valuable species for its cultural significance to tribes and its commercial uses.

The risk to western red cedar from climate change is high based on a variety of traits. Western red cedar has low genetic diversity from a population bottleneck between 10,000- and 6,000-years BP (El-Kassaby et al. 1994). Land uses have fragmented populations along the lower Skagit River and degraded the riparian habitat. Western red cedar thrives in floodplains, along the edge of wetlands and waterbodies, and in upland areas with moist soils. It is shade tolerant, but plants can survive in full sun in moist conditions— making it susceptible to droughts (Goodrich et al. 2023), particularly those that extend for multiple consecutive growing seasons (Andrus et al., 2023). With climate change, habitat area will decrease, and growing conditions will become less suitable (Mote and Salanthé 2010; Elsner et al. 2010; Littell et al. 2011).

The Seedlot Selection Tool identified Astoria, Oregon as a seed lot for the planting site. Input parameters were trees adapted to 2041 to 2070 using RCP 4.5, western red cedar 0 to 2000 feet as the transfer zone, and mean coldest month temperature and mean summer precipitation as the climate variables.

The Karasov-Olson et al. (2021) risk analysis found the risks posed by assisted western red cedar population migration to the lower Skagit River riparian restoration project to be acceptable. The confidence scores were high, there was no single category that made the project unacceptably risky, and the general distribution of risk was low enough to avoid catastrophic problems (Table 2).

Table 2. Karasov-Olson et al. (2021) matrix to assess risk of assisted western red cedar population migration in lower Skagit River riparian restoration project.

Risk	Confidence
Low	High
Moderate	Moderate
High	Low
Very High	

Section	Risk Criteria				
Risk of:	A	B	C	D	E
I. No action	No action to target	No action to recipient ecosystem			
II. Action to the target	Risk to relocated individuals	Risk to source population withstanding decrease in numbers	Risk of removing target will negatively impact key function in source ecosystem	Relocated population causing undesired evolution in target	Other: 1. Target not adapted to future climate. 2. Effect on supply chain
III. Action to non-targets	Risk of target transmitting novel disease or associated pest	Risk of competitive interaction negatively affecting abundance or distribution of non-targets	Risk of consumptive effects reducing the abundance or distribution of non-targets	Risk of driving undesired evolution in non-targets	Other
IV. Action to recipient ecosystem	Risk of indirect and negative impacts on ecosystem structure	Risk of changing ecosystem function	Other		
V. Spread and invasion	Risk of invasion within the intended recipient ecosystem	Risk of invasion beyond the recipient ecosystem	Risk of irreversibility of the managed relocation action	Other	
VI. Adverse socio-economic values	Risk to a culturally or economically important species	Risk to a valued ecosystem service	Other		

The level of risk associated with no action ranged from high (risk to the target species) to moderate (risk to the ecosystem). Western red cedar trees are declining within their current range and without assisted migration there is a high risk that the planted trees will do poorly in the changing climate. With the loss of this key species, there is a risk that riparian habitats will lose functionality, but the decline of western red cedar is one of several factors degrading riparian habitat.

The level of risk posed by assisted population migration to the target species ranged from moderate to high (risk to translocated population) to low (risk to the source population). The survivorship of translocated individuals may be low because western red cedar is a climax species that struggles to survive in the ruderal environment common to restoration sites. Furthermore, the relocated population may have limited genetic diversity that could result in poor survival. At the same time, the source population can withstand losing a small portion of the seeds for the relocation effort.

The level of risk associated with assisted population migration to non-targets is moderate to high. The risk of transmitting a new disease or associated pest is moderate. There are secondary insects and diseases present in the recipient ecosystem that infest dead or weakened trees, but few are the primary cause of mortality. The risk of competitive interaction affecting non-target individuals is high since the non-relocated western red cedars already present in the ecosystem will rely on the same resources as the relocated individuals. The risk of driving undesired change in the genetic characteristics of local populations in non-target individuals is moderate as the relocation of new trees may result in new physical or behavioral traits in the existing trees, but this is unlikely to lead to negative changes.

We did not assess the risk of the action on higher order attributes of the recipient ecosystem. Western red cedar already exists in the ecosystem and should therefore have no indirect and negative impacts on ecosystem structure and should result in no change in ecosystem function.

The level of risk associated with biological invasion ranges from low (invasion within the intended recipient ecosystem) to high (irreversibility of the managed relocation action). Western red cedar lacks invasive species characteristics. At the same time, it will be difficult to detect and eradicate the offspring of relocated individuals.

The level of risk associated with socio-economic values ranges from moderate (culturally or economically important species) to low (valued ecosystem services). Western red cedar is a culturally valued species, but targeted relocation is unlikely to reduce the abundance or fitness of that species. The riparian ecosystem associated with western red cedar provides several important functions that are unlikely to be negatively affected by the relocated individuals.

Case study: Seattle Parks and Recreation Forest Restoration Program

The Seattle Parks and Recreation's Forest Restoration Program began in 1994 with city funding that recognized urban forests as valuable assets. The Seattle Urban Nature Project's inventory of public land habitats in 1999 to 2000 helped establish the Green Seattle Partnership which, guided by a 20-year strategic plan initiated in 2004, adopted a model of urban forest sustainability that prioritized community engagement and the restoration of the City's forested parkland.

Forest restoration was mentioned in the City of Seattle's 2013 Climate Action Plan as part of an objective to "protect and enhance natural systems." The restoration efforts described in the City's climate adaptation actions aim to increase stewardship capacity, identify species suitable for anticipated temperature changes, enhance species diversity in vulnerable areas, and extend the watering season and tree establishment period with the use of efficient conservation technologies. The City incorporated Green Seattle Partnership into the 2012 Urban Forest Stewardship Plan, with a mid-term action (5 to 10 years) to diversify seed sources and adapt urban forest restoration and reforestation to changing climate conditions.

In 2017, the Green Seattle Partnership updated the strategic plan to reflect the program's progress, identify future opportunities, and justify stewardship beyond 2025, prompting Seattle Parks to develop more detailed guidance for prioritizing restoration tasks. The resulting Forest Stewardship Report highlighted that 49 percent of Seattle Park's forests face multiple threats to their long-term health and resilience due to low diversity and the prevalence of climate-vulnerable species. The dense canopy dominated by broadleaf species limited new tree establishment. The vulnerability assessment identified numerous species at risk from climate impacts, including rare and long-lived species, those with limited adaptive traits, and isolated or small populations. Notably, 13 out of 14 tree species had moderate to high vulnerability scores, with concerns that bigleaf maple and western red cedar are susceptible to increased temperatures, extreme droughts, and pathogens. Additionally, about 300 acres of parkland hosted unique forest types, like Pacific madrone (*Arbutus menziesii*) forests, which may require special management attention. The assessment recommended integrating southern seed provenances and evaluating assisted gene flow within the species' ranges to promote longer-lived, climate-resilient species.

Until the late 2010s, the Green Seattle Partnership prioritized materials from the Puget Sound seed zone, which aligned with common forestry and restoration practices. In 2019, following the updated strategic plan, the Green Seattle Partnership adopted an assisted gene flow strategy for key evergreen species such as Douglas-fir, western hemlock, western red cedar, and Pacific madrone as a way for urban forests to adapt to new environmental conditions. This new initiative aimed to relocate genotypes within a few degrees of latitude to match the anticipated temperature and moisture regimes of the future.

The Seedlot Selection Tool was instrumental in this process. It provided a data-driven method to select seed sources that align with the projected climate in Seattle, while considering variables like temperature and drought. The Tool determined the Willamette Valley seed zone was a safe reach where seedlings might be adapted to warmer conditions and resilient to colder temperatures during wintertime.

The availability of plant material from the Willamette Valley and Oregon varied in Washington commercial nurseries. Building relationships with nurseries in the desired seed source area was crucial for seed collection, material acquisition, and logistics. The Green Seattle Partnership considered using bareroot stock, which benefits difficult to access restoration sites. Furthermore, it allows practitioners to grow plants in pots to assess quality before installation. This effort is ongoing.

Conclusion

This document aimed to provide guidance to practitioners on the use of assisted migration in restoration projects, but there are few available results from the case studies or other assisted migration experiments. In 2025, the Skagit River System Cooperative will receive climate adapted western red cedar seedlings that the Northwest Natural Resource Group contracted Fourth Corner Nursery to grow from Willamette Valley, Oregon seed. After installation in a restoration site in the Lower Skagit Watershed, the Skagit River System cooperative plans to monitor these with seedlings sourced from the Skagit River watershed. Three-year results from the Stossel Creek, Washington study show that mortality is higher in Douglas fir sourced from Washington than Oregon or California (26.7, 10.0, and 6.7 percent, respectively) but mortality is lower in western red cedar sourced from Washington than from Oregon (51.1 and 61.1 percent) (Krownbell 2023). Since empirical data remains sparce, the responsibility remains on restoration practitioners to make informed decisions on the use of climate adapted plants in restoration projects.

Resources

- The Forest Adaptation Network (https://www.nnrg.org/climateadaptation/forest-adaptation-network/) is a collaboration established to share information on forest adaptation in the Pacific Northwest. Interested organizations from across the Pacific Northwest are welcome to join.
- The SeedLot Selection Tool (https://seedlotselectiontool.org/sst/) uses available climate-interpolation models to define seed zones.
- Karasov-Olson et al. (2021) provides a risk analysis (https://irma.nps.gov/DataStore/Reference/Profile/2284919) and spreadsheet (https://irma.nps.gov/DataStore/Reference/Profile/2280035) for practitioners to assess the ecological risk of assisted migration.
- The Forest Seedling Network Directory (https://rngr.net/marketplace/directory) provides a directory of plant and seed sources searchable by state .
- Adaptive Silviculture for Climate Change project (https://www.adaptivesilviculture.org/) describes several case studies of resistance, resilience, and transition (some include assisted migration).
- What will the climate feel like in 60 years? (https://fitzlab.shinyapps.io/cityapp/) provides a map describing climate change scenarios.
- Northwest Natural Resources Group Climate Adaptation Strategies page (https://www.nnrg.org/climateadaptation/) contains several climate adaptation resources including links to assisted migration monitoring studies and lectures from the 2019 workshop series on Climate Adaptation Strategies for Pacific Northwest Forests.
- The University of Washington Climate Impacts Group (https://cig.uw.edu/) provides a range of technical resources that can be used to help address climate impacts including datasets, analysis tools, publications, and special reports.
- U.S. Department of Agriculture Northwest Climate Hub (https://www.climatehubs.usda.gov/hubs/northwest) serves Alaska, Idaho, Oregon, and Washington by delivering science-based, region-specific technologies and practical information to assist with climate-informed decision making.
- U.S. Department of Agriculture Climate Change Resource Center Pacific Northwest Region (R6) Resources (https://www.fs.usda.gov/ccrc/pacific-northwest-resources) provides the latest additions in educational resources, climate change and carbon tools, videos, and topic-specific briefings for the Forest Service's Pacific Northwest Region.
- Salish Sea Restoration Wiki (https://salishsearestoration.org/wiki) is a peer-to-peer learning platform with lots of local information about climate change and restoration projects.
- Data Basin (https://databasin.org/) is a science-based mapping and analysis platform that supports learning, research, and sustainable environmental stewardship. Practitioners can explore data sets showing the historical, current, and modeled distribution of plant species and ecoregions.
- The Multivariate Adapted Constructed Analog Future Time Series Tool (https://climate.northwestknowledge.net/MACA/vis_timeseries.php) is a statistical downscaling method for removing biases from global climate model outputs. The visualization tool provides map

summaries of future climate for variables such as temperature, precipitation, soil moisture, and run-off, among others.

- PNW Temperature, Precipitation, and SWE Trend Analysis Tool (https://climate.washington.edu/climate-data/trendanalysisapp/) allows users to analyze monthly temperature and precipitation trends around the Pacific Northwest.
- The Forest Service National Center for Reforestation, Nurseries, and Genetic Resources (https://rngr.net/) is a source of technical information for nurseries and land managers regarding production and planting of trees and other native plants for reforestation, restoration, and conservation.

References Cited

Agne, M. C., Beedlow, P. A., Shaw, D. C., Woodruff, D. R., Lee, E. H., Cline, S. P., and Comeleo, R. L. 2018. Interactions of predominant insects and diseases with climate change in Douglas-fir forests of western Oregon and Washington, USA. Forest Ecology and Management, 409, 317-332.

Anderson, J. T. and Song, B. H. 2020. Plant adaptation to climate change—Where are we? Journal of Systematics and Evolution 58(5):533-545.

Backus, G.A. and Baskett, M.L. 2021. Identifying robust strategies for assisted migration in a competitive stochastic metacommunity. Conservation Biology 35:1809–1820.

Benomar, L., Elferjani, R., Hamilton, J., O'Neill, G.A., Echchakoui, S., Bergeron, Y., and Lamara, M. 2022. Bibliometric analysis of the structure and evolution of research on assisted migration. Current Forestry Reports 8(2):199-213.

Betzen, J.J., Ramsey, A., Omdal, D., Ettl, G.J., and Tobin, P.C. 2021. Bigleaf maple, Acer macrophyllum Pursh, decline in western Washington, USA. Forest Ecology and Management 501:119681.

Bower, A.D., St.Clair, J.B., and Erickson, V. 2014. Generalized provisional seed zones for native plants. Ecological Applications 24(5)913–919.

Bowman, G., Perret, C., Hoehn, S., Galeuchet, D.J., and Fischer, M. 2008. Habitat fragmentation and adaptation: a reciprocal replant-transplant experiment among 15 populations of *Lychnis flos-cuculi*. J Ecol 96: 1056–1064.

Breed, M.F., Stead, M.G., Ottewell, K.M., Gardner, M.G. and Lowel, A.J. 2012. Which provenance and where? Seed sourcing strategies for revegetation in a changing environment. Conservation Genetics 14:1–10.

Broadhurst, L. M., Lowe, A., Coates, D. J., Cunningham, S. A., McDonald, M., Vesk, P. A., and Yates, C. 2008. Seed supply for broadscale restoration: maximizing evolutionary potential. Evolutionary Applications 1(4):587-597.

Bucharova, A., Bossdorf, O., Hölzel, N., and Kollmann, J. 2019. Mix and match: regional admixture provenancing strikes a balance among different seed-sourcing strategies for ecological restoration. Conservation Genetics 20:7–17.

Campbell, R. K. and F. C. Sorensen. 1978. Effect of test environment on expression of clines and on delimitation of seed zones in Douglas-fir. Theoretical and Applied Genetics 51:233-246.

Clifton, B.C. and Hood, W.G. 2023. Milltown Island Restoration Project Final Vegetation Management Plan. Prepared for the Washington Department of Fish and Wildlife. Skagit River System Cooperative. Burlington, Washington. 35 pp.

Coops, N.C., Waring, R.H., Beier, C., Roy-Jauvin, R., and Wang., T. 2011. Modeling the occurrence of 15 coniferous tree species throughout the Pacific Northwest of North America using a hybrid approach of a generic process-based growth model and decision tree analysis. Applied Vegetation Science 14 402–414.

Coops, N.C., Waring, R.H., Plowright, A., Lee, J., and Dilts, T.E. 2016. Using Remotely-Sensed Land Cover and Distribution Modeling to Estimate Tree Species Migration in the Pacific Northwest Region of North America. Remote Sensing 8:65-80.

Dumroese, R.K., Williams, M.I., Stanturf, J.A., and Bradley St. Clair, J. 2015. Considerations for restoring temperate forests of tomorrow: forest restoration, assisted migration, and bioengineering. New Forests 46:947-964.

El-Kassaby, Y A., Russell, J., and Ritland, K. 1994. Mixed Mating in an Experimental Population of Western Red Cedar, Thuja plicata. Journal of Heredity 85: 227–231.

Elsner, M., Cuo, L., Voisin, N., Deems, J., Hamlet, A., Vano, J., Mickelson, K., Lee, S., and Lettenmaier, D. 2010. Implications of 21st century climate change for the hydrology of Washington State. Climatic Change 102:225-260.

Erickson, V., Aubry, C., Berrang, P., Blush, T., Bower, A., Crane, B., DeSpain, T., Gwaze, D., Hamlin, J., Horning, M., Johnson, R., Mahalovich, M., Maldonado, M., Sniezko, R., and St. Clair, B. 2012. Genetic Resource Management and Climate Change: Genetic Options for Adapting National Forests to Climate Change. USDA Forest Service, Forest Management, Washington, DC. 24 pp.

Flannigan, M.D., Stocks, B.J., and Wotton, B.M. 2000. Climate change and forest fires. Science of The Total Environment 262: 221–229.

Gandon, S. and Michalakis, Y. 2002. Local adaptation, evolutionary potential and host-parasite coevolution: interactions between migration, mutation, population size and generation time. Journal of Evolutionary Biology 15:451–462.

Goodrich, B., Fischer, M., and Buhl, C. 2023. Western redcedar dieback. U.S. Forest Service, Washington, D.C. https://storymaps.arcgis.com/stories/1405dab5f59246aa83849ec43f72b15a accessed 7/3/24.

Grossnickle, S. C. and Russell, J. H. 2010. Physiological variation among western redcedar (*Thuja plicata* Donn ex D. Don) populations in response to short-term drought. Annals of Forest Science 67(5): 506.

Grossnickle, S.C., Fan, S., and Russell, J.H. 2005. Variation in gas exchange and water use efficiency patterns among populations of western redcedar. Trees 19:32-42.

Halofsky, J.E., Peterson, D.L., and Harvey, B.J. 2020 Changing wildfire, changing forests: the effects of climate change on fire regimes and vegetation in the Pacific Northwest, USA. Fire Ecology 16(1):1-26.

Handler, S., Pike, C., and St. Clair, B.; 2018. Assisted Migration. USDA Forest Service Climate Change Resource Center. 8 pp. https://www.fs.usda.gov/ccrc/topics/assisted-migration accessed 7/1/2024.

Hudec, J.L., Halofsky, J.E., Peterson, D.L., and Ho, J.J. 2019. Climate change vulnerability and adaptation in southwest Washington. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, Oregon. General Technical Report PNW-GTR-977. 249 pp.

Iverson, L. R., Peters, M. P., Matthews, S., and Prasad, A. (2013). An overview of some concepts, potentials, issues, and realities of assisted migration for climate change adaptation in forests. In: Browning, J. and Palacios, P., comps. Proceedings of the 60th Annual Western International Forest Disease

Work Conference; 2012 Oct. 8-12; Tahoe City, CA. Western International Forest Disease Work Conference: 25-34.

Jakobsson, A. and Dinnetz, P. 2005. Local adaptation and the effects of isolation and population size-the semelparous perennial Carlina vulgaris as a study case. Evolutionary Ecology 19:449–466.

Karasov-Olson, A., Schwartz, M.W., Olden, J.D., Skikne, S., Hellmann, J.J., Allen, S., Brigham, C., Buttke, D., Lawrence, D.J., Miller-Rushing, A.J., Morisette, J.T., Schuurman, G.W., Trammell, M., and Hoffman, C.H. 2021. Ecological Risk Assessment of Managed Relocation as a Climate Change Adaptation Strategy. National Park Service U.S. Department of the Interior. Natural Resource Report NPS/NRSS/CCRP/NRR—2021/2241. 126 pp.

Kawecki, T.J. and Ebert, D. 2004. Conceptual issues in local adaptation. Ecology Letters 7: 1225–1241.

Keith, A.R. 2017. Community genetics, interacting foundation species, and assisted migration: genetic variation in populus and its effects on associated arthropod communities. Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Biology. Northern Arizona University, Flagstaff, Arizona. 93 pp.

Keller, M., Kollmann, J., and Edwards, P.J. 2000. Genetic introgression from distant provenances reduces fitness in local weed populations. J. Appl. Ecol. 37, 647–659

Krownbell, D. 2023. Stossel Creek Climate Adaptation Project: Assisted Migration Planting Three Years In-What Have We Seen? North Sound Riparian Conference, January 26th, 2023, 9:30 am to 3:00 pm. Skagit Watershed Council, Mount Vernon, Washington. https://www.youtube.com/watch?v=H-17ufHWdew&list=PLEnbiE6Lcz3RJYa4hJ49HwqG4UMhA26IF&index=4 accessed 10/11/2024.

Leimu, R. and Fischer, M., 2008. A meta-analysis of local adaptation in plants. PloS one 3(12):e4010.

Littell, J.S., Elsner, M.M., Mauger, G. S., Lutz, E., Hamlet, A.F., and Salathé, E. 2011. Regional Climate and Hydrologic Change in the Northern US Rockies and Pacific Northwest: Internally Consistent Projections of Future Climate for Resource Management. Project report for USFS JVA 09-JV-11015600-039, Climate Impacts Group, University of Washington, Seattle, Washington, 109 pp.

Littell, J.S., Raymond, C.L., Rochefort, R.M., and Klein, S.L. 2014. Climate Change and Vegetation in the North Cascade Range. In: Raymond, C.L., Peterson, D.L., and Rochefort, R.M. (eds.) Climate Change Vulnerability and Adaptation in the North Cascades Region, Washington. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, Oregon. General Technical Report, PNW-GTR-892, pp. 113-176.

Mote P.W. and Salanthe, E.P., Jr. 2010. Future climate in the Pacific Northwest. Climate Change 102:29–50.

NNRG. 2022. Using climate-adapted plants for Puget Sound area restoration and GSI. Northwest Natural Resource Group, Seattle, Washington. 11 pp.

Office of the Washington State Climatologist. 2024. PNW Temperature, Precipitation, and SWE Trend Analysis Tool. Office of the Washington State Climatologist, Seattle, Washington. Online dataset. https://climate.washington.edu/climate-data/trendanalysisapp/. Accessed 9/9/2024.

Peterson, D.L. 2021, January 19. Building Forest Resilience in a Changing Climate. 2021 North Sound Riparian Conference, Mount Vernon, Washington. https://www.youtube.com/watch?v=-trWeWY5aHs&t=111s accessed 7/3/24.

Peterson St-Laurent, G., Hagerman, S., and Kozak, R., 2018. What risks matter? Public views about assisted migration and other climate-adaptive reforestation strategies. Climatic change 151(3):573-587.

Randall, W.K. and Berrang, P. 2002. Washington tree seed transfer zones. Washington State Department of Natural Resources, Olympia, Washington. Pp 4 – 5.

Raymond, C., Morgan, H., Peterson, D., and Halofsky, J. 2022. A Climate Resilience Guide for Small Forest Landowners in Western Washington. A Collaboration of the University of Washington Climate Impacts Group, the U.S. Forest Service, and the Northwest Climate Hub. 29 pp.

Raymond, C.L., Peterson, D.L. and Rochefort, R.M. 2014. Climate Change Vulnerability and Adaptation in the North Cascades Region, Washington. U.S. Department of Agriculture, Forest Service Pacific Northwest Research Station, Portland, Oregon. General Technical Report PNW-GTR-892. 291 pp.

Rogers, D.L., Washburn, L.K., Birker, C., Labbé, M.A., Campbell, M.A., and A.D. Schreier. 2024. Genomic and common garden data reveal significant genetic differentiation in the endangered San Fernando Valley spineflower *Chorizanthe parryi* var. *fernandina*. Conservation Genetics (2024) 25:879–896.

Rybczyk, J.M., Hamlet, A.F., MacIlroy, C. and Wasserman, L. 2019. Introduction to the Skagit Issue—From Glaciers to Estuary: Assessing Climate Change Impacts on the Skagit River Basin. Northwest Science 90(1): 1-4.

Saltonstall, K. 2002 Cryptic invasion by a non-native genotype of the common reed, Phragmites australis, into North America. Proceedings of the National Academy of Sciences 99:2445–2449.

Sansilvestri, R., Frascaria-Lacoste, N., and Fernández-Manjarrés, J. 2015. Reconstructing a deconstructed concept: Policy tools for implementing assisted migration for species and ecosystem management. Environmental Science & Policy 51:192-201.

Schwartz, M.W., Hellmann, J.J., Mclachlan, J.M., Sax, D.F., Borevitz, J.O., Brennan, J., Camacho, A.E., Ceballos, G., Clark, J.R., Doremus, H., Early, R., Etterson, J.R., Fielder, D., Gill, J.L., Gonzalez, P., Green, N., Hannah, L., Jamieson, D.O., Javeline, D., Minteer, B.A., Odenbaugh, J., Polasky, S., Richardson, D.M., Root, T.L., Safford, H.D., Sala, O., Schneider, S.H., Thompson, A.R., Williams, J.W., Vellend, M., Vitt, P., and Zellmer, S. 2012. Managed Relocation: Integrating the Scientific, Regulatory, and Ethical Challenges. BioScience 62: 732–743.

Simler, A.B., Williamson, M.A., Schwartz, M.W., and Rizzo, D.M. 2019. Amplifying plant disease risk through assisted migration. Conservation Letters 12(2):e12605.

Ste-Marie, C., Nelson, E.A., Dabros, A., and Bonneau, M. 2011. Assisted migration: introduction to a multifaceted concept. The Forestry Chronicle 87(6):724-730.

Turner, N.J., Armstrong, C.G., and Lepofsky, D. 2021. Adopting a Root: Documenting Ecological and Cultural Signatures of Plant Translocations in Northwestern North America. People and Nature 6(1):286-300.

University of California MERCED Climatology Lab. 2024. Multivariate Adapted Constructed Analog Future Time Series Tool. 2024. University of California MERCED Climatology Lab. Merced, California. Online dataset. https://climate.northwestknowledge.net/MACA/index.php. Accessed 9/3/2024.

V´azquez, D.P., Gianoli, E., Morris, W.F., and Bozinovic, F. 2017. Ecological and evolutionary impacts of changing climatic variability. Biological Reviews 92:22–42.

Weiskittel, A.I., Crookston, N.L., and Rehfeldt, G.E. 2012. Projected future suitable habitat and productivity of Douglas-fir in western north America. Schweiz Z Forstwes 163(3):70-78.

Williams, M.I. and Dumroese, R.K. 2013. Preparing for Climate Change: Forestry and Assisted Migration Journal of Forestry 111(4):287–297.