# Chapter 8

# Decision Support: Vulnerability, Conservation, and Restoration

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## Executive Summary

Current predictive tools, management options, restoration paradigms, and conservation programs are insufficient to meet the challenges of climate change in western North America. Scientific and management capabilities and resources will be sapped trying to identify risks to genetic resources and ecosystems and determine new approaches for mitigating and managing changing environments. Developing new tools will require innovative research, improvement and creation of predictive models, continuous evaluation of management outcomes, and integration with social scientists and economists.

Climate change threatens the biodiversity of grasslands, shrublands, and deserts at scales ranging from the gene to complex ecosystems. The rate of climate change may overcome normal ecosystem resilience, disrupting ecosystem functioning and provision of critical services. Guidelines for identifying and conserving at-risk species through a variety of experimental methods are available and being utilized. Nonetheless, these approaches and models for predicting future risks are evolving and not universally accepted or applicable.

Elements used to identify species or systems vulnerable to climate change include effects of exposure to climate change, sensitivity or the level to which the organism or system is altered, and its capacity to adjust to the change. Vulnerability assessments focus on unique variables or combinations of variables for comparison of organisms, natural systems, or human systems and range widely in their objectives; all rely on projections of future conditions. These assessments aid in planning adaptation strategies and prioritizing management. Available assessment tools include: vulnerability indices, process simulations, evaluation of shifts in species or community distribution, and integrated models. Research must focus on improved climate change predictions, species and habitat response models, identification of new community compositions, and management options.

Selection of appropriate plant materials for restoration necessitates an understanding of genetic variation and structure across the landscape. Species-specific seed zones are available for commercial trees but only for a few other species. A number of bioclimatic tools are used to delineate provisional seed zones, and broadly adapted seed

sources are being developed for selected species and zones. Although western plant communities have constantly reassembled over time in response to changing climatic conditions, rapid climate change will increase fragmentation and cause appropriate habitat to appear in new locations. Assisted migration of native plants, a form of ex situ conservation, involves moving pre-adapted genotypes into remaining portions of the species range or moving a species into new but remote habitat. This approach remains controversial from biological and sociological standpoints. There is an urgent need to better understand future climate scenarios and appropriate transfer of genetic material and to provide analysis and discussion of natural and assisted future redistributions of species.

Climate change impacts on grassland, shrubland, and desert species and ecosystems are expected to increase but are difficult to predict for many areas. There is an immediate need for improved tools and approaches for assessing vulnerabilities at all levels, conserving diversity, and developing new techniques for selecting appropriate native plant materials for restoring disturbed areas and for moving genetic materials to new locations as climatic conditions change. Resources needed to accomplish these goals include genecologists, modelers, nursery and plant materials specialists, biologists, social scientists, and economists.

## Introduction

Conservationists and land resource managers are gravely concerned about the impact of climate change because it will involve large numbers of species in diverse ecosystems, climate change interactions with ecosystems are wrought with complicated uncertainties, and our response will be limited by available human resources. Managers require effective tools now to manage natural resources under current climatic conditions. Managers will also need new methods and tools to help identify species and ecosystems at greatest risk of harm due to climate change and how to mitigate, or exploit, that change. To focus limited resources in the most effective and efficient manner, these tools should identify potential management intervention points (e.g., identify how systems are likely to be harmed) and address uncertainties in future conditions modeled by climate model projections and species' responses to those future conditions.

This chapter has three main topics:

- First, we discuss the ramification of the interactions of biodiversity and climate change and why conserving biodiversity is paramount.
- Second, we discuss how biodiversity, either from a species or ecosystem standpoint, can be assessed for its vulnerability to climate change. Vulnerable species or systems can then be identified and targeted for restoration.
- Third, we discuss how appropriate genetic material of vulnerable plant species or systems is currently transferred and may need to be transferred in the future to ensure successful restoration.

## Climate Change and Biodiversity

Biodiversity affords ecosystems the plasticity to respond to natural disturbances, including naturally changing climate (Risser 1995). Climates are, however, changing at a rate faster than observed historically, thereby compromising these natural biological responses (Hughes 2000; Parmesan and Yohe 2003). It is therefore critical to identify conservation efforts at all scales (genetic, population, species, and ecosystem) in order to maintain plasticity and ecosystem function (Hannah and others 2002).

The general research consensus is that biodiversity (genetic variation, population variation, species richness, and ecosystem complexity) is threatened by climate change (Hannah and others 2002; Midgley and others 2002; Schwartz 1992; Schwartz and others 2006). Climate change has the potential to reduce valuable ecosystem services (such as production of food, pharmaceuticals, timber, and clean water) can contribute to floods and droughts, and can disrupt biogeochemical cycles (Daily 1997; Hughes and others 1997). Climate change may compromise ecosystem resiliency by reducing or eliminating plant and animal species (Thomas and others 2004) through range shifts in plant distributions (Beckage and others 2008; Soja and others 2007; Thomas 2010), increases in invasive species pressure (Smith and others 2000), and associated changes in disturbance regimes (McKenzie and others 2004). Significant habitat loss, disturbance, and increased habitat fragmentation also threaten native species' genetic diversity through inbreeding depression (Holt 1990; Johnson and others 2010; Thomas and others 2004). In grassland, shrubland, and desert ecosystems of the Great Basin, climate change effects have been forecasted and documented (Friggens and others, Chapter 1 this volume) as they relate to rare and vulnerable species (Fleishman 2008) and water resources, agriculture, native ecosystems, biodiversity, and recreation (summarized in Chambers 2008). The direct pressures on grassland, shrubland, and desert ecosystem biodiversity in the West are varied. Higher-elevation ecosystems are expected to shrink or vanish (Ledig and others 2010); ephemeral riparian and wetland systems may vanish (Hurd and others 1999); and highly invasive species may negatively affect native species through competition or altered fire regimes (Ziska and others 2005).

Conversation surrounding the loss of biodiversity due to climate change is contentious. Although we have clear guidelines, both globally (NatureServe) and nationally (Endangered Species Act; ESA), for identifying species at risk of extinction and conserving them (e.g., the black-footed ferret [*Mustela nigripes*], the models and assessments used for predicting future biodiversity losses of species still relatively abundant have yet to gain wide acceptance (Botkin and others 2007; Hannah and others 2002). In addition, the appropriate conservation strategies (i.e., in management areas [in situ], via assisted colonization [ex situ], or via germplasms, botanical gardens, or captive breeding programs [in vitro]) are under scrutiny (Hoegh-Guldberg and others 2008; Ricciardi and Simberloff 2009). Even so, germplasm of plants critically imperiled on a global level are currently being conserved in vitro (cryogenic storage of germplasm) by the Forest Service's National Seed Laboratory and Agricultural Research Service, while land managers work to protect plant and animal species under the ESA. However, efforts may not be adequate or sufficiently proactive to mitigate species and genetic losses due to climate change (Hoegh-Guldberg and others 2008).

To be sufficiently proactive, we need to identify, develop, and use appropriate vulnerability assessment tools to predict climate related increases in the risk of species extinction and population bottlenecking. To preserve biotic diversity, these assessments must provide potential management actions and refine research needs. These tools also must integrate bioclimatic modeling, genecology, and climate interactions with disturbance, invasive species, and species autecology. It is only through the development of these tools that we will be able to accurately assess and identify effective management actions for the preservation or restoration of critical habitats and biodiversity.

## Assessing Species Vulnerability to Climate Change

Vulnerability is commonly defined as a function of exposure, sensitivity, and adaptive capacity (IPCC 2007; Stein and others 2011) and how these elements relate to the likelihood that species or systems are affected by climate change, the degree to which they are impacted by change, and their capacity to deal with change. Vulnerability assessments, using models, scoring systems, and comprehensive synthesis of the literature, determine which species or systems are most likely to be affected by climate change. Assessments usually target a unique variable or set of variables that act as the measure of vulnerability. Biodiversity and degree of expected change in microclimate are common measures to compare habitats, whereas vulnerability comparison among species depends on exposure levels and the possession (or lack thereof) of specific characteristics. Assessments may focus narrowly on species in select habitats or be global in perspective, but all evaluate the potential sensitivity, exposure, and adaptive capacity of their targets and all rely on projections of future conditions.

Climate change vulnerability assessments include a broad array of documents and analyses that synthesize many predictions and projections, and may take the form of qualitative evaluation of species traits or ecosystem function or involve statistical analysis of the relative influence of various parameters on population trends. Climate change vulnerability assessments vary in their objectives and can target human systems, natural systems, and processes of both (Füssel and Klein 2005). Vulnerability assessments are often the first step in planning adaptation strategies and management. By providing information on susceptibility to climate change impacts, assessments help identify targets for mitigation, enable managers to prioritize management activities and resources, and assist with implementing adaptive strategies (Füssel and Klein 2005).

Although many types of assessment tools are used, most fall into four broad categories: (1) vulnerability indices; (2) simulated processes; (3) community distribution shifts; and (4) complex, integrated models.

### *Vulnerability Indices*

Several assessments rely on an indicator or index of vulnerability, which is used to compare the relative vulnerability of plant or animal species or systems. For example, the NatureServe Climate Change Vulnerability Index (http://www.natureserve.org/prodServices/climatechange/ccvi.jsp), designed for both plant and animal species, was used in Nevada and Massachusetts (Galbraith and O'Leary 2011; Young and others 2011); and SAVS, a System for Assessing Vulnerability of Species to climate change (Bagne and others 2011), was used to assess terrestrial vertebrate species in New Mexico (Finch and others 2011; Friggens and others, in prep.) and Arizona (Bagne and Finch 2010; Coe and others, in prep.). On a broader scale, the Environmental Protection Agency has a scoring system that has been applied nationally to assess the combined impact of climate change and non-climate related vulnerabilities for threatened and endangered species (Galbraith and Price 2011; U.S. EPA 2009). Other regional assessments incorporate indices and other projection tools (e.g., Czúcz and others 2009; Tremblay-Boyer and Anderson 2010). For example, an analysis of climate effects for the Pacific Northwest includes the use of sensitivity indicators (traits), downscaled climate projections, and dynamic global vegetation models (Case and Lawler 2011; Lawler and others 2009). This approach is commonly used to prioritize intervention or management actions or to identify research needs. It may also serve to identify new management targets when assessments reveal significant impact for targets not currently of concern.

### *Process Simulation*

Assessments that use models that simulate processes, most commonly biogeochemical models or dynamic global vegetation models, can provide important information for management and policy decision. For example, WaterSim (Gober and Kirkwood 2010) estimates water shortages in the Phoenix area under different scenarios of population growth; the MAPSS biogeography model (Hanson and others 2001) projects biome response to climate changes in forests; and Hauer and others (1997) simulated impacts of climate change on freshwater ecosystems in North America's Rocky Mountains. These types of models formed the basis for species distribution analyses used by Glick and Wilson (2011), Lawler and others (2009), and Rehfeldt and others (2006). Assessments based on these methods are strongly influenced by the quality of data used in generating output, including the projections for future conditions.

### *Shifts in Species or Community Distributions*

A number of assessments use estimates of shifts in species or community distributions to infer climate change impacts, which takes the form of an occupancy or niche modeling effort that relates future species distribution to climate or other abiotic conditions based on current environmental conditions. Future conditions are estimated based on climate projections created from downscaled GCMs or future expectations for biogeochemical processes predicted from computational models. Rehfeldt and others (2006) showed that changes in biotic community and individual plant species distributions for the western United States will be great under a number of different climate scenarios (Friggens and others, Chapter 1 this volume). In the western hemisphere, they predicted 90% of nearly 3000 vertebrate species will be lost from certain habitats (Lawler and others 2009), with some species experiencing declining distribution (e.g., fresh water fishes; Eaton and Scheller 1996) and some experiencing expanded distribution (Humphries and others 2002; Meyer and others 1999; Shutter and Post 1990). These efforts are data intensive but are able to provide scenarios for a potential future. They can be used to infer potential loss of habitat suitability for species or communities.

### *Complex Analyses*

The most complex analyses attempt to integrate adaptive strategies with vulnerability assessments to gauge how actions influence relative susceptibility to climate change impacts. One analysis incorporates sensitivity scores with an analytical framework to create output relevant to both management and policy decisions (Luers 2005) whereas others integrate regional assessments, adaption planning frameworks, and a number of climate modeling tools (Enquist and Gori 2008, described in McCarthy and Enquist 2011; NatureServe Vista found at: http://www.natureserve.org/prodServices/vista/overview.jsp).

### *Current Assessment Tools*

We list, albeit not comprehensively, many widely and freely available tools for managers to assess species or ecosystem vulnerability to climate change (table 8-1). Other syntheses of assessment tools can be obtained from the U.S. Forest Service, Pacific Northwest Research Station (http://www.fs.fed.us/nw/corvallis/mdr/mapss) and the Nairobi Work Programme, under the United Nations Framework Convention on Climate Change (http://unfccc.int/adaptation/nairobi_workprogramme/knowledge_resources_and_publications).

**Table 8-1.** Examples of the types of tools and data commonly used to assess vulnerability to climate change.

| Type Name | Description | Target/ Scope | Sources/Websites |
|---|---|---|---|
| **Scoring tools** | Typically quantify vulnerability through a tally of traits or characteristics associated with increased risk of negative impact | | |
| 1. NatureServe Climate Change Vulnerability Index | Classifies species into six categories: six possible scores are Extremely Vulnerable, Highly Vulnerable, Moderately Vulnerable, Not Vulnerable/Presumed Stable, Not vulnerable/Increase Likely, and Insufficient Evidence | Animal and plant species | www.natureserve.org/prodServices/climatechange/ClimateChange.jsp |
| 2. System for Assessing Vulnerability of Species SAVS | Uses a questionnaire format create a score indicating relative vulnerability to expected changes in future conditions | Terrestrial vertebrate species | http://www.fs.fed.us/rm/grassland-shrubland-desert/products/species-vulnerability/savs-climate-change-tool/ |
| 3. EPA Framework | See text | T&E Species | EPA/600/R-09/01 |
| 4. Vulnerability Surface | Uses a three-dimensional analytical surface to determine relative vulnerability | Applicable to variety of systems | Luers 2005; Luers and others 2003 |
| **Habitat and species distribution (e.g., bioclimatic) models** | Use biophysical measures to define climate space of species or communities. | Typically vegetation communities | |
| 1. Climate surface models for plant species* | Use climate surfaces and observed species-climate relationships to predict species distributions | Plant communities and species | Rehfeldt and others 2006; http://forest.moscowfsl.wsu.edu/climate/customData/index.php |
| 3. Genetic Algorithm for Rule-Set Prediction (GARP) niche model | Uses spatial data on temperature, rainfall, and elevation with point data on species range to estimate potential range | Native and non-native species | nhm.ku.edu/destopgarp |
| 4. Maximum entropy (Maxent) Habitat model | Uses set of environmental variables and georeferenced occurrence locations to produce models of species' ranges | Animal or plant species | Philips and others 2006; Elith and others 2011; http://www.cs.princeton.edu/~schapire/maxent/ |
| 5. Random Forest | Classification system that produces robust estimates of species presence. Used in Rehfeldt and others 2006. | Various | Breiman 2001; Cutler and others 2007; http://www.stat.berkeley.edu/~breiman/RandomForests/cc_home.htm |
| 7. Climate FVS* | Models species climate profiles. Users input species profile and elevation to get projected distributions under a variety of climate scenarios | Forests/tree species | http://www.fs.fed.us/fmsc/fvs/description/climate-fvs.shtml |
| ***Biogeochemical models*** | Model changes in climate parameters, including | | |

**Table 8-1.** Continued.

| Type Name | Description | Target/ Scope | Sources/Websites |
|---|---|---|---|
| | temperature and relative humidity. Often inform parameterization of the above class of tools. | | |
| 1. Instantaneous canopy flux model (PnET) | Merge of three computational models that simulate carbon, water, and nitrogen dynamics | Forest ecosystems | Aber and Federer 1992; http://www.pnet.sr.unh.edu /download.html |
| 2. Soil Organic Matter Model (CENTURY) | Simulates nutrient/hydrological flows and includes fire/harvest frequency | Watershed | www.nrel.colostate.edu/proj ect/century5/ |
| 6. BIOCLIM (BIOMAP) | Prediction systems that uses mean monthly climate estimates to predict energy and water balances at specified location | Area defined by user | software.infromer.com/getfr ee-bioclim-download-software |
| 3. Mapped Atmosphere-Plant-Soil systems—MAPSS | Equilibrium model that calculates plant available water and temperature thresholds according to climatic zone, life form, and plant type. | Area defined by user | See Bachelet and others 2001; www.fs.fed.us/pnw/corvaliis /mdr/mapss |
| **Coupled models** | | | |
| ***Dynamic global vegetation models*** | Incorporate vegetation projections and general circulation models (GCMs) with the purpose to inform climate dynamics (e.g., albedo and water evaporation rates) | | Botkin and others 2007 |
| 1. MC1 | Combines CENTURY and MAPSS | | http//www.fsl.orst.edu/dgvm |
| ***Hydrological Models*** | Model changes in ground water, stream flow, evaporation, etc. | | Christensen and others 2008 |
| 1. Regional Hydro-Ecologic Simulation System (RHESSys) | GIS based hydro-ecological model simulates water, carbon and nutrient flow | Watershed | fiesta.bren.ucsb.edu/~rhessy s/setup/downloads/downloa ds.html |
| 2.Sea Level Affecting Marshes Model- SLAMM | Models processes dominating wetland conversion and shoreline modification | Coastal areas | Glick and others 2010; http://www.slammview.org |
| ***Others*** | | | |
| 1. The Terrestrial Observation and Prediction System (TOPS) | Simulation framework—links historical climate data, remotely sensed data, climate projections, and response models | | Nemani and others 2009; http://gcmd.nasa.gov/records /NASA_ARC_TOPS.html |
| 2. Program to Assist in Tracking Critical Habitat (PATCH) | Models species vulnerability by linking landscape pattern and species traits | Ideal for habitat specialists | www.epa.gove/wed/pages/ news/03June/schumaker.htm |
| **Statistical decision support** | Statistical methods to estimate potential response of targets to risk factors and uncertainty. | | Bernliner and others 2000; Prato 2009 |

**Table 8-1.** Continued.

| Type | Name | Description | Target/ Scope | Sources/Websites |
|---|---|---|---|---|
| | 1. Bayesian Analysis Toolkit | Software package that allows users to compare model predictions to data, test model validity, and extract values of free parameters of models. | | http://www.mppmu.mpg.de/bat/ |
| | 2. Treeage Pro | Decision support software that uses various methods to distinguish between models and decisions options | | www.treeage.com/products.index.html |
| | 3. Delphi Decision Aid site | Data gathering tool for forecasting purposes | | armstrong.wharton.upenn.edu/delphi2/ |
| **Conceptual models** | | Qualitative descriptions and diagrams of attributes and processes of concern | Species, habitats or ecosystems | Heemskerk and others 2003; www.fileheap.com/sofware/conceptual_data_model.html |
| **Data sources** | | | | |
| | 1. U.S. Geological Survey's Gap Analysis Program (GAP) | Online tool to aid in analysis and retrieval of species distribution data | Land cover and vertebrate species | http://www.nbii.gov/portal/server.pt/community/gap_online_analysis_tool/1851 |
| | 2. National Atlas | Provide GIS format data on land cover, land use, hydrography, climate, digital elevation models | Varies | http://www.nationalatlas.gov/atlasftp.html |
| | 3. Multi-Resolution Land Characteristics Consoritum | Landcover databases | Bioregions | http://www.mrlc.gov/mrlc2k_nlcd.asp |
| | 4. Vegetation/Ecosystem modeling and analysis Project—VEMAP | Uses historical and future projected climate data, soils and vegetation maps, and a number of process models (Century, biome-bgc, gtec, lpj, mc1, tem) to project communities across the globe | Vegetation types/biomes | Kittel and others 1995, 1996; http://www.cgd.ucar.edu/vemap/ |
| | 5. ClimateWizard | Estimates historical and future temperature and precipitation changes as absolute or percent change | Climate variables | http://www.climatewizard.org/ |

The selection of an appropriate assessment tool depends upon stakeholder objectives (see Glick and Stein 2011). Each assessment tool described in table 8-1 varies in how it may be applied (spatial and temporal scales) to systems and used for adaptation planning. Assessments meant to inform policy makers need to be focused on a key outcome as influenced by multiple stressors (e.g., outcome-based approach described in Luers 2005), whereas assessments that describe biological-based vulnerabilities or encompass multiple outcome variables are likely to be more informative from an ecological and research perspective.

Tools that rank species or habitats can provide relatively quick methods for assessing climate change vulnerabilities. However, summarizing the complexity of climate change impacts into a single variable may limit the application of these methods (Patt and others 2009). Those that rely on species distribution models allow users to visualize potential future conditions and responses, which can aid in adaptation planning. Such modeling efforts often inform the creation process for indices of sensitivity (Bagne and others 2011; Young and others 2011). Caution must be used when selecting and applying these models because estimates of future distributions can be biased and users should be aware of the limitations of scope of chosen tools (Graham and others 2004). Still, those ecosystems that are projected to incur the greatest change should be most vulnerable to climate change. Similarly, ecosystems or species that persist under high annual variations in climate, which can be estimated from some of these analyses, should be more resilient to climate change. Mechanistic models form the basis of many distribution modeling efforts and are useful for projecting future climate conditions relevant to species presence. These tools, as well as those commonly used to guide decision making processes (e.g., conceptual models and statistical decision trees), are often critical components of the assessment process.

### *Assessment Work Within the U.S. Forest Service*

The following is research by RMRS and cooperators relevant to the assessment of biodiversity and ecosystem function in grassland, shrubland, and desert ecosystems of the western United States:

- The U.S. Forest Service is mandated by the Renewable Resources Planning Act (RPA, 1974) to conduct periodic assessments of forest and rangeland resources; since 1990, this includes a requirement to address climate change. RMRS provides technical assistance and analysis for each RPA assessment. The 2000 RPA assessment focused on climate impacts to forest systems, and the 2010 assessment was expanded to include climate impacts on water and wildlife. To see a complete list of RPA climate change publications or further description of ongoing projects, see http://www.fs.fed.us/rmrs/climate-change/assessments or http:/www.fs.fed.us/rm/landscapes/Research/Climate.shtml.
- RMRS scientists are developing an index to assess potential effects of climate change on biodiversity and wildlife habitat. Contact Linda Joyce (ljoyce@fs.fed.us) or Curt Flather (cflather@fs.fed.us) for more information.
- RMRS developed a scoring tool, System for Assessing Vulnerability of Species (SAVS) to climate change (Bagne and others 2011), to assess vulnerability of terrestrial vertebrates to climate change. Using this system, managers can prioritize actions for species conservation and management. This scoring tool is available at http://www.fs.fed.us/rm/grassland-shrubland-desert/products/species-vulnerability/savs-climate-change-tool/.
- Rehfeldt and others (2006) produced maps (http://forest.moscowfsl.wsu.edu/climate/) of current and future vegetation species and biotic communities for North America.

### *Research Needs*

In order to develop and improve application of vulnerability assessment tools and frameworks to the grasslands, shrublands, and deserts of the western United States, research areas should focus efforts to:

- Continue to refine our capacity to identify new community composition; this work has the highest priority because of its relevance to inform future management needs and best courses of action.
- Improve accuracy of models and methods used to generate climate change predictions and habitat suitability maps. This includes continued development and improvement of habitat response models (both mechanistic and correlative) for animal and plant species. In addition, distribution models for forest and rangeland habitats and species should incorporate dispersal mechanisms.
- Develop and refine systems for assessing plant species vulnerability.
- Develop physiologically based models of species occurrence (see Glick and Stein 2011).
- Identify measures of species adaptive capacity (Czúcz and others 2009).
- Build tools to identify synergistic effects of climate change, species interactions, and other disturbances.
- Integrate management scenarios with scenarios for climate change.
- Identify the appropriate framework for analyzing vulnerability with respect to adaptation strategies, including potential application of existing frameworks (e.g., National Center for Ecological Analysis and Synthesis).
- Identify need to develop new frameworks for creating adaptation strategies that integrate vulnerability with management decision processes.
- Complete cost benefit analyses that incorporate multiple scenarios, including the validity of inaction as an option. Passive restoration techniques may be more cost effective and feasible for many areas (Birch and others 2010) and should be considered among management options.
- Identify and implement methods to make tools more available and useful for decision makers.

## Plant Conservation and Restoration

We discuss some of the specific methods and tools used for selecting, collecting, and deploying native plant materials to ensure proper conservation of genetic resources. These activities provide foundation for, and are particularly relevant to, our future capacity under climate change to manage and restore lands with appropriate genetic materials.

### *Approaches and challenges for selecting native plant material*

Historically, restoration activities made use of "off the shelf," agronomically developed, introduced plant materials to fill specific needs (see Monsen and others 2004). This was particularly true in the Intermountain West where semi-arid and arid lands were often especially challenging sites (Monsen and Shaw 2001). These introduced species were developed through selection and breeding programs for improved germination, establishment, reproduction, and quality (e.g., palatability or erosion control)

(Monsen and others 2004). Consequently, native plants that often had complex germination requirements and unique establishment criteria were discriminated against with little research completed on them. The U.S. Forest Service and other Federal agencies are, however, mandated to use genetically diverse, locally adapted native plants to maintain or restore self-sustaining ecosystems to protect the services (e.g., soil stabilization, clean water, and forage) they provide (Johnson and others 2010; USDI and USDA 2002; USDA 2008). With realization of this mandate, emphasis is now being placed on research that identifies functional traits contributing to native plant competitive ability; improves availability of plant materials; reduces plant materials cost; improves techniques for identifying and describing site conditions suitable for native plants; identifies appropriate species or combinations of species for planting; and identifies effective planting strategies (Call and Roundy 1992; James and Svejcar 2010; Johnson and others 2010; Sheley and James 2010).

Paramount for appropriate use of native plants to meet legislative mandates is an understanding of the patterns of genetic (adaptive) variation and structure in the morphology, phenology, and reproduction of native plants across varied landscapes. For commercial tree species, this is relatively well known, but only a paucity of information exists for most other native plants despite a growing need to better manage them (Hufford and Mazer 2003; Johnson and others 2004; Lesica and Allendorf 1999).

When genetic variation and structure are understood, species-specific genetic transfer zones (commonly referred to as "seed zones") can be mapped and transfer guidelines can be developed to describe how far plant materials can be moved from their point of origin and the risks associated with that movement. To properly understand this genetic variation and structure, researchers enlist genecological studies that entail collecting germplasm representing the variety of climatic and environmental conditions present within a large portion or the entire range of the species. These collections are grown in common gardens and evaluated for survival, growth, and reproduction characteristics. The described genetic diversity is correlated to climatic variation among collection sites through regression models and is mapped to provide seed zones. Although seed zones for western conifer species are provided by Rehfeldt (1986), genecological studies and subsequent seed zones for grasses, forbs, and shrubs are more recent and have been achieved for only a handful of native species in the western United States (e.g., Darris and others 2008; Doede 2005; Erickson and others 2004; Horning and others 2010; Johnson and others, submitted; Kitzmiller 2009; Wilson and others 2008). This research is difficult, time consuming, and expensive, so genetic information is lacking for many native plants of interest to land managers.

When genetic information is lacking, however, the current management paradigm is to use plant materials proximal to their point of origin. This "local is best" prescription is supported by a plethora of studies (Johnson and others 2010; Rice and Knapp 2008), but a major disadvantage is defining "local" (McKay and others 2005) and often this paradigm is more conservatively restrictive than needed. Fortunately, a number of climatic and biogeographic tools can be used as surrogates to aid in matching available plant materials to environmental conditions at the planting site. Referred to as provisional seed zones, these estimates of genetic appropriateness do not address the specificity of adaptation that can vary greatly among species. Thus, provisional seed zones are not expected to provide a best fit for all or any species. Their development, based on climate and ecological factors, can, however, provide interim science-based, decision-making support for land managers until empirical knowledge of adaptive variation is obtained and translated into seed zones and transfer guidelines for individual species (Bower and others 2010).

Commonly used surrogates to species-specific seed zones are:

- Ecoregion maps (Bailey 1995, 2009; Omernik 1987) that consider floristic regions, soils, and other parameters. Subdivision level can be selected to provide broad or narrow zones.
- USDA Cold Hardiness Zones are useful for species with distributions limited by minimum temperatures (Cathey 1990).
- Plant adaptation region maps (Vogel and others 2005) that combine ecoregions with USDA Cold Hardiness Zones.
- Climatic models (Bower and others 2010) that combine multiple climatic variables.
- Focal point models that combine biogeoclimatic characteristics of a region and indicate degree of similarity between potential seed collection and planting sites.
- The Data Extraction Tool (Gearrard and others 2006) that permits users to extract information from a number of data layers.
- The Center for Forest Provenance Data, an online database that archives data from long-term provenance tests and seedling genecology tests. The database currently includes only tree data but may eventually be expanded to include other species (St. Clair and others 2010).
- Seed Zones for Native Plants, an online mapping application for provisional and species specific seed zones for plant materials development, gene conservation and native plant restoration (USDA FS WWETAC 2011).
- An online seed transfer decision-support tool (e.g., Seedlot selection tool http://www.fs.fed.us/ccrc/tools/seedlot.shtml) to aid in selecting appropriate seedlots that can be applied to multiple species using multiple climatic variables and various climate change scenarios (B. St. Clair, personal communication).
- Online databases, such as the Web Soil Survey (USDA NRCS 2009), the Ecological Site Information System (USDA NRCS 2010), and climatic databases such as PRISM (Prism climate group 2010), can aid in describing biotic and abiotic characteristics of seed origin and planting sites.

In the Interior West, current genecological-based and provisional seed zone mapping efforts illustrate the climatic complexities associated with western ecosystems; they are much more complex than those found in the eastern half of the United States. Therefore, impacts of climate change and resulting efforts to manage plant communities will be more difficult in the West, particularly the Intermountain West, as boundaries on seed zone maps diverge from the environmental conditions used to create them. Success where underlying conditions are most complex, however, should readily translate to less complicated systems.

### *Managing Collections of Genetic Materials Within Species-Specific and Provisional Seed Zones*

An ecological approach to providing plant materials for use within species-specific or provisional seed zones requires that multiple seed collections of a species be made from diverse locations within the zone, each representing multiple parent plants. Once pooled, the progeny from these collections provide genetically broad-based materials, maximizing the likelihood that some seeds will be pre-adapted to planting site conditions and capable of adapting to future environmental fluctuations, including climate change. This approach also minimizes the potential for inbreeding and outbreeding depression (Johnson and others 2010; McKay and others 2005; Withrow-Robinson and Johnson 2006).

## Selecting Native Plant Material Under Future Climate Scenarios

Climate change may also require movement of genetic material to locations where it currently does not exist. Such anthropogenic movement, referred to as assisted colonization, assisted migration, or managed relocation, may be necessary because climate change is occurring more rapidly than species can adapt and/or disperse along environmental gradients (Warren and others 2001), or anthropogenic activities have narrowed or disrupted natural dispersion corridors (Marris 2008; Minteer and Collins 2010).

## Assisted Colonization

Assisted colonization can be accomplished at two levels: (1) moving discrete genetic resources of a species into a new area already occupied by that species (e.g., moving seeds of warmer ecotypes into areas currently occupied by colder ecotypes), or (2) moving genetic resources of a species into areas where that species does not currently exist.

The first scenario attempts to augment current genetic diversity. For example, a collection of seeds from a high-elevation seed zone could be augmented with seeds from a lower-elevation seed zone in anticipation that the higher-elevation site will become warmer because of climate change. This approach leverages diverse genetic mixtures from within seed transfer zones by incorporating genetic material from adjacent seed transfer zones; leading to the expression of new desired traits.

The second scenario, introducing species into areas where they currently do not exist in order to facilitate their continued existence in response to climate change, has become a lightning rod among ecologists and conservationists. Opponents of assisted colonization cite potential for unintended and unpredicted consequence on the recipient ecosystem, such as creation of new invasive species, disruption of evolutionary and ecological processes at the reintroduction site, and negative genetic interactions between relocated and native populations (Ricciardi and Simberloff 2009; Seddon and others 2009; Vitt and others 2009). Fazey and Fischer (2009) argued that assisted colonization is a short-term fix that ignores causal reasons for plant extinction, and Sandler (2010) stated that ethical, philosophical, and socioeconomic values may not be a justifiable method for preserving, through assisted colonization, the value of a species. Proponents purport that such harmful consequences are overstated, can be managed (Sax and others 2009; Schlaepfer and others 2009), and exceed the consequences of species extinction. In fact, such movement is obligate under the Endangered Species Act (Shirey and Lamberti 2009). Indeed, many scientists see assisted colonization as one part of a multi-faceted solution to conserve and preserve genetic diversity, and decision-support matrices have been suggested for such implementation (Hoegh-Guldberg and others 2008; Hunter 2007; Richardson and others 2009; Vitt and others 2009).

## Assembled Ecosystems

This assisted colonization debate, unfortunately, often fails to recognize the transitory nature, in terms of species composition, of functional ecosystems; current ecosystems have no historic analogs and will, under climate change, probably not persist (Williams and Jackson 2007). Thus, land managers perhaps need not only contemplate moving species to ensure their survival, but contemplate assembling new "ecosystems" representing novel species compositions in order to provide ecosystem function and vital delivery of ecological services (e.g., clean water, fiber supply, and healthy soil) necessary to civilization (Minteer and Collins 2010). In addition, climate change, species introductions, and human activities may cause shifts in land use patterns, thus requiring land managers to conduct adaptive ecosystem management of drastically altered sites (domesticated or severely degraded) back to a naturally sustainable state (Hobbs and others 2006; Hobbs and others 2009; Seastedt and others 2008). Both of these management activities would require a holistic evaluation to maintain a sustainable suite of symbiotic flora, and fauna are present to ensure sustainability.

## *Genetic Transfer Work Within the Forest Service*

The following is ongoing research by RMRS and cooperators in plant materials development and use in grassland, shrubland, and desert ecosystems of the western United States:

- Delineation of provisional seed zones based on biogeoclimatic factors.
- Genecological studies of widespread native grass and forb species.
- Increase of genetically diverse, locally adapted stock seed of native forbs and grasses for provisional and species-specific zones.
- Evaluation of native species existing in long-established stands of exotic species as potential competitive native plant materials (rapid evolution research) (Leger 2008; Mealor and others 2004).
- Identification of selective climatic gradients of importance to big sagebrush distribution and development of climate responsive seed zones for the entire range of big sagebrush.
- Design of a website tool for managers to match big sagebrush seed sources to restoration sites.

## *Research Needs*

The following are research areas for developing genetic transfer guidelines to mitigate climate change impacts in grasslands, shrublands, and desert ecosystems of the western United States:

- Develop risk assessment tools for selecting seeding and planting sites to reduce negative impacts and the incidence of failures.
- Continue development of provisional and species-specific seed zones and seed transfer guidelines.
- Refine tools for identifying and mapping future environments suitable for these species.
- Provide recommendations for developing seed production areas of genetically diverse populations pre-adapted to climatic change and other environmental perturbations.
- Examine autecology and adaptive characteristics of key restoration species and species at risk from climate change and other biotic and abiotic stressors (species that are long-lived, inbreeding, or characterized by small or disjunct populations or species with low genetic variation and rare species).
- Research and develop approaches for managing genetic variation to influence plant response to climate change; enhance and conserve genetic diversity within seed zones; and promote natural migration, gene flow (establish outlier populations) and assisted migration.

- Examine completed research on native species and species specific seed zones for generalizations regarding such areas as specificity in environmental requirements, capacity for in situ adaptation to climate change, and potential rates of migration.
- Provide for *ex situ* and *in situ* conservation.
- Develop a simple, readily accessible tool for nursery managers, seed producers, and land managers to help them move plants across the landscape in a genetically appropriate manner to conserve genetic diversity, facilitate current management decisions, and provide a foundation for reaction to climate change.
- Investigate the intersection of socioeconomic, environmental, and philosophical debate toward a better understanding of the difficult decisions associated with assisted colonization of plants and animals to new locations. A decision support matrix that conceptualizes and quantifies the advantages and disadvantages of assisted colonization is required. Use paleobotanic and paleoclimatic data to further understand and model plant community evolution from the last glaciation to contemporary associations, and how those processes can be leveraged toward ensuring development of new, non-analogous ecosystems under evolving climate conditions.

## RMRS Expertise and Partners

The GSD Program includes a cadre of scientists and their collaborators working with wildland restoration from plant selection, to seed increase, nursery stock production, outplanting, monitoring, and management. Multiple partners are essential for progress due to the large number of plant species and variety of landscapes involved as well as the multidisciplinary nature and immense time commitment of the research. Forest geneticists in RMRS and Pacific Northwest Research Station are now providing leadership for non-conifer genecology research and plant response to climate change. Our current sponsors, collaborators, and partners include: U.S. Forest Service National Forest System Regions 1, 2, 3, 4, 6, and 8, Research and Development, and State and Private Forestry; USDA Agricultural Research Service and Natural Resources Conservation Service; USDI Bureau of Land Management, National Park Service, and U.S. Fish and Wildlife Service; Department of Defense; U.S. Geological Survey; universities; state departments of natural resources; state and private crop improvement associations and foundation seed programs; non-profit organizations; and the native plant and seed industries.

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