Ensuring that Forests are Adapted to Future Climates

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Successful reforestation requires that planted or naturally regenerated seedlings are well suited to a site. Genetic studies of forest trees provide ample evidence of large differences among seed sources in adaptive traits—traits such as the timing of growth initiation and cessation, cold and drought hardiness, and growth rates. Much of this variation is related to the temperature and moisture regimes of the seed sources. In general, seed sources from near a planting site survive and grow well, whereas distant seed sources are often maladapted. These findings are reflected in the wide use of seed zones and seed transfer guidelines that specify using generally local seed sources for reforestation. These guidelines, however, assume that climates are static over the long term, an assumption we now know is unlikely.

Climates are naturally variable. Despite this variability, evidence from multiple sources indicates that global average temperatures have increased over the last century by about 1.3°F. Climates were warmer in the last two decades than at any period during the last 1,300 years. Although different models and different assumptions about future emissions of greenhouse gases result in a wide range of predictions, all projections indicate continued warming. Projections for the Pacific Northwest indicate an average rate of warming of 0.5°F per decade, with a range from 0.2 to 1.0°F per decade (see http://cses.washington.edu/cig/fpt/ccscenarios.shtml). Although projections for precipitation are less certain, warming without significant increases in summer precipitation will result in considerably more drought stress. The rate of warming is unprecedented in historical or recent geological times. Although tree species were able to migrate in response to changing climates in the past, indications are that the rate of migration needed to keep pace with projected climate change is an order of magnitude larger than any evidence for past migration rates.

These predicted changes in climate are bound to have important impacts on forests. In the short-term, forest productivity may increase slightly. Beyond the second half of the century, however, projected increases in warming are expected to result in increasingly maladapted forest stands with accompanying losses in productivity and increased risk of loss from fire and pests. Seed sources adapted to future climates may be found at distant sites, but will likely require human intervention to move populations to locations where they are adapted. For example, in a study of Douglas-fir in Oregon and Washington, we found that populations expected to be adapted to the climate at the end of this century are located 1,500 to 3,700 feet lower in elevation and 130 to 350 miles further south in latitude. This article addresses concerns of the impacts of changing climates on forests by discussing management actions that influence the genetic composition of forest stands to ensure that trees are adapted to future climates.

Planning for climate change

To evaluate management options for responding to climate change, we must first evaluate the risk inherent in climate change. Risk is defined as the product of the probability of occurrence of an event and the impact of that occurrence. Both are difficult to estimate. Although there is a scientific consensus that temperatures will rise, the exact amount of warming is uncertain. Furthermore, we must consider the risk of extremes in climates, including the potential for fall and spring cold events in the near-term, even if the future brings long-term warming. To evaluate the impact of climate trends and extremes, we need to know about genetic variation in adaptive traits. For some species such as Douglas-fir and lodgepole pine, we have good information, but for others, particularly non-commercial species, we know much less.

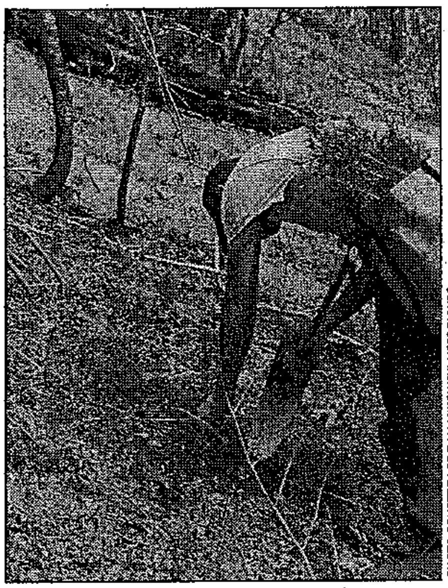
Recommendations for planning for climate change include:

• **Develop your management plans based on your own perspective on risk.** Given the uncertainty inherent in predicting future climates and forest responses, each landowner should evaluate their perspective on risk and needs. Private forest landowners may have different perspectives than state and federal agencies. For some, financial risks may be particularly important, but for others, ecological risks may be their primary concern. Risk includes missed opportunities as well as potential negative impacts. Although the ecological, financial and social risks of different management options should be considered, there is currently insufficient information to quantify these risks accurately.

• **Manage for uncertainty.** Because future climates, forest responses and economic environments are unknown, managing for uncertainty around expected responses is important. Just as one would diversify an investment portfolio for long-term gains, managing forests for uncertainty involves diversification. A diverse approach includes incorporating a diversity of genetic material and stand structures across the landscape. The varied ownerships and management objectives of family forest landowners should contribute to a diversity of approaches at the landscape level.

• **Prioritize species and populations for vulnerability to climate change.** Some species may be less sensitive to climate change than others. For example, western redcedar and western white pine are considered generalists because differences among seed sources are relatively small, but Douglas-fir and lodgepole pine are considered specialists because they have considerable seed source variation that is associated with climate. Populations at the lower elevations and southern boundaries of a species' range may be more vulnerable because there are no populations from warmer environments that can migrate into these areas as warming occurs. Small populations may be more vulnerable owing to low genetic diversity.

• **Monitor for climate change impacts.** Changes in species composition, reforestation problems associated with drought, changes in the tim-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Post-fire restoration may provide an opportunity for reforestation with mixed species or populations adapted to a future climate.

ing of bud flush and bud set, and increased disease and insect problems may all be indicative of climate change. Landowners should monitor their forests and collect the information needed to detect climate change impacts as they occur, and determine what their trigger should be for concluding that management approaches should be changed.

• **Plan your response.** Responses to climate may be 'reactive' or 'anticipatory.' If you plan to react to climate change once adverse effects are observed (i.e., based on your trigger), it would be wise to know exactly what your management responses will be. Some responses may be quick to implement, but others may take years to plan and carry out. For example, fires may provide excellent opportunities to adjust species and seed source composition via planting, but acquiring the appropriate seed sources may require advanced planning. Furthermore, practices may need to be changed to plant new species and seed sources in areas that have been regenerated naturally in the past.

Genetic options for naturally regenerated forests

• **Maintain species and genetic diversity.** Genetic diversity is critical for the capacity of populations to adapt to climate change via natural selection. Species and genetic diversity may be greater in areas of high environmental heterogeneity, such as might be found in mountainous areas with steep elevational gradients.

• **Maintain corridors for gene flow.** Genetic diversity may be enhanced in native forests by promoting gene flow through pollen and seed migration. Introduced genetic variation via gene flow from adjacent stands may increase the frequency of adapted genotypes and allow for natural selection. Forest landowners can help maintain gene flow by preventing fragmentation caused by the conversion of forestlands to other uses.

• **Establish "genetic outposts."** Stands that are expected to be genetically adapted to future climates may be planted adjacent to native forests to increase the potential for migration of pollen and seed into naturally regenerated forests. A small number of genetic outposts may be sufficient, and commercial plantations next to native forests may serve this function. The concept of genetic outposts is a departure from the previous view that 'pollen contamination' was considered detrimental to conservation objectives.

Although naturally regenerated forests may be made more resistant and resilient through silvicultural approaches, plant populations may become increasingly maladapted and unable to keep pace with climate change. Therefore, we should begin thinking about conserving ecosystem functions, not necessarily current ecosystems, and it may become necessary to use artificial regeneration in areas that were formerly regenerated naturally to maintain vital ecosystem functions.

Genetic options for planted forests

• **Create seed banks for vulnerable populations.** Given the potential for loss of species and genetic diversity, it becomes more important to collect

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seed for long-term storage in seed banks. This is particularly true for unique or isolated populations that may be threatened by fire or pests. Although large-scale seed collection and storage may be easier for large landowners and public agencies, family forest owners may contribute by locating and collecting seed from unique or isolated populations.

• **Gradually change species and seed sources for reforestation in anticipation of future warming.** The movement of species, provenances or breeding populations from areas where they currently occur to new sites where they are expected to be adapted in the future is called "assisted migration" or "assisted colonization." Long distance movements, however, involve risk because trees must be adapted to climates now in addition to whatever climates they are exposed to in the future. In the short-term, the risk of cold damage may actually increase because weather extremes may become more frequent, and because warming in late winter and spring may cause seedlings to de-acclimate earlier, making them more susceptible to rare cold events. Nevertheless, it may be wise to begin moving genotypes from warmer to colder environments within existing seed zones, and perhaps across adjacent seed zone boundaries.

• **Mix seed sources to hedge your bets.** The uncertainty of future climates may be mitigated by planting mixtures of seed sources to increase genetic diversity. Mixtures may be deployed at the stand level or they may be deployed across the landscape by planting different areas with different seed sources.

• **Plant at higher densities to allow for natural and human selection by thinning.** Planting mixtures at the stand level may be combined with higher planting densities to allow for higher mortality or the silvicultural thinning of slow-growing trees that show evidence of maladaptation.

• **Plant seedlings that are selected for future climates.** Genetic variation exists for cold hardiness, drought hardiness, growth phenology, and disease and insect resistance, traits that may be important in future climates. For species within tree improvement programs, it may be possible to specifically select for these traits. Breeding programs, however, are long-term and expensive endeavors, and silvicultural options may be more feasible to deal with stresses such as new diseases or insects. Breeding for broadly adapted genotypes may also be possible, although its efficacy has not been tested.

Needed tools and research

With funding from the U.S. Forest Service Global Change Research Program, the authors are currently developing an interactive web-based tool that will allow users to display current seed zones or breeding zones, characterize those zones for climate variables important to the adaptation of a chosen species, and show how those zones may shift given alternative future climate scenarios. Furthermore, a national database for provenance (seed source) test data is being initiated that will ensure that data from many of the earlier provenance tests will not be lost, and will be made available for study in relation to climate change.

The U.S. Forest Service Pacific Northwest Research Station also recently established new long-term field tests in collaboration with several small- to medium-sized forestry companies to test the limits of moving coastal Douglas-fir seed sources. Field tests and short-term seedling studies of geographic variation are needed for unstudied and other key species. Characterizing material in tree improvement programs for adaptive traits will help determine which genotypes will be most valuable for buffering against uncertain future climates. Studies of reproduction and establishment from seed are needed to better understand the consequences of climate change on naturally regenerated forests. Meanwhile, family forest owners may hedge their bets for long-term climate change by paying attention to the seed sources used in reforestation and maintaining ecological and genetic diversity. ■

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