Genetic Options for Adapting Forests to Climate Change

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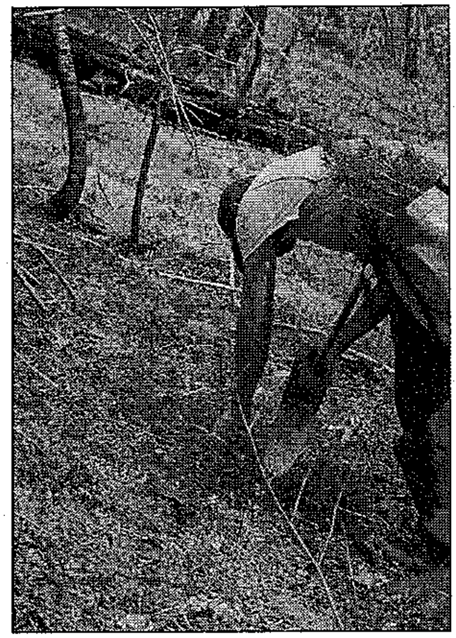
Successful reforestation requires planted or naturally regenerated seedlings that are well suited to the site. Genetic studies of forest trees provide ample evidence of large differences among seed sources in adaptive traits—traits such as the timing of growth initiation and cessation, cold and drought hardiness, and growth rates. Furthermore, much of this variation is related to the temperature and moisture regimes of the seed sources. In general, populations are at or near their optimum for their climates. As a result, seed zones and seed transfer guidelines have been developed and widely used that specify using relatively local seed sources for reforestation. These guidelines, however, assume that climates are static over the long term, an assumption that we now know is unlikely.

The continued use of local seed sources will likely lead to a decline in the health and productivity of both planted and native forests during the next century given projected changes in climate. In a study of Douglas-fir in western Oregon and Washington, the authors found that the continued use of local sources (i.e., current seed zones) would result in a high risk of maladapted stands by the end of the century. Douglas-fir populations expected to be adapted to the climate at the end of this century are located 500-1,000 meters lower in elevation and 2-5 degrees further south in latitude. A study in British Columbia by Tongli Wang and others based on an extensive set of lodgepole pine provenance tests indicated that productivity would increase (up to seven percent) given warming of about 1.5°C, but would substantially decline given greater warming, particularly in southern British Columbia, with some populations being extirpated. Productivity could be increased by as much as 14-36 percent, however, by changing seed transfer recommendations and moving populations to their optimal climates.

Concerns over impacts of climate change on forest productivity and health, and questions about appropriate management responses, led to the formation of the Taskforce on Adapting Forests to Climate Change (http://tafcc.forestry.oregonstate.edu). An accompanying article discussed silvicultural approaches to deal with climate change. This article discusses genetic options including management actions that could be taken to influence the natural or human selection of genotypes, movement of genotypes across the landscape and conservation of genetic diversity.

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



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Post-fire restoration may provide an opportunity for reforestation with mixed species or populations adapted to a future climate.

predict. Although scientific consensus predicts that temperatures will rise, projections for the Pacific Northwest vary considerably (0.1-0.6°C per decade) with a best estimate of 0.3°C per decade (http://cses.washington.edu/cig/fpt/ccscenarios.shtml#anchor2). Although projections for precipitation are less certain, warming without increases in summer precipitation will result in considerably more drought stress. Managers must also 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 organization's perspective on risk.*** Given the uncertainty inherent in predicting future climates and forest responses, each organization should evaluate their perspective on risk and needs. State and federal agencies may have different perspectives than private interests. For some organizations, financial risks may be particularly important, but for others, ecological risks may be their primary concern. Although the ecological, financial and social risks of different management options should be considered, there is currently insufficient information to quantify these risks accurately.

• ***Prioritize species and populations for vulnerability to climate change.*** Some species may be less sensitive to climate change than others. For example, western white pine is considered a generalist because differences among seed sources are relatively small, but Douglas-fir is considered a specialist because it has considerable seed source variation that is associated with climate. Populations at the 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 timing of bud flush because of poor winter chilling, and increased disease and insect problems may all be indicative of climate change. Organizations should monitor their forests and collect the data needed to detect climate change impacts as they occur, and determine what their "trigger" should be for concluding that management approaches should be changed.

• ***Manage for uncertainty.*** One approach to managing for uncertainty is to diversify. A diverse approach includes incorporating both genetic diversity and a diversity of silvicultural approaches across the landscape. The varied ownership and management of forests in the western United States should help.

• ***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, large fires may provide excellent opportunities to adjust species and seed source composition via planting, but acquiring the appropriate seed sources may require years of 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 provides populations with the capacity to adapt to climate change via natural selection. Existing genetic diversity can be conserved by locating reserves in areas of high environmental heterogeneity and high genetic diversity (such as might be found in mountainous areas with steep elevational gradients) and by using silvicultural practices that make stands more resistant to fire and pests, such as thinning or prescribed fire.

• ***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.

• ***Establish "genetic outposts."*** Stands that are 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, organizations should give greater emphasis to seed collections for long-term storage in seed banks. This is particularly true for unique or isolated populations that may be at an increased threat from fire or pests.

- ***Move species and populations to match future climates.*** 'Assisted migration' is 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. Although large movements may not be wise at this time, it may be wise to begin moving genotypes from colder to warmer to environments within existing seed zones, and perhaps across adjacent seed zones.
- ***Mix provenances to hedge your bets.*** The uncertainty of future climates may be mitigated by increasing genetic diversity through planting provenance mixtures. Mixtures may be deployed at the stand level or they may be deployed across the landscape by planting different areas to different provenances.
- ***Plant at higher densities to allow for natural and human selection by thinning.*** Planting provenance mixtures at the stand level may be combined with higher planting densities to allow for higher mortality or the thinning of slow growing trees that show evidence of maladaptation.
- ***Select and breed trees for future climates.*** Genetic variation exists for cold hardiness, drought hardiness, growth phenology, and disease and insect resistance. For species within tree improvement programs, it may be possible to specifically select for traits such as drought hardiness that may be important in the future. Initiating a breeding program can, however, be a long-term and expensive prospect, and silvicultural options may be more feasible for some traits, for example, for 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 test data is being initiated that will ensure that the data from many of the earlier established provenance tests will not be lost and will be made available for study given the new context of climate change.

The USFS Pacific Northwest Research Station is also initiating new long-term field tests in collaboration with several small- to medium-sized forestry companies to push the limits of moving coastal Douglas-fir provenances. Provenance tests and short-term seedling common garden studies are needed for unstudied and other key species. Characterizing breeding populations and genotypes for adaptive traits should help to understand deployment options for tree improvement programs. Studies of reproduction and establishment from seed are needed to better understand the consequences of climate change on native forests. Continued research on genetic variation in response to climate and development of the tools to transfer knowledge of that research will contribute to our ability to act from a base of knowledge about likely outcomes from different management options. ◆

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Citations

St.Clair, J.B. and G.T. Howe. 2007. Genetic maladaptation of coastal Douglas-fir seedlings to future climates. Global Change Biology 13:1441-1454.

Wang, T., A. Hamann, A. Yanchuck, G.A. O'Neill, and S.N. Aitken. 2006. Use of response functions in selecting lodgepole pine populations for future climates. Global Change Biology 12:2404-2416.

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