Silvicultural Approaches to Maintain Forest Health and Productivity Under Current and Future Climates

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Climate modeling based on a variety of scenarios for the Pacific Northwest suggests that over the next century temperatures may increase and that the abundance of summer precipitation may decline. Historically, climate changes at the century scale have been accompanied by adjustments in species population sizes and the composition of vegetation communities. Silvicultural practices may be employed to assist in forest adaptation to climate changes, principally by influencing stand structure and species composition throughout stand development. Forest managers might consider a primary silviculture objective over the next century of increasing forest vigor to increase both resistance and resilience to direct and indirect stresses arising from climate variation.

Plant populations may adjust to climate change in three ways: 1) by expressing an inherent capacity for environmental tolerance by alterations in physiology and development; 2) by migrating to new habitats; or 3) by adaptation in place through natural selection on genetic traits important to survival in the dynamic climate.

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Underplanted **conifers augment natural regeneration in a thinning designed to Increase structural complexity and biotic diversity in a young second-growth Douglas-fir stand in the Oregon Coast Range.**

The relative roles of tolerance or adaptive processes will depend on the biological characteristics of the individual species and the time frame considered. However, changes in climate may occur at rates that provide little opportunity for tree populations to migrate or to evolve in place. While plant species with short generation times may have sufficient opportunity to migrate or to evolve in place over a 100- to 200-year period, this is generally not true for forest trees. The trees living today will likely comprise the forests for the next century or longer. In coastal Douglas-fir forests, for example, stand-replacing natural disturbances typically occur at intervals of 200 years or longer, although disturbances may become more frequent in the future. Long-term adaptation to climate changes will require healthy and productive forests in the short-term-an objective that can be facilitated by silvicultural manipulations.

To address silvicultural and genetic approaches to forest adaptation, a multi -disciplinary and multi -agency team of managers and scientists formed the Taskforce on Adapting Forests to Climate Change (http://tafcc.forestry.oregonstate.edu). The principal role of the task force is to provide public and private land managers with science-based management options for meeting a broad spectrum of objectives under alternative climate change scenarios. This article addresses some of the silvicultural issues and options for adaptation being considered by taskforce partners. Genetic considerations and options for adaptation are discussed in a companion article in this issue.

Silvicultural options to facilitate adaptation

It is important to recognize that it is not simply the changes in average temperature or precipitation, but often the increased variation in extent and timing of climatic conditions that will determine climate-related stresses experienced by forests. For example, a simple increase in average temperature may not induce stress in established forests; however, when combined with decreased summer moisture availability, forests may experience drought resulting in decreased vigor and possibly increased mortality. Alternatively, increased winter temperatures may create mild conditions, yet hinder natural regeneration through failure to meet chilling requirements for seed germination or appropriate timing of budbrealc.

To date, most climate predictions have been made at broad regional scales; the ability to predict changes at finer, site-specific scales is yet to be developed. Thus, forest managers will also need to account for local physiographic influences on weather and site resource availability, particularly in mountainous areas of strong topographic relief.

In adapting forests to climate change, silvicultural options need to be focused on addressing forest vulnerabilities arising from climate change stressors. Vulnerability is the degree to which a forest can be negatively impacted by a climate-related stress or associated disturbance agent. For example, in a regenerating forest, vulnerability may be seedling mortality arising from excessive heat load and moisture deficit. Silvicultural options for the regenerating stand may include providing shade and decreasing the abundance of competing vegetation. In contrast, vulnerabilities in a young, dense stand in the stem-exclusion phase may be insect outbreak or fire, as vigor can decline and waves of mortality may result in fuels loading. In this case, the young stand could be thinned to improve vigor by creating a better balance among the amounts of canopy foliage, soil moisture and evaporative demand. Thus, silvicultural options need to address c1imate-related stressors that vary over time and stage of stand development. This plays to intrinsic strengths of silviculture-the conceptualization of forest stands as developmentally dynamic entities in a landscape context, and scenario building as a means to develop prescriptions and project the influences of management actions to future stand and landscape dynamics.

Active management of forest vegetation may increase forest resistance and resilience to climate changes and mitigate some ecosystem responses to climate changes. Silvicultural practices can be applied adaptively as climate and disturbance regimes change over time. Across the western United States, several long-term, large-scale silviculture experiments are underway that explore the influence of alternative silviculture treatments on ecological structures and processes and the provision of goods and services. These studies can also provide managers scientific knowledge and tools needed to address climate change issues. Based on existing and developing knowledge, the following management options can be recommended:

• *Thin to avoid overstocked stands susceptible to increased mortality from drought, insects, disease and wildfire.* Maintain lower densities of canopy foliage as site resources, particularly soil moisture, become more limiting. Decreased levels of site occupancy will decrease stress and will also decrease fuels loading, thus making forests more resistant to disturbance agents such as insects and fire.

- *Underplant thinned stands with adapted species or genotypes when existing regeneration is unacceptable for future conditions.* Although understory regeneration is often limited in dense second-growth stands, overstory density management may provide opportunities to introduce regeneration better suited to a future climate through underplanting. Although few, there have been studies that provide insight to species or genetic populations that may successfully regenerate under a partial canopy. For example, a comparison of six conifer and two deciduous tree species planted under stands thinned to three different densities has been conducted in the Oregon Coast Range, and a study comparing the performance of underplanted seedlings of various Douglas-fir families is ongoing on the Capital State Forest in Washington.

• *Provide structural features at stand and landscape scales to meet the varying habitat requirements of plants and animals.* Provide diversity of stand structures favoring a greater diversity of species and genotypes across the landscape. This biological diversity underpins forest resilience to disturbance. Furthermore, it is important to recognize the values arising from the ecosystem as a whole and not simply the tree component of forests.

• *Use vegetative buffers to mitigate effects of harvest on stream and riparian microclimates and habitat.* Protect unique in-stream and riparian habitats by maintaining riparian functions of energy and nutrient exchange, filtration, bank stabilization and wood production. Tolerance limits to stream temperatures demonstrated by populations of fishes and other aquatic organisms provide some of the best examples of threshold responses to environmental change.

• *Where practiced, use intensively managed plantations as an opportunity to facilitate the migration of adapted genotypes or species.* Regeneration cycles characteristic of commercial timber production may provide an opportunity to relatively quickly distribute commercial species and genotypes better adapted to future environments.

• *Following disturbance, manage for prompt revegetation with adapted plant communities.* Attain site occupancy with desired species or genotypes before weedy or invasive species establish. Explore options for establishing species or genotypes better adapted to future environments and disturbance regimes. Consideration should be given not only to desired tree species, but also to forb, grass or shrub species that may provide desired community composition.

• *Promote development of mixed-species or multi-prouenance forests.* Decrease risks associated with major pest outbreaks and promote greater genetic diversity and more broadly adapted populations. Consider deploying a mixture of seedlings including some species or provenances adapted to more stressful environments. Areas of transition between forest types and population boundaries may be areas to initially consider for incremental shifts in a species distribution.

• *Monitor the effectiveness of management options.* The efficacy of active management in addressing climate-related stresses will often be site-specific and, therefore, will require follow-up observation for assessment. The objective and value in adaptive management is the accumulation of knowledge across experiences that can be leveraged to develop future innovations.

Challenges to existing silviculture tools

Although a wealth of information and experience exists from which to craft innovative management practices addressing climate-related stresses, there are emerging challenges to some of our basic silvicultural tools.

Site index has been fundamental to projecting potential forest growth and productivity. These indices describing relationships between tree size and age are assumed to be relatively constant characteristics oflocation. However, growth patterns over time may become unstable with rapid changes in climate. In recent years, plant associations have been defined to classify forest sites in terms of potential vegetation community development. Such plant associations have been incorporated as proxy measures of site productive potential in some forest growth simulation models (e.g., Forest Vegetation Simulator). However, as species respond differently to climate changes, there is likely to be a reorganization of species assemblages that may not be recognized under current classification schemes. Thus, use of plant associations to provide a stronger ecological link to the empirical indices of site productivity may also become less useful.

Silviculturists and other resource managers rely on models to project forest development and productivity into the future. Existing models are predominantly driven by empirical growth and yield relationships that inherently assume a constant environment. A major challenge to silvicultural adaptation of forests is to develop new forest growth and development models that explicitly incorporate dynamic climate changes to better predict forest composition and productivity under alternative future climate and management scenarios.

Thoughtful, innovative application of existing silvicultural principles and practices are likely to benefit forest vigor and therefore forest resistance and resilience to climate change stressors for some time into the future. We can draw on a wealth of scientific and practical knowledge gained through a century of forest research and management to develop innovative management schemes that address emerging climate-related stresses. Adaptively applying these innovations will facilitate future adjustment to ecological and social changes. •

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