IUFRO
Proceeding
Breeding and Genetic Resources of Five-Needle Pines:
Ecophysiology, Disease Resistance and Developmental Biology
Yangyang, Korea 2008

Sustaining *Pinus flexilis* Ecosystems of the Southern Rocky Mountains (USA) in the Presence of *Cronartium ribicola* and *Dendroctonus ponderosae* in a Changing Climate

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Limber pine, *Pinus flexilis* James, is characterized by a patchy distribution that displays metapopulation dynamics and spans a broad latitudinal and elevational range in North America (Webster and Johnson 2000). In the southern Rocky Mountains limber pine grows from below the forest-grassland ecotone up to the forest-alpine ecotone, from ~1600 m above sea level in the short grass steppe to > 3300 m at the continental divide (Schoettle and Rochelle 2000). In this region, limber pine's altitudinal range is wider than any of its co-occurring tree species. Limber pine ecosystems serve a variety of important ecological roles, such as (1) occupying and stabilizing dry habitats, (2) defining ecosystem boundaries (treelines), (3) being among the first tree species to colonize a site after fire, (4) facilitating the establishment of late successional species and (5) providing diet and habitat for animals (Schoettle 2004).

Limber pine appears to have very broad environmental tolerances (Schoettle and Rochelle 2000) and may therefore be expected to adjust to a changing climate via migration of populations or acclimation within populations. Assuming full dispersal, some models (McKinney and others 2007) suggest that limber pine will increase its area of distribution yet populations will shift northward and, although not modeled, presumably to higher elevations (Aitken and others 2008). These projections however only consider direct impacts of climate on the species' distribution and do not account for novel stresses such the presence of *Cronartium ribicola*, the non-native fungus that causes white pine blister rust (WPBR), or the warming trend driven expansion of the distribution of the mountain pine beetle (*Dendroctonus ponderosae* Hopkins), both of which will further affect population sustainability.

Within species genetic variation is the foundation for survival and evolution in the face of threats such as WPBR, mountain pine beetle (MPB) and climate change. The full suite of adaptive and life history traits and biotic interactions need to be considered when developing management options to sustain this ecologically important species into the future. Unfortunately, range-wide common garden studies have not been done to evaluate genetic variation in limber pine, but indications of geographic variation have been noted (Jorgensen and others 2002; Mitton and others 2000; Steinhoff and Andresen 1971). Provisional seed transfer guidelines for limber pine define five zones in the Interior West and recommend limiting the elevational movement within each zone (Mahalovich 2006).

Sustaining limber pine populations in the face of novel stresses will require maintenance of high genetic diversity and a functioning regeneration cycle (Figure 1). Proactive management to position the ecosystem and the regeneration cycle for resiliency will enable the ecosystem to continue to function and provide opportunity for the populations to adapt. Stimulating natural regeneration will increase the number of genetic combinations on the landscape, providing a higher probability of unique combinations that prove to be adaptive. In the case of WPBR, increasing the frequency of resistance traits in the pine population prior to rust invasion will uphold the regeneration cycle as the resistant seedlings will mature before the susceptible mature trees die therefore ensuring the presence of seed-bearing trees even during the period of maximum mortality (Schoettle and Sniezko 2007). The presence of MPB imposes an additional stress as the beetles preferentially kill the mature seed-bearing trees in the populations. Infusing the

In: Noshad David; Noh Eun Woon; King, John; Sniezko, Richard A. (Eds. 2009) Breeding and Genetic Resources of Five-Needle Pines. Proceedings of the Conference 2008, Yangyang, Korea. Korea Forest Research Institute, Seoul 104p. ISBN 978-89-8176-605-4 (93520)

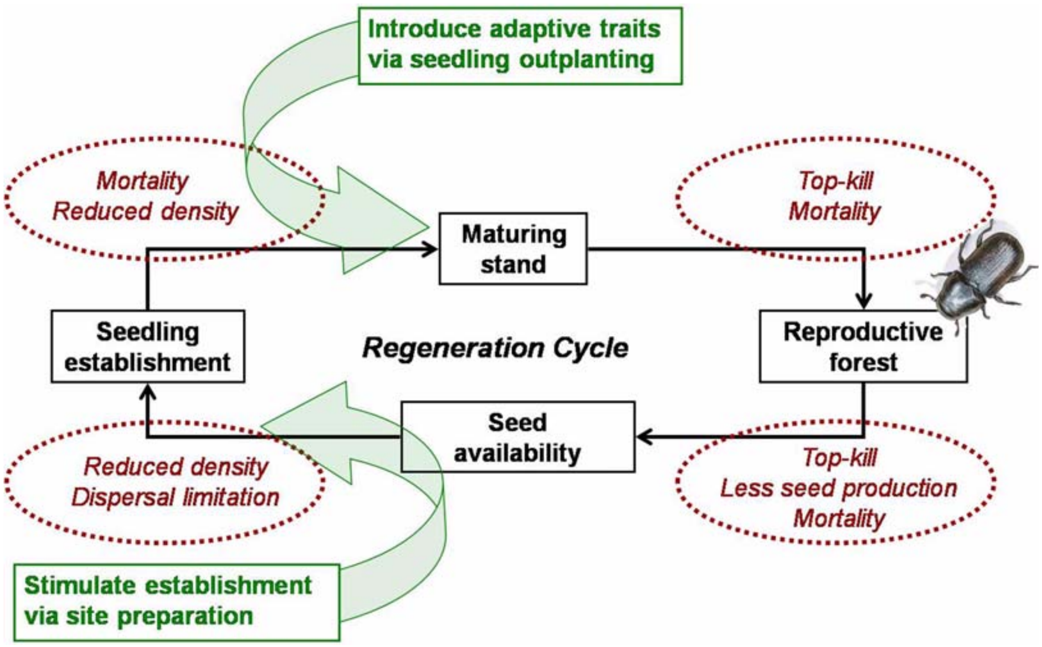

Figure 1. Forest regeneration cycle. White pine blister rust can cause impacts at all stage (ovals) and the mountain pine beetle preferentially kills larger trees. Broad arrows depict intervention options for increasing population resiliency under the threat of novel stressors. (Redrawn from Schoettle and Sniezko 2007).

regeneration cycle with adaptive traits and accelerating generation times will increase the capacity of these slow growing long-lived species to adapt (Schoettle and Sniezko 2007) and help increase the resiliency of populations to the rust and other novel stresses such as those that will accompany climate change (Figure 1).

Resistance to WPBR in limber pine is essential to the future of limber pine populations given the lethality of the disease and its continued spread. As in several other native white pine species, limber pine most likely possesses several types of rust resistance. Screening for complete resistance (canker-free trait) is rapid (~2 yrs) compared to the assessment of partial resistance traits (~7 yrs). Geographic variation in complete resistance, which leads to moderate levels of canker-free seedlings, has been observed in several species (Kinloch and Davis 1996; Kinloch and others 2003; Sniezko, unpublished data; Sniezko and others 2007) suggesting a possible correlation with other adaptive traits or evolutionary legacies. Partial resistance mechanisms in whitebark pine (*P. albicaulis*) have also been shown to vary geographically (Mahalovich and others 2006; Sniezko and others 2007) and in one study their frequency has been noted to be inversely related to cold hardiness, supporting the hypothesis that rust resistance may not be independent of other adaptive traits (Mahalovich and others 2006). Evidence for an association between disease resistance and adaptive traits has been shown in other pathosystems (e.g. Tauer 1978; Powers and Matthews 1980).

Complete resistance to WPBR in limber pine has been evaluated in a limited number of sites and varies among sites from a frequency of 1 to 29%; the data suggest a greater frequency of resistance in higher than lower elevation populations and higher frequencies of rust resistance in populations in Northern Colorado than elsewhere in the Southern Rockies (Schoettle, Sniezko and Burns, unpublished data). Assessment of the frequency of the partial resistance mechanisms in limber pine is underway (Schoettle, Sniezko and Pineda in process). Ultimately, the frequency of resistance to WPBR and its distribution will provide further guidelines for effective conservation and restoration.

Regrettably, the same populations where rust resistance was found are also experiencing a MPB epidemic. It is estimated that MPB infestations will put most of these populations at risk (Gibson and others 2008). *In situ* and *ex situ* genetic conservation methods are being used to ensure that a mosaic of populations in the Southern Rockies with rust resistance survives the MPB epidemic thus providing opportunities for adaptation to climate change in the future. Each of these three stressors justify urgency for intervention, but the coincidence of the MPB epidemic in populations with rust resistance adds further necessity for expedient technology development.

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