White Pine Blister Rust Resistance in *Pinus monticola* and *P. albicaulis* in the Pacific Northwest U.S. – A Tale of Two Species

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Western white pine (*Pinus monticola* Dougl. ex D. Don) and whitebark pine (*P. albicaulis* Engelm.) are white pine species with similar latitudinal and longitudinal geographic ranges in Oregon and Washington (figs. 1 and 2). Throughout these areas, whitebark pine generally occurs at higher elevations than western white pine. Both of these long-lived forest tree species are highly susceptible to white pine blister rust, caused by the non-native fungus *Cronartium ribicola*, and both have suffered extensive mortality in many parts of their range (Aubry et al. 2008, Fins et al. 2001, Geils et al. 2010, Schwandt et al. 2010). The high susceptibility of these two species to blister rust has limited their use in reforestation and restoration. In July 2011, due to multiple threats, including blister rust, whitebark pine was added as a candidate species eligible for protection under the United States Endangered Species Act and assigned a listing priority number of 2, which means the threats are of high magnitude and are imminent (U.S. Fish and Wildlife Service 2011). Gene conservation efforts with whitebark pine are underway (Mangold 2011; Sniezko et al. 2011b).

Genetic diversity and genetic resistance to pathogens and insects are a species' primary defense and avenue to evolving in the face of threats such as blister rust and climate change. Several operational programs in forest tree species to utilize this natural genetic resistance to help mitigate the impacts of invasive pathogens are well underway (Sniezko 2006; Sniezko et al. 2011a). Active research and management to identify and utilize the low frequency of genetic resistance to blister rust within western white pine and whitebark pine populations offers the best potential for successful long-term reforestation or restoration. Planting resistant seedlings will likely be necessary to retain these white pine species as viable components in many ecosystems (Fins et al. 2001, Harvey et al. 2008, Keane and Schoettle 2011) and to help increase the frequency of the resistance genes throughout the range. In the Pacific Northwest, an operational program to find and utilize naturally occurring genetic resistance in western white pine has been ongoing for more than 50 years, while the program for whitebark pine has been in progress for only a decade (Kegley and Sniezko 2004; King et al. 2010; McDonald et al. 2004; Sniezko et al. 2007, 2011a). However, the program for whitebark pine has benefited greatly from the existence of facilities and expertise in use for the western white pine program.

For both species, parent trees are rated for resistance based on performance of their seedling progeny in artificial inoculation trials. In the first cycle of selection and testing, using wind-pollinated seed from selections in the forest, progeny of over 4,200 parent trees of western white pine have been evaluated for resistance, and progeny of 360 parent trees of whitebark pine have been evaluated or are currently in testing. Resistance screening of hundreds of additional whitebark pine seedling families is anticipated in the next 5 years. After inoculation, seedlings are assessed annually for up to 5 years to examine genetic variation in a range of resistance types, including number of needle lesions ('spots'), type of needle spots (normal or hypersensitive-like response, HR), number of stem symptoms, type of stem symptoms (normal cankers or bark reactions), timing of stem symptom appearance, and severity of infection (Kegley and Sniezko 2004; Sniezko et al. 2007, 2011a).

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Although western white pine and whitebark pine inhabit similar geographic distributions in the Oregon and Washington portions of their geographic ranges, there are both similarities and differences in their resistance to blister rust. Nearly 100 percent of the seedlings of both species develop needle spots in artificial inoculation trials at the U.S. Department of Agriculture, Forest Service's Dorena Genetic Resource Center (DGRC) in Cottage Grove, Oregon. Ninety to 100 percent of the seedlings in the most susceptible families develop stem infections, usually within 8 to 24 months after inoculation (Kegley and Sniezko 2004; Sniezko et al. 2007, 2011a). Progeny of a small percentage of western white pine parents from western Oregon show signs of a hypersensitive-like response in the needles (HR) (Kinloch et al. 1999, 2003), but no whitebark pine with HR have been noted to date (Sniezko, unpublished data[2]). In western white pine, HR appears to be present only in western Oregon and in parts of California, and virulence to this resistance has been documented in parts of the range (Kinloch et al. 2003, 2004).

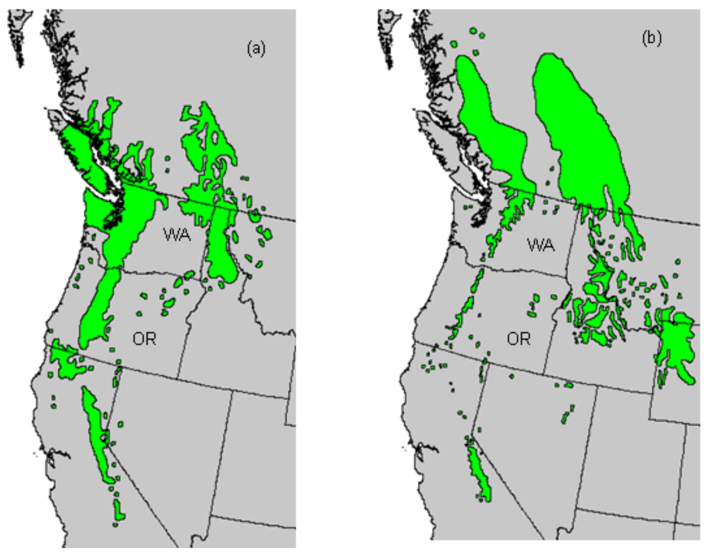

Figure 1—Range maps for (a) western white pine (*Pinus monticola*) and (b) whitebark pine (*P. albicaulis*) (adapted from U.S. Geological Survey 1999).

Moderate levels of other types of resistance, such as canker-free (and not HR) and bark reaction, are relatively rare in wind-pollinated seedling families of western white pine from parents selected in Pacific Northwest forests (Kegley and Sniezko 2004). Only a few non-HR families of western white pine show canker-free levels of >30 percent in the seedling testing at DGRC (Kegley and Sniezko 2004, Sniezko 2006; Sniezko and Kegley 2003a, 2003b). This is in contrast to whitebark pine, which appears to have a higher frequency of progenies with moderate levels of canker-free seedlings (Kegley et al., Blister rust resistance among 20 families of whitebark pine, *Pinus albicaulis*, from Oregon and Washington – early results from an artificial inoculation trial, these proceedings; Sniezko et al. 2007, 2011a). Preliminary summary of the early trials of whitebark pine families indicate that the highest frequency of parents with moderate levels of canker-free seedlings occur in the Cascade Range from central Oregon to central Washington, with a much lower frequency of resistance in eastern Oregon (Kegley et al., Blister rust resistance among 20 families of whitebark pine, *Pinus albicaulis*, from Oregon and Washington – early results from an artificial inoculation trial, these proceedings; Sniezko et al. 2007, 2011a). In some of these areas, many of the families tested have 20 to 50 percent (or more) canker-free seedlings (Sniezko, unpublished, see footnote 2). The highest resistant (and non-HR) families of both species show several common resistance attributes including

[2] Unpublished data from blister rust testing at Dorena GRC – 2004 and 2007 trials. On file: USDA Forest Service, Dorena Genetic Resource Center, Cottage Grove, OR 97424.

a lower frequency of seedlings with cankers, more latent infections, more bark reactions, and longer time to mortality (Sniezko and Kegley 2003a, Sniezko et al. 2007). Only a small number of seedlots of whitebark pine from outside Oregon and Washington have been tested at DGRC and none of these seedlots show the level of resistance exhibited by many of the seedlots from the Cascade Range (Sniezko et al. 2011a; Sniezko, unpublished, see footnote 2).

Figure 2—(a) whitebark pine (WBP) at Crater Lake National Park, (CRLA), (b) western white pine (WWP) at CRLA, (c) WBP in eastern Oregon, (d) WBP with blister rust at CRLA, (e) blister rust susceptible and resistant WBP seedling families in rows in rust resistance testing, (f) dead WWP with >100 rust cankers, directly adjacent to WWP field trial in southern Oregon. (Photo credits: Richard Sniezko: a, b, d, e, f; Chris Jensen: c)

It is encouraging that both western white pine and whitebark pine show family variation in resistance to *C. ribicola*. For both species, more information is needed on the number of resistant mechanisms and their inheritance as well as their expected efficacy and durability in the presence of an evolving pathogen and a changing climate. For western white pine, breeding zones are established, seed orchards are producing seed, breeding to increase resistance is underway, and a large number of field trials have been established (see Sniezko et al., White pine blister rust resistance of 12 western white pine families at three field sites in the Pacific Northwest, these proceedings, for results from some field trials). For whitebark pine, seed zones have been established (Aubry et al. 2008) and land managers will be notified about which parent trees show resistance to facilitate additional seed collection for restoration; a few small field trials have recently been established. For both species, the field trials will serve to help validate the results of artificial inoculation trials, to provide land managers with updated information on efficacy of rust resistance over a range of sites, and to monitor for changes in durability of resistance or changes in general health of the species with changing climate. The parent trees selected previously in the field will be rated for resistance based on their progeny rust resistance, and they can serve as valuable long-term monitors of changes in efficacy of resistance over time or changes in virulence of the pathogen.

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