# CHAPTER 12.

## Monitoring the Health of *Pinus strobiformis*: Early Impacts of White Pine Blister Rust Invasion

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## INTRODUCTION

Southwestern white pine (*Pinus strobiformis*, abbr. PIST), a tree native to Arizona, New Mexico, and western Texas in the U.S. Southwest (Little 1971), is threatened by a potentially lethal invasive fungal pathogen, *Cronartium ribicola* (white pine blister rust, abbr. WPBR) (Conklin and others 2009). Researchers detected the disease around 1990 in New Mexico's Sacramento Mountains (Hawksworth 1990), where it has since infected as much as 40 percent of the PIST population and inflicted increasing mortality (Conklin and others 2009). By 2004, WPBR was observed in PIST in New Mexico's Gila Mountains, and in 2009, researchers identified the first infected trees on the Fort Apache Indian Reservation in the White Mountains of Arizona (Fairweather and Geils 2011).

The purpose of this study was to provide a scientific basis for managing the WPBR invasion in Arizona and New Mexico by extending previous research on PIST ecology and documenting the distribution and effects of WPBR on PIST. Specifically, our objective for the research presented here was to determine the present distribution of WPBR and other damaging agents in less-investigated areas of Arizona and New Mexico, and how WPBR has impacted trees within infected areas. This research has been published as part of a M.S. thesis at Northern Arizona University (Looney 2012), with portions also published in the peer-reviewed literature (Looney and Waring 2012, 2013).

## METHODS

### Study Areas

We investigated mixed-conifer stands on the Coconino, Apache-Sitgreaves, Coronado, Gila, and Santa Fe National Forests of Arizona and New Mexico, and the Fort Apache Indian Reservation of Arizona (fig. 12.1). We based sampling on Forest Service, U.S. Department of Agriculture stand examination data, or permanent plot data where stand exam data were unavailable. Sampling intensity was based on the availability of stand data and time constraints. Sampling was more intense in eastern Arizona due to abundant stand data, as well as our goal to better characterize WPBR in this recently discovered infection center. We sampled only stands with PIST basal areas ≥6.9 $m^2 ha^{-1}$ and avoided sampling adjacent stands to better characterize the landscape. To generate one random point per stand, we used stratified sampling in Hawth's tools in ArcGIS® 9.3.1 (ESRI 2009) and fTools in QGIS® 1.6.0. (Quantum GIS Development Team 2011). At each point, we installed a single 0.1-ha plot (20 m by 50 m). Each plot included at least five PIST ≥12.7 cm diameter at breast height (1.37 m, d.b.h.) or was randomly relocated. Plots were oriented with the short axis downhill to minimize elevation change. Each plot was subdivided into three 10 m by 10 m and 5 m by 5 m nested subplots (combined area = 0.03 ha and 0.0075 ha, respectively) for measuring saplings (trees <5.0 inches d.b.h. and >1.37 m height), and recording seedlings (trees <1.37 m height), surface cover, and counts of

*Ribes* plants. We installed 59 plots between 2010 and 2011 (fig. 12.1). Detailed descriptions of plot installation can be found in Looney (2012) and Looney and Waring (2012). We examined additional stands for WPBR infection and other damaging agents in PIST (hereafter 'walk-through surveys') based on the same stand exam data. Across the Southwest, soils are commonly derived from basalt and other volcanic materials, but coarse-grained igneous, sedimentary, and metamorphic parent materials are present (Laing and others 1987, Miller and others 1995). The climate is generally characterized by cold, wet winters and a summer monsoon precipitation pattern (Sheppard and others 2002).

We identified major abiotic and biotic damaging agents of live overstory PIST. We rated dwarf mistletoe infections using Hawksworth's (1977) dwarf mistletoe rating system and examined all trees of sapling size or larger for signs of both *Atropellis piniphila* canker (a native pathogen with similar signs and symptoms to WPBR) and WPBR. We relied on aecial blisters on PIST as signs of WPBR (Tainter and Baker 1996) from mid-May through mid-July. We also considered trees infected if they bore at least three of the main five WPBR symptoms: flagging, animal chewing, resin flow outside the bark, roughened bark on young trees, and stem or branch swelling (Tomback and others 2005). For all infected overstory trees, we recorded canopy dieback (percent of crown affected by recent death of shoots and branches) using ocular estimates aided by crown profiles drawn on transparent crown grids (Millers and others

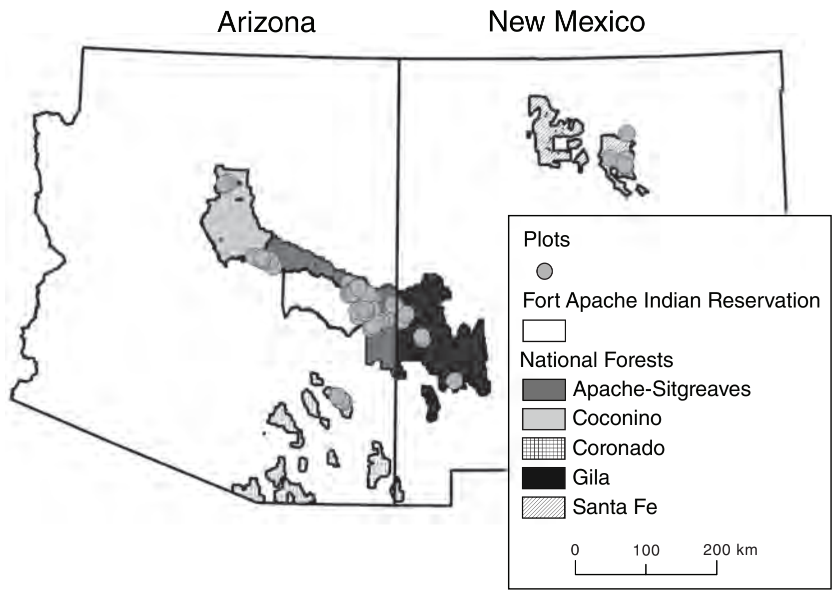


*Figure 12.1—Context map of Arizona and New Mexico showing the* Pinus strobiformis *plot locations established for this study. Locations were within the National Forest System except for the Fort Apache Indian Reservation in Arizona.* P. strobiformis *found on the Santa Fe National Forest and northern Coconino National Forest are of uncertain taxonomy and may represent intergradation with* P. flexilis *(Conklin and others 2009, Little 1971). Reprinted from Looney and Waring (2012) with permission from Elsevier.*

1991, Schomaker and others 2007). We divided each tree into three location categories to record canker location: (1) branches, (2) bole, and (3) branches and bole (Arvanitis and others 1984). We did not count cankers due to the large size of many overstory PIST trees and high potential for missing cankers within the upper crown area. We then classified canopy dieback location using the following categories:

0 = no shoot death, 2 = top ¼ of crown, 3 = top ½ of crown, 4 = bottom ½ of crown, 5 = middle crown only, and 6 = entire crown (Innes 1993). We used a rating of leader condition based on Innes (1993): 1 = normal, 2 = shorter than side branches, 3 = dead, 4 = missing, 5 = replaced by side branches, or 6 = exhibiting complete loss of apical dominance. For saplings, we recorded WPBR presence/absence and, if present, WPBR canker location. We did not record WPBR on seedlings. Walk-through stand surveys were limited to presence/absence of WPBR, dwarf mistletoe, and *Atropellis*. We quantified canopy dieback and leader condition for a subsample of 16 trees on uninfected plots for comparison with infected trees. We tested whether canopy dieback was higher in infected trees using a two-sample t-test with unequal variances. We tested whether leader condition was poorer in infected trees using a two-sample Mann-Whitney U test, as those data were non-normal but had comparable variances.

## RESULTS

Site characteristics varied (Looney and Waring 2012) and reflected a variety of past management and disturbance histories, including recent mixed-severity fire. Damaging agents of living PIST, including WPBR, were fairly rare and only affected 3.7 percent (S.E. = 0.7) of PIST basal area (fig. 12.2). White pine blister rust was the most common damaging agent, followed by animal damage at 3.2 percent (S.E. = 0.6) and fire at 2.8 percent (S.E. =0.5), though no significant differences were found between these three agents. The majority of animal damage was partial-to-complete girdling from black bear clawing, with minor ungulate antler rubbing on small trees. Fire damage included both old and recent fire scars, as well as crown scorch on several recently burned plots. Abiotic damage agents included lightning damage and sun scald. Logging damage included minor bole and branch damage associated with operations. Bark and twig beetle damage was highly uncommon on living trees.

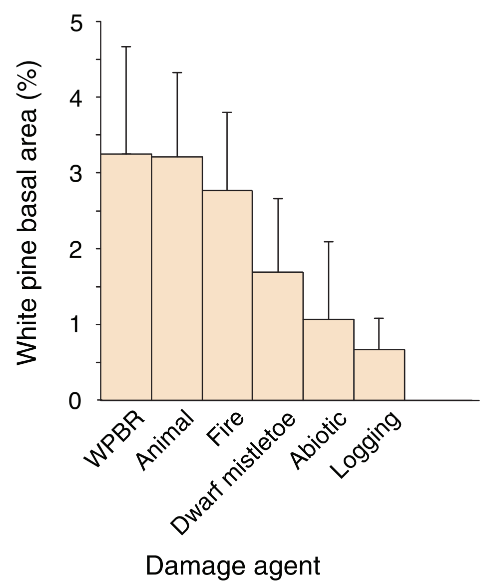


*Figure 12.2—Major damage to live southwestern white pines by damaging agent and percent total basal area (mean + 1 standard error). The most common abiotic damages included sun scald and crushing. Reprinted from Looney (2012). WPBR= white pine blister rust.*

Dwarf mistletoe (*Arceuthobium apacheum*) occurred on 6.7 percent of plots (fig. 12.2), with an average dwarf mistletoe plot rating of 2.7 (S.E. = 0.6). *Atropellis piniphila* affected four trees on just one plot on the Alpine Ranger District of Apache-Sitgreaves National Forest, AZ. We also found *Atropellis* cankers on saplings adjacent to two plots on the Mogollon Rim district of Coconino National Forest, AZ. Dwarf mistletoe, *Atropellis*, and WPBR did not co-occur on any plot. We found WPBR infection on 18.3 percent of plots sporadically distributed on the Fort Apache Indian Reservation, Apache-Sitgreaves National Forest, and Gila National Forest (fig. 12.3). While affecting 3.3 percent (S.E. = 0.7) of live PIST basal area (fig. 12.2), WPBR infected 4.4 percent of trees $ha^{-1}$ (S.E. = 1.6). Considering only trees within infected plots, WPBR incidence was 22.9 percent of total PIST trees $ha^{-1}$ (S.E. = 6.1).

We performed an additional 23 walk-through surveys for WPBR, dwarf mistletoe, and *Atropellis* (fig. 12.3). Four of these stands were infected with WPBR (17.4 percent), while an additional four were infected with dwarf mistletoe (fig. 12.2). We did not find any additional stands with *Atropellis* infection. All WPBR detections were within the White Mountains region of Apache-Sitgreaves National Forest, AZ. We detected dwarf mistletoe on the White Mountains area of Apache-Sitgreaves National Forest and scattered across Gila National Forest, NM. We made an additional nine incidental detections of WPBR in addition to planned plot measurements or walk-through surveys (fig. 12.3).

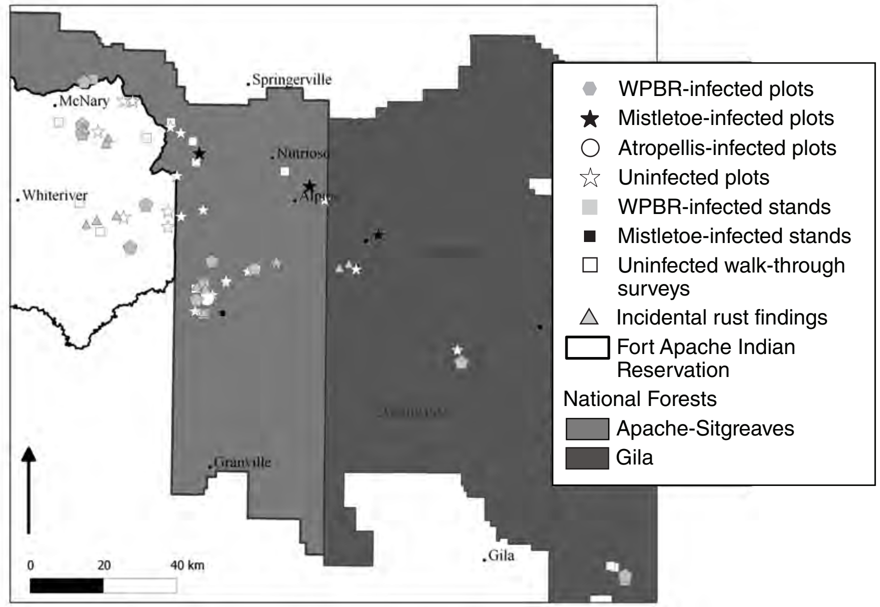


*Figure 12.3—Detail of eastern Arizona and western New Mexico showing white pine blister rust (WPBR) detections (other surveyed areas not shown; see fig. 12.1 for all plot locations). Stands are distinguished from plots, as several stands were visited for determining WPBR presence/absence only. In one stand that contained a plot, we found infected trees but these were not located on the plot. Dwarf mistletoe detections are reported for* Arceuthobium apacheum *infections on* P. strobiformis *only. Adapted from Looney (2012).*

Within the 11 WPBR-infected plots, we found a total of 31 infected trees (table 12.1). Infection incidence varied by 10-cm diameter class, with most infected trees smaller than 40 cm (table 12.1). Cankers were most common on branches (canker location = 1), with few trees displaying infections on bole (canker location = 2) or both boles and branches (canker location = 3). Canopy dieback was slight, but

**Table 12.1—Characteristics [mean (standard error)] of *Pinus strobiformis* within 11 plots with white pine blister rust-infected trees on Apache-Sitgreaves National Forest, Gila National Forest, and the Fort Apache Indian Reservation, Arizona and New Mexico**

| Diameter class midpoint | Total N PIST | Incidence | Canker location[a] | Canopy dieback[b] | Dieback location[c] | Animal[d] | Leader cond.[e] |
|---|---|---|---|---|---|---|---|
| *cm* | | *%* | | *%* | | *%* | |
| 5 | 15 | 26.7 | 0.0 (0.0) | N/A | N/A | N/A | N/A |
| 15 | 24 | 41.7 | 1.0 (0.3) | 4.4 (1.7) | 3.1 (0.8) | 11.1 (0.1) | 0.6 (0.6) |
| 25 | 28 | 21.4 | 1.3 (0.3) | 4.8 (2.7) | 4.2 (0.6) | 0.0 (0.0) | 1.3 (1.0) |
| 35 | 24 | 29.1 | 1.3 (0.3) | 5.8 (0.9) | 4.6 (0.4) | 14.3 (0.1) | 2.3 (0.9) |
| 45 | 9 | 11.1 | 1.0 (0.0) | 6.5 | 6 | 0 | 1 |
| 55 | 3 | 66.7 | 1.0 (0.0) | 5.0 (1.0) | 5.0 (0.0) | 0.0 (0.0) | 0.5 (0.5) |
| 65 | 6 | 0 | N/A | N/A | N/A | N/A | N/A |
| 75 | 1 | 0 | N/A | N/A | N/A | N/A | N/A |
| 85 | 1 | 100 | 1 | 0 | 4 | 0 | 6 |

N/A= not available.

Note: Southwestern white pines are pooled (Total N PIST), both infected and uninfected, across all 11 plots and by 10-cm diameter class. Incidence refers to white pine blister rust-infected trees as a percentage of PIST by diameter class; animal refers to animal chewing; leader cond. refers to leader condition. Incidence, canker location, canopy dieback, dieback location, animal chewing, and leader condition statistics are calculated for the pooled sample of infected trees only and do not represent inter-plot variability, as not all size classes were present on individual plots. As a result, standard error cannot be calculated for incidence.

[a] (1) branches; (2) bole; (3) branches and bole (Aravanitis and others 1984).

[b] Percent of crown affected by recent death of shoots and branches (Schomaker and others 2007).

[c] Location of canopy dieback within live crown. Excludes bole and isolated, low branches (Innes 1994). Classifications are as follows: 0 = no shoot death; 2 = top ¼ of crown; 3 = top ½ of crown; 4 = bottom ½ of crown; 5 = middle crown only; 6 = entire crown.

[d] Evidence of small rodent chewing on infected tissues.

[e] Rating of leader damage: 1 = normal; 2 = shorter than side branches; 3 = dead; 4 = missing; 5 = replaced by side branches; 6 = complete loss of apical dominance. Adapted from Innes (1993).

Source: Adapted from Looney (2012).

tended to be dispersed throughout the live crown. Infected trees did not show significantly more dieback than uninfected trees ($t = 0.33$, $p = 0.747$). We detected few cases of animal chewing (7.7 percent). Leader condition was generally unaffected by WPBR, with topkill or disfigurement (ratings >2) rare (table 12.1), and WPBR infected trees did not show significantly poorer leader condition than uninfected trees [$w = 346$, $p = 0.6189$ (adjusted for ties)]. There were no apparent relationships between disease incidence, canker location, and canopy dieback with increasing PIST diameter.

## DISCUSSION

Serious damaging agents were rare in PIST. Black bear damage, involving the partial or complete girdling of trees, was the most common form of major animal damage and was generally confined to the White Mountains of Arizona. Black bear damage occurs as a result of the bear feeding on sugary resin and can increase at low stand densities (Nolte and others 2003), though we did not investigate the relationship between bear damage and stand density in our data. Fire damage was also common in mature trees on burned plots, but actual mortality was rare, supporting previous evidence that PIST is fire tolerant when mature (Dieterich 1983). Dwarf mistletoe was fairly uncommon but widespread, with detections in several disjunct PIST populations. Overall incidence of both dwarf mistletoe and *Atropellis* canker were low, and we did not detect either disease on WPBR-infected plots. The low incidence of dwarf mistletoe and *Atropellis* canker should help avoid misidentification of WPBR in the study areas given the similar symptomatology of the three diseases (Geils and Hawksworth 2002, Nevill and others 1989). Bark beetle damage was not detected in our study, although small pockets of PIST killed by mountain pine beetle (*Dendroctonus ponderosae*) were observed in the Pinaleños Mountains in Arizona in 2011 (USDA Forest Service 2012). This is in stark contrast to recent large-scale outbreaks of mountain pine beetle in *Pinus flexilis* and *P. albicaulis* in the Rocky Mountains (Gibson and others 2008). The typically low to moderate densities of PIST, combined with its occurrence in diverse mixed-conifer forests, may put it at relatively low risk of bark beetle attack (Gibson and others 2008).

We better described WPBR incidence within eastern Arizona and portions of New Mexico. The WPBR in western New Mexico and eastern Arizona appears locally intense but sporadic, consistent with recent spread into the region (Kearns and Jacobi 2007). The low frequency of infections likely reflects the relatively recent arrival of WPBR between 1988 and the early 2000s (Fairweather and Geils 2011), whereas the earlier studies investigated infections up to 40 years old (Kearns and Jacobi 2007, Smith and Hoffman 2001). Despite the disease's rarity, WBPR infection incidence was comparable to these two studies in terms of trees bearing infection within infected plots. Burns (2006) reported similar between- and within-plot incidence figures in southern Colorado, where the disease had been present since the early

1990s. White pine blister rust severity on individual trees was light, with many trees having a single evident canker or area of WPBR-related dieback. The prevalence of branch cankers and the general lack of bole damage or topkill suggest relatively recent introduction (Smith and Hoffman 2000). We did not find any trees within the plots that had succumbed to WPBR, further suggestive of recent WPBR infection.

Neither canopy dieback nor leader damage in WBPR-infected trees was significantly elevated compared to uninfected trees. Several trees showed signs of infection without disfigurement, and our severity metrics probably have a response lag of several years. When present, WPBR-related canopy dieback was scattered throughout the live crown, a pattern previously reported in the Southwest (Conklin and others 2009). The uncommonness of animal chewing makes WPBR identification by symptoms more difficult but preserves signs of the disease. The lack of leader damage and topkill suggests WPBR will not rapidly affect PIST height growth.

In our relatively small sample size (n = 31), we found an inconsistent relationship between tree size and infection probability with increasing diameter. Probability of infection typically increases with size, likely reflecting greater crown area (Burns and others 2010, Conklin 2004, Kearns and Jacobi 2007). Compared to studies of shorter *P. albicaulis* and *P. flexilis*, our ability to detect infections on taller PIST was limited. Viewing conditions were difficult given tall trees, dense stands, and high contrast during the monsoon season. Also in contrast to previous studies, an inverse relationship between damage severity and tree diameter was not evident in our data (Conklin 2004, Kearns and Jacobi 2007, Smith and Hoffman 2000). Smaller-diameter trees did not show higher bole canker incidence, canopy dieback, or more frequent topkill compared to larger trees. These patterns will likely change in the near future, as disease progression is often faster in smaller trees given shorter distances between infected foliage and boles (Kearns and Jacobi 2007, Tainter and Baker 1996) and shorter time required to girdle smaller stems (Kearns and others 2009).

The early stage of the WPBR invasion in much of Arizona and New Mexico suggests widespread tree mortality will not occur quickly. Furthermore, the rarity or absence of white pine blister rust alternate hosts could limit the spread of the disease to certain populations, such as the Mogollon Rim of central Arizona (Conklin and others 2009, Looney 2012) and isolated mountains of southern Arizona (Conklin and others 2009). Proactive management, such as silvicultural treatments, intended to conserve *P. strobiformis* would help prepare the landscape for WPBR invasion, particularly given the current limited progression of the disease (Burns and others 2008, Schoettle and Sniezko 2007).

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