Changes in intensity of white pine blister rust on western white pine across time, space, and changing climate in the interior northwestern USA

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Introduction

Western white pine (WWP; *Pinus monticola*) is a keystone species in temperate, moist forests of western North America, where it displays adaptation to a range of climates and resilience to native root diseases (e.g., Harvey et al. 2008). Since *Cronartium ribicola*, the cause of white pine blister rust (WPBR), was introduced to North America in the early 1900s, WPBR has become well established and caused a dramatic reduction of WWP across its range (e.g., Neuenschwander et al. 1999; Harvey et al. 2008). Over recent decades, casual observations have indicated that WPBR incidence rates may be lower in some naturally regenerated WWP stands than was historically reported in the decades following the introduction of *C. ribicola* into WWP stands of northern Idaho, USA and adjacent regions (G.I. McDonald and others, person observations). In general, WPBR incidence historically increased on average by ca. 3% per year on WWP between the ages of 2-40 years (e.g., Carlson and Toko, 1968; Ketcham et al. 1968). Analyses of recent WPBR incidence rates in regenerated WWP sites may be useful to identify sites with reduced WPBR intensity where natural regeneration of WWP should be encouraged by forest managers to foster forest resilience. Although WWP is considered a generalist with populations that exhibit relatively broad climatic adaptation, ongoing climate change will likely alter its geographic range (e.g., Rehfeldt et al. 2020). For future forests, increased reliance on WWP might offer some resilience to climate change, provided that the concomitant WPBR intensity allows for sufficient WWP growth and survival to maturity.

Objectives

The objective of this study was to revisit a subset of WWP stand sites examined by Carlson and Toko (1968) and determine WPBR disease progress curves on naturally regenerated WWP for a contemporary time period of 15 years (2006-2020) for comparison with historical disease progress curves. The overall goal of this project is to determine if WPBR intensity has ameliorated over the last 60 years, while also identifying areas where WWP regeneration should be encouraged to increase forest resilience to climate change and other abiotic/biotic disturbances.

Materials and Methods

The WPBR survey notes and data from Carlson and Toko (1968) are housed at the USDA Forest Service, Rocky Mountain Research Station, Forestry Sciences Laboratory in Moscow, ID, USA. During summer of 2021, a subset representing 19 of the 106 historical sites examined by Carlson and Toko (1968) were selected to determine contemporary disease progress for WPBR within naturally regenerated WWP stands in the inland, northwestern USA (northeastern Washington, northern Idaho, northwestern Montana) (Fig. 1). Contemporary survey sites are representative of the geographic range of the survey sites reported by Carlson and Toko (1968) (Fig. 1). At each survey site, a curvilinear transect was followed, with a goal of surveying 30 naturally regenerated WWP of at least

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15 years of age, as available. Branch whorls were counted to determine the age of each tree, and counting whorls from the branch tip determined the approximate age of each WPBR canker, with the assumption that cankers were the result of *C. ribicola* infection of first-year needles (Fracker 1936). Characteristic sign and symptoms (e.g., aeciospore production, orange coloration of canker, branch swelling, branch flagging, rough bark, and/or resinosis) were used for identifying WPBR cankers (Fig. 2). Historical WPBR disease progress curves were constructed using historical WPBR incidence (% of trees infected) data that were collected at the same 19 sites in 1967, including all WPBR cankers on a tree and their approximate ages (year of infection) on felled WWP trees that had been growing since ca. 1940. The 15-year WPBR increase rates (1946-1960) from the historical records were used for comparison with contemporary 15-year (2006-2020) WPBR disease progress curves (Fig. 3). Area under the disease progress curve (AUDPC) was calculated to quantify disease progress curves for both time periods at each site using IdeTo (Simko 2021). Associated tree data, such as DBH, height, GPS location, photographs, and other health issues, were also collected. In addition, perfunctory observational surveys were also conducted to record any alternate hosts of *C. ribicola*, such as *Ribes*, *Castilleja*, and/or *Pedicularis*, at each site.

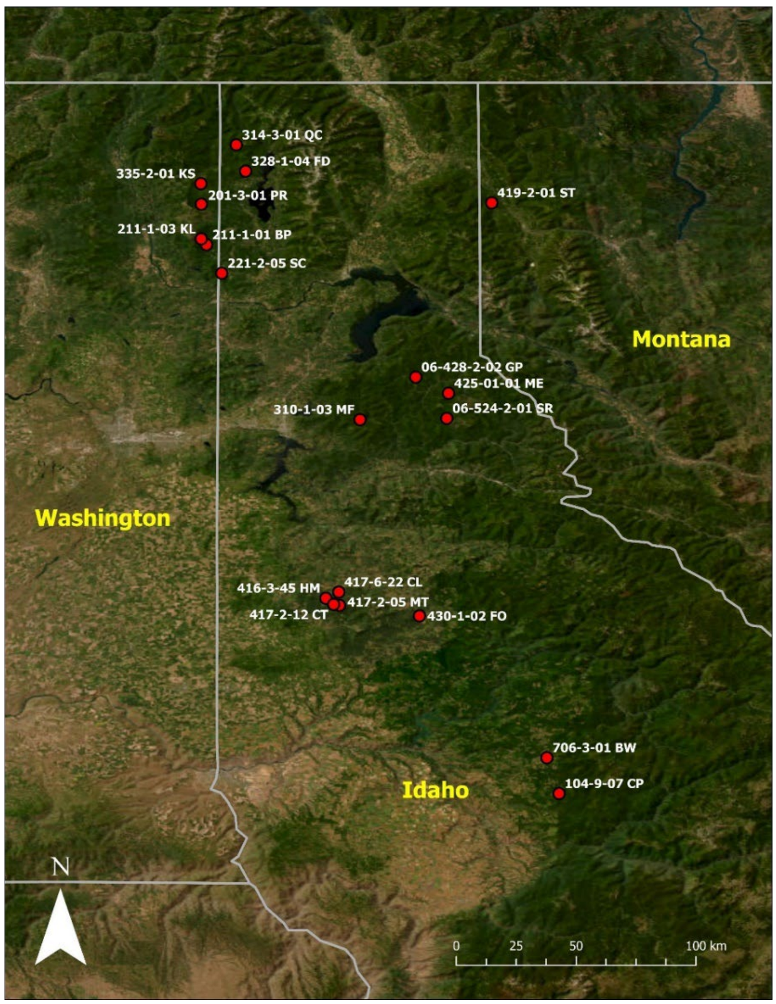

Figure 1. White pine blister rust (caused by *Cronartium ribicola*) survey sites in northern Idaho, northeastern Washington, and northwestern Montana, USA. 335-2-01 KS (Kalispell); 201-3-01 PR (UWB Priest River); 211-1-01 BP (Bear Paw); 211-1-03 KL (Kings Lake); 328-1-04 FD (Fedar); 221-2-05 SC (Snow Creek); 425-01-01 ME (Miners); 310-1-03 MF (Montford); 419-2-01 ST (Star); 417-2-05 MT (PD Masutake); 417-6-22 CL (Charlie); 430-1-02 FO (Fossil Dig); 706-3-01 BW (Browns); 104-9-07 CP (Lolo Polkadot); 416-3-45 HM (Humes); 417-2-12 CT (PD Chanterelle); 06-524-2-01 SR (Saint Regis); 314-3-01 QC (Quartz Crystals); 06-428-2-02 GP (Griffith Peak)

Figure 2. White pine blister rust (caused by *Cronartium ribicola*) canker on western white pine (*Pinus monticola*) with aeciospores present in orange pustules.

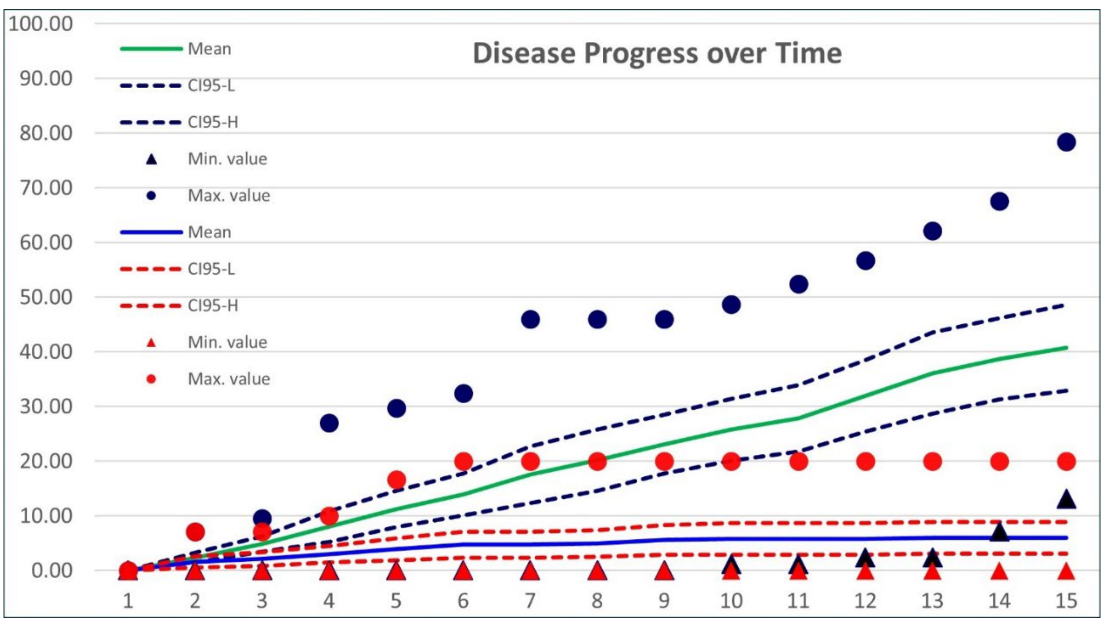

Figure 3. Comparisons of white pine blister rust (caused by *Cronartium ribicola*) canker incidence (Y axis: % of trees infected:) rates on western white pine (*Pinus monticola*) over a 15-year period (X axis) for contemporary (2006-2020: bright blue and red colors) and historical (1940-1954: green and dark-blue colors) time periods at 19 sites. Site locations and abbreviations are described in Fig. 1. Red-colored circles and triangles are WPBR determined from the recent (2020) surveys and dark-blue-colored circles and triangles are the historical WPBR incidence rates that were determined from data collected ca. 60 years before for the 1946-1960 time period. The green line depicts the mean of the historical disease progress curves, and the bright-blue line depicts the mean of the contemporary disease progress curves.

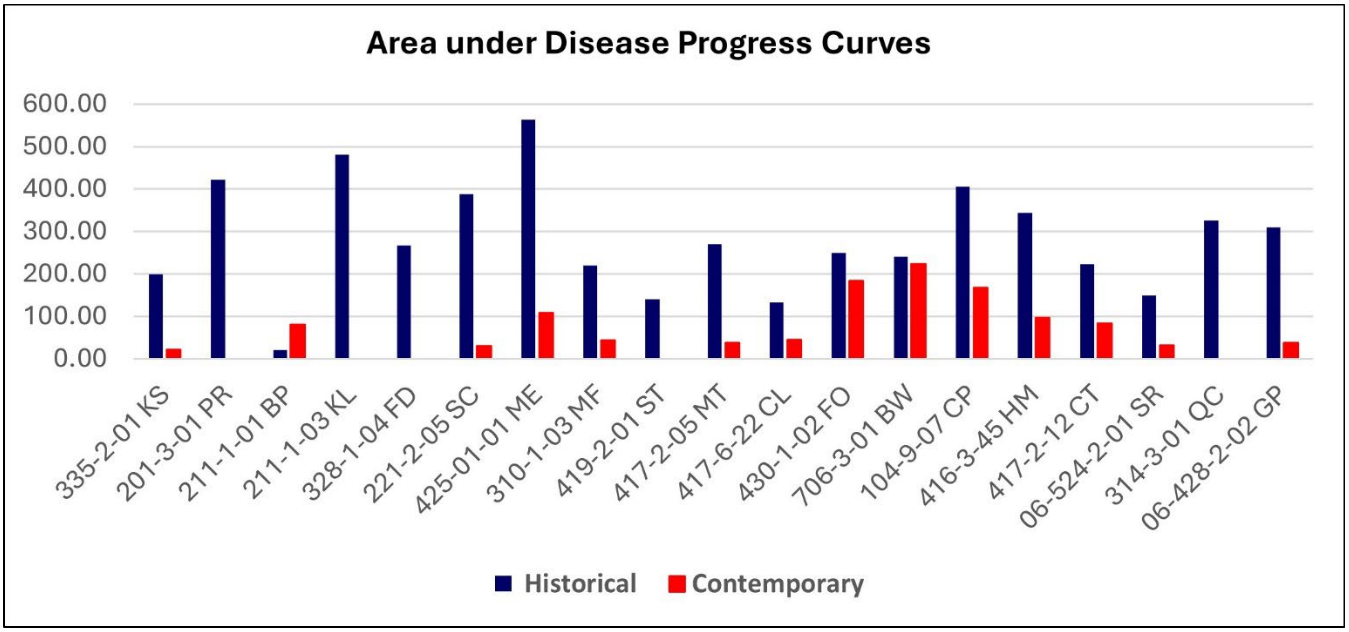

Figure 4. Comparisons of area under disease progress curves between contemporary (2006-2020) and historical (1940-1954) rates of white pine blister rust (caused by *Cronartium ribicola*) on western white pine (*Pinus monticola*). Site locations and abbreviations are described in Fig. 1.

Preliminary Results

- Across most sites, the contemporary WPBR disease progress rates and AUDPCs have decreased compared to the historical WPBR disease progress rates and AUDPCs at the site (Figs. 3 and 4).
- WPBR disease progress rates appear to vary among sites (Figs. 3 and 4)
- For most sites, WPBR intensities appear to be low enough that WWP regeneration should be encouraged, with continued stand monitoring for WPBR.
- The influence of climate on WPBR disease incidence rates does not appear to be significant within the limited area of study; however, further analyses are needed to verify the influence of climate on WPBR.

On-going Analyses

Areas where naturally regenerated WWP is exhibiting low or sustainable WPBR intensity will be identified along with geographic areas where WWP is predicted to remain climatically adapted.

Management Implication

It is unknown if lower WPBR disease progress rates and AUDPCs at most sites is due to increased WPBR resistance in WWP and/or *Ribes*, decreased *C. ribicola* virulence, interaction with other biotic components (e.g., endophytes or other biocontrol agents), interactions with *Ribes*, direct and indirect effects of changes in microenvironment and light conditions (e.g., contemporary denser canopies vs. historical open canopies), or changes in general environmental conditions (e.g., climate or weather). On most sites, rates of WPBR are sufficiently low (≤ 20% after 15 years), and WWP regeneration should be encouraged, especially if future climate is predicted as suitable for WWP. This information may assist resource managers to prioritize areas that appear suitable for WWP restoration through natural regeneration, which will help to counteract anticipated losses in forest productivity and ecological diversity.

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