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Five-Needle Pine Monitoring on Wyoming Bureau of Land Management Forests in the Greater Yellowstone Ecosystem

(nps.gov article series)

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Listing Description (255 char limit):

Learn how and why the Greater Yellowstone Network monitors limber pine and whitebark pine—the 2 five-needle pines of the Greater Yellowstone Ecosystem—on Wyoming Bureau of Land Management forests and what they are finding. The data summary article in this series is updated each year.

Lead-in (500 character limit):

Five-needle pine trees are vital to forest health where they occur in the western US. But they are threatened by white pine blister rust infection, mountain pine beetle attack, dwarf mistletoe, and other stressors. This series describes how and why the NPS Greater Yellowstone Network monitors whitebark

pine and limber pine on Wyoming Bureau of Land Management forests throughout the Greater Yellowstone Ecosystem and what they are finding. The data summary article in this series is updated each year.

Tags:

GRYN, whitebark pine, limber pine, IM, monitoring, Greater Yellowstone Network, series, Greater Yellowstone Ecosystem, five-needle pine

Article 1 – (Introduction)

Five-Needle Pine Monitoring Program on Wyoming Bureau of Land Management Forests in the Greater Yellowstone Ecosystem – Overview



Five-needle pine monitoring plot at Brent Creek, Wyoming. NPS

This article begins the article series, “Five-Needle Pine Monitoring on Wyoming Bureau of Land Management Forests in the Greater Yellowstone Ecosystem.”

The Greater Yellowstone Ecosystem is home to 2 five-needle pine species, both of which play important ecological roles: whitebark pine (*Pinus albicaulis*) and limber pine (*Pinus flexilis*).

Whitebark pine is a keystone species of subalpine forests, regulating many ecological processes and influencing biodiversity (Tomback and Kendall 2001; Ellison et al. 2005). Whitebark pine is considered a "pioneer" species due to its tolerance of harsh environmental conditions and ability to establish and persist where other species cannot. In doing so, whitebark pine can alter the microclimate and enable species such as subalpine fir (*Abies lasiocarpa*) to establish in these otherwise inhospitable regions (Tomback et al. 1993). Although whitebark pine has very little commercial value, its seeds provide seasonal forage for a variety of wildlife, including grizzly bears (*Ursus arctos horribilis*), red squirrels (*Tamiasciurus hudsonicus*), Clark's nutcrackers (*Nucifraga columbiana*), and a variety of granivorous small mammals.

Limber pine occurs in western North America across a broad elevational gradient from the Canadian Rocky Mountains into parts of New Mexico and Arizona and from southern California eastward to the few, isolated populations existing on the western boundary of the Dakotas and Nebraska (Steele 1990; Schoettle and Rochelle 2000). A relatively adaptable five-needle pine, it is typically encountered on rocky, xeric sites with limestone or sandstone soils (Steele 1990). In Wyoming, limber pine is an important species in montane and lower woodland ecosystems, where it provides ecosystem functions similar to those of whitebark pine (Thompson et al. 1976; Steele 1990; Kearns and Jacobi 2007). Like whitebark pine, limber pine depend principally on Clark's nutcrackers (*Nucifraga columbiana*) to disseminate their wingless seeds (Lanner and Vander Wall 1980).

Current Threats to Five-Needle Pines

Multiple ecological disturbances currently impact whitebark pine and limber pine. White pine blister rust (hereafter, blister rust) caused by the introduced fungus *Cronartium ribicola*, mountain pine beetle (*Dendroctonus ponderosae*), dwarf mistletoe (*Arceuthobium* spp.), wildfires, and drought all pose significant threats to the persistence of healthy five-needle populations.

In the last century, blister rust has caused significant whitebark pine mortality in the Pacific Northwest and parts of the northern Rockies (Arno 1986). Between 2000 and 2010 widespread infestations of mountain pine beetle in high elevation stands have killed expansive swaths of mature whitebark pine forest (Logan et al. 2009). In the Greater Yellowstone Ecosystem (GYE) the combination of blister rust damage and mortality from mountain pine beetles has shifted whitebark pine populations to smaller sized trees and threatened whitebark pine reproduction and overall survival (Shanahan et al. 2016). Furthermore, fire regimes, which have historically been important for whitebark pine persistence, are becoming more frequent and increasing in intensity as snowpack melts earlier and faster due to rising temperatures (Westerling et al. 2011). These combined threats led the US Fish and Wildlife Service to list the whitebark pine as Threatened under the Endangered Species Act on January 17, 2023.

Limber pine dwarf mistletoe (*Arceuthobium cyanocarpum*; dwarf mistletoe) poses health impacts somewhat unique to limber pine. Dwarf mistletoe has caused extensive mortality in limber pine populations throughout areas of the Rocky Mountains (Mathiasen and Hawksworth 1988). Once indicators of dwarf mistletoe are visually apparent, it is generally assumed that infection is present at an advanced stage (5 to 7 years plus). Tree vigor is greatly compromised by mistletoe infection, as evidenced by a reduction in tree growth and damage to the upper canopy of an infected tree. While mistletoe can cause more rapid mortality in smaller, understory trees, larger, mature trees can live for 100+ years with mistletoe infections (Geils et al. 2002). Since the initiation of whitebark pine monitoring in the Greater Yellowstone Ecosystem (GYE) in 2004, occasional dwarf mistletoe infections have been noted in a small number of whitebark pine trees in the GYE. Recent work on Wyoming Bureau of Land Management (BLM) forests, however, has documented an increase in dwarf mistletoe presence in some populations of surveyed limber pine.



Limber pine dwarf mistletoe (*Arceuthobium cyanocarpum*). ©BILL CIESLA, Colorado State Forest Service.

Monitoring Program

Whitebark pine is a Threatened species under the Endangered Species Act and limber pine is a species of concern on Wyoming BLM lands. To understand the many challenges faced by five-needle pines and to track their health status, the Wyoming BLM initiated a pilot monitoring program on Wyoming BLM lands where five-needle pine species occur within the GYE. Based on data collected in 2013 and 2014, long-term monitoring of five-needle pines on Wyoming BLM lands was assimilated into the interagency whitebark pine monitoring program. While similar to the *Interagency Whitebark Pine Monitoring Protocol for the Greater Yellowstone Ecosystem* (GYWPMWG 2011) (hereafter, the monitoring protocol), Wyoming BLM monitoring objectives include both whitebark pine and limber pine and additional data are collected using a rapid assessment sampling methodology designed for this endeavor (Shanahan et al. 2022).

The rapid assessment sampling method was developed in 2013–2014 to augment five-needle pine surveys on Wyoming BLM lands where five-needle pine densities were expected to be lower in some areas compared to other locations sampled within the GYE. The main difference in the rapid assessment method is that trees are not tagged and only a subset of individual tree measurements are recorded. This method enables field crews to survey more transects per delineated stand (compared to one transect per stand following the monitoring protocol), thus gaining a more comprehensive understanding of overall five-needle pine health from several locations throughout a stand.

Measurable Objectives

Measurable objectives of the Wyoming BLM five-needle pine monitoring program:

1. Estimate the proportion of live, five-needle pine trees (>1.4 m tall) infected with white pine blister rust.
2. Document blister rust infection severity by the occurrence and location of persisting and new infections.
3. Determine mortality of five-needle pine trees and describe potential factors contributing to the death of trees.
4. Assess the multiple components of the recruitment of understory five-needle pine into the reproductive population.

These objectives are similar to the objectives of the GYE interagency whitebark pine monitoring program (GYWPMWG 2011) but include both whitebark pine and limber pine.

Study Area

The five-needle pine study area encompasses portions of BLM lands in Wyoming within the GYE. These Wyoming BLM areas were identified as habitat for five-needle pines and ground-surveyed by Wyoming BLM personnel prior to initiation of the sampling effort (Figure 1).

Eight geographic strata were selected for surveying, including Brent Creek (Brent), Teton Valley Ranch Camp (TVRC), Rattlesnake (Rattle), Clark's Fork Canyon (CFC), Pine Grove/Deadline Ridge (PGDR), Commissary Ridge (CR), Scab Creek (Scab), and Sublette Range/Huff Creek (SRHC) (Figure 1).

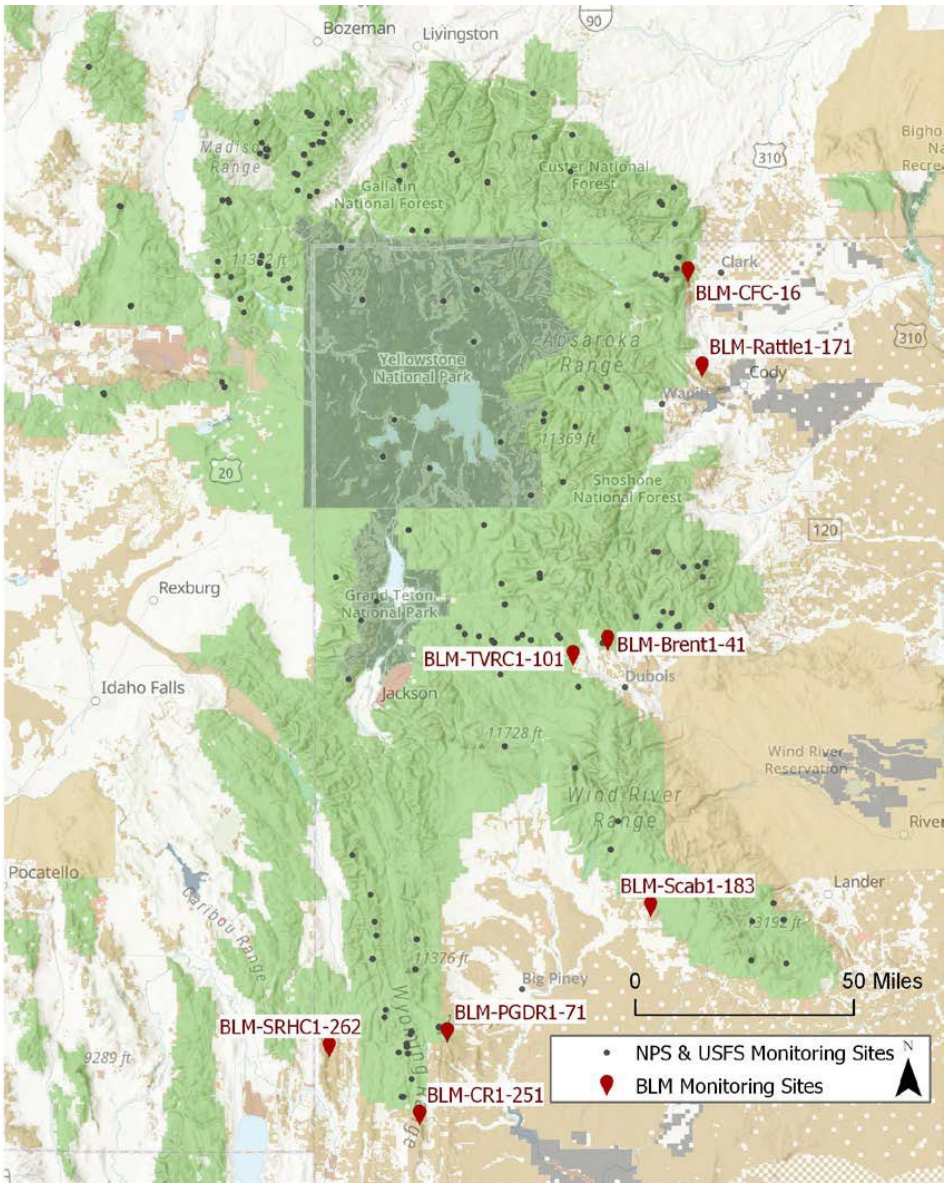


Figure 1. Map of Wyoming Bureau of Land Management (BLM) five-needle pine study sites. Map also shows additional National Park Service (NPS) and US Forest Service (USFS) whitebark pine monitoring sites in the region. Site abbreviations are: Brent Creek (Brent), Teton Valley Ranch Camp (TVRC), Rattlesnake (Rattle), Clark's Fork Canyon (CFC), Pine Grove/Deadline Ridge (PGDR), Commissary Ridge (CR), Scab Creek (Scab), and Sublette Range/Huff Creek (SRHC).

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Article 2 – (Results)

White Pine Blister Rust Infection Status, Mortality, and Recruitment of Five-Needle Pines on Wyoming Bureau of Land Management Forests in the Greater Yellowstone Ecosystem—Data Summary of Monitoring in 2023



Arizona Creek, Bridger-Teton National Forest, Wyoming. NPS/Shanahan

This is the second article in the article series, "Five-Needle Pine Monitoring on Wyoming Bureau of Land Management Forests in the Greater Yellowstone Ecosystem." It summarizes data collected to meet the following four objectives of monitoring five-needle pine species on Wyoming Bureau of Land Management (BLM) forests in the Greater Yellowstone Ecosystem:

Objectives:

1. Estimate the proportion of live, five-needle pine trees (>1.4 m tall) infected with white pine blister rust.
2. Document blister rust infection severity by the occurrence and location of persisting and

new infections.

3. Determine mortality of five-needle pine trees and describe potential factors contributing to the death of trees.
4. Assess the multiple components of the recruitment of understory five-needle pine into the reproductive population.

Within the study area of eight geographic strata, one panel containing two strata is sampled each year, for a four-year revisit schedule (see *Methods* article in this series). Each geographic stratum is considered a sample frame and may contain multiple map units. In 2023, we sampled one permanent transect in each of the two strata and up to 5 of 10 possible rapid transects for each map unit within a stratum on Panel 4, which includes the Brent Creek and the Sublette Range/Huff Creek sampling frames (Table 1). This resulted in 57 total transects surveyed in 2023.

Sample Frame/ Geographic Stratum	Map Unit and Number of Transects Sampled within It	Number of Transects Visited but Not Sampled	Number of Transects Not Visited
Brent Creek	Brent1 = 5*	2	4
Brent Creek	Brent2 = 5	5	0
Brent Creek	Brent3 = 2	8	0
Brent Creek	Brent4 = 5	1	4
Brent Creek	Brent5 = 1	9	0
Brent Creek	Brent6 = 6	2	2
Brent Creek	Brent7 = 5	1	4
Brent Creek	Brent8 = 5	1	4
Brent Creek	Brent9 = 5	1	4
Brent Creek	Brent10 = 5	0	5
Sublette Range/Huff Creek	SRHC1 = 5*	3	3
Sublette Range/Huff Creek	SRHC2 = 3	7	0
Sublette Range/Huff Creek	SRHC3 = 5	5	0

*Includes one permanent transect.

Table 1. Two Panel 4 sample frames from the five-needle pine monitoring program on Wyoming Bureau of Land Management lands were surveyed in 2023. Brent Creek sample frame contains 10 map units and Sublette Range/Huff Creek has three. While three to five transects within each map unit are targeted for rapid sampling (out of a total of 10 possible transect locations), plus one permanent transect at each sample frame, not all transects attempted will meet the protocol requirements (number of transects visited but not sampled). Once the desired number of transect surveys are accomplished, the remaining transects are not attempted (number of transects not visited). Asterisk indicates that one permanent transect is included in the count.

Sampling methods for each objective are detailed in the *Methods* article of this series. Results for past years are available on the Greater Yellowstone Network website, including a summary of results

for 2013 to 2017 (Shanahan et al. 2022). We will revisit Wyoming BLM permanently established transects according to the panel schedule in the *Methods* article to conduct rapid assessment transects in those assigned map units within the targeted geographic strata. In addition, we will collect stand structure and composition information to inform potential silvicultural treatment opportunities for enhancement of five-needle pine on Wyoming BLM lands. Should we continue to note dwarf mistletoe infection in limber pine populations from targeted geographic strata, we may consider more in-depth data collection on this metric.

Results for Objective 1—White Pine Blister Rust Infection



White pine blister aeciospores erupt from a canker caused by the nonnative fungus, *Cronartium ribicola*. The canker will kill the underlying bark on this branch, including the cambium layer. This prevents nutrients from reaching areas of the branch above the canker. NPS/Shanahan

Within permanent transects, all five-needle pine trees >1.4 m tall are tagged. Rapid assessment survey transects trees are not tagged and only a subset of individual tree measurements are recorded. Therefore, infection status is documented for all 57 transects, whereas change in infection status can only be documented in the two permanent transects.

Trees Infected with White Pine Blister Rust

We examined 347 live tagged trees in the two permanent transects and 55 rapid assessment survey transects from Panel 4 for blister rust infection in 2023. A total of 169 (49%) trees were documented with blister rust infection and 178 (51%) had no infection present. Of these 169 infected trees, 112 (66%) had bole infections (Figure 1).

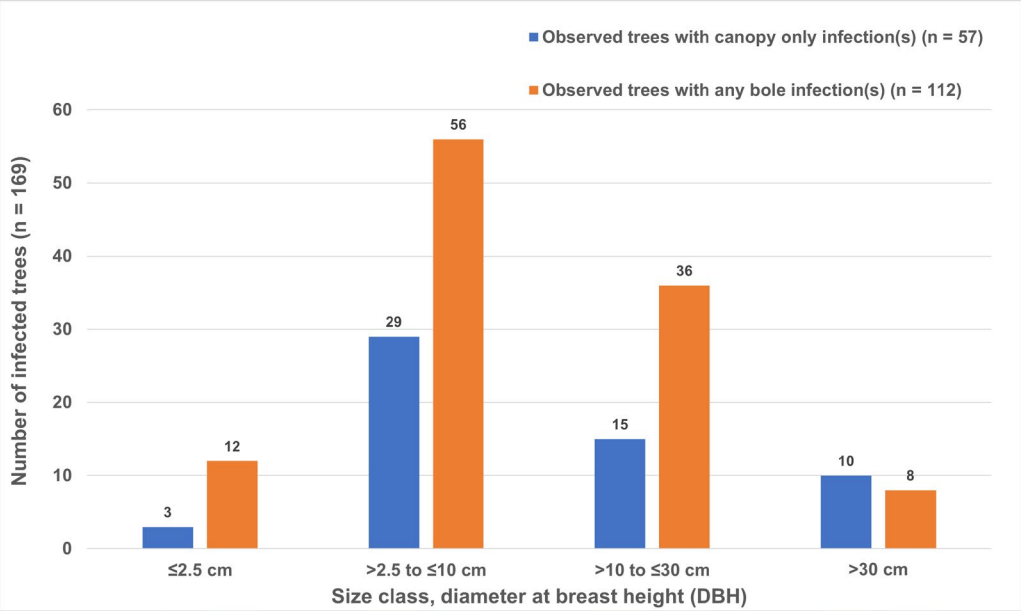


Figure 1. Blister rust infection was detected on 169 live five-needle pine trees during 2023 surveys of permanent and rapid assessment transects in Panel 4 on Wyoming Bureau of Land Management land. Trees are grouped by size class and blister rust location (canopy only or bole infection).

Change of Infection Status Over Time: Tagged Trees Live in 2019 and 2023

Because live tagged trees on the permanently established transects are visited every four years, infection transition can be documented through time. Infection transition is not reported for rapid transect data. Of the 15 live trees on the two permanent transects that were surveyed on Panel 4 transects in 2019 and again in 2023, approximately 9 (60%) had no evidence of blister rust infection, 5 (33%) were infected in both years, 1 (7%) transitioned from no evidence of infection to infected, and none went from infected to uninfected (Table 2). A transition from infected to uninfected could result from observer error, an earlier-documented infection based on indicators that upon resurvey no longer meet the established standards of three indicators in the same location, or infected branches that self-pruned.

Table 2. Blister rust infection and transition status among live, tagged five-needle pine trees on Wyoming Bureau of Land Management Panel 4 permanent transects surveyed in 2019 and again in 2023.

Infection Status	**Number of Live Trees (n = 15)**
Remained Uninfected	9 (60%)
Remained Infected	5 (33%)
Uninfected to Infected	1 (7%)
Infected to Uninfected	0

Results for Objective 2—White Pine Blister Rust Infection Transition

On the two permanent transects, infection location changed for trees that were documented with blister rust in 2019 and again in 2023 (Figure 2). One tree with a canopy only infection in 2019 that remained infected in 2023 transitioned to a more severe state of infection in the bole by 2023. This transition occurred in the larger size class, >10 cm DBH. Four trees remained infected in the bole between 2019 and 2023.

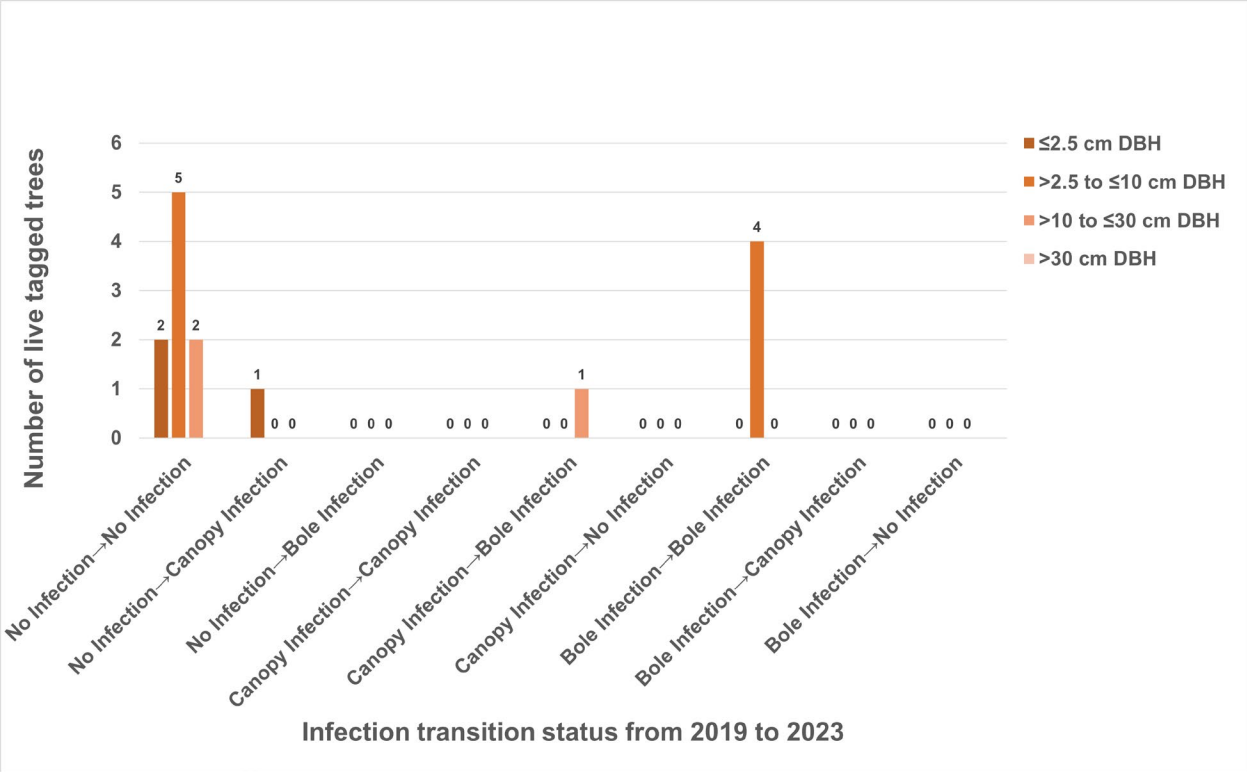


Figure 2. Infection transition status by DBH (diameter at breast height) category for live, tagged five-needle pine trees on Panel 4 transects surveyed in 2019 and again in 2023. The total count of live, tagged trees surveyed in both years was 15. Note that none of the trees were >30 cm DBH.



Orange aeciospores are visible just under the bark of this five-needle pine tree, along with visible chewing. Cankers on the bole of a tree prevent vital nutrients from reaching areas above the canker and therefore are more detrimental to the overall health of the tree than canopy cankers. NPS Shanahan.

Results for Objective 3—Mortality



Mountain pine beetle (black oblong insect) deterred from entering a boring hole that the tree has filled with pitch to fight off attacking beetles. This is a pitch tube. NPS photo

In 2023, we observed no new dead tagged trees on the two permanent transects. Dead trees are no longer recorded on rapid assessment survey transects.

Results for Objective 4—Recruitment



Five-needle pine seedling. NPS/Shanahan

On both permanent and rapid transects, recruitment data are collected at two scales: the 10 × 50 m belt transects, and 1/300 acre subplots associated with the belt transects.

10 x 50 m Belt Transects

Regeneration and Growth

In 2023, we counted 268 understory five-needle pines (≤1.4 m tall) on 57 transects (Table 3). This equates to an average density of approximately 5 small trees per transect. Eleven of these small trees were infected with blister rust.

No new trees had surpassed 1.4 m tall since the last survey in the permanent transects.

Table 3. Number of small five-needle pine trees ≤140 cm tall documented on the Brent Creek and Sublette Range/Huff Creek sample frame transects on Wyoming Bureau of Land Management land in 2023. Permanent transects, Brent1-41 and SRHC1-262, are included in this table.

Sample Frame/ Geographic Stratum	Map Unit / Number of Transects Sampled	Number of small trees (<140 cm)	Number of small trees infected	Number of small trees uninfected	Number of small trees with infection unknown
Brent Creek	Permanent Brent1-41 = 1	3	0	3	0
	Brent1= 4	18	2	16	0
	Brent2 = 5	3	0	3	0
	Brent3 = 2	7	1	6	0
	Brent4 = 5	13	0	13	0
	Brent5 = 1	0	0	0	0
	Brent6 = 6	29	1	28	0
	Brent7 = 5	46	4	42	0
	Brent8 = 5	11	2	9	0
	Brent9 = 5	14	0	14	0
	Brent10 = 5	14	1	13	0
Sublette Range / Huff Creek	Permanent SRHC1-262 = 1	0	0	0	0
	SRHC1 = 4	5	0	5	0
	SRHC2 = 3	11	0	11	0
	SRHC3 = 5	94	0	94	0

Cone Production



Whitebark pine cones. NPS/Shanahan.

Cone production evidence (current year cones, previous year cone scars, or male pollen cones) was recorded for 21 trees in 2023 (Figure 3). Reproducing trees ranged across three of the four DBH size classes. No cones were recorded on trees ≤2.5 m tall. Of the trees with cone evidence, 8 (38%) had signs of blister rust infection.

For reproducing trees, cones are counted and categorized into five bins: 0 = no cones, 1 = 1–5 cones visible, 2 = 6–10 cones visible, 3 = >10 cones visible, and S = cone scars but no current year cones visible. Of the Panel 4 trees documented with cones, the largest number, at 15 (79%), fall into the cone scar category, while the remaining trees were observed with 1–5 cones. An additional 29 whitebark and seven limber pine were identified to species due to the presence of male pollen cones. While this is a reliable metric to determine species, once pollen cones begin to senesce, it can be difficult to positively tell the difference between the two trees. By tracking cone production over time, we will gain valuable insight on the trajectory of future five-needle pine recruitment.

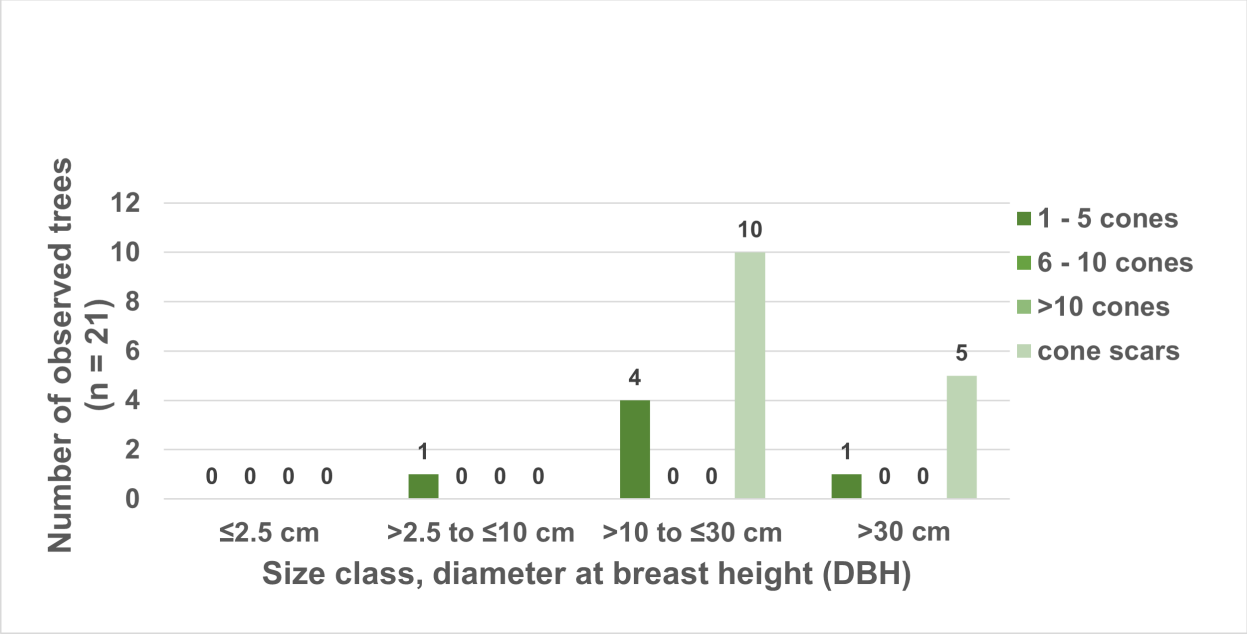


Figure 3. Number of cone-producing five-needle pine trees (21 total) grouped by number of cones visible (cone bin) and DBH category on Wyoming Bureau of Land Management Panel 4 transects in 2023. The majority of trees, 20 (95%), were >10 cm DBH.

1/300 acre Recruitment Subplots

In 2023, we completed 166 recruitment subplots (typically three per transect). In these 1/300 acre recruitment subplots, we recorded the number of five-needle pines in four height categories (>0–15 cm, 15.1–61 cm, 61.1–140 cm, >140 cm; note that trees in the >140 cm category typically have tags already if they are within the 10 × 50 m transect boundary). All other tree species (lodgepole pine (*Pinus contorta*), fir (*Abies lasiocarpa, Pseudotsuga menziesii*), spruce (*Picea engelmannii*), and sometimes aspen (*Populus tremuloides*)) are recorded in two height categories (15–140 cm, >140 cm). We examined each five-needle pine tree for signs of blister rust. In addition, we recorded ground cover, vegetation cover, and dominant and codominant vegetation species.

Recruitment subplot data will not be collected on rapid assessment survey transects after 2023. This is based on thoughtful review of the type of data needed to assess recruitment of understory whitebark pine into the reproducing population—Objective 4. The goal of this objective is to track change through time, but the statistical method for inference based on rapid transects does not translate to Objective 4 as intended. The methodology was designed to track recruitment on permanently established transects (i.e., long-term monitored transects), where repeat surveys are conducted at the same location on the same individual trees through time. As a result, 2023 will be the final year that we collect data in recruitment subplots for rapid assessment survey efforts. However, we will continue documenting recruitment subplot data for the eight (two per panel cycle) permanently established Wyoming BLM transects.

Learn More

This web article will be updated periodically with new results. Results for 2023 are summarized in a resource brief for 2023. For more results from past years please visit the Greater Yellowstone Network website.

Article 3 – (Methods)

Methods for Five-Needle Pine Monitoring on Wyoming Bureau of Land Management Forests in the Greater Yellowstone Ecosystem



Collecting data at a tagged whitebark pine tree. NPS Shanahan.

This is the third and final article in the article series, "Five-Needle Pine Monitoring on Wyoming Bureau of Land Management Forests in the Greater Yellowstone Ecosystem." It describes the methods used to measure white pine blister rust infection status, mortality, and recruitment in five-needle pines (whitebark pine (*Pinus albicaulis*) and limber pine (*Pinus flexilis*)) on Bureau of Land Management (BLM) forests in Wyoming.

Methods for monitoring five-needle pines on Wyoming BLM forests follow the *Interagency Whitebark Pine Monitoring Protocol for the Greater Yellowstone Ecosystem* (GYWPMWG 2011), with one important exception: in Wyoming BLM forests, five-needle pines are also monitored using rapid assessment transects. These "rapid" transects differ slightly in methodology from permanent transects because trees and transect boundaries are not permanently marked, and fewer data are collected at each tree to expedite the survey. Otherwise, the same detailed methods apply as described in "Methods for the Interagency Whitebark Pine Monitoring Program in the Greater Yellowstone Ecosystem," which is part of the "Whitebark Pine Monitoring in the Greater Yellowstone Ecosystem" article series on NPS.gov. Detailed methods, including example data forms, are also available from a summary of five-needle pine monitoring between 2013 and 2017 on Wyoming BLM forests (Shanahan et al. 2022).

Sampling Design

We appraised five-needle pine health on Wyoming BLM lands by combining a permanent transect approach, which follows the *Interagency Whitebark Pine Monitoring Protocol for the Greater Yellowstone Ecosystem,* with a rapid assessment method specifically designed for this Wyoming BLM effort (Shanahan et al. 2022). The interagency whitebark pine monitoring protocol assesses long-term trends in whitebark pine health by surveying permanent belt transects (10 meters by 50 meters) and tagged trees within designated stands of whitebark pine in the Greater Yellowstone Ecosystem. These delineated stands tend to support high densities of whitebark pine. Given the sparsity of five-needle pines often encountered on Wyoming BLM lands, the rapid assessment method allows for more samples, which helps to more accurately evaluate blister rust infection levels and overall five-needle pine health.

The sampling design for both types of surveys (permanent and rapid) was a stratified two-stage cluster sample. Each geographic area identified by Wyoming BLM was considered a geographic stratum. The first-stage sampling unit was a map unit (primary sampling unit; map units ≥2.5 ha; e.g., Commissary Ridge 1), and the secondary sampling unit was a point within a map unit (Figure 1).

The number of map units varied by geographic stratum. Secondary sampling units (10 meter by 50 meter belt transects) were selected using the Generalized Random Tessellation Stratified design (GRTS). The GRTS design is a spatially balanced sampling methodology that distributes coverage across the entire area of interest using a stochastic approach (Brown et al. 2015). The observation unit (the object on which a measurement was taken) was each qualifying, five-needle pine tree within the secondary sampling unit.

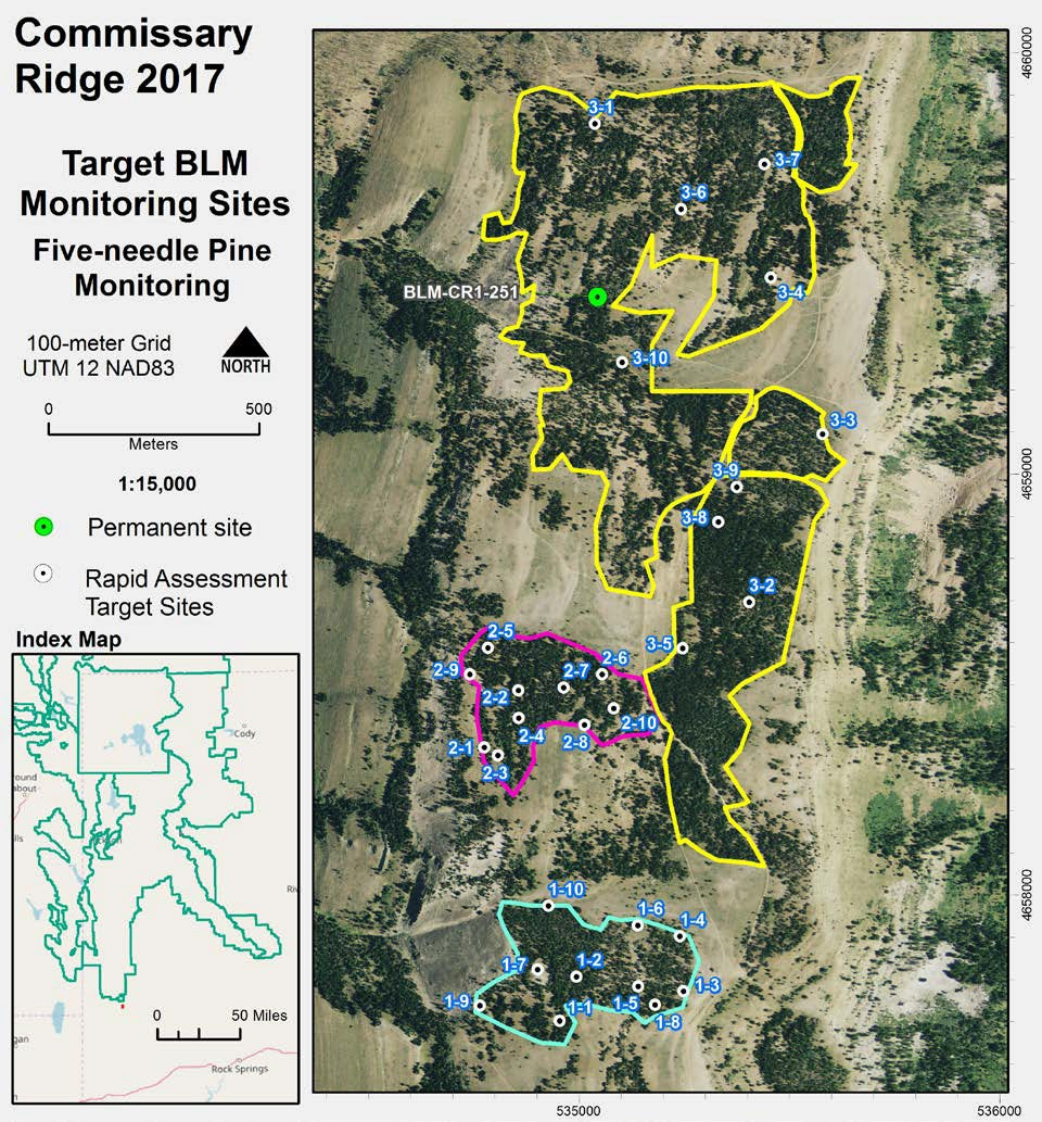


Figure 1. Example of a geographic stratum (Commissary Ridge), three primary sampling units (map units), and 10 secondary sampling unit targets (10 random point locations) located within each of the three map units. All areas outlined in yellow are connected, though they appear to be separated.

Transect Establishment and Visit Schedule

Permanent Transects

Eight permanent transects were established in 2013 and 2014 following the 2011 interagency whitebark pine monitoring protocol. Within these transects, a total of 146 live, individual trees >1.4 m tall were permanently marked with tags to monitor long-term changes in blister rust infection and survival rates. These eight permanent transects are divided into four panels of two transects each, which are revisited on a rotating schedule every four years (Figure 2).

Survey Schedule			Time 1			Time 2				Time 3				
Sample Panel	Transects per panel	Geographic stratum	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	
1	2	Scab TVRC	Establishment of 8 permanent transects		No surveys conducted; Rapid Assessment methodology evaluation period	blister rust & mortality				blister rust & mortality				Continued monitoring 2024 forward
2	2	CFC CR					blister rust & mortality				blister rust & mortality			
3	2	PGDR Rattle						blister rust & mortality				blister rust & mortality		
4	2	Brent SRHC							blister rust & mortality				blister rust & mortality	

Figure 2. Wyoming Bureau of Land Management five-needle pine monitoring panel revisit schedule for permanent sites. Transects are revisited in conjunction with interagency whitebark pine monitoring transects. Geographic stratum abbreviations: Brent Creek (Brent), Teton Valley Ranch (TVRC), Rattlesnake (Rattle), Clark's Fork Canyon (CFC), Pine Grove/Deadline Ridge (PGDR), Commissary Ridge (CR), Scab Creek (Scab), and Sublette Range/Huff Creek (SRHC).

Rapid Transects

Rapid assessment transects follow the same establishment methods and criteria used for permanent transects (following the monitoring protocol for whitebark pine), but neither the transect nor the trees within the 10 meter by 50 meter boundary of the transect are permanently marked. In addition, fewer data are collected on individual trees to expedite the survey for each rapid assessment transect, reducing the time spent per transect and allowing for increased sample size.

Rapid assessment transects are surveyed in conjunction with the associated permanent transect within each geographic stratum. Up to five rapid assessment transects are slated for measurement within each map unit throughout the Wyoming BLM area of interest. These rapid assessment transects are drawn from a selection of 10 possible GRTS-derived randomly ordered center points.

A handheld GPS unit is used to locate the rapid assessment coordinates. Points are visited according to their randomly assigned order, so that for random points 1 through 10, 1 is visited first, 2 is visited second, and so on. If a given random point does not qualify for a rapid assessment evaluation (no live, five-needle pines >1.4 m tall) the next random point in the selection is visited and assessed for inclusion. If a site is suitable for sampling (i.e., had at least one live, five-needle pine tree >1.4 m tall) a 10 meter by 50 meter area is surveyed. Once a maximum of five qualifying transects are successfully surveyed or all 10 random points are exhausted for inclusion, sampling in the map unit is completed. Because the transects are not permanently monumented, a GRTS selection of 10 new random points is generated for each map unit for subsequent revisits.

Collecting Blister Rust, Mortality, and Recruitment Data

Detailed methods for collecting mortality, recruitment, and white pine blister rust infection data on *permanent* 10 meter by 50 meter five-needle pine transects, as well as their associated 1/300 acre recruitment subplots, are identical to and can be accessed from "Methods for the Interagency Whitebark Pine Monitoring Program in the Greater Yellowstone Ecosystem." Here we provide an overview.

Data for all four monitoring objectives follow the same collection methods at both permanent and rapid transects, with two exceptions: for rapid transects, trees and transect boundaries are not permanently marked, and fewer data are collected (Table 1).

Table 1. Five-needle pine data collected during permanent and rapid assessment transects at Wyoming Bureau of Land Management sites. An "x" indicates metrics surveyed for each type of transect.

Metric	Permanent Transect	Rapid Transect
Date of survey	x	x
Elevation	x	x
Transect coordinates (UTMs; beginning, center, end)	x	center only
Transect orientation (azimuth)	x	x
Habitat type	x	x
Cover type	x	x
Tree species (*Pinus albicaulis*, *Pinus flexilis*, or Unknown)	x	x
Clump number	x	x
Clump letter	x	–
Diameter breast height category	x	x
Height class	x	x
Tree status (live, recently dead, dead)	x	x
Count of blister rust cankers with blister rust aecia spores in canopy in upper 1/3rd, middle 1/3rd, lower 1/3rd	x	–
Count of blister rust cankers with blister rust indicators in canopy in upper 1/3rd, middle 1/3rd, lower 1/3rd	x	–
Count of blister rust cankers with blister rust aecia spores in bole in upper 1/3rd, middle 1/3rd, lower 1/3rd	x	–
Count of blister rust cankers with blister rust indicators in bole in upper 1/3rd, middle 1/3rd, lower 1/3rd	x	–
Tally of indicators (rodent chewing, flagging, swelling, roughened bark, oozing sap)	x	–
Presence of blister rust aecia spores on bole	–	x
Presence of blister rust aecia spores on branches	–	x
Presence of at least three secondary indicators on bole	–	x
Presence of at least three secondary indicators on branches	–	x
Upper live canopy volume (%)	x	x
Pitch tube category	x	x
Presence of mountain pine beetle galleries (recently dead or dead trees only)	x	x
Presence of mountain pine beetle frass	x	x
Presence of cones	x	x
Tree health code	x	x
Total trees in plots ≤1.4 m tall with blister rust	x	x
Total trees in plots ≤1.4 m tall without blister rust	x	x
Total trees in plots ≤1.4 m tall with unknown blister rust status	x	x
Presence of mistletoe	x	x

Documenting White Pine Blister Rust Infection

The presence or absence of blister rust infection is recorded for all live trees within each transect. A

tree is considered infected if either aecia or cankers are present. To document the severity of infection, the location of blister rust canker is recorded as occurring in the canopy (branches) or on the bole (trunk) of an infected tree.



Measuring the length of white pine blister rust (*Cronartium ribicola*) cankers. NPS Shanahan.

Documenting Mortality

All trees >1.4 m tall are recorded as alive or dead. For live trees, we record evidence of blister rust infection, dwarf mistletoe infection, mountain pine beetle attack (pitch tubes, frass), impact from fire, or other mortality influencing factors, such as windfall or avalanche. For dead trees we record any J-shaped galleries under the bark from mountain pine beetle activity.

Documenting Recruitment



Emergent five-needle pine seedling. NPS Shanahan

We record data for three indices of five-needle pine recruitment for each transect:

- the number of trees less than or equal to 1.4 meters (≤1.4 m) tall
- the number of trees that grow to more than 1.4 meters (>1.4 m) tall
- the number of live tagged trees, regardless of height, that show signs of reproductive activity

We also record cone-production as an indication of current and potential future tree recruitment.

On permanently established transects only, additional information about factors affecting recruitment, such as the abundance and composition of non-five-needle pine understory tree species and ground cover, is collected in three circular 1/300 acre subplots centered at the beginning, middle, and ending points of each belt transect. The beginning and ending circular subplots partially overlap the belt transect, while the center recruitment subplot falls entirely within the belt transect. Detailed methods for recruitment plot setup and metrics are available in "Methods for the Interagency Whitebark Pine Monitoring Program in the Greater Yellowstone Ecosystem."

References (hidden behind collapsing panel)

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