Limber Pine and White Pine Blister Rust Monitoring and Assessment Guide for Rocky Mountain National Park[1]

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Table of Contents

Section 1. Overview

Limber pine, designated by Rocky Mountain National Park (RMNP) as a Species of Management Concern, is a keystone species that maintains ecosystem structure, function, and biodiversity. Limber pine is declining in the park due to the interacting effects of recent severe droughts and the climate-exasperated mountain pine beetle (*Dendroctonus ponderosae*) outbreak, and is threatened by the invasion of the non-native pathogen (*Cronartium ribicola*) that causes the lethal disease white pine blister rust (WPBR). White pine blister rust was confirmed in the park in 2010 (Schoettle et al. 2011; Schoettle et al. 2018b) and several new infections were discovered in this area during the fall of 2017 (Burns 2018). The disease is expected to spread and intensify, thereby causing mortality and negative impacts to biodiversity, ecosystem processes, and park resources in a changing climate. These same stressors are causing widespread mortality throughout much of limber pine's range and basal area losses are projected to exceed 40% over the next 15 years (Cleaver et al. 2015, Kearns and Jacobi 2007, Krist et al. 2014). Loss of this keystone species will ultimately lead to cascading ecological impacts and loss of biodiversity in RMNP.

The Limber Pine Conservation Strategy has been prepared to guide efforts to sustain limber pine populations and diversity in the park into the future (Schoettle et al. 2015). The Strategy integrated the science foundation generated from the RMNP collaboration with the USDA Forest Service (USFS) Rocky Mountain Research Station (RMRS) and USFS Forest Health Protection (FHP), initiated in 2008. The Strategy recommendations are specifically tailored to the unique genetic, biological, and geographic features of RMNP and the greater Protected Area Centered Ecosystem (PACE) (Goetz et al. 2010). One of the six recommendations of the Strategy is to increase the *Forest Health Monitoring Network* with the addition of an *Early Detection Monitoring Network*. Currently, there are permanent plots established in ten of the 17 limber pine research sites, stratified across elevations, in addition to three permanent plots installed by FHP in the park. In the greater PACE area, FHP has an additional 29 plots that are being reassessed every five years (Burns et al. 2012). Sites where riparian areas and limber pine coincide were identified and plots established in these areas that are at high risk for WPBR infection to complete the limber pine *Monitoring Networks* (i.e. *Forest Health*, *Early Detection*, *WPBR Virulence Networks*).

Limber Pine and White Pine Blister Rust Monitoring Networks
(1) *Forest Health Monitoring Network* is currently comprised of 13 plots in the research sites with 3 established in 2006 and 10 in 2013.
(2) *Early Detection Monitoring Network* currently includes six riparian monitoring plots, established in 2015-2016, for early detection and mitigation of WPBR.
(3) *WPBR Virulence Monitoring Network* is currently comprised of 29 individual trees inferred in 2015 to have *Cr4* complete resistance to WPBR for monitoring virulence in the rust.

Rocky Mountain National Park is at the infection front for WPBR; therefore limber pine forest conditions in the park will be dynamic during the next 10-20 years. This guide is intended to provide direction to continue the recommended long-term monitoring. The new riparian monitoring areas, in addition to the existing plots, complement the 29 additional FHP plots in the greater PACE area to further contribute to the landscape-scale monitoring network to guide limber pine conservation in the southern Rocky Mountains. As WPBR is found in the park additional plots could be added to these networks.

Note: The Limber Pine Conservation Strategy (Schoettle et al. 2015) has been expanded and adapted to cover the greater RMNP area including northern Colorado and southern Wyoming (Schoettle et al. 2018a). The methods described in this report are recommended for application to the larger area as well.

Section 2. Forest Health Monitoring Network

Thirteen Forest Health plots in the research sites have been established (3 in 2006 and 10 in 2013). Five limber pine research sites (Rainbow Curve, Many Parks, Upper Ute, Lower Ute, and Mills Lake) still require installation of forest health plots to complete the Forest Health Monitoring Network (Figure 1). More plots could be added to track WPBR spread as WPBR continues to be discovered in the park.

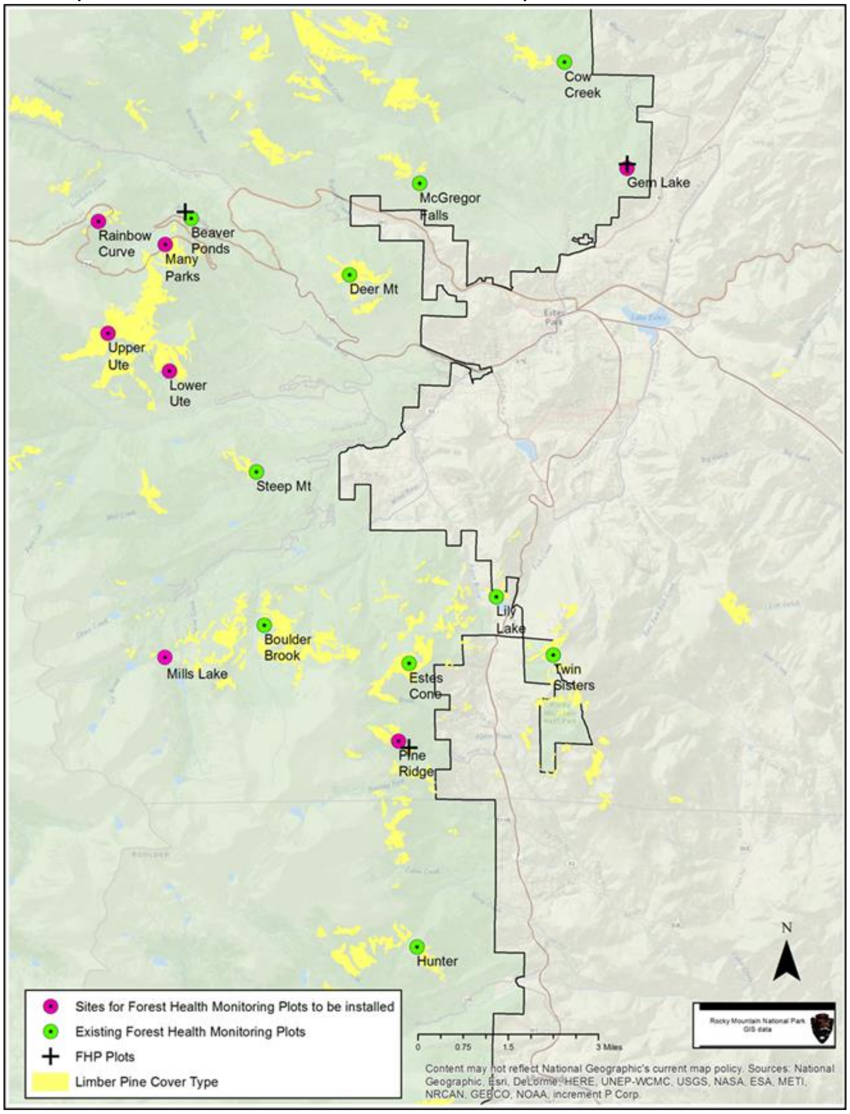

Figure 1. The Forest Health Monitoring Network within Rocky Mountain National Park.

Methods for Installing Forest Health Plots

Methods for installing long-term monitoring plots are described in Burns and others (2012) and are adapted from the Whitebark Pine Ecosystem Foundation (Tomback et al. 2004) and Six and Newcomb (2005), and are consistent with those used in the Greater Yellowstone Ecosystem (Greater Yellowstone Network Whitebark Pine Monitoring Working Group 2011). Long-term monitoring plots should be placed in stands with 20% or greater limber pine component. Distribute plot locations by elevation, intensity of WPBR (when available), and over a range of site and stand conditions. Data forms can be found in Appendix 1.

Plot Layout

Plots are 200 by 50 feet and divided into three sections (Figure 2). A circular, fixed area (1/100 acre, 11.8-foot radius) subplot is placed at the center of each section to assess regeneration and understory vegetation. Monument plots with a labeled wooden stake at the beginning and end and at each of the three subplots. Collect GPS coordinates at each wooden stake.

Plot Data

Plot-level data collected includes transect bearing, elevation, slope, aspect, slope position, stand structure, and disturbance history. Record the three most common shrub species within each section by genus and species. Tally all white pine regeneration within the plot in the following classes: healthy, infected, dead, or wpbr-killed. Note whether or not *Ribes* species and/or other alternate hosts occur within the plot.

Tree Data

Data recorded for all trees greater than 4.5 feet tall[3] (1.4 m) includes tree tag number*, stem clump number, section number*, species*, health status* (healthy, declining, dying, recent dead, old dead), diameter at breast height (dbh)*, height*, crown ratio, crown class, percent canopy kill (topkill), height to lowest live branch with needles within 1 foot of stem, percent of outer branch tips with fresh green cones per crown third, and all damages and their severities impacting more than 5 percent of the tree. Take note if recently killed trees were killed by WPBR, bark beetles (estimate year of death), or a combination of both.

Each white pine is evaluated for signs and symptoms of WPBR and presence or absence is noted. Record the number of branch cankers per crown third tallying the number with visible aecia (the fruiting structures produced by the fungus – see Appendix 4), the number with at least three secondary indicators, and the number of dead cankers. Secondary indicators (i.e. symptoms – see Appendix 4) include flagging, swelling, roughened bark, rodent chewing, and oozing resin and are noted on the form. The same process is done for stem cankers (includes all cankers on the main stem or within 6 inches of it) by dividing the stem into thirds. For each infected tree, record up to 5 branch canker sizes (inches) per crown third. Use a decimal place of .0 for branch tips that are dead and .1 for branch tips that are alive. For example, 12.1 means 12” canker with living tip. Repeat for middle/bottom. Note: do not tally or measure cankers on dead trees but note if they were apparently killed by WPBR.

Quantify crown damage by dividing the crown into thirds horizontally and recording crown condition (no visible branch infections, < 25 percent branches infected, 25 to 50 percent branches infected, > 50 percent branches infected). Similarly, quantify stem damage by dividing the stem into thirds and recording stem condition (no stem infections, 1 to 25 percent bole circumference girdled, 25 to 50 percent circumference girdled, and > 50 percent circumference girdled). Calculate disease severity for each tree based on cumulative crown and stem damage (Six and Newcomb 2005).

Subplot Data

For each subplot, tally all regeneration (trees < 4.5 feet tall), regardless of species, by species and height class (0-10 inches or 10-54 inches) and record WPBR infection for white pine species. Estimate percent ground cover of litter, rock, bare soil, tree stems, shrubs, and forbs within each subplot.

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[3] Variables with an asterisk were recorded for all species. All variables were recorded for white pines unless otherwise noted.

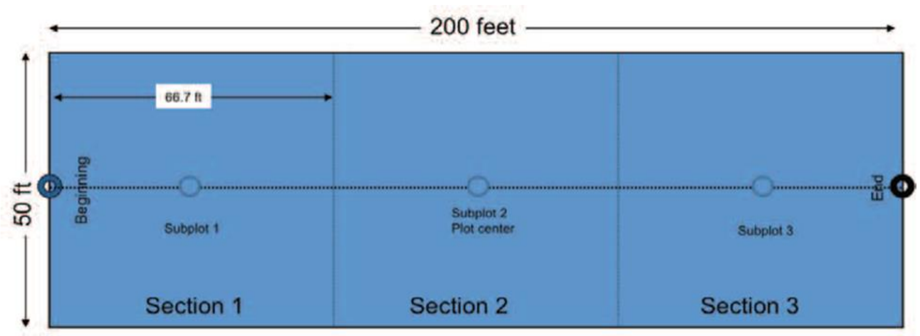

Figure 2. Diagram of limber pine forest health plot.

Section 3. Early Detection Monitoring Network

Riparian areas are likely locations for early detection of WPBR and offer the opportunity for eradication efforts to slow the spread of WPBR in the park. All of the WPBR-infected trees found in RMNP have been in the greater Beaver Ponds riparian area (Schoettle et al. 2018b; Burns 2018). Riparian areas are conducive to WPBR infection because they tend to have the high humidity and cool temperatures optimal for spore release, transport, and germination and the *Ribes* species that serve as the best alternate hosts for *C. ribicola* often grow there (Van Arsdel and Geils 2004).

The six Early Detection monitoring plots (Figure 3, Table 1), including an assessment of the alternate host species at these riparian locations, will assist with early detection and identification of WPBR infection centers to quantify early invasion dynamics. Additionally, quantifying early invasion dynamics in RMNP, a genetically and biologically unique location, will expand the knowledge of WPBR pathology and epidemiology and complements ongoing WPBR research in Great Sand Dunes National Park and Preserve (Burns 2006).

Because RMNP management goals include control of the establishment and perpetuation of non-native species, sanitation pruning is appropriate during the initial stages of WPBR infestation to slow disease spread and allows for more time to implement, and increase the efficacy of other conservation efforts as recommended in the RMNP Limber Pine Conservation Strategy (Schoettle et al. 2015) and the Proactive Limber Pine Conservation Strategy for the Greater Rocky Mountain National Park Area (Schoettle et al. 2018a). Infections found in the Beaver Pond area were removed by sanitation pruning or tree removal (Schoettle et al. 2018b; Burns 2018).

Table 1. Georeferenced locations for the start and end points of the six Early Detection Monitoring plots installed in RMNP in 2015-2016. Datum is WGS84.

Site Area	Site ID	Start Point		End Point	
		Latitude	Longitude	Latitude	Longitude
Boulder Brook	EDBB	40.300799	-105.617926	40.301214	-105.617895
Beaver Ponds	EDBP	40.398246	-105.637128	40.398629	-105.637957
Mills Lake	EDML	40.299004	-105.638195	40.298565	-105.637826
Pine Ridge	EDPR	40.273832	-105.574608	40.274074	-105.574916
Sandbeach Lake	EDSB	40.221485	-105.589515	40.221081	-105.589182
Lower Ute	EDUT	40.364281	-105.650212	40.363652	-105.650005

Early Detection Results and Recommendations

In 2015 and 2016, six early detection monitoring plots were installed in RMNP at Beaver Ponds, near Mills Lake, along the Boulder Brook trail, along the Lower Ute trail, near the Sandbeach Lake trail, and at Pine Ridge (see protocols and data forms in Appendix 2). A location near Black Canyon was explored as a potential site but did not have enough limber pine to warrant plot installation. Rocky Mountain National Park volunteers and USFS RMRS and FHP employees completed the plot installations.

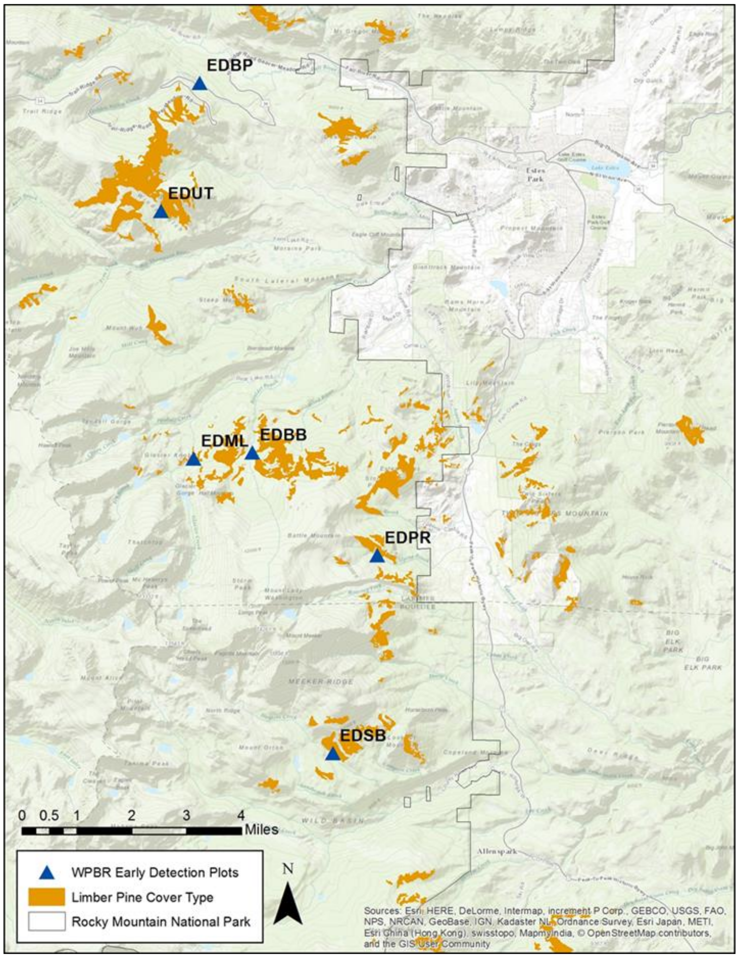

Figure 3. White Pine Blister Rust Early Detection Plots in Rocky Mountain National Park.

Overall, 239 live limber pines were evaluated and of those, 24 were seedlings (< 4.6 ft (1.4 m) in height). Diameter at breast height (dbh) ranged from 0 to 15 inches (38.3 cm) and averaged 4.6 inches (11.8 cm). Heights ranged from 0.7 to 60.7 ft (0.2 to 18.5 m) and averaged 17.4 ft (5.3 m). Average crown dieback was 6.4% and ranged from 0 to 90%. No WPBR cankers were positively identified (aecia must be visible for positive identification). One limber pine in the Lower Ute plot (EDUT) exhibited four of the five WPBR symptoms (flagging, swelling, roughened bark, and oozing sap – see Appendix 4) and should be examined carefully in subsequent examinations. Additional limber pines were casually examined for WPBR on the way to each plot and in the area of the plot. Limber pine dwarf mistletoe (*Arceuthobium cyanocarpum*) was noted on three trees at Beaver Ponds (EDBP) and was noted in other areas on limber pine (e.g. along Boulder Brook trail) but was not present in any other plots. Evidence of twig beetles (*Pityophthorus* spp. and *Pityogenes* spp.) were found on 24% of trees, porcupine damage on 7%, and evidence of mountain pine beetle attack (pitchout only) on 2% of trees. Other damage agents noted included *Bifusella* needle cast (*Bifusella* spp.), animal damage other than porcupine damage, red ring rot (*Porodaedalea pini*), and *Ips* bark beetles (*Ips* spp.).

The spring of 2015 was very wet and cool, which is ideal for WPBR but may have delayed aecia production. Aecia were not noted near Pole Mountain in southern Wyoming (where WPBR is present and flourishing) until at least mid-June of 2015. *Ribes* leaves were likely not out yet at higher elevations during the time of 2015 plot installation. Future monitoring efforts should take place in mid-June to coincide with timing of aecia formation. Late June might be best (especially for higher elevations). During the 2015 assessments, many small to medium-sized lodgepole and limber pine in several areas were observed with dead needles on the previous year's growth which is likely due to a fall freeze event in 2014 (Figure 5).

Figure 4. Damage agents recorded on evaluated limber pines included limber pine dwarf mistletoe (left), porcupine damage (center), and evidence of mountain pine beetle (right).

Figure 5. Limber pine needles with Bifusella *needle cast (left) and with damage from a sudden temperature drop that occurred in fall 2014 (right).*

Early Detection Plot Installation

About 20 candidate riparian areas were identified using GIS by overlapping the RMNP limber pine cover layer and the WPBR risk map (up to 20 m in elevation above a stream bed). Six sites that were spatially distributed (N to S) across the park were selected based on accessibility. Monitoring protocols were developed and upon arrival to candidate sites, the stand was assessed for suitability including presence of limber pine and proximity to the riparian area; presence of WPBR alternate hosts (*Ribes*, *Castilleja*, and *Pedicularis* species) was also noted as this can increase the risk of WPBR but is not necessary for successful WPBR establishment on site since the rust spores can travel in the wind from other locations. Since the objective of the WPBR early detection monitoring plots is to detect WPBR, plot locations within the stand were non-random and transects were positioned parallel to the riparian area and attempted to capture at least 30 limber pine, or more where possible. Using a variable length transect allowed for increasing the sampling area, and therefore the number of limber pine (> 30 trees) inspected, in less dense stands.

Equipment needed for plot installation is listed in Table 2. Once the measuring tape was stretched tautly, parallel to the stream, to represent the transect line, 1 ½" top aluminum rebar monuments (pre-labeled with "ROMO PIFL RMRS" for "Rocky Mountain National Park *Pinus flexilis* Rocky Mountain Research Station" and "ED_ _" for "Early Detection + 2 or 3 letter site code") with a plastic insulator were installed at each end, GPS'ed (lat/long, WGS84), and photo documented to aid in relocation of transect in subsequent years. If the soil was not conducive to rebar installation, then the nearest tree was tagged at the tree base with an oblong tree tag labeled "ED-END." Two aluminum nails were inserted next to one another near the base of one live tree (any species) along the transect to denote transect center and aid with remeasurement. Transect position (bearing and length) and site information (aspect, slope, topographic position, other species present, and WPBR alternate host presence) were recorded for each plot.

Table 2. Field equipment needed for Early Detection Monitoring Plot installation.

✓	Item	✓	Item
	Tatum		Wire
	Datasheets		Measuring tape (300 ft (100m))
	Maps		Dbh tape
	Camera		Compass
	Binoculars		Clinometer
	GPS unit		Hand saw or pruners
	Monuments and rebar		Flagging
	Tree tags and nails		Chaining pin (candy cane stake)
	Hatchet		Small dry erase board
	Laser range finder		Pole pruner

Only standing live limber pines (no minimum height) were evaluated, starting with the tree closest to the start (up or down hill of transect) and then first evaluating limber pines on the downhill side of the transect tape and then trees on the uphill side, starting from the end and working towards start (Figure 7). There was no maximum distance from transect when selecting limber pines to evaluate, but trees were generally no farther than 60 ft (18 m). Transect tape distance, direction from transect tape (uphill or downhill), and distance from transect to tree (using a range finder) were recorded. Documented tree attributes included dbh, height estimate, tree status (live, recently dead, or dead), crown dieback (percent), dwarf mistletoe rating (0-6) (Hawksworth 1977), mountain pine beetle (pitchout, strip attack, successful attack), WPBR symptoms with no aecia present (rodent chewing, flagging, swelling, roughened bark, oozing sap – see Appendix 4), twig beetles, porcupine damage, and notes (any other observable damages or information). While no WPBR was confirmed during 2015 plot installation, protocols were in place and are described as follows: if WPBR was confirmed by the presence of aecia, the tree was tagged using an oblong tree tag labeled "WPBR - #" and canker location (upper, middle, or bottom third of tree) of branch and bole cankers and presence of aecia or other symptoms (rodent chewing, flagging, swelling, roughened bark, oozing sap), canker size (in), and if the branch tip is dead were recorded for each canker. Cankers were then pruned according to the sanitation pruning guideline in the Limber Pine Conservation Strategy (Schoettle et al. 2015).

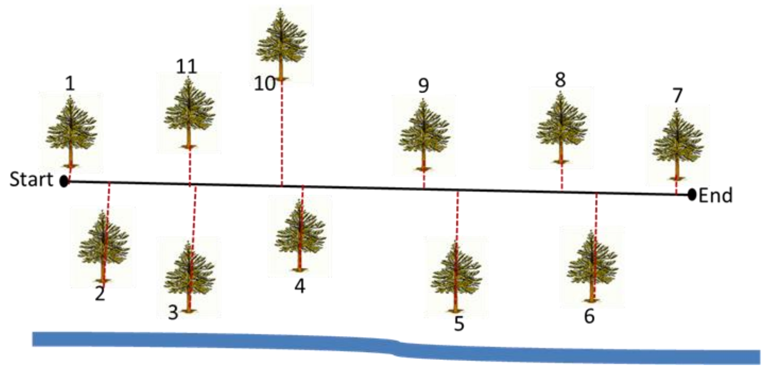

Figure 6. Diagram of Early Detection Plot transect.

Early Detection Plot Monitoring

Monitoring of WPBR Early Detection plots should take place as often as feasible, at least every 3-5 years, and start no earlier than mid to late June. Prior to entering the field, populate field datasheets using previous monitoring data with site name and ID, directions to the site, GPS coordinates and descriptions of the beginning and end monuments, and transect bearing and length. Populate tree data, including tree number and clump letter, transect tape distance, direction from transect tape, and distance from transect. Bring a copy of the previous monitoring data to refer to as needed. Data will be stored with Kelly Burns (ksburns@fs.fed.us).

Navigate to plot start monument or tree tag using GPS, description, and site photos. Position transect (measuring) tape beginning at plot start monument and ending at plot end monument. Record other species present and WPBR alternate host presence. Locate and evaluate each limber pine within the plot starting on the downhill side of the transect tape first then working on the uphill side, starting at the end working towards the start. Record tree attributes as listed above.

If a sign of WPBR is confirmed by the presence of aecia, tag the tree using an oblong tree tag stamp-labeled “WPBR - #” and record canker location (upper, middle, or bottom third of tree) of branch and bole cankers and presence of aecia or other symptoms (rodent chewing, flagging, swelling, roughened bark, oozing sap), canker size (in), and if the branch tip is dead for each canker. Prune cankers according to the sanitation pruning guideline in the Limber Pine Conservation Strategy (Schoettle et al. 2015).

Section 4. WPBR Virulence Monitoring Network

Natural genetic resistance (lower susceptibility) to WPBR is present in each of the North American white pine species, including limber pine (King et al. 2010). Limber pine populations in northern Colorado and RMNP have a high frequency of complete resistance conferred by a single major gene named Cr4 (Schoettle et al. 2014). Trees that carry the Cr4 resistance allele will remain WPBR disease-free until the rust mutates to overcome the single-gene resistance. It is not known how long the Cr4 complete resistance will protect limber pine from the disease or, if a virulent strain of the rust does arise, how effective the virulent rust strain will spread within the rust population in the park and greater landscape. At present, Cr4 resistance is the only genetic resistance to WPBR we have found in the park, so detecting virulence and following its spread can help predict, and manage for, future limber pine mortality in the park. Currently, the only method to detect virulence in the rust populations is through detection of signs and symptoms of WPBR on trees inferred to carry Cr4 resistance from our early research.

This network monitors for newly evolved virulence in the rust that can overcome the Cr4 resistance in limber pine. Twenty-nine individual limber pine trees in RMNP have previously been inferred to have Cr4 complete resistance to WPBR through artificial inoculation tests of their progeny (see Appendix 3). Assessing the inferred Cr4 limber pine trees for signs and symptoms of WPBR comprises the WPBR Virulence Monitoring Network. Early summer is the best time to assess trees for WPBR as the rust can be sporulating at that time. Any one sign of infection or three or more symptoms of infection (indicators) on a Cr4 tree may indicate that the rust has mutated and developed virulence (see Appendix 4).

Signs (positive identifiers) of WPBR include:

a) Small, honey-colored droplets (pycnia) at the canker margin in spring and summer, and may be visible later in the year than aecia.
b) Blister-like pustules (aecia) erupt through the bark in late spring or early summer, releasing masses of orange dust-like spores (aeciospores).
c) Remnant aecial fragments and aeciospores can often be found later in the summer after spore dispersal (late May/early June) (wind and weather degrade signs of the disease but close examination of bark crevices of a suspected canker can reveal signs).
d) Cankers are often orange at the margin, the fungus is active in this zone and beyond. Wetting the bark surface may make this more visible.

Symptoms of WPBR infection include:

a) Rodent Chewing: Rodents often gnaw on cankers as they are attracted to their high sugar content. Rodents may also gnaw dwarf mistletoe infections.
b) Roughened Bark: Cankered bark becomes rough and cracked over time as the result of previous years' fruiting.
c) Branch Flagging: When a canker girdles a branch, the branch dies and becomes "flagged". Twig beetles and dwarf mistletoe also cause flagging.
d) Branch Swelling: Infected branch and stem tissue is often swollen. Dwarf mistletoe also cause swelling.
e) Oozing Resin: Abundant resin exudation is typical at canker margins.

Documentation of inspection of each inferred Cr4 tree should be completed annually, preferably in June (see Appendix 3 for the field data form). The entire tree should be inspected with binoculars with special focus on the growing tips, as the early infections and cankers will develop close to the foliated portion of the twigs. If a tree has a sign of disease or at least three symptoms please:

1. Take note of the seed tree's tag number and date;
2. Take photos of the tree and observed signs and symptoms;
3. Notify Forest Health Protection (ksburns@fs.fed.us, 303-236-8006) or Rocky Mountain Research Station (aschoettle@fs.fed.us, 970-498-1333) as soon as possible.

If signs and symptoms of WPBR are found on a tree not previously tested for Cr4, please:

1. Tag the tree at the base with an aluminum tag and take note of number;
2. Collect GPS coordinates for the tree – note Datum (preferably lat/long; WGS84);
3. Notify Forest Health Protection (ksburns@fs.fed.us, 303-236-8006) or Rocky Mountain Research Station (aschoettle@fs.fed.us, 970-498-1333) as soon as possible.

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Appendix 1

Forest Health Monitoring Data Collection Forms (3 pages)

Plot:__________

Crew:__________

Date:__________

SITE, REGEN, VEG FORM

1/100 ac. = 11.8 ft radius

ht class: 1 = 10" or less; 2 = 10-54"

SITE DATA

elev	bearing	decl	slope	asp	latitude	longitude	pos	struc	dist

	#TotRegen (live + dead)	#Live_rust (live)	#Dead_Rust	#Dead_Other	Ribes (list species)	Pedicularis (y/blank)	Castilleja (y/blank)	Comments
PIFL								
PIAL								
PIAR								

REGENERATION SUBPLOTS

plot	sub	spp	ht_class	tally	infected#	comments

VEGETATION SUBPLOTS

plot	sub	soil	litter	veg	lich_moss	tree_log	rock	shrub1	shrub2	shrub3	instructions for locating plot
	1										
	2										
	3										

TREE FORM

Date:_______________ Crew: ___________

Plot:________________ Page _____ of _____

tree (#)	old (#)	type	clmp	sec	spp	stat	dbh (0.0 in)	hgc (0.0 ft)	cc	cr	kill (%)	cones_top	cones_mid	cones_low	dmg1	sev1	dmg2	sev2	dmg3	sev3	MPB (yr)	rust	Comments

DATE:________________ CANKER FORM CREW: ____________

PLOT:________________ Page _____ of _____

	TOP								MIDDLE								BOTTOM								INDICATORS					
Tree	BC_active (#)	BC_indicators (#)	BC_dead (#)	SC_active (#)	SC_indicators (#)	SC_dead (#)	Crown_severity (0-3)	Stem_severity (0-3)	BC_active (#)	BC_indicators (#)	BC_dead (#)	SC_active (#)	SC_indicators (#)	SC_dead (#)	Crown_severity (0-3)	Stem_severity (0-3)	BC_active (#)	BC_indicators (#)	BC_dead (#)	SC_active (#)	SC_indicators (#)	SC_dead (#)	Crown_severity (0-3)	Stem_severity (0-3)	RoughBark (y/blank)	Flagging (y/blank)	Swelling (y/blank)	Sap (y/blank)	Gnawing (y/blank)	Comments
e.g.	*3*						*1*	*0*							*0*	*0*		*1*					*1*	*0*	*y*	*y*	*y*	*y*	*n*	*Canker counts + indicators*
e.g.	*8.0*	*6.1*	*4.1*														*10*													*Canker size info*

SITE, REGEN, VEG FORM KEY

SITE DATA		
	elev	Elevation in feet
	bearing	Bearing of the transect
	decl	Declination of compass
	slope	Slope (%)
	asp	Aspect (degrees)
	latitude	Latitude
	longitude	Longitude
	pos	Slope Position (SU=summit/ridgetop; SH=shoulder; BS=backslope; FS=footslope; TS=toeslope; VB=valley bottom)
	struc	Stand Structure (SS=closed canopy single story; MS=closed canopy multi-storied; SI=open canopy scattered individuals; SC=open canopy scattered clumps; MO=mosaic)
	dist	Disturbance History (1=site prep; 2=art. Regen; 3=nat. regen; 4=tsi; 5=cutting; 6=fire; 7=other silv.; 8=other human; 9=nat. dist; 10=land clearing; 11=insect/disease; 12=animal dmg; 13=type conversion; 14=mining;
	#TotRegen	Total number 5NP in plot (live + dead) by species (PIFL, PIAL, PIAR)
	#Live_Rust	Total number of infected 5NP seedlings in plot (live only) by species (PIFL, PIAL, PIAR)
	#Dead_Rust	Total number of WPBR-killed 5NP seedlings in plot by species (PIFL, PIAL, PIAR)
	#Dead_Other	Total number 5NP that are dead, cause not WPBR by species (PIFL, PIAL, PIAR)
	Ribes	List Ribes species present in plot
	Pedicularis	Record "y" if Pedicularis is present in the plot
	Castilleja	Record "y" if Castillaja is present in the plot
	Comments	Add any notes here
REGENERATION SUBPLOTS		
	plot	Unique ID to identify plot
	sub	Subplot number (1, 2, or 3)
	spp	Regeneration species (USFS codes)
	height	Height class (1=0"-10"; 2=10.1"-52")
	tally	Total number of seedlings within the subplot of this species and height class
	infected	Total # seedlings of this species and height class that are infected with WPBR
	comments	Additional pertinent information
VEGETATION SUBPLOTS		
	plot	Unique ID to identify plot
	sub	Subplot number (1, 2, or 3)
TOTAL EQUALS 100% Look under plants to estimate % ground surface available for seedling establishment	soil	% ground surface covered by mineral soil and pea gravel
	litter	% ground surface covered by dead plant material
	veg	% ground surface covered by plant stems
	lich_moss	% ground surface covered by lichens/moss
	tree_log	% covered by tree trunks/logs in direct contact with the ground
	rock	% ground surface covered by by rocks
	shrub1/2/3	1st, 2nd and 3rd most common shrub species within subplot (USFS codes)
	Add any info you can think of to help locate plot in the future	

TREE FORM KEY

	Field	Description
Verify info is correct & change if necessary	plot	Plot#
	tree	Tree#
	type	**I** = ingrowth, **cnft** = could not find tree, **added** = missed last time but added, **cut** = tree was cut, **new#** = gave the tree a new number
	clmp	Stem clump letter
	sec	Section number (1-3)
	spp	Species
	stat	Health Status **1** = healthy, **2**=declining (6-50% of crown showing symptoms), **3**=dying (>50% of crown showing symptoms or damage), **4**=recent dead (no green needles, red needles and fines still present), **5**=old dead (no fine twigs or needles)
	dbh	DBH (diameter at 4.5 ft to nearest 1/10 inch. No DBH on krummholtz).
	cc	Crown Class **OP = open-grow**n (crowns receive full light from above and from all sides); **DO = dominant** (crown receives full light from above and partly from sides. Crown extends above the general level of the crown cover of others of same stratum and are not physically restricted from above, although may be crowded on sides); **CO = codominant** (crowns receive full light from above, but comparatively little from the sides. Crowns form a general level of crown stratum, are not physically restricted from above, but are crowded by other trees from the sides); **IN = intermediate** (crowns occupy a subordinate position and are subject to strong lateral competition from crowns of DO/CO. They receive little direct light from above, but no light from sides); **OV = overtopped** (crowns receive no direct light from above or from the sides and are entirely below the general level of dominant and codominant trees); **KR = krummholtz** (shrubby, multistemmed form assumed by trees near treeline).
	cr	Crown Ratio: Length of the live crown divided by tree height, assessed from the uppermost live leader or branch to the lowest live branch. Visually adjust large openings or lopsided crowns by transferring lower branches to fill in the holes. DO NOT compress the live crown length because it appears "sparse" or contains "unhealthy" foliage.
	kill	Canopy Kill: The canopy includes all main branches that begin as bifurcations off the trunk and encompasses all foliage and supporting twigs and side branches. The percentage killed is considered as a portion of the entire canopy volume. Branches may be dead for only a portion of their length. Ignore branches obviously shaded out.
	cones_top/mid/low	Estimate the % of branch tips that possess fresh green cones by canopy third.
	dmg1/dmg2/dmg3	Damages (see "damage codes" sheet)
	sev1/sev2/sev3	Severity (see "damage codes" sheet)
	MPB	Estimate the year the tree was killed by MPB (e.g current year attack will still be green but mass attacked; 1-yr ago needles still intact but fading/yellow; 2-yrs ago starting to lose some needles; 3-yrs ago few needles, losing fine twigs; 4-yrs ago no needles, few fines; 5-yrs ago losing fines; etc...
	rust	WPBR presence/absence (**0 = no rust; 1 = infected; 2 = killed by WPBR**). NOTE: If tree was infected previously but no rust can be detected now, please give an explanation for why you think that is the case.

DAMAGE CODES

See Common Stand Exam Guide, Appendix K
https://www.fs.fed.us/nrm/fsveg/

dmg	description	severity
10.000	general insects	
11.000	bark beetles	1 = pitchout, 2=strip attack, 3= successful hit; 4=topkill
11.006	mountain pine beetle	
11.012	red terpentine beetle	
11.030	engraver beetles (Ips)	
11.039	twig beetles	
12.000	defoliators	
15.000	boring insects/woodborers	
20.000	biotic damage	
21.000	root disease	
22.000	cankers (unk)	
22.001	heart rot	
22.025	cytospora (aspen)	
23.001	mistletoe	Hawksworth 6-class rating
24.000	decline complexes/dieback	
25.005	needlecast	
26.000	stem rust (unknown)	
26.002	western gall rust	
26.004	comandra blister rust	
30.001	wildfire	
41.000	animal damage	
41.006	porcupine	
41.008	sapsucker	
41.009	squirrels	
41.012	elk	
50.005	frost	
50.008	lightning	
60.000	competition	
80.000	mulit-damage	
90.000	unknown	
99.000	physical effects	
99.001	broken/missing top	% of original height missing (1-10)
99.005	forked below DBH	
99.002	dead top	% of total tree height that is dead (1-10)
99.006	crook or sweep	
99.018	uprooted	1=stem failure; 2= root plate; 3= root disease; 4=downed (generic)
99.036	fire scar	
99.037	leaning tree	% lean from vertical (1-10)
sev	use these severity codes unless otherwise noted above	
1=	< 30 % damage	
2=	33-50 % dmg	
3=	> 50% dmg	

CANKER FORM KEY		
	Variable	***Description***
	Tree	Tree number
Repeat for each crown and stem third (top, middle, bottom).	**BC_active**	Total number of branch cankers within each crown third with aecia present (or if pycnia or bright orange canker margin are identified).
	BC_indicators	Total number of branch cankers within each crown third that appear to be alive, do NOT have aecia present, but have at least 3 indicators present (roughened bark, swelling, oozing sap, rodent chewing, or flagging).
	BC_dead	Total number of branch cankers within each crown third that are dead.
	SC_active	Total number of stem cankers within each crown third with aecia present (or if pycnia or bright orange canker margin are identified).
	SC_indicators	Total number of stem cankers within each crown third that appear to be alive, do NOT have aecia present, but have at least 3 indicators present (roughened bark, swelling, oozing sap, rodent chewing, or flagging).
	SC_dead	Total number of stem cankers within each crown third that are dead.
	Crown_severity	Rate each crown third (planar method) separately and score as follows: 0=no visible branch infections; 1=<25% branches infected/killed by rust; 2=25-50% branches infected/killed by rust; 3=>50% branches infected/killed by rust. Portions killed by rust get a 3.
	Stem_severity	WPBR stem severity calculated by dividing the stem into thirds and rating each third as follows: 0=no visible infections; 1=<25% of stem circumference infected; 2=25-50% of stem circum. infected; 3=>50% of stem circum. infected. Portions of the tree entirely killed by rust get a 3.
	RoughBark	Roughened bark observed (y/blank)
	Flagging	Flagging present (y/blank)
	Swelling	Swelling present (y/blank)
	Sap	Oozing sap present (y/blank)
	Gnawing	Rodent gnawing present (y/blank)
	Comments	Add any additional pertinent information
	Canker Sizes	For each infected tree, record up to 5 branch canker sizes (to the nearest inch) per crown third in the dark shaded area under where you recorded the tree's canker counts and indicators. Use a decimal place of .0 for branch tips that are dead and .1 for branch tips that are alive. For example, 12.1 means 12" canker with living tip. Repeat for middle/bottom.
	<u>NOTE</u>: Branch cankers within 6" of main stem are considered stem cankers. Please record in the notes if this is the case.	

Appendix 2

White Pine Blister Rust Early Detection Monitoring Plot Protocol

Early Detection Plot installation protocol:

1. Arrive at site – determine best location for plot installation to assess the most live limber pines in the riparian area (within 66 ft (20 m) elevation above the stream), preferably with WPBR alternate hosts.
    a. Run transect parallel to water; along slope contour if possible.
    b. Transect length can be variable (Previously established transects ranged from 104 to 240 ft (32 to 73 m)).
    c. Transect may need to change bearing due to limiting topographical features (e.g. cliff). In this case install second (end) monument at end of first bearing. Use "end" tree tag for end of second transect with 2nd bearing.
    d. Attempt to include at least 30 limber pine.
    e. Use chaining pin (candy cane stake) to secure beginning of transect tape; have 2nd person standing at transect end as a guide and lay out metric measuring tape.
2. Install start and end monuments flush with ground with rebar and hatchet.
3. Record GPS coordinates of start and end monuments using UTM WGS84.
    a. Label start: ED_ _ (2 or 3 letter site code).
    b. Label end: ED _ _ END.
4. Photo document using dry erase board with Site Name, Site ID, date, transect location and direction of photo taken:
    a. Start and End monuments.
    b. Directions 2 ways of start and end transect.
    c. Middle of transect in direction of transect).
    d. Change in transect bearing if applicable.

Site information and datasheet:

Site name: Designated site name (e.g. Beaver Ponds, Mills Lake, Boulder Brook, Lower Ute, Sandbeach Lake).
Site ID: ED _ _ (2 or 3 letter site code: BP, ML, BB, UT, SB).
Date: XX/XX/XXXX.
Datum: WGS84.
Crew: First and last names of all crew members.
Trailhead, hiking directions, location of transect: Describe route to plot and location of plot.
Start and end monument GPS and ID with location description: Record GPS coordinates (UTM WGS84) and the ID of the monument (or tree tag if necessary) with descriptive location of monument.
Transect bearing (degrees): Direction of transect from start point to the end point.
Transect Length (ft): Length of transect.
Aspect of slope (degrees): Direction which the slope faces. Take compass reading directly downslope from plot beginning. If flat then code as 0.

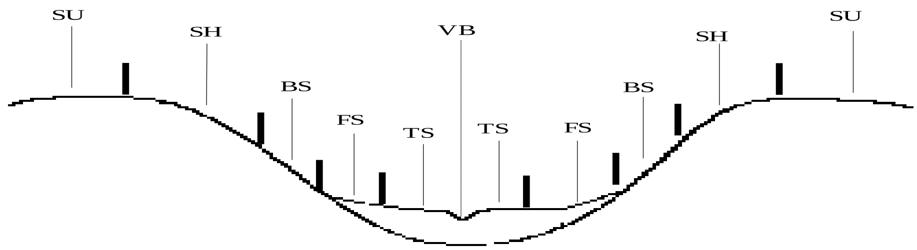
- If aspect changes gradually across the setting, record an average aspect.
- If aspect changes across the setting but is predominately of one direction, code predominate direction, rather than the average.
- If the setting falls on or straddles a canyon bottom or narrow ridge top, code the aspect of the ridgeline or canyon bottom.
- If the setting falls on a canyon bottom but most of the area lies on one side hill, code the aspect of the side hill.

Slope (%): Slope is defined as the ratio of vertical rise divided by the horizontal distance.

- If slope changes gradually across the setting, record an average slope.
- If slope changes across the setting but is predominately of one direction, code predominate slope percentage rather than the average.
- If the setting falls directly between two side hills, code the average slope of the side hill(s).
- If the setting falls on a canyon bottom or on a narrow ridge top, but most of the area lies on one side hill, code the slope of the side hill.

Topographic position: Record the plot position on the landscape. See National Soil Survey Handbook (Title 430-VI).

Code	Description
SU	**Summit/Ridgetop/Plateau**. The topographically highest hillslope position of a hillslope profile and exhibiting a nearly level surface.
SH	**Shoulder**. The hillslope position that forms the uppermost inclined surface near the top of a hillslope. It comprises the transition zone from backslope to summit.
BS	**Backslope**. The hillslope position that forms the steepest inclined surface and principal element of many hillslopes. In profile, backslopes are commonly steep, linear, and bounded by a convex shoulder above and descending to concave footslope. They may or may not include cliff segments. Backslopes are commonly erosional forms produced by mass movement and running water.
FS	**Footslope**. The hillslope position that forms the inner, gently inclined surface at the base of a hillslope. In profile, footslopes are commonly concave. It is a transition zone between upslope sites of erosion and transport.
TS	**Toeslope**. The hillslope position that forms the gently inclined surface at the base of a hillslope. Toeslopes in profile are commonly gentle and linear, and are constructional surfaces forming the lower part of a hillslope continuum that grades to valley bottom.
VB	**Valley Bottom**. Wide valley bottom beyond influence of toeslope.



Photos: Taken of start, middle, and end of transect. Record direction the photo was taken and number of photos in field notebook.
Other species present: Record other tree and shrub species present in the area.
White pine blister rust alternate hosts:

- ***Ribes* species present:** Record species of *Ribes* present in the area.
- ***Castilleja*:** Record presence of any *Castilleja* species in the area.
- ***Pedicularis*:** Record presence of any *Pedicularis* species in the area.

Tree information and datasheet:

PIFL # and clump letter: For each plot, start numbering at 1. Each stem is designated a unique number, but include clump letter (a,b,c, etc.) if stems are part of a clump.
Transect tape distance (ft): Distance on transect tape that tree is located.
Direction from transect tape: up: uphill, dn: downhill.
Distance from transect to tree: Use laser range finder to determine distance from transect tape to tree. Make sure measurement is perpendicular to tape and starts from recorded transect tape distance.
DBH (in): Diameter at breast height; record using dbh tape or Biltmore stick.
Tree height estimate (ft): Measure or estimate tree height using known height of crewmember standing next to tree.
Tree status: L: live, RD: recently dead, D: dead
Crown dieback (%): Percentage of dead foliage as compared to the entire crown.
DMR- Dwarf Mistletoe Rating: Hawksworth 0-6 class system

- Divide crown into thirds
- Rate each third
- 0=no mistletoe infections
- 1= < 50% branches have infections
- 2= > 50% branches have infections
- Add each third for a total between 0-6.

MPB: mountain pine beetle

- Pitchout: unsuccessful bole attack: pitch tubes
- Strip attack: galleries and brood present
- Successful

WPBR Indicators: check boxes only if indicators are present without aecia. Turn to WPBR section if aecia are present.

- Rodent chewing
- Flagging
- Swelling
- Roughened bark
- Oozing sap

Twig beetles: Check box for evidence present.
Porcupine: Check box for damage present.
GPS: GPS tree location and record if tree is identified as having WPBR. Note name in GPS: **ED_ _(tree#) WPBR#**
Notes: Include other damages and additional information.
*****Nail 2 nails ~1 ft. from tree base on any tree species touching the transect tape towards the middle of the transect and record on datasheet in notes section that you have done so.**

White pine blister rust (WPBR) information and back side of datasheet:

PIFL #: designated from front side of data sheet **(one CANKER per line)**
WPBR Tag #: Tag the tree using the WPBR tags created "WPBR - #" and note tag number on datasheet. Continue with consecutive order of tags.
Branch and Bole Cankers: Check boxes that correspond to branch and bole canker locations (A: aecia present, I: indicator).
Indicators: Check noted indicators that helped ID the WPBR canker.
Canker size (in): Estimate canker size (inches).
Tip dead (y/n): Is the portion of tissue above the canker dead?
Canker pruned (y/n): Was the canker pruned?
Notes: Include additional information.
*****Photo document cankers and trees with WPBR. Take photo of tree tag.**

White Pine Blister Rust Early Detection Monitoring Plot Data Collection Form (2 pages wide)

page 1 of 2

Rocky Mountain National Park White Pine Blister Rust Early Detection Monitoring Plots

Site name	Site ID	Date	Datum	Crew	Trailhead/hiking directions/location of transect

Monuments	Latitude	Longitude	ID	Description	Transect bearing	Transect length (ft)	Aspect	Slope (%)	Topo
Start									
End					PHOTO ✓		Start	Mid	End

Other Species Present	Ribes spp.	Castilleja	Pedicularis

PIFL # and clump letter	Transect tape distance (ft)	Direction from transect tape (up/dn)	Distance from transect (ft)	DBH (in)	Height Estimate (ft)	Tree status (L, RD, D)	Crown Dieback (%)	DMR (0-6)	MPB			WPBR Indicators (no aecia)					Twig beetles	Porcupine	GPS WPBR Trees		Notes (include other damages)
									Pitchout	Strip Attack	Successful	Rodent chewing	Flagging	Swelling	Roughened bark	Oozing sap			Latitude	Longitude	

page 2 of 2

White pine blister rust

PIFL #	WPBR Tag #	Branch Cankers						Bole Cankers						Indicators					Canker size (cm)	Tip Dead (y/n)	Canker Pruned (y/n)	Notes
		Upper third		Middle third		Bottom third		Upper third		Middle third		Bottom third		Rodent chewing	Flagging	Swelling	Roughened bark	Oozing sap				
		A	I	A	I	A	I	A	I	A	I	A	I									

Appendix 3

White Pine Blister Rust Virulence Monitoring Data Collections Form

WPBR Virulence Monitoring

page 1 of 2

Check if present

Date of inspection	Site	Seed Tree ID	SIGNS of WPBR: Pycnia	Aecia	Remnant Aecial fragments	Orange-margined Canker	SYMPTOMS of WPBR: Rodent Chewing	Rough Bark	Branch Flagging	Branch Swelling	Oozing resin	Contact FHP/RMRS?
	Cow Creek	CC-3069										
	Deer Mnt	DM-3038										
	Estes Cone	EC-3640										
	Estes Cone	EC-981										
	Estes Cone	EC-988										
	Gem Lake	GL-3089										
	Gem Lake	GL-3121										
	Gem Lake	GL-3127										
	Gem Lake	GL-3357										
	Hunter	HU-3112										
	Lily Lake	LIL-3005										
	Lily Lake	LIL-3006										
	Lily Lake	LIL-3049										
	MacGregor Falls	MF-3017										
	MacGregor Falls	MF-3047										
	Pine Ridge	PIR-3107										
	Pine Ridge	PIR-3318										
	Rainbow Curve	RAC-3022										
	Rainbow Curve	RAC-3030										
	Rainbow Curve	RAC-3031										
	Steep Mtn	STE-3084										
	Steep Mtn	STE-3466										
	Twin Sisters	TS-3327										
	Twin Sisters	TS-3480										
	Twin Sisters	TS-3481										
	Upper Ute Trail	UT-3455										
	Upper Ute Trail	UT-3456										
	Upper Ute Trail	UT-3460										
	Upper Ute Trail	UT-3460										

WPBR Virulence Monitoring

page 2 of 2

SIGNS	Pycnia	Small, honey-colored droplets (pycnia) at the canker margin in spring and summer and may be visible later in the year
	Aecia	Blister-like pustules (aecia) erupt through the bark in late spring or early summer, releasing masses of orange dust-like
	Remnant Aecial fragments	Following spore dispersal (late May/early June), wind and weather degrade signs of the disease but remnant aecial fragments and aeciospores can usually be found by carefully examining bark crevices within the aecial scars of the canker.
	orange-margined canker	Cankers are often orange at the margin, the fungus is active in this zone and beyond. Wetting the bark surface will make this more visible.

SYMPTOMS	Rodent Chewing	Rodent Chewing: Rodents often gnaw on cankers as they are attracted to their high sugar content.
	Rough Bark	Roughened Bark: Cankered bark becomes rough and cracked over time as the result of previous years fruiting.
	Branch Flagging	Branch Flagging: When a canker girdles a branch, the branch dies and becomes “flagged”. Twig beetles and dwarf mistletoe also cause flagging.
	Branch Swelling	Branch Swelling: Infected branch and stem tissue is often swollen, dwarf mistletoe also cause swelling.
	Oozing resin	Oozing Resin: Abundant resin exudation is typical at canker margins.

Each inferred Cr4 tree should be thoroughly inspected each summer . The entire tree should be inspected with binoculars with special focus on the growing tips as the early infections and cankers will develop close to the foliaged portion of the twigs.
If a tree has a sign of disease or at least three symptoms please:

1. Take note of the seedtree’s tag number and date;
2. Take photos of the tree and observed signs and symptoms;
3. Notify Forest Health Protection (ksburns@fs.fed.us, 303-236-8006) or Rocky Mountain Research Station (aschoettle@fs.fed.us, 970-498-1333) as soon as possible.

If signs and symptoms are found on a tree not previously tested for Cr4, please:

1. Tag the tree at the base with an aluminum tag and take note of number;
2. Collect GPS coordinates for the tree (preferably lat/long);
3. Notify Forest Health Protection (ksburns@fs.fed.us, 303-236-8006) or Rocky Mountain Research Station (aschoettle@fs.fed.us, 970-498-1333) as soon as possible.

Appendix 4

White Pine Blister Rust Identification Guide (prepared by KS Burns)

White Pine Blister Rust

Identifying Infected Five-Needle Pines in the Field

Signs of Infection – Positive Identifiers

Small, honey-colored droplets (Pycnia) form at the canker margin in spring and summer and may be visible later in the year than aecia (this picture was in early August).

Blister-like pustules (aecia) erupt through the bark in late spring or early summer, releasing masses of orange dust-like spores (aeciospores).

Cankers are often orange at the margin, the fungus is active in this zone and beyond. Wetting the bark surface will make this more visible.

Following spore dispersal (late May/early June), wind and weather degrade signs of the disease but remnant aecial fragments and aeciospores can usually be found by carefully examining bark crevices within the aecial scars of the canker.

Symptoms that Indicate Infection

*If **3 or more symptoms** are present the tree may be infected*

Rodent Chewing
Rodents often gnaw on cankers as they are attracted to their high sugar content.

Roughened Bark
Cankered bark becomes rough and cracked over time as the result of previous years fruiting. Note the branch swelling and flagging also visible in this image.

Branch Flagging
When a canker girdles a branch, the branch dies and becomes "flagged". Twig beetles and dwarf mistletoe also cause flagging.

Swelling
Infected branch and stem tissue is often swollen.

Oozing Resin
Abundant resin exudation is typical at canker margins.

If you see a tree with SIGNS of disease or with *at least 3 SYMPTOMS* please:

- Tag the tree at the base with an aluminum tag, take note of number.
- Take photos of the tree and observed symptoms.
- Collect GPS coordinates for the tree (preferably lat/long).
- Notify Forest Health Protection (ksburns@fs.fed.us, 303-236-8006) or Rocky Mountain Research Station (aschoettle@fs.fed.us, 970-498-1333) as soon as possible.