National Park Service
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Natural Resource Stewardship and Science

Monitoring Five-Needle Pine on Bureau of Land Management Lands in Wyoming

Summary Report for 2013, 2014, 2016, 2017—Republished

Natural Resource Report NPS/GRYN/NRR—2022/2412

ON THIS PAGE
National Park Service monitoring crew en route to a BLM sample frame.
NPS/E. SHANAHAN

ON THE COVER
BLM Rapid Assessment transect that fell partly in a mosaic of timber and meadow, Spring Mountain, Wyoming.
NPS/E. SHANAHAN

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June 2022

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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Abstract

Whitebark pine (*Pinus albicaulis*) grows at high elevations and in subalpine communities in the Pacific Northwest and Northern Rocky Mountains. Limber pine (*Pinus flexilis*) 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). Both of these five-needle pine species play a variety of ecological roles and are considered key components in the their environments. Currently, whitebark pine and limber pine are being impacted by multiple ecological disturbances. White pine 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. An effort was initiated in 2013 by the National Park Service and the Wyoming Bureau of Land Management (WYBLM) to evaluate and monitor the long-term health trajectory of five-needle pines on WYBLM lands within the Greater Yellowstone Ecosystem (GYE). With guidance from the Interagency Whitebark Pine Monitoring Program protocol, and employing a rapid assessment survey technique specifically designed for this endeavor, we monitored whitebark pine trees in 2013, 2014, 2016, 2017. We estimated the proportion of live, five-needle pine trees (>1.4 m tall) infected with white pine blister rust, documented blister rust infection severity by the occurrence and location of persisting and new infections, determined mortality of five-needle pine trees and described potential factors contributing to the death of trees, and assessed the multiple components of recruitment of understory five-needle pine into the reproductive population. White pine blister rust was widespread throughout WYBLM lands within the GYE. Using a combined ratio estimator we found that the proportion of live, >1.4 m tall five-needle pine trees infected with white pine blister rust was 0.156 (±0.054 SE; this estimate combines all surveyed trees). Bole cankers were 25% more prevalent than branch cankers in all five-needle pines observed. Mortality of surveyed trees on WYBLM lands was predominantly attributed to mountain pine beetle. For seedlings and saplings, a total of 4003 live, ≤1.4 m tall five-needle pines were documented. Cones or cone scars were recorded on 745 of the live trees. Of these reproducing trees, 44 were recorded with white pine blister rust infection. Long-term monitoring on five-needle pines on WYBLM lands will continue into the future.

Acknowledgments

We thank all of the biological technicians, including Cayley Faurot-Daniels, Megan Rockwell, Kami Crockatt, Liana Edwards, Alyssa Millard, Suzanne Stevenson, Dillon Osleger, and Chris Olsen for their field data collection efforts and Kami Crockatt for her meticulous attention to detail with the data entry process. We thank former Greater Yellowstone Network ecologist Rob Bennetts for his contribution to the sample design and development of the whitebark pine monitoring protocol, Steve Cherry from Montana State University for ensuring statistical validity of the whitebark pine sampling regime, and Siri Wilmoth, formerly of the USGS, for her extensive contributions to the Rapid Assessment statistical investigation and analysis. We also thank Jim Gates for his advice and field and logistical support. In addition we would like to recognize the late Robert Means, whose initial interest in the health status of five-needle pines on Wyoming Bureau of Land Management lands initiated this endeavor. Base funding for this program is provided by the Wyoming Bureau of Land Management with additional support provided through the Greater Yellowstone Network.

Introduction

Importance of Five-Needle Pines

Whitebark pine (*Pinus albicaulis*) grows at high elevations and in subalpine communities in the Pacific Northwest and Northern Rocky Mountains. It is a key component in the upper ranges of these ecosystems, where it plays a variety of ecological roles, including regulating snowpack and providing high-energy food sources to birds and mammals. As a stone pine species, it produces indehiscent cones (closed cones that do not open to release mature seeds) and relies primarily on Clark's nutcracker (*Nucifraga columbiana*) for seed dispersal.

Limber pine (*Pinus flexilis*) 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 where soils are composed of limestone or sandstone (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). Limber pine depend principally on Clark's nutcrackers to disseminate their wingless seeds (Lanner and Vander Wall 1980).

Current Threats to Five-Needle Pines

Currently, whitebark pine and limber pine are being impacted by multiple ecological disturbances. White pine 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 on the landscape.

White pine blister rust (blister rust) is an exotic fungal pathogen with a propensity for infecting white pine species (whitebark pine, limber pine, and western white pine; *Pinus monticola*). Blister rust is ubiquitous throughout the Greater Yellowstone Ecosystem (GYE), although the level and magnitude of infection vary geographically (GYWPMWG 2012). Introduced into Vancouver, Canada, around 1910, blister rust thrived in the maritime climate (Kendall and Arno 1990, Keane and Arno 1993). From its coastal landing, blister rust successfully dispersed inland and was first discovered in the GYE in 1937 (Kendall and Asebrook 1998). To complete its life cycle, blister rust requires primary and secondary host species. Originally, white pines and species of the genus *Ribes*, such as currant and gooseberry, were thought to be the primary and alternate hosts for blister rust (McDonald and Hoff 2001, Zambino et al. 2007). However, three other species, parrot's beak (*Pedicularis racemosa*), bracted lousewort (*Pedicularis bracteosa*), and giant red Indian paintbrush (*Castilleja miniata*), all common flora of whitebark pine communities, were recently identified as successful intermediary hosts as well (McDonald et al. 2006, Zambino e al. 2007, Geils et al. 2010).

In the GYE, a bird's eye view presents a striking panorama of mortality in the overstory population of five-needle pines. Mass mortality of five-needle pines has occurred at a landscape level largely attributable to the recent mountain pine beetle outbreak (Logan et al. 2009, Burns et al. 2011, MacFarlane et al. 2013, Shanahan et al. 2016). Mountain pine beetles are one of the many species of

endemic bark beetles that are present in the western United States (Logan and Powell 2001). Mountain pine beetle typically attack lodgepole pine (*Pinus contorta* var. *latifolia*), but will also attack whitebark pine and limber pine (Furniss and Carolyn 1977, Cleaver 2014). Whitebark pine trees that are less than 10 cm DBH generally are not large enough to successfully support mountain pine beetle brood, and for limber pine, trees with a DBH greater than 20 cm are the preferred hosts (Furniss and Carolyn 1977, Cleaver 2014). Variations in climate are largely responsible for the success of mountain pine beetle outbreaks. Mild summers and winters tend to favor outbreaks, while cold winters and hot summers tend to decrease beetle activity and increase brood mortality (Kipfmueller and Swetnam 2002). Evidence has shown that mountain pine beetles tend to attack and are more successful when attacking trees that are already weakened by some other process, such as drought stress or pathogens (Kipfmueller and Swetnam 2002, Shanahan et al. 2016).

In addition to blister rust and mountain pine beetle, dwarf mistletoe is known to cause substantial damage in limber pine populations in areas of the Rocky Mountains (Cleaver 2014). Since the initiation of the whitebark pine monitoring program in 2004, occasional dwarf mistletoe infections have been noted in a small number of whitebark pine trees in the GYE. Recent work on Bureau of Land Management lands (BLM) in Wyoming, however, has documented an increase in dwarf mistletoe presence in some populations of surveyed limber pine.

Finally, wildland fire and drought are further contributors to five-needle pine decline in the GYE. As climate changes augment drought severity across the western United States, the probability of wildland fire is expected to increase (Westerling et al. 2011, Shanahan et al. 2017). While wildland fire has historically been an important component for the maintenance of five-needle pine forests (Arno 1986), predicted warming trends may increase the frequency and severity of fire events to the detriment of five-needle pine stands (Keane et al. 2016, Shanahan et al. 2017). Furthermore, individual five-needle pine trees that cannot tolerate drier conditions (i.e., smaller size class trees) may be increasingly susceptible to drought-induced mortality.

Background of Program

Both whitebark pine and limber pine are listed as sensitive species on BLM lands. Therefore, in an effort to understand the many challenges faced by five-needle pines and to track their health status, the Wyoming BLM (WYBLM) initiated a pilot monitoring program on WYBLM lands where five-needle pine occur within the GYE. After assessment of the data collected in 2013 and 2014, a five-needle pine long-term monitoring effort on WYBLM lands was assimilated into the Interagency Whitebark Pine Monitoring program.

Measurable Objectives

The specific WYBLM measurable objectives are to

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; and
4. Assess the multiple components of the recruitment of understory five-needle pine into the reproductive population.

These objectives are similar to those in the Interagency Whitebark Pine Monitoring program (GYWPMWG 2011) but include both whitebark and limber pine.

Study Area

The WYBLM five-needle pine study area encompasses portions of BLM lands in Wyoming that are within federally protected lands delineated as the GYE. These BLM areas were identified as habitat for five-needle pines and ground-surveyed by WYBLM 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/Hull Creek (SRHC) (Figure 1). In 2016, three newly identified geographic strata (Baldwin Creek, Spring Creek, and Whiskey Mountain/Torrey Creek) were surveyed using only the rapid assessment methodology.

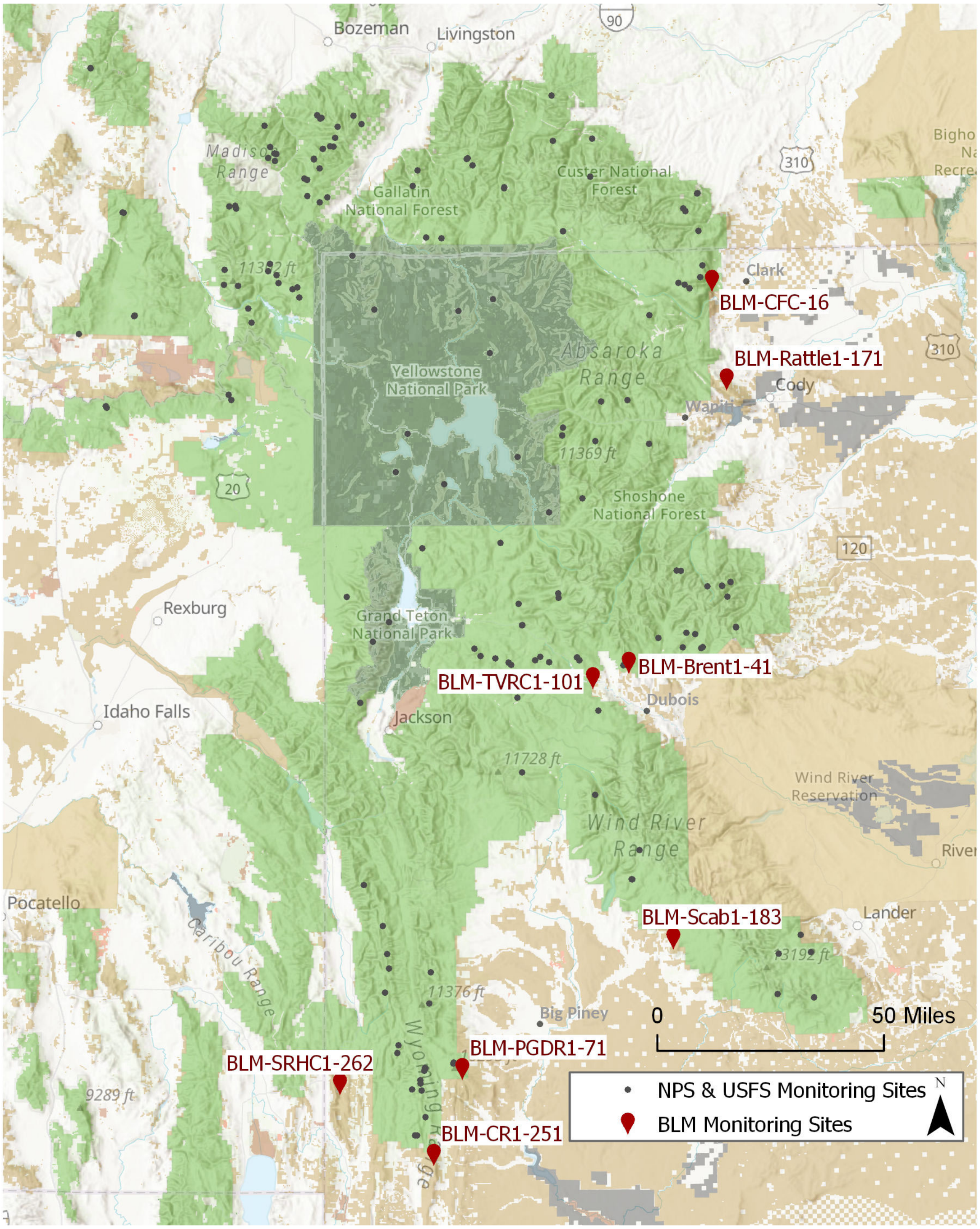


Figure 1. Map of Wyoming Bureau of Land Management (BLM) five-needle pine study sites. Map also shows additional National Park Service (NPS) and US Forest Service (USFS) whitebark pine monitoring sites in the region.

Methods

Sampling Design

We appraised five-needle pine health on WYBLM lands using a combined, permanent transect approach (following the *Interagency Whitebark Pine Monitoring Protocol for the Greater Yellowstone Ecosystem* methods) and a rapid assessment method specifically designed for this WYBLM effort (see Appendices 1 and 2 attached to this report). The interagency whitebark pine monitoring protocol assesses long-term trends in whitebark pine health by surveying permanent transects and tagged trees within designated stands of whitebark pine in the GYE. These delineated stands tend to support higher densities of whitebark pine. Given the sparsity of five-needle pines (whitebark pine and limber pine) often encountered on WYBLM lands, the data gathered using the rapid assessment method allow for larger sample sizes to more accurately evaluate blister rust infection levels and overall five-needle pine health.

The sampling design for both types of surveys was a stratified two-stage cluster sample. Each geographic area identified by WYBLM (Figure 1) 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 2).

Map units were initially delineated by WYBLM personnel. In some cases, these areas were further refined to reflect realistic map unit boundaries (e.g., areas of nonforest cover included in the original delineation were removed). The number of map units varied by geographic stratum. For example, Commissary Ridge geographic stratum contained three map units, while Rattlesnake was composed of 10 map units. Secondary sampling units (10 × 50 m belt transects) were selected using the Generalized Random Tessellation Stratified design (GRTS), which is a spatially balanced sampling methodology where coverage is distributed 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.

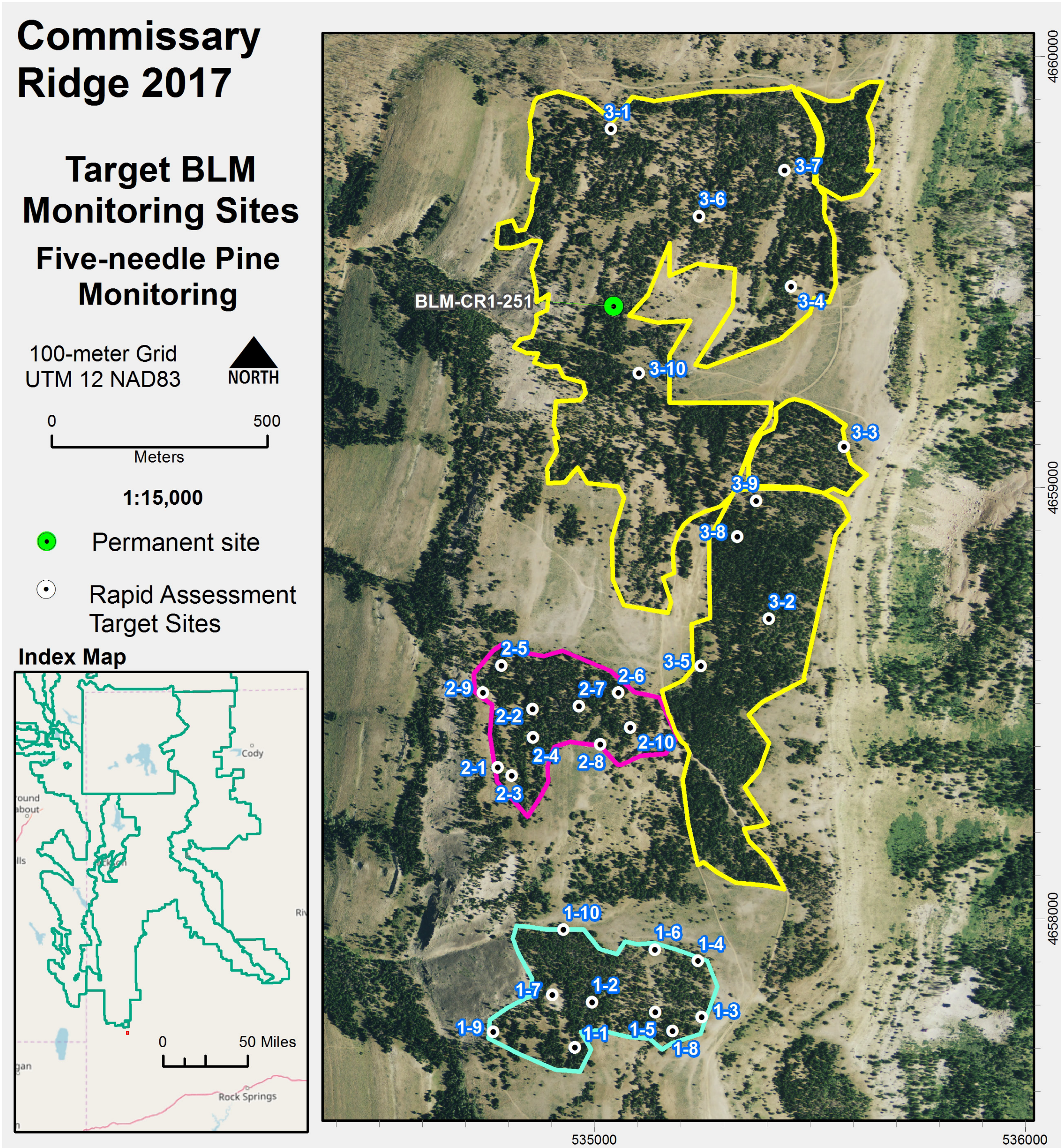


Figure 2. Example of a geographic stratum (Commissary Ridge), three primary sampling units (map units), and 10 secondary sampling unit targets (10 random point locations) located within each of the three map units.

Inference Design

A probabilistic sampling design allows for drawing inferences to all five-needle pine on WYBLM lands (within the GYE boundary). However, inferences can be compromised by unquantified sources of error. In survey sampling, total survey error is considered and composed of the following components: non-sampling errors (coverage error, non-response error, measurement error, processing error) and sampling error (Lessler and Kalsbeek 1992). Ideally, a survey design is constructed to minimize all of these sources of error, particularly the sources related to non-sampling error. Non-sampling errors are any errors or variability in the data that cannot be attributed to the process of observing only some of five-needle pine trees on WYBLM lands. In this survey, possible non-sampling errors are related to recording a tree as uninfected when in fact it is infected with blister rust (false negative or detection errors), mapping errors (excluding or including map units that are not composed of five-needle pine), and data recording/entry errors. Sampling error is just the inherent variability that happens from sample-to-sample. In other words, we have selected a probabilistic sample within the sample frame; we do not observe all five-needle pine on WYBLM lands. Therefore, the data collected from one set of GRTS points would vary from a different set of GRTS points. This sampling error or variation is accounted for within the statistical design-based estimators. Specifically, we report our uncertainty regarding the proportion of five-needle pine infected with blister rust by way of a confidence interval.

We assume that all data from permanent and rapid assessment transects from all panels (see Temporal Revisit Design section below) within a 4-year time period would be used in a status estimate (the proportion of trees infected with blister rust every four years). The 4-year time period, called a time-step, follows the *Interagency Whitebark Pine Monitoring Protocol for the Greater Yellowstone Ecosystem* (hereafter, monitoring protocol).

Field Methodology and Data Collection

Permanent transects were established following the 2011 monitoring protocol (https://www.nps.gov/im/gryn/whitebark-pine.htm). Since the establishment of eight permanent transects on WYBLM lands (2013–2014), some transects have been revisited for a second time.

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

Up to five rapid assessment transects were slated for measurement within each map unit throughout the WYBLM area of interest (Figure 2). These rapid assessment transects were drawn from a selection of 10 possible GRTS-derived randomly ordered center points.

A handheld GPS was used to locate the rapid assessment coordinates. Points were visited according to their randomly assigned order such that for random points 1 through 10, 1 was visited first, 2 was visited second, and so on. If a given random point did not qualify for a rapid assessment evaluation (no live, five-needle pines >1.4 m tall) the next random point in the selection was visited and

assessed for inclusion. If a site was suitable for sampling (i.e., had at least one live, five-needle pine tree >1.4 m tall) a 10 × 50 m rapid assessment transect was surveyed. Once a maximum of five qualifying transects were successfully surveyed or all 10 random points were exhausted for inclusion, sampling in the map unit was completed.

Table 1 describes all data collected for both permanent and rapid assessment transects.

Table 1. Five-needle pine data collected during permanent and rapid assessment transects between 2013 and 2017 at Wyoming Bureau of Land Management sites. An "x" indicates transects included that sampling metric.

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

Table 1 (continued). Five-needle pine data collected during permanent and rapid assessment transects between 2013 and 2017 at Wyoming Bureau of Land Management sites. An "x" indicates transects included that sampling metric.

Metric	Permanent Transect	Rapid Transect
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

We recorded a tree as reproducing if we observed cones, conelets, or cone scars on the tree.

The criteria for inclusion of cankers in the blister rust canker count are based on non-aecia blister rust indicators in Hoff (1992) (Figure 3). A complete description of these indicator standards are provided in the monitoring protocol, but in brief, these include branch girdling as a result of rodent chewing, flagging, swelling, roughened or split bark, and oozing sap (GYWPMWG 2011).

In addition, we assigned canker locations based on tree structure definitions specified in the monitoring protocol (GYWPMWG 2011).

Instructions for identifying evidence of mountain pine beetle were provided by USFS Forest Health Protection entomologists.

We conducted counts and evaluated blister rust infection on each permanent and rapid assessment survey for all five-needle pine trees ≤1.4 m tall within the boundaries of the belt transects (snow-free belt transects only).

On permanent transects only, we added new trees to the sample during revisit periods when an understory tree on a given permanent belt transect attained a height of >1.4 m tall. We marked these newly added individuals and recorded all attributes (as described in the tree tagging process in the monitoring protocol).

Figure 3. Indicators of the presence of white pine blister rust cankers on five-needle pine trees. Top row, left to right: flagging, swelling, roughened bark. Bottom row, left to right: rodent girdling/chewing, oozing sap. All photos NPS/ERIN SHANAHAN, except swelling branch, by USFS/RAY HOFF

Temporal Revisit Design

In 2016, we randomly assigned the eight permanent transects in the eight geographic strata to one of the four existing panels of the interagency whitebark pine monitoring long-term monitoring program. Each panel consists of two WYBLM permanent belt transects (Figure 1). We revisit panels once every four years on a rotating schedule (Figure 4). This design is sufficient to detect change in blister rust infection (McDonald and Hoff 2001). A full panel rotation is complete when all four panels are revisited in a given 4-year period.

Rapid assessment transects are surveyed in conjunction with the associated permanent transect within each geographic stratum. As per the rapid assessment sampling method standard operating procedure (refer to Appendix 1), these transects are not permanently monumented; therefore, a GRTS selection of 10 new random points will be generated for each map unit for subsequent revisits.

Survey Schedule			Time 1		Time 2					Time 3				Continued Monitoring 2024 forward
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	br & mortality				br & mortality				
2	2	CFC CR					br & mortality				br & mortality			
3	2	PGDR Rattle						br & mortality				br & mortality		
4	2	Brent SRHC							br & mortality				br & mortality	

Figure 4. Wyoming Bureau of Land Management (WYBLM) permanent sites panel revisit schedule. WYBLM permanent transects are revisited in conjunction with interagency whitebark pine monitoring transects. Geographic stratum abbreviations are as follows: 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/Hull Creek (SRHC).

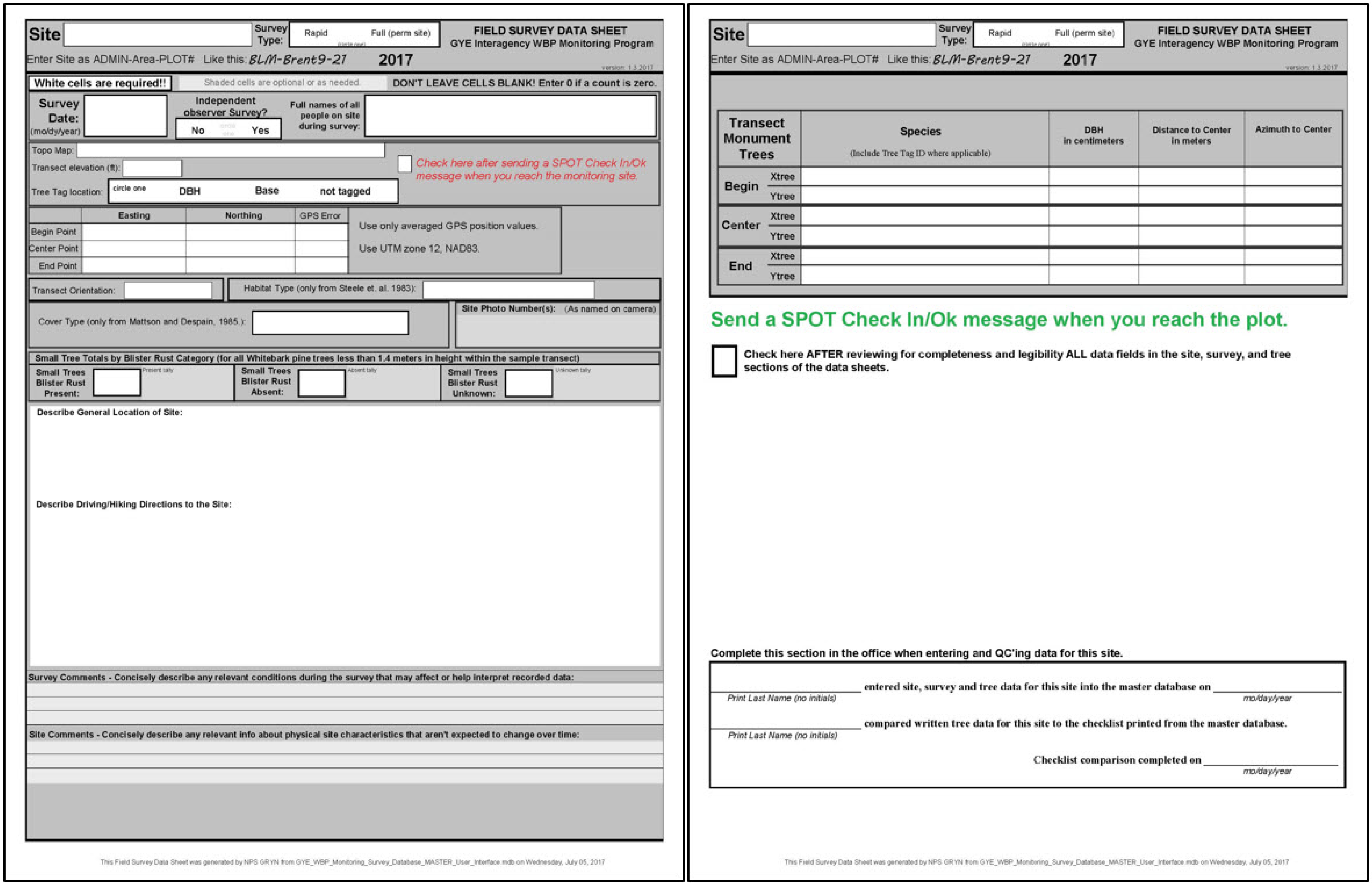
In 2016, three additional geographic strata (Baldwin Creek, Spring Creek, and Whiskey Mountain/Torrey Creek) were surveyed using only the rapid assessment methodology. These areas were assessed for five-needle pine health but were not added as part of the panel revisit cycle. The rationale for the omission of these three geographic strata was related to the probabilistic sampling design (described in detail above) used to estimate five-needle pine health on WYBLM lands. A recurrent addition of geographic strata beyond 2014 (when the original eight stratum were identified and permanently established) continually alters the sampling design, which in effect changes the spatial scope of inference. Analysis would have to be continually altered to incorporate comparing subsets of geographic strata based on when a stratum was added to the sample frame (i.e., eight permanents are a subset, three from 2016 are a subset, etc.). This type of analysis is manageable for a temporal approach, but it becomes problematic when trying to estimate trends over time and would require updating the statistical coding and estimators every time the design changed (i.e., with each new addition of a stratum).

Data Management and Analysis

Prior to analysis, all data are subjected to rigorous quality assurance and quality control (QA/QC) procedures as outlined in the protocol (GYWPMWG 2011). Due to minor retroactive updates to the master database as part of ongoing quality controls, an insignificant amount of variability (typically <1% difference) may occur when comparing data reported in previous years. All computational analyses and corresponding charts and graphs were produced using Microsoft Excel and the statistical computing language R (R Development Core Team 2011). A combined ratio estimator that includes the secondary variance component for a stratified, two-stage cluster design is used to calculate the proportion of all five-needle pine infected with blister rust (refer to Appendix 2 for analysis methodology).

Data Forms

The following data forms were used to collect transect characteristics and <1.4 m tall seedling and sapling data (Figure 5), overstory tree data on permanent transects (Figure 6), and overstory tree data on rapid assessment transects (Figure 7).



Site | Survey Type: Rapid / Full (perm site) (circle one) | FIELD SURVEY DATA SHEET
GYE Interagency WBP Monitoring Program

Enter Site as ADMIN-Area-PLOT# Like this: BLM-Brent9-21 2017

version: 1.3.2017

White cells are required!! Shaded cells are optional or as needed. DON'T LEAVE CELLS BLANK! Enter 0 if a count is zero.

Survey Date: (mo/dy/year) | Independent observer Survey? No / Yes (circle one) | Full names of all people on site during survey:

Topo Map:

Transect elevation (ft):

Check here after sending a SPOT Check In/Ok message when you reach the monitoring site.

Tree Tag location: (circle one) DBH / Base / not tagged

	Easting	Northing	GPS Error
Begin Point			
Center Point			
End Point			

Use only averaged GPS position values.

Use UTM zone 12, NAD83.

Transect Orientation:

Habitat Type (only from Steele et. al. 1983):

Cover Type (only from Mattson and Despain, 1985.):

Site Photo Number(s): (As named on camera)

Small Tree Totals by Blister Rust Category (for all Whitebark pine trees less than 1.4 meters in height within the sample transect)

Small Trees Blister Rust Present: (Present tally) | Small Trees Blister Rust Absent: (Absent tally) | Small Trees Blister Rust Unknown: (Unknown tally)

Describe General Location of Site:

Describe Driving/Hiking Directions to the Site:

Survey Comments - Concisely describe any relevant conditions during the survey that may affect or help interpret recorded data:

Site Comments - Concisely describe any relevant info about physical site characteristics that aren't expected to change over time:

This Field Survey Data Sheet was generated by NPS GRYN from GYE_WBP_Monitoring_Survey_Database_MASTER_User_Interface.mdb on Wednesday, July 05, 2017

Site | Survey Type: Rapid / Full (perm site) (circle one) | FIELD SURVEY DATA SHEET
GYE Interagency WBP Monitoring Program

Enter Site as ADMIN-Area-PLOT# Like this: BLM-Brent9-21 2017

version: 1.3.2017

Transect Monument Trees		Species (Include Tree Tag ID where applicable)	DBH in centimeters	Distance to Center in meters	Azimuth to Center
Begin	Xtree				
	Ytree				
Center	Xtree				
	Ytree				
End	Xtree				
	Ytree				

Send a SPOT Check In/Ok message when you reach the plot.

Check here AFTER reviewing for completeness and legibility ALL data fields in the site, survey, and tree sections of the data sheets.

Complete this section in the office when entering and QC'ing data for this site.

________ (Print Last Name (no initials)) entered site, survey and tree data for this site into the master database on ________ (mo/day/year)

________ (Print Last Name (no initials)) compared written tree data for this site to the checklist printed from the master database.

Checklist comparison completed on ________ (mo/day/year)

This Field Survey Data Sheet was generated by NPS GRYN from GYE_WBP_Monitoring_Survey_Database_MASTER_User_Interface.mdb on Wednesday, July 05, 2017

Figure 5. Wyoming Bureau of Land Management front and back five-needle pine seedling-sapling survey datasheets for both permanent and rapid assessment transects.

Site ____________ Full Survey **2018** TREE DATA SHEET
GYE Interagency WBP Monitoring Program

Entered in database (date and initials) ____

version: 11/23/2018

Please write carefully, neatly, and legibly. **Review and double-check all entries for quality.**

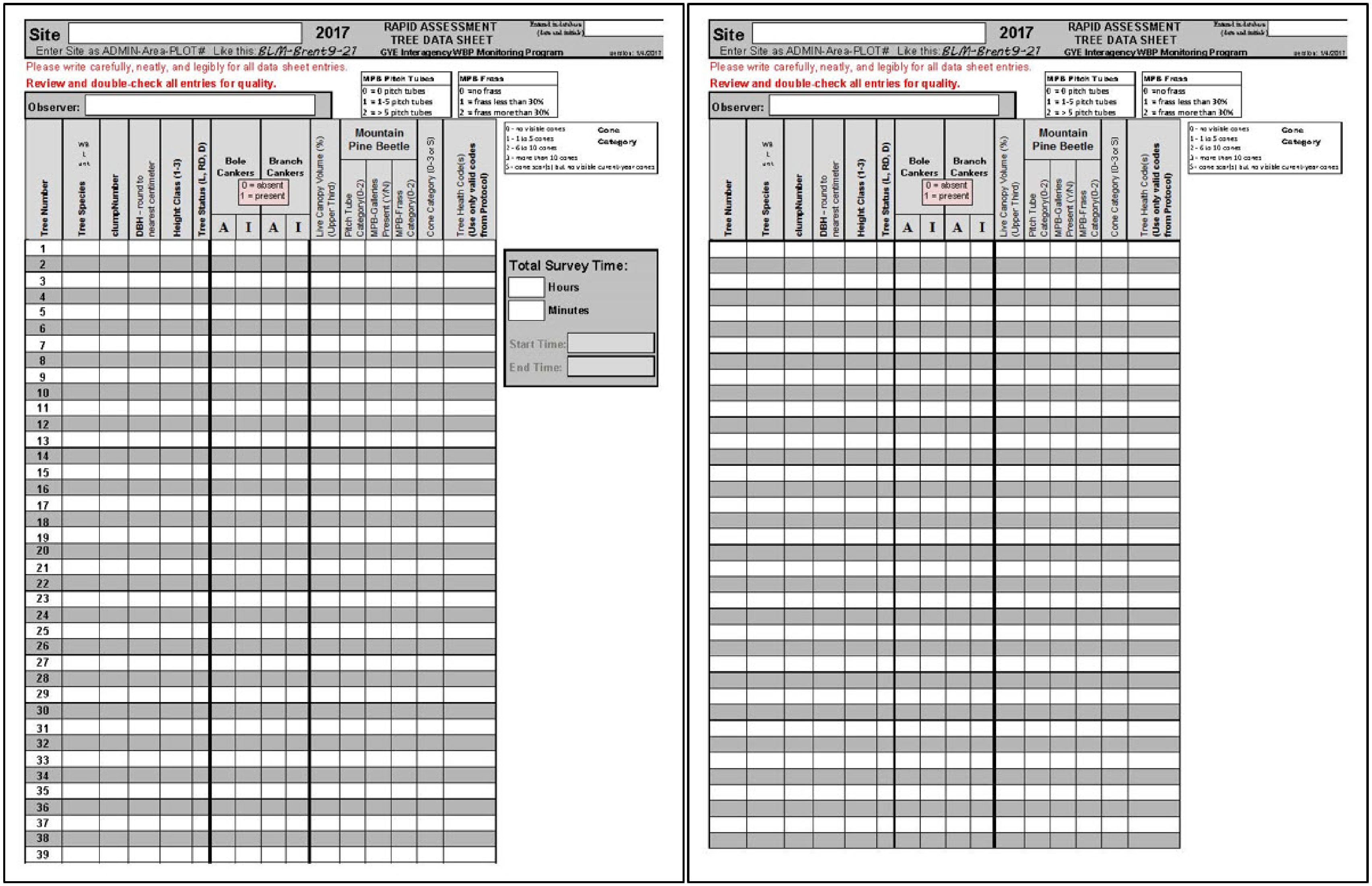
For Independent-observer Surveys, EACH observer records their own values. Please read the Data Recording Instructions.	MPB Pitch Tubes	MPB Frass	Cone Category
	1 = 1-5 pitch tubes 2 = >5 pitch tubes	1 = frass less than 30% 2 = frass more than 30%	0 - no visible cones 1 - 1 to 5 cones 2 - 6 to 10 cones 3 - more than 10 cones 5 - cone scar(s) but no visible current-year cones

Tree Tag #	Tree Species	Observer's Initials	Clump Number	Clump Letter	Tree Status (L, RD,	DBH (cm)	Height Class (1-	Branch Cankers						Bole Cankers						Do Not Enter Y or N Indicators Enter Total Count					Live Canopy Volume (%) (Upper Third)	Mountain Pine Beetle			Cone Category (see above)	Tree Health Code(s) (Use only valid codes from Protocol)
								Upper Third		Middle Third		Bottom Third		Upper Third		Middle Third		Bottom Third		Rodent Chewing	Flagging	Swelling	Roughened Bark	Oozing Sap		Pitch Tube Category(0-2)	MPB-Galleries Present (Y/N)	MPB-Frass Category(0-2)		
								A	I	A	I	A	I	A	I	A	I	A	I											

Comments on individual trees **(Objective and concise comments only please.)**

Tree ID	Comment

Figure 6. Wyoming Bureau of Land Management five-needle pine overstory tree data form for permanent transects.



Site | 2017 | RAPID ASSESSMENT TREE DATA SHEET | GYE Interagency WBP Monitoring Program

Enter Site as ADMIN-Area-PLOT# Like this: BLM-Brent9-21

Please write carefully, neatly, and legibly for all data sheet entries.

Review and double-check all entries for quality.

Observer:

MPB Pitch Tubes
0 = 0 pitch tubes
1 = 1-5 pitch tubes
2 = > 5 pitch tubes

MPB Frass
0 = no frass
1 = frass less than 30%
2 = frass more than 30%

Cone Category
0 - no visible cones
1 - 1 to 5 cones
2 - 6 to 10 cones
3 - more than 10 cones
S - cone scar(s) but no visible current-year cones

Bole Cankers / Branch Cankers: 0 = absent, 1 = present

Tree Number	Tree Species (WB, L, unk)	clumpNumber	DBH - round to nearest centimeter	Height Class (1-3)	Tree Status (L, RD, D)	Bole Cankers A	Bole Cankers I	Branch Cankers A	Branch Cankers I	Live Canopy Volume (%) (Upper Third)	Mountain Pine Beetle: Pitch Tube Category(0-2)	Mountain Pine Beetle: MPB-Galleries Present (Y/N)	Mountain Pine Beetle: MPB-Frass Category(0-2)	Cone Category (0-3 or S)	Tree Health Code(s) (Use only valid codes from Protocol)
1															
2															
3															
4															
5															
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39															

Total Survey Time: Hours Minutes

Start Time: End Time:

Figure 7. Wyoming Bureau of Land Management front and back five-needle pine overstory tree data form for rapid assessment transects.

Results

Permanent Transects

A total of eight permanent transects were established in the eight identified geographic stratum in 2013 and 2014. Within these transects, a total of 146 live, individual trees ≥1.4 m tall were permanently marked to monitor long-term changes in blister rust infection and survival rates (Table 2). Between 2016 and 2019 (revisit time-step; T2; Figure 4), these same eight transects will be surveyed again and all previously tagged trees will be observed for changes in blister rust infection and survival status. Currently, we have completed revisits to four of the eight permanent transects. In 2015 while we worked closely with the WYBLM and USGS to determine how this monitoring program should proceed, permanent or rapid assessment transects were not conducted.

Table 2. Summary survey and five-needle pine characteristic statistics from permanent transects established in 2013 and 2014 on Wyoming Bureau of Land Management land.

Metric	Count
Number of Geographic Stratum	8
Number of Map Units	8
Number of Permanent Transects	8
Total Live Trees	146
Total Dead Trees	0
Total Live Whitebark Pine	12
Total Whitebark Pine with Blister Rust	4
Total Live Limber Pine	20
Total Limber Pine with Blister Rust	9
Total Live Unknown 5-Needle Species	114
Total Unknown 5-Needle Species with Blister Rust	15

Rapid Assessment Transects

A maximum of five, rapid assessment transects were surveyed in each map unit for each geographic stratum: Brent Creek, Teton Valley Ranch Camp, Rattlesnake, Clark's Fork Canyon, Pine Grove/Deadline Ridge, Commissary Ridge, Scab Creek, and Sublette Range/Hull Creek. In 2016, three additional geographic stratum (Baldwin Creek, Spring Creek, and Whiskey Mountain/Torrey Creek) and six additional map units were identified and surveyed in the Brent Creek geographic stratum and were surveyed using the rapid assessment approach only (Figure 8).

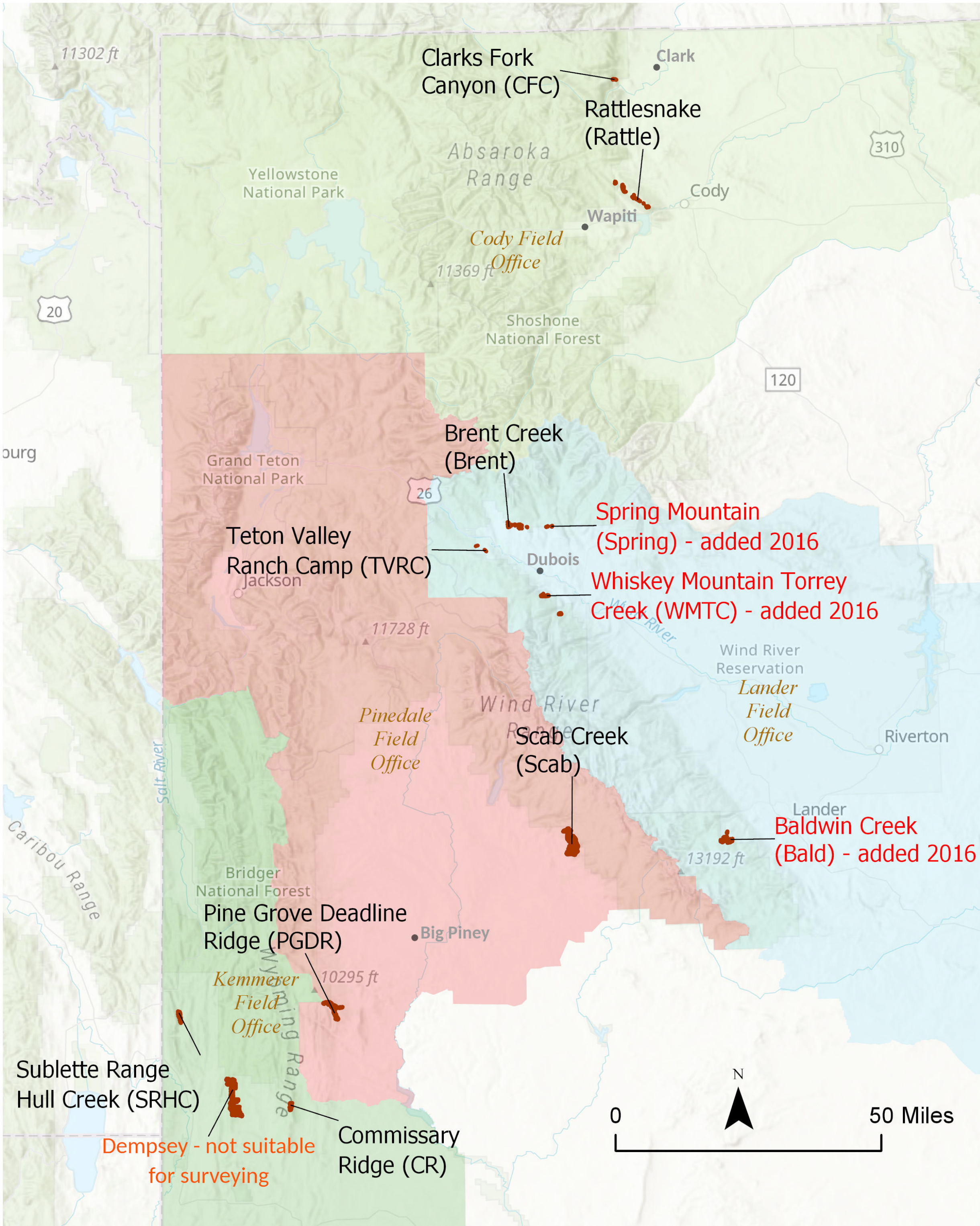

Figure 8. Eight Wyoming Bureau of Land Management geographic strata containing permanently established five-needle pine monitoring transects and the three additional geographic strata added in 2016, which are denoted in red text. A field crew visited Dempsey Ridge in 2013 and did not find enough five needle pines to survey.

A total of 4234 live trees have been surveyed on 241 rapid assessment transects between 2013 and 2017 (no surveys in 2015). Table 3 displays the summary information for the number of trees surveyed during rapid assessments.

Table 3. Summary statistics for the five-needle pine rapid assessment transects surveyed in 2013, 2014, 2016 and 2017 on Wyoming Bureau of Land Management lands.

Metric	Count
Number of Geographic Stratum	11
Number of Map Units	62
Number of Transects	241
Total Live Trees	4234
Total Dead Trees	981
Total Whitebark Pine	392
Total Live Whitebark Pine	391
Total Live Whitebark Pine with Blister Rust	157
Total Limber Pine	349
Total Live Limber Pine	344
Total Live Limber Pine with Blister Rust	133
Total Unknown 5-Needle Species	4474
Total Live Unknown 5-Needle Species	3499
Total Live Unknown 5-Needle Species with Blister Rust	968

White Pine Blister Rust

During surveys in 2013 and 2014 only, all eight geographic strata had some level of blister rust infection. A summary of statistical findings from five-needle pine surveying efforts conducted in 2013 and 2014 are described in Appendix 2. Using a combined ratio estimator, the baseline estimate for the proportion of live, >1.4 m tall, confirmed whitebark pine infected with blister rust on WYBLM lands adjacent to the GYE was 0.302 (± 0.17 SE). For confirmed limber pine, the proportion was 0.167 (± 0.089 SE). The overall baseline estimate for the proportion of live, five-needle pine >1.4 m tall on WYBLM lands with blister rust was 0.156 (± 0.054 SE; this estimate combined all surveyed trees).

While we report on the baseline estimates for the proportion of live, five-needle pine infected with blister rust for the establishment period in 2013 and 2014, status and trend assessments are more meaningful after many years of monitoring with comparable data accumulated over time (Witwicki 2012). For the WYBLM five-needle pine monitoring program, more intensive evaluation of monitoring data is scheduled at 4-year intervals after all eight permanent transects are resurveyed and

data from rapid assessment transects from each successive revisit are compiled. Comparisons between years based on a single panel revisit are misleading because each panel is composed of an entirely different set of transects. A status and trend report will be completed after all panels are resurveyed in their scheduled revisit cycle by the end of the 2019 field season.

Bole cankers that are located on the lower portion of the bole (middle to bottom third) are generally considered lethal to trees. Cankers that are found in the upper third of the bole are not automatically lethal but they can have a negative impact on cone production. Bole cankers were 25% more prevalent than branch cankers in all five-needle pine observed in 2013, 2014, 2016, and 2017.

Mortality

A total of 766 of the 981 recorded dead trees on both the permanent and rapid assessment transects surveyed between 2013 and 2017 died with sign of mountain pine beetle. Thirty live trees were recorded with sign of mountain pine beetle on both transect types, with no new mountain pine beetle infestations documented after 2014. In 2016, the Lava Mountain Fire outside of Dubois, Wyoming, burned all 27 tagged trees on the permanent transect in the Teton Valley Ranch Camp geographic stratum. Currently, there are no live tagged trees on that permanent transect.

Recruitment

We evaluated recruitment using cone production estimates and the occurrence of seedling and sapling (≤1.4 m tall) understory five-needle pines from 2013 to 2017. Known reproducing trees made up approximately 17% (735) of the surveyed population. Of the reproducing trees, 55% (402) were verified as whitebark pine and 45% (333) were identified as limber pine. Blister rust was recorded on 42% (307) of the reproducing trees. Reproductive status was categorized as unknown due to the absence of cones or cone scars. Therefore, we recognize that these estimates are likely conservative in quantifying the reproducing population given that a tree may not exhibit signs of reproduction at the time that is was observed.

At total of 4003 ≤1.4 m tall trees were counted, with only 1% (44) documented as infected with blister rust. The density of trees ≤1.4 m tall averaged 16 understory trees per 500 m^2.

Discussion

Our preliminary results indicate that the occurrence of blister rust is widespread throughout Wyoming Bureau of Land Management (WYBLM) lands within the Greater Yellowstone Ecosystem (GYE) (i.e., 100% of all geographic strata had some level of infection). While observed across a vast spatial extent, the proportion of trees infected remains lower than estimates of infection for solely whitebark pine populations within the GYE. When grouping both whitebark pine and limber pine in the baseline estimate, it is important to note that environmental conditions that are more conducive to supporting limber pine (i.e., xeric sites) may be less favorable to the transfer of blister rust spores. All phases of blister rust transmission require high humidity for successful infection of five-needle pines (Kendall and Keane 2001). Overall, blister rust has had less of an impact on five-needle pines in drier locations (Kendall and Keane 2001). Because crews were not able to identify the majority of five-needle pines surveyed in 2013 and 2014 (83% recorded as Unknown species), it is possible that the preponderance of those unidentified trees were limber pine located on these more xeric sites.

As in most other parts of the GYE, mountain pine beetle infestations have moderated to localized outbreaks on BLM lands in Wyoming. The majority of recorded dead, five-needle pines with sign of mountain pine beetle are likely relics from the recent epidemic that peaked from 2008 to 2009. This noted decline in mountain pine beetle activity is supported with no new attacks observed in live, five-needle pines on WYBLM transects since 2014.

While the contemporary threats to five-needle pines on BLM lands in Wyoming continue to be blister rust and wildland fire (at this point in time mountain pine beetle is considered to be present endemically and more of a threat to isolated populations of five-needle pines), limber pine dwarf mistletoe was noted in 2017 in two of the eight geographic strata (Teton Valley Ranch Camp and Clark's Fork Canyon).

Limber pine dwarf mistletoe (dwarf mistletoe; *Arceuthobium cyanocarpum*; Figure 9) has been documented as a cause of 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 evident 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).

We are continuing to document recruitment on BLM lands in Wyoming as noted by cone producing trees and understory constituents.

Figure 9. Limber pine dwarf mistletoe (*Arceuthobium cyanocarpum*). ©BILL CIESLA, Colorado State Forest Service.

Future Monitoring

In 2018 and 2019, we will revisit Wyoming BLM permanently established transects in Panels 3 and 4 respectively for the second time and continue 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.

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Appendix 1: Standard Operating Procedure for the Rapid Assessment Sampling Method for Five-Needle Pine Monitoring

The rapid assessment sampling method was developed in 2013–2014 to augment surveying for five-needle pines on Bureau of Land Management (BLM) lands in Wyoming (WYBLM) where five-needle pine densities were expected to be lower in some areas in comparison to other locations sampled within the Greater Yellowstone Ecosystem (GYE). While similar to the *Interagency Whitebark Pine Monitoring Protocol for the Greater Yellowstone Ecosystem* (GYWPMWG 2011) (hereafter, the monitoring protocol), the main difference in the rapid assessment method is that trees are not tagged and a subset of individual tree measurements are recorded. This method enables field crews to survey more transects per delineated stand (as 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:

The rapid assessment sampling falls within the measurable objectives of overall WYBLM five-needle pine monitoring. These objectives are to

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; and
4) Assess the multiple components of the recruitment of understory five-needle pine into the reproductive population.

Target Population

As with overall five-needle pine sampling on WYBLM land, the target population for rapid assessment sampling is accessible stands of mixed five-needle pine on WYBLM lands within the GYE boundary.

Sampling Design

The sampling design for the rapid assessment transects (as well as the combined rapid and permanent transects) was a stratified two-stage cluster sample. Each geographic area identified by WYBLM (i.e.; Commissary Ridge; Figure 1-1) can be considered a geographic stratum. The first-stage sampling unit is a map unit (primary sampling unit, e.g., CommissaryRidge1), and the secondary sampling unit is a point within a map unit (e.g., the points randomly drawn from within CommissaryRidge1). Secondary sampling units (10 × 50 m belt transects) are selected using the Generalized Random Tessellation Stratified design (GRTS), which is a spatially balanced sampling methodology where coverage is distributed across the entire area of interest using a stochastic approach (Brown et al. 2015). The observation unit (the object on which a measurement is taken) is each qualifying five-needle pine within the secondary sampling unit.

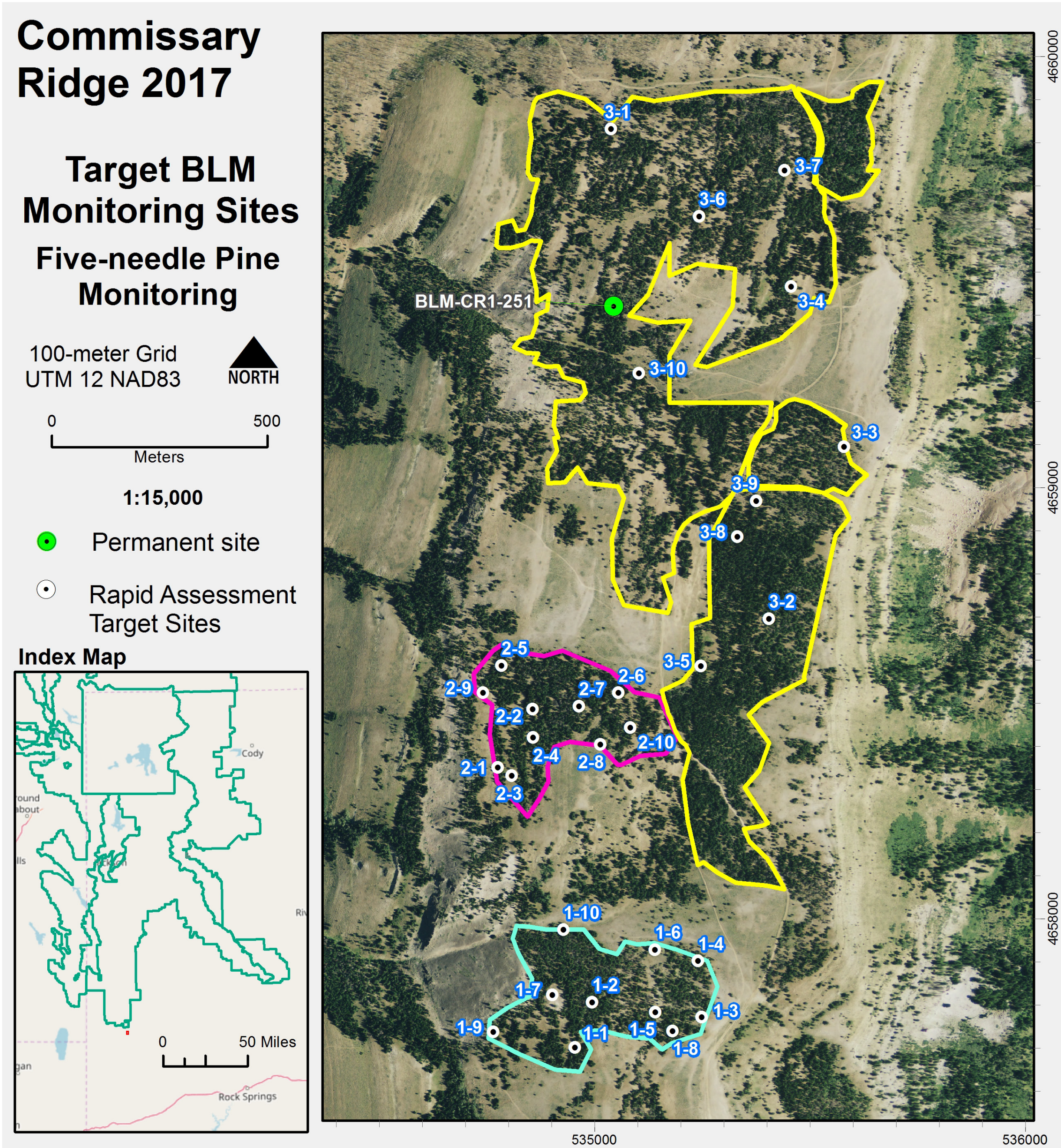


Figure 1-1. Example of a geographic stratum (Commissary Ridge), three primary sampling units (map units), and 10 secondary sampling unit targets (10 random point locations) located within each of the three map units.

Inference Design

A probabilistic sampling design allows for drawing inferences to all five-needle pine on WYBLM lands (within the GYE boundary). However, inferences can be compromised by unquantified sources of error. In survey sampling, total survey error is considered and composed of the following components: non-sampling errors (coverage error, non-response error, measurement error, processing error) and sampling error (Lessler and Kalsbeek 1992). Ideally, a survey design is constructed to minimize all of these sources of error, particularly the sources related to non-sampling error. Non-sampling errors are any errors or variability in the data that cannot be attributed to the process of observing only some of five-needle pine trees on WYBLM lands. In this survey, possible non-sampling errors are related to recording a tree as uninfected when in fact it is infected with blister rust (false negative or detection errors), mapping errors (excluding or including map units that are not composed of five-needle pine), and data recording/entry errors. Sampling error is just the inherent variability that happens from sample-to-sample. In other words, we have selected a probabilistic sample within the sample frame; we do not observe all five-needle pine on WYBLM lands. Therefore, the data collected from one set of GRTS points would vary from a different set of GRTS points. This sampling error or variation is accounted for within the statistical design-based estimators. Specifically, we report our uncertainty regarding the proportion of five-needle pine infected with blister rust by way of a confidence interval.

We assume that all data from permanent and rapid assessment transects from all panels within a 4-year time period (time-step; following the interagency whitebark pine monitoring protocol time-step schedule) would be used in a status estimate (the proportion of trees infected with blister rust every four years). A panel consists of a unique set of transects that are surveyed every four years.

Field Methods

Rapid assessment transects follow the same establishment methods and criteria as used to survey a permanent transect (following the monitoring protocol for whitebark pine), but neither the transect nor the trees within the 10 × 50 m boundary of the transect are permanently marked.

Up to five rapid assessment transects are targeted for measurement within each map unit assigned in the BLM area of interest, also known as geographic stratum (refer to Figure 1-1 of Commissary Ridge). These rapid assessment transects are drawn from a selection of 10 possible GRTS-derived randomly ordered centerpoints.

A handheld GPS is used to locate the rapid assessment coordinates. Points are visited according to their randomly assigned order such 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., has at least one live, five-needle pine tree ≥1.4 m tall) a 10 × 50 m rapid assessment transect is surveyed. Once a maximum of five qualifying transects have been successfully surveyed or all 10 random points have been exhausted for inclusion, sampling in the map unit is complete.

The following table describes all data collected for both permanent and rapid assessment transects (Table 1-1):

Table 1-1. Five-needle pine data collected during permanent and rapid assessment transects between 2013 and 2017 at Wyoming Bureau of Land Management sites. An "x" indicates that transects included that sampling metric.

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

Table 1-1 (continued). Five-needle pine data collected during permanent and rapid assessment transects between 2013 and 2017 at Wyoming Bureau of Land Management sites. An "x" indicates that transects included that sampling metric.

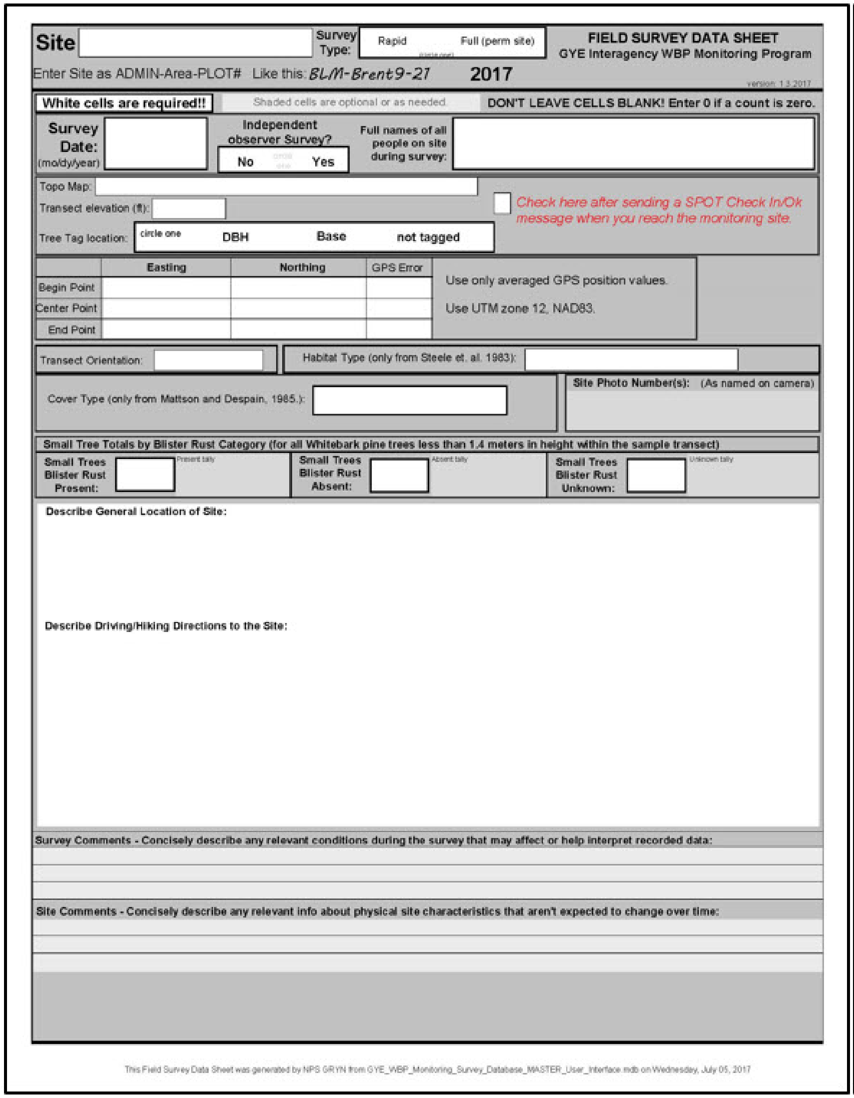
Metric	Permanent Transect	Rapid Transect
Presence of mountain pine beetle frass	x	x
Presence of cones	x	x
Tree health code	x	x
Total trees in plots ≤1.4 m tall with blister rust	x	x
Total trees in plots ≤1.4 m tall without blister rust	x	x
Total trees in plots ≤1.4 m tall with unknown blister rust status	x	x

The following is a list of data fields included on rapid assessment transects for all dead or recently dead trees within the 10 × 50 m boundary:

- Diameter at Breast Height
- Tree Status (Recently Dead, Dead)
- Presence of Mountain Pine Beetle Galleries (Yes/No)

Data Forms

The following data forms are used to collect transect characteristics and <1.4 m tall seedling and sapling data (Figure 1-2) and overstory tree data (Figure 1-3) on rapid assessment transects.



Site | Survey Type: Rapid / Full (perm site) (circle one)

FIELD SURVEY DATA SHEET
GYE Interagency WBP Monitoring Program

Enter Site as ADMIN-Area-PLOT# Like this: BLM-Brent9-21 2017

version: 1.3.2017

White cells are required!! | Shaded cells are optional or as needed. | DON'T LEAVE CELLS BLANK! Enter 0 if a count is zero.

Survey Date: (mo/dy/year) | Independent observer Survey? No / Yes (circle one) | Full names of all people on site during survey:

Topo Map:

Transect elevation (ft):

Tree Tag location: circle one DBH / Base / not tagged

Check here after sending a SPOT Check In/Ok message when you reach the monitoring site.

	Easting	Northing	GPS Error
Begin Point			
Center Point			
End Point			

Use only averaged GPS position values.

Use UTM zone 12, NAD83.

Transect Orientation: | Habitat Type (only from Steele et. al. 1983):

Cover Type (only from Mattson and Despain, 1985.): | Site Photo Number(s): (As named on camera)

Small Tree Totals by Blister Rust Category (for all Whitebark pine trees less than 1.4 meters in height within the sample transect)

Small Trees Blister Rust Present: (Present tally) | Small Trees Blister Rust Absent: (Absent tally) | Small Trees Blister Rust Unknown: (Unknown tally)

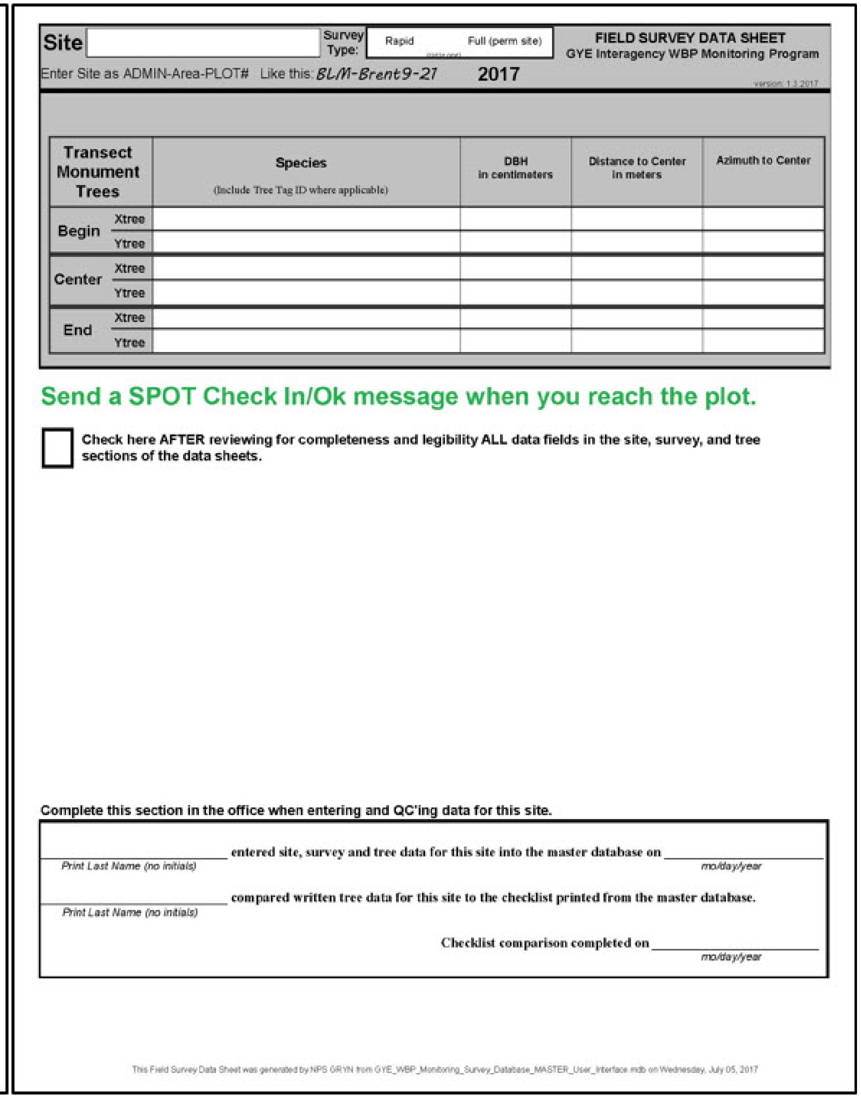
Describe General Location of Site:

Describe Driving/Hiking Directions to the Site:

Survey Comments - Concisely describe any relevant conditions during the survey that may affect or help interpret recorded data:

Site Comments - Concisely describe any relevant info about physical site characteristics that aren't expected to change over time:

This Field Survey Data Sheet was generated by NPS GRYN from GYE_WBP_Monitoring_Survey_Database_MASTER_User_Interface.mdb on Wednesday, July 05, 2017



Site | Survey Type: Rapid / Full (perm site) (circle one)

FIELD SURVEY DATA SHEET
GYE Interagency WBP Monitoring Program

Enter Site as ADMIN-Area-PLOT# Like this: BLM-Brent9-21 2017

version: 1.3.2017

Transect Monument Trees		Species (Include Tree Tag ID where applicable)	DBH in centimeters	Distance to Center in meters	Azimuth to Center
Begin	Xtree				
	Ytree				
Center	Xtree				
	Ytree				
End	Xtree				
	Ytree				

Send a SPOT Check In/Ok message when you reach the plot.

Check here AFTER reviewing for completeness and legibility ALL data fields in the site, survey, and tree sections of the data sheets.

Complete this section in the office when entering and QC'ing data for this site.

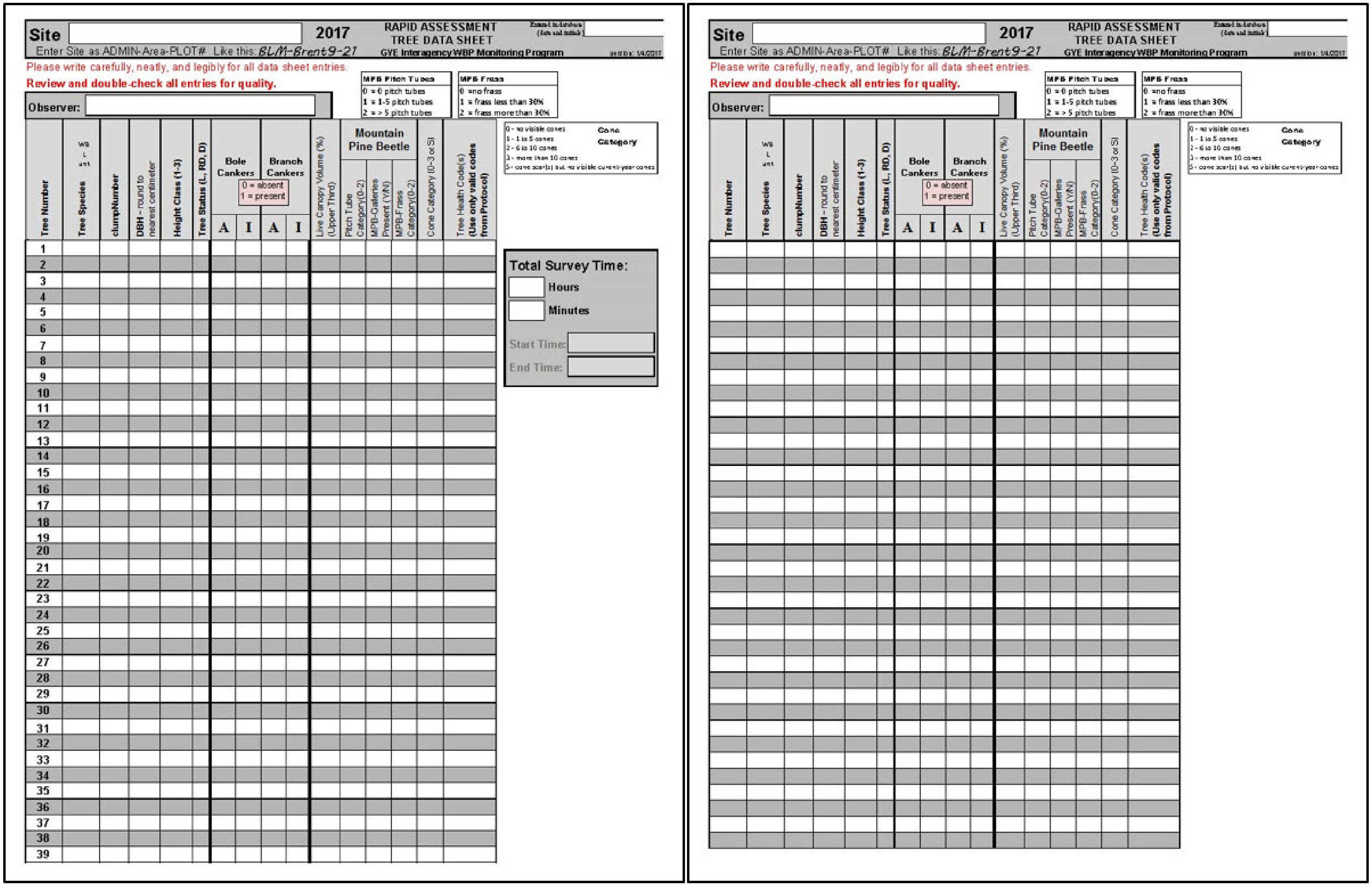
________ entered site, survey and tree data for this site into the master database on ________
Print Last Name (no initials) | mo/day/year

________ compared written tree data for this site to the checklist printed from the master database.
Print Last Name (no initials)

Checklist comparison completed on ________
mo/day/year

This Field Survey Data Sheet was generated by NPS GRYN from GYE_WBP_Monitoring_Survey_Database_MASTER_User_Interface.mdb on Wednesday, July 05, 2017

Figure 1-2. Wyoming Bureau of Land Management front and back five-needle pine seedling-sapling survey datasheets for both permanent and rapid assessment transects.



Site ______ **2017** RAPID ASSESSMENT TREE DATA SHEET

Enter Site as ADMIN-Area-PLOT# Like this: BLM-Brent9-21 — GYE Interagency WBP Monitoring Program

Please write carefully, neatly, and legibly for all data sheet entries.

Review and double-check all entries for quality.

Observer: ______

MPB Pitch Tubes
0 = 0 pitch tubes
1 = 1-5 pitch tubes
2 = > 5 pitch tubes

MPB Frass
0 = no frass
1 = frass less than 30%
2 = frass more than 30%

Cone Category
0 - no visible cones
1 - 1 to 5 cones
2 - 6 to 10 cones
3 - more than 10 cones
S - cone scar(s) but no visible current-year cones

Tree Number	Tree Species	clumpNumber	DBH - round to nearest centimeter	Height Class (1-3)	Tree Status (L, RD, D)	Bole Cankers (0 = absent, 1 = present) A	Bole Cankers I	Branch Cankers A	Branch Cankers I	Live Canopy Volume (%) (Upper Third)	Mountain Pine Beetle: Pitch Tube Category(0-2)	MPB-Galleries Present (Y/N)	MPB-Frass Category(0-2)	Cone Category (0-3 or S)	Tree Health Code(s) (Use only valid codes from Protocol)
1															
2															
3															
4															
5															
6															
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38															
39															

Total Survey Time:
Hours
Minutes
Start Time:
End Time:

Site 2017 RAPID ASSESSMENT TREE DATA SHEET
Enter Site as ADMIN-Area-PLOT# Like this: BLM-Brent9-21 — GYE Interagency WBP Monitoring Program
Please write carefully, neatly, and legibly for all data sheet entries.
Review and double-check all entries for quality.
Observer:

Figure 1-3. Wyoming Bureau of Land Management front and back five-needle pine overstory tree data form for rapid assessment transects.

Data Management

Once field crews return to a base location where a working copy of the GYE Whitebark Pine Database is available (Microsoft Access), data from field data sheets are entered in the computerized database as soon as possible. Prior to analysis, all data are subjected to rigorous quality assurance and quality control (QA/QC) procedures as outlined in the protocol (GYWPMWG 2011).

Analysis

All analyses and corresponding figures are produced using Microsoft Excel and the statistical computing language R (R Development Core Team 2011) specific to each objective. A combined ratio estimator that includes the secondary variance component for a stratified, two-stage cluster design is used to calculate the proportion of all five-needle pine infected with blister rust (refer to Appendix 2 for analysis methodology).

References

Brown, J. A., B. L. Robertson, and T. McDonald. 2015. Spatially balanced sampling: application to environmental surveys. Procedia Environmental Sciences 27:6–9.

Greater Yellowstone Whitebark Pine Monitoring Working Group (GYWPMWG). 2011. Interagency whitebark pine monitoring protocol for the Greater Yellowstone Ecosystem, Version 1.1. Greater Yellowstone Coordinating Committee, Bozeman, Montana.

Lessler, J. T., and W. D. Kalsbeek. 1992. Nonsampling error in surveys. John Wiley and Sons, Inc. New York.

R Development Core Team. 2011. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org.

Appendix 2: Statistical Summary of Wyoming Bureau of Land Management Five-Needle Pine Field Surveys: 2013 and 2014

Prepared by: S. Wilmoth and K. Irvine, US Geological Survey, Bozeman MT

This statistical report is in support of Wyoming Bureau of Land Management (WYBLM) five-needle monitoring efforts and this work was supported by an interagency agreement (IAA NO. L12PG00218) between BLM and USGS (PI Kathryn M. Irvine). This collaborative effort is the newest component of the interagency monitoring effort supported by the National Park Service, U.S. Forest Service, U.S. Geological Survey, and Bureau of Land Management in coordination with the Greater Yellowstone Coordinating Committee.

Report Objectives

This report summarizes the statistical investigation to inform long-term monitoring of five-needle pines on Bureau of Land Management (WYBLM) lands in Wyoming adjacent to the delineated Greater Yellowstone Ecosystem (GYE). This effort will increase the geographical extent of the monitoring of five-needle pine within the GYE that has been ongoing since 2004. For this initial pilot study (2013–2014), a two-pronged approach was used to assess the status of white pine blister rust (infection in five-needle pine on WYBLM lands within the GYE and outside of the grizzly bear Primary Conservation Area (PCA)). In 2013 and 2014, the *Interagency Whitebark Pine Monitoring Protocol for the Greater Yellowstone Ecosystem* (Greater Yellowstone Whitebark Pine Monitoring Working Group 2011) was implemented on WYBLM lands. The interagency protocol establishes 1 or 2 transects within a map unit for long-term monitoring with no replication within a map unit. In addition, a rapid assessment (RA) method was developed and instigated to help determine the sampling effort necessary within a map unit (delineated area of potential five-needle pine). The status estimators for prevalence of white pine blister rust (BR) within the GYE ignore the variation among transects within a map unit, even when there is more than one transect. The data gathered using the rapid assessment method allows for larger sample sizes such that we can investigate whether more transects are needed within a map unit (delineated area of potential five-needle pine). The rapid protocol recorded simplified metrics for BR infection and evidence of mountain pine beetle.

Sampling Design

The WYBLM target population is accessible stands of mixed five-needle pine on lands within the GYE boundary. The sampling frame for site selection was based on digitized maps created from aerial flight and foot-based surveys for five-needle pine conducted by the WYBLM. Eight distinct geographic areas of five-needle pine within the WYBLM Wyoming High Desert District were identified and each considered a stratum in the sampling design. Within each area or stratum, there were one or more delineated polygons (within GIS) of potential five-needle pine (hereafter, map units). For the WYBLM sampling design, a map unit was included if it was greater than 2.5 ha in size. All map units included in this analysis for both 2013 and 2014 met this minimum size requirement.

To locate permanent monitoring transects, one map unit was randomly selected with equal probability within an area or stratum (inclusion probability for map unit i in area h, $\pi_{ih} = 1/N_h$ where N_h is the number of map units in area h). Using a random number generator in Excel, the map units were ordered within an area. The random order was used to identify the map unit(s) in which a long-term monitoring transect would be established, and the first map unit in the random order was selected for the permanent transect.

Within all map units, 10 random points were selected using the Generalized Random Tessellation Stratified (GRTS) design implemented using the grts() function within the spsurvey package in R (Kincaid and Olsen 2017; R-code in files: BLM_WBPRandomPointDraw2013.txt and RandomPointDraw2014.txt). The GRTS algorithm produces an ordered list of point locations for possible belt transect placement. This is the second-stage of the sampling design.

To select the permanent site within a map unit, each location was visited in GRTS order and assessed for the minimum requirements (i.e., has at least one live WBP tree >1.4 m tall) until the permanent transect was established. The remaining map units within an area that were not randomly selected for permanent transects were visited in GRTS order for the rapid assessment transects (trees not tagged and belt transects not monumented).

The sampling design for the permanent transects is an unequal probability sample with no replication within map units. This design follows since areas had variable numbers of map units, N_h, and thus the probability of randomly selecting any given map unit within an area will differ, i.e., the probability of selecting map unit i in area h is given by $\pi_{ih} = 1/N_h$. And again, since only one permanent transect was established per area (and therefore per map unit), there is no replication within an area nor within a map unit. One option to estimate the proportion of whitebark pine (WBP) or five-needle pine infected with blister rust based on permanent transects is to use an unequal probability ratio estimator as in Thompson (2002, p. 76–79; Appendix 2A for formulas). This estimator would be appropriate to draw inferences to the identified WYBLM areas thought to contain WBP within the GYE boundary.

The sampling design for the rapid transects (as well as the combined rapid and permanent transects) is a stratified two-stage cluster sample. Each geographic area identified by WYBLM (i.e., Brent Creek) can be considered a geographic stratum. The first-stage sampling unit is a map unit (primary sampling unit, e.g., Brent1), and the secondary sampling unit is a point within a map unit (e.g., the GRTS points randomly drawn from within Brent1). In the case where more than one map unit is surveyed within an area (rapid or rapid + permanent transects), the appropriate estimator for the proportion of WBP or five-needle pine infected with blister rust on WYBLM areas within the GYE boundary is either a stratified, two-stage ratio estimator (as used for GYE-wide estimates) or an unbiased two-stage cluster estimator (Appendix 2B for formulas). One benefit of ratio estimation over the unbiased estimator is that it is more precise than the unbiased estimator, meaning that confidence intervals should be narrower. Ratio estimation is also apropos since we are interested in estimating a ratio – the proportion of live five-needle pine trees with blister rust.

Summary of Field Survey Data

During the summers of 2013 and 2014, map units of five-needle pines were evaluated that occur on the range-margins of whitebark pine. In total, 137 rapid assessment transects were completed across 36 different map units within 8 different identified areas of five-needle pines. A total of 8 permanent transects were established within 8 different map units, one in each of the 8 identified areas of five-needle pines. A list of areas and abbreviations used in this report appears below (Table 2-1), and a summary of these visits was provided in the 2013 and 2014 WYBLM Trip Reports (Shanahan 2013; 2014).

Table 2-1. List of areas identified in WYBLM five-needle pine surveys in Wyoming High Desert BLM Districts and Wind River/Bighorn Basin WYBLM Districts, as well as their abbreviations, jurisdictions, total map units, total map units surveyed, and total transects surveyed (rapid and permanent transects).

Area	Year	Abbreviation	Jurisdiction	Total Map Units	Surveyed Map Units	Total Transects Surveyed
Brent Creek	2014	Brent	BLM, Lander Field Ofc.	10	10	38
Clark's Fork Canyon	2014	CFC	BLM, Cody Field Ofc.	1	1	1
Rattlesnake Mountain	2014	Rattle	BLM, Cody Field Ofc.	10	10	42
Teton Valley Ranch Camp	2014	TVRC	BLM, Lander Field Ofc.	2	2	9
Commissary Ridge	2013	CR	BLM, Kemmerer Field Ofc.	3	3	15
Pine Grove Deadline Ridge	2013	PGDR	BLM, Pinedale Field Ofc.	6	6	20
Scab Creek	2013	Scab	BLM, Pinedale Field Ofc.	4	2	9
Sublette Range Hull Creek	2013	SRHC	BLM, Kemmerer Field Ofc.	3	3	11
	Total			**39**	**37**	**145**

Sampling Frame Errors

Sampling frame errors are inevitable in environmental and ecological surveys where information on the members or areal units of the target population is based on maps, which themselves contain error. The WYBLM target population is accessible stands of mixed five-needle pine on lands adjacent to previously defined GYE boundaries. Several identified areas of five-needle pines were very sparse, and, as a result, several points were not suitable for surveying. This was the case for Dempsey Ridge, Scab Creek, and Sublette Range Hull Creek areas. For example, the field report notes that, “after traversing the 3 map units [of Dempsey Ridge] and visiting 19 out of the 30 randomly selected potential survey sites, no five-needle pines were encountered at the randomly selected sites.” (Shanahan 2013). Additionally, two map units in Scab creek and points within the areas of Sublette Range Hull Creek and Clark’s Fork Canyon were inaccessible. In this report, we provide estimators of the proportion of five-needle pines with blister rust with and without an adjustment for these non-target points within map units and points. We also assume they could have been surveyed for blister rust and the accessible units are representative of the inaccessible units within an area (Scab Creek, Sublette Range Hull Creek and Clark’s Fork Canyon).

There are a couple of options for adjusting for the non-target points within a map unit. For the Dempsey area, since the entire area was considered non-target, it was eliminated from the sampling frame (no data was collected there in 2013 or 2014). This decision should be evaluated, as we are assuming that while the entire area contains isolated five-needle pines, there are not enough map units to warrant long-term monitoring.

One option for accounting for over-coverage errors is to reduce the map unit area and then estimate the proportion of trees within this reduced area with blister rust. This adjustment could be made for Scab Creek map units 2 and 4 and PGDR map unit 3, and the Clark's Fork Canyon map unit, among others. The adjustment could be done one of two ways: 1) assume the proportion of points deemed target out of the total surveyed is an estimate of mapping accuracy; this proportion can be multiplied by the area to adjust it downwards, as follows: $\left\{\widehat{Area} = Area \times \frac{n^{TS}+n^{IN}}{n^{TS}+n^{IN}+n^{NT}}\right\}$ where n^{TS} is the number of points in map unit *i* and area *h* that were target and sampled, n^{IN} is the number of points in map unit *i* and area *h* that were inaccessible, and n^{NT} is the number of points in map unit *i* in area *h* that were non-target with no five-needle pine; or 2) ground-truth the polygon boundaries to correct the GIS coverage from which map unit boundaries were created. Note, the total selected within each map unit was 10. These area adjustments may affect the estimated second-stage variance components (variability within map units).

For this analysis, we have used information from site evaluations to proportionally adjust the area of the entire polygon (map unit).

Response Measurement Design

Rapid assessment and permanent transects capture essentially the same information, with an extra layer of detail for permanent transects. Each row in the data corresponds to an observed tree, while some of the variables measured for trees are transect-level or even map unit-level measures. The following data are available for both rapid assessment and permanent transects:

- Date
- Elevation
- Habitat Type
- Cover Type
- Total trees in plot ≤ 1.4 m with BR
- Total trees in plot ≤ 1.4 m without BR
- Total trees in plot ≤ 1.4 m with unknown BR status
- Tree Species
- Clump Number
- DBH category
- Height class
- Tree Status (Live/Dead)
- Presence of BR Aecia on Bole
- Presence of BR Aecia on Branches
- Presence of at least 3 secondary BR indicators on Bole

- Presence of at least 3 secondary BR indicators on Branches
- Upper Live Canopy Volume (%)
- Pitch Tube Category (none, ≤5, >5)
- Presence of MPB Galleries
- Presence of MPB Frass
- Presence of Cones

Since individual trees ≤ 1.4 meters tall (seedlings/saplings) are not monumented, they are simply counted and assessed for presence or absence of white pine blister rust at each full survey. Other data fields correspond to tagged trees > 1.4 m tall. In addition to these tree attributes, surveys at permanent transects included greater detail for tree attributes, as well as squirrel middens. Specifically, these additional metrics were tree DBH and the total count of active or inactive squirrel middens in a transect that have or have not been excavated by bears. For blister rust cankers (and *indicator* cankers) in the tree canopy, the data were broken down into counts of cankers in various portions of the tree canopy. Additionally for blister rust cankers (and *indicator* cankers) in the bole of the tree, the data are broken down by the portion of the bole containing that canker (lower, middle, upper). Specific types of secondary indicators have been recorded as well, including counts of rodent chewing, flagging, swelling, roughened bark, and oozing sap.

Analysis Questions of Interest Based on 2013–2014 WYBLM Surveys

We analyzed the pilot data from the 2013 and 2014 field seasons to give insight into the general patterns of estimated blister rust prevalence on WYBLM lands adjacent to the GYE, explored different available estimators for prevalence appropriate for WYBLM specific estimates, and assessed the adequacy of sample sizes (number of transects) within map units. Specifically, we:

1) Determined the proportion of live trees > 1.4 m tall with evidence of white pine blister rust infection using several design-based estimators based on using all the data (rapid and permanent), just rapid transects, or just permanent transects.
2) Estimated the variability among transects within map units to determine the number of transects (second-stage sample units) needed and whether current sample sizes are sufficient.

Data Summaries

WYBLM data include observations on five-needle pine trees present in the Greater Yellowstone Ecosystem – Whitebark Pine (*Pinus albicaulis*, abbreviated as either WBP or PIAL) and Limber Pine (*Pinus flexilis*, abbreviated as either LP or PIFL). Field surveys were conducted during July of 2013 and from the period between July and September of 2014. Table 2-2 displays basic numeric summaries of total trees recorded across transects (either full or rapid assessment). Trees recorded as “unknown” were an unknown species of five-needle pine.

A total of 37 map units were surveyed during the field seasons of 2013 and 2014 (Table 2-1), 36 of which had at least one rapid transect, and 8 of which had at least one permanent transect (Table 2-2). Total map units with combined rapid and permanent data is not additive from the number of map units with permanent transects and the number of map units with rapid transects, due to overlap, i.e., some map units had both permanent and rapid transects, and one map unit had only one transect

(CFC, see Appendix 2C). The number of transects per map unit ranged from 1 to 5 (Figure 2-1). Specific numbers of transects containing the species of interest per map unit are also provided in Table 2-3 for a closer examination of the data.

Table 2-2. Numeric summaries of total trees recorded for each transect type for combined data from 2013 and 2014 field seasons. Where relevant, proportions are reported inside parentheses. Total refers to the count of trees pooling across transects and map units.

Metric	Count for Permanent Transects	Count for Rapid Transects
Total map units	8	36
Total transects	8	137
Total trees	146	3006
Total dead trees	0	779
Total WBP	12	96
Total Live WBP	12/12 (1.000)	95/96 (0.990)
Total Live WBP with BR	4/12 (0.333)	24/95 (0.253)
Total WBP with MPB	0/12 (0.000)	5/96 (0.052)
Total Limber Pine	20	246
Total Live Limber Pine	20/20 (1.000)	241/246 (0.980)
Total Live Limber Pine with BR	9/20 (0.450)	85/241 (0.353)
Total Limber Pine with MPB	0/20 (0.000)	6/246 (0.024)
Total UNK trees	114	2664
Total Live UNK trees	114/114 (1.000)	1891/2664 (0.710)
Total Live UNK trees with BR	15/114 (0.132)	457/1891 (0.242)
Total UNK trees with MPB	0/114 (0.009)	141/2664 (0.053)

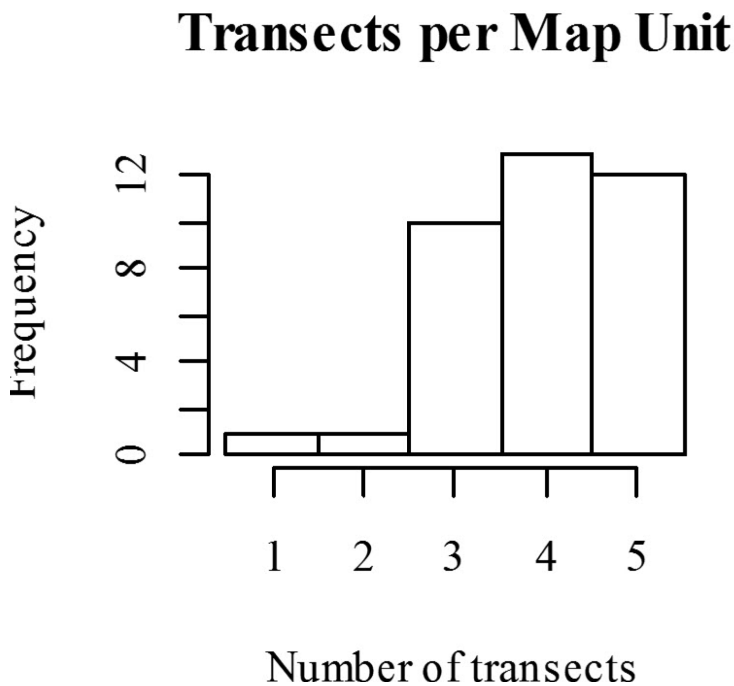

Figure 2-1. Counts of transects within map units for all WYBLM from both 2013 and 2014. Counts of transects are pooled across transect types (*i.e.*, rapid vs. permanent). For example, Brent Creek Transect 1 (Brent1) had 1 permanent transect and 3 rapid transects and is here recorded as 4.

Table 2-3. Numbers of transects within each map unit that contain the species of interest (WBP, LP, or unknown five-needle pines) by transect type (only permanent transects, only rapid transects, or all transects combined). An "X" indicates that there were no trees of that species observed in transects within that specific map unit. Transect counts are for 2013 and 2014 WYBLM field data.

	Whitebark Pine			Limber Pine			Unknown Species		
Map Unit	**Perm.**	**Rapid**	**Total**	**Perm.**	**Rapid**	**Total**	**Perm.**	**Rapid**	**Total**
Brent1	X	X	X	X	X	X	1	3	4
Brent2	X	1	1	X	3	3	X	3	3
Brent3	X	X	X	X	X	X	X	4	4
Brent4	X	1	1	X	X	X	X	4	4
Brent5	X	X	X	X	1	1	X	2	2
Brent6	X	X	X	X	X	X	X	4	4
Brent7	X	4	4	X	3	3	X	5	5
Brent8	X	X	X	X	X	X	X	3	3
Brent9	X	X	X	X	X	X	X	3	3
Brent10	X	1	1	X	1	1	X	4	4
CFC	X	X	X	1	X	1	X	X	X

Table 2-3 (continued). Numbers of transects within each map unit that contain the species of interest (WBP, LP, or unknown five-needle pines) by transect type (only permanent transects, only rapid transects, or all transects combined). An "X" indicates that there were no trees of that species observed in transects within that specific map unit. Transect counts are for 2013 and 2014 WYBLM field data.

	Whitebark Pine			Limber Pine			Unknown Species		
Map Unit	**Perm.**	**Rapid**	**Total**	**Perm.**	**Rapid**	**Total**	**Perm.**	**Rapid**	**Total**
CR1	1	2	3	X	X	X	1	4	5
CR2	X	5	5	X	X	X	X	5	5
CR3	X	3	3	X	X	X	X	5	5
PGDR1	1	1	2	X	X	X	1	2	3
PGDR2	X	4	4	X	X	X	X	5	5
PGDR3	X	2	2	X	X	X	X	3	3
PGDR4	X	X	X	X	X	X	X	3	3
PGDR5	X	X	X	X	1	1	X	2	2
PGDR6	X	2	2	X	X	X	X	3	3
Rattle1	1	X	1	1	2	3	1	3	4
Rattle2	X	X	X	X	1	1	X	3	3
Rattle3	X	X	X	X	4	4	X	4	4
Rattle4	X	X	X	X	4	4	X	4	4
Rattle5	X	X	X	X	5	5	X	5	5
Rattle6	X	X	X	X	4	4	X	5	5
Rattle7	X	X	X	X	4	4	X	4	4
Rattle8	X	X	X	X	4	4	X	5	5
Rattle9	X	X	X	X	3	3	X	3	3
Rattle10	X	X	X	X	2	2	X	5	5
Scab1	X	X	X	1	3	4	X	1	1
Scab3	X	1	1	X	2	2	X	2	2
SRHC1	X	X	X	1	4	5	X	X	X
SRHC2	X	X	X	X	2	2	X	X	X
SRHC3	X	X	X	X	4	4	X	X	X
TVRC1	1	1	2	1	1	2	1	4	5
TVRC2	X	1	1	X	2	2	X	4	4

Plots of blister rust (BR) and mountain pine beetle (MPB) prevalence within transects illustrate the variability across all transects within the WYBLM data. Blister rust indicators were assessed for live trees only, while evidence of mountain pine beetle was recorded for both live and dead five-needle pines.

The data from each of the eight permanent transects appear consistent with other observations taken within the same map unit and stratum. In other words, though total counts of trees were highly variable across areas, they appear consistent within an area. Similarly, the proportion of trees with blister rust was consistent across map units within an area. This is illustrated well in Table 2-4, where counts of trees are highly variable across all transects in the study, but similar to those within the same map unit (see Appendix 2C as well as Figures 2-2 to 2-4 illustrating proportions across all transects; also see Figures 2-5 to 2-10, which compare transects within map units).

Table 2-4. Total numbers of trees by species in the 8 permanent transects. An "X" indicates that there were no trees of that species observed in transects within that specific map unit.

Map Unit	Transect Number	Total WB	Total LP	Total UNK	Total Trees
Brent1	41	X	X	11	11
CFC	16	X	5	X	5
CR1	251	8	X	4	12
PGDR1	71	2	X	62	64
Rattle1	171	1	6	12	19
Scab1	183	X	4	X	4
SRHC1	262	X	4	X	4
TVRC1	101	1	1	25	27

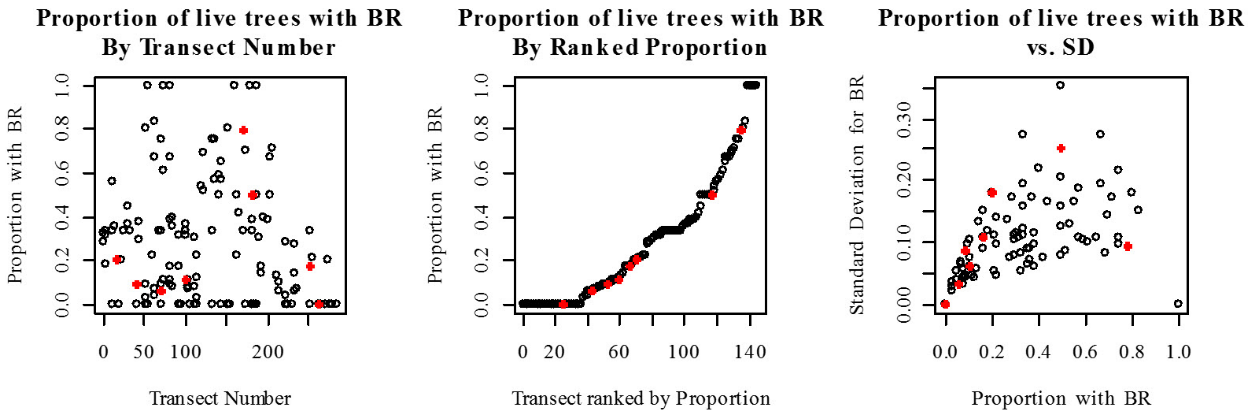

Figure 2-2. Observed proportion of trees with blister rust for each transect for 2013 and 2014 data combined. Black points represent rapid assessment surveys, while red points represent permanent transects. Panel A illustrates the proportion of BR within each transect by transect number (arbitrary, but similar for transects within map unit). Panel B illustrates the ranked proportion of BR within each transect. Panel C illustrates the proportion of BR within each transect by its binomial standard error.

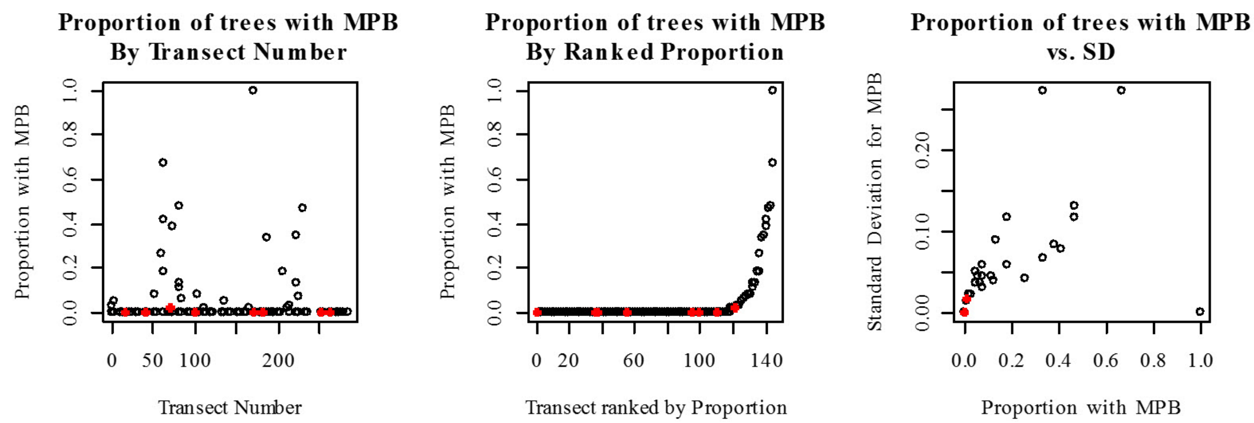

Figure 2-3. Observed proportion of trees with mountain pine beetle for each transect for 2013 and 2014 data combined. Black points represent rapid assessment surveys, while red points represent permanent transects. Panel A illustrates the proportion of MPB within each transect by transect number (arbitrary, but similar for transects within map units). Panel B illustrates the ranked proportion of MPB within each transect. Panel C illustrates the proportion of MPB within each transect by its binomial standard error.

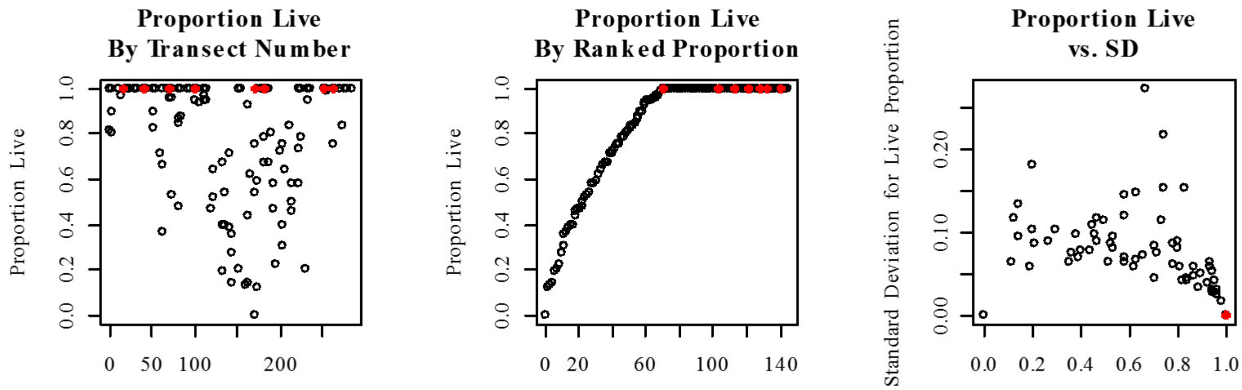

Figure 2-4. Observed proportion of live trees for each transect for 2013 and 2014 data combined. Black points represent rapid assessment transects, while red circles represent permanent transects. Panel A illustrates the proportion of live trees within each transect by transect number (arbitrary, but similar for transects within map units). Panel B illustrates the ranked proportion of live trees within each transect. Panel C illustrates the proportion of live trees within each transect by its binomial standard error.

The rapid assessment transects allow for a more thorough examination of the variability among transects within map units. We can estimate the secondary variance component as more than one or two transects within a map unit were surveyed. For the WYBLM data from both 2013 and 2014, we illustrate the variability of transects within map units (*i.e.*, stands) with plots of the proportion of BR by transects within map units, which illustrates this secondary variance component (Figures 2-5 and 2-6). Also included are plots of the proportion of trees by transect having MPB (Figures 2-7 and 2-8) and plots of the proportion of live trees by transect within stands (Figures 2-9 and 2-10).

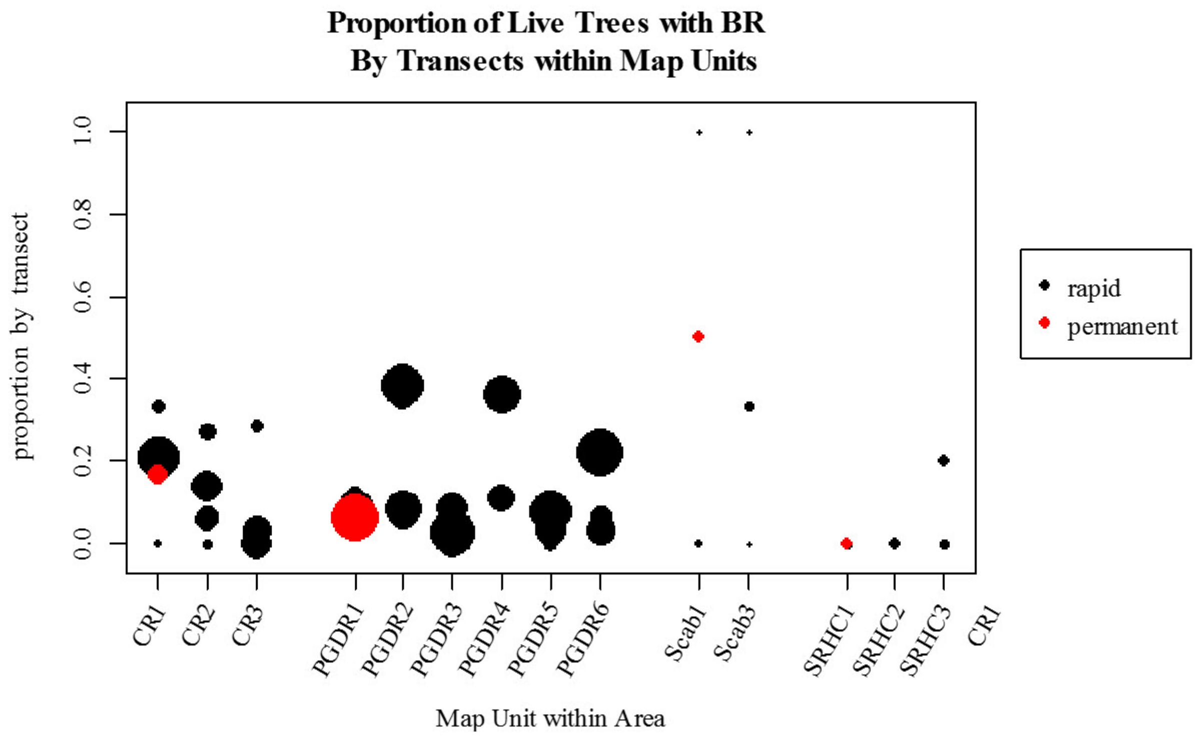

Figure 2-5. Proportions of live trees with BR by transect within each of 14 map units for 2013 field season data. Symbol size is proportional to total live trees per transect with rapid transects in black and permanent transects in red. For map unit abbreviations and areas, see descriptions in Table 2-1.

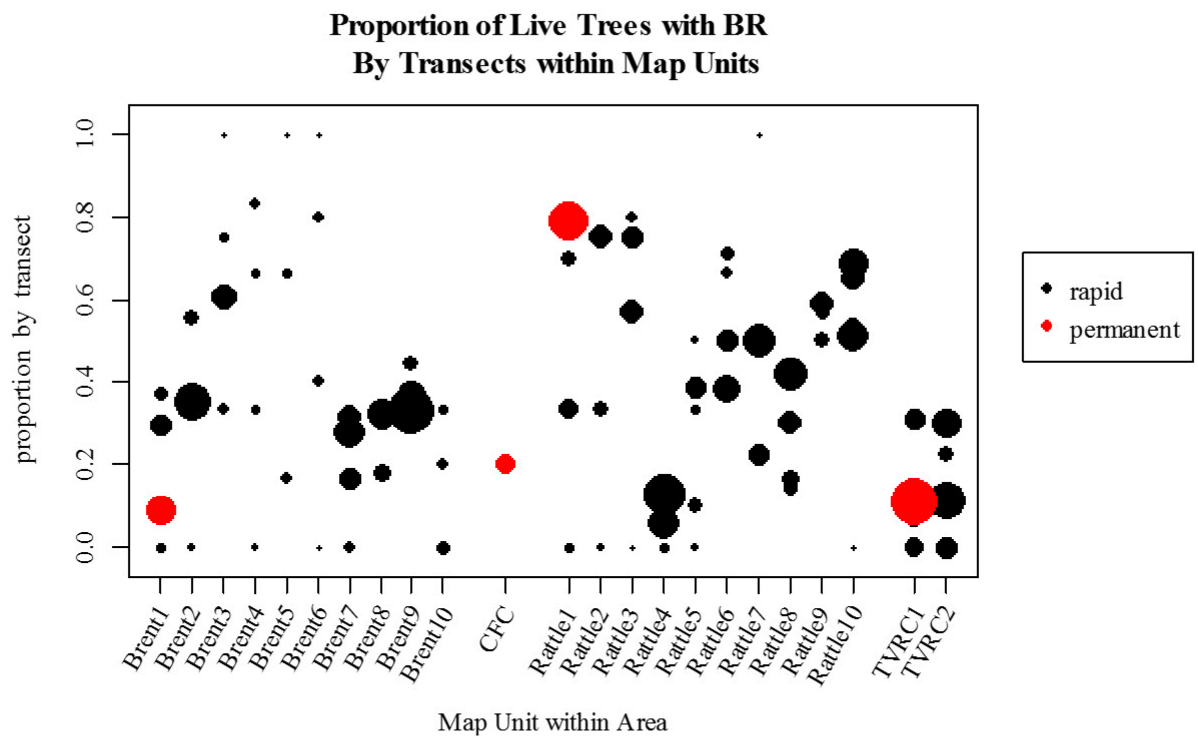

Figure 2-6. Proportions of live trees with BR by transect within each of 23 map units for 2014 field season data. Symbol size is proportional to total live infected trees per transect with rapid transects in black and permanent transects in red. For map unit abbreviations and areas, see descriptions in Table 2-1.

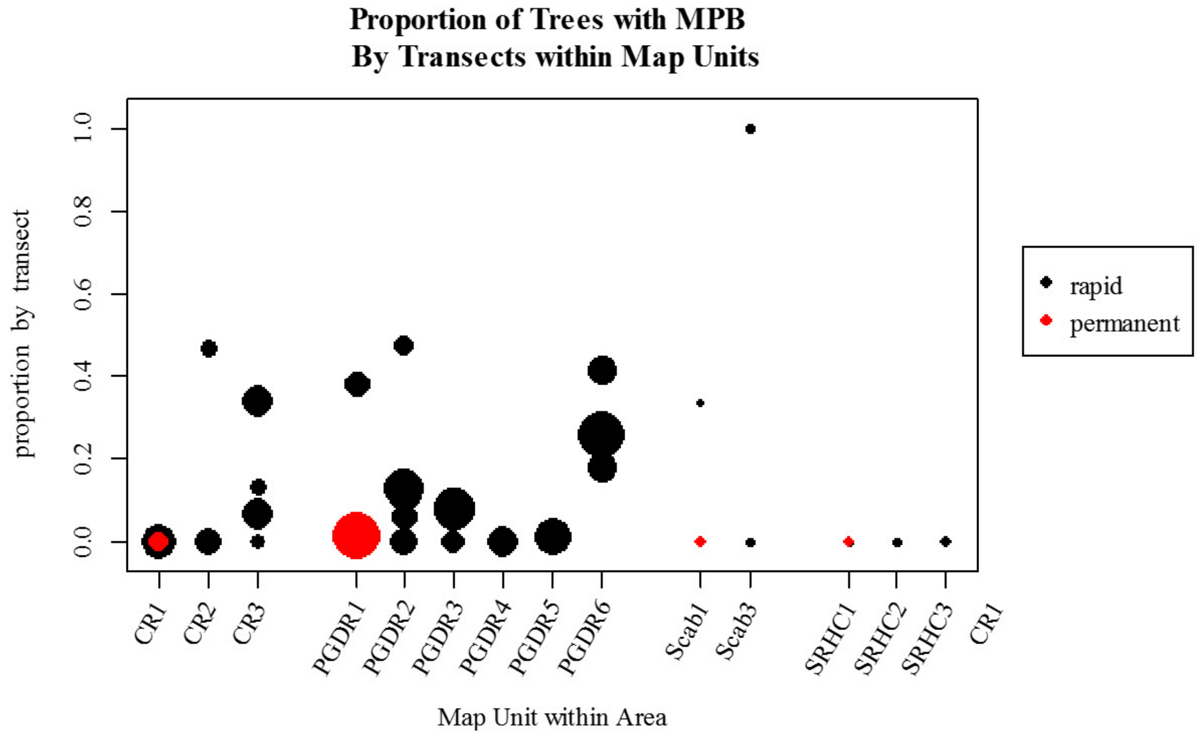

Figure 2-7. Proportions of trees with MPB by transect within each of 14 map units for 2013 field season data. Symbol size is proportional to total trees with MPB per transect with rapid transects in black and permanent transects in red. For map unit abbreviations and areas, see descriptions in Table 2-1.

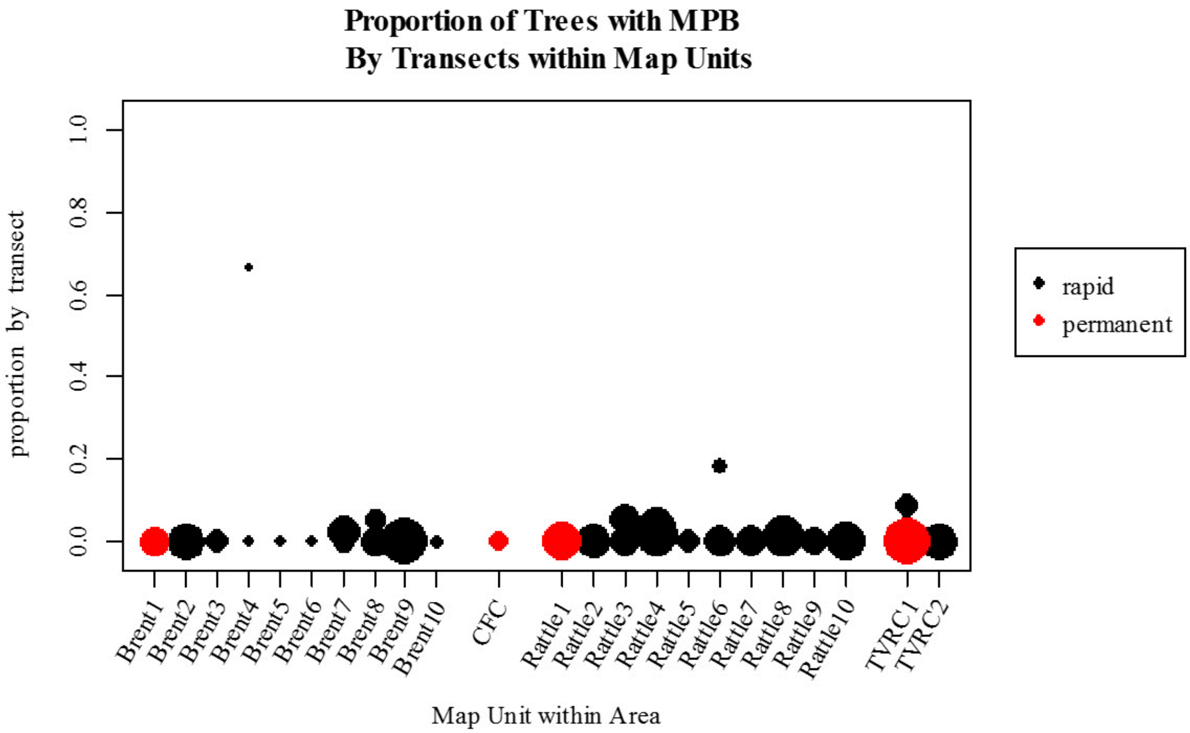

Figure 2-8. Proportions of trees with MPB by transect within each of 23 map units for 2014 field season data. Symbol size is proportional to total trees with MPB per transect with rapid transects in black and permanent transects in red. For map unit abbreviations and areas, see descriptions in Table 2-1.

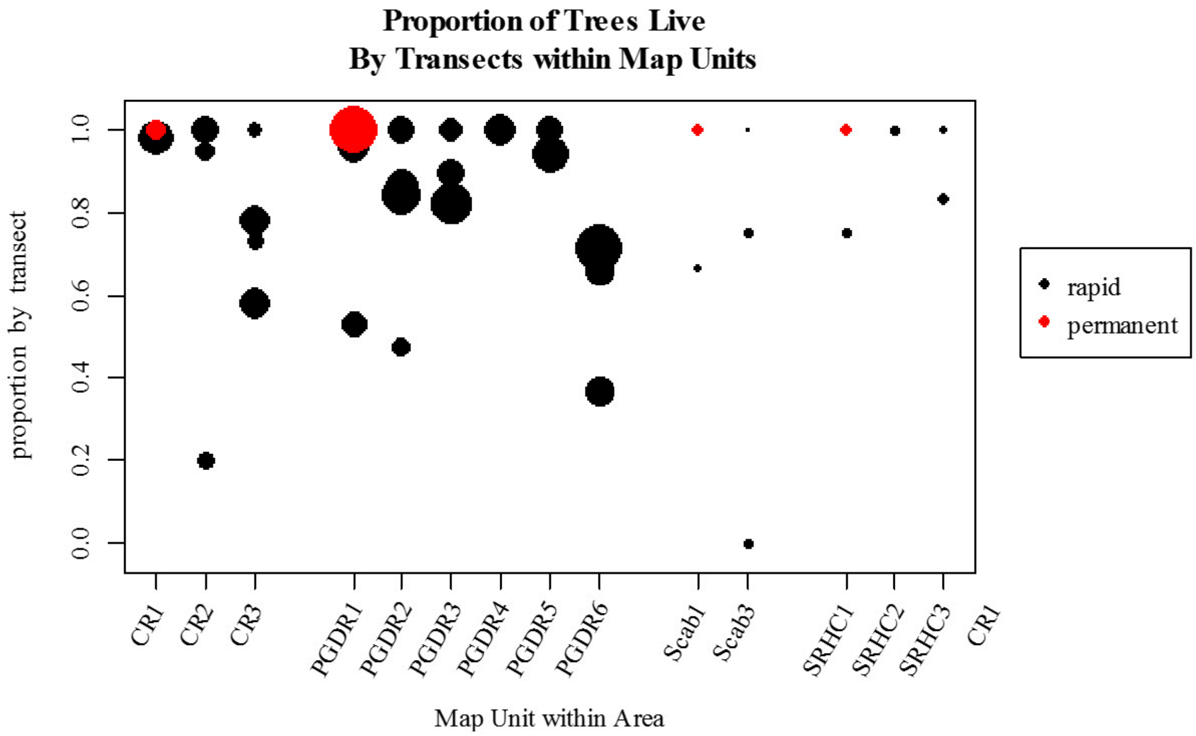

Figure 2-9. Proportions of live trees by transect within each of 14 map units for 2013 field season data. Symbol size is proportional to total trees per transect with rapid transects in black and permanent transects in red. For map unit abbreviations and areas, see descriptions in Table 2-1.

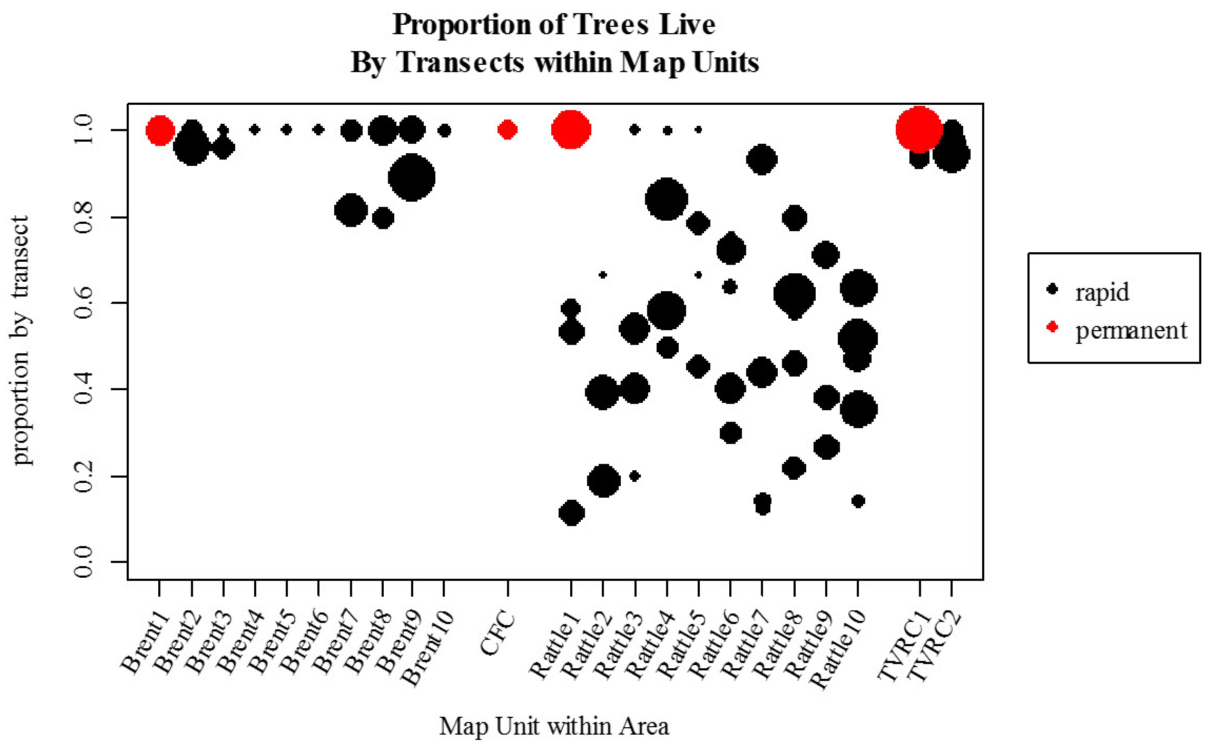

Figure 2-10. Proportions of live trees by transect within each of 23 map units for 2014 field season data. Symbol size is proportional to total trees per transect with rapid transects in black and permanent transects in red. For map unit abbreviations and areas, see descriptions in Table 2-1.

Estimating Proportion of Five-Needle Pine with Evidence of Blister Rust on WYBLM Lands Adjacent to GYE

Since only one permanent transect was established per area, estimates of the proportion of trees with BR using only data from permanent transects are computed using the Horvitz-Thompson unequal probability ratio estimator (for formulas, see Appendix 2A). For estimates based on combined data from rapid and permanent transects, separate and combined ratio estimators for a stratified, two-stage cluster design were used, as well as the unbiased estimator which does not incorporate the size of the map unit (for formulas, see Appendix 2B). The ratio estimator is ideal when we are estimating a ratio, as we have here with the proportion of live trees infected with BR. Additionally, the ratio estimator is expected to outperform the unbiased estimator for the proportion since it can be inefficient when the sizes of the clusters (*i.e.*, size of the map unit or stand) are variable (Lohr 2010). For the WYBLM field data from 2013 and 2014, map unit area ranged between 2.7 and 1670.4 hectares, with a median area of 9.3 hectares (Appendix 2D). Since our map units have such highly variable area, we can expect confidence intervals to be wider for unbiased estimates than for ratio estimates.

The ratio and unbiased estimators used here are the same estimators calculated for GYE four-year reporting. However, the interagency ratio estimator for the proportion of trees with BR ignores the potential variation among transects within map units (stands). There is no viable way to estimate this quantity using the interagency WBP monitoring data as only 1 or 2 transects are surveyed within a

stand. We assume that one or two transects are representative of the entire stand in the context of the long-term monitoring program. Here, using the WYBLM rapid assessment surveys, we can explore this assumption by comparing the estimators including the secondary variance component and excluding the secondary variance component (*i.e.*, the variation among transects within map units). In Figures 2-11 through 2-13, we display these estimated proportions of trees infected with BR for WBP alone, for LP alone, and for all five-needle pine (WBP + LP + unknown five-needle pine).

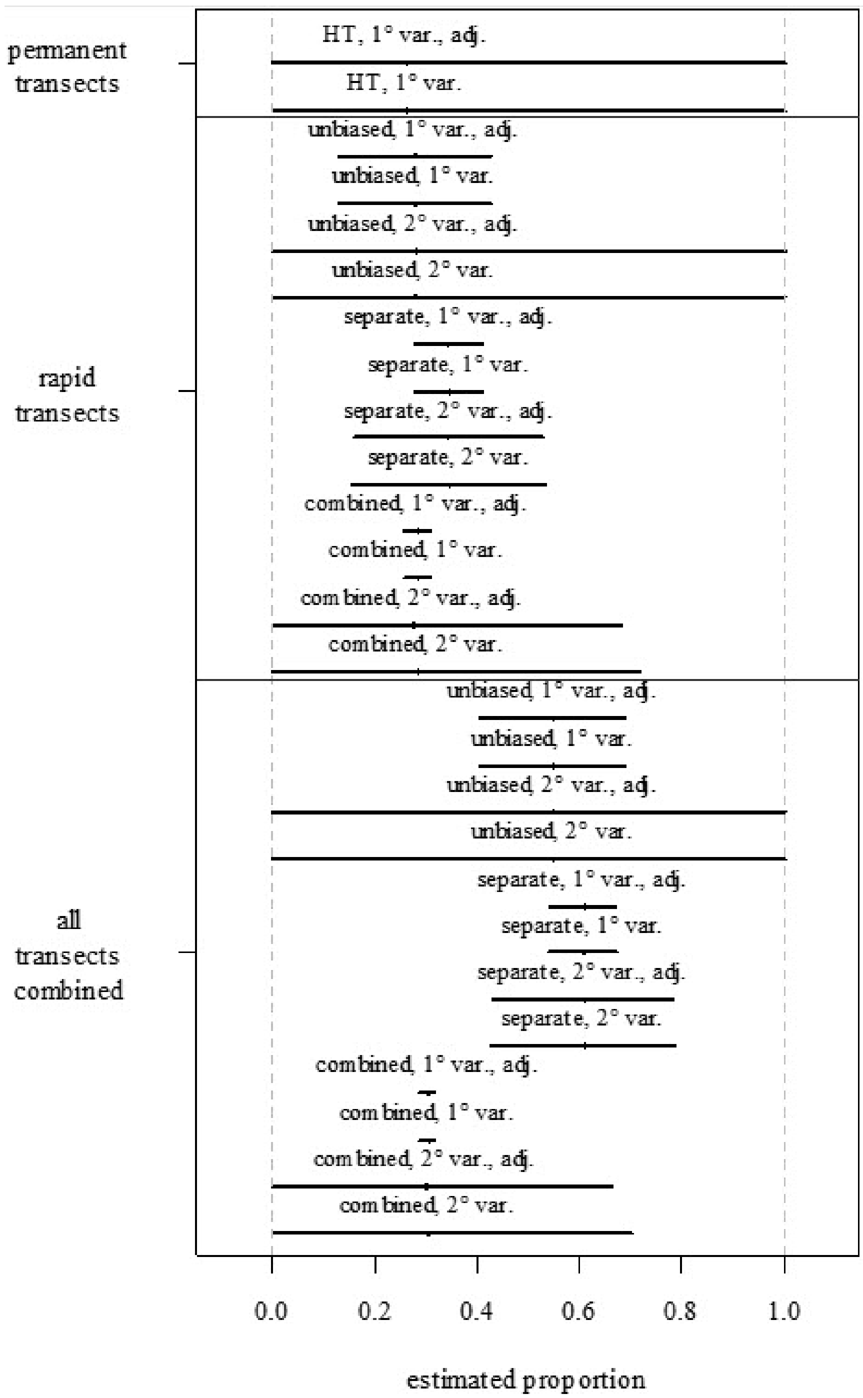

Figure 2-11. Estimated proportion of whitebark pine infected with BR and associated 95% confidence intervals for different subsets of 2013–2014 WYBLM data. Estimates for permanent transects are marked “HT”, signifying the Horvitz-Thompson unequal probability ratio estimator. Intervals indicated with “separate” or “combined” use ratio estimation, while those marked “unbiased” use the unbiased estimator. Estimates may or may not include the secondary variance component and are marked either “2° var.” or “1° var. only”. Additionally, some estimates have been adjusted (“adj.”) to correct for overcoverage frame errors within map units. Endpoints of some confidence intervals were truncated to fall within the logical bounds of 0 and 1 for a proportion.

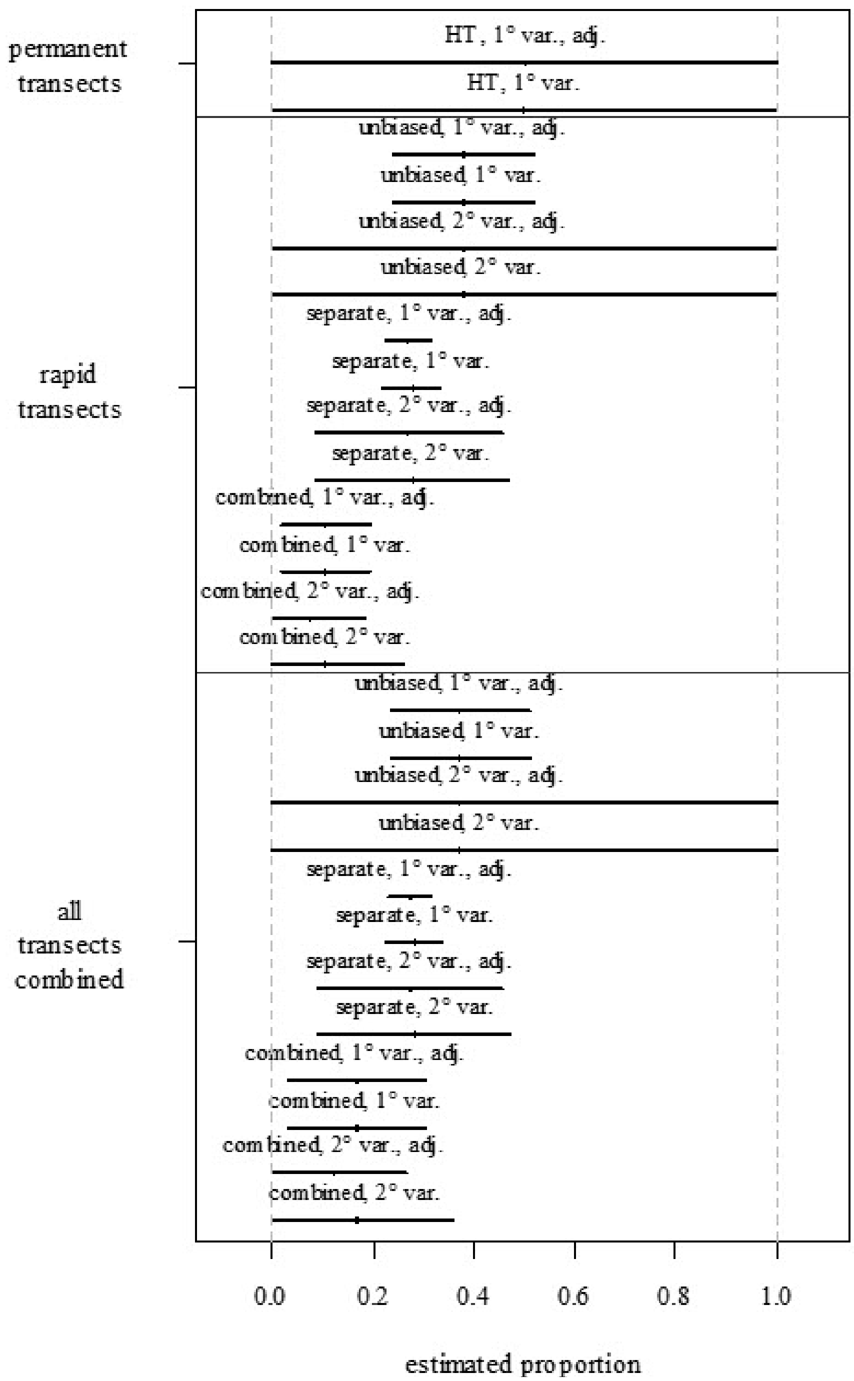

Figure 2-12. Estimated proportion of limber pine infected with BR and associated 95% confidence intervals for different subsets of 2013–2014 WYBLM data. Estimates for permanent transects are marked "HT", signifying the Horvitz-Thompson unequal probability ratio estimator. Intervals indicated with "separate" or "combined" use ratio estimation, while those marked "unbiased" use the unbiased estimator. Estimates may or may not include the secondary variance component and are marked either "2° var." or "1° var. only". Additionally, some estimates are adjusted ("adj.") to correct for overcoverage frame error within map units. Endpoints of some confidence intervals were truncated to fall within the logical bounds of 0 and 1 for a proportion.

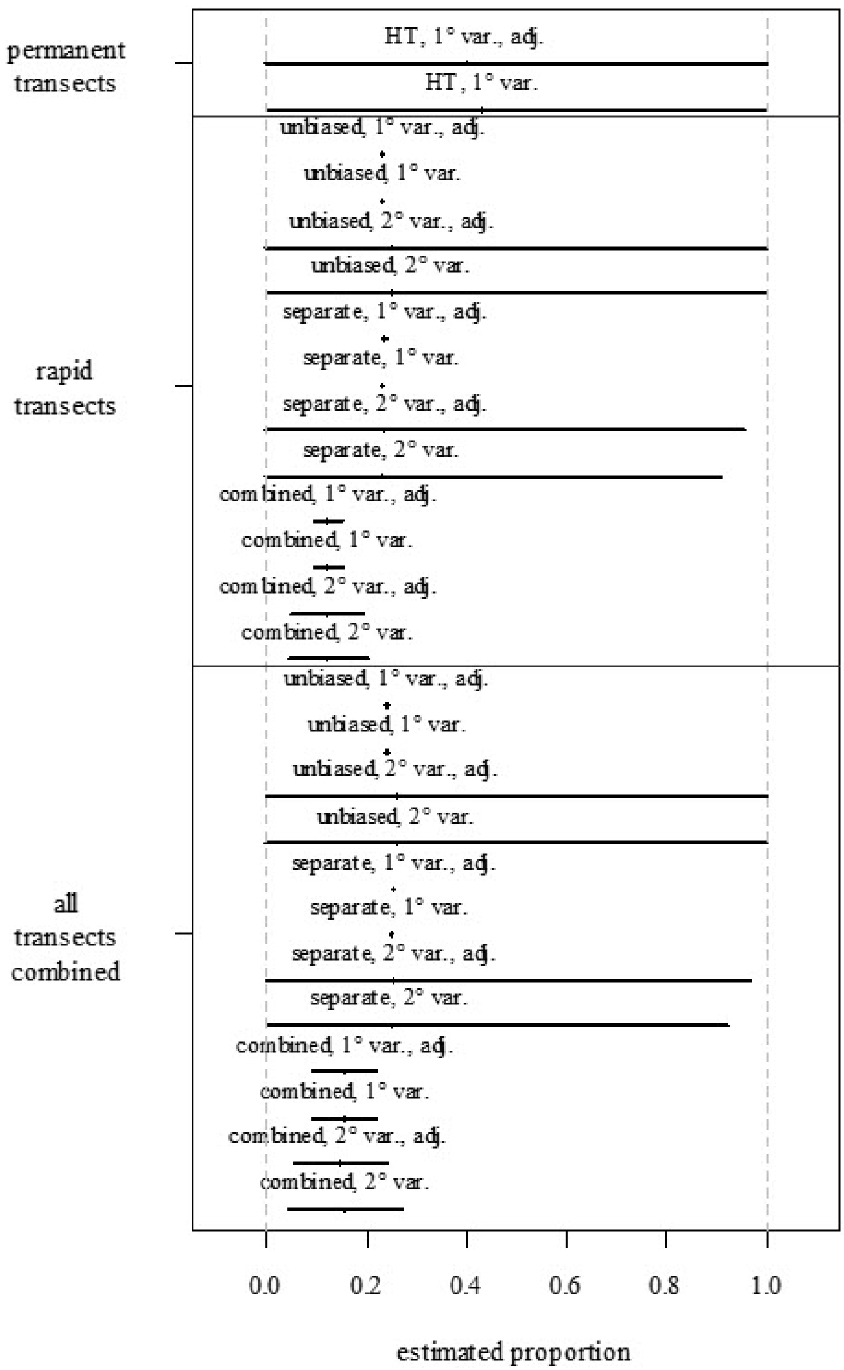

Figure 2-13. Estimated proportion of all five-needle pine infected with BR and associated 95% confidence intervals for different subsets of 2013–2014 WYBLM data. Estimates for permanent transects are marked "HT", signifying the Horvitz-Thompson unequal probability ratio estimator. Intervals indicated with "separate" or "combined" use ratio estimation, while those marked "unbiased" use the unbiased estimator. Estimates may or may not include the secondary variance component and are marked either "2° var." or "1° var. only". Additionally, some estimates are adjusted ("adj.") to correct for overcoverage frame error within map units. Endpoints of some confidence intervals were truncated to fall within the logical bounds of 0 and 1 for a proportion.

Examining the proportion of trees infected with blister rust, several patterns are apparent, regardless of species. Many of the confidence intervals are wide (Figures 2-11 to 2-13), and often less informative than we would like. This is especially true for estimates from only permanent transects, but it is also frequently occurs when using the unbiased estimator since it is less efficient than the ratio estimators. Also, in general, confidence intervals that include the secondary variance component are less precise than those that do not for the same estimator. For example, for WBP (rapid + permanent), the unadjusted, combined ratio estimator excluding the primary variance component spans the interval from 0.286 to 0.317, and including the secondary variance component it spans the interval from 0 to 0.703 (Figure 2-11 and Table 2E-10 in Appendix 2E). The interval is substantially wider when we account for the variance among transects within a map unit. Another general observation was that adjustments made to estimates to account for overcoverage frame error tend to decrease the standard error of the estimate. For the same WBP example (rapid + permanent), the confidence interval for the combined ratio estimator including the primary variance spanned the interval from 0 to 0.703 without an adjustment (Figure 2-11 and Table 2E-10, Appendix 2E), and it spanned the interval from 0 to 0.662 with an adjustment (Figure 2-11 and Table 2E-9, Appendix 2E).

Taking a closer look at the WBP data, the many different estimators produce somewhat confusing results. For the combined data (rapid + permanent, unadjusted), the estimated proportion of WBP infected with BR is 0.548 using the separate ratio estimator, 0.606 using the unbiased estimator, and 0.302 using the combined ratio estimator (Figure 2-11 and Table 2E-10 in Appendix 2E). This is due to sparsity of the data and the way the estimators are calculated. Two of the areas (Rattle and Scab) each only had one map unit with identified WBP, and within that map unit, only one transect, and within that transect only one WBP tree, and it was observed with BR (Table 2C-1, Appendix 2C). In the calculation of the unbiased and separate ratio estimators, since the proportions of BR are calculated separately for the areas before they are merged into a single proportion, these two areas (Rattle and Scab) both contributed proportions of 1. The combined ratio estimator, however, calculates the proportion of infected trees once for all the data together and, thus, is not skewed by these small sample sizes. The sparsity of the data also has the effect of increasing the width of confidence intervals for the WBP data, because some areas had very little replication, if any (e.g., Brent, Rattle, Scab and TVRC; see Table 2C-1, Appendix 2C). Even though confidence intervals for WBP were already wide, these interval estimates are known to be underestimates since the variability among map units within an area cannot be calculated when data exist for only one map unit in that area (e.g., Rattle and Scab, see Table 2-3). Therefore, we suggest that the combined ratio estimator including the secondary variance component be used as the 'best' baseline estimate for the proportion of live WBP with BR for WYBLM lands adjacent to the GYE , which is 0.302 ± 0.17 (proportion ± 1 SE, or an unadjusted 95% CI from 0 to 0.703, Figure 2-11 and Table 2E-10 in Appendix 2E). Again, this reported confidence interval is likely too narrow due to the inestimable variance within some areas (in this case, two areas – Rattle and Scab).

Examining the LP estimates, in general, confidence intervals were narrower than for WBP. This is likely due to larger sample sizes and the amount of replication available for this species. For example, the confidence interval using the combined data (rapid + permanent) and the unadjusted, combined ratio estimator including the secondary variance component spanned from 0 to 0.357 for

LP (Figure 2-12, Table 2E-12, Appendix 2E), while it spanned from 0 to 0.703 for WBP (Figure 2-11, Table 2E-10, Appendix 2E). Also, point estimates for the proportion of live LP with BR were generally lower than for WBP (compare 0.167 with 0.302, Figures 2-11 and 2-12, Tables 2E-12 and 2E-10 in Appendix 2E). Similar to WBP, sparse counts of LP in two map areas (e.g., CFC and PGDR) means that the variability among map units within these two areas cannot be estimated. Again, although confidence intervals for LP were already wide, these estimates are known underestimates as the variability among map units cannot be calculated when data exist for only one map unit (e.g., CFC and PGDR, see Table 2-3). We suggest using the combined ratio estimator including the secondary variance component as the 'best' baseline estimate of the proportion of live LP with BR for WYBLM lands adjacent to the GYE, which is 0.167 ± 0.089 (proportion ± 1 SE, or a 95% CI from 0 to 0.357).

The estimated proportions of live five-needle pine infected with BR were lower than for confirmed LP and WBP singly. Our 'best' baseline estimate for the proportion of live five-needle with BR is 0.156 ± 0.054 (proportion ± 1 SE, or a 95% CI from 0.045 to 0.268 using the unadjusted, combined ratio estimator including the secondary variance component, Table 2E-14, Appendix 2E). The confidence intervals for all five-needle pine are also narrower than those for WBP or LP alone. This is the result of larger sample sizes. The dataset contains over 2,700 five-needle pine of unknown species on rapid and permanent transects, with fewer than 300 identified LP on rapid and permanent transects and just over 100 WBP on rapid and permanent transects (Table 2-2). There is greater certainty about the proportion of all five-needle pine with BR because it includes those unknown species of five-needle pine. It is also interesting to note that confidence intervals for the separate and unbiased estimates that only include the primary variance component are extremely narrow (Figure 2-13). This is because, theoretically, we have sampled every map unit in the population. If we were to draw another sample, it would include the same map units. Essentially, by ignoring the secondary variance component we are assuming we have a census of map units, and thus the sampling variability is 0 (due to the finite population correction factor being 0). For the combined, five-needle pine data, we do not have the same problems of inestimable variance that we had with WBP alone or LP alone. Each area had at least two map units with data, meaning the variability among map units could be calculated. An exception is the CFC area, which had a total population of only one map unit, which was surveyed. Thus, no among-map-unit variability is possible here, but all units in the population were sampled. And lastly, the widths of confidence intervals using the separate ratio estimator for all of the five-needle pine data are wider than those for WBP or LP alone. This results from the highly variable densities of trees in Brent, Rattle and CR (Table 2C-1, Appendix 2C).

Using a Model-Based Framework to Examine the Data Variability

One valuable asset of this dataset is that it provides the opportunity to examine the magnitude of the variation among transects within map units, something not possible when there is only 1 or 2 transects within a stand (map unit) as in the GYE data. To examine this secondary variance component, we can look at the extra contribution it makes to the width of confidence intervals (Figures 2-11 to 2-13). This is using a design-based approach. We could also use a model-based framework to compare the contributions of variance within and among map units.

For a model-based approach, we used a generalized linear mixed model for a binary response (BR presence/absence) which accounts for the correlation of observations within the same map unit and area. For the initial survey results from the 2013 field season data we found that the variation within a map unit was greater than the variation among map units ($\hat{\sigma}_{map\ unit} = 0.65$, while $\hat{\sigma}_{transect} = 0.74$, from a generalized linear mixed effects model specifying only an intercept term for the fixed effects as well as both nested random effects for the 2013 field season data). This could be partly due to the fact that counts of five-needle pine were very sparse for map units surveyed during the 2013 field season. For example, two areas (Scab Creek and Sublette Range Hull Creek) had sparse counts of live trees, ranging from between 1 to 5 five-needle pine per transect for both areas (Table 2-5). When considering field season data for both 2013 and 2014, however, the trend is different. For the binary response of blister rust infection among all five-needle pine observed on all transect types, the variance among transects *within* a map unit was lower than the variance among map units ($\hat{\sigma}_{map\ unit} = 0.801$, while $\hat{\sigma}_{transect} = 0.699$, from a generalized linear mixed effects model specifying only an intercept term for the fixed effects as well as both nested random effects for the 2013 and 2014 field season data). This could be attributable to greater numbers of live trees per transect within a map unit in the 2014 field season data (Table 2-5).

Table 2-5. Mean number of living trees per map unit averaged across all transects within that map unit and the estimated total number of living trees for the entire map unit ($M_i\bar{x}_i$).

Map Unit	Year	Mean Live Trees per Transect	Estimated Total Live Trees ($M_i\bar{x}_i$)
CR1	2013	18.2	29,234.5
CR2	2013	16.6	3,268.7
CR3	2013	19.2	4,340.0
PGDR1	2013	43.0	6,999.7
PGDR2	2013	37.4	6,953.6
PGDR3	2013	43.3	199,907.9
PGDR4	2013	25.7	4,154.7
PGDR5	2013	37.0	178,874.5
PGDR6	2013	40.3	15,257.6
Scab1	2013	2.0	66,817.5
Scab3	2013	1.2	197.5
SRHC1	2013	2.2	890.8
SRHC2	2013	3.5	7,352.9
SRHC3	2013	3.0	2,157.8
Brent1	2014	9.8	722.4
Brent2	2014	8.5	1,067.1

Table 2-5 (continued). Mean number of living trees per map unit averaged across all transects within that map unit and the estimated total number of living trees for the entire map unit ($M_i\bar{x}_i$).

Map Unit	Year	Mean Live Trees per Transect	Estimated Total Live Trees ($M_i\bar{x}_i$)
Brent3	2014	3.5	297.8
Brent4	2014	3.8	591.9
Brent5	2014	2.3	186.3
Brent6	2014	11.0	1,421.5
Brent7	2014	35.8	6,592.0
Brent8	2014	14.0	845.4
Brent9	2014	5.3	301.8
Brent10	2014	20.8	1,739.5
CFC	2014	5.0	2,529.4
Rattle1	2014	11.8	1,309.3
Rattle2	2014	3.3	1,035.7
Rattle3	2014	29.5	20,187.4
Rattle4	2014	6.3	1,806.8
Rattle5	2014	12.2	853.8
Rattle6	2014	20.8	8,727.7
Rattle7	2014	11.0	5,924.9
Rattle8	2014	12.0	2,768.3
Rattle9	2014	27.3	12,247.9
Rattle10	2014	13.6	1,096.6
TVRC1	2014	19.0	1,025.9
TVRC2	2014	28.0	1,944.0

Though these stories seem different, the model-based results are corroborated by the design-based results. Specifically, the combined ratio estimate for all five-needle pine was 0.156 ± 0.031 (proportion ± 1 SE) when excluding the secondary variance component, and it was 0.156 ± 0.054 (proportion ± 1 SE) when including the secondary variance component (Table 2E-14, unadjusted estimates). If we tease apart these pieces, we see that the contribution due to the primary variance component is 0.031 and 0.023 due to the secondary variance component (0.054 − 0.031 = 0.023). The extra variability due to differences among transects within a map unit is an important and necessary piece, but here it is not bigger than the variability due to differences among map units alone.

Optimal Number of Transects within Map Units

In order to maximize statistical power to detect long-term change, it is important to consider survey effort. For example, for the identified WBP, the width of the confidence interval may be too wide to detect any real, long-term change in estimates of blister rust infection (adjusted 95% CI from 0 to 0.662 for the combined ratio estimate including the secondary variance component, Table 2E-9 in Appendix 2E). One option to consider is increasing the number of transects within a map unit to reduce the secondary variance component (variance within a map unit).

When considering how WYBLM should survey in the future, we want to consider how to minimize the uncertainty around our estimate. The secondary variance component is a weighted average of the within-map-unit sample variances. The weights are $\left(\frac{M_i \bar{x}_i}{\sum_{i \in h} M_i \bar{x}_i}\right)$, so map units with higher density of live trees contribute more to the secondary variance component (see Table 2-5 for estimated total live trees per map unit). If we allocate more transects to those map units, it should reduce the variance estimates (shrinking the confidence intervals). Note that the map units with the largest variance were those with the lowest numbers of trees (Scab Creek and Sublette Range Hull Creek), but they are weighted less compared to those with more estimated total trees.

To determine the optimal number of transects (or SSUs, secondary sampling units), we estimate the variance using different subsets of the WYBLM data from the 2013 and 2014 field seasons (for estimators see Appendix 2A and E). Since the combined five-needle pine data and the WBP data are of special interest, we provide variance estimates for these data, assuming a minimum of two transects within each map unit. For those areas with only one map unit with observed WBP, we specify that that map unit contributes nothing to the weighted average of the among-PSU variance. There is no way to estimate the variability among map units if only one map unit is observed, but this means that the variance estimate is an underestimate. This was the same issue (inestimable variance components within some areas) that occurred with the observed data estimates. The number of map units assumed within each area is depicted in Table 2-6.

Table 2-6. Counts of map units (out of total) within each area observed in the 2013 and 2014 field season WYBLM data for whitebark pine (WBP) and for all species combined (all), considering either all transects combined (rapid + permanent) or rapid alone. An "X" indicates that there were no map units within that area within the given combination of species and transect type.

		Area							
Species	**Transect Type**	**Brent**	**CFC**	**CR**	**PGDR**	**Rattle**	**Scab**	**SRHC**	**TVRC**
WBP	rapid + permanent	4/10	X	3/3	4/6	1/10	1/4	X	2/2
WBP	rapid	4/10	X	3/3	4/6	X	1/4	X	2/2
all	rapid + permanent	10/10	1/1	3/3	6/6	10/10	2/4	3/3	2/2
all	rapid	10/10	X	3/3	6/6	10/10	2/4	3/3	2/2

In Figures 2-14 to 2-17 we plot the standard errors for the estimated proportion of trees with blister rust for different assumed effort levels (total number of transects surveyed) using two methods of allocating transects to map units:

1. Equal allocation, where each map unit had the same number of transects
2. Proportional allocation, where the proportion of the total number of transects m allocated to a map unit is determined by the estimated number of total trees within a map unit relative to the total estimated number of live trees within an area, as follows

$$\left(\frac{M_i \bar{x}_i}{\sum_{i \in h} M_i \bar{x}_i}\right) m$$

where $M_i \bar{x}_i$ is the estimated total living trees in map unit i and $\sum_{i \in h} M_i \bar{x}_i$ is the estimated total living trees within area h, and *m* is the total number of transects to apportion within area h.

For proportional allocation, each map unit was allocated a minimum of two transects. For the purposes of these calculations, the total number of transects surveyed was allowed to vary. We assumed that the estimated within-map-unit sample variance, average number of living trees, and average number of infected trees for a map unit using the 2013 and 2014 data were reasonable and would not vary with an increase in sampling effort. Also, we estimate the total living trees within each map unit ($M_i \bar{x}_i$) based on the original area, not the adjusted area.

Figures 2-14 to 2-17 display estimates of the standard errors when increasing the total number of transects. Estimates of standard errors for proportional allocation are nearly always less than those for equal allocation (red lines lower than blue lines). Also, the combined ratio estimator is more efficient compared to the separate ratio estimator, in that it achieves lower estimated standard errors for the same number of transects (circles lower than triangles).

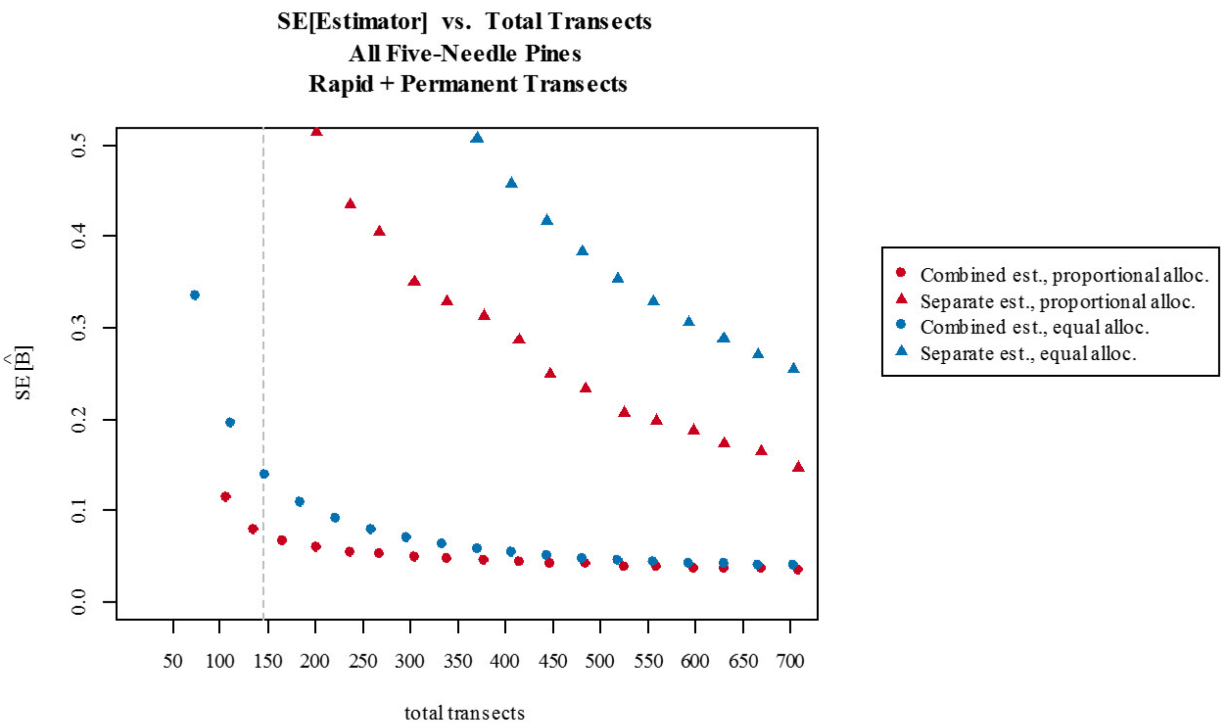

Figure 2-14. Estimated standard errors for blister rust status estimates using the combined and separate estimators for all five-needle pines across transect types. Proportional allocation gave map units with greater estimated totals of living trees a greater proportion of the total transects, whereas equal allocation gave each map unit the same number of transects. Subsampling sizes (the total number of transects) were allowed to vary, and all other quantities were considered fixed. For each of the eight WYBLM areas, data were observed in each map unit and thus were censused, implying that there was no among-PSU variance, only within-PSU variance (see Table 2-6 for counts of map units within areas). The actual number of transects completed in this study is depicted with a gray vertical line (145 for this subset of the data).

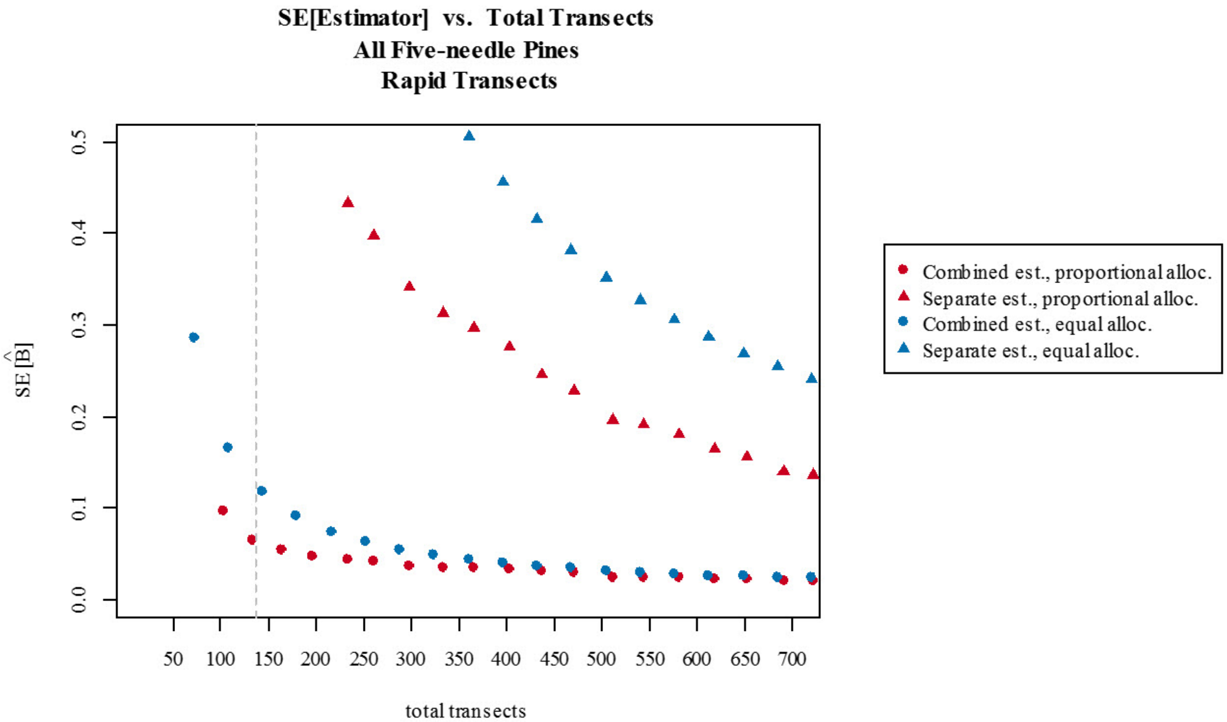

Figure 2-15. Estimated standard errors for blister rust status estimates using the combined and separate estimators for all five-needle pines across transect types. Proportional allocation gave map units with greater estimated totals of living trees a greater proportion of the total transects, whereas equal allocation gave each map unit the same number of transects. Subsampling sizes (the total number of transects) were allowed to vary, and all other quantities were considered fixed. Data were observed in nearly all map units of all areas, and thus were censused, implying that there was no among-PSU variance, only within-PSU variance (see Table 2-6 for counts of map units within areas). The actual number of transects completed in this study is depicted with a gray vertical line (137 for this subset of the data).

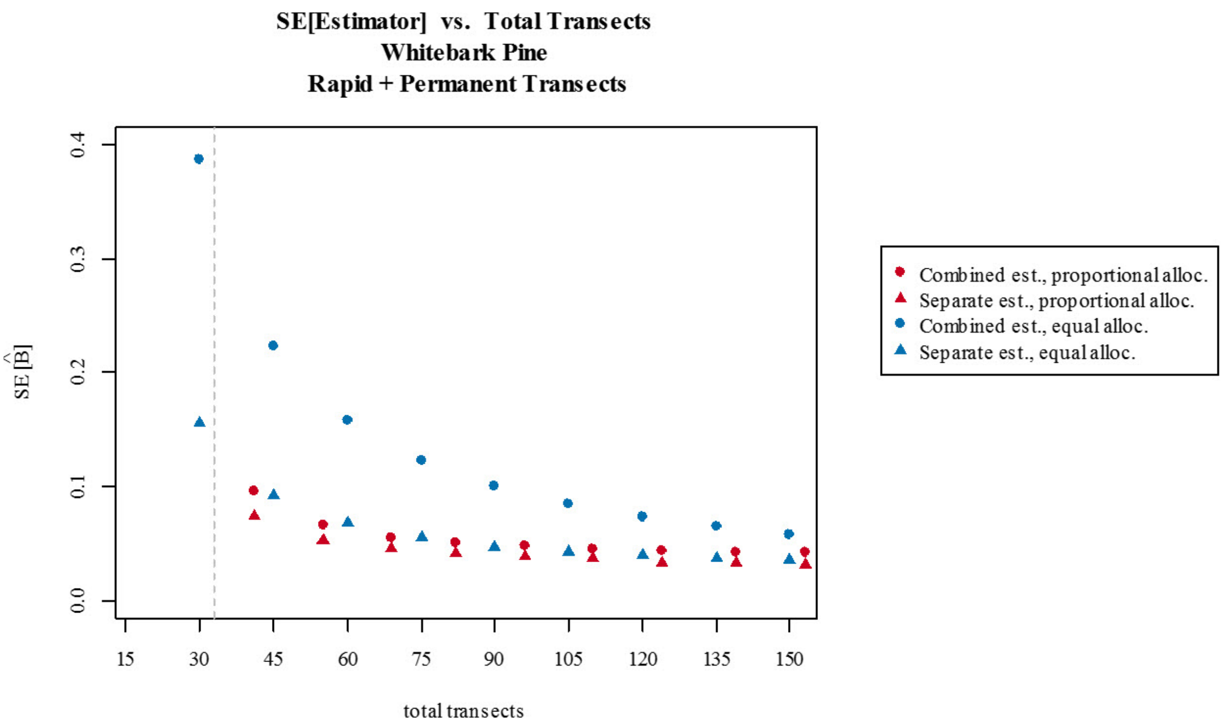

Figure 2-16. Estimated standard errors for blister rust status estimates using the combined and separate estimators for whitebark pine across transect types. Proportional allocation gave map units with greater estimated totals of living trees a greater proportion of the total transects, whereas equal allocation gave each map unit the same number of transects. Subsampling sizes (the total number of transects) were allowed to vary, and all other quantities were considered fixed. For two areas, data were observed in all map units and were censused, implying that there was no among-PSU variance, only within-PSU variance (see Table 2-6 for counts of map units within areas). The actual number of transects completed in this study is depicted with a gray vertical line (33 for this subset of the data).

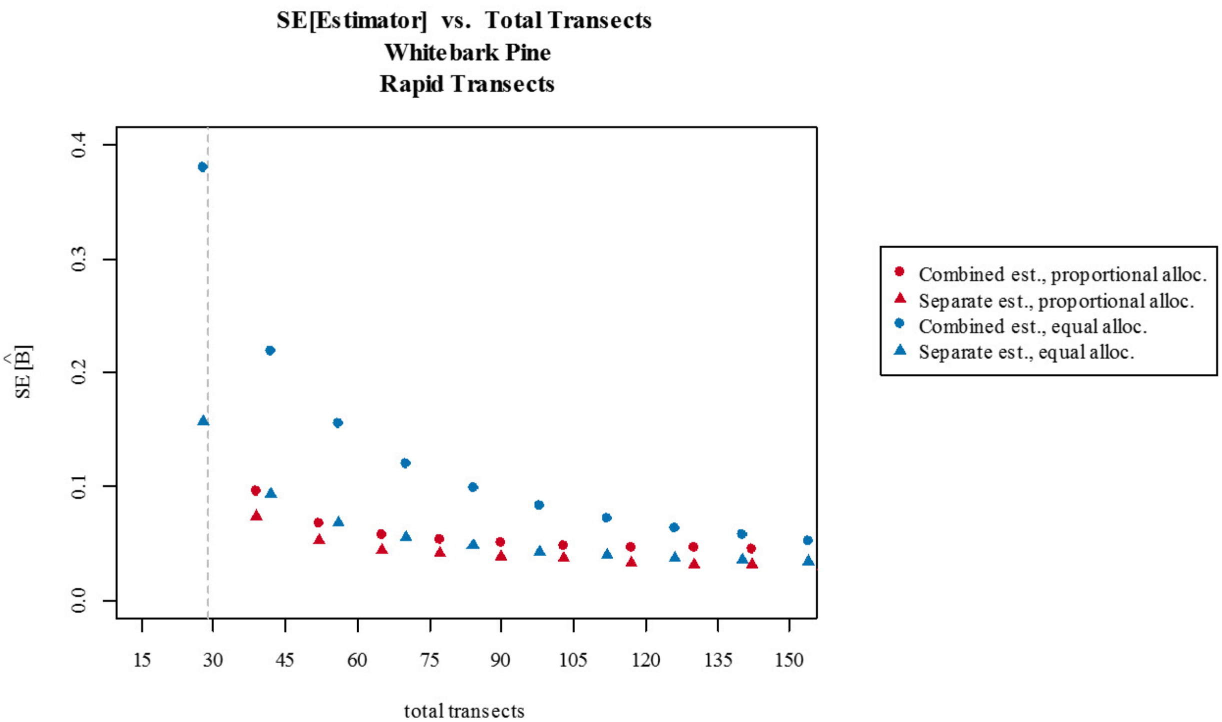

Figure 2-17. Estimated standard errors for blister rust status estimates using the combined and separate estimators for whitebark pine across transect types. Proportional allocation gave map units with greater estimated totals of living trees a greater proportion of the total transects, whereas equal allocation gave each map unit the same number of transects. Subsampling sizes (the total number of transects) were allowed to vary, and all other quantities were considered fixed. For two areas, data were observed in all map units and were censused, implying that there was no among-PSU variance, only within-PSU variance (see Table 2-6 for counts of map units within areas). The actual number of transects completed in this study is depicted with a gray vertical line (29 for this subset of the data).

To employ this more efficient allocation of transects according to a map unit's estimated number of living trees, we include examples of how transects could be allocated to map units (Table 2-7). Allocations are identical to those producing standard error estimates in Figures 2-14 to 2-17. Table 2-7 presents three scenarios for total number of transects for WBP ranging between 41 and 69, while the actual number of transect with identified WBP was 33. These numbers were chosen as a realistic total effort similar to that invested during 2013 and 2014. Similarly, for all five-needle pine, the illustrated allocation was between 136 and 202 total transects, while 145 were actually completed during 2013 and 2014 (Table 2-7).

Table 2-7. Example allocations of transects to map units proportional to the total number of living trees based on 2013–2014 surveys. Total number of transects allocated is indicated as “m=x” as indicated in the label. For estimated total living trees in each map unit, see Table 2-5.

	WBP, All Transects				WBP + LP + UNK, All Transects			
Map Unit	Actual m=33	m=41	m=55	m=69	Actual m=145	m=136	m=166	m=202
Brent1	–	–	–	–	4	2	2	3
Brent2	1	2	3	4	4	2	3	4
Brent3	–	–	–	–	4	2	2	2
Brent4	1	3	4	5	4	2	2	2
Brent5	–	–	–	–	3	2	2	2
Brent6	–	–	–	–	4	3	4	5
Brent7	4	3	4	5	5	14	19	24
Brent8	–	–	–	–	3	2	2	3
Brent9	–	–	–	–	3	2	2	2
Brent10	1	2	2	2	4	4	5	6
CFC	–	–	–	–	1	3	4	5
CR1	3	5	8	11	5	7	10	12
CR2	5	2	2	2	5	2	2	2
CR3	3	2	2	2	5	2	2	2
PGDR1	2	2	2	2	3	2	2	2
PGDR2	4	2	2	2	5	2	2	2
PGDR3	2	7	11	15	3	9	12	15
PGDR4	–	–	–	–	3	2	2	2
PGDR5	–	–	–	–	3	8	10	13
PGDR6	2	2	2	2	3	2	2	2
Rattle1	1	2	3	4	4	2	2	2
Rattle2	–	–	–	–	3	2	2	2
Rattle3	–	–	–	–	4	11	14	18
Rattle4	–	–	–	–	4	2	2	2
Rattle5	–	–	–	–	5	2	2	2
Rattle6	–	–	–	–	5	5	6	8
Rattle7	–	–	–	–	4	3	4	5

Table 2-7 (continued). Example allocations of transects to map units proportional to the total number of living trees based on 2013–2014 surveys. Total number of transects allocated is indicated as “m=x” as indicated in the label. For estimated total living trees in each map unit, see Table 2-5.

	WBP, All Transects				WBP + LP + UNK, All Transects			
Map Unit	**Actual m=33**	**m=41**	**m=55**	**m=69**	**Actual m=145**	**m=136**	**m=166**	**m=202**
Rattle8	–	–	–	–	5	2	2	2
Rattle9	–	–	–	–	3	7	9	11
Rattle10	–	–	–	–	5	2	2	2
Scab1	–	–	–	–	4	6	8	10
Scab3	1	2	3	4	5	2	2	2
SRHC1	–	–	–	–	5	2	2	2
SRHC2	–	–	–	–	2	6	8	11
SRHC3	–	–	–	–	4	2	2	3
TVRC1	2	2	2	2	5	2	3	3
TVRC2	1	3	5	7	4	4	5	7
TOTAL	33	41	55	69	145	136	166	202

Discussion of Results

Below we list the four most important findings from this analysis, in no particular order, to be considered moving forward.

First, the secondary variance component (*i.e.*, the variance among transects within a map unit) is substantial, and to ignore it implies that we have greater certainty than we actually possess about estimates for the proportion of trees infected with BR. Because we can estimate the secondary variance component using the rapid assessment transect data, we can examine the previous assumption that replication within a stand contributes little to the variance estimate for the proportion of WBP infected with BR. This analysis reveals that incorporating the secondary variance component is essential on WYBLM areas within the GYE. Again, the observed wide confidence intervals are due to the contribution from this secondary variance component (see plots of confidence intervals in Figures 2-11 through 2-13 for increased variability when including the secondary variance component). If we omit this piece from variance estimates for the design-based estimators, we are assuming that stands are homogeneous, when this dataset suggests they are not. We have also found that this secondary variance component could be driven down most efficiently by allocating more subsamples (*i.e.*, transects) to the map units with greater numbers of living trees (Figures 2-14 to 2-17 and Table 2-7). We recommend that these results should be considered in the context of the previously established GYE monitoring of WBP effort as well.

Second, if only the established permanent transects are monitored, WYBLM will be unable to detect any biologically meaningful change in BR prevalence. This observation is based on the width of confidence intervals for both WBP data alone as well as all five-needle pine data combined. Confidence intervals for all five-needle pine data, as well as WBP and LP alone spanned the entire range from 0 to 1, when considering only the permanent transect data. Although point estimates from permanent transects were similar to those from rapid transects (compare 0.260 to 0.281 for the estimated proportion of WBP infected with BR, using the HT estimator in Table 2E-1 and the combined ratio estimator in Table 2E-4), the standard errors are much greater. We cannot make any informative statements about the estimated proportion with permanent transects alone. Therefore, for these range margin areas on WYBLM land, we suggest to meet WYBLM measurable objectives that rapid assessment transects should be used for monitoring prevalence of BR within all five-needle pine and confirmed WBP.

Third, we are likely under-estimating the standard errors for the estimated proportion of WBP and LP with BR because of the low numbers of confirmed WBP and LP trees. The lack of replication of map units within an area means that the area-specific variance is inestimable (*e.g.,* Rattle and Scab for the WBP data and CFC and PGDR for the LP data, specifically the terms s_{xh}^2 in the combined ratio estimators). We have made the enormous assumption here that areas with only one map unit per area have no variability at this level, and contribute nothing to the primary variance component. Intuitively, a lack of replication does not indicate that there is no variability. Thus, all the reported confidence intervals for WBP and LP are likely too narrow. For all of the five-needle pine data combined, however, we do not run into this issue, because of ample replication. One possible solution to this issue is the eventual positive species identification of the many unknown five-needle pine. For example, among permanent and rapid transects, only 108 WBP and only 266 LP were confirmed, but there were 2,778 five-needle pine of unknown species. Some of the observed statistical challenges due to the observed data would be resolved by correct species classification for these trees. The lack of replication is simply due to the spatial distribution of five-needle pine in these range-margin areas and inherent challenges of distinguishing WBP from LP in mixed stands. Since one of the WYBLM specific objectives is to examine *all* five-needle pine, monitoring these unknown species is not unproductive.

And fourth, the number of GRTS points that were evaluated and deemed not suitable for surveying should be considered. In all mapping efforts, there will inevitably be some misalignment in assigning the boundaries for a given species of interest. Accurate specification of map unit area is important to correctly estimate the total number of living trees and the total number of BR-infected trees within a map unit, since these are directly based on those area measurements. Under ideal situations, every five-needle pine within stands of at least 2.5 ha in size would have a non-zero chance of being selected and would be accessible. There is a potential for bias whenever part of the target population is excluded from the sampling frame or whenever inaccessible map units or specific points within them have different characteristics from those that were surveyed.

There are several ways to adjust for these mapping errors, and here we make the adjustment statistically. Our method of reducing the map unit area relies on the assumption that the points

surveyed are representative of the whole map unit. This may not be justified, however, since about three-quarters of all map units had five or fewer points surveyed. To compound the issue, some map units are very large, for example, PGDR3 is 231 ha and Scab1 is 1,670 ha (see Appendix 2D). Both of these map units had GRTS points without any five-needle pine, and thus we estimate that the total area of five-needle pine is substantially less than originally portrayed (Appendix 2D). This may be a large leap. The adjusted areas for three map units (Brent3, Brent 5 and Brent9) were less than the minimum requirement of 2.5 ha, though their initial delineations did meet this requirement. Also, for this analysis we assume that inaccessible points would have had five-needle pine had they been surveyed. This decision was made based on the opinion of the lead field surveyor (E. Shanahan, pers. comm. with K. M. Irvine and S. Wilmoth, March 20, 2015). We suggest reevaluating the delineated map unit boundaries (sampling frame) on WYBLM lands adjacent to the GYE.

Long-term monitoring of all five-needle pine for BR on WYBLM lands

The first objective for WYBLM monitoring is to estimate the proportion of all five-needle pines infected with BR every four years (B. Means, personal communication with PIs via teleconference, May 7, 2014). This goal may be best achieved with the following initial suggestions:

Firstly, we suggest reevaluating the boundaries of map units to inform potential mapping errors that can induce statistical bias in the estimates of BR prevalence.

Secondly, continuing to survey the rapid assessment transects in addition to the permanent transects is important because using only the permanent transects for estimating the proportion of all five-needle pines with BR resulted in confidence intervals spanning the entire interval between 0 and 1 (Figure 2-14). Rapid assessment transects are crucial to estimating the proportion of all five-needle pines with BR since 2 or more transects are needed per map unit in order to calculate the secondary variance component.

Thirdly, WYBLM will get the most bang-for-its-buck by completing more transects in map units with more live trees. We outlined in Table 2-7 what this could look like, but Table 2-5 also lists the estimated total live trees per map unit, which could guide effort. For example, it would be better to put more effort into larger map units that were densely populated with trees than to put the same effort into each map unit (see Figure 2-14, red lines lower than blue lines). Ideally, repeating all surveys in four-year increments, and surveying additional rapid transects in those map units with the highest densities of live trees (Table 2-5 and Table 2-7) would improve statistical inferences.

Lastly, we found that the combined ratio estimator that includes the secondary variance component for a stratified, two-stage cluster design is preferred to estimate the proportion of all five-needle pine infected with BR.

Long-term monitoring of whitebark pine for BR on WYBLM lands

The second objective for WYBLM monitoring is to estimate the proportion of whitebark pine infected with BR every four years (B. Means, personal communication with PIs via teleconference, May 7, 2014). This goal may be best achieved with the following initial suggestions:

First, we again suggest a concerted effort to precisely specify map unit boundaries and correct the sampling frame to the extent possible.

Secondly, an effort to accurately identify the species of all unknown five-needle pine will hopefully rectify the issue with inestimable variances for some WYBLM areas.

Thirdly, continuing to survey the rapid assessment transects in addition to the permanent transects (as stated above) should improve estimates for the prevalence of BR in live WBP on WYBLM lands within the GYE.

Fourthly, WYBLM survey efforts will again be most efficient when more transects are completed in map units with more live trees (Table 2-5 and Table 2-7, as stated above).

Lastly, the combined ratio estimator that includes the secondary variance component for a stratified, two-stage cluster design to calculate the proportion of live whitebark pine infected with BR on WYBLM lands within the GYE is preferred based on these analyses.

Incorporating WYBLM findings into the GYE estimate for BR

The interagency effort provides an estimate of the proportion of WBP with evidence of BR infection. Strictly following the interagency protocol would suggest only data collected on WBP "qualify." The reality is that within these mixed species stands many tagged trees were listed as unknown for their species identification. In 2013 and 2014, only 12 confirmed whitebark were surveyed within the permanent transects as well as 114 unknown species on WYBLM lands (Table 2-2). In terms of the ratio estimator for a GYE-wide estimate, these 12 trees would be considered representative of all WYBLM mapped areas. Further, we should consider the possible adjustments to the mapped areas when constructing the weights for WYBLM sampled transects relative to other administrative areas (see *Sampling Frame Errors* Section).

To align the temporal revisit design of WYBLM efforts to that currently used in the GYE (Table 2-8), we suggest randomly assigning 8 permanent transects to one of four panels, such that two are visited every year and all eight are visited in the four-year period from 2016 – 2019. This will also have the benefit of minimizing any geographically confounding variables. This allows for the WYBLM data from permanent transects to be incorporated into any model-based investigations, such as examining the severity of BR infection; examining the effects of BR, MPB and fire on WBP mortality; and assessing WBP recruitment in the understory (Shanahan et al. 2014). Caution is needed because currently there are only 12 identified WBP trees on permanent transects; however, there are 114 unknown five-needle pine trees on permanent transects (Table 2-2).

Table 2-8. Temporal revisit design for whitebark pine surveys within the Greater Yellowstone Ecosystem at 150 randomly selected stands (176 plots) randomly assigned to panels (~ 44 per panel). An “X” denotes full survey visit for MPB and BR indicators in live trees and MPB in dead trees. An “O” denotes partial surveys for MPB in live and dead trees. Revisit time number is noted by the letter “T”.

	Year							
Panel	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
1	X	–	O	–	X	–	–	–
2	–	X	–	O	–	X	–	–
3	O	–	X	–	O	–	X	–
4	–	O	–	X	–	X	–	X
Revisit	**T1**	**T1**	**T1**	**T1**	**T2**	**T2**	**T2**	**T2**

Rapid transects, however, could be re-visited as they were in the pilot study. For example, CR, PGDR, Scab and SRHC were surveyed in 2013 and would be surveyed again in 2017, with at least 55 transects completed (the number completed in 2013). Similarly, Brent, CFC, Rattle and TVRC were surveyed in 2014 and would be slated for revisit in 2018, with at least 90 transects completed (the number completed in 2014). Alternatively, they could be randomly assigned to a panel; however, the number of years between revisiting would not be equal if this is done. For example, the lag between the first survey and the next revisit could vary between 2 to 6 years. Granted, once monitoring progresses these revisits will recur every four years, the issue of varying lags will only occur between the first and second surveys. The assumption is BR infection within a tree is a very slow ecological process and re-surveying every four years is sufficient to detect any meaningful changes in BR infection, on average.

Additionally, there is potential to combine the WYBLM data from both rapid and permanent transects (confirmed WBP only) with the GYE-wide data to estimate the proportion of live WBP infected with BR across the GYE and on WYBLM lands adjacent to the GYE. In order to estimate this proportion, WYBLM must include both data from permanent and rapid transects. This is because of the lack of replication among map units within an area in the permanent transects. Also, WYBLM will run into the same problem of underestimating the total variance if only one map unit within an area has confirmed WBP trees. This will likely be corrected when trees now recorded as unknown five-needle pine are identified as LP or WBP; however, since trees are not tagged on rapid transects this may always be an issue for a given survey year as cones and other characteristics for distinguishing between LP and WBP may be unavailable.

The WYBLM monitoring effort of WBP and all five-needle pine has provided a unique opportunity for managers to reconsider the survey design. We have shown that multiple transects within a map unit are an invaluable addition to the analysis. While the information gained from the rapid transects increases our confidence in understanding five-needle pine health, it is also a more expensive undertaking. We have also suggested options for WYBLM to monitor blister rust infection

prevalence in both WBP and all five-needle pine. The considerations we have outlined for proper inferences to the target population should be considered moving forward.

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Appendix 2A: Unequal Probability Ratio Estimator

To calculate the estimates for the proportion of trees with blister rust in permanent transects for the WYBLM data (specifically WYBLM data, not GYE data), the unequal probability ratio estimator was used (Thompson 2002, p. 76–79). Essentially, the numerator and denominator are Horvitz-Thompson estimators for the total number of infected trees and total number of trees, respectively. Since only one map unit was selected within each area, and only one transect completed within each map unit, there can be no estimate of the variability within a map unit. We assume that transects are representative of a PSU, similar to the current approach for the interagency monitoring effort.

Let h be the number of strata (areas) sampled. For these data, we have $h = 8$.

Let N be the total number of map units and N_h the number of map units within an area h. Thus, we have $N = \sum_{h=1}^{8} N_h$.

Let n be the total number of permanent transects, where $= \sum_{h=1}^{8} n_h$, and $n_h = 1 \; \forall \; h$.

To calculate the selection probabilities, we use equations for stratified simple random sampling, where $\pi_i = \frac{n_h}{N_h}$ for $i \in S_h$ is the probability of map unit i being selected in the sample.

The first-order inclusion probabilities (π_i) can be seen in Table 2A-1.

Table 2A-1. First-order inclusion probabilities of transects within areas.

Area	*h*	N_h	n_h	π_i
Brent	1	10	1	1/10
CFC	2	1	1	1/1
CR	3	3	1	1/3
PGDR	4	6	1	1/6
Rattle	5	10	1	1/10
Scab	6	4	1	1/4
SRHC	7	3	1	1/3
TVRC	8	2	1	1/2

Since the selection in one stratum is independent of all selections in any other stratum (area), we have the following second-order inclusion probabilities (π_{ij}):

$$\pi_{ij} = \frac{n_h}{N_h}\frac{n_{h'}}{N_{h'}} = \pi_i \pi_j \text{ if } i \in h \text{ } and \text{ } j \in h', h \neq h'$$

$$\pi_{ij} = \frac{n_h}{N_h}\frac{(n_h-1)}{(N_h-1)} \text{ if } i, j \in h \text{ .}$$

The estimated proportion of trees infected with blister rust within permanent transects (Thompson 2002, p. 76–79) is given by $\hat{\beta}$:

$$\hat{\beta} = \frac{\sum_{i=1}^{h}\left({(M_i y_i)}/{\pi_i}\right)}{\sum_{i=1}^{h}\left({(M_i x_i)}/{\pi_i}\right)}$$

where M_i is the total possible number of 10m×50m belt transects within map unit *i*, x_i is the number of living trees in the permanent transect in map unit *i*, y_i is the number of trees infected with blister rust in the permanent transect in map unit *i*, and π_i is the inclusion probability of map unit *i*.

Several map units had transects (random points) with no 5-needle pine. This is overcoverage, and considered a frame error. To account for this overcoverage frame error, we can adjust the total area of the map unit proportional to the number of target points as follows,

$$\widehat{Area} = Area \times \frac{n^{TS} + n^{IN}}{n^{TS} + n^{IN} + n^{NT}}$$

where n^{TS} is the number of points and their associated transects within a map unit that contained 5-needle pine and were surveyed (Target Sampled, TS); n^{IN} is the number of points and their

associated transects within a map unit that were inaccessible due to either logistics or snow (Inaccessible, IN); to be conservative, we assume that points that were inaccessible for logistic reasons *did* in fact contain 5-needle pines; and lastly, n^{NT} is the number of points and their associated transects within a map unit that did not contain any 5-needle pine (Not Target, NT) (Table 2A-2). The adjustment for the overcoverage frame error really comes into play in the number of possible transects within a map unit, or M_i.

Table 2A-2. Counts of GRTS point locations that were target and sampled (TS), inaccessible (IN), non-target (NT), or not needed and thus no visit was attempted (NN) within map units having a permanent transect. Adjusted area was computed as in equation above, where points that were IN (inaccessible) were considered members of the target population.

Map Unit	*h*	*TS*	*IN*	*NT*	*NN*	*Total Points*	*Area*	$\widehat{Area}$
Brent1	1	4	0	1	5	10	37,046	29,637
CFC	2	1	4	4	1	10	252,937	140,521
CR1	3	5	0	0	5	10	803,146	803,146
PGDR1	4	3	0	0	7	10	81,392	81,392
Rattle1	5	4	0	0	6	10	55,713	55,713
Scab1	6	4	0	3	3	10	16,704,385	9,545,363
SRHC1	7	5	0	1	4	10	202,445	168,704
TVRC1	8	5	0	0	5	10	26,997	26,997

Adapting the variance for the unequal probability ratio estimator for the total (Horvitz-Thompson p. 78 Equation 10, Thompson 2002) to one for the proportion $\hat{\beta}$, we have an estimated variance of:

$$\widehat{Var}(\hat{\beta}) = \frac{1}{(\sum M_i \bar{x}_i)^2}\left[\sum_i \left(\frac{1-\pi_i}{{\pi_i}^2}\right){\hat{y}_i}^2 + \sum_i \sum_{j \neq i} \left(\frac{\pi_{ij} - \pi_i \pi_j}{\pi_i \pi_j}\right)\frac{\hat{y}_i \hat{y}_j}{\pi_{ij}}\right]$$

where $\hat{y}_i = M_i \bar{y}_i - \hat{\beta}(M_i \bar{x}_i)$. Notice that, as we do not have the *known* number of total trees in the population, we estimate that quantity by the term $\sum M_i \bar{x}_i$.

Appendix 2B: Separate, Combined and Unbiased Estimators

We used several estimators to calculate the proportion of live trees infected with BR – two are ratio-based estimators and one is an unbiased estimator. The ratio estimators are recommended when estimating a proportion or in the case of a two-stage cluster design with unequal cluster sizes (as we have here). The following formulas are based on Sharon Lohr's (2010) *Sampling: Design and Analysis* Textbook.

The separate ratio estimator assumes that primary sampling units (PSUs) were selected using a stratified design with 8 strata, where each area is a stratum (Brent, CFC, CR,PGDR, Rattle, Scab, SRHC, and TVRC), such that $H = 8$. The formulas are as follows,

$$\hat{B}_{sep} = \sum_{h=1}^{H} \frac{N_h}{N} \hat{B}_h$$

where

$$\hat{B}_h = \frac{\sum_i M_i \bar{y}_i}{\sum_i M_i \bar{x}_i},$$

for h = Brent, CFC, CR, PGDR, Rattle, Scab, SRHC, or TVRC.

$$\hat{V}(\hat{B}_h) = \left[\frac{1}{n(n-1)(\overline{M_i \bar{x}_i})^2} \sum (M_i \bar{y}_i - \hat{B} M_i \bar{x}_i)^2\right] + \frac{1}{nN(\overline{M_i \bar{x}_i})^2} \sum_{i \in S} (M_i \bar{x}_i)^2 (1 - \frac{m_i}{M_i}) \frac{s_i^2}{m_i}$$

where $s_i^2 = \frac{1}{m_i - 1} \sum_j (y_{ij} - \overline{y_i})^2$. This variance estimate includes the second stage variance component.\

Then, to combine the separate variance estimates, use

$$\hat{V}(\hat{B}_{sep}) = \sum_{h=1}^{H} \left(\frac{N_h}{N}\right)^2 \hat{V}(\hat{B}_h).$$

The combined ratio estimator also assumes that psus were selected using a stratified design with H strata. The formulas for the combined ratio estimator are as follows,

$$\hat{B}_{comb} = \frac{\hat{t}_{y,str}}{\hat{t}_{x,str}} = \frac{\sum_{h=1}^{H} \sum_{i \epsilon h} \frac{N_h}{n_h} M_i \bar{y}_i}{\sum_{h=1}^{H} \sum_{i \epsilon h} \frac{N_h}{n_h} M_i \bar{x}_i}$$

$$\hat{V}(\hat{B}_{comb}) = \left(\frac{1}{\hat{t}_{x,str}}\right)^2 \left[\hat{V}\left(\hat{t}_{y,str}\right) + \hat{B}^2 \hat{V}\left(\hat{t}_{x,str}\right) - 2\hat{B} C\hat{O}V\left(\hat{t}_{x,str}, \hat{t}_{y,str}\right)\right]$$

where

$$\hat{V}(\hat{t}_{x,str}) = \sum_{h=1}^{H} \left(1 - \frac{n_h}{N_h}\right) N_h^2 \frac{s_{xh}^2}{n_h}$$

$$\hat{V}(\hat{t}_{y,str}) = \sum_{h=1}^{H}\left(1-\frac{n_h}{N_h}\right)N_h^2\frac{s_{yh}^2}{n_h}$$

$$C\hat{O}V(\hat{t}_{x,str},\hat{t}_{y,str}) = \sum_{h=1}^{H}\left(1-\frac{n_h}{N_h}\right)N_h^2\frac{s_{xh}s_{yh}r_h}{n_h}$$

$$s_{xh}^2 = \sum_{i\epsilon h}\frac{(M_i\bar{x}_i-\bar{x}_h)^2}{n_h-1}$$

$$s_{yh}^2 = \sum_{i\epsilon h}\frac{(M_i\bar{y}_i-\bar{y}_h)^2}{n_h-1}$$

$$r_h = cor(M_i\bar{y}_i, M_i\bar{x}_i),$$

where $x\epsilon s_h$ and $y\epsilon s_h$.

To extend to include the second stage of sampling,

$$\hat{V}(\hat{t}_{x,str}) = \sum_{h=1}^{H}\left[\left(1-\frac{n_h}{N_h}\right)N_h^2\frac{s_{xh}^2}{n_h}+\frac{N_h}{n_h}\sum_{i\in S_h}\left(1-\frac{m_{ih}}{M_{ih}}\right)M_{ih}^2\frac{s_{x,ih}^2}{m_{ih}}\right]$$

$$\hat{V}(\hat{t}_{y,str}) = \sum_{h=1}^{H}\left[\left(1-\frac{n_h}{N_h}\right)N_h^2\frac{s_{yh}^2}{n_h}+\frac{N_h}{n_h}\sum_{i\in S_h}\left(1-\frac{m_{ih}}{M_{ih}}\right)M_{ih}^2\frac{s_{y,ih}^2}{m_{ih}}\right]$$

where $s_{x,ih}^2 = \frac{1}{m_i-1}\sum_j(x_{ij}-\overline{x_i})^2$ and $s_{y,ih}^2 = \frac{1}{m_i-1}\sum_j(y_{ij}-\overline{y_i})^2$.

$$C\hat{O}V(\hat{t}_{x,str},\hat{t}_{y,str}) = \sum_{h=1}^{H}\left(1-\frac{n_h}{N_h}\right)N_h^2\frac{s_{xh}s_{yh}r_h}{n_h}$$

The third estimator used is an unbiased estimator, not weighted by the size of the stand. So just using the proportion of infected trees on transect j in stand i as follows,

$$\hat{B}_{unbias} = \sum_{h=1}^{H} \frac{N_h}{N_{total}} p_h$$

where

$$p_h = \frac{\sum_{i \epsilon s_h} \overline{p}_i}{n_h},$$

$$\overline{p}_i = \sum_j \frac{y_{ij}}{x_{ij}} / n_i,$$

and

$$\hat{V}(\hat{B}_{unbiased}) = \sum_{h=1}^{H} \left(1 - \frac{n_h}{N_h}\right) \left(\frac{N_h}{N_{total}}\right)^2 \frac{S_{ih}^2}{n_h} + \sum_h \left(\frac{N_h}{N_{total}}\right)^2 \frac{1}{n_h N_h} \sum_{i \in h} \left(1 - \frac{m_i}{M_i}\right) M_i^2 \frac{s_i^2}{m_i}.$$

where $S_{ih}^2 = \frac{1}{n_h - 1} \sum_{i \in h} (\overline{p}_i - p_h)^2$ and $s_i^2 = \frac{1}{m_i - 1} \sum_j (p_{ij} - \overline{p}_i)^2$. The above variance estimate includes the second variance component.

Appendix 2C: Transect-level Data Summaries

Table 2C-1 shows the data summaries for transects within map units.

Table 2C-1. Data summaries for transects within map units, including survey year, associated map unit, transect ID number, survey type (rapid or permanent), numbers of each species of five-needle pine (whitebark pine, WBP; limber pine, LP; and unknown five-needle pine, UNK), counts of live trees, dead trees, total trees in a transect, as well as counts of trees with blister rust (BR) and mountain pine beetle (MPB) within a transect.

Year	Map Unit	Transect	Type	WB	LP	UNK	Live	Dead	Total	BR	MPB
2014	BLM-Brent1	41	permanent	0	0	11	11	0	11	1	0
2014	BLM-Brent1	42	rapid	0	0	3	3	0	3	0	0
2014	BLM-Brent1	44	rapid	0	0	8	8	0	8	3	0
2014	BLM-Brent1	45	rapid	0	0	17	17	0	17	5	0
2014	BLM-Brent2	71	rapid	0	0	4	4	0	4	3	0
2014	BLM-Brent2	72	rapid	0	3	3	6	0	6	2	0
2014	BLM-Brent2	73	rapid	0	1	0	1	0	1	1	0
2014	BLM-Brent2	74	rapid	2	1	21	23	1	24	14	0
2014	BLM-Brent3	63	rapid	0	0	6	6	0	6	5	0
2014	BLM-Brent3	64	rapid	0	0	3	3	0	3	2	2
2014	BLM-Brent3	69	rapid	0	0	3	3	0	3	1	0
2014	BLM-Brent3	70	rapid	0	0	2	2	0	2	0	0
2014	BLM-Brent4	81	rapid	0	0	1	1	0	1	1	0
2014	BLM-Brent4	82	rapid	0	0	3	3	0	3	2	0
2014	BLM-Brent4	83	rapid	2	0	4	6	0	6	1	0
2014	BLM-Brent4	84	rapid	0	0	5	5	0	5	2	0
2014	BLM-Brent5	52	rapid	0	0	1	1	0	1	0	0

Table 2C-1 (continued). Data summaries for transects within map units, including survey year, associated map unit, transect ID number, survey type (rapid or permanent), numbers of each species of five-needle pine (whitebark pine, WBP; limber pine, LP; and unknown five-needle pine, UNK), counts of live trees, dead trees, total trees in a transect, as well as counts of trees with blister rust (BR) and mountain pine beetle (MPB) within a transect.

Year	Map Unit	Transect	Type	WB	LP	UNK	Live	Dead	Total	BR	MPB
2014	BLM-Brent5	53	rapid	0	5	0	5	0	5	4	0
2014	BLM-Brent5	56	rapid	0	0	1	1	0	1	1	0
2014	BLM-Brent6	92	rapid	0	0	19	19	0	19	6	0
2014	BLM-Brent6	93	rapid	0	0	18	18	0	18	3	0
2014	BLM-Brent6	94	rapid	0	0	1	1	0	1	0	0
2014	BLM-Brent6	95	rapid	0	0	6	6	0	6	0	0
2014	BLM-Brent7	1	rapid	2	5	37	36	8	44	10	1
2014	BLM-Brent7	2	rapid	0	0	34	34	0	34	11	0
2014	BLM-Brent7	3	rapid	2	1	17	16	4	20	5	1
2014	BLM-Brent7	4	rapid	1	0	10	11	0	11	2	0
2014	BLM-Brent7	5	rapid	2	2	88	82	10	92	27	0
2014	BLM-Brent8	31	rapid	0	0	9	9	0	9	4	0
2014	BLM-Brent8	32	rapid	0	0	30	30	0	30	11	0
2014	BLM-Brent8	33	rapid	0	0	3	3	0	3	1	0
2014	BLM-Brent9	21	rapid	0	0	8	8	0	8	0	0
2014	BLM-Brent9	22	rapid	0	0	5	5	0	5	1	0
2014	BLM-Brent9	25	rapid	0	0	3	3	0	3	1	0
2014	BLM-Brent10	11	rapid	0	0	2	2	0	2	0	0
2014	BLM-Brent10	12	rapid	0	0	18	18	0	18	6	0

Table 2C-1 (continued). Data summaries for transects within map units, including survey year, associated map unit, transect ID number, survey type (rapid or permanent), numbers of each species of five-needle pine (whitebark pine, WBP; limber pine, LP; and unknown five-needle pine, UNK), counts of live trees, dead trees, total trees in a transect, as well as counts of trees with blister rust (BR) and mountain pine beetle (MPB) within a transect.

Year	Map Unit	Transect	Type	WB	LP	UNK	Live	Dead	Total	BR	MPB
2014	BLM-Brent10	13	rapid	0	0	9	9	0	9	5	0
2014	BLM-Brent10	14	rapid	1	2	53	54	2	56	19	0
2014	BLM-CFC	16	permanent	0	5	0	5	0	5	1	0
2013	BLM-CR1	251	permanent	8	0	4	12	0	12	2	0
2013	BLM-CR1	252	rapid	0	0	2	2	0	2	0	0
2013	BLM-CR1	253	rapid	0	0	6	6	0	6	2	0
2013	BLM-CR1	254	rapid	11	0	47	57	1	58	12	0
2013	BLM-CR1	255	rapid	2	0	12	14	0	14	3	0
2013	BLM-CR2	231	rapid	2	0	13	3	12	15	0	7
2013	BLM-CR2	232	rapid	2	0	9	11	0	11	3	0
2013	BLM-CR2	233	rapid	5	0	14	18	1	19	1	0
2013	BLM-CR2	234	rapid	5	0	31	36	0	36	5	0
2013	BLM-CR2	235	rapid	4	0	11	15	0	15	1	0
2013	BLM-CR3	221	rapid	2	0	13	11	4	15	0	2
2013	BLM-CR3	222	rapid	0	0	7	7	0	7	2	0
2013	BLM-CR3	223	rapid	5	0	45	29	21	50	1	17
2013	BLM-CR3	224	rapid	3	0	43	36	10	46	0	3
2013	BLM-CR3	225	rapid	0	0	13	13	0	13	0	0
2013	BLM-PGDR1	71	permanent	2	0	62	64	0	64	4	1

Table 2C-1 (continued). Data summaries for transects within map units, including survey year, associated map unit, transect ID number, survey type (rapid or permanent), numbers of each species of five-needle pine (whitebark pine, WBP; limber pine, LP; and unknown five-needle pine, UNK), counts of live trees, dead trees, total trees in a transect, as well as counts of trees with blister rust (BR) and mountain pine beetle (MPB) within a transect.

Year	Map Unit	Transect	Type	WB	LP	UNK	Live	Dead	Total	BR	MPB
2013	BLM-PGDR1	72	rapid	0	0	49	47	2	49	4	0
2013	BLM-PGDR1	73	rapid	1	0	33	18	16	34	2	13
2013	BLM-PGDR2	81	rapid	11	0	42	46	7	53	4	6
2013	BLM-PGDR2	82	rapid	4	0	73	65	12	77	25	10
2013	BLM-PGDR2	83	rapid	0	0	19	9	10	19	1	9
2013	BLM-PGDR2	84	rapid	2	0	30	28	4	32	10	2
2013	BLM-PGDR2	85	rapid	4	0	35	39	0	39	3	0
2013	BLM-PGDR3	51	rapid	7	0	32	35	4	39	3	3
2013	BLM-PGDR3	52	rapid	3	0	82	70	15	85	2	7
2013	BLM-PGDR3	54	rapid	0	0	25	25	0	25	0	0
2013	BLM-PGDR4	101	rapid	0	0	3	3	0	3	1	0
2013	BLM-PGDR4	102	rapid	0	0	47	47	0	47	17	0
2013	BLM-PGDR4	103	rapid	0	0	27	27	0	27	3	0
2013	BLM-PGDR5	111	rapid	0	0	70	66	4	70	5	1
2013	BLM-PGDR5	112	rapid	0	9	0	9	0	9	0	0
2013	BLM-PGDR5	113	rapid	0	0	36	36	0	36	1	0
2013	BLM-PGDR6	61	rapid	3	0	105	77	31	108	17	28
2013	BLM-PGDR6	62	rapid	1	0	40	15	26	41	1	17
2013	BLM-PGDR6	63	rapid	0	0	44	29	15	44	1	8

Table 2C-1 (continued). Data summaries for transects within map units, including survey year, associated map unit, transect ID number, survey type (rapid or permanent), numbers of each species of five-needle pine (whitebark pine, WBP; limber pine, LP; and unknown five-needle pine, UNK), counts of live trees, dead trees, total trees in a transect, as well as counts of trees with blister rust (BR) and mountain pine beetle (MPB) within a transect.

Year	Map Unit	Transect	Type	WB	LP	UNK	Live	Dead	Total	BR	MPB
2014	BLM-Rattle1	171	permanent	1	6	12	19	0	19	15	0
2014	BLM-Rattle1	172	rapid	0	3	25	15	13	28	5	0
2014	BLM-Rattle1	173	rapid	0	0	26	3	23	26	0	0
2014	BLM-Rattle1	174	rapid	0	5	12	10	7	17	7	0
2014	BLM-Rattle2	151	rapid	0	0	5	1	4	5	0	0
2014	BLM-Rattle2	153	rapid	0	2	3	5	0	5	4	0
2014	BLM-Rattle2	155	rapid	0	0	4	4	0	4	0	0
2014	BLM-Rattle3	211	rapid	0	33	41	62	12	74	8	1
2014	BLM-Rattle3	213	rapid	0	7	13	10	10	20	1	0
2014	BLM-Rattle3	214	rapid	0	7	55	36	26	62	2	2
2014	BLM-Rattle3	215	rapid	0	4	18	10	12	22	1	0
2014	BLM-Rattle4	181	rapid	0	2	1	3	0	3	1	0
2014	BLM-Rattle4	182	rapid	0	8	15	18	5	23	7	0
2014	BLM-Rattle4	183	rapid	0	2	1	2	1	3	0	0
2014	BLM-Rattle4	186	rapid	0	1	1	2	0	2	1	0
2014	BLM-Rattle5	201	rapid	0	12	24	26	10	36	10	0
2014	BLM-Rattle5	202	rapid	0	11	29	16	24	40	8	0
2014	BLM-Rattle5	203	rapid	0	3	17	6	14	20	4	0
2014	BLM-Rattle5	204	rapid	0	3	5	6	2	8	3	0

Table 2C-1 (continued). Data summaries for transects within map units, including survey year, associated map unit, transect ID number, survey type (rapid or permanent), numbers of each species of five-needle pine (whitebark pine, WBP; limber pine, LP; and unknown five-needle pine, UNK), counts of live trees, dead trees, total trees in a transect, as well as counts of trees with blister rust (BR) and mountain pine beetle (MPB) within a transect.

Year	Map Unit	Transect	Type	WB	LP	UNK	Live	Dead	Total	BR	MPB
2014	BLM-Rattle5	205	rapid	0	5	6	7	4	11	5	2
2014	BLM-Rattle6	161	rapid	0	1	7	1	7	8	1	0
2014	BLM-Rattle6	162	rapid	0	3	38	18	23	41	4	0
2014	BLM-Rattle6	163	rapid	0	0	14	2	12	14	1	0
2014	BLM-Rattle6	164	rapid	0	9	34	40	3	43	20	0
2014	BLM-Rattle6	165	rapid	0	11	58	43	26	69	18	1
2014	BLM-Rattle7	191	rapid	0	5	20	20	5	25	6	0
2014	BLM-Rattle7	192	rapid	0	2	10	7	5	12	1	0
2014	BLM-Rattle7	193	rapid	0	6	20	12	14	26	2	0
2014	BLM-Rattle7	194	rapid	0	3	20	5	18	23	2	0
2014	BLM-Rattle8	141	rapid	0	4	27	22	9	31	13	0
2014	BLM-Rattle8	142	rapid	0	0	26	10	16	26	5	0
2014	BLM-Rattle8	143	rapid	0	1	25	7	19	26	4	0
2014	BLM-Rattle8	144	rapid	0	3	53	20	36	56	13	0
2014	BLM-Rattle8	145	rapid	0	1	6	1	6	7	0	0
2014	BLM-Rattle9	121	rapid	0	1	31	15	17	32	8	0
2014	BLM-Rattle9	122	rapid	0	10	52	32	30	62	22	0
2014	BLM-Rattle9	123	rapid	0	5	50	35	20	55	18	0
2014	BLM-Rattle10	132	rapid	0	3	48	20	31	51	15	0

Table 2C-1 (continued). Data summaries for transects within map units, including survey year, associated map unit, transect ID number, survey type (rapid or permanent), numbers of each species of five-needle pine (whitebark pine, WBP; limber pine, LP; and unknown five-needle pine, UNK), counts of live trees, dead trees, total trees in a transect, as well as counts of trees with blister rust (BR) and mountain pine beetle (MPB) within a transect.

Year	Map Unit	Transect	Type	WB	LP	UNK	Live	Dead	Total	BR	MPB
2014	BLM-Rattle10	133	rapid	0	0	47	9	38	47	3	0
2014	BLM-Rattle10	134	rapid	0	0	3	2	1	3	0	0
2014	BLM-Rattle10	135	rapid	0	3	37	16	24	40	12	0
2014	BLM-Rattle10	136	rapid	0	0	39	21	18	39	12	2
2013	BLM-Scab1	183	permanent	0	4	0	4	0	4	2	0
2013	BLM-Scab1	185	rapid	0	0	1	1	0	1	0	0
2013	BLM-Scab1	186	rapid	0	1	0	1	0	1	1	0
2013	BLM-Scab1	187	rapid	0	3	0	2	1	3	0	1
2013	BLM-Scab3	171	rapid	0	0	4	0	4	4	0	4
2013	BLM-Scab3	172	rapid	0	1	3	3	1	4	1	0
2013	BLM-Scab3	173	rapid	0	1	0	1	0	1	0	0
2013	BLM-Scab3	175	rapid	0	1	0	1	0	1	0	0
2013	BLM-Scab3	178	rapid	1	0	0	1	0	1	1	0
2013	BLM-SRHC1	262	permanent	0	4	0	4	0	4	0	0
2013	BLM-SRHC1	263	rapid	0	2	0	2	0	2	0	0
2013	BLM-SRHC1	264	rapid	0	4	0	3	1	4	0	0
2013	BLM-SRHC1	265	rapid	0	1	0	1	0	1	0	0
2013	BLM-SRHC1	266	rapid	0	1	0	1	0	1	0	0
2013	BLM-SRHC2	283	rapid	0	2	0	2	0	2	0	0

Table 2C-1 (continued). Data summaries for transects within map units, including survey year, associated map unit, transect ID number, survey type (rapid or permanent), numbers of each species of five-needle pine (whitebark pine, WBP; limber pine, LP; and unknown five-needle pine, UNK), counts of live trees, dead trees, total trees in a transect, as well as counts of trees with blister rust (BR) and mountain pine beetle (MPB) within a transect.

Year	Map Unit	Transect	Type	WB	LP	UNK	Live	Dead	Total	BR	MPB
2013	BLM-SRHC2	284	rapid	0	5	0	5	0	5	0	0
2013	BLM-SRHC3	272	rapid	0	3	0	3	0	3	0	0
2013	BLM-SRHC3	274	rapid	0	6	0	5	1	6	1	0
2013	BLM-SRHC3	277	rapid	0	2	0	2	0	2	0	0
2013	BLM-SRHC3	280	rapid	0	2	0	2	0	2	0	0
2014	BLM-TVRC1	101	permanent	1	1	25	27	0	27	3	0
2014	BLM-TVRC1	102	rapid	1	0	16	16	1	17	5	0
2014	BLM-TVRC1	103	rapid	0	0	14	14	0	14	1	0
2014	BLM-TVRC1	104	rapid	0	1	23	24	0	24	2	2
2014	BLM-TVRC1	105	rapid	0	0	15	14	1	15	0	0
2014	BLM-TVRC2	112	rapid	5	1	28	33	1	34	10	0
2014	BLM-TVRC2	113	rapid	0	0	18	18	0	18	0	0
2014	BLM-TVRC2	114	rapid	0	1	54	52	3	55	6	0
2014	BLM-TVRC2	115	rapid	0	0	9	9	0	9	2	0

Appendix 2D: Site Evaluation Status and Area Adjustments by Map Unit

Table 2D-1 shows the counts of GRTS point locations used.

Table 2D-1. Counts of GRTS point locations that were target and sampled (TS), inaccessible (IN), non-target (NT), or not needed and thus no visit was attempted (NN) within each map unit surveyed. Adjusted area was computed as in Appendix 2A, where points that were IN (inaccessible) were considered target. Area is in meters squared. Note that adjusted area for the following map units is < 2.5 ha (*i.e.*, 25,000 m^2), the minimum requirement for inclusion in GYE protocol: Brent3, Brent5 and Brent9.

Map Unit	NT	IN	TS	NN	Total	Area	$\widehat{Area}$
Brent1	1	0	4	5	10	37,046	29,637
Brent2	0	0	4	6	10	62,770	62,770
Brent3	6	0	4	0	10	42,547	17,019
Brent4	0	0	4	6	10	78,926	78,926
Brent5	3	0	3	4	10	39,912	19,956
Brent6	1	0	4	5	10	64,614	51,691
Brent7	0	0	5	5	10	92,067	92,067
Brent8	0	0	3	7	10	30,192	30,192
Brent9	2	0	3	5	10	28,292	16,975
Brent10	0	0	4	6	10	41,915	41,915
CFC	4	4	1	1	10	252,937	140,521
CR1	0	0	5	5	10	803,146	803,146
CR2	0	0	5	5	10	98,456	98,456
CR3	0	0	5	5	10	113,021	113,021
PGDR1	0	0	3	7	10	81,392	81,392
PGDR2	0	0	5	5	10	92,962	92,962
PGDR3	1	0	3	6	10	2,306,630	1,729,973
PGDR4	0	0	3	7	10	80,935	80,935
PGDR5	0	0	3	7	10	2,417,223	2,417,223
PGDR6	0	0	3	7	10	189,144	189,144
Rattle1	0	0	4	6	10	55,713	55,713
Rattle2	2	0	3	5	10	155,361	93,217
Rattle3	1	0	4	5	10	342,160	273,728
Rattle4	2	0	4	4	10	144,543	96,362
Rattle5	0	0	5	5	10	34,991	34,991

Table 2D-1 (continued). Counts of GRTS point locations that were target and sampled (TS), inaccessible (IN), non-target (NT), or not needed and thus no visit was attempted (NN) within each map unit surveyed. Adjusted area was computed as in Appendix 2A, where points that were IN (inaccessible) were considered target. Area is in meters squared. Note that adjusted area for the following map units is < 2.5 ha (*i.e.*, 25,000 m^2), the minimum requirement for inclusion in GYE protocol: Brent3, Brent5 and Brent9.

Map Unit	NT	IN	TS	NN	Total	Area	$\widehat{Area}$
Rattle6	0	0	5	5	10	209,801	209,801
Rattle7	0	0	4	6	10	269,314	269,314
Rattle8	0	0	5	5	10	115,344	115,344
Rattle9	0	0	3	7	10	224,047	224,047
Rattle10	1	0	5	4	10	40,318	33,598
Scab1	3	0	4	3	10	16,704,385	9,545,363
Scab3	3	0	5	2	10	82,285	51,428
SRHC1	1	0	5	4	10	202,445	168,704
SRHC2	8	0	2	0	10	1,050,419	210,084
SRHC3	5	1	4	0	10	359,627	179,814
TVRC1	0	0	5	5	10	26,997	26,997
TVRC2	1	0	4	5	10	34,715	27,772

Appendix 2E: Tables of Estimates for Proportion of Trees with Evidence of Blister Rust

The following tables provide the point estimates for the proportion of trees with blister rust and their associated 95% confidence intervals for various subsets of the 2013 WYBLM data. We used three different estimators for the proportion of infected trees: combined ratio estimator, separate ratio estimator, and unbiased estimator. Below are estimates for the proportion of trees infected with blister rust including the secondary variance component but setting it to zero for map units with only one transect. The estimated proportions of infected trees are alarming (Tables 2E-1 to 2E-14). Large standard errors cause confidence intervals to extend beyond of the logical boundaries for a proportion, i.e., 0 and 1.

Table 2E-1. Unadjusted, design-based Horvitz-Thompson unequal probability ratio estimates for the proportion of trees with blister rust for 2013 and 2014 WYBLM five-needle pine data. Each row corresponds to a specific subset of the permanent data as indicated by species. Estimate accounts for unequal probability selection of map units within areas. Estimator provided in Appendix 2A.

Transect Type	Species	n_i (map units)	BR proportion	SE	95% CI
Permanent	WBP	4	0.260	0.626	[0, 1]
Permanent	LP	5	0.500	0.233	[0, 1]
Permanent	WBP + LP + UNK	8	0.431	1.159	[0, 1]

Table 2E-2. Adjusted, design-based Horvitz-Thompson unequal probability ratio estimates for the proportion of trees with blister rust for 2013 and 2014 WYBLM five-needle pine data. Each row corresponds to a specific subset of the permanent data as indicated by species. Estimate accounts for unequal probability selection of map units within areas. Estimator provided in Appendix 2A.

Transect Type	Species	n_i (map units)	BR proportion	SE	95% CI
Permanent	WBP	4	0.260	0.626	[0, 1]
Permanent	LP	5	0.503	0.402	[0, 1]
Permanent	WBP + LP + UNK	8	0.399	1.591	[0, 1]

Table 2E-3. Adjusted, design-based ratio estimates for the proportion of whitebark pine (WBP) trees with blister rust for 2013 and 2014 WYBLM five-needle pine data. Each row corresponds to one of 3 different methods of calculating the estimate (strata combined, strata separately, and unbiased) and with or without the secondary variance component of transects within a map unit. Estimates are adjusted for frame error.

Estimator	Transect Type	Species	n_i (map units)	BR proportion	SE	95% CI
combined, 1° var.	rapid	WBP	14	0.281	0.011	[0.256, 0.307]
combined, 2° var.	rapid	WBP	14	0.273	0.166	[0.000, 0.679]
separate, 1° var.	rapid	WBP	14	0.343	0.027	[0.276, 0.409]
separate, 2° var.	rapid	WBP	14	0.343	0.075	[0.158, 0.528]
unbiased, 1° var.	rapid	WBP	14	0.277	0.060	[0.131, 0.424]
unbiased, 2° var.	rapid	WBP	14	0.277	23.668	[0.000, 1.000]

Table 2E-4. Unadjusted, design-based ratio estimates for the proportion of whitebark pine (WBP) trees with blister rust for 2013 and 2014 WYBLM five-needle pine data. Each row corresponds to one of 3 different methods of calculating the estimate (strata combined, strata separately, and unbiased) and with or without the secondary variance component of transects within a map unit. Estimates have not been adjusted for frame error.

Estimator	Transect Type	Species	n_i (map units)	BR proportion	SE	95% CI
combined, 1° var.	rapid	WBP	14	0.281	0.011	[0.256, 0.307]
combined, 2° var.	rapid	WBP	14	0.281	0.179	[0.000, 0.719]
separate, 1° var.	rapid	WBP	14	0.344	0.027	[0.278, 0.411]
separate, 2° var.	rapid	WBP	14	0.344	0.077	[0.156, 0.532]
unbiased, 1° var.	rapid	WBP	14	0.277	0.060	[0.131, 0.424]
unbiased, 2° var.	rapid	WBP	14	0.277	31.332	[0.000, 1.000]

Table 2E-5. Adjusted, design-based ratio estimates for the proportion of limber pine (LP) trees with blister rust for 2013 and 2014 WYBLM five-needle pine data. Each row corresponds to one of 3 different methods of calculating the estimate (strata combined, strata separately, and unbiased) and with or without the secondary variance component of transects within a map unit. Estimates are adjusted for frame error.

Estimator	Transect Type	Species	n_i (map units)	BR proportion	SE	95% CI
combined, 1° var.	rapid	LP	22	0.105	0.041	[0.018, 0.192]
combined, 2° var.	rapid	LP	22	0.076	0.050	[0.000, 0.184]
separate, 1° var.	rapid	LP	22	0.270	0.021	[0.226, 0.314]
separate, 2° var.	rapid	LP	22	0.270	0.086	[0.086, 0.454]
unbiased, 1° var.	rapid	LP	22	0.378	0.065	[0.238, 0.517]
unbiased, 2° var.	rapid	LP	22	0.378	346.151	[0.000, 1.000]

Table 2E-6. Unadjusted, design-based ratio estimates for the proportion of limber pine (LP) trees with blister rust for 2013 and 2014 WYBLM five-needle pine data. Each row corresponds to one of 3 different methods of calculating the estimate (strata combined, strata separately, and unbiased) and with or without the secondary variance component of transects within a map unit. Estimates have not been adjusted for frame error.

Estimator	Transect Type	Species	n_i (map units)	BR proportion	SE	95% CI
combined, 1° var.	rapid	LP	22	0.105	0.041	[0.018, 0.192]
combined, 2° var.	rapid	LP	22	0.105	0.073	[0.000, 0.262]
separate, 1° var.	rapid	LP	22	0.277	0.027	[0.220, 0.334]
separate, 2° var.	rapid	LP	22	0.277	0.089	[0.087, 0.468]
unbiased, 1° var.	rapid	LP	22	0.378	0.065	[0.238, 0.517]
unbiased, 2° var.	rapid	LP	22	0.378	605.738	[0.000, 1.000]

Table 2E-7. Adjusted, design-based ratio estimates for the proportion of all five-needle pine trees with blister rust for 2013 and 2014 WYBLM five-needle pine data. Each row corresponds to one of 3 different methods of calculating the estimate (strata combined, strata separately, and unbiased) and with or without the secondary variance component of transects within a map unit. Estimates are adjusted for frame error.

Estimator	Transect Type	Species	n_i (map units)	BR proportion	SE	95% CI
combined, 1° var.	rapid	WBP + LP + UNK	36	0.123	0.013	[0.097, 0.149]
combined, 2° var.	rapid	WBP + LP + UNK	36	0.123	0.035	[0.050, 0.195]
separate, 1° var.	rapid	WBP + LP + UNK	36	0.236	0.000	[0.236, 0.236]
separate, 2° var.	rapid	WBP + LP + UNK	36	0.236	0.351	[0.000, 0.955]
unbiased, 1° var.	rapid	WBP + LP + UNK	36	0.233	0.000	[0.233, 0.233]
unbiased, 2° var.	rapid	WBP + LP + UNK	36	0.250	230.800	[0.000, 1.000]

Table 2E-8. Unadjusted, design-based ratio estimates for the proportion of all five-needle pine trees with blister rust for 2013 and 2014 WYBLM five-needle pine data. Each row corresponds to one of 3 different methods of calculating the estimate (strata combined, strata separately, and unbiased) and with or without the secondary variance component of transects within a map unit. Estimates have not been adjusted for frame error.

Estimator	Transect Type	Species	n_i (map units)	BR proportion	SE	95% CI
combined, 1° var.	rapid	WBP + LP + UNK	36	0.123	0.013	[0.097, 0.149]
combined, 2° var.	rapid	WBP + LP + UNK	36	0.123	0.039	[0.044, 0.203]
separate, 1° var.	rapid	WBP + LP + UNK	36	0.230	0.000	[0.230, 0.231]
separate, 2° var.	rapid	WBP + LP + UNK	36	0.230	0.331	[0.000, 0.909]
unbiased, 1° var.	rapid	WBP + LP + UNK	36	0.233	0.000	[0.233, 0.233]
unbiased, 2° var.	rapid	WBP + LP + UNK	36	0.250	403.851	[0.000, 1.000]

Table 2E-9. Adjusted, design-based ratio estimates for the proportion of whitebark pine (WBP) trees with blister rust for 2013 and 2014 WYBLM five-needle pine data. Each row corresponds to one of 3 different methods of calculating the estimate (strata combined, strata separately, and unbiased) and with or without the secondary variance component of transects within a map unit. Estimates are adjusted for frame error.

Estimator	Transect Type	Species	n_i (map units)	BR proportion	SE	95% CI
combined, 1° var.	rapid + permanent	WBP	15	0.302	0.007	[0.286, 0.317]
combined, 2° var.	rapid + permanent	WBP	15	0.298	0.154	[0.000, 0.662]
separate, 1° var.	rapid + permanent	WBP	15	0.606	0.027	[0.541, 0.670]
separate, 2° var.	rapid + permanent	WBP	15	0.606	0.074	[0.431, 0.781]
unbiased, 1° var.	rapid + permanent	WBP	15	0.548	0.060	[0.406, 0.690]
unbiased, 2° var.	rapid + permanent	WBP	15	0.548	23.581	[0.000, 1.000]

Table 2E-10. Unadjusted, design-based ratio estimates for the proportion of whitebark pine (WBP) trees with blister rust for 2013 and 2014 WYBLM five-needle pine data. Each row corresponds to one of 3 different methods of calculating the estimate (strata combined, strata separately, and unbiased) and with or without the secondary variance component of transects within a map unit. Estimates have not been adjusted for frame error.

Estimator	Transect Type	Species	n_i (map units)	BR proportion	SE	95% CI
combined, 1° var.	rapid + permanent	WBP	15	0.302	0.007	[0.286, 0.317]
combined, 2° var.	rapid + permanent	WBP	15	0.302	0.170	[0.000, 0.703]
separate, 1° var.	rapid + permanent	WBP	15	0.606	0.027	[0.542, 0.671]
separate, 2° var.	rapid + permanent	WBP	15	0.606	0.075	[0.428, 0.785]
unbiased, 1° var.	rapid + permanent	WBP	15	0.548	0.060	[0.406, 0.690]
unbiased, 2° var.	rapid + permanent	WBP	15	0.548	31.266	[0.000, 1.000]

Table 2E-11. Adjusted, design-based ratio estimates for the proportion of limber pine (LP) trees with blister rust for 2013 and 2014 WYBLM five-needle pine data. Each row corresponds to one of 3 different methods of calculating the estimate (strata combined, strata separately, and unbiased) and with or without the secondary variance component of transects within a map unit. Estimates are adjusted for frame error.

Estimator	Transect Type	Species	n_i (map units)	BR proportion	SE	95% CI
combined, 1° var.	rapid + permanent	LP	23	0.167	0.064	[0.032, 0.302]
combined, 2° var.	rapid + permanent	LP	23	0.122	0.067	[0.000, 0.264]
separate, 1° var.	rapid + permanent	LP	23	0.273	0.021	[0.229, 0.317]
separate, 2° var.	rapid + permanent	LP	23	0.273	0.086	[0.090, 0.456]
unbiased, 1° var.	rapid + permanent	LP	23	0.372	0.065	[0.234, 0.511]
unbiased, 2° var.	rapid + permanent	LP	23	0.372	199.888	[0.000, 1.000]

Table 2E-12. Unadjusted, design-based ratio estimates for the proportion of limber pine (LP) trees with blister rust for 2013 and 2014 WYBLM five-needle pine data. Each row corresponds to one of 3 different methods of calculating the estimate (strata combined, strata separately, and unbiased) and with or without the secondary variance component of transects within a map unit. Estimates have not been adjusted for frame error.

Estimator	Transect Type	Species	n_i (map units)	BR proportion	SE	95% CI
combined, 1° var.	rapid + permanent	LP	23	0.167	0.064	[0.032, 0.302]
combined, 2° var.	rapid + permanent	LP	23	0.167	0.089	[0.000, 0.357]
separate, 1° var.	rapid + permanent	LP	23	0.282	0.027	[0.225, 0.339]
separate, 2° var.	rapid + permanent	LP	23	0.282	0.089	[0.093, 0.471]
unbiased, 1° var.	rapid + permanent	LP	23	0.372	0.065	[0.234, 0.511]
unbiased, 2° var.	rapid + permanent	LP	23	0.372	349.746	[0.000, 1.000]

Table 2E-13. Adjusted, design-based ratio estimates for the proportion of all five-needle pine trees with blister rust for 2013 and 2014 WYBLM five-needle pine data. Each row corresponds to one of 3 different methods of calculating the estimate (strata combined, strata separately, and unbiased) and with or without the secondary variance component of transects within a map unit. Estimates are adjusted for frame error.

Estimator	Transect Type	Species	n_i (map units)	BR proportion	SE	95% CI
combined, 1° var.	rapid + permanent	WBP + LP + UNK	37	0.156	0.031	[0.093, 0.219]
combined, 2° var.	rapid + permanent	WBP + LP + UNK	37	0.146	0.045	[0.053, 0.238]
separate, 1° var.	rapid + permanent	WBP + LP + UNK	37	0.253	0.000	[0.253, 0.253]
separate, 2° var.	rapid + permanent	WBP + LP + UNK	37	0.253	0.349	[0.000, 0.967]
unbiased, 1° var.	rapid + permanent	WBP + LP + UNK	37	0.240	0.000	[0.240, 0.240]
unbiased, 2° var.	rapid + permanent	WBP + LP + UNK	37	0.259	165.759	[0.000, 1.000]

Table 2E-14. Unadjusted, design-based ratio estimates for the proportion of all five-needle pine trees with blister rust for 2013 and 2014 WYBLM five-needle pine data. Each row corresponds to one of 3 different methods of calculating the estimate (strata combined, strata separately, and unbiased) and with or without the secondary variance component of transects within a map unit. Estimates have not been adjusted for frame error.

Estimator	Transect Type	Species	n_i (map units)	BR proportion	SE	95% CI
combined, 1° var.	rapid + permanent	WBP + LP + UNK	37	0.156	0.031	[0.093, 0.219]
combined, 2° var.	rapid + permanent	WBP + LP + UNK	37	0.156	0.054	[0.045, 0.268]
separate, 1° var.	rapid + permanent	WBP + LP + UNK	37	0.248	0.000	[0.248, 0.248]
separate, 2° var.	rapid + permanent	WBP + LP + UNK	37	0.248	0.329	[0.000, 0.922]
unbiased, 1° var.	rapid + permanent	WBP + LP + UNK	37	0.240	0.000	[0.240, 0.240]
unbiased, 2° var.	rapid + permanent	WBP + LP + UNK	37	0.259	290.016	[0.000, 1.000]

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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