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Status of Whitebark Pine in the Greater Yellowstone Ecosystem

A Step-trend Analysis Comparing 2004-2007 to 2008-2011

Natural Resource Technical Report NPS/GRYN/NRTR—2014/917

ON THE COVER

Whitebark pines, Sweetwater Gap, Bridger-Teton National Forest
Photo credit: Erin Shanahan, NPS

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Contents

Figures

Page

Tables

Executive Summary

Whitebark pine (*Pinus albicaulis*) is a foundation and keystone species in upper subalpine environments of the northern Rocky Mountains that strongly influences the biodiversity and productivity of high-elevation ecosystems (Tomback et al. 2001, Ellison et al. 2005). Throughout its historic range, whitebark pine has decreased significantly as a major component of high-elevation forests. As a result, it is critical to understand the challenges to whitebark pine—not only at the tree and stand level, but also as these factors influence the distribution of whitebark pine across the Greater Yellowstone Ecosystem (GYE).

In 2003, the National Park Service (NPS) Greater Yellowstone Inventory & Monitoring Network identified whitebark pine as one of twelve significant natural resource indicators or vital signs to monitor (Jean et al. 2005, Fancy et al. 2009) and initiated a long-term, collaborative monitoring program. Partners in this effort include the U.S. Geological Survey, U.S. Forest Service, and Montana State University with representatives from each comprising the Greater Yellowstone Whitebark Pine Monitoring Working Group. The objectives of the monitoring program are to assess trends in (1) the proportion of live, whitebark pine trees (>1.4-m tall) infected with white pine blister rust (blister rust); (2) to document blister rust infection severity by the occurrence and location of persisting and new infections; (3) to determine mortality of whitebark pine trees and describe potential factors contributing to the death of trees; and (4) to assess the multiple components of the recruitment of understory whitebark pine into the reproductive population. In this report we summarize the past eight years (2004-2011) of whitebark pine status and trend monitoring in the GYE.

Our study area encompasses six national forests (NF), two national parks (NP), as well as state and private lands in portions of Wyoming, Montana, and Idaho; this area is collectively described as the GYE here and in other studies. The sampling design is a probabilistic, two-stage cluster design with stands of whitebark pine as the primary units and 10x50 m belt transects as the secondary units. Primary sampling units (stands) were selected randomly from a sample frame of approximately 10,770 mapped pure and mixed whitebark pine stands ≥2.0 hectares in the GYE (Dixon 1997, Landenburger 2012). From 2004 through 2007 (monitoring transect establishment or initial time-step), we established 176 permanent belt transects (secondary sampling units=176) in 150 whitebark pine stands and permanently marked approximately 4,740 individual trees >1.4 m tall to monitor long-term changes in blister rust infection and survival rates. Between 2008 and 2011 (revisit time-step), these same 176 transects were surveyed and again all previously tagged trees were observed for changes in blister rust infection and survival status.

Objective 1. Using a combined ratio estimator, we estimated the proportion of live trees infected in the GYE in the initial time-step (2004-2007) to be 0.22 (0.031 SE). Following the completion of all surveys in the revisit time-step (2008-2011), we estimated the proportion of live trees infected with white pine blister rust as 0.23 (0.028 SE; Table 2). We detected no significant change in the proportion of trees infected in the GYE between the two time-steps.

Objective 2. We documented blister rust canker locations as occurring in the canopy or bole. We compared changes in canker position between the initial time-step (2004-2007) and the revisit time-step (2008-2011) in order to assess changes in infection severity. This analysis included the 3,795 trees tagged during the initial time-step that were located and documented as alive at the end of the revisit time-step. At the end of the revisit time-step, we found 1,217 trees infected with blister rust. This includes the 287 newly tagged trees in the revisit time step of which 14 had documented infections. Of these 1,217 trees, 780 trees were infected

with blister rust in both time steps. Trees with only canopy cankers made up approximately 43% (519 trees) of the total number of trees infected with blister rust at the end of the revisit time-step, while trees with only bole cankers comprised 20% (252 trees), and those with both canopy and bole cankers included 37% (446 trees) of the infected sample. A bole infection is considered to be more consequential than a canopy canker, as it compromises not only the overall longevity of the tree, but its functional capacity for reproductive output as well (Kendall and Arno 1990, Campbell and Antos 2000, McDonald and Hoff 2001, Schwandt and Kegley 2004). In addition to infection location, we also documented infection transition between the canopy and bole. Of the 780 live trees that were infected with blister rust in both time-steps, approximately 31% (242) maintained canopy cankers and 36% (281) retained bole infections at the end of the revisit time-step. Infection transition from canopy to bole occurred in 30% (234) of the revisit time-step trees while 3% (23) transitioned from bole to canopy infections during this period.

Objective 3. To determine whitebark pine mortality, we resurveyed all belt transects to reassess the life status of permanently tagged trees >1.4 m tall. We compared the total number of live tagged trees recorded during monitoring transect establishment to the total number of resurveyed dead tagged trees recorded during the revisit time-step and identified all potential mortality-influencing conditions (blister rust, mountain pine beetle, fire and other). By the end of the revisit time-step, we observed a total of 975 dead tagged whitebark pine trees; using a ratio estimator, this represents a loss of approximately 20% (SE=4.35%) of the original live tagged tree population (GYWPMWG 2012).

Objective 4. To investigate the proportion of live, reproducing tagged trees, we divided the total number of positively identified cone-bearing trees by the total number of live trees in the tagged tree sample at the end of the revisit time-step. To approximate the average density of recruitment trees per stand, trees ≤1.4 m tall were summed by stand (within the 500 m^2 transect area) and divided by the total number of stands. Reproducing trees made up approximately 24% (996 trees) of the total live tagged population at the end of the revisit time-step. Differentiating between whitebark pine and limber pine seedlings or saplings is problematic given the absence of cones or cone scars. Therefore, understory summaries as presented in this report may include individuals of both species when they are sympatric in a stand. The average density of small trees ≤1.4 m tall was 53 understory trees per 500 m^2. Raw counts of these understory individuals ranged from 0-635 small trees per belt transect. In addition, a total of 287 trees were added to the tagged tree population by the end of 2011. These newly tagged trees were individuals that upon subsequent revisits had reached a height of >1.4 m tall and subsequently added to the sample.

Throughout the past decade in the GYE, monitoring has helped document shifts in whitebark pine forests; whitebark pine stands have been impacted by insect, pathogen, wildland fire, and other disturbance events. Blister rust infection is ubiquitous throughout the ecosystem and infection proportions are variable across the region. And while we have documented mortality of whitebark pine, we have also recorded considerable recruitment. We provide this first step-trend report as a quantifiable baseline for understanding the state of whitebark pine in the GYE. Many aspects of whitebark pine health are highly variable across the range of its distribution in the GYE. Through sustained implementation of the monitoring program, we will continue efforts to document and quantify whitebark pine forest dynamics as they arise under periodic upsurges in insect, pathogen, fire episodes, and climatic events in the GYE. Since its inception, this monitoring program perseveres as one of the only sustained long-term efforts conducted in the GYE with a singular purpose to track the health and status of this prominent keystone species.

Acknowledgements

This endeavor has been made possible by the generous support and collaboration of the numerous agencies that comprise the Whitebark Pine Monitoring Working Group. We thank both current and past members of the group for their continued assistance, encouragement, and logistical backing. This report would not have come to fruition without the enduring character of the numerous field technicians who have participated in data collection over the duration of the Interagency Whitebark Pine Monitoring Program. It is to these dedicated and hardy individuals that we owe the success of this endeavor.

We greatly appreciate the rigorous evaluations provided by numerous reviewers throughout the preparation of this report.

Funding for the Interagency Whitebark Pine Monitoring Program has been provided by the National Park Service Inventory and Monitoring Program; the U. S. Forest Service Forest Health Protection, Ecological Monitoring, and Gallatin National Forest; Greater Yellowstone Coordinating Committee; the U.S. Fish and Wildlife Service; the U.S. Geological Survey; the Cooperative Ecosystem Studies Unit; and Montana State University.

This report was produced in coordination with the Whitebark Pine Monitoring Working Group and has been included as part of a Master's thesis requirement for Erin Shanahan.

Introduction

Whitebark pine (*Pinus albicaulis*) is a foundation and keystone species in upper subalpine environments of the northern Rocky Mountains that strongly influences the biodiversity and productivity of high-elevation ecosystems (Tomback et al. 2001, Ellison et al. 2005). A member of the subsection Cembrae (stone pines), whitebark pine is the only representative of this group found in North America (Lanner 1990, Lanner 1996). Although commonly encountered in both pure and mixed-species stands from about 2,000 m to treeline, this drought-resistant tree also establishes on exposed ridges at lower elevations (Arno 1986). Whitebark pine occupy dry and rocky habitats that appear to be intolerable for most montane forest species. Ridge and treeline whitebark pine contributions to subalpine environments are numerous, but principal among these are the collection and maintenance of mountain snowpack throughout the fall and winter (Weaver 2001). As warming temperatures arrive in subalpine environments, whitebark pine's wide canopies retain snow and moderate snowmelt rates (Arno and Hoff 1990, Smith et al. 2008, Farnes 1990). Whitebark pine also creates microsites that provide protection and fertile habitat for shade-tolerant species such as subalpine fir (*Abies lasiocarpa*; Tomback et al. 2001, Keane and Arno 1993). In addition, the seeds of whitebark pine are a valuable food source for a variety of wildlife including grizzly bears (*Ursus arctos horribilis*), Clark's nutcrackers (*Nucifraga columbiana*), and red squirrels (*Tamiasciurus hudsonicus*; Tomback et al. 2001).


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Whitebark pine stand at Crow Creek Bridger-Teton National Forest, Wyoming.

Throughout its historic range, whitebark pine has decreased significantly as a major component of high-elevation forests. A century's worth of altered fire regimes and insect and pathogen outbreaks have combined to reduce whitebark pine stands in many regions (Keane and Arno 1993, Kendall and Keane 2001, Zeglen 2002, Smith et al. 2008, Tomback and Achuff 2010, MacFarlane et al. 2013). White pine blister rust (*Cronartium ribicola*; hereafter, blister rust), an exotic fungal pathogen, is considered a principal threat to the long-term survival of whitebark pine across its range. In the early 1900s, blister rust was introduced inadvertently to western North America from imported European nursery stock (Kendall and Arno 1990, Keane and Arno 1993). With a propensity for infecting five-needle pines, this pathogen thrived in the Pacific Northwest climate and dispersed inward from its coastal landing to infect many white pine species (Smith and Hoffman 2000). Blister rust requires a primary and secondary host to complete its complex life cycle. White pines and species of the genus *Ribes*, such as currant and gooseberry,

originally were believed to be the primary and alternate telial hosts for blister rust (Smith and Hoffman 2000, Zambino et al. 2007). Efforts to thwart the spread of blister rust began in earnest in the 1930s using widespread *Ribes* spp. eradication programs that employed both physical and chemical means of control (Ketcham et al. 1968). Given the abundance of *Ribes* spp., combined with the extensive dispersal ability of blister rust aeciospores (the fruiting bodies of blister rust), little success resulted from these labors. Consequently, organized endeavors to suppress blister rust were later abandoned (Benedict 1981, Ketcham et al 1968) and this pathogen has continued to impact geographic regions where white pines occur. In addition to whitebark pine and *Ribes* spp., two other species, giant red Indian paintbrush (*Castilleja miniata*) and elephanthead lousewort (*Pedicularis racemosa*), common flora of whitebark pine communities, also were discovered to function as intermediary hosts in the blister rust cycle (McDonald et al. 2006).

Whitebark pine with aeciospores.

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The pathway for infection by blister rust is well understood; basidiospores enter a tree through the needles (McDonald and Hoff 2001). After successful infection, it takes approximately two to four years for aecia (the fruiting body of blister rust) to fully erupt on infected tree branches and release aeciospores (McDonald and Hoff 2001). Because most of these primary infections are located in the crown of a tree, canopy branches tend to be affected in the early stages of the disease process. Aecia can damage tree structure both directly and indirectly. Growth patterns of the spores themselves lead to swelling and subsequent bark girdling, which occludes nutrient accessibility to healthy tissue distal to the canker (Tainter and Baker 1996, Smith et al. 2000). Indirectly, aeciospores and associated tree sap act as attractants for rodents and various insects; consumption of sap can cause extensive girdling on affected branches and boles (Zeglen 2002, Schwandt and Kearns 2011). Because whitebark pine cones grow on the outermost portions of upper-canopy limbs, girdling of cone-bearing branches can have a tremendous impact on reproductive potential (Maloney et al. 2012). A tree may experience diminished cone production due to a decrease in the number of cone-bearing branches, or in extreme cases, the complete loss of reproductive ability following top kill. Although a tree can persist for decades after infection, cankers found on the lower portions of the bole eventually lead to the death of the tree. Bole cankers have a higher probability of killing smaller trees because they have fewer branches and the distance an infection has to travel from the branch to the main bole is typically shorter than in larger-diameter trees (Koteen 2002, Newcomb 2003). Thus, in addition to losing future reproductive potential, smaller trees may die from blister rust infection more rapidly than larger infected cohorts (Smith and Hoffman 2000).

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Barstow Lake area, Bridger-Teton National Forest, Wyoming.

The endemic mountain pine beetle (*Dendroctonus ponderosae*) also influences the health and abundance of whitebark pine (Logan et al. 2010). An aggressive pest of several coniferous species, mountain pine beetle periodically escalates to epidemic levels of outbreak in lodgepole pine (*P. contorta*), ponderosa pine (*P. ponderosa*), and whitebark pine forests (Perkins and Swetnam 1996, Furniss and Renkin 2003, Six et al. 2014). In whitebark pine, trees measuring >10 cm diameter at breast height (DBH) are preferentially selected by mountain pine beetle for infestation (Furniss and Carolin 1977). Many of these larger-DBH individuals also represent the cone-bearing, reproductive segment of the population. Raffa et al. (2013) hypothesized that because mountain pine beetle outbreaks historically occurred intermittently in high-elevation forests, whitebark pine potentially lack defense mechanisms necessary to block an attack. As a result, whitebark pine can be particularly vulnerable to extensive mortality caused by mountain pine beetles (Raffa et al. 2013). As climate conditions become warmer (Pedersen et al. 2011), shorter intervals between epidemic mountain pine beetle cycles are expected (Raffa et al. 2013). At least three outbreaks of mountain pine beetle have occurred in regions within the Greater Yellowstone Ecosystem (GYE) over the last century (1909-1940, 1970-1980s, 2000-present; (Furniss and Carolyn 1977, Furniss and Renkin 2003, Logan et al. 2010). The most recent occurrence began in the early 2000s with peak mortality observed around 2009 (Olliff et al. 2013, Hayes 2013). This latest infestation has been labeled as "unprecedented" due to the widespread death of multiple forest species, the novel areas in which mortality has occurred, and the fact that whitebark pine has experienced unparalleled losses to the overall population (Logan et al. 2010, Macfarlane et al. 2013). As is evident in the GYE, bark beetles can swiftly cause mass mortality across vast expanses of forest. Although whitebark pine has survived both endemic and epidemic levels of beetle outbreak, the additional stress of climatic conditions presents unprecedented challenges to its long-term survival in the GYE.

It is critical to understand the challenges to whitebark pine—not only at the tree and stand level, but also as these factors influence the distribution of whitebark pine across the GYE. Identifying the multiple stressors to whitebark pine health, and the potential dynamic interactions among stressors, is an important component of this understanding. Acquiring this degree of in-depth knowledge requires a whitebark pine monitoring program that is spatially representative and long term. In 2003, the National Park Service (NPS) Greater Yellowstone Inventory & Monitoring Network identified whitebark pine as one of twelve significant natural resource indicators or vital signs to monitor (Jean et al. 2005, Fancy et al. 2009), and initiated a long-term, collaborative monitoring program. Partners in this effort include the NPS, U.S. Geological Survey, U.S. Forest Service, and Montana State University with representatives from each comprising

the Greater Yellowstone Whitebark Pine Monitoring Working Group (GYWPMWG; hereafter, monitoring group).

In this report we summarize the past eight years (2004-2011) of whitebark pine status and trend monitoring in the GYE. During this time period, our monitoring not only captured the change in the status of blister rust infection in the GYE, but also chronicled the transformation of endemic mountain pine beetle to epidemic levels. As well as providing critical baseline information to land managers, continuous documentation of this event has assisted in the development of species recovery plans, enabled investigation into the possible synergistic interaction of blister rust and mountain pine beetle on whitebark pine mortality, and resulted in a collaborative monitoring protocol that can be used across the GYE regardless of landownership (GYCCWPS 2011, GYWPMWG 2011). Perhaps even more relevant to the long-term survival of whitebark pine in the ecosystem, monitoring data will allow the formulation of predictive models on future survival and recruitment potential of whitebark pine in the presence of blister rust infection and other stand-altering phenomena such as beetle, fire, and climate change.

Report Objectives

Following the objectives outlined in the Interagency Whitebark Pine Monitoring Protocol (GYWPMWG 2011), the intent of this trend report is to:

1. Describe the estimated proportion of live whitebark pine trees (>1.4-m tall) infected with white pine blister rust during 2004-2007 (permanent belt transect monitoring establishment period) and 2008-2011 (belt transect revisit period) and assess evidence of blister rust infection change between the two time periods;

2. Document blister rust infection severity by the occurrence and location of persisting and new infection by the end of 2011 and evaluate the rate at which infection transitioned from canopy to bole cankers between time periods 2004-2007 and 2008-2011;

3. Determine mortality of whitebark pine trees between 2004-2007 and 2008-2011 and describe potential factors contributing to death of tagged individuals; and

4. Assess the multiple components of recruitment of understory whitebark pine into the reproductive population.

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Double Cabin peaks, Shoshone National Forest, Wyoming.

Study Area

Our study area encompasses six national forests (NF), two national parks (NP), as well as state and private lands in portions of Wyoming, Montana, and Idaho (Figure 1); this area is collectively described as the GYE here and in other studies. The GYE is geographically defined as the Yellowstone Plateau volcanic fields and the 14 surrounding mountain ranges above 2,130 m (Marston and Anderson 1991).

Whitebark pine stands occupy over 800,000 hectares in the high, mountainous zones of the GYE (Marston and Anderson 1991, GYWPMWG 2011, GYCCWPS 2011). This environment is subject to harsh weather including excessive winds, extreme cold temperatures, and significant snow accumulation. Snow collects early and may persist until late spring and occasionally into mid-summer. Summers tend to be warm and dry. Sample sites in the study area range in elevation from 2,400 m to 3,172 m and extend to the boundaries of the ecosystem (GYWPMWG 2011).

To illustrate the conditions of this region, we used DAYMET 1 km grid cell values (Thornton et al. 2014) to describe the annual averaged climate conditions from 1980 to 2011 for the 176 transects (Table 1). Stand-level physical attributes (slope, aspect, elevation) were obtained from a 30 m digital elevation model (GYWPMWG 2011).

Table 1. Summary of climatic indicators (i.e. annual precipitation, mean annual temperature, total annual rain, total annual snow) from 1980-2011 and stand-level physical attributes for the 176 monitoring transects.

Averages for 176 transects	Precipitation (mm)	Temperature (deg C)	Rain (mm)	Snow (mm)	Maximum Snowpack (mm)	Slope (degrees)	Aspect (degrees)	Elevation (m)
Minimum	238	-1	104	112	112	1	0.2	2,401
Maximum	1,636	4	578	1,271	1,243	45	360	3,172
Average	858	1	303	556	465	20	182	2,787
Standard Deviation	227	1	91	180	173	9	91	173

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Snow can linger in the higher elevations until mid-summer.

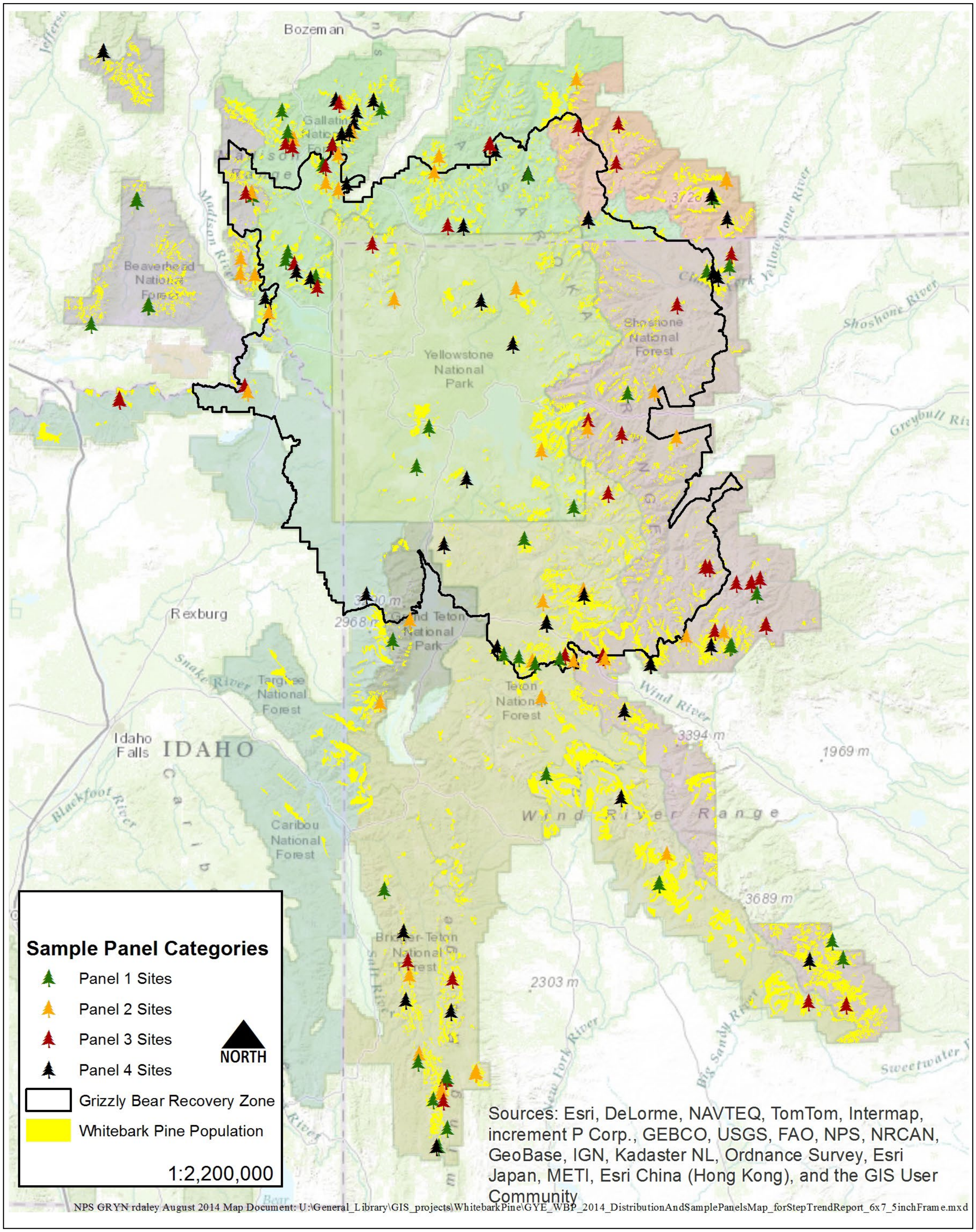


Figure 1. Whitebark Pine Monitoring Program study area in the GYE.

Methods

In this section we describe the methodologies we used in the whitebark pine long-term monitoring program; for more information, refer to the Interagency Whitebark Pine Monitoring Protocol (GYWPMWG 2011).

Sampling Design

The sampling design is a probabilistic, two-stage cluster design with stands of whitebark pine as the primary units and 10x50 m belt transects as the secondary units. Primary sampling units (stands, *n*=150) were selected randomly from a sample frame of approximately 10,770 mapped pure and mixed whitebark pine stands ≥2.0 hectares in the GYE (Dixon 1997, Landenburger 2012). Stands were stratified according to their location inside or outside of the Grizzly Bear Recovery Zone (an area delineated in the GYE by the U.S Fish and Wildlife Service identified as grizzly bear-sustaining habitat; USFWS 1993) and within an administrative unit boundary (Beaverhead-Deerlodge NF, Bridger-Teton NF, Caribou-Targhee NF, Custer NF, Gallatin NF, Shoshone NF, Grand Teton NP, and Yellowstone NP; Figure 1). Areas that had experienced wildland fire since 1970 were excluded from the sample frame (GYWPMWG 2011). From 2004 through 2007, we established 176 permanent belt transects (secondary sampling units=176) in 150 whitebark pine stands and permanently marked approximately 4,740 individual trees >1.4 m tall to monitor long-term changes in blister rust infection and survival rates. We installed two permanent belt transects in twenty-six of the 150 stands in order to investigate within-stand variability.

Field Methodology and Data Collection

We typically start field sampling the last week in June when snow accumulation is sufficiently depleted to allow access to high-elevation sites and end the last week in September when unpredictable weather may interfere with field work. We established the 10x50 m belt transects within each selected stand using the methodology outlined in the protocol (GYWPMWG 2011); and permanently marked them for future revisits (Figure 2). We tagged all whitebark pine trees >1.4-m tall and examined them for blister rust during full survey visits.

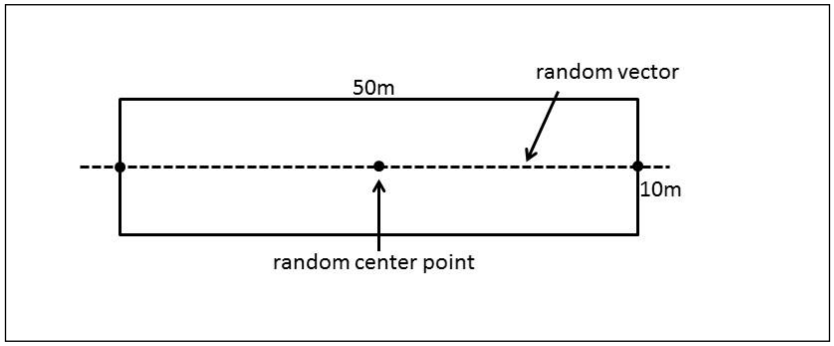


Figure 2. Belt transect layout. Permanent markers were placed at the two end points and the center point.

We recorded the following tree attributes for every tagged tree (see field data form in Appendix A):

- clump membership (number and letter),
- DBH (measured at 1.4 m from the ground),
- height,
- tree status (live=green needles still present, recently dead=red or brown needles remaining on tree, or dead=tree is completely denuded of needles),
- cone production (Y/N),
- blister rust cankers (number and location in the tree=upper third, middle third, or lower third),
- number of blister rust indicators (flagging, rodent chewing, swelling, roughened bark, and oozing sap),
- upper tree canopy volume (percentage of canopy in the upper one third of the foliage that is alive),
- mountain pine beetle indicators (pitch tubes, frass, or J-shaped galleries), and
- tree health codes (can have multiple per tree such as dead top, fading crown, fire, etc.).

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 Hoff's non-aecia blister rust indicators (1992). A complete description of these indicator standards are provided in the monitoring protocol, but in brief, these include branch girdling, 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 protocol (GYWPMWG 2011). Instructions for identifying evidence of mountain pine beetle were provided by USFS Forest Health Protection entomologists. We noted additional information including UTM coordinates of beginning, center, and end points of the belt transect (Figure 2), elevation, habitat type (from Steele et al. 1983), and cover type (from Mattson and Despain 1985). We conducted counts and evaluated blister rust infection for all five-needle trees ≤1.4 m tall within the boundaries of the belt transects (snow-free belt transects only). We added new trees to the sample during the first revisit period between 2008 and 2011 when an understory tree on a given belt transect attained a height of >1.4 m tall, in which case we marked it and recorded all attributes for the new individual (as described in the tree tagging process).

Temporal Revisit Design

In 2008, we randomly assigned individual stands to one of four panels. Each panel consisted of approximately 44 belt transects (Figure 3), the number of belt transects that could be visited in a field season by one, two-person field crew. We revisited panels once every four years on a rotating schedule, which was designed to be sufficient to detect change in blister rust infection (McDonald and Hoff 2001). A full panel rotation is completed when all four panels are revisited in a given four-year period; this four-year period is referred to as a time-step.

The first time-step was the initial transect visit period from 2004-2007 (hereafter, initial time-step; in figures and tables also referred to as T0) and the second time-step occurred between 2008 and 2011 after all 176 belt transects were revisited (hereafter, revisit time-step; in figures and tables also referred to as T1). With the increase in whitebark pine mortality due to mountain pine beetle (Gibson 2003), the monitoring group became concerned that a revisit interval of four years might not capture the potentially changing rates of overall mortality of whitebark pine trees >1.4 m tall. In response, the design was temporarily modified to a two-year revisit schedule to detect the dynamic nature of the recent mountain pine beetle epidemic. With this design, we surveyed two of the four panels annually; one panel was subject to the full survey documenting blister rust infection and mountain pine beetle indicators, and the second panel was subject to a partial survey focused on mountain pine beetle indicators (Figure 3). Both surveys recorded tree status as live, dead, or recently dead.

We successfully resurveyed all 176 belt transects for blister rust infection and mortality during the 2008-2011 revisit time-step period. In the case where a belt transect no longer had any live, tagged trees >1.4 m tall, the panel revisit schedule was maintained in order to document potential

Survey Schedule		Time-step 0	Time-step 1				Time-step 2				Continued Monitoring 2016 forward
Sample Panel	Sites per panel	2004 thru 2007	2008	2009	2010	2011	2012	2013	2014	2015	
1	43	initial surveys for all 176 transects	br & mpb		mpb only		br & mpb				
2	45			br & mpb		mpb only		br & mpb			
3	44		mpb only		br & mpb		mpb only		br & mpb		
4	44			mpb only		br & mpb		mpb only		br & mpb	

Figure 3. Panel sampling revisit schedule (br=blister rust, mpb=mountain pine beetle).

recruitment of understory individuals into the tagged tree size class and to collect other data on understory cohorts.

Data Management and Statistical Analyses

We trained field observers to carry and use a detailed data recording guide to help ensure legible, valid entries and maximize the quality of recorded values. Network personnel entered data from field data sheets into a Microsoft Access database on a regular basis throughout the field season using a customized data entry form that included a cascading system of data validation controls. We subjected data 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, there may have been an insignificant amount of variability (typically <1% difference) when comparing data reported in previous years.

All analyses and corresponding figures were produced using Microsoft Excel and the statistical computing language R (R Development Core Team 2011) specific to each objective.

We have presented some of the results described in this trend narrative as preliminary findings in past versions of the Interagency Whitebark Pine Monitoring Program (monitoring program) annual reports (e.g., GYWPMWG 2012). This document provides results for the full eight years of data collection and analysis in order to present a complete assessment of changes over time across the sample frame. Our results are presented based on the following monitoring objectives.

Objective 1. Investigate changes in blister rust infection between initial transect visit time-step (2004-2007) and revisit time-step (2008- 2011).

We estimated the proportion of trees infected with blister rust in the sampled population of 10,770 whitebark pine stands identified in the GYE. We used a combined ratio estimator for both time-steps separately. A combined ratio estimator is appropriate for estimating a proportion from data collected using a stratified (e.g., Grizzly Bear Recovery Zone and administrative unit) two-stage cluster sample (Lohr 2010). The probabilistic sampling design allows inferences to the entire sampled population of mapped whitebark in the GYE.

To investigate the evidence of a change in the proportion of stands infected with blister rust a nonparametric Wilcoxon signed-ranked test was used (wilcox.test in R). For the 26 double belt transect stands, we calculated the overall average proportion for the stand to account for the potential lack of independence of belt transects nested within stands.

Objective 2. Document blister rust infection severity: new infection and canker transition.

We documented white pine blister rust canker locations as occurring in the canopy or bole. We compared changes in canker position between the initial time-step (2004-2007) and the revisit time-step (2008-2011) in order to assess changes in infection severity. This analysis included the approximately 3,795 trees tagged during the initial time-step that were located and documented as alive at the end of the revisit time-step. We reported canker location summaries as individual categories: branch only, bole only, or branch/bole combination. A more thorough investigation of canker transition is slated for future analysis.

Objective 3. Determine mortality from initial transect visit time-step to revisit time-step.

To determine whitebark pine mortality, we resurveyed all belt transects to reassess the life status of permanently tagged trees >1.4 m tall. We compared the total number of live tagged trees to the total number of dead tagged trees and identified all potential mortality-influencing conditions (blister rust, mountain pine beetle, fire and other). We estimated the proportion of whitebark pine mortality in the GYE using a ratio estimator to determine the cumulative proportion of dead trees within the sample frame based on the original collection of live tagged trees. The revisit schedule for life status (mountain pine beetle only visit) occurred at two-year intervals. For two-year estimates of the proportion of dead trees (mortality), we used a ratio estimator because not all administrative units were visited in a given two-year interval, thus we ignored the stratification. A stratified ratio estimator (e.g., combined ratio estimator used for blister rust within a four-year window) could not be used because of zero or low sample sizes within the different strata.


NPS ERIN SHANAHAN

Tree measurement at Sweetwater Gap, Bridger-Teton National Forest, Wyoming.

We conducted an in-depth examination on the probability of mortality in a separate analysis using a multi-level logistic regression model (Gelman and Hill 2007). Specifically, this evaluation explored the potential synergistic effects of mountain pine beetle and blister rust on whitebark pine mortality.

Objective 4. Investigate recruitment potential.

To investigate the proportion of live reproducing tagged trees, we divided the total number of positively identified live, cone-bearing trees by the total number of live trees remaining in the tagged tree sample at the end of the revisit time-step. To approximate the average density of recruitment trees per stand, we summed trees ≤1.4 m tall by stand (within the 500 m^2 transect area) and divided by the total number of stands. Some stands were precluded from the ≤1.4 m tall survey due to lingering snow cover. In the case where there were two belt transects per stand (26 cases), we averaged the count of small trees over the two belt transects for one stand total.

Results

The following results are based on data collected by the monitoring program between the initial and the revisit time-steps.

Objective 1: Blister Rust Infection Proportions

We estimated the proportion of live trees infected in the GYE in the initial time-step (2004-2007) to be 0.22 (0.031 SE). Following the completion of all surveys in the revisit time-step (2008-2011), we estimated the updated proportion of live trees infected with white pine blister rust as 0.23 (0.028 SE; Table 2). There was no significant change in the proportion of trees infected in the GYE between the two time-steps. In addition, the mortality of infected and uninfected trees did not appear to impact these results. Of the 975 tagged trees that died by the end of 2011, 554 were recorded as uninfected while 421 were documented as infected when last observed for the presence of blister rust.

We estimated a 4% increase in the mean percentage of trees infected with blister rust within a stand from the initial time-step to the revisit time-step (*n*=150, Wilcoxon signed ranked test, *V*=2415.5, *P*-value=0.0049; Figure 4).

Objective 2: Blister Rust Infection Severity

At the end of the revisit time-step, we found 1,217 of 4,081 living trees infected with blister rust. This includes the 287 newly tagged trees in the revisit time step of which 14 had documented infections. Trees with only canopy cankers made up approximately 43% (519 trees) of the total number of trees infected with blister rust at the end of the revisit time-step, while trees with only bole cankers comprised 20% (252 trees), and those with both canopy and bole cankers included 37% (446 trees) of the infected sample. Of the documented reproducing trees (996 trees), 45% (444) trees were infected with blister rust and 43% (190) of these infected trees had bole cankers.

Table 2. Design-based ratio estimates for the proportion of blister rust-infected whitebark pine trees >1.4 m tall in T0 and T1.

Time-step	2004-2007 [T0]	2008-2011 [T1]
Number of transects	176	176
Number of stands	150	150
Number of live trees	4,742	3,770
Proportion transects infected	0.812	0.858
Combined Ratio Estimates		
Proportion of live trees infected	0.225	0.231
Proportion of live trees infected standard error (SE)	0.031	0.028
Confidence interval (CI) for proportion of live trees infected	[0.163, 0.287]	[0.175, 0.287]

Infection Transition from Initial Time-step to Revisit Time-step

We recorded 174 of the originally tagged trees transitioned from infected to uninfected from the initial time-step to the revisit time-step, whereas 423 previously uninfected in the initial time-step were recorded as infected at the revisit time-step. Positive infection status was static for 780 trees, whereas a total of 2,418 trees remained uninfected between the two time steps (Table 3).

Of the 780 live trees that were infected with blister rust in both time-steps, approximately 31% maintained canopy cankers and 36% maintained bole infections at the end of the revisit time-step. Infection transition from canopy to bole occurred in 30% of the revisit time-step trees while 3% transitioned from bole to canopy infections during this period (Table 4). We assigned trees infected with both canopy and bole cankers to the bole canker category for this analysis.

Table 3. Infection transition status for the total number of trees tagged in the initial time-step (T0) that remained alive at the end of the revisit time-step (T1).

Tree Infection Transition Status T0-T1	
Uninfected to uninfected	2,418
Uninfected to infected	423
Infected to infected	780
Infected to uninfected	174

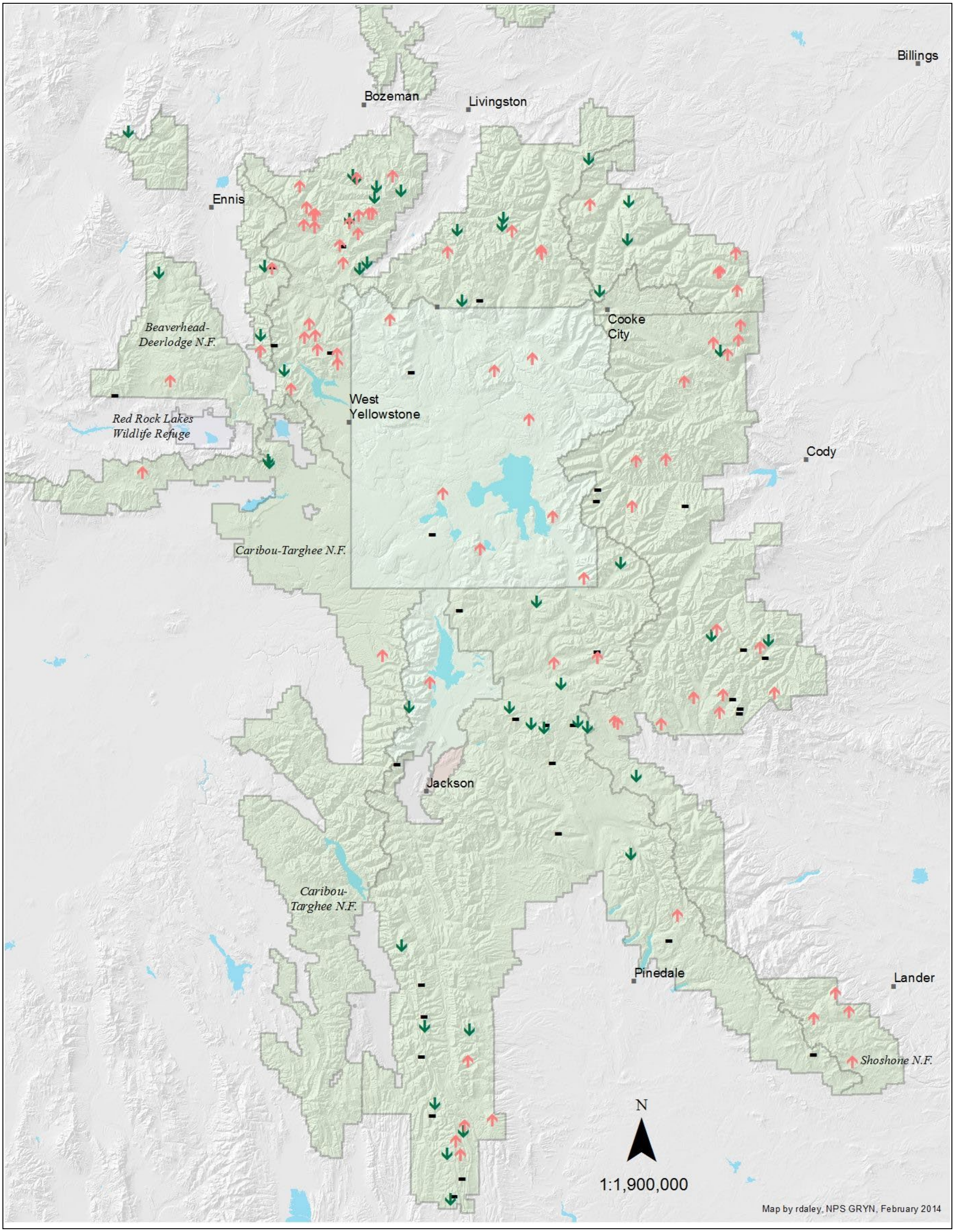


Figure 4. The change in the proportion of trees infected within each stand between the initial and revisit time-steps (↑ =increase, ↓ =decrease, "-" no change).

Table 4. Canker location transitions from live tagged trees in the initial time-step that remained live by the end of the revisit time-step and their canker positions following resurvey in the revisit time-step.

Infected T0	→	Infected T1
Canopy only (480)	→	Canopy only (245)
		Bole (235)
Bole (300)	→	Bole (280)
		Canopy only (20)

Objective 3: Whitebark Pine Mortality

By the end of the revisit time-step, we observed a total of 975 dead tagged whitebark pine trees; this represents a loss of approximately 20% of the original live tagged tree sample (GYWPMWG 2012). Approximately 40% (395 trees) of the dead trees died with evidence of mountain pine beetle infestation only. The majority of these trees were within the >10-30 cm DBH size class. The remaining 60% (583 trees) of dead trees died with signs of fire; blister rust; a combination of fire, mountain pine beetle, or blister rust; or with other factors such as structural or animal damage (Figure 5). When considering tree mortality associated with blister rust alone or acting in combination with any of the other health-influencing factors (e.g., mountain pine beetle or fire) we recorded approximately 43% (421 trees) of the dead trees as positive for blister rust, whereas the remaining 57% (554 trees) of dead trees had no signs of infection prior to death.

Documented mortality of tagged trees peaked in 2009 and 2010 with approximately 65% (637 trees) of the dead trees examined recorded as dead within those two years (Figure 6). The estimated overall proportion of recently dead whitebark pine trees was approximately 20% in the GYE (SE=4.35%) at the end of the revisit time-step. The probability of mountain pine beetle-induced mortality increased as DBH increased. The generally observed possible synergistic effect of mountain pine beetle and blister rust on whitebark pine mortality was that smaller-DBH trees with evidence of infection on the bole had a higher estimated probability of mortality from mountain pine beetle compared to trees with no or low blister rust infection (<20 cm DBH).

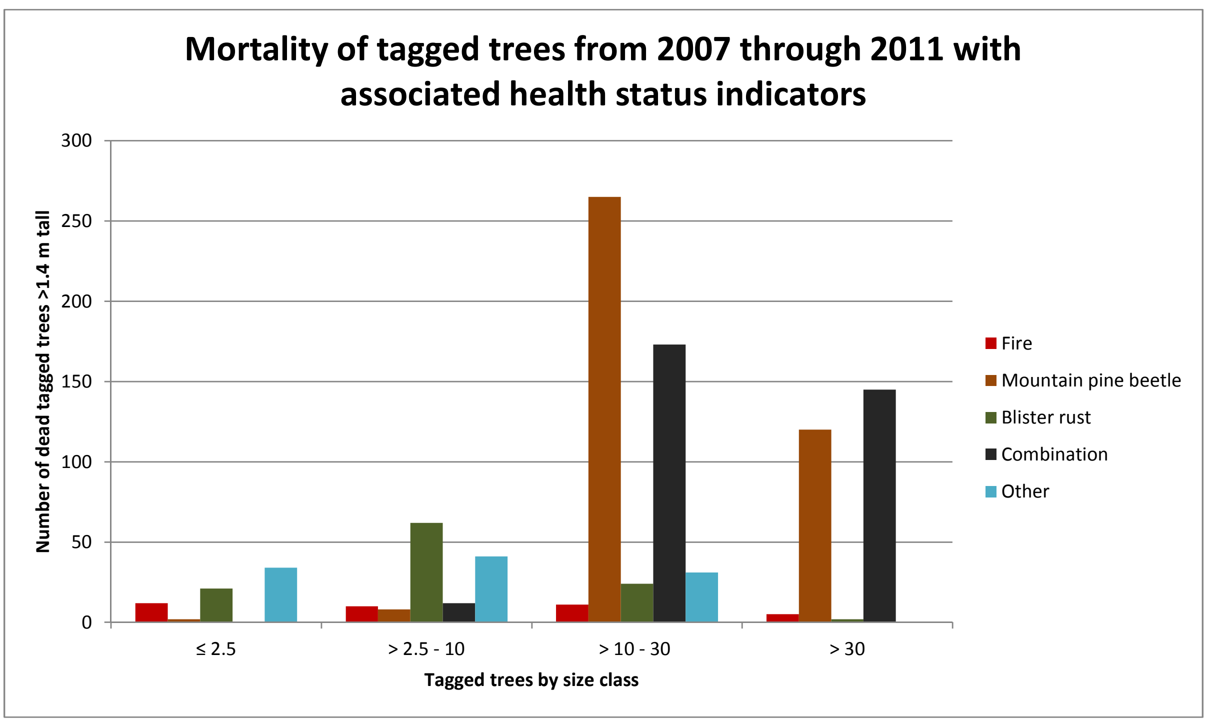
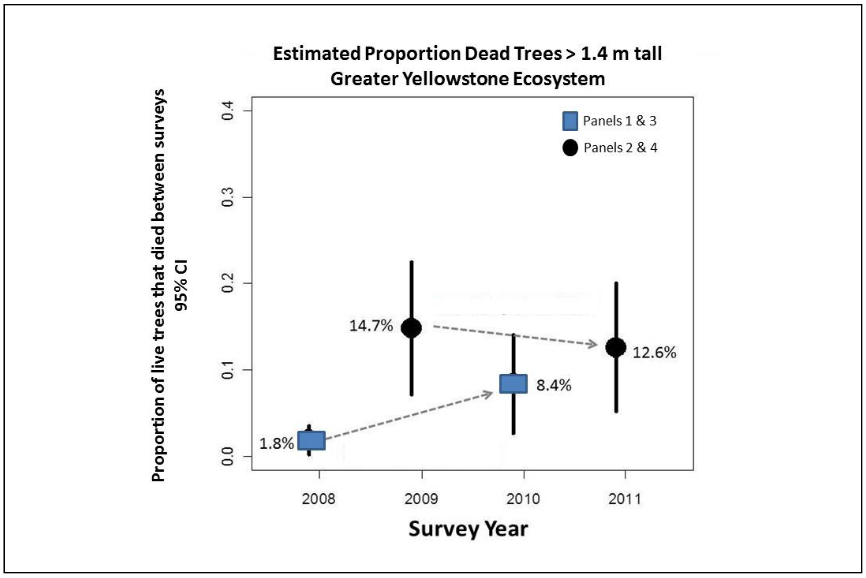


Figure 5. Mortality of tagged trees on all four panels by size class and indicators such as fire, mountain pine beetle, and blister rust.

Figure 6. Mortality estimates of whitebark pine trees >1.4 m tall in the GYE at two-year intervals based on pooled data that ignores strata membership. We surveyed panels 1 and 3 in 2008 and 2010 and panels 2 and 4 in 2009 and 2011. The directional arrows indicate the comparisons between years when the same panels were visited.



Objective 4: Recruitment

We assessed recruitment by tracking the number of cone-producing trees and recording new seedlings and saplings in the understory. We tagged 287 trees that grew to >1.4 m tall since the initial time-step.

Cone-producing Trees

Reproducing trees made up approximately 24% (996 trees) of the total live tagged population at the end of the revisit time-step (Figure 7). Although we documented reproduction across all four size classes, the smaller-DBH trees usually did not produce as many cones. These typically younger trees tended to have fewer canopy branches and less overall canopy volume compared to their larger-DBH counterparts. Seventeen trees were documented with an unknown reproductive status, while 76% (3,085) had no observable signs of past, present, or future cone production.

Understory Seedlings and Saplings

Differentiating between whitebark pine and limber pine seedlings or saplings is problematic given the absence of cones or cone scars. Therefore, understory summaries as presented in this report may include individuals of both species when they are sympatric in a stand. The density of trees ≤1.4 m tall averaged 53 understory trees per 500 m^2. Raw counts of these understory individuals ranged from 0-635 small trees per belt transect (Figure 8). We documented only 64 of these small trees as having some level of blister rust infection.

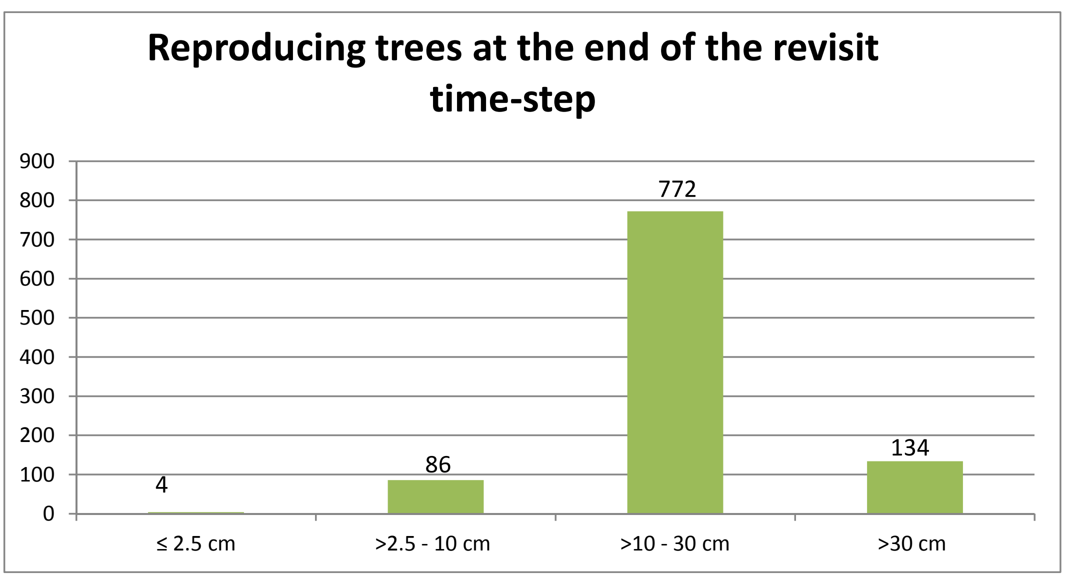


Figure 7. Reproducing tagged trees (996) in the belt transect population at the end of the revisit time-step differentiated by size class.

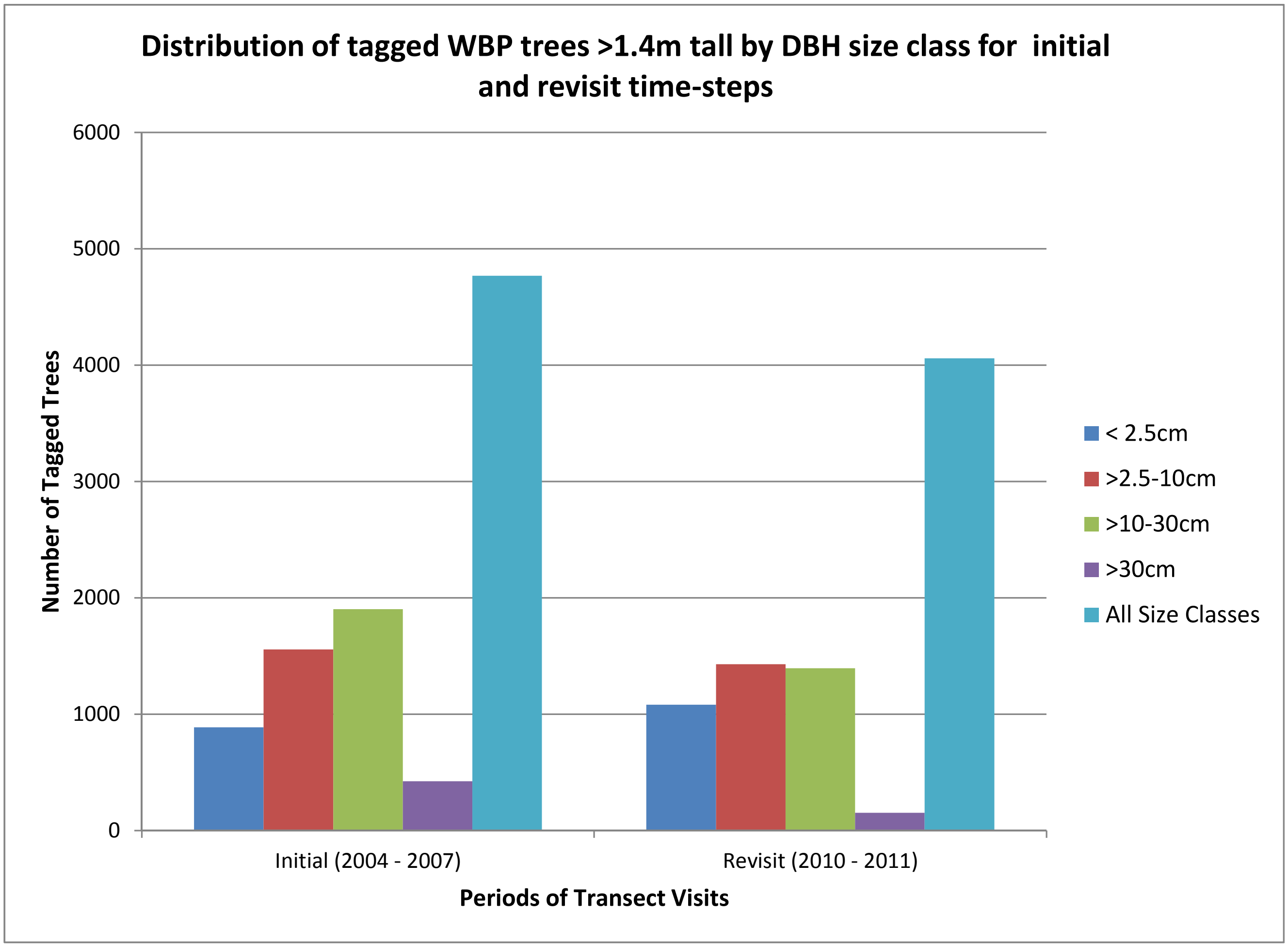


Figure 8. Variability in the distribution of tagged trees across the monitoring belt transects at the end of 2011.

Whitebark pine cones (left) and male pollen cones (right).

Discussion

The estimated proportion of whitebark pine trees infected with blister rust in the GYE was similar between the two time-steps. The overall percentage of whitebark pine trees >1.4 m tall infected with blister rust in the GYE was estimated to be between 20% and 30%. While variation (increases and decreases) in blister infection occurred across the 176 monitoring transects and resulted in shifts in the proportion of infection for the majority (77%) of stands, we detected no significant difference between the time-steps on an ecosystem level. From an ecological perspective, we recognize that the mortality event that occurred between the initial time-step and the revisit time-step (influenced by mountain pine beetle, fire, blister rust, and other causes) had the potential to impact the overall infection proportion in the GYE. In our analysis process, we did not find strong evidence to support this notion. We found that mortality decreased the number of trees in the sample with mountain pine beetle and fire acting as the major drivers of mortality. Trees with or without blister rust were attacked or killed by mountain pine beetle and fire in relatively equal numbers.

When we initiated the monitoring program in 2004, mountain pine beetle populations were just beginning to increase in the GYE (Hayes 2013, Olliff et al. 2013). At the time, whitebark pine mortality levels attributable to mountain pine beetle were relatively low and mountain pine beetle was considered a secondary threat to whitebark pine, in contrast to the ubiquitous pathogen, blister rust. As monitoring efforts transitioned from initial transect establishment to revisits, however, field data captured the shift in magnitude from what most observers considered endemic levels of mountain pine beetle infestation to those of epidemic proportions (Logan et al. 2010, Hayes 2013, Olliff et al. 2013). The ensuing mortality within the whitebark pine population was predominantly exhibited by those trees >10 cm DBH and congruent with known mountain pine beetle size preferences (Furniss and Carolin 1977). Within the 176 permanently established belt transects, roughly 50% of the trees initially tagged in the initial time-step were >10 cm DBH (GYWPMWG 2012; Figure 9). Approximately 36% of the tagged trees in this >10 cm DBH size class had some degree of blister rust infection. Consequently, as the mortality of infected tagged trees occurred on monitored belt transects, the proportion of infection for a given belt transect was affected (following the monitoring protocol, we evaluated only live trees for the presence of blister rust infection). At the same time, we documented 423 tagged trees as transitioning from uninfected in the initial time-step to infected in the revisit time-step. Therefore, it is plausible that mountain pine beetle-caused mortality of infected trees combined with gains in new infections observed in the revisit time-step resulted in neither a net gain nor loss in overall proportion of trees infected with blister rust by the end of the revisit time-step.

The monitoring program is distinguished by the extensive volume of data collected from repeat sampling of tagged whitebark pine trees over an extended period of time. Other accounts of blister rust levels in the GYE are, for the most part, founded on data derived from short-term studies where infection change over time is not measurable (Larson and Kipfmueller 2010, Bockino and Tinker 2012, Kendall et al 1996). In addition, unlike the monitoring program effort, many of these studies and their subsequent reports are centered on specific areas within the GYE. In 2007, Grand Teton NP staff established 26 additional permanent monitoring transects in the park modeled after the Interagency Whitebark Pine Monitoring Protocol (GYWPMWG 2011; in addition to the two established by the monitoring program) and found that the proportion of trees infected with blister rust fluctuated annually with a range from 34-60% in samples collected from 2007 to 2013 (McCloskey pers. com).

Infection severity of blister rust has been defined in many ways by multiple studies (Newcomb 2003, Six and Adams 2007,

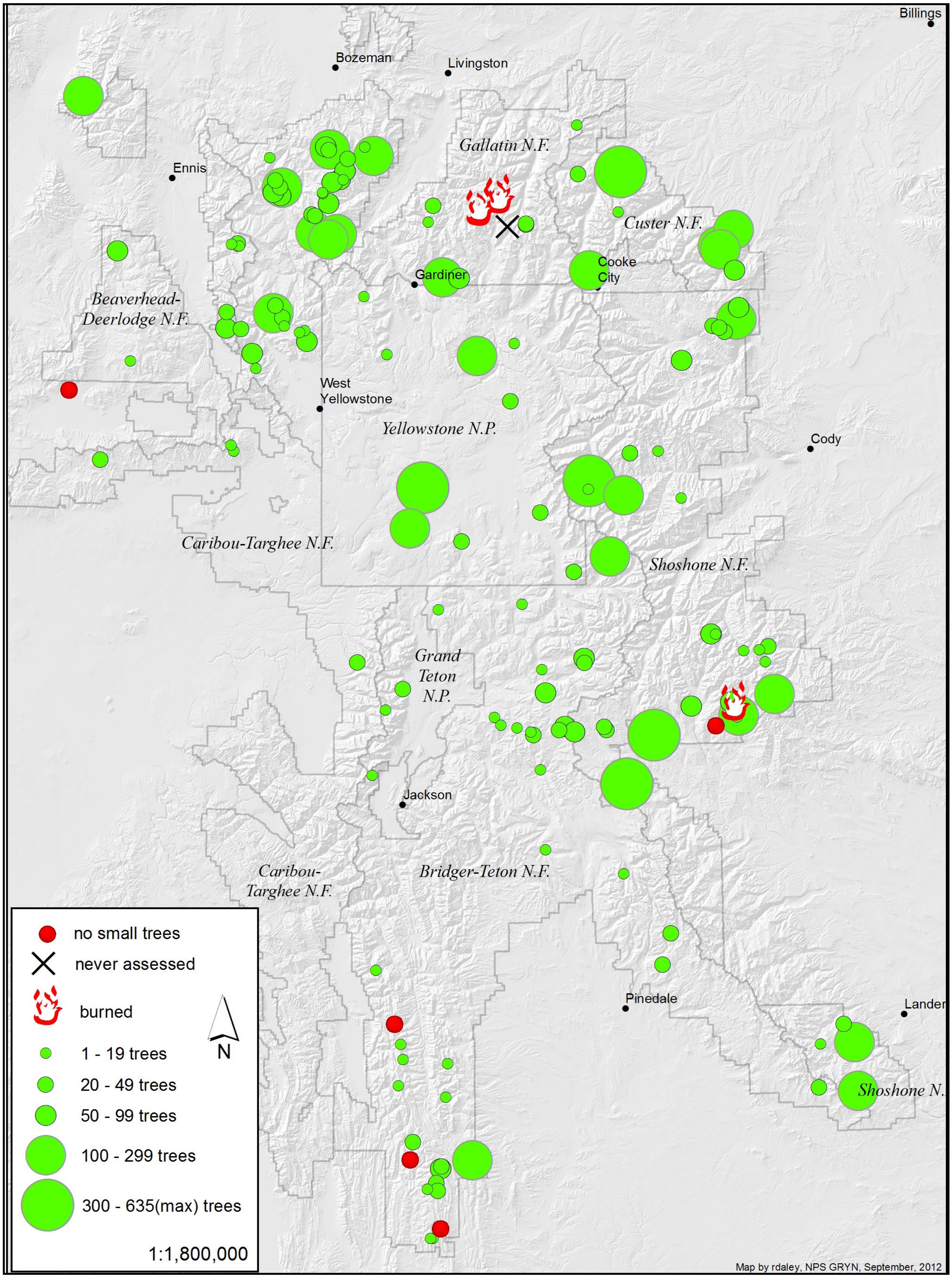


Figure 9. Maximum count of ≤1.4 m tall whitebark pine trees (per 500 m^2) in monitored stands from surveys 2004 through 2011.

Six and Newcomb 2006). The monitoring program distinguishes infection severity by the specific location of infection on a diseased tree (GYWPMWG 2011). Infection severity fluctuated between the two time-steps. Some trees documented as infected during the initial time-step, no longer exhibited visible signs of infection when surveyed in the revisit time-step. For example, we recorded a total of 174 tagged trees with some level of infection during the initial time-step, but upon revisit were absent of infection. We regarded this as a transition in infection status from infected to non-infected. As observed in several species of white pine, branches with blister rust cankers further than 0.6 m from the main bole of the tree can self-prune (Maloy 2001). With this type of self-pruning, infection may no longer be detectable on a tree that possessed observable cankers when initially inspected.

Another explanation for decreased signs of infection in subsequent revisits is that cankers can change phenotypically as they age and with normal environmental exposure. As outlined in the Greater Yellowstone Whitebark Pine Monitoring Protocol (GYWPMWG 2011), a canker without visible aecia can be recorded as a positive blister rust infection when there is evidence of three of five possible secondary indicators of blister rust infection identified on a tree. These secondary indicators include flagging, swelling, roughened bark, rodent/insect chewing or stripped bark, and oozing sap (Hoff 1992). Over time, due to natural aging and weathering of the tree, it is possible that a canker may no longer meet the established set of indicator standards (see GYWPMWG 2011). If these specifications are not met, then infection criteria may simply not be noted during subsequent examinations, regardless of a previous infection state.

Lastly, although established procedures are implemented to minimize observer variability as a component of the monitoring program, this variability may play a role in both individual tree and proportional changes in infection (Huang 2006). Any of these scenarios may be acting separately or in combination to affect infection rate summaries and are all potential explanations for the shift in infection observed at the stand level. As the monitoring program evolves, we will take steps to quantify the confounding effects of each factor in order to understand how they are influencing recorded rates of infection.

By the end of the revisit time-step, approximately 57% of blister rust infections occurred on the bole of infected trees. This type of blister rust infection is considered to be more consequential than a canopy canker, as it compromises not only the overall longevity of the tree, but its functional capacity for reproductive output as well (Kendall and Arno 1990, Campbell and Antos 2000, McDonald and Hoff 2001, Schwandt and Kegley 2004). Though a tree can live for decades infected with blister rust (Mielke 1937, McDonald et al. 1981), an infected tree may be more vulnerable to other stressors such as mountain pine beetle (Six and Adams 2007, Bockino and Tinker 2012). Results from more recent investigations into this potential interaction indicate an additive pathogen-insect effect on mortality occurred only in smaller-DBH trees.

In addition to potentially increasing the susceptibility to other stressors, blister rust can affect a tree's ability to reproduce (Smith and Hoffman 2000, Maloney et al. 2012). Cones are produced on the outer branches in the upper canopy of whitebark pine; portions of a branch that are located above an active canker are often precluded from vital nutrients necessary to sustain normal tree function, healthy foliage, and cone production (Maloney et al. 2012). As a result, death of infected upper branches can occur and negatively impact cone production. Although there has been no significant change in the overall proportion of trees infected with blister rust in the GYE, monitoring data indicate that many of the trees that remained alive and infected between the initial time-step and the revisit time-step transitioned from a less lethal (canopy) form of infection to one considered more detrimental (bole) to the health and

status of the tree. We plan to evaluate the possible influence of time and DBH on canker transition in future analyses.

Infection by blister rust is a relatively slow process and it can take up to four years before infection is physically apparent to an observer (McDonald and Hoff 2001). Two time-steps comprising only eight years of data collection may not be adequate to fully describe the extent of blister rust infection on the whitebark pine population. As the monitoring program continues, we expect more precise estimates on its overall effects in the GYE.

Mortality of whitebark pine occurred in all DBH size classes since the initial transect establisment. Although no specific cause of mortality is ascribed to dead trees in the monitoring program, we documented conditions that potentially influence the mortality of a given tree. Mountain pine beetle infestation was evident on the majority of recorded dead whitebark pine >10 cm DBH in the belt transect population (Figure 5). Slowly building in the early 2000s, the mountain pine beetle outbreak intensified around 2007 (Hayes 2013, Olliff et al. 2013). The subsequent mortality that followed became demonstrably evident throughout the GYE and was particularly apparent in and around 2009 and 2010 (Figure 6). Mortality levels in the monitoring belt transects coincided with the period described by others (Hayes 2013, Olliff et al. 2013); though in some cases, documentation of mortality may have been delayed due to the modified two-year revisit timeline. For example, we may have documented a particular tree as live, successfully attacked by mountain pine beetle, and with a fading crown in 2008, but not recorded an actual mortality until 2010 when crews observed that tree during the assigned panel revisit schedule.

White pine blister rust was the sole attribute in 13% of the total number of dead tagged trees by the end of the revisit time-step.

Along with mountain pine beetle and blister rust, whitebark stands have also been affected by wildland fires across the ecosystem. Between the two time-steps, six of the 150 monitoring stands had been affected by wildland fire. Under projected climate change conditions, wildland fire events are predicted to increase in the GYE (Westerling et al. 2011). Consequently, we expect an increase in the number of stands affected by fire in the future.

Although approximately 20% of the tagged tree population has died, we observed reproducing trees, regeneration in the understory, and recruitment into the tagged tree population. We documented 26% of the live tree population as producing cones, demonstrating that there is some seed present on the landscape. Regeneration varies dramatically across the 176 belt transects. Counts of whitebark pine trees ≤1.4 m tall ranged from 0 to 635 trees per 500 m^2 belt transect (Figure 9). Our estimates suggest that there are about 50 five-needle pines ≤1.4 m tall per 0.04 ha. In addition, by the end of the revisit time-step, we tagged an additional 287 new trees within the belt transects that had grown into the >1.4-m tall height category.

NPS ERIN SHANAHAN

Dead whitebark pine overstory at Sweetwater Gap, Bridger-Teton National Forest.

Conclusions

Throughout the past decade in the GYE, monitoring has helped document shifts in whitebark pine forests; whitebark pine stands have been impacted by insect, pathogen, wildland fire, and other events. Blister rust infection is ubiquitous throughout the ecosystem and infection proportions are variable across the region. For instance, we observed a higher prevalence of blister rust on the monitoring transects in the northwestern portion of the study area compared to transects located in the southeastern part of the Wind River Range (Figure 10). We also observed an estimated loss of approximately 20% of whitebark pine trees >1.4 m tall across the GYE at the end of the revisit time-step in 2011. It is important to note that estimates presented here reflect data collected from ground-based monitoring efforts as opposed to other studies that report higher estimates of mortality based on aerial and remote sensing detection (McFarlane et al. 2013, Logan et al. 2010). Remote sensing tends to focus on canopy-occupying individuals. On the monitoring belt transects, mortality in the overstory constituted approximately 42% (414 trees) of the trees recorded as dead by the end of the revisit time-step. Overstory trees ranged in size from 11.5-122 cm DBH and were recorded as >10 m in height.

Monitoring belt transects reflect the overall trend in whitebark pine stands throughout the GYE. Mortality of overstory cohorts in many stands throughout the GYE has prompted considerable interest and emphasized the need for investigating the growth of the whitebark pine understory. Due to the potential for observers to miss understory whitebark pine trees within the extensive bounds of a 10x50 m belt transect, we piloted additional efforts in 2010 to more accurately assess recruitment of small trees into the >1.4 m height category. In addition, we consider overall species competition and the effects of canopy openings on whitebark pine understory growth. This aspect is a recent addition to the monitoring program protocol, and we will incorporate our results into future reports.

The monitoring program continues to impart meaningful information to the broader regional assessment of trends in the health and status of whitebark pine. The monitoring program acts as an important resource for a variety of organizations embarking on five-needle pine monitoring and has provided contemporary data to agencies such as the U.S. Fish and Wildlife Service, which listed whitebark pine as warranted but precluded under the Endangered and Threatened Species Act (USFWS 2011).

We provide this step-trend report as a quantifiable baseline for understanding the state of whitebark pine in the GYE. Many aspects of whitebark pine health are highly variable across the range of its distribution in the GYE. Through sustained implementation of the monitoring program, we will continue efforts to document and quantify whitebark pine forest dynamics as they arise under periodic upsurges in insect, pathogen, fire episodes, and other climatic events in the GYE. Since its inception, this monitoring program perseveres as one of the only sustained long-term efforts conducted in the GYE with a singular purpose to track the health and status of this prominent keystone species.

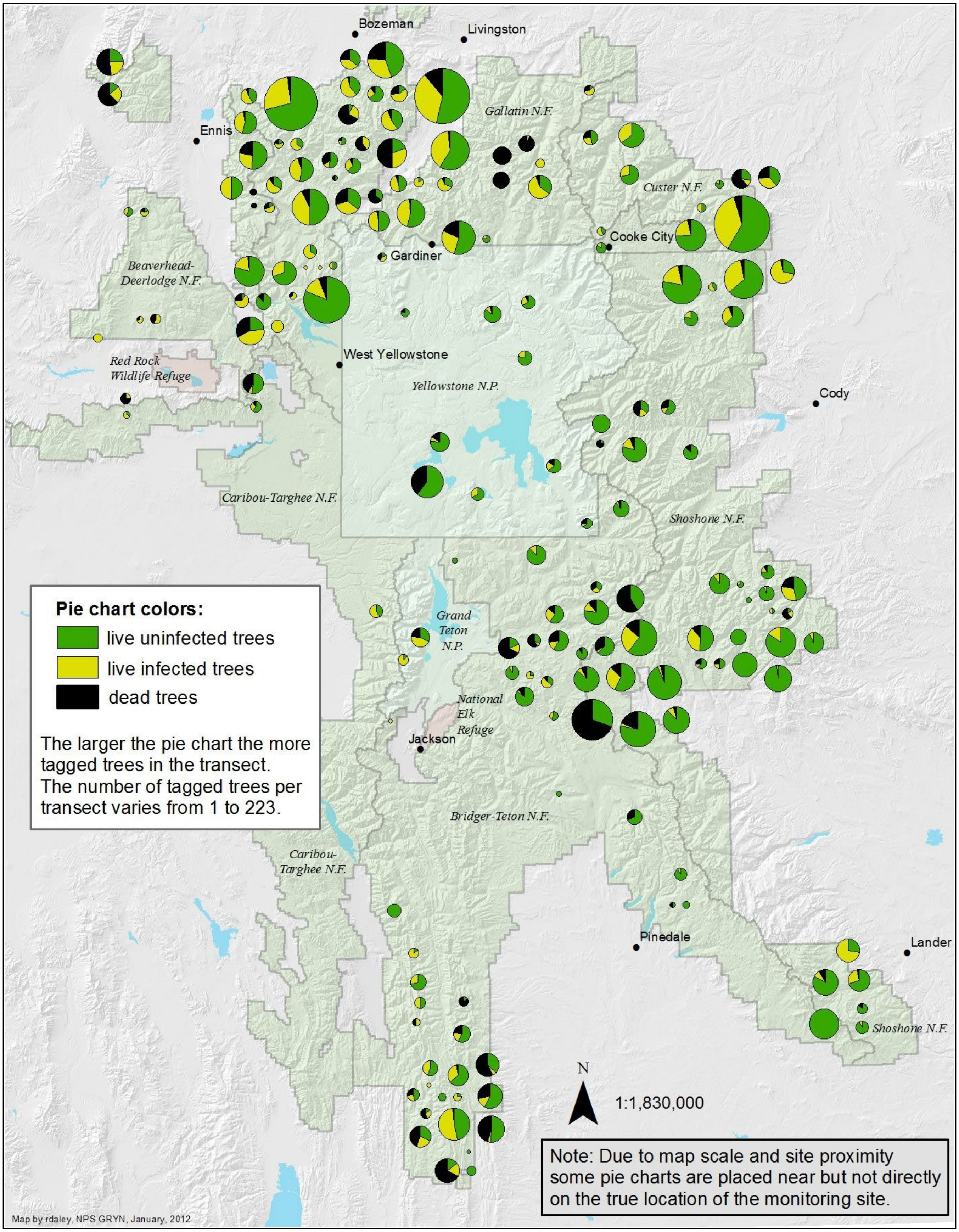


Figure 10. Distribution of blister rust-infected trees in sampled transects in the GYE at the end of 2011.

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Appendix A Field Form

Site 10596-2 | **Panel 3 Full Survey** | **2014 GYE Interagency WBP Monitoring Program** | TREE DATA SHEET | version: 2/3/2014

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

Always enter Tree ID, DBH, and Height Class for new trees

For Independent-observer Surveys, EACH observer records their own values with no interaction with other crew members.

MPB Pitch Tubes	MPB Frass
0 = 0 pitch tubes	0 =no frass
1 = 1-5 pitch tubes	1 = frass less than 30%
2 = > 5 pitch tubes	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 curent-year cones	

Tree ID (tag no.) (grn = L, red = D, brn=RD)	Tree Species	Observer's Initials	Clump Number	Clump Letter	DBH (cm)	Height Class (1-3)	Tree Status (L, RD, D)	Branch Cankers Upper Third A	Branch Cankers Upper Third I	Branch Cankers Middle Third A	Branch Cankers Middle Third I	Branch Cankers Bottom Third A	Branch Cankers Bottom Third I	Bole Cankers Upper Third A	Bole Cankers Upper Third I	Bole Cankers Middle Third A	Bole Cankers Middle Third I	Bole Cankers Bottom Third A	Bole Cankers Bottom Third I	Indicators: Rodent Chewing	Indicators: Flagging	Indicators: Swelling	Indicators: Roughened Bark	Indicators: Oozing Sap	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 (see above)	Tree Health Code(s) (Use only valid codes from Protocol)
60	PIAL		-	-	1	1																								
61	PIAL		1	a	6.5	1																								
62	PIAL		1	b	8	2																								
63	PIAL		2	a	5	1																								
64	PIAL		2	b	3.5	1																								
65	PIAL		-	-	3.5	1																								
66	PIAL		-	-	4	1																								
67	PIAL		-	-	5	1																								
68	PIAL		-	-	2	1																								
69	PIAL		-	-	5.5	1																								
70	PIAL		-	-	1	1																								
173	PIAL		-	-	3	1																								

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

Tree ID	Comment

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.

NPS 101/126860, 136/126860 October 2014

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