National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Summary of Preliminary Step-trend Analysis from the Interagency Whitebark Pine Long-term Monitoring Program—2004-2013

Prepared for the Interagency Grizzly Bear Study Team

Natural Resource Data Series NPS/GRYN/NRDS—2014/600

ON THE COVER

Top: Whitebark pines (photo by J. Fothergill).
Bottom: Whitebark pine cones (photos by J. Fothergill) and grizzly bear (photo by J. Peaco)

Summary of Preliminary Step-trend Analysis from the Interagency Whitebark Pine Long-term Monitoring Program—2004-2013

Prepared for the Interagency Grizzly Bear Study Team

Natural Resource Data Series NPS/GRYN/NRDS—2014/600

Authors

Greater Yellowstone Whitebark Pine Monitoring Working Group
Bozeman, Montana 59715

Prepared by

Kristin Legg, Erin Shanahan, and Rob Daley

Greater Yellowstone Inventory and Monitoring Network
National Park Service
2327 University Way, Suite 2
Bozeman, Montana 59715

Kathryn M. Irvine

U.S. Geological Survey
Rocky Mountain Science Center
Bozeman, MT 59715

Editor

Nina Chambers

Northern Rockies Conservation Cooperative
P.O. Box 2705
Jackson, WY 83001

January 2014

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

Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols. This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

This report is available from http://science.nature.nps.gov/im/units/gryn/.index.cfm and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/). To receive this report in a format optimized for screen readers, please email irma@nps.gov.

Please cite this publication as:

Greater Yellowstone Whitebark Pine Monitoring Working Group. 2014. Summary of preliminary step-trend analysis from the Interagency Whitebark Pine Long-term Monitoring Program—2004-2013: Prepared for the Interagency Grizzly Bear Study Team. Natural Resource Data Series NPS/GRYN/NRDS—2014/600. National Park Service, Fort Collins, Colorado.

NPS 101/123424, January 2014

Contents

Figures

Tables

Acknowledgements

We thank the all the field technicians and volunteers who braved the bugs, snow, rain, and long-distance hikes to collect these data. We thank former Greater Yellowstone Network ecologist Rob Bennetts for his contributions to the sample design and development of the monitoring protocol, and Steve Cherry from Montana State University for ensuring statistical validity to the sampling regime. We thank the many individuals who have provided advice and field and logistic support over the past 10 years. Base funding for this program was provided by the NPS Greater Yellowstone Inventory & Monitoring Network. Additional funding and in-kind support for this program is provided by the USDA Forest Service Forest Health Monitoring, USDA Forest Service Evaluation Monitoring, U.S. Geological Survey, the Greater Yellowstone Coordinating Committee, the U.S. Fish and Wildlife Service, the USDA Forest Service, and from Yellowstone and Grand Teton national parks.

Members of the Greater Yellowstone Whitebark Pine Working Group include:

Jodie Canfield, Forest Biologist
USDA Forest Service
Gallatin District, Gallatin National Forest

Gregg DeNitto, Forest Pathologist
USDA Forest Service
Forest Health Protection

Karl Buermeyer, Subcommittee Chair
USDI Greater Yellowstone Coordinating Committee
Whitebark Pine Subcommittee

Frank VanManen, Study Team Leader
USDI Geological Survey
Interagency Grizzly Bear Study Team

Kathi Irvine, Statistician
USDI Geological Survey

Kristin Legg, Program Manager
Rob Daley, Data Manager
Erin Shanahan, Field Ecologist/Crew Leader
USDI National Park Service
Greater Yellowstone Inventory and Monitoring Network

Kelly McCloskey, Vegetation Ecologist
USDI National Park Service
Grand Teton National Park

Dan Reinhart, Vegetation Resources Program Manager
USDI National Park Service
Yellowstone National Park

Dave Roberts, Department Head
Montana State University
Department of Ecology

Introduction

In mixed and dominant stands, whitebark pine (*Pinus albicaulis*) occurs in over two million acres within the six national forests and two national parks that comprise the Greater Yellowstone Ecosystem (GYE). Currently, whitebark pine, an ecologically important species, is impacted by multiple ecological disturbances; white pine blister rust (*Cronartium ribicola*), mountain pine beetle (*Dendroctonus ponderosae*), wildfire, and climate change all pose significant threats to the persistence of whitebark pine populations. Substantial declines in whitebark pine populations have been documented throughout its range.

Under the auspices of the Greater Yellowstone Coordinating Committee (GYCC), several agencies began a collaborative, long-term monitoring program to track and document the status of whitebark pine across the GYE. This alliance resulted in the formation of the Greater Yellowstone Whitebark Pine Monitoring Working Group (GYWPMWG), which consists of representatives from the U.S. Forest Service (USFS), National Park Service (NPS), U.S. Geological Survey (USGS), and Montana State University (MSU). This ground-based monitoring program was initiated in 2004 and follows a peer-reviewed protocol (GYWPMWG 2011). The program is led by the Greater Yellowstone Inventory and Monitoring Network (GRYN) of the National Park Service in coordination with multiple agencies. More information about this monitoring effort is available at: http://science.nature.nps.gov/im/units/gryn/monitor/whitebark_pine.cfm.

The purpose of this report is to provide a draft summary of the first step-trend analysis for the interagency, long-term monitoring of whitebark pine health to the Interagency Grizzly Bear Study Team (IGBST) as part of a synthesis of the state of whitebark pine in the GYE. Due to the various stages of the analyses and reporting, this is the most efficient way to provide these results to the IGBST.

JOHN FOTHERGILL

Whitebark pine in the high country of the Greater Yellowstone Ecosystem.

Study Design and Methods

The following results are preliminary and based on analyses of data presented in published reports and draft manuscripts currently being prepared or under review. The two draft manuscripts that use the interagency long-term whitebark pine monitoring data in the GYE are focused on investigating the association of mountain pine beetle and white pine blister rust with whitebark pine mortality (Irvine et al. in review), and completing the first step-trend analysis for white pine blister rust infection (Shanahan et al. in prep). Included in these preliminary results are provisional 2013 field data, and therefore subject to change in interpretation.

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, there may be an insignificant amount of variability (typically <1% difference) 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.

Overview of the Monitoring Sample Design and Strategy

Target population: All whitebark pine stands in the GYE

Sampling frame: Mapped stands of whitebark pine greater than 2.5 ha and not recently burned (i.e., after 1970)

Number of stands mapped: 10,770 (8,408 within the grizzly bear recovery zone; 2,362 outside the recovery zone)

Number of stands monitored: 150

Number of transects: 176 (some stands have two transects in order to look at within-stand viability); transect =10x50 m plot

Trees: Whitebark pine trees greater than1.4 m tall are tagged within a transect. The number of tagged whitebark pine trees changes as trees die (i.e., mortality) and others grow to 1.4 m tall and are tagged (i.e., recruitment).

Panels: Transects were randomly assigned to four panels (i.e., temporal sampling strata) in 2008; approximately 44 transects are assigned to each panel (Figure 1).

Survey Schedule: Following the study design outlined in the monitoring protocol (GYWPMWG 2011), 176 transects were established and initial surveys were conducted from 2004 to 2007. Transects were then portioned into temporal sampling strata (termed "panels") and scheduled for resurvey every four years. From 2008 to 2013, we increased the frequency of tree mortality surveys from every four years to every two years during the mountain pine beetle outbreak. Transects partitioned to Panels 1 and 3 were resurveyed in years 2008, 2010, and 2012, whereas transects portioned to Panels 2 and 4 were resurveyed 2009, 2011, and 2013.

YEAR	ACTIVITY
2004 -2007	176 transects established, initial surveys conducted on all transects
2008, 2010, 2012	Panel 1 and Panel 3 resurveyed
2009, 2011, 2013	Panel 2 and Panel 4 resurveyed

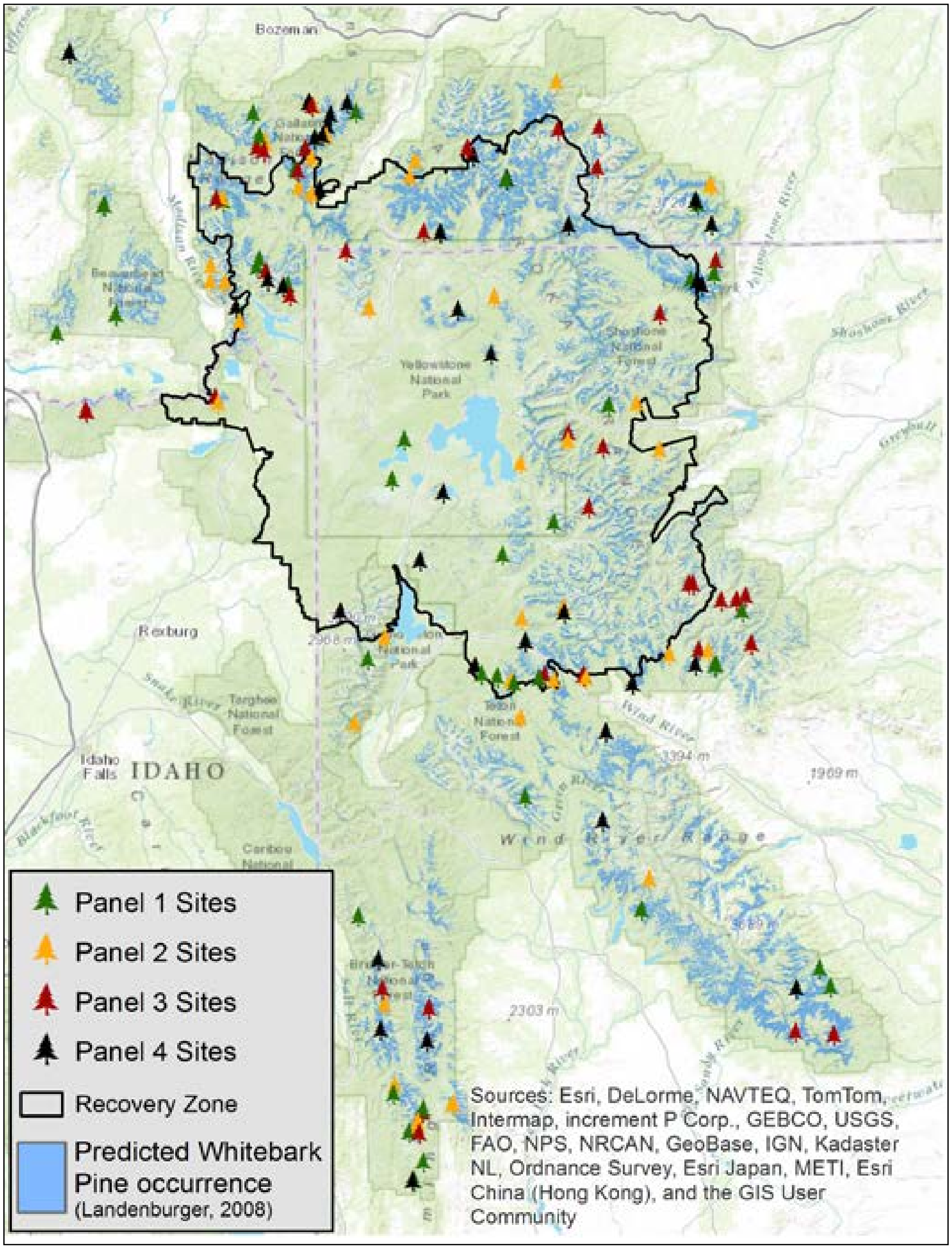


Figure 1. Location of whitebark pine survey transects, Greater Yellowstone Ecosystem. The black line denotes the grizzly bear recovery zone boundary and the light blue shading indicates the predicted areas of whitebark pine (Landenburer 2008).

Objectives

Generally, the overall objective of this whitebark pine long-term monitoring program is to detect and monitor change in the whitebark pine population across the GYE due to infection by white pine blister rust, attack by mountain pine beetle, and affects from other environmental and anthropogenic agents. Specifically, the monitoring protocol (GYWPMWG 2011) describes the following four objectives:

Objective 1 - To estimate the proportion of whitebark pine trees (>1.4 m in height) within the Greater Yellowstone Ecosystem (Grand Teton and Yellowstone national parks and the Gallatin, Beaverhead-Deerlodge, Caribou-Targhee, Bridger Teton, Shoshone, and Custer national forests) infected with white pine blister rust, and to estimate the rate at which infection of trees is changing over time.

Objective 2 - Within infected transects, to determine the relative severity of infection (i.e., stage and magnitude of infection and proportion of canopy kill) and to estimate the change in severity over time of white pine blister rust in whitebark pine trees >1.4 m tall within the Greater Yellowstone Ecosystem (two national parks and six national forests).

Objective 3 – To estimate survival of individual whitebark pine trees >1.4 m tall in the Greater Yellowstone Ecosystem (two national parks and six national forests), explicitly taking into account the possible association with the presence and severity of white pine blister rust infection, infestation by mountain pine beetle, and fire.

Objective 4 – Assess recruitment of whitebark pine ≤1.4 m into the cone-producing population (the specifics of this objective are under development).

Results by Objective

Following are the results for each objective with the report or manuscript cited from which the information was derived.

Objective 1: White pine blister rust infection in whitebark pine trees >1.4 meters tall and change in infection rate over time (see Shanahan et al. in prep, GYWPMWG 2013).

This monitoring program is designed to estimate the percent of white pine blister rust infection in live whitebark pine trees >1.4 m within the GYE after each four-year survey interval. A paired t-test is completed to document change at the transect level between time periods while a design-based ratio estimator is used to provide an overall estimate of the prevalence of white pine blister rust for the GYE. This ratio estimator is appropriate for this monitoring program, since it is a two-stage cluster sampling design with variable number of trees within each transect and the size of each whitebark pine stand is different (Lohr 2010). In the case of stratified sampling, a separate or combined ratio estimator can be used for estimating proportion (Lohr 2010). We present both the separate and combined ratio estimators for the two time periods (2004-2007 and 2008-2011) based on stratification by the grizzly bear recovery zone (inside or outside) and land management administrative unit (forest or park units;Table 1).

Comparing white pine blister rust infection by transect between the initial survey visit period (2004-2007) and the first revisit period (2008-2011), we detected no significant difference in the presence of blister rust infection using a paired t-test (paired t (df)=175, p=0.15). Using the design-based ratio estimator, we estimated 20-30% of whitebark pine trees >1.4 m are infected with white pine blister rust across the GYE. This percent was similar when we used either a separate or combined ratio estimator (Table 1).

The next analysis for rates of blister rust infection will occur after 2015 when all 176 transects have been surveyed a third time for white pine blister rust infection.

Table 1. Design-based ratio estimates for the percent of infected whitebark pine trees >1.4 m tall in 2004-2007 and 2008-2012 survey periods (Shanahan et al. in prep.).

Survey Period	2004-2007	2008-2011
Number of Transects	176	176
Number of Stands	150	150
Number of Live Tagged Trees	4,742	3,680
Proportion Transects Infected	81%	86%
Separate Ratio Estimates		
Proportion of live trees infected	25%	27%
Proportion of live trees infected Standard Error (SE)	2%	2%
Confidence Interval (CI) for proportion of live trees infected	[20%, 29%]	[23%, 32%]
Combined Ratio Estimates		
Proportion of live trees infected	23%	23%
Proportion of live trees infected Standard Error (SE)	3%	3%
Confidence Interval (CI) for proportion of live trees infected	[16%, 29%]	[18%, 29%]

Objective 2: Relative severity of blister rust infection and change in severity over time in whitebark pine >1.4 m tall (see Shanahan et al. in prep).

The severity of white pine blister rust infection is an indicator of the health of whitebark pine. Following the protocol data collection methods (GYWPWG 2011), a live tree >1.4 m tall is recorded as not having blister rust or having blister rust infection with the locations of infection recorded as either in the canopy (branch canker) or on the bole of a tree. Bole cankers are considered more lethal to a tree. For each survey period (2004-2007 and 2008-2011) we calculated the total number of trees that were infected with either type of canker, and the transition from uninfected to infected or infected to uninfected (Table 2), and the number of trees that exhibited canker transition (branch to bole or bole to branch) between the initial visit period and the subsequent revisit.

At the end of 2011, our sample included over 3,780 live trees >1.4 m tall. Of these, approximately 1,203 were recorded with blister rust infection and 2,577 as uninfected. We have investigated relationships of transition from branch to bole cankers in the step-trend analysis report (Shanahan et al. in prep) and will continue to analyze these transitions in the future to better understand if the changes noted here are within the expected natural range.

Table 2. White pine blister rust infection transition for 3,780 live trees >1.4 m tall between two time periods, initial surveys (2004-2007) and the first resurvey (2008-2011). Trees either remained uninfected or infected, or changed from uninfected to infected or infected to uninfected (Shanahan et al. in prep.).

Transition	Remained Unifected	Remained Infected	Uninfected to Infected	Infected to Uninfected
Number of Live Trees	2,404	788	415	173

JOHN FOTHERGILL

Whitebark pine bearing cones.

Objective 3. Estimated survival of whitebark pines >1.4 meters tall taking into account the effect of blister rust infection, mountain pine beetle, and fire.

In order to track whitebark pine tree mortality across the GYE during the mountain pine beetle epidemic, we increased the frequency of surveying panels from four years to every two years from 2008 to 2013. Therefore, Panels 1 and 3 where visited in 2008, 2010, and 2012 and Panels 2 and 4 in 2009, 2011, and 2013.

Whitebark Pine Mortality Estimates for the Greater Yellowstone Ecosystem

Appendix A provides an in-depth description of the analysis for whitebark pine mortality in the GYE using the long-term monitoring data and includes the provisional 2013 field data. In addition, data and methods are presented in a manuscript under revision (Irvine et al. in review) and the draft step-trend analysis report (Shanahan et al. in prep.).

To estimate whitebark pine tree mortality across the GYE, we used a non-stratified ratio estimator. We estimated the cumulative proportion of dead whitebark pine trees >1.4 m tall to be 26.9% (95% confidence interval: 18% to 35.7%) for the GYE, since the initiation of the monitoring program in 2004.

When comparing across panel survey years (Panels 1 and 3: 2008, 2010, 2012 and Panels 2 and 4: 2009, 2011, 2013), there appears to be a downward trend in the proportion of trees that had died in 2012 and 2013 since the last survey visits in 2010 and 2011 (Figure 2).

The pattern of the proportion of dead whitebark pine trees >1.4 m tall across years is similar when estimated either inside or outside the grizzly bear recovery zone (Appendix A). While not significantly different, the proportion of mortality was greater in the recovery zone compared to outside the recovery zone, although this pattern was reversed in 2013 when mortality was greater outside the recovery zone.

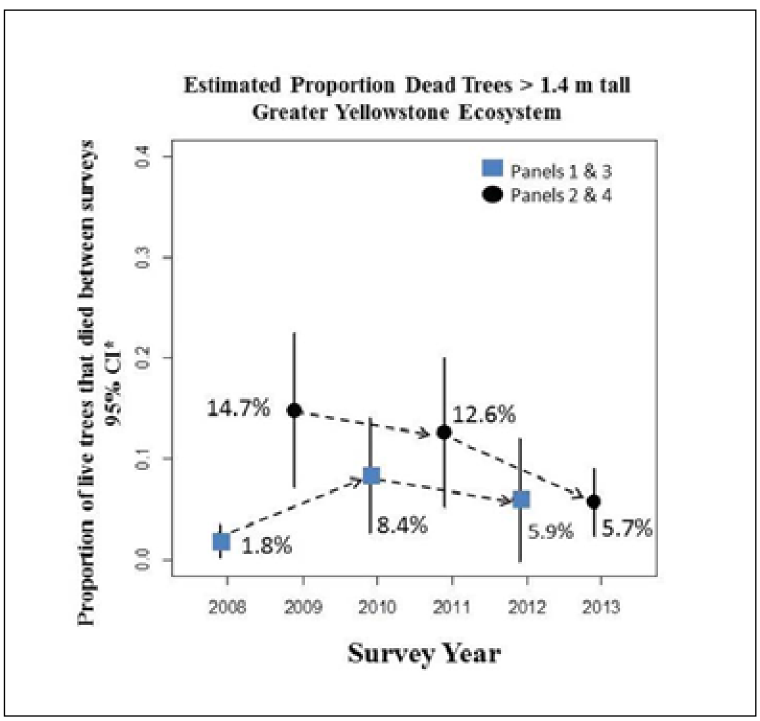


Figure 2. Ratio estimates for the proportion of trees >1.4m tall that had died in the GYE since last surveyed. The directional arrows indicate the comparisons between panel survey years (Panels 1 and 3 surveyed in 2008, 2010, 2012 and Panels 2 and 4 surveyed in 2009, 2011, 2013). These estimates do not account for stratification inside and outside the grizzly bear recovery zone and land management administrative unit.

Mortality estimates at the individual tree level (whitebark pine trees >1.4meters tall)

The following summarizes data from the long-term, interagency whitebark pine monitoring database at the end of the 2013 field season. Similar figures were presented in the monitoring program's 2012 annual data summary report (GYWPMWG 2013). Here, we have included the provisional 2013 field data.

Since the initiation of the monitoring program in 2004, field crews have tagged over 5,000 live whitebark pine trees >1.4 meters tall within transects. Of the 5,000 trees, over 400 of these trees were tagged during the panel revisits starting in 2008. A tree within a transect boundary is tagged and added to the sample frame after having attained a height of >1.4 m tall.

Of the tagged trees, 1,410 of these were recorded as dead by the end of the 2013 field season. Seventy percent of those dead trees were >10 cm diameter at breast height (DBH; Figure 3). During the initial surveys (2004-2007), 1,897 live trees were >10 cm ≤ 30 cm and 423 live trees were >30 cm DBH; all were tagged for monitoring. At the end of the 2013 field season, 694 (37%) of the tagged trees >10 cm ≤30 cm and 303 (72%) of the tagged trees >30 cm DBH had died.

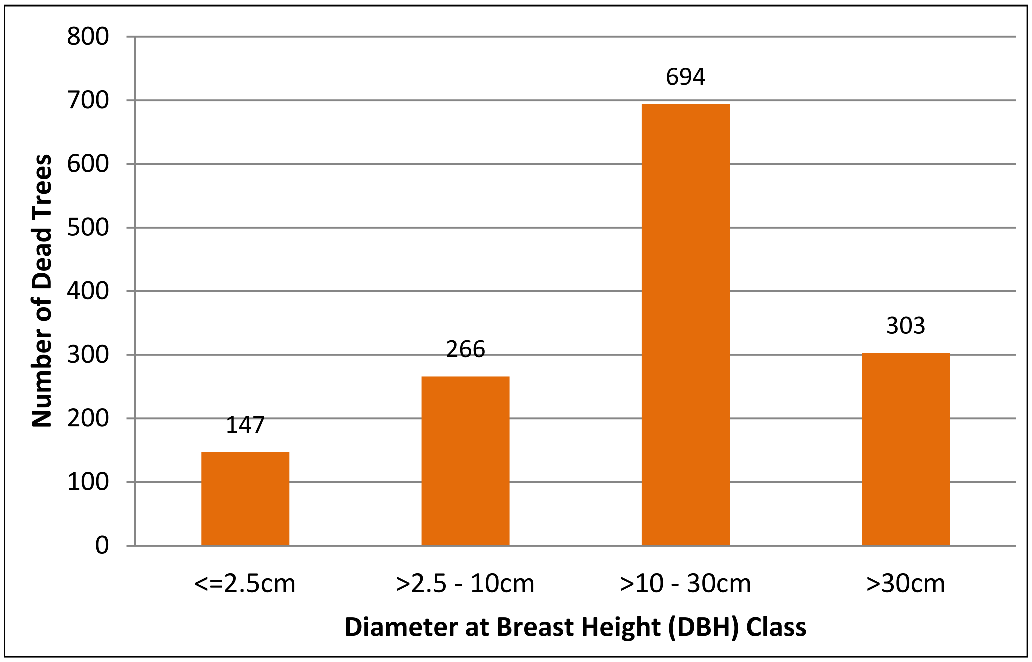
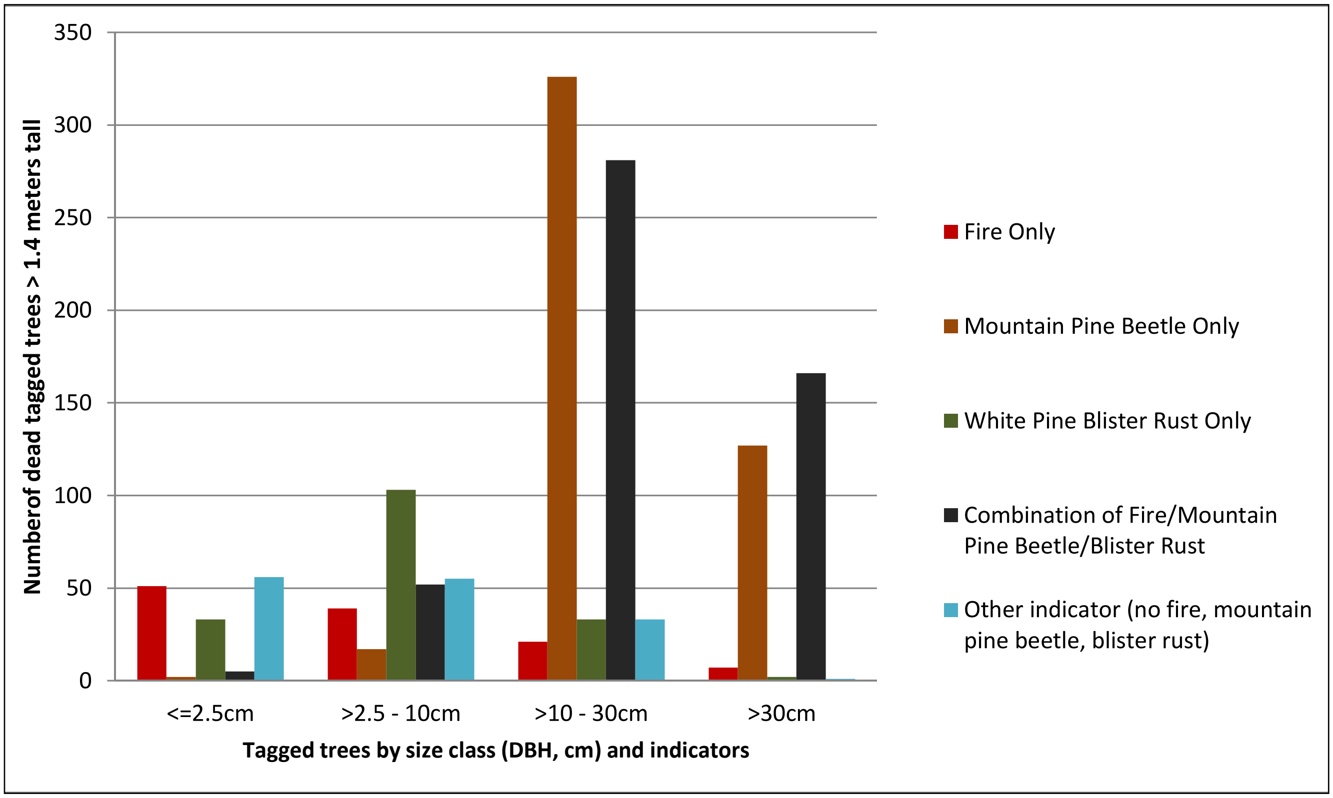


Figure 3. Distribution of the 1,410 dead tagged trees at the end of 2013 into four DBH size classes (≤2.5 cm, >2.5-10 cm, >10-30 cm, and >0 cm).

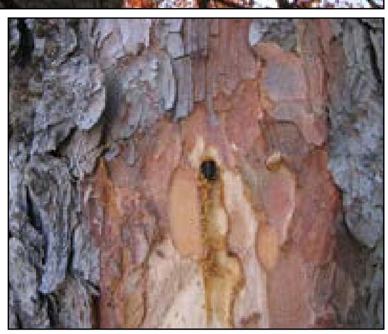
Based on the monitoring protocol, we record various health status indicators (evidence of blister rust, mountain pine beetle, fire, and other such as avalanche, wind fall, structural damage, or unknown). Dead tagged whitebark pine trees >10 cm DBH had more evidence of mountain pine beetle infestation than trees ≤10 cm DBH (Figure 4). As other studies have indicated, this is consistent with mountain pine beetle preference for larger-diameter pine trees.

From the initial surveys through the end of the 2013 field season, 50 of 176 transects (28.4%) had no evidence of mountain pine beetle infestation across all survey visits. A total of 14 (8%) transects have been affected by wildland fire. And while most of these transects have experienced severe, stand-replacing fires, a few transects have retained a handful of surviving trees. In 2012, the Millie Fire on the Gallatin National Forest burned four monitoring transects. During revisit surveys to these four transects in 2013, approximately 170 tagged trees, combined across all four transects, were recorded as dead with sign of fire.



JOHN FOTHERGILL

Figure 4. Mortality of tagged trees since transect establishment through 2013 with associated indicators. Evidence of fire, mountain pine beetle, white pine blister rust, a combination of the three, or other were recorded for each dead tagged tree by DBH size class (≤2.5 cm, >2.5-10 cm, >10-30 cm, and >30 cm).



Following a successful attack, the canopy of an infested whitebark pine rapidly starts to fade from green to red (upper photo). Mountain pine beetle enter host trees through the bark; and as a defense mechanism, the infested tree will attempt to pitch out the beetle resulting in a pitch tube (lower left). Beetles feed in galleries under the bark of the host tree (lower right).

Objective 4. Assess recruitment of whitebark pine trees ≤1.4 meters tall (see Shanahan et al. in prep, GYWPMWG 2013).

Three indices of recruitment of whitebark pine trees are derived from transect surveys: the number of trees ≤1.4 m tall, the number of whitebark pine trees that grow to >1.4m tall, and the number of live whitebark pine trees, regardless of size, that show signs of reproductive activity either by having cones or cone scars present.

As part of the monitoring effort, whitebark pine trees ≤ 1.4 meters tall are tallied within the bounds of the 10x50 m transect. Since 2004, we have counted over 8,700 trees ≤1.4 m tall across all transects. Occurrence of whitebark pine trees ≤1.4 m tall per transect range from zero to over 600. As noted under Objective 3 results, over 400 trees have reached a height of >1.4 m tall and have therefore been added to the tagged tree sample.

Tagged trees are also observed for cone production as indicated by the presence of cones or cone scars. Figure 5 shows the number of reproducing live tagged trees at the end of 2013. It is interesting to note that cones have also been observed on a few smaller whitebark pine trees (≤2.5 cm DBH).

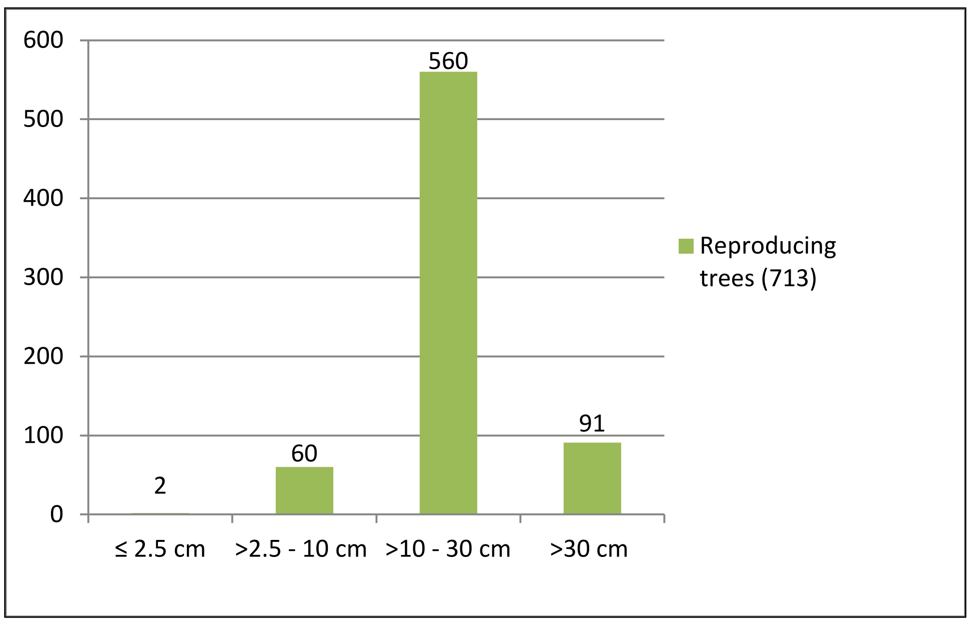


Figure 5. The number of live tagged trees recorded as reproducing across all panels at the end of 2013 by DBH size class (≤2.5 cm, >2.5-10 cm, >10-30 cm, and >30 cm).

JOHN FOTHERGILL

RACHAEL SIMONS

New whitebark pine seedlings.

Conclusion

In summary, this report provided a compilation of preliminary trend results from the interagency whitebark pine monitoring program in the GYE. We anticipate the step-trend analysis of data collected between 2004 and 2011 to be completed in 2014 (Irvine et al. in review, Shanahan et al. in prep). Monitoring is scheduled to continue into the future and following the panel revisit schedule, Panel 3 is scheduled for resurvey in 2014. The next opportunity to complete an analysis comparing data across time periods will be after 2015 when we will have completed a revisit to all four panels.

ERIN SHANAHAN

Bear claw marks on a whitebark pine trunk.

ERIN SHANAHAN

As a result of their deep and sturdy roots, whitebark pine snags, often referred to as ghost trees, remain an iconic fixture on the landscape for decades.

Literature Cited

Greater Yellowstone Whitebark Pine Monitoring Working Group (GYWPMWG). 2013. Monitoring whitebark pine in the Greater Yellowstone Ecosystem: 2012 annual report. Natural Resource Data Series NPS/GRYN/NRDS—2013/498. National Park Service, Fort Collins, Colorado.

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.

Irvine, K., C. Holliman, E. Shanahan, and K. Legg. In review. Evaluating synergistic effects of an introduced pathogen and native bark beetle on whitebark pine mortality.

Landenburger, L., R. L. Lawrence, S. Podruzny, and C. C Schwartz. 2008. Mapping regional distribution of a single tree species: Whitebark pine in the Greater Yellowstone Ecosystem. *Sensors* 8(8):4983-4994.

Lohr, S. 2010. Sampling: design and analysis, 2nd edition. Brooks/Cole Cengage Learning, Boston, Massachusetts. pp. 145-146.

Shanahan, E. K., K. Irvine, C. Holliman, K. L. Legg. In prep. Health and status of whitebark pine in the Greater Yellowstone Ecosystem: A trend analysis from 2004-2007 and 2008-2011.

Appendix A Design-based whitebark pine mortality estimates for interagency monitoring program: 2008-2013

November 14, 2013

Prepared by Dr. Kathi Irvine, USGS, for the Greater Yellowstone Network, NPS

The following statistical estimates are based on data gathered by the interagency whitebark pine monitoring group. The sampling design is a two-stage cluster sample with randomly selected mapped whitebark pine polygons (hereafter, "stands") within and outside of the recovery zone. One or two permanent belt transects (10x50 m) were randomly placed within each stand for long-term monitoring. We use a design-based estimator for the proportion of dead whitebark pine greater than 1.4 m tall within the Greater Yellowstone Ecosystem.

Two of the four panels were surveyed for tree mortality each year from 2008 through 2013, alternating years when the same two panels were surveyed. Specifically, Panels 1 and 3 were surveyed in 2008, 2010, and 2012 and Panels 2 and 4 were surveyed in 2009, 2011, and 2013. As surveys have been conducted each year, we report the estimates by year. To assess patterns in mortality across years comparisons should be made among even or odd years such that comparisons are based on the same set of stands.

We estimate the proportion of dead whitebark pine using the ratio estimator (Lohr 2010). Let $\bar{y}_i$ equal the average number of dead trees for stand *i*, $\bar{x}_i$ equal the average number of trees (live and dead) per stand *i*, M_i is the area of stand *i*, the ratio estimator is

$$\hat{B}_h = \frac{\sum M_i \bar{y}_i}{\sum M_i \bar{x}_i} \quad \text{for a given strata h} \qquad (1)$$

The variance estimate for a given strata is

$$\hat{V}(\hat{B}_h) = [(n(n-1)(\overline{M_i \bar{x}_i})^2]^{-1} \sum (M_i \bar{y}_i - \hat{B}_h M_i \bar{x}_i)^2 \qquad (2)$$

For the separate ratio estimator we use a weighted average of the strata specific estimates for both the point estimate and the variance estimate. Specifically, the point estimate is

$$\hat{B}_{sep} = \sum_{h=1}^{H} \frac{N_h}{N} \hat{B}_h \qquad (3)$$

and the variance estimator is

$$\widehat{V(\hat{B}_{sep})} = \sum_{h=1}^{H} (\frac{N_h}{N})^2 \hat{V}(\hat{B}_h) \qquad (4)$$

For further details refer to the protocol (GYWPMWG 2011).

Using the non-stratified ratio estimator, the estimated cumulative proportion of dead trees >1.4 m tall based on the original tagged trees is 26.9% (95% confidence interval: 18% to 35.7%). This is for tree mortality documented regardless of indicator (blister rust, mountain pine beetle, fire, other) since the initiation of the monitoring program. We visually display the estimates in Figures A1 and A2 and report them in tabular form in Table A1 and Table A2.

If we ignore the recovery zone boundaries and simply pool all the data together and then apply the ratio estimator (Equations 1 and 2), the estimated proportion of dead trees shows a downward trend based on the 2012 and 2013 data (Figure A1).

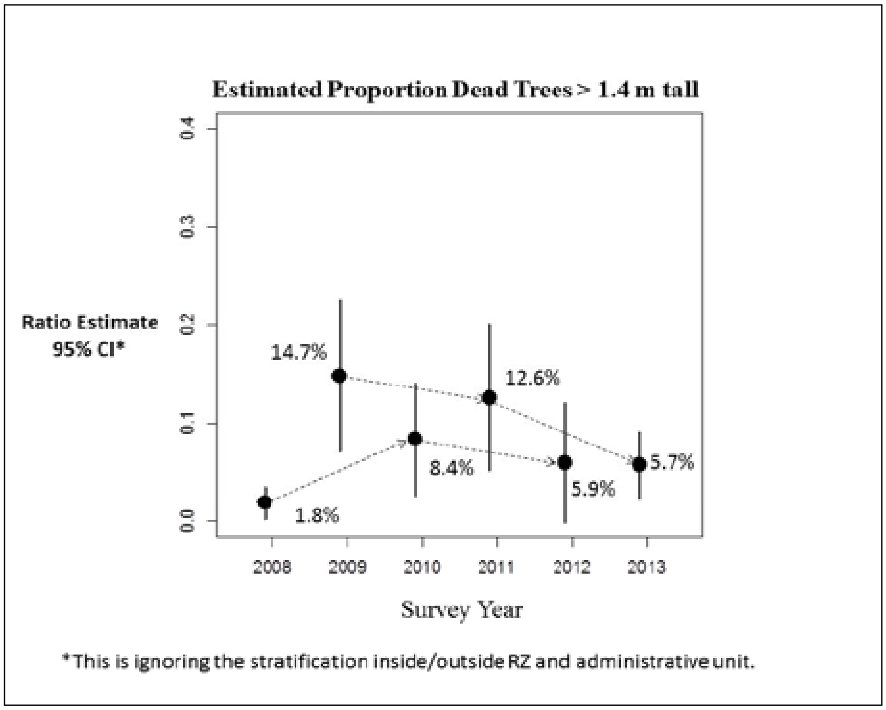


Figure A1. Ratio estimate based on pooling data and ignoring strata membership. Panels 1 and 3 were surveyed in 2008, 2010, and 2012 and Panels 2 and 4 were surveyed in 2009, 2011, and 2013. The directional arrows indicate the comparisons among years when the same panels were visited.

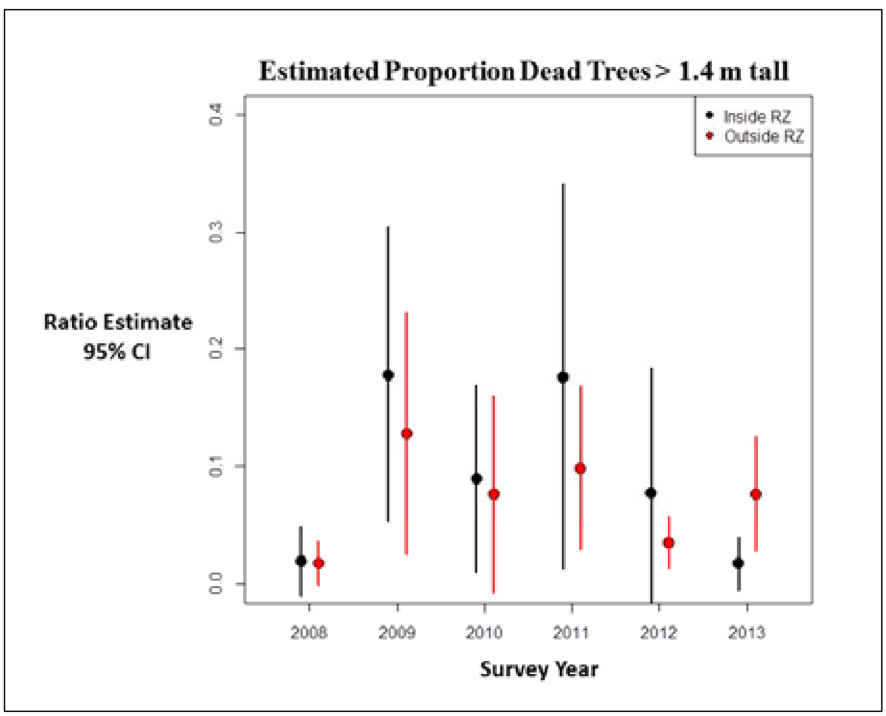


Figure A2. Ratio estimates for the proportion of dead whitebark pine trees >1.4 m tall within the recovery zone (RZ) and outside the recovery zone by year. Panels 1 and 3 surveyed in 2008, 2010, and 2012 and Panels 2 and 4 surveyed in 2009, 2011, and 2013.

Table A1. Overall estimated proportion of dead trees within the GYE using a separate ratio estimator (Equations 3 and 4) and just a ratio estimator (ignoring strata, pooling data and using equations 1 and 2; presented in Figure A1). Sample size is the number of stands visited each year and within each stand there were one or two transects.

Mortality Design-Based Estimates Separate Ratio Estimates, assuming stratification inside and outside the recovery zone					
	Proportion Dead Trees >1.4 m tall	SE proportion	Lower 95% CI	Upper 95% CI	Sample Size
2008	0.018	0.008	0.002	0.033	73
2009	0.139	0.042	0.056	0.223	76
2010	0.080	0.034	0.013	0.146	74
2011	0.116	0.032	0.052	0.180	75
2012	0.045	0.014	0.016	0.073	73
2013	0.063	0.019	0.026	0.101	74
Ratio Estimates, Ignoring Stratification					
2008	0.018	0.009	0.001	0.035	73
2009	0.148	0.039	0.071	0.225	76
2010	0.084	0.029	0.027	0.141	74
2011	0.126	0.037	0.052	0.200	75
2012	0.059	0.031	-0.002	0.120	73
2013	0.057	0.017	0.023	0.091	74

Table A2. Estimates displayed in Figure A2. Sample size is the number of stands visited each year and within each stand there were one or two transects.

Inside the Grizzly Bear Recovery Zone					
	Proportion Dead Trees >1.4 m tall	SE proportion	Lower 95% CI	Upper 95% CI	Sample Size
2008	0.019	0.014	-0.010	0.048	30
2009	0.179	0.062	0.053	0.304	34
2010	0.090	0.039	0.010	0.169	30
2011	0.177	0.080	0.014	0.340	32
2012	0.078	0.052	-0.028	0.184	30
2013	0.017	0.011	-0.005	0.040	32
Outside the Grizzly Bear Recovery Zone					
	Proportion Dead Trees >1.4 m tall	SE proportion	Lower 95% CI	Upper 95% CI	Sample Size
2008	0.018	0.009	-0.001	0.036	43
2009	0.128	0.051	0.026	0.231	42
2010	0.077	0.042	-0.007	0.161	44
2011	0.099	0.034	0.030	0.168	43
2012	0.035	0.011	0.013	0.057	43
2013	0.076	0.024	0.028	0.125	42

The estimated proportion of dead trees greater than 1.4 m tall within the recovery zone was greater than outside the recovery zone for 2008 until 2012, but was less than outside the recovery zone in 2013 (based on using Equations 1 and 2, Figure A2). Both strata display similar patterns that indicate a decline in mortality from 2010 to 2012 and 2011 to 2013.