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Status of Whitebark Pine in the Greater Yellowstone Ecosystem

A Step-Trend Analysis with Comparisons from 2004 to 2019

Examining a whitebark pine tree in the Bridger-Teton National Forest, Wyoming.
NPS / ERIN SHANAHAN

Status of whitebark pine in the Greater Yellowstone ecosystem: A step-trend analysis with comparisons from 2004 to 2019

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Abstract

Whitebark pine (*Pinus albicaulis*) is a high-elevation conifer of western North America. Its nutritious cones are forage for the federally threatened grizzly bear (*Ursus arctos*), Clark's nutcracker (*Nucifraga columbiana*), red squirrel (*Tamiasciurus hudsonicus*), and numerous other subalpine species. It is a pioneer species in harsh, exposed subalpine zones, creating microclimates that help other conifers establish, such as subalpine fir (*Abies lasiocarpa*). However, substantial damage from a nonnative pathogen, white pine blister rust (*Cronartium ribicola*), unprecedented mountain pine beetle (*Dendroctonus ponderosae*) outbreaks, fire, and drought, have contributed to the widespread decline of whitebark pine in high-elevation forests throughout its range. The resulting mortality, particularly of large cone producing trees, has led to losses in cone production and declines in the ecosystem services provided by whitebark pine. Consequently, it was listed as a federally threatened species in 2023 by the U.S. Fish and Wildlife Service. Given the long-standing concerns for this high-elevation keystone species, the Greater Yellowstone Network has been monitoring whitebark pine as part of the Interagency Greater Yellowstone Ecosystem Whitebark Pine Monitoring Program since 2004. This program tracks whitebark pine population condition and trends on National Park Service, U.S. Forest Service, and Bureau of Land Management lands in the region. This report documents the prevalence of blister rust infection, tree mortality, and recruitment of whitebark pine and compares results of the current time-step period 2016 to 2019 with earlier time-step periods since monitoring began. Tree mortality has continued to stabilize after peaking in 2008 to 2011, with 219 new trees dying from 2016 to 2019. Further, we tagged an additional 240 trees in 2016 to 2019 that passed the >1.4 m height threshold for monitoring. This was an increase in the number of new trees tagged over the previous 2012 to 2015 period. Estimates of blister rust infection prevalence are higher than previously reported due to an improved modeling approach, but within each sampling period, they have consistently remained at approximately 30% of all whitebark pines in the Greater Yellowstone Ecosystem infected. Additionally, nearly half of trees observed with cones or cone scars were infected with blister rust. We continued to observe a decline in tree diameter size, with a shift towards smaller diameter trees after heavy mortality due to the mid 2000s beetle outbreak, fire, and disease. This remains a critical concern because over 94% of cone-producing trees are larger-diameter trees. These changes are tracked in detail through continued annual monitoring and regular trend reporting.

Background

Whitebark pine (*Pinus albicaulis*) is an upper subalpine conifer of the northern Rocky Mountains and the Sierra Nevada Mountains north to the Cascades in the Pacific West. It is a keystone species that strongly influences the community assembly and productivity of high-elevation ecosystems (Tomback et al. 2001). Whitebark pine is considered a "pioneer" species due to its tolerance of harsh environmental conditions and ability to establish and persist where other species cannot. In doing so, whitebark pine can alter the microclimate and enable species such as subalpine fir (*Abies lasiocarpa*) to establish in these otherwise inhospitable regions (Tomback et al. 1993). Although whitebark pine has very little commercial value, its seeds provide seasonal forage for a variety of wildlife, including grizzly bears (*Ursus arctos*), red squirrels (*Tamiasciurus hudsonicus*), Clark's nutcrackers (*Nucifraga columbiana*), and a variety of granivorous small mammals.

Throughout its historical range, whitebark pine abundance has significantly decreased as a major component of high-elevation forests due to multiple threats. These threats include nonnative white pine blister rust (*Cronartium ribicola;* blister rust), endemic mountain pine beetle (*Dendroctonus ponderosae*), wildfire, and drought. Because of the persistent, high mortality of whitebark pine and ongoing threats across its range, the U.S. Fish and Wildlife Service listed it as a federally threatened species under the Endangered Species Act in January 2023 (Federal Register 2022). Of significant concern is the death of mature, large-diameter trees that contribute substantially to recruitment and positive population growth, and the resultant loss of ecosystem services that these older trees provide. Understanding these challenges to whitebark pine—not only at the tree- and stand-level, but also at a landscape scale—is critically important to conserve and manage this iconic subalpine conifer in the Greater Yellowstone Ecosystem (GYE).

Purpose and Objectives

To track the health status of whitebark pine in the GYE, several agencies have collaborated since 2004 under the auspices of the Greater Yellowstone Coordinating Committee to implement an interagency whitebark pine monitoring program, led by the National Park Service's Greater Yellowstone Inventory and Monitoring Network. This report summarizes Time-Step 4 (2016–2019) of whitebark pine health status and trend monitoring in the GYE in comparison with the previous three time-steps: Time-Step 1 (2004–2007), Time-Step 2 (2008–2011), and Time-Step 3 (2012–2015). This represents our third step-trend report on whitebark pine health status in the GYE and complements Shanahan et al. (2021), which published much of the novel information for this third trend analysis.

The objectives of the GYE interagency whitebark pine monitoring program are to

1. assess trends in the proportion of live whitebark pine trees (>1.4 m tall) infected with white pine blister rust,
2. document blister rust infection severity and changes over time by the occurrence and location on the tree of new and persisting infections,
3. assess trends in mortality of whitebark pine trees and describe contributing mortality factors, and
4. document the recruitment of whitebark pine into the reproductive population and assess the multiple factors that influence overall recruitment success over time.

Methods

The complete methods for this long-term effort are published by the Greater Yellowstone Whitebark Pine Monitoring Working Group (GYWPMWG) in the *Interagency Whitebark Pine Monitoring Protocol for the Greater Yellowstone Ecosystem* (GYWPMWG 2011), as well as in Article 5 (Methods) of the *Whitebark Pine Monitoring in the Greater Yellowstone Ecosystem* online article series.

In summary, 176 permanent 10 × 50 m belt transects were established within 150 stands of pure and mixed whitebark pine from 2004 to 2007 (Figure 1). We used a design-based statistical sampling method that allowed inference of the monitoring results to the mapped population of whitebark pine in the GYE. All live, >1.4 m tall trees were permanently tagged to enable long-term monitoring of individuals on a four-year rotating schedule. Whitebark pine stand transects were divided into four different panels, each sampled in a different year, so that all transects were sampled at least once every four years (Table 1).

Previous reports for Time-Steps 1, 2, and 3 estimated the proportion of trees infected with blister rust using a design-based ratio estimator suitable for the sampling design (Lohr 2010). Whereas this approach was appropriate for timeframes spanning 2004–2015, recent computational and statistical advances have greatly improved our ability to incorporate the numerous biotic and abiotic factors influencing tree health and to assess species status and trends more accurately across the GYE whitebark pine population. Therefore, in this report, we introduce a model-based approach for estimating blister rust prevalence (comparable with proportion) in the GYE. Non-detection error or the failure of an observer to detect the presence of a species or characteristic of a species is a common source of statistical estimation bias in a field-based, observational monitoring program such as this. Potential bias can influence the efficacy, diminish reliability, and devalue program results. As such, for Time-Step 4, we employed a Bayesian hierarchical model with the flexibility to account for multiple sources of variation, including observer variability (i.e., imperfect detection) in a field-based observational monitoring program such as this (Shanahan et al. 2021). Although we transitioned to this model-based approach beginning in Time-Step 4, we "back-analyzed" the previous three time-steps (Time-Steps 1, 2, and 3) with the Bayesian model to address monitoring objectives related to blister rust detection.

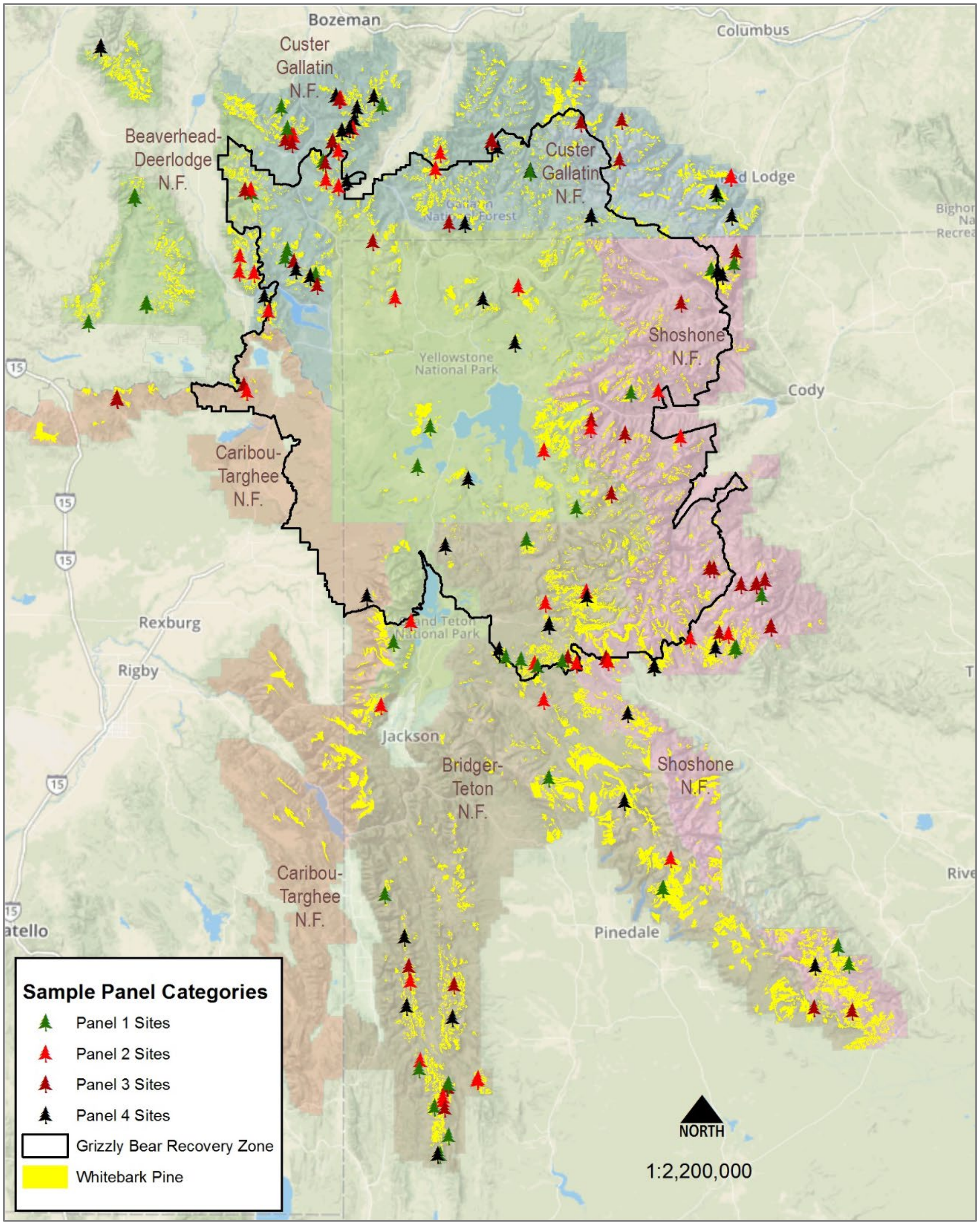

Figure 1. Interagency whitebark pine monitoring program study area in the Greater Yellowstone Ecosystem (all shaded regions). The whitebark pine population layer of this map was assembled in 2004–2006 from multiple data sources: stands larger than 2 ha identified in the 1980s grizzly bear cumulative effects model, and the most current and comprehensive US Forest Service timber stand surveys and ecological unit inventories at the time. Tree stands affected by wildland fire between 1971 and 2002 are excluded. For more information, see [Methods for the Interagency Whitebark Pine Monitoring Program in the Greater Yellowstone Ecosystem](). NPS

Table 1. Panel sampling revisit schedule for whitebark pine in the Greater Yellowstone Ecosystem. The schedule includes full surveys of whitebark pine for blister rust and mortality, and surveys for mortality only conducted during the mountain pine beetle epidemic. This table denotes the designated time series for each time-step assignment (Time-Step 1: 2004–2007 [baseline], Time-Step 2: 2008–2011, Time-Step 3: 2012–2015, Time-Step 4: 2016–2019, Time-Step 5: 2020–2023). NPS

Time-Step	Year(s)	Panel 1 (43 transects)	Panel 2 (45 transects)	Panel 3 (44 transects)	Panel 4 (44 transects)
1	2004–2007	Set up surveys and document initial health status	Set up surveys and document initial health status	Set up surveys and document initial health status	Set up surveys and document initial health status
2	2008	Blister rust and mortality surveys	–	Mortality only surveys	–
	2009	–	Blister rust and mortality surveys	–	Mortality only surveys
	2010	Mortality only surveys	–	Blister rust and mortality surveys	–
	2011	–	Mortality only surveys	–	Blister rust and mortality surveys
3	2012	Blister rust and mortality surveys	–	Mortality only surveys	–
	2013	–	Blister rust and mortality surveys	–	Mortality only surveys
	2014	–	–	Blister rust and mortality surveys	–
	2015	–	–	–	Blister rust and mortality surveys
4	2016	Blister rust and mortality surveys	–	–	–
	2017	–	Blister rust and mortality surveys	–	–
	2018	–	–	Blister rust and mortality surveys	–
	2019	–	–	–	Blister rust and mortality surveys
5	2020	Blister rust and mortality surveys	–	–	–
	2021	–	Blister rust and mortality surveys	–	–
	2022	–	–	Blister rust and mortality surveys	–
	2023	–	–	–	Blister rust and mortality surveys

Results

We report our findings from Time-Step 4 (2016–2019) for the four main monitoring objectives, comparing them across time-steps, since monitoring started in 2004. We also summarize the shift towards smaller whitebark pine trees in the Greater Yellowstone Ecosystem over the four time-steps.

Objective 1: Status of Blister Rust

Similar to prior reports, we did not detect an increase in the proportion of whitebark pine trees infected with blister rust in the GYE over time, via either the design-based ratio estimator or the model-based, Bayesian analysis approach (Table 2). The ratio estimator ignores observation error and any potential heterogeneity in white pine blister rust infection among trees, whereas the Bayesian hierarchical occupancy model accounts for imperfect detection by observers (e.g., observer error) as well as variation or the heterogeneity among tree-level infection probabilities related to tree size (diameter at breast height (DBH)) and elevation. Using the Bayesian hierarchical model, which is more flexible and can account for confounding factors, blister rust prevalence in the GYE has remained near 30% of trees infected: 0.34 (SE = 0.037) in Time-Step 1, 0.32 (SE = 0.036) in Time-Step 2, 0.29 (SE = 0.033) in Time-Step 3, and 0.34 (SE = 0.039) in Time-Step 4 (Table 2; Figure 2). However, the probability of an individual tree becoming infected has increased since 2004 (see Figure 5 in Shanahan et al. 2021). We note that slight, non-statistically different changes from previously reported ratio estimator results may be presented in these data. These changes are a direct result of updates in the database, which include removing improperly tagged trees during site visits. We continue to improve our field methods, data management, and analytical processes over the life of this long-term monitoring program.

Table 2. Design-based ratio estimates of blister rust infection proportion and Bayesian hierarchical occupancy model estimates for blister rust prevalence for whitebark pine in the Greater Yellowstone Ecosystem, 2004–2019. Estimates are reported with standard error, along with 95% confidence intervals (design-based estimator) or 95% credible intervals (Bayesian model).

Estimation Method	Time-Step	Infection Proportion or Prevalence	95% Confidence or Credible Interval
Design-based estimator	2004–2007	0.20 (SE = 0.037)	0.13–0.27
	2008–2011	0.20 (SE = 0.036)	0.13–0.27
	2012–2015	0.17 (SE = 0.040)	0.09–0.25
	2016–2019	0.18 (SE = 0.039)	0.10–0.25
Bayesian hierarchical model	2004–2007	0.34 (SE = 0.037)	0.27–0.42
	2008–2011	0.32 (SE = 0.036)	0.25–0.40
	2012–2015	0.29 (SE = 0.033)	0.22–0.35
	2016–2019	0.34 (SE = 0.039)	0.27–0.42

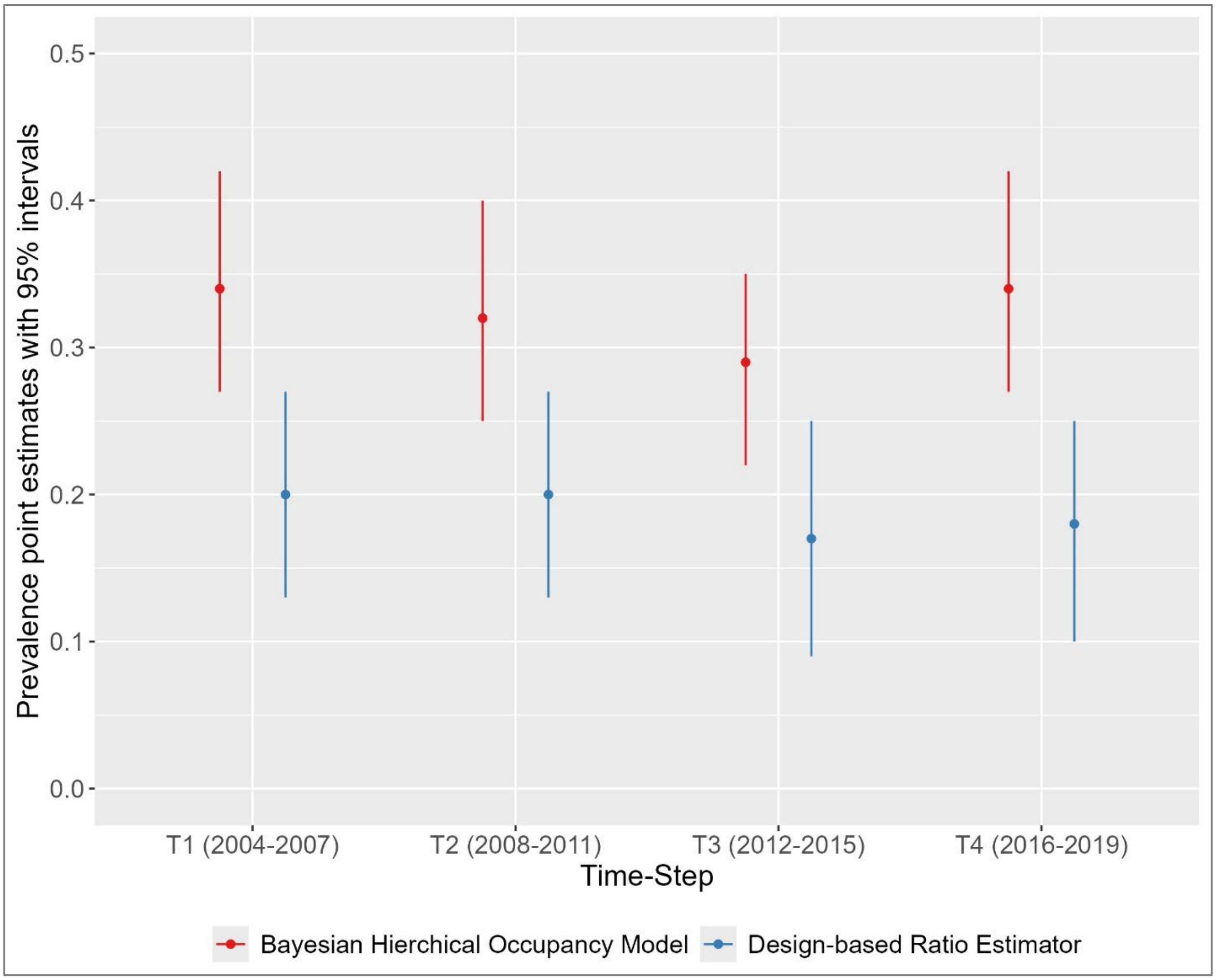

Figure 2. Comparison of estimated blister rust infection prevalence in whitebark pine from 2004 to 2019 based on two different statistical approaches. The Bayesian hierarchical occupancy model is the upper series of estimates, in red, and the design-based ratio estimator is the lower series of estimates, in dark blue. Figure is adapted from Shanahan et al. (2021) for estimating blister rust infection prevalence in whitebark pine in the Greater Yellowstone Ecosystem across four time-steps spanning 2004–2019. NPS

Objective 2: Infection Severity

We examined the location of blister rust infection on the tree to assess severity. Blister rust can infect the canopy (branches) or the bole (trunk) of a tree, or both, with bole infections being more severe.

A 2017 analysis of monitoring data collected from 2004 to 2015 examined observer consensus regarding blister rust presence or absence and location of infection (Wright and Irvine 2017). Their study revealed high agreement among observers for determining presence or absence of blister rust infections; however, they also identified observer discrepancies for the exact location of infections on individual trees. Although we continue to report on blister rust severity based on location and rate of change in the location of the infection, our Objective 2 severity metric is not as reliable as our estimation of infection presence or absence in Objective 1.

At the conclusion of Time-Step 4, we found that 27%, or 1,001 live, tagged trees (out of *n* = 3,687 on all transects) were infected with blister rust. Trees with only canopy cankers represented 34% (343 trees) of the total number of trees infected with blister rust, whereas trees with bole cankers comprised 66% (658 trees) of the infected sample. A bole infection is more consequential than a canopy canker; not only does it compromise the overall longevity of the tree, but it also impedes functional capacity for reproductive output as well (Kendall and Arno 1990).

Over the span of the monitoring program (2004–2019), we chronicled changes in the infection location (canopy or bole) in trees that have remained alive across the 16-year timeframe (Time-Steps 1 to 4). We found that 50% (258) of trees recorded with canopy cankers in Time-Step 1 transitioned to bole cankers by Time-Step 4. For this Time-Steps 1 to 4 comparison, revisits were separated by 9 to 15 years, depending on the transect and its assigned panel revisit schedule. For Time-Steps 3 to 4, which had a more consistent revisit interval of four years for all transects on all panels (with one exception in 2013), only 11% (58) of canopy cankers transitioned to bole cankers. Additionally, once an infection was identified on the bole of a tree, the likelihood of that same tree exhibiting only a canopy canker (bole to canopy 'transition') at a later visit was unlikely. This information demonstrates the value of long-term monitoring to evaluate the implications of the severity of blister rust infection through time.

Objective 3: Whitebark Pine Mortality

Since 2008 through the end of Time-Step 4, we estimated the proportion of mortality occurring in all monitored stands in the GYE as 0.27 (SE = 0.05) with the design-based ratio estimator. We estimated the proportion of whitebark pine >1.4 m tall in the GYE that have died only during Time-Step 4 (2016–2019) as 0.053 (SE = 0.017), based on the design-based ratio estimator (Figure 3). This proportion has continued to stabilize after mortality peaked during Time-Step 2 (2008 to 2011), when mountain pine beetle populations were at epidemic levels (Shanahan et al. 2014). In Time-Step 4, we documented 219 new dead trees. Approximately 14% (*n* = 30) of the dead tagged trees had signs of mountain pine beetle activity, with all of these individuals >10 cm DBH. Wildland fire has also had an impact on whitebark pine in the GYE. Since the initiation of survey revisits in 2008, 16 of the transects have burned, resulting in 248 tagged trees dying with signs of fire burns or scorching. In Time-Step 4, two transects were newly recorded as burned during visits in 2016. Figure 4 shows cumulative mortality over all four time steps by size class and mortality influencing conditions.

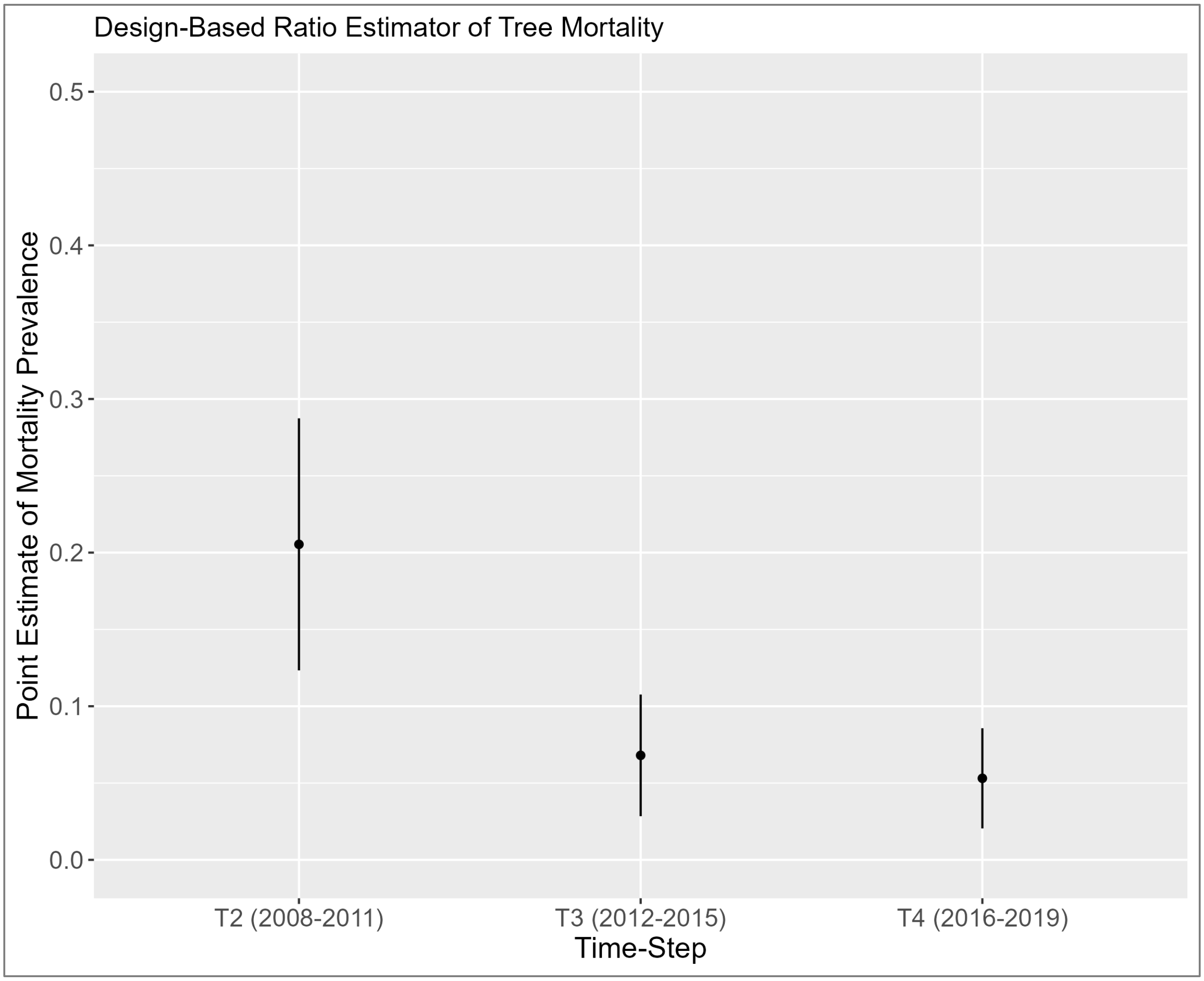

Figure 3. Proportion of dead whitebark pine trees in Greater Yellowstone Ecosystem monitoring plots estimated during each time-step using the design-based ratio estimator, 2008–2019. Dead trees were >1.4 m tall during Time-Step 2 (“T2”, 2008–2011), Time-Step 3 (“T3”, 2012–2015), and Time-Step 4 (“T4”, 2016–2019). The proportion of mortality occurring in Time-Step 1 (2004–2007) is not presented because only live trees were tagged during these visits. Each estimated proportion is distinct for the time-period; it does not represent cumulative mortality. NPS

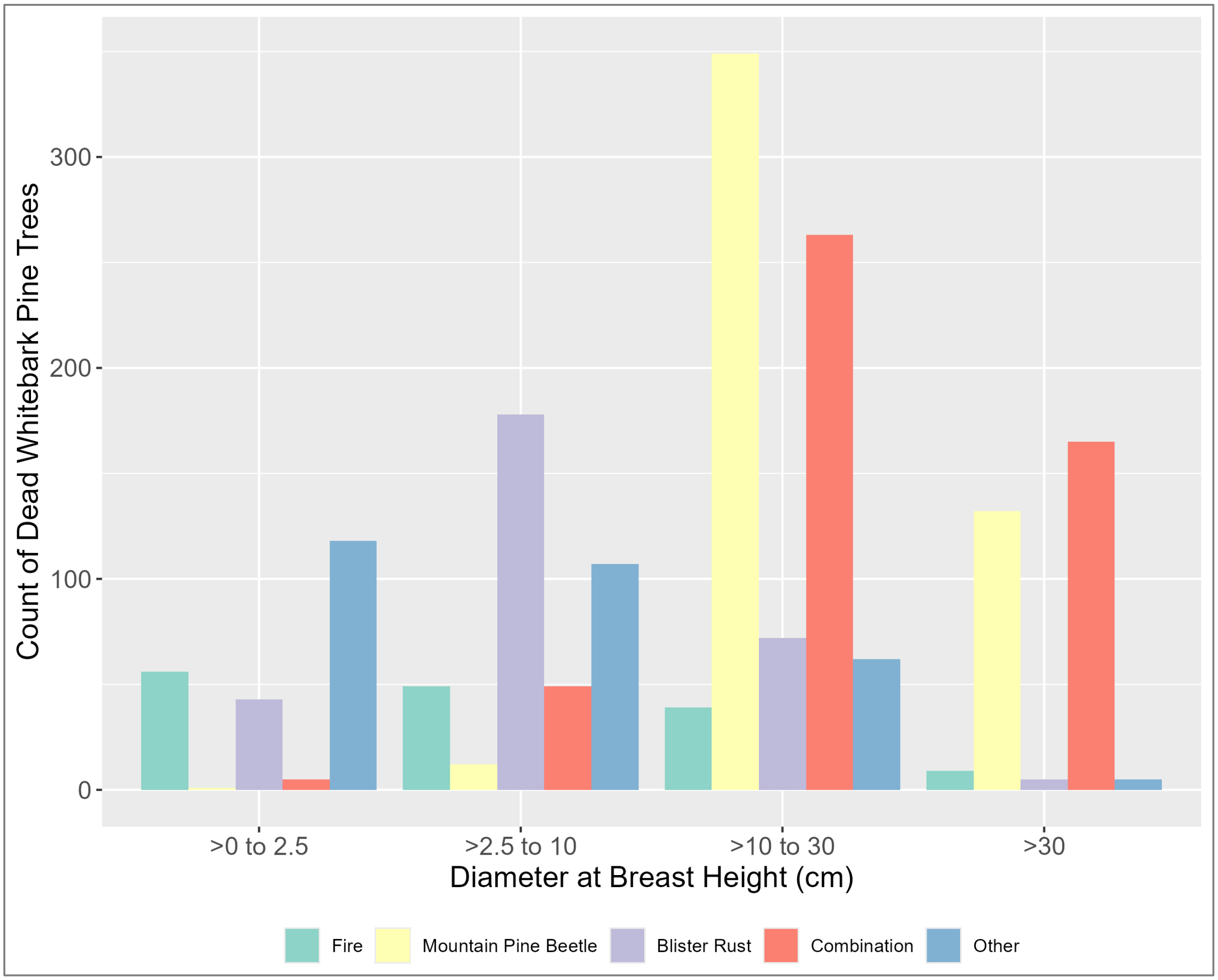

Figure 4. Cumulative mortality of monitored whitebark pine trees in the Greater Yellowstone Ecosystem from 2008 to 2019 by size class and conditions observed at the time of survey visit. For each size class, from left to right, mortality influencing conditions are fire, mountain pine beetle, blister rust, a combination of fire, beetle, or blister rust, or other (e.g., avalanche damage, broken top). NPS

Objective 4: Whitebark Pine Recruitment

Recruitment and regeneration are crucial in determining the whitebark pine population trajectory. For Objective 4 of the monitoring program, we define recruitment as the sum of factors influencing the addition of whitebark pine to the reproducing population (Helms 1998). Recruitment includes regeneration, which refers to counts of live, five-needle pine trees ≤1.4 m tall. Because young whitebark pine cannot be distinguished from young limber pine (*Pinus flexilis*) without cones or genetic analysis, small tree counts are generalized to all five-needle pines.

Newly Tagged Trees in Time-Step 4

From 2008 to 2015, 447 small trees had reached a height of >1.4 m and were added to the tagged and monitored tree cohort by the end of 2015. In Time-Step 4, an additional 240 trees grew to >1.4 m tall and were tagged (Table 3). Since initial transect establishment, this brings the count of newly tagged trees added to monitoring to a total of 685 (Table 4). After the Time-Step 2 count of new trees added

(n = 286), Time-Step 4's count of new trees is the second highest number in a time-step since transect establishment (159 new trees were incorporated into monitoring in Time-Step 3).

Table 3. Five-needle pine trees that reached the >1.4 m tall threshold were tagged and added to the monitored tree population on Greater Yellowstone Ecosystem transects. A total of 240 were tagged in Time-Step 4 (2016–2019).

Year	New Trees Added in Time-Step 4 (n = 240)			
	Panel 1	Panel 2	Panel 3	Panel 4
2016	39	–	–	–
2017	–	58	–	–
2018	–	–	69	–
2019	–	–	–	74

Table 4. Five-needle pine trees that reached the >1.4 m tall threshold in each time-step on Greater Yellowstone Ecosystem transects.

Time-step	New Trees Added (n = 685)
1 (2004–2007)	n/a
2 (2008–2011)	286
3 (2012–2015)	159
4 (2016–2019)	240

Regeneration: Five-Needle Pine Understory

In Time-Step 4, we recorded an average density of 52 small trees (≤1.4 m tall) per 500 m² on the belt transects. This shows a continued stabilization after an increase from Time-Step 1 of 37 trees per 500 m² (Time-Step 2 = 53 trees per 500 m²; Time-Step 3 = 51 trees per 500 m²).

Raw counts of these understory individuals ranged from 0 to 497 small trees per transect (n = 176 transects). We documented 40 trees (<1%; n = 497) with some level of blister rust infection (Table 5).

Table 5. Blister rust infection status of recorded understory five-needle pine trees ≤1.4 m tall in Time-Step 4 (2016–2019), by panel, on Greater Yellowstone Ecosystem monitoring transects.

Panel	Small Trees ≤1.4 m Tall (*n* = 8,977)			
	Blister Rust Absent	Blister Rust Present	Infection Status Unknown	Total
1	2,413	9	1	2,423
2	1,676	12	0	1,688
3	2,427	5	6	2,438
4	2,414	14	0	2,428

Cone-Producing Trees

Known reproducing trees were approximately 13% (*n* = 496) of the total, live tagged trees (*n* = 3,687) on all transects at the end of Time-Step 4. Most of the reproducing trees were in the >10 to ≤30 cm DBH size class (Table 6). Depending on the revisit schedule, trees may not be observed with cones or other signs of reproduction if the tree is not visited while a tree is exhibiting signs of reproduction. Most (*n* = 248) of the reproducing trees had anywhere from 1 to 5 cones, whereas 83 had from 6 to 10, 67 had >10 cones, and 98 were observed with cone scars only.

Table 6. Size class distribution of whitebark pine trees documented as reproducing in Time-Step 4 (2016–2019) on Greater Yellowstone Ecosystem monitoring transects, by panel. DBH = diameter at breast height.

Size Class (cm, DBH)	Number of Reproducing Whitebark Pine Trees by Size Class in Time-Step 4 (n = 496)				
	Panel 1	Panel 2	Panel 3	Panel 4	Total
≤2.5	1	0	0	0	1
>2.5 to ≤10	2	5	11	7	25
>10 to ≤30	87	98	124	86	395
>30	24	10	18	23	75

Of the 496 reproducing trees, almost half (44%; 220) were documented with blister rust. Of infected trees, 42% (93) had bole infections. Only nine trees had signs of mountain pine beetle infestation throughout the Time-Step 4 period.

Recruitment Potential: Upper Live Canopy Volume

An intact, healthy canopy is often a determining factor in the volume of cone production. Once a tree reaches reproductive maturity, the quantity and quality of living upper canopy is a good metric for predicting cone production potential. Further, trees with little to no upper live canopy volume remaining have poor potential recruitment—the exception is when a lower canopy branch grows vertically and subsequently produces cones. In Time-Step 4, 64% (2,346 trees) of live trees (*n* = 3,687) had 75–100% of upper live canopy volume and 343 trees had no upper live canopy remaining

(Table 7). Table 8 shows the count of trees by percentage of upper live canopy volume for the subset of trees infected by blister rust.

Table 7. Percentage of live upper canopy volume by tree size class for live, tagged whitebark pine trees (*n* = 3,687) in Time-Step 4 (2016–2019) on Greater Yellowstone Ecosystem transects. Trees with zero % live canopy will not produce cones, and trees with <25% live canopy likely will not produce cones.

Percentage of the Canopy Alive	Number of Trees by Size Class (diameter at breast height, DBH)				Total Number of Trees
	≤2.5 cm [A]	>2.5 to ≤10 cm	>10 to ≤30 cm	>30 cm	
0	49	148	140	6	343
>0 to ≤25	41	49	58	4	152
>25 to ≤50	84	104	68	9	265
>50 to ≤75	165	213	179	18	576 [B]
>75 to 100	694	733	832	81	2,343 [C]

[A] Excluding four trees that lacked canopy data.

[B] One tree was missing a DBH measurement.

[C] Three trees were missing a DBH measurement.

Table 8. Percentage of live upper canopy volume by blister rust infection status for infected whitebark pine trees (*n* = 1,001) in Time-Step 4 (2016–2019) on Greater Yellowstone Ecosystem transects. Trees with zero % live canopy will not produce cones, and trees with <25% live canopy likely will not produce cones.

Percentage of the Canopy Alive	Trees with Bole Infection Only	Trees with Canopy Infection Only	Trees with Both Bole and Canopy Infections	Total Number of Infected Trees
0%	185	17	32	234
>0 to ≤25%	40	15	13	68
>25 to ≤50%	42	25	18	85
>50 to ≤75%	58	51	40	149
>75 to 100%	157	235	72	464
N/A—no canopy data collected	0	0	1	1
Total	482	343	176	1,001

Live, Tagged Tree Size Distribution History

Previously, we reported an overall shift in the GYE's whitebark pine population to smaller-sized trees, based on diameter at breast height, following the mountain pine beetle outbreak in Time-Step 2 (Shanahan et al. 2016). The size class distribution at the end of Time-Step 4 remains consistent with this pattern, and thus, limited change has occurred between Time-Step 3 and Time-Step 4 (Figure 5). A decrease in tree count for any size class for Time-Step 4 versus Time-Step 3 is from mortality events (e.g., wildfire that burned multiple trees on a transect) that caused a reduction in the overall

number of trees in a specific size class. Increases in a given size class, such as the ≤2.5 cm DBH class (i.e., Time-Step 2 to Time-Step 3), were the result of trees reaching the >1.4 m tall threshold when they were tagged and added to the monitoring cohort.

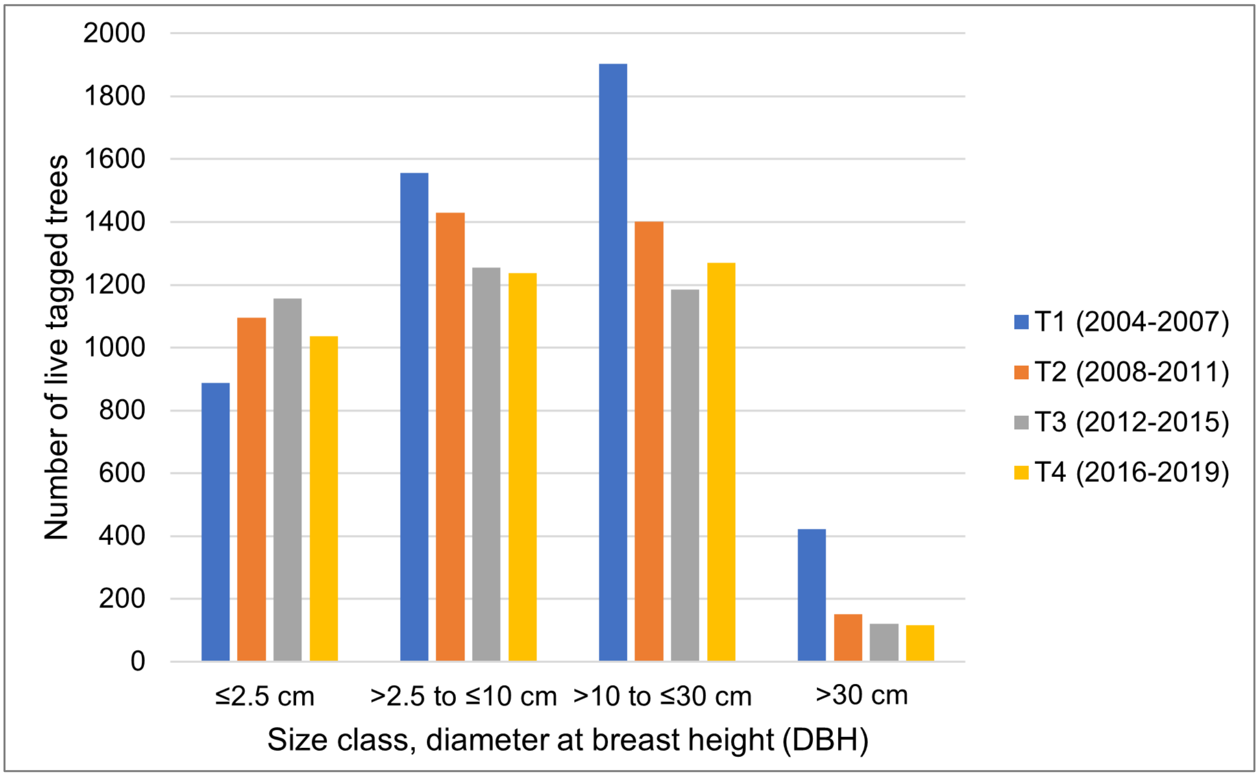

Figure 5. Size class distribution for live, tagged whitebark pine trees over the course of the 16-year whitebark pine monitoring program in the Greater Yellowstone Ecosystem, 2004–2019. NPS

Management Applications

Throughout the past decade in the Greater Yellowstone Ecosystem, the Interagency Whitebark Pine Monitoring Program has documented the health status and demographic shifts in whitebark pine forests in response to insects, pathogens, wildland fire, and other disturbances. Information from this dynamic and expanding program has several applications:

- supports data-driven management decisions (e.g., state of whitebark pine in wilderness study areas, Endangered Species Act listing of whitebark pine as threatened in January 2023)
- guides restoration activities and planning strategies
- provides valuable resources such as sampling designs and database structure, and empirical data for a variety of research studies of whitebark pine
- informs conservation actions throughout the GYE and across the distribution of whitebark pine in western North America

The interagency protocol has also been adopted and adapted by multiple agencies, including state agencies, initiating five-needle pine monitoring activities in other regions.

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