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A 2013 UPDATE:

WHITEBARK PINE MONITORING IN GRAND TETON NATIONAL PARK 2007 -2013

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ABSTRACT

The magnitude of current white pine blister rust (*Cronartium ribicola*) and mountain pine beetle (MPB; *Dendroctonus ponderosae*) impacts, combined with the effect of climate change on beetle population dynamics in whitebark pine (PIAL; *Pinus albicaulis*) ecosystems in the Greater Yellowstone Ecosystem (GYE) are placing this foundation species in a precarious state. This monitoring project, initiated in 2007 and conducted annually in Grand Teton National Park (GRTE), indicates that whitebark mortality, beetle activity, blister rust severity and regeneration abundance are spatially variable. The proportion of whitebark with evidence of cone production is spatially variable and decreasing over time. Both blister rust incidence and regeneration presence is ubiquitous. Overall MPB activity has decreased since 2010, although areas of activity remain. Rust severity continues to increase annually. In 2007, among whitebark sampled 17% were dead, 14% attacked by the beetle, 55% symptomatic for rust, 30% have evidence of cone production, and the mean canker severity category was 2.26. In 2007, whitebark regeneration was 96.3% rust free, present on 100% of sampled transects and ranged from 20 to 1580 rust free seedlings per hectare. In 2010, among whitebark sampled 31% were dead, 21% attacked by the beetle, 43% symptomatic for rust, 29% have evidence of cone production, and the mean canker severity category was 4.43. In 2010, whitebark regeneration was 95.8% rust free, present on 96% of sampled transects, and ranged from 0 to 2280 rust free seedlings per hectare. In 2013, among whitebark sampled 33% were dead, 25% attacked by the beetle, 37% symptomatic for rust, 17% have evidence of cone production, and the mean canker severity category was 4.35. In 2013, whitebark regeneration was 97.6% rust free, present on 91% of sampled transects and ranged from 0 to 4420 rust free seedlings per hectare. MPB activity and blister rust severity was significantly greater at elevations <9500’ and on transects with south aspects. Individual whitebark with greater rust severity had significantly higher MPB attack incidence. Blister rust severity was greatest on transects <9500’, on south aspects, and on larger diameter whitebark. This information is critical to future monitoring efforts, successful restoration strategies, and an overall understanding of whitebark ecology.

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Introduction (From 2010 Document)

Justification

As fundamental components of alpine and northern latitudinal habitats, where changes in climatic conditions and vegetative structure are occurring (Romme & Turner 1991), whitebark (*Pinus albicaulis*) are significant "barometers of change". The magnitude of current white pine blister rust (*Cronartium ribicola*) and mountain pine beetle (MPB; *Dendroctonus ponderosae*) impacts, combined with the effect of a changing climatic setting on beetle population dynamics in whitebark ecosystems in the Greater Yellowstone Ecosystem is placing this foundation species in a precarious state. Disturbance-induced change and the spatial pattern of biotic residuals is intricately linked to future stand structure and composition, successional trajectories, energy and nutrient fluxes, ecosystem function and services, and complex spatial configurations on the landscape (Turner et al. 2001).

The loss of these otherwise stalwart pines, which can reach ages in excess of a thousand years, will have far-reaching consequences. Successful conservation of this critical conifer will be complex, challenging, and ongoing. Understanding whitebark ecosystem dynamics has become vital to the conservation of this charismatic high elevation conifer. An understanding of whitebark physiology and biology, the spatial and temporal distribution of tree mortality and damage, the intensity, severity, and distribution of beetles and blister rust, and whitebark regeneration abundance, distribution and potential is essential. This information must be coupled with coordinated efforts and information sharing to promote the development of accurate and successful preservation and restoration strategies.

Whitebark Ecology

Whitebark pine is a member of the genus *Pinus*, subgenus *Strobus*, and subsection *Cembra*, one of five stone pines worldwide (Critchfield & Little 1966). Although commercially insignificant, the value of whitebark rests in the realm of ecosystem services, biological integrity, and aesthetics. This slow growing, long-lived pine is often the only conifer species capable of establishment and survival on cold, harsh sites with poorly developed soil, high winds, and extreme temperatures (Arno & Hoff 1990).

Whitebark exhibits its influence at multiple scales throughout the western United States and Canada (Tomback et al. 2001a). A keystone species has an ecological role disproportionately large relative to its abundance, and a foundation species is one that defines ecosystem structure, function, and process (Tomback et al. 2001a). Characterized as both, the architectural, functional, and physiological characteristics of whitebark influence biodiversity and forest structure and process (Ellison et al. 2005). Specifically, these trees maintain hydrological quality by trapping snow, regulating snowdrift retention, spring melt and run-off, and erosion on steep sites (Arno & Hoff 1990; Farnes 1990). These influences affect agricultural lands and urban communities hundreds of miles away. Whitebark facilitate regeneration following disturbance, influencing community composition, structure, and succession (Tomback & Linhart 1990; Tomback et al. 2001a).

Whitebark exhibit several unique reproductive strategies that facilitate their foundational roles in forest structure, function, and resilience to disturbance-induced change and indicate they evolved in unpredictable and severe environments (Tomback & Linhart 1990). Recent findings show that whitebark exhibit delayed seed germination resulting in a soil seed bank not present in any other *Pinus* species (Tomback et al. 2001b). Their large, thick-coated seeds provide nutrients to a germinating seedling, allowing for rapid initial growth, and are an adaptation to xeric, cold conditions and short growing seasons (Tomback et al. 2001a).

Episodic cone crops produce abundant lipid-rich seeds which are an essential vegetative food source for some wildlife species, including the endangered grizzly bear (*Ursus arctos horriiblis*) (Mattson et al.1994). The Clark's nutcracker (*Nucifraga columbiana*) is the primary dispersal vector for the wingless seeds and they cache thousands throughout the landscape, transporting seeds several hundred meters up to over 12 kilometers (Hutchins & Lanner 1982). Nutcrackers over wintering and courting in forests below the subalpine zone, and nestlings hatched in early spring depend on whitebark seeds as an energy-rich food source; nutcracker-pine interdependence is a nearly obligate mutualism (Tomback 1982; Tomback & Linhart 1990; Lanner 1996). Nutcrackers drive whitebark geographical distribution, genetic structure, and pioneer role on recently disturbed sites (Weaver & Dale, 1974; Lanner 1980; Tomback & Linhart 1990; Tomback et al.1995).

Disturbance

Although during the 20th century two significant MPB events occurred in whitebark ecosystems, the current extent, severity and subsequent losses of whitebark throughout their distribution have resulted from unprecedented, temperature-driven, beetle activity that began in approximately 2000. Additionally, whitebark faces further and continual damage from an exotic blister rust fungus. The magnitude of these impacts has placed whitebark in a precarious situation. Interpretation of 2007 satellite imagery by the USDA Remote Sensing Applications Center indicated over 40% of whitebark stands contained some level of canopy mortality (Goetz et al 2009). Data from the 2008 Forest Health Protection aerial survey in the GYE found beetle activity in more than 50% of whitebark stands, and 81% were infected with blister rust (Schwartz et al. 2007; Bockino 2008). Most recently, during the summer of 2009, aerial evaluation at a sub-watershed level documented the spatial extent and severity of whitebark damage from MPB outbreaks across the entire GYE. Data from this project indicates that over 50% of whitebark stands in the GYE have already suffered high to complete mortality of mature trees and 95% of forest stands containing whitebark have measurable MPB activity (MacFarlane et al. 2010). In the northern Rocky Mountains, mortality rates are as high as 90% (Gibson et al. 2007). In the Interior Columbia Basin, whitebark populations have declined by at least 45% (Keane & Kendall 2001).

As agents of change, MPB are considered regulators of ecosystem processes (Romme & Turner 1991). This native insect resides and reproduces within the subcortical tissues of coniferous trees. The beetle exhibits a broad range of aggressiveness in their host selection behavior, depending upon both host characteristics and beetle population dynamics (Wallin & Raffa 2004). Temporally coincident adult emergence enables beetles to collectively overcome tree defensive resin and supports epidemic populations (Safranyik et al. 1975). The coalescence of localized beetle activity is dependent on synchrony of critical bark beetle phenological events driven directly by temperature. Conventional wisdom held that whitebark ecosystems were simply too cold for bark beetles (Amman & Schmitz 1988). Shifts in MPB life cycles from maladaptive to adaptive seasonality and population transitions from endemic to epidemic, attributable to increased temperatures, has resulted in intensification of bark beetles within their historic range and expansion into high elevation ecosystems (Logan & Powell 2001).

In contrast, blister rust is a non-native pathogen accidently introduced into the western United States in the early 1900s. Spores enter through leaf stomata, fungal mycelia colonize living bark and cambial tissue, destroy the water and nutrient transport system, and form cankers or spore producing fruiting bodies. Blister rust decreases whitebark recruitment potential by extensive damage to cone bearing branches, seedlings and saplings (Tomback et al. 1995). Blister rust is continuing to spread throughout the GYE, and due to its perpetual presence, is considered the most damaging agent to whitebark.

Objectives

The objectives of our project in Grand Teton National Park are to track the condition of the whitebark population over time and space through the: *i)* installation of permanent monitoring transects throughout the whitebark zone to be read annually to detect temporal change; *ii)* quantification of the spatial distribution of blister rust and beetles; *iii)* quantification of the severity of blister rust and MPB; *iv)* identification of areas of low beetle activity or rust infection; *v)* description any relationships between edaphic factors and disturbance severity; and *vi*) quantification of the spatial distribution and abundance of regeneration.

Methods (From 2010 Document)

Project Area

In 2005, a vegetation mapping project was completed and U.S. National Classification vegetation associations and alliances were attributed to all map units within GRTE. GRTE encompasses over 333,000 acres of which 53,000 or 16 % are coded as whitebark or subalpine forests (Nature Serve 2005). This monitoring focuses on whitebark found in the upper sub-alpine to tree line where stands are often patchy or form ribbon forests and krummholz that extend into the alpine. Whitebark often intermixes with spruce-fir and is often present as a minor component in high-elevation spruce-fir stands.

Data Collection

In May 2007 potential transect locations were randomly selected within GRTE using Hawth's tool in ArcGIS. Polygons established by the above mentioned 2005 vegetation map were used in a stratified random selection of potential transect locations. Two sets of polygons were established; those coded as whitebark pine (FWB) and those with whitebark pine present (FSF) and elevation > 8400'. Within each set, 100 polygons were randomly selected and then five random transect starting points (UTMs, NAD 83) were placed in each of the 200 polygons. Transects were read in 2007, 2008, 2009 and 2010, 2011, 2012, and 2013 and annual monitoring will continue.

From among the random points in these polygons, based on the accessibility of the terrain in the field, from June to August 2007 24 transects were established and read. Two transects were added in 2008 (Table 1; Figure 1). Transect data was collected based on a modified version of the Interagency Whitebark Pine Monitoring Protocol for the GYE (GYWPMWG 2007). Transect metadata recorded included: slope, aspect, elevation, UTM location, vegetation association, habitat type, cover type, presence and abundance of squirrel middens, and overstory tree composition by total % canopy cover and % canopy cover by species.

Within each polygon a random vector was used to establish a 10 x 50 m transect. Transects are monumented with 12" steel nails and large washers driven in at ground level at the beginning and end. Within each transect all live whitebark >1.4 meters tall were tagged and examined. Dead whitebark were recorded, and only recently dead were tagged. Individual tree data recorded included: diameter breast height (DBH), height class, live/dead status, blister rust infection, MPB activity, needle color, and evidence of cone production (current year cones or cone skeletons observed in crown).

To estimate individual tree blister rust infection each tree was visually divided into thirds (Newcomb & Six 2005). The total number of detectable cankers in each section of the bole and crown were recorded. Detectable cankers were placed in two categories, active or inactive. Active cankers were only recorded when white aecial blisters or orange aeciospores were present. The presence of two or more of the following denoted inactive cankers: *i*) branch flagging; *ii*) rodent chewing at canker site; *iii*) roughened, dead bark; *iv)* branch tissue with thin, smooth, or swollen sections, or *v)* oozing sap (Hoff 1992). In 2012, blister rust infection severity was converted to categorical data to increase ease, efficiency and objectivity of field data recording. Rust severity categories remain separate for bole and crown are:

Notes on scoring:

Branch Cankers (separate score for active and inactive cankers)	Bole Cankers
0 = no cankers present	0 = no cankers present
1 = 1-5 cankers present	1 = canker present and active
2 = 6-10 cankers present	2 = lethal/girdled/top kill
3 = >10 cankers present	

1. If bole only had inactive cankers and no dead top, it scored 0
2. If tree had a dead top, it scored 2 wherever the highest active or inactive cankers were located (upper, middle, lower) and if there were active cankers below that point, the tree scored a 1
3. Each tree is given a total rust severity for bole (maximum of 6) and a total rust severity, separately for active and inactive, for branches (maximum of 18).
4. These two categories are summed for a total rust severity for each tree and ranges from 0 to 24.

MPB activity was determined by the presence of: *i*) pitch tubes, which are mixtures of tree resin and beetle-produced boring dust; *ii*) boring dust in bark crevices particularly around root collar of tree; *iii*) entrance holes with inconspicuous pitch tubes; *iv*) small (≈2 mm diameter) emergence holes; *v)* beetles actively chewing into bark; or *vi*) j-shaped galleries beneath bark (Safranyik et al. 1974).

In 2008, whitebark <1.4 meters in height were individually tagged on transects with less than 20 individuals. Data recorded for each tree includes: live/dead status, basal diameter, height, blister rust infection, distance from object and object type.

Data Analysis

Data was summarized annually from 2007 to 2013. In addition, in 2008 two-dimensional chi-square tests of independence to determine statistical significance of the differences between two variables for a variety of host tree characteristics (SAS 2006). These tests corroborate relationships among variables, and the strength, direction and shape of the associations identified. Chi-square analyses compare observed frequencies to expected frequencies which were derived from my sample statistics, based on a model of complete independence.

RESULTS

SUMMARY OF WHITEBARK CONDITIONS

From 2007 to 2013, at the individual tree- and transect-level, whitebark mortality, beetle activity, and blister rust severity increased over time, while incidence of blister rust decreased slightly overtime as whitebark killed by MPB and rust were removed from the sample population. Overall whitebark mortality, beetle activity, blister rust severity, and regeneration abundance are spatially variable. The majority of whitebark mortality is due to beetle activity, although tree mortality due to blister rust has increased overtime. Mountain pine beetle activity peaked in 2010 and decreased slightly in 2011 to 2013. The proportion of whitebark with evidence of cone production is relatively consistent overtime, spatially variable, and increases in 2007 and 2010 which reflects episodic cone cycles seen in whitebark pine throughout the GYE (Table 2). In 2009 and 2012 only 9 and 7 transects respectively were sampled, thus capturing a smaller geographic distribution of variables sampled.

Specifically, at the individual tree-level for whitebark sampled from 2007 to 2013, mortality increased from 17% to 33%, mountain pine beetle activity increased from 14% in 2007 to peak at 32% in 2011 and decreased to 25% in 2013, blister rust incidence decreased from 55% to 37%, and blister rust severity (canker category) doubled (Table 2).

At the transect-level, from 2007 to 2013, the proportion of monitoring sites with mortality increased from 63% to 87%, beetle activity increased from 50% to 71% in 2010 and then to 65% in 2013, evidence of cone production decreased from 100% to 65%, presence of regeneration decreased from 100% to 91%, and blister rust incidence decreased from 100% to 87% (Table 2).

MOUNTAIN PINE BEETLE ACTIVITY – SPATIAL DISTRIBUTION & INTENSITY

Beetle activity increased from 2007 to 2010 and decreases slightly from 2011 to 2013. The intensity of mountain pine beetle activity varies among transects, from no activity to 100% infestation rates. Beetle activity is most intense on the eastern slope of the range, and conversely least intense near the Teton Crest (Figure 6). Beetles are present more than expected at lower elevation (<9500') transects and on south aspects (Table 9). On individual whitebark, beetle activity is positively related to increased blister rust severity (Table 9).

BLISTER RUST – SPATIAL DISTRIBUTION & SEVERITY

Whitepine blister rust incidence is consistent throughout GRTE where 87% of transects have blister rust infection (Table 2), however infection severity is spatially and temporally variable. The proportion of live whitebark on each transect that exhibit blister rust symptoms range from 0 to 100% (Table 5). Among transects, the blister rust severity category for individual whitebark ranges from 0 to 12 (Table 5) and was greatest in the southern and eastern portions of the park (Figures 7). Blister rust severity was greatest on transects <9500', on south aspects, and on larger diameter whitebark. Blister rust severity is positively related to elevations lower than 9500', south aspects, and larger diameter whitebark (Table 9). Among years, blister rust severity increased from 2007 to 2013 and blister rust incidence by individual live whitebark decreased (Table 2). This decrease in rust incidence among live whitebark reflects the loss of sampled whitebark by beetles or lethal rust infection.

WHITEBARK CONE DISTRIBUTION & ABUNDANCE

During all years, among transects, evidence of cone production is spatially variable (Table 4). On each transect, the portion of individual whitebark producing cones is relatively consistent over time. Among all individual whitebark sampled cone production decreased from 30% in 2007 to 17% in 2013 and among transects also decreased from 100% in 2007 to 65% in 2013. In 2010 cone production increased to 29%. Overall, the proportion of transects and individual whitebark with cones decreased from 2007 to 2013 (Table 2).

WHITEBARK REGENERATION DISTRIBUTION & ABUNDANCE

Whitebark regeneration is present throughout GRTE and seedling abundance varies spatially. From 2007 to 2013 the incidence of rust on seedlings has remained very low, ranging from 1 to 3.6% (Table 2). Among transects from 2007 to 2013 regeneration abundance increased on 58% of transects, decreased on 21% and remained the same on 21% (Table 8). Among transects, regeneration density ranges from 0 to 3440 seedlings per hectare.

Discussion (from 2010 Document)

This monitoring program in Grand Teton Park provides vital information of the extent, distribution, intensity, and severity of disturbance within high elevation whitebark ecosystems. We continue to quantify the spatial distribution and severity of blister rust infection and beetle activity and identify areas of low rust infection and beetle activity. We examine the spatial and temporal patterns of spread by blister rust and beetles. This monitoring work also identifies relationships among edaphic variables, MPB activity, blister rust severity, and regeneration presence. Several of these relationships are discussed in the following.

This monitoring project indicates that blister rust severity is positively related to MPB activity. These results correspond to three studies reporting that whitebark exhibiting greater blister rust severity were more likely to be selected as host trees by the MPB (Kegley et al. 2004; Six & Adams 2007; Bockino 2008).

Differences in host tree vigor may be related to the presence and severity of blister rust (Manion 1991; Tomback et al. 1995). The chemical composition of a tree responding to severe blister rust may provide the MPB with greater quantity, quality, or variety of phenolic groups that serve as metabolic precursors to their aggregation and breeding pheromone system (Hudgins et al. 2004). Chemical defenses in pines are constitutive and inducible (Raffa et al. 2005; Seybold et al. 2006), suggesting that these defenses are limited. Perhaps whitebark responding to invasion by blister rust have less chemical resources available for defensive reactions to MPB colonization.

We recorded MPB activity and blister rust severity significantly higher at elevations <9500' and on transects with south aspects. These findings are supported by research indicating that beetle productivity is greatest at warmer temperatures. MPB are well-adapted for immediate and opportunistic response to changes in climatic conditions, due to the lack of a diapause phase in their life history. A dramatic illustration of the thermally opportunistic nature of the MPB is the increase in the proportion of univoltine synchronous MPB brood, survivorship, and greater cold tolerance, due to increases in mean minimum temperatures since the 1980s. Univoltinism is directly related to outbreak intensity and MPB host colonization success (Bentz et al. 1991; Bentz et al. 2001; Powell et al. 2000; Logan & Powell 2004; Logan & Powell 2007).

This monitoring project also demonstrates that rust severity was greater on larger diameter whitebark. This corresponds with findings, from research conducted on limber pine (*Pinus flexilus*), of increased blister rust severity with greater tree diameter (Hunt 1983; Campbell & Antos 2000; Kearns & Jacobi 2007).

Conclusion

In conclusion, in Grand Teton National Park, whitebark mortality and beetle activity is spatially variable. The 2013 mortality rate of 33% is mainly attributable to beetle activity, although several whitebark have died from blister rust. Blister rust incidence is widespread and severity is increasing. Incidence has decreased from 55% to 37%, in part due to the loss of sampled whitebark by beetles or lethal rust infection. Regeneration is present on 91% of transects, blister rust incidence is less than 3% and abundance is variable. MPB activity has begun to decrease since 2011. MPB activity is greatest in whitebark with greater blister rust infection, at lower elevations and on south aspects. Blister rust severity is positively related to tree diameter and greatest at lower elevations and on south aspects. Evidence of cone production has decreased from 30 to 17%.

The future distribution and abundance of whitebark in Grand Teton is unknown and will reflect the biology and ecology of whitebark, combined with the effects of the current blister rust and beetle disturbance. Limited propagule availability due losses to MPB and blister rust impacts may decrease future colonization rates (McKinney & Tomback 2007; Resler & Tomback 2008). In mixed conifer stands, where whitebark is seral, beetle-caused mortality may release suppressed whitebark and promote increased growth rates. Current disturbances may promote this response in the GYE, as many stands contain several understory cohorts of whitebark (Bockino *in prep*).

Knowledge of the location of residual stands of whitebark and areas with abundant whitebark regeneration are critical to successful management strategies. Areas with low incidence of MPB and blister rust should be targeted as potential restoration sites. In addition, areas of high blister rust infection rates should be surveyed more closely to identify potentially rust resistant individual whitebark.

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TABLES

Table 1. Grand Teton National Park Monitoring Transects - Metadata (Nad 83, Zone 12)

GRAND TETON NATIONAL PARK WHITEBARK MONITORING TRANSECTS				
Transect	***Elevation***	***Aspect***	***Easting***	***Northing***
Amphitheater Lake	9866	160	517623	4842058
Boundary Lake	9889	300	510297	4853186
Carr Lake	9798	260	512965	4861732
Cascade Forks	8985	24	513384	4845575
Death Canyon Shelf	9647	132	507646	4832964
Delta Lake	9263	20	518545	4841906
Forellen	9729	30	514208	4872792
Garnet	9900	150	516879	4841538
Hanging Canyon	9104	110	519768	4847318
Holly Lake	9412	80	516466	4848178
Jackson Hole Mtn Resort	10076	300	510314	4827506
Lake Taminah	9802	142	515707	4839671
Marion	9256	155	506020	4829976
Mount Hunt	9700	115	511780	4830277
Mount Moran	9121	150	519171	4852524
North Fork Cascade Cache	9019	320	512955	4848389
Ortenberger Lake	9711	188	512692	4857774
Paintbrush	8906	220	518284	4849749
South Fork Cascade	9822	68	514181	4844851
Static	9396	255	514409	4835168
Stewarts	9169	136	516323	4836462
Survey Peak	8494	104	513426	4876401
Teewinot Apex	9118	127	519092	4843213
Teewinot South	8950	18	519113	4842883
Twenty-five Short	8599	100	518013	4838563
Upper Death Canyon	8745	280	508864	4833519

Table 2. Summary of whitebark pine conditions in Grand Teton National Park 2007-2013.

GRAND TETON NATIONAL PARK WHITEBARK MONITORING SUMMARY DATA

Year of Sample	***2007***	***2008***	***2009***	***2010***	***2011***	***2012***	***2013***
Number Transects Sampled	24	22	9	21	14	7	23
Variable	*Percentage of Transects Sampled* [a]						
Dead PIAL	63	77	78	81	93	71	87
Mountain pine beetle	50	68	56	71	57	57	65
Blister rust (live PIAL only)	100	100	100	100	93	86	87
Evidence of Cones (live PIAL only)[d]	100	68	67	66	85	71	65
Regeneration Present	100	95	100	95	93	100	91

Year of Sample	***2007***	***2008***	***2009***	***2010***	***2011***	***2012***	***2013***
Number Individual PIAL Sampled	452	400	172	405	276	122	447
Variable	*Percent of Individual Whitebark* [b]						
Dead PIAL	17	28	22	31	39	37	33
Mountain pine beetle	14	24	7	21	32	32	25
Blister rust (live PIAL only)	55	60	50	43	54	34	37
Rust Severity (live and killed by rust)[c]	2.26	3.42	2.71	4.43	3.56	4.29	4.35
Evidence of Cones (live PIAL only)[d]	30	21	19	29	18	16	17
Rust Free Regeneration	96.3	98	99	95.8	97.5	97.6	97.5

a. The proportion of transects.
b. The proportion of individual sampled whitebark pine.
c. Not a proportion - Each live or dead tree >1.4 meters tall is given a total rust severity for bole (maximum of 6) and a total rust severity, separately for active and inactive, for branches (maximum of 18). These two categories are summed for a total rust severity for each tree and ranges from 0 to 24.
d. Live PIAL that have evidence of cone production (cones or cone skeletons).

Table 3. Overstory PIAL (>1.4 meters tall) summary data for tree mortality and mountain pine beetle infestation by monitoring transects 2007-2013.Gray boxes indicate years transects were not visited.

GRAND TETON NATIONAL PARK WHITEBARK MONITORING OVERSTORY TREE DATA 2007-2013

Updated October 2013

Transect	***% PIAL Dead***							***% PIAL with MPB***						
	2007	***2008***	***2009***	***2010***	***2011***	***2012***	***2013***	***2007***	***2008***	***2009***	***2010***	***2011***	***2012***	***2013***
Amphitheater Lake	0	0	0	0	4	4	4	8	0	0	0	0	0	0
Boundary Lake	0		4		4		4	0		0		0		0
Carr Lake	8		8					8		8				
Cascade Canyon	20	20		50		50		0	10		50		50	
Death Canyon Shelf	0	0		0			0	0	3		0			0
Delta Lake	0	40		40	40		50	0	40		40	40		50
Forellen	32	33		33			11	0	2		2			2
Garnet	0	0						0	0					
Hanging Canyon	47	63		68	72		68	47	68		68	67		68
Holly Lake	0	0		0		0	0	0	0		0		0	0
Jackson Hole Mtn Resort	9	9		14	14		41	0	0		0	0		0
Lake Taminah	7	7	14	32	26	26	32	0	0	21	21	21	13	14
Marion	63	63		63			63	63	63		63			63
Mount Hunt	13	13		13			25	0	38		0			0
Mount Moran	8		17		23		26	0		0		0		4
North Fork Cascade Cache	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ortenberger Lake	2		29				20	21		21				33
Paintbrush Canyon		22		28	33		28		22		22	17		22
South Fork Cascade	0	11		11	11		22	0	0		0	0		0
Static	33	78	78	78	78	78	78	67	78	78	78	78	78	78
Stewarts	0	65	75	100	94	89	89	24	94	94	100	94	89	89
Survey Peak	3	3		6			18	3	13		3			6
Teewinot Apex	50	57		86	86		93	50	50		71	86		93
Teewinot South	63	79		89	100		100	79	79		95	100		100
Twenty-Five Short		80		80			100		100		80			100
Upper Death Canyon	22	22		50			40	44	33		50			40

Table 4. Overstory (>1.4 meters tall) PIAL summary data for cone production by monitoring transects 2007-2013. Gray boxes indicate years transects were not visited.

GRAND TETON NATIONAL PARK WHITEBARK MONITORING OVERSTORY TREE DATA 2012-2013

Updated October 2013

Transect	***% PIAL with Evidence of Cones***						
	2007	***2008***	***2009***	***2010***	***2011***	***2012***	***2013***
Amphitheater Lake	40	40	40	40	40	42	36
Boundary Lake	4	4	4	4	4		21
Carr Lake	27	27	27	27	27		
Cascade Canyon						50	
Death Canyon Shelf	35	35	35	35	35		27
Delta Lake	50	50	50	50	50		0
Forellen	62	62	62	62	62		49
Garnet	33	33	33	33	33		
Hanging Canyon	10	10	10	10	10		33
Holly Lake	60	60	60	60	60	0	60
Jackson Hole Mtn Resort	5	5	5	5	5		8
Lake Taminah	4	4	4	4	4	4	0
Marion	100	100	100	100	100		67
Mount Hunt	57	57	57	57	57		50
Mount Moran							4
North Fork Cascade Cache	30	30	30	30	30	30	30
Ortenberger Lake	64	64	64	64	64		75
Paintbrush Canyon							8
South Fork Cascade	70	70	70	70	70		57
Static	58	58	58	58	58	0	0
Stewarts	18	18	18	18	18	0	0
Survey Peak	3	3	3	3	3		4
Teewinot Apex	29	29	29	29	29		0
Teewinot South	14	14	14	14	14		
Twenty-Five Short							0
Upper Death Canyon	14	14	14	14	14		0

Table 5. Overstory (>1.4 meters tall) PIAL summary data for blister rust infection and severity by monitoring transect 2007-2013. Gray boxes indicate years transects were not visited.

GRAND TETON NATIONAL PARK WHITEBARK MONITORING OVERSTORY TREE DATA 2007-2011

Updated October 2013

Transect	***% Live PIAL with Rust***							***Rust Severity (Live and Killed by Rust)***						
	2007	***2008***	***2009***	***2010***	***2011***	***2012***	***2013***	***2007***	***2008***	***2009***	***2010***	***2011***	***2012***	***2013***
Amphitheater Lake	44	48	56	60	58	63	60	1.2	2.48	4.04	4.96	4.64	5.2	4.85
Boundary Lake	33		33		29		29	0.63		0.7		0.96		1.08
Carr Lake	46		46					0.82		1.63				
Cascade Canyon	63	88		50		50		2	5.38		2.5		2.5	
Death Canyon Shelf	45	48		61			42	2.45	3.34		5.39			4.85
Delta Lake	80	67		67	67		60	3.7	4.83		6.17	6.5		6.2
Forellen	28	45		66			60	0.83	1.67		3.41			4.32
Garnet	60	53						1.87	2.93					
Hanging Canyon	90	86		83	83		83	5	7.58		7.5	8.5		10
Holly Lake	80	80		80		80	80	3.6	6.2		6		7	9.2
Jackson Hole Mtn Resort	65	55		61	53		31	2.93	3.97		3.71	4.76		5.19
Lake Taminah	54	62	67	58	43	39	46	1.42	2.2	2.88	3.16	2.37	2.79	3.14
Marion	66	66		66			67	3	4.33		6			6
Mount Hunt	86	100		100			100	3.86	6		6.42			7.86
Mount Moran	26		30		71		65	0.26		1.35		1.59		1.39
North Fork Cascade Cache	30	40	50	60	60	50	60	0.7	1.3	2.5	3.3	3.6	3.5	3.9
Ortenberger Lake	82		90				83	0.3		5.5				6.75
Paintbrush Canyon		43		46	25		23		0.71		.48	0.71		0.64
South Fork Cascade	78	75		75	75		71	2.55	4.89		6.78	7.44		6.88
Static	92	100	100	100	100	100	100	5.12	7.75	9	10.5	11.25	12	12
Stewarts	88	83	NA	NA	0	0	0	6.35	6.67	NA	NA	0	0	0
Survey Peak	58	65		64			59	2.68	4.09		4.45			5.48
Teewinot Apex	71	100		100	100		100	3.14	6.33		10.5	10		11
Teewinot South	100	100		100	NA		NA	5.71	9.25		8.5	NA		NA
Twenty-Five Short		100		100			0		4		5			0
Upper Death Canyon	29	57		75			67	2	2.43		3			2.17

Table 6. Overstory PIAL summary data for monitoring transects sampled annually

GRAND TETON NATIONAL PARK WHITEBARK MONITORING OVERSTORY TREE DATA 2007-2013 *Updated October 2013*																					
	% PIAL Dead							***% PIAL with MPB***							***% PIAL with Evidence of Cones***						
Year	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Amphitheater Lake	0	0	0	0	4	4	4	8	0	0	0	0	0	0	40	24	36	16	38	42	36
Lake Taminah	7	7	14	32	26	26	32	0	0	21	21	21	13	14	4	0	4	0	4	4	0
NFC Cache	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	30	20	10	30	30	30
Static	33	78	78	78	78	78	78	67	78	78	78	78	78	78	58	25	0	0	0	0	0
Stewarts	0	65	75	100	94	89	89	24	94	94	100	94	89	89	18	17	0	0	0	0	0

Table 7. Understory PIAL summary data for monitoring transects sampled annually.

GRAND TETON NATIONAL PARK WHITEBARK MONITORING UNDERSTORY TREE DATA 2007-2013 *Updated October 2013*														
	Total Seedlings Per Hectare							***Percent Rust-Free Seedlings***						
Year	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Amphitheater Lake	1240	1680	1800	1520	1380	1640	1580	100	100	100	99	99	100	100
Lake Taminah	740	1220	1140	2060	1780	1940	1160	97	100	93	89	93	93	95
North Fork Cascade Cache	320	700	660	640	620	3440	860	100	100	97	100	97	99	98
Static	220	2640	2080	880	1000	740	360	91	100	100	100	100	100	100
Stewarts	1580	2460	2720	2280	1920	1520	1540	99	100	99	98	99	96	96

Table 8. Understory PIAL summary data by monitoring transect 2007-2013. Gray boxes indicate years transects were not visited.

GRAND TETON NATIONAL PARK WHITEBARK MONITORING UNDERSTORY TREE DATA

Updated October 2013

	Total Seedlings Per Hectare							***Percent Rust-Free Seedlings***						
Year	***2007***	***2008***	***2009***	***2010***	***2011***	***2012***	***2013***	***2007***	***2008***	***2009***	***2010***	***2011***	***2012***	***2013***
Amphitheater Lake	1240	1680	1800	1520	1380	1640	1580	100	100	100	99	99	100	100
Boundary Lake	700		1740		2380		4420	100		100		100		100
Carr Lake	240		240					100		100				
Cascade Canyon	60	40		120		1580		67	100		100		99	
Death Canyon Shelf	620	460		400			200	94	83		90			96
Delta Lake	740	760		980	1200		1040	100	100		98	98		98
Forellen	840	1300		2080			1920	100	100		100			100
Garnet	420	640						100	100					
Hanging Canyon	1080	860		1060	940		880	100	98		98	100		100
Holly Lake	320	200		420		560	520	100	100		100		100	100
Jackson Hole Mtn Resort	940	1740		1200	1160		1260	100	99		92	95		97
Lake Taminah	740	1220	1140	2060	1780	1940	1160	97	100	93	89	93	93	95
Marion	20	20		40			20	0	0		100			100
Mount Hunt	280	100		120			120	100	100		100			100
Mount Moran	320		480		520		480	100		79		96		96
North Fork Cascade	320	700	660	640	620	3440	860	100	100	97	100	97	99	98
Ortenberger Lake	160		660				240	88		94				92
Paintbrush Canyon		20		20	0		0		100		100			
South Fork Cascade	180	180		160	160		160	100	67		75	75		100
Static	220	2640	2080	880	1000	740	360	91	100	100	100	100	100	100
Stewarts	1580	2460	2720	2280	1920	1520	1540	99	100	99	98	99	96	96
Survey Peak	900	1200		1160			1020	84	92		88			88
Teewinot Apex	120	80		100	100		80	83	50		80	80		100
Teewinot South	280	440		580	800		760	100	100		100	100		100
Twenty-Five Short		0		0			0		NA		NA			0
Upper Death Canyon	100	60		60			20	80	100		100			100

Table 9. Univariate analysis - 2007 Data.
Observed frequency ratios that exceed expected ratios are in bold, indicating significant dependent variables.

GRAND TETON NATIONAL PARK WHITEBARK MONITORING – UNIVARIATE ANALYSIS
October 2008

Variable	*Categories*	*Frequency Ratios*†	χ^2††	*Interpretation*
Cone Evidence		*Cones Absent: Cone Evidence*		
	# Cankers	Expected = 1 : 0.44		Both rust & cone evidence greater on wb with more branches
	0	1 : 0.26		
	1-3	1 : 0.37		
	4-15	**1 : 0.92**		
	>15	**1 : 0.58**	19.07; p=0.0003	
Elevation *Low (<9500')* *High (>9500')*		*Low:High*		
	# Cankers	Expected = 1 : 1.9		Rust severity is greater at lower elevations (<9500")
	0	**1 : 3.3**		
	1-3	**1 : 3.5**		
	4-15	1 : 1.6		
	>15	1 : 0.4	49.95; p<0.0001	
Aspect *North* *(0-70 & 280-360°)* *South* *(70-280°)*		*North: South*		
	# Cankers	Expected = 1 : 1.70		Rust severity is greater on south aspects (70-280°)
	0	1 : 1.22		
	1-3	**1 : 1.95**		
	4-15	**1 : 1.77**		
	>15	**1 : 3.80**	11.07; p=0.113	
Rust Presence		*Rust Absent: Rust Present*		
	DBH (cm)	Expected = 1: 1.19		Rust presence increases tree diameter
	0.1-10	1: 0.46		
	10.1-20	1: 1.05		
	20.1-30	**1: 3.10**		
	30.1-40	**1: 9.70**		
	40.1-50	**1: 10.5**		
	>50	**1: 10.5**	84.81; p<0.0001	
MPB Presence		*MPB Absent: MPB Present*		
	# Cankers	Expected = 1 : 0.05		MPB activity increases with rust severity
	0	1 : 0.02		
	1-3	1 : 0.05		
	4-15	**1 : 0.07**		
	>15	**1 : 0.13**	8.6650; p=0.0341	
MPB Presence		*MPB Present: MPB Absent*		
	Aspect	Expected = 1: 0.18		Mpb activity is greater on south aspects (70-280°)
	North	1: 0.10		
	South	**1: 0.23**	7.490; p=0.0062	
MPB Presence		*MPB Present: MPB Absent*		
	Elevation	Expected = 1: 0.18		Mpb activity is greater at lower elevations (<9500')
	<9500'	**1: 0.50**		
	>9500'	1: 0.14	18.15; p<0.0001	

†Frequency ratios calculated by dividing the observed number of whitebark selected as hosts by the MPB by the observed number of whitebark not selected. We calculated this ratio for category indicated.
††Pearson's chi-square calculates expected ratios based on the null hypothesis that all variables are independent.

FIGURES

Figure 1. Grand Teton National Park Whitebark Monitoring Transects.

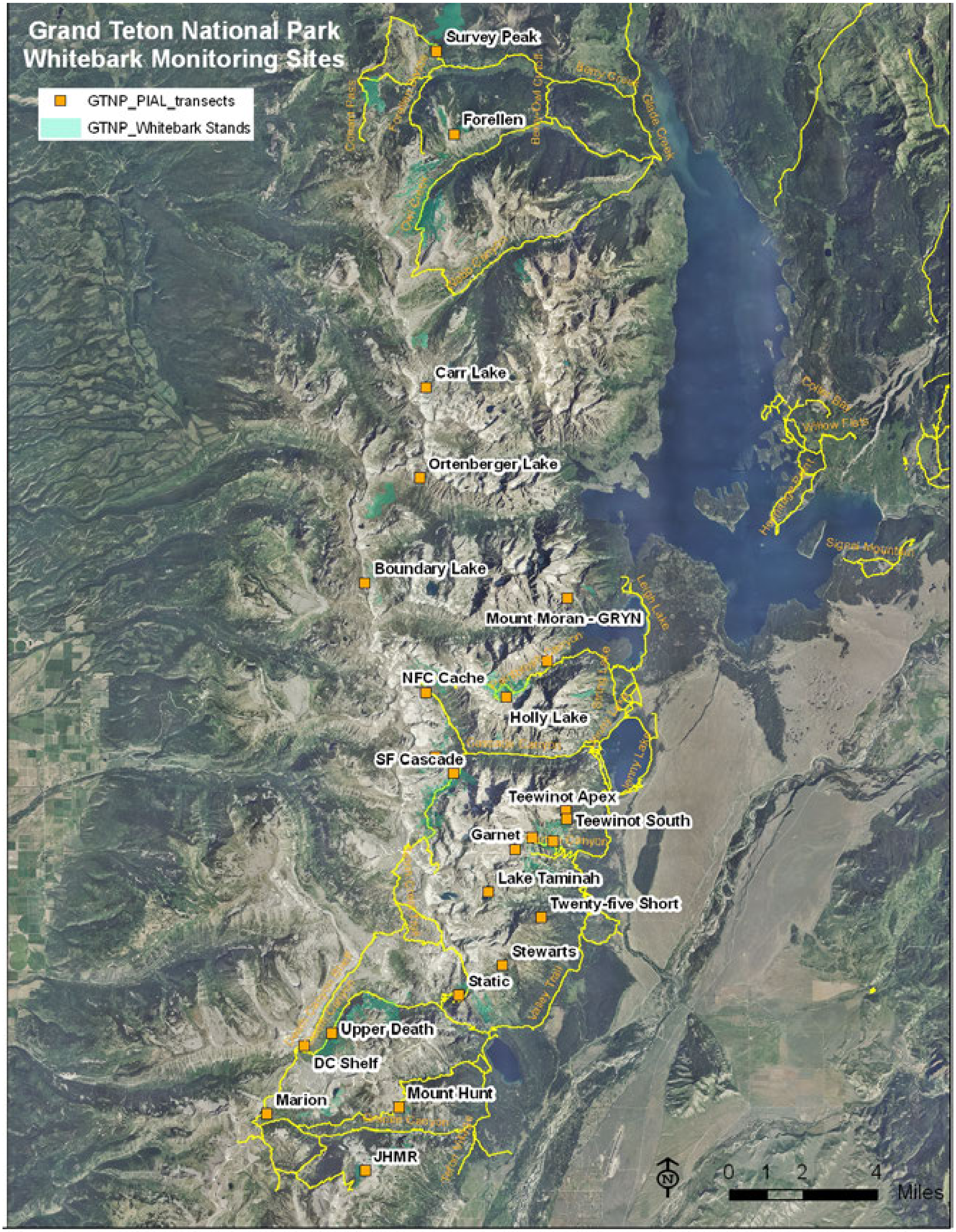
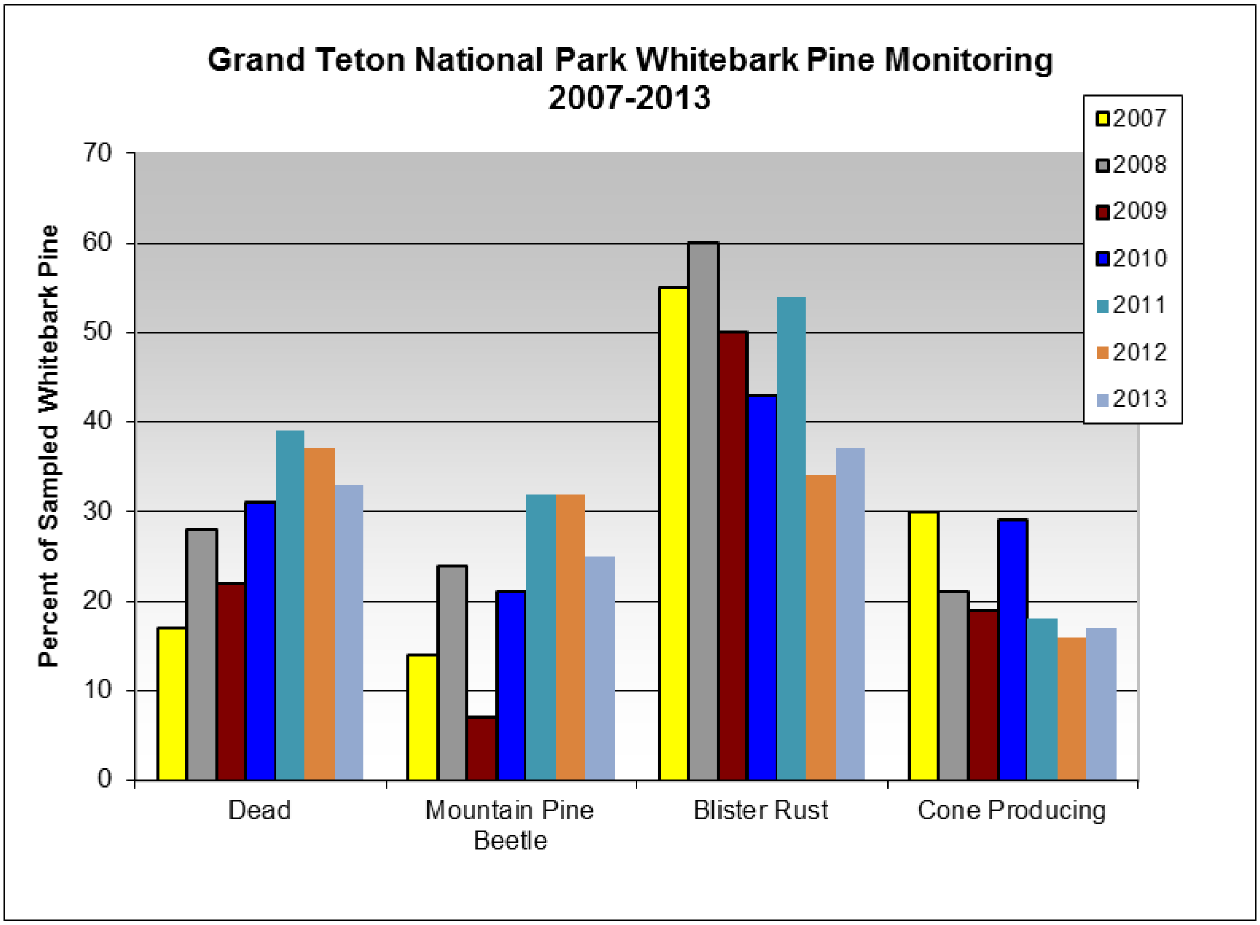


Figure 2. Distribution by status of individual whitebark sampled in Grand Teton National Park 2007-2010.



Notes on Figure 2:

1. **Annual sample sizes vary** (Table 2).
2. Whitebark that grow to >1.4 meters are moved from the “understory” to “overstory”. Thus new trees are added to the sample size.
3. Notes on DEAD category:
   - In 2009 and 2012, fewer individual whitebark were sampled, and those sampled had lower overall mortality, which resulted in a decrease in the proportion of dead whitebark.
4. Notes on MOUNTAIN PINE BEETLE category:
   - In 2009 and 2012, fewer individual whitebark were sampled, and those sampled had lower overall beetle attack, which resulted in a decrease in the proportion of whitebark with beetles.
5. Notes on BLISTER RUST category:
   - The decrease in blister rust incidence is partially because whitebark with rust were removed from sample population due to mortality.
   - Rust incidence did NOT follow the same annual pattern as mortality and beetle attack indicating lower spatial variability in rust incidence.

Figure 3. Overstory tree mortality, MPB activity and cone production by year for transects sampled annually from 2007 to 2013.

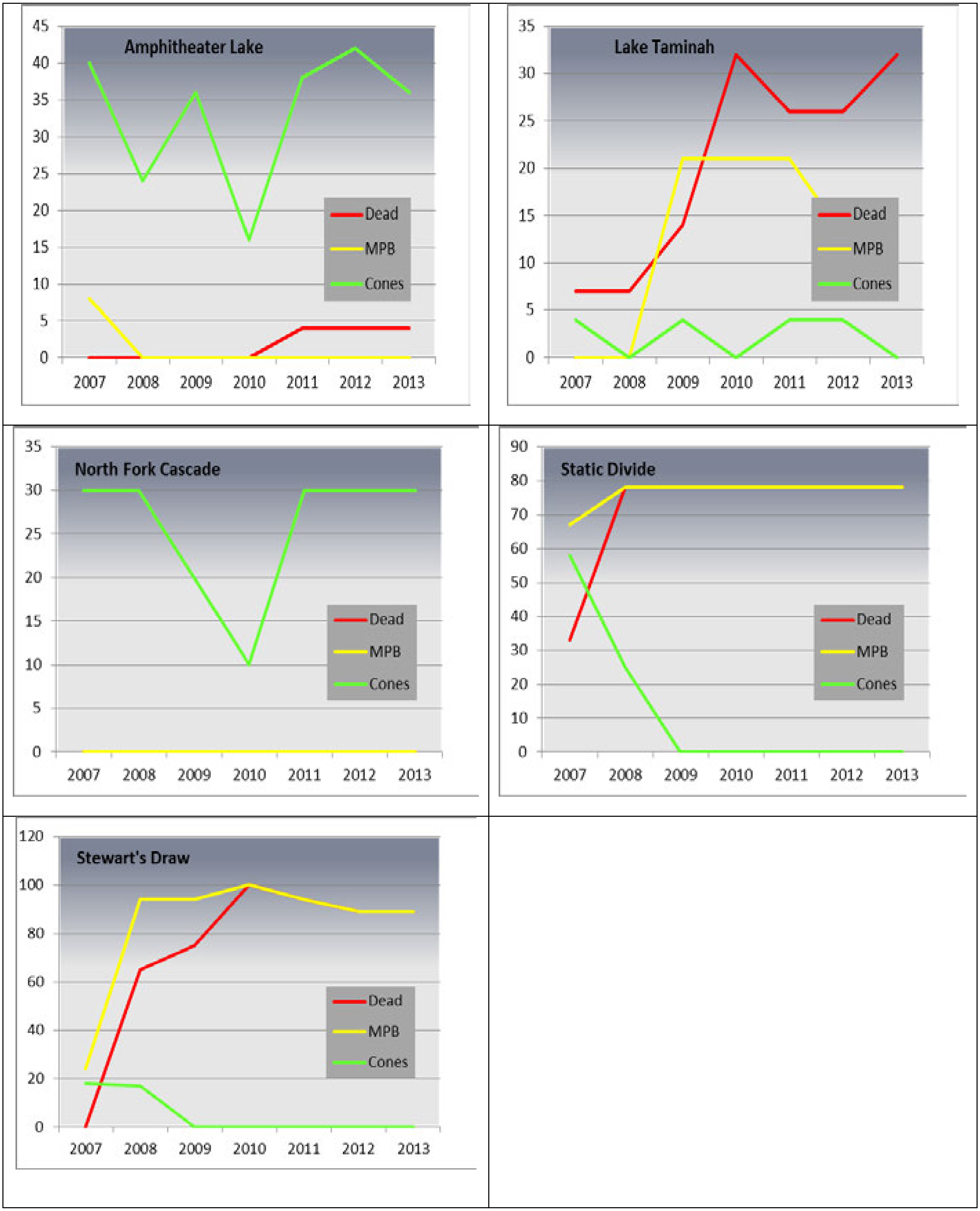


Figure 4. Rust severity by year, location of infection on individual trees sampled, and total severity. See methods for explanation of severity ratings on y-axis. Maximum branch severity is 18. Maximum bole severity is 6. Maximum total severity is 24.

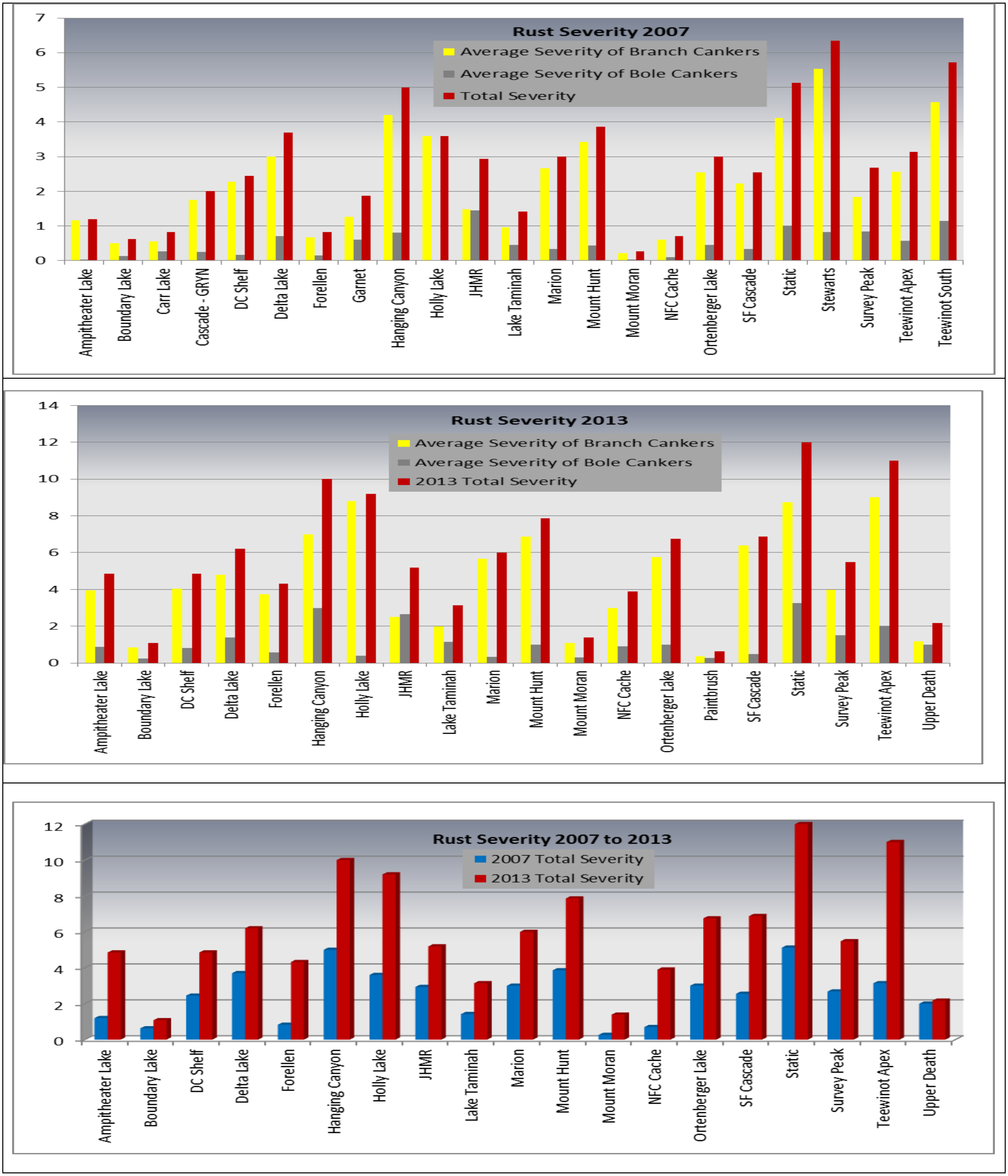


Figure 5. Whitebark mortality 2007 and 2013.

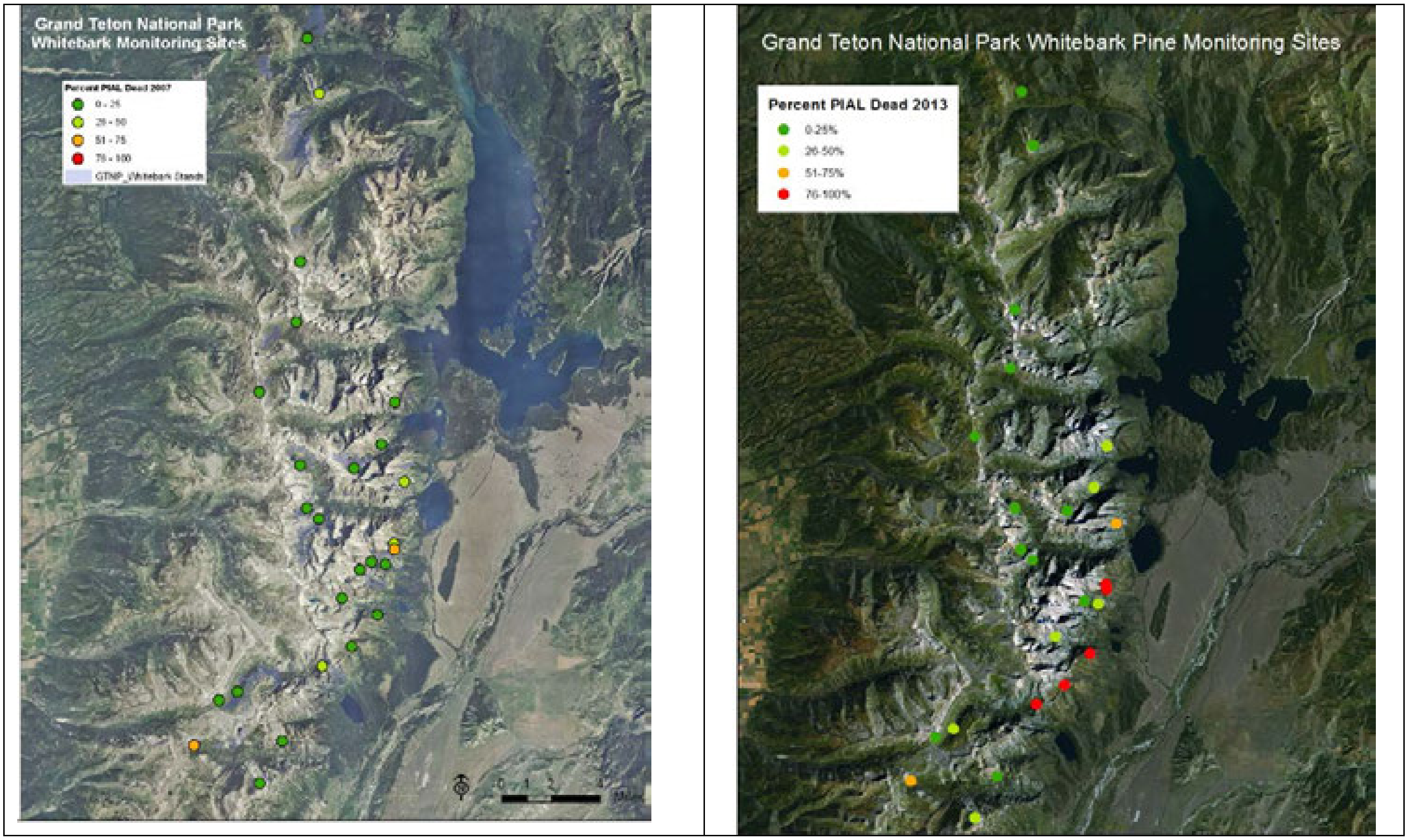


Figure 6. Mountain pine beetle activity in whitebark 2007 and 2013.

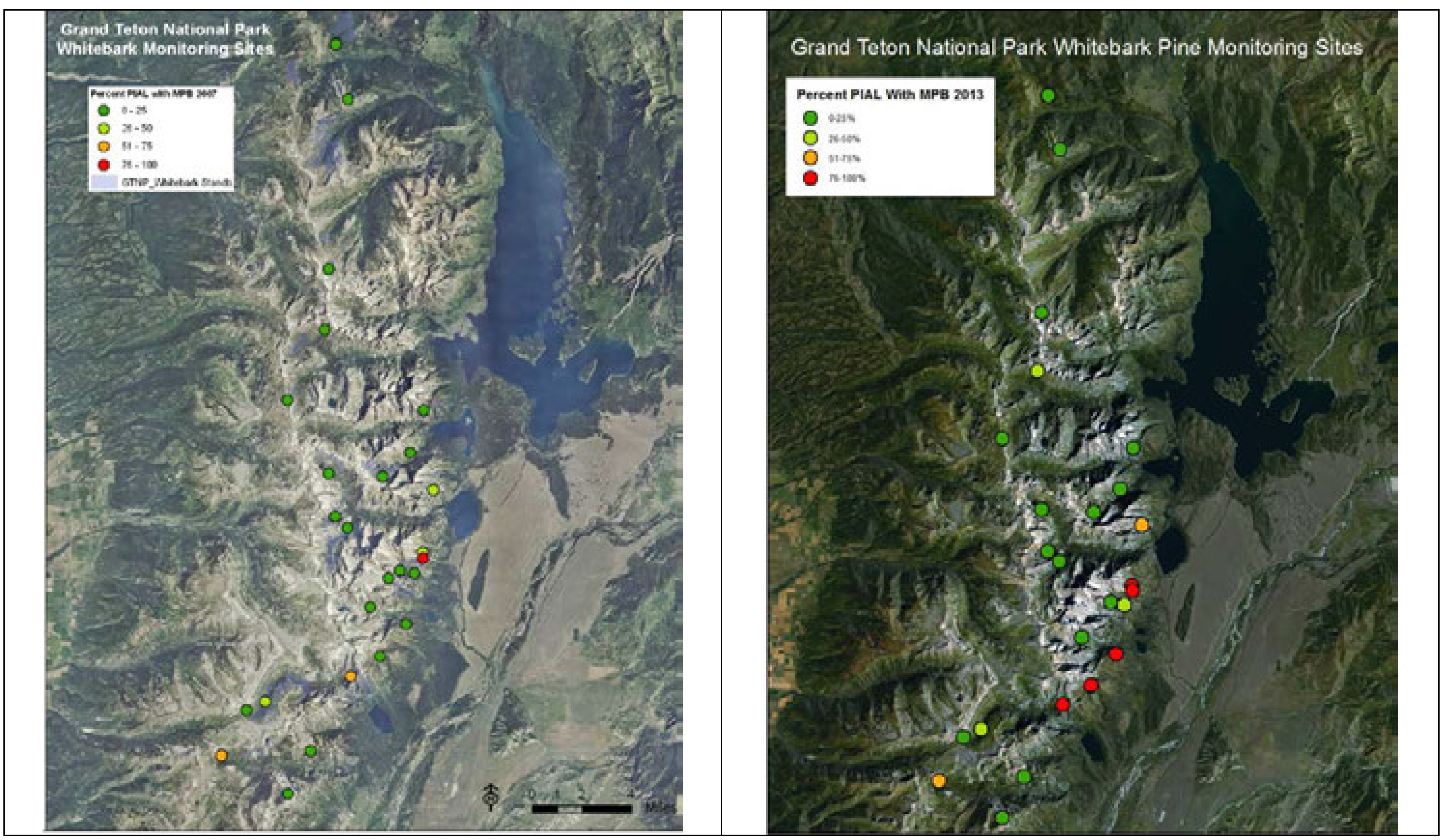


Figure 7. Proportion LIVE whitebark with blister rust 2007 and 2013