Assessment of Whitebark Pine Regeneration in Burned Areas of the Shoshone and Bridger-Teton National Forests and Wind River Reservation, Wyoming

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Summary

Whitebark pine (*Pinus albicaulis* Englem.) forests in northwestern Wyoming, including the Wind River Reservation, Shoshone National Forest and Bridger-Teton National Forest, have been severely affected by mountain pine beetle (*Dendroctonus ponderosae* Hopkins) (MPB)-, wildfire-, and white pine blister rust (*Cronartium ribicola* J.C. Fisch.) (WPBR)- induced mortality. In previously burned areas, there is limited critical information on the regeneration of whitebark pine seedlings. The purpose of this study was to determine and compare the amount of regeneration in burned and non-burned areas, and to determine what site factors impacted regeneration occurrence. A survey of whitebark pine regeneration in six areas that have experienced stand replacing fires 8 to 32 years previous was conducted in the Wind River and Absaroka Mountain Ranges in summer 2007. Fires were divided into polygons of similar aspects, elevations, and forest types. Potential seed source was measured in surrounding forests. Tree regeneration was tallied by species, and height class; and standard tree measurements, including MPB and WPBR incidence, were taken for whitebark pine along with site and stand conditions in burned and non-burned areas. The amount of regeneration was variable for all species and more than 25% of the plots did not have whitebark pine. Aspect of the site was related to the density of whitebark pine regeneration in burned areas. The amount of whitebark pine regeneration smaller than 200cm tall in burned areas on south facing slopes was 7.6 stems/ha (half LSD = +15.8, -5.1) and 167.5 stems/ha (half LSD= +274.5, -104.0) on north facing slopes ($p=0.0508$). Site and stand conditions, such as vegetation type, amount of potential seed source, and amount of other species regeneration were positively related to the density of whitebark pine regeneration in burned areas. The largest percent of whitebark pine regeneration occurred under the protection of downed woody debris, logs and roots in both the burned and

non-burned areas (63.9% and 47.3%, respectively). The percent of live whitebark pine infected with WPBR was generally low for most fires and ranged from 0 to 10.7%. The loss of mature, cone bearing trees to the current MPB outbreak will impact the future potential for whitebark pine regeneration for most of the fires surveyed. Burned areas with cool and wet north facing slopes with potential seed source within the range of the Clark's Nutcracker (*Nucifraga columbiana* Wilson) may be areas where whitebark pine will regenerate, while south facing slopes or areas with mostly grass cover may either take longer than north facing slopes to regenerate or may not regenerate to whitebark pine without the help of artificial planting.

Introduction

Whitebark pine (*Pinus albicaulis* Englem.) is assumed to be fire-dependant for regeneration. In the southern extent of the species, the Wind River Mountain region, there is limited critical information on the survival of whitebark pine seedlings in previously burned areas. Whitebark pine is vital to high elevation alpine ecosystems. Birds, specifically the Clark's Nutcracker (*Nucifraga columbiana* Wilson), and several mammal species rely on the large seeds for sustenance. In effect, the only form of seed dispersal for whitebark pine is by way of the Clark's Nutcracker; and caching sites are usually in open areas, such as those created by recent fires (Tomback 2001).

Whitebark pine on the Wind River Reservation, as well as the Shoshone and Bridger-Teton National Forests has been severely affected by mountain pine beetle (*Dendroctonus ponderosae* Hopkins) (MPB)-, wildfire-, and white pine blister rust (*Cronartium ribicola* J.C. Fisch.) (WPBR)-induced mortality. Likewise, restoration activities in the region would benefit from information on the survival and health of whitebark pine regeneration in previously burned areas. The objective of this study was to: 1) determine the incidence of whitebark pine regeneration in previously burned areas compared to unburned areas; 2) determine what site and stand factors are related to the presence of whitebark pine regeneration; and 3) document the incidence and severity of damage agents on whitebark pine regeneration and mature trees, such as white pine blister rust and mountain pine beetle, in burned and non-burned areas.

Materials and methods

Plot Locations and Sampling

Permanent regeneration monitoring plots were established in non-burned forested areas and forested areas burned 8 to 32 years previous, with a total of 6 fires sampled (Fig. 1, Table 1). Sampled fires were in areas of potential whitebark pine habitat – defined by elevation and surrounding vegetation – and within an hour hike from a road in the Shoshone NF, Bridger-Teton NF, and Wind River Reservation (Fig. 1).

Fires were divided into polygons of similar aspects, elevations, and forest types; with each polygon comprising a minimum area of burned forest of 1.76ha (80m x 220m) and an associated minimum area of non-burned forest of 1.10ha (50m x 220m). A total of 14 polygons were surveyed. Trees, along with any regeneration, within a polygon were sampled within plots placed along a transect that followed elevational contours. In burned areas, three to five transects were randomly selected from the maximum number of transects that would fit inside the polygon. The two transects placed in non-burned areas were selected in the same manner as burned areas. The ends of transects were 10m from the nearest non-burned area in burned portions of a polygon and 10m from the nearest burned area in non-burned portions of a polygon.

Transects in both burned and non-burned areas were monumented with a tagged and red or yellow painted rebar and a tagged and painted log, tree or stump.

A transect consisted of a minimum of 5 plots, each 2m by 40m in length. Every other plot was skipped in large polygons to maximize the distance along a transect within a polygon sampled. A minimum of 30m and a maximum of 100m existed between two adjacent transects within a polygon. A total of 396 plots were measured, with 256 plots in burned areas and 140 in non-burned areas.

Within each plot on the transect, the number of each tree species present within height classes (< 20cm, 20-100cm, 100-200cm, 200-300cm, ≥300cm) were tallied, and for whitebark pine, crown class, microsite conditions, health class, abiotic or biotic damage incidence and damage severity were collected. Microsites were classified as: base of tree or under low tree canopy; under protection of downed woody debris, logs, or roots; open, no protection from wind or solar; under protection of rocks; and in cracks or holes in trees. Health class was on a scale from 1 (healthy) to 5 (dead without fine twigs or needles). The aspect (degrees, categorized as north and south), percent slope, disturbance types (crown fire, surface fire, salvage logging, selective cuts, burn piles, planting or interplanting of seedlings), percentage of top three species of ground cover, percentage of bare ground, percentage of litter, and percentage of surface area disturbed by pocket gophers (*Thomomys talpoides*) were recorded. Vegetation was categorized as either associated with wet or dry site conditions. *Vaccinium scoparium* was the major species associated with cool and wet conditions (Arno, 2001). The species associated with dry site conditions were: *Carex* spp., *Juncus* spp., *Arnica cordifolia*, and bunch grasses (Arno, 2001). The basal area of all tree species along with health class, damage agent incidence, damage severity, whether cones have been present and diameter class were assessed at the ends of each plot using a basal area angle gauge (5 BAF (ft^2/acre) in burned areas and 10 BAF (ft^2/acre) in non-burned areas), along with recording GPS coordinates.

In several of the permanent research plots, there were indications of tree interplanting. To determine which trees were planted, the age of five-needle pine regeneration was determined by counting branch whorls, with trees of the same age as planted regeneration excluded from most analysis. Determination of the species of five-needle pine regeneration was not possible so species designation was based on surveying surrounding mature, live white pine species. Regeneration was assumed to be whitebark pine if the surrounding forest consisted only of whitebark pine and not limber pine. The differentiation of mature whitebark pine from limber pine was by comparison of male and female cones.

Seed Source

To assess the nearest whitebark pine seed source, non-burned forest 10m from the perimeter of the fire was surveyed with variable radius plots, each recording the basal area of all tree species along with the health class, damage agent, damage incidence and severity, diameter class and whether whitebark pine or limber pine cones were present. Variable radius plots were spaced 80m apart and surrounded the fire in potential whitebark pine habitat.

Meterological data

Monthly averages of precipitation, and minimum and maximum temperatures at four National Oceanic and Atmospheric Administration weather stations surrounding the Wind River Mountain Range were obtained from the National Climatic Data Center. Weather stations used were: Lander, Jackson, Moran, and Dubois, WY.

Data analysis

Tests for spatial auto- and cross-correlation between plots within fires ($p<0.05$) were performed using spatial proximity weights equal to the inverse of the distance between plots, defining a neighborhood for each fire that ranged from 10 to 45m. Analysis of spatial correlation was carried out using R 2.6.1 (The R Foundation for Statistical Computing, 2007) with additional functions to calculate and test Moran's *I* (Robin Reich, Colorado State University, personal communication).

To determine differences in tree density between burned and non-burned areas, and north and south facing slopes, a mixed model analysis of variance was run with aspect and status as fixed effects and polygon, transect, plot as random effects (SAS/STAT 9.1, MIXED procedure). Since spatial correlation was observed, the coordinates associated with each plot were used to fit a spatial power model for the residuals. The density of trees was positively skewed and to meet the assumption of normality, the data was transformed to the $\log_{10}$ scale for analysis. The back-transformed data is presented which corresponds more to the median than to the mean (James zumBrunnen, Colorado State University, Statistical Laboratory, personal communication).

Results

Stands in this study consisted of a mix of whitebark pine, Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.) and lodgepole pine (*Pinus contorta* Douglas ex Louden), with the proportion of each species differing for each fire (Table 1). Though limber pine was encountered at two of the fires, Unit 40 and Willow Creek, sampling did not occur at lower elevation portions of the fire where limber pine occurred and regeneration was considered whitebark pine based on the whitebark found in the surrounding higher elevation areas.

Tree Regeneration

The density of whitebark pine was variable, with more than 25% of the plots without the presence of whitebark pine (Table 2). The back-transformed adjusted means for the density of whitebark pine within height classes was noticeably lower than the mean not transformed and not accounting for the experimental design (Table 2).

The amount of whitebark pine regeneration, separated into height classes, were significantly lower in burned areas than in non-burned areas and ranged from 1.3 to 12.3 stems/ha in burned areas and 3.2 to 65.2 stems/ha in non-burned areas (Fig. 2). Whitebark pine density was not significantly different on different aspects when all plots were within the model. Covariates that were positive in these models were the percent cover of vegetation associated with wet conditions, density of all other species (seedlings to mature trees), and density of only lodgepole pine (seedlings to mature trees). Percent cover of litter was a negative covariate in the model for the density of whitebark pine that was 100-200cm in height.

Grouping the three shortest height classes together (whitebark pine less than 200cm in height), there was a significant interaction between aspect and whether the plot was in a burned or non-burned area (Table 3). South facing slopes that had burned had significantly less number of whitebark pine smaller than 200cm in height than on north facing aspects and non-burned areas (Table 3). The percent cover of vegetation associated with wet conditions was a positive covariate for this model.

When removing non-burned plots from the models, the density of whitebark pine separated into height classes were greater on north aspects compared to south aspects for the two lowest height classes (whitebark pine less than 100cm in height) (Fig. 3). Covariates that were positive in the models for the height classes < 100cm in height were: basal area of nearest whitebark pine potential seed source, percent cover of shrubs, number of years since the fire, and density of lodgepole pine (seedlings to mature trees). Percent cover of grass and minimum distance to potential whitebark pine seed source were negative covariates.

Whitebark pine were found growing in clusters of 2 to 10 trees, with an average of 3.1 ± 0.12 whitebark pine per cluster. There was an average (back-transformed from $\log_{10}$) of 7.7 clusters/ha (half LSD= +1.7, -1.3).

In addition to whitebark pine, the regeneration species were: subalpine fir, Engelmann spruce, lodgepole pine, and to a minimal degree, Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) on the Willow Creek Fire. As with the whitebark pine regeneration, there was significant variation in the density of regeneration (Fig. 4). Comparing density of regeneration in burned and non-burned areas, only Engelmann spruce had lower densities of regeneration in burned areas than non-burned areas though this does not reflect the age structure of the regeneration (Fig. 4). The amount of regeneration for non-whitebark pine species was not significantly different on north slopes compared to south slopes.

Site and Stand Conditions Related to Regeneration

The potential whitebark pine seed source was considered mature trees that were cone bearing or had the potential to be cone bearing. The average minimum distance for each fire from plots to potential seed source ranged from 89.7 to 367.9 m. The basal area of mature live whitebark pine that were potentially cone bearing ranged from 3.2 to 7.0 m^2/ha for each fire.

Bare ground and litter ranged from 0 to 80% cover and from 0 to 60% cover, respectively. Vegetation associated with wet conditions (*Vaccinium scoparium*) was a component in 25% of the plots and ranged from 1 to 60% cover. Ninety-three percent of the plots had a component of vegetation associated with dry conditions and ranged from 2 to 100% cover. After each fire, there were fluctuations of dry/hot and wet/cool periods (Fig. 5).

Most measures of regeneration and stand characteristics had positive spatial auto- and cross-correlation at the plot level for all of the fires except for Willow Creek. The percent cover of grass and vegetation associated with dry site conditions generally had negative spatial cross-correlations with most regeneration and stand measures. In 4 of the 6 fires, there were either negative or null spatial cross-correlations of the density of other species or lodgepole pine regeneration to the density of whitebark pine regeneration.

The microsites with downed woody debris, logs and roots were where a large percentage of whitebark pine that were less than or equal to 100cm in height were found (Table 4). In the burned area, there were significantly less whitebark pine regeneration under the protection of tree bases or under a low tree canopy compared to non-burned areas, which is likely related to the lack of canopy cover in burned areas (Table 4).

The age of whitebark pine was estimated by counting the number of whorls for trees less than or equal to 100cm in height. Whitebark pine less than 20cm in height and 20 to 100cm in height were younger in the burned areas compared to the non-burned areas (p-value=0.0522, p=0.0028 respectively) (Table 5). A regression analysis on the age of whitebark pine to height in the burned and non-burned areas shows that the slopes of the trend lines are different, though the trajectories are similar (Fig.6).

The presence of harvesting, domestic grazing, and pocket gophers was not significantly related to the amount of whitebark pine regeneration found in burned or non-burned areas. Harvesting and grazing occurred in the burned and non-burned areas in 68% and 46% of the plots, respectively. In the burned areas, salvage logging occurred 85% and grazing in 51% of the plots. Pocket gophers and their tunnels were present in 54% of the burned plots and 16% of the non-burned plots.

The Geyser Creek, Unit 40, Willow Creek, and Dry Cottonwood fires were planted, at least 6 years prior to the survey, with lodgepole pine, though the success of these plantings were different for each fire and within each fire. The planting of lodgepole pine at the Willow Creek fire was generally not successful because of a period of drought when the trees were planted (Eric Rhodenbaugh, Department of Forestry, Wind River Reservation, personal communication). At the Geyser Creek, Unit 40 and Dry Cottonwood fires, artificial regeneration was successful on north facing slopes. The interplanting of whitebark pine at the Geyser Creek fire was generally unsuccessful on the south facing slope due to exposure to the wind and solar radiation, along with heavy snow drifts during the winter (Ellen Jungck, Shoshone National Forest, personal communication).

Damage Agents

Dead tops and browsing or rubbing from animals were major damages on whitebark pine regeneration in both burned and non-burned areas (Table 6). Incidence of WPBR occurred in all height classes except for trees less than 20cm in height (Table 6). The amount of infection in burned and non-burned area was less than 6.4% of total whitebark pine density (seedlings to mature trees) (Table 6).

Both WPBR and MPB activity occurred in the non-burned forest. The incidence of live whitebark pine (with a measurable DBH) infected with WPBR ranged from 0 to 10.7%, with a low average severity for infected trees (0 to 14% stems infected) except for whitebark pine in the Unit 40 area (50% stems infected) (Table 1). Mountain pine beetle had been causing mortality in the whitebark pine before and after the fires. The time since mortality by mountain pine beetle was estimated by the amount of bark and branch degradation and whether dead trees were burned in the fire. The estimates of MPB-induced mortality that occurred before the fires ranged from 0 to 22% of the density of susceptible (DBH>20.3cm) whitebark pine (Table 1). Also, there was extensive recent mortality that had occurred since the fires due to MPB that ranged from 17.1 to 51.5% of the density of susceptible whitebark pine (Table 1).

Discussion

The density of whitebark pine regeneration in burned and non-burned areas was variable, and does seem to be related to specific site and stand characteristics. Each fire had different conditions that contributed to the amount of whitebark pine regeneration, such as aspect, vegetation type, non-burned tree species composition, and the amount of potential seed source. The cool and wet site conditions on northern slopes along with the success of other species of regeneration were positively related to the density of whitebark pine regeneration in burned areas. The conditions that make other tree species successful also make whitebark pine regeneration successful, though these conditions may be spotty throughout the burned areas.

Because aspect was a significant factor in the amount of regeneration in burned areas, there is evidence that dry and hot periods may negatively affect successful whitebark pine regeneration. More research should be conducted on the survival of seedlings during yearly shifts in temperature and precipitation. The high yearly temperature and low yearly precipitation after the most recent fire - Moccasin Basin Fire in 1999 - along with the southerly facing slope, may have had an effect on the potential for regeneration and may be partially responsible for the lack of regeneration of any tree species at this site.

The planting of lodgepole pine in 4 of the 6 fires may have affected the density of whitebark pine regeneration by either deterring caching of seeds by birds or by competition. However, beyond the spatial analysis that showed there was a trend towards a negative to a null cross-correlation of whitebark pine regeneration to the amount of lodgepole pine regeneration there was little evidence that the amount of lodgepole pine regeneration (which tended to be mostly artificially planted) was preventing the successful regeneration of whitebark pine.

Regeneration density for whitebark pine and Engelmann spruce were greater in non-burned areas as compared to burned areas. Though the density of whitebark pine regeneration was less in burned areas, the regeneration grew more rapidly and has a much greater potential of becoming mature canopy trees than do the over-topped regeneration in non-burned areas.

The microsite conditions where seeds were cached were associated with objects, such as logs and bases of trees, may alter the moisture and temperature of a site and be more favorable for regeneration growth. A greater percentage of whitebark pine regeneration was found in microsites created by downed woody debris, logs, and roots. Similarly, Tomback et al. (1993) found the greatest occurrence of whitebark pine regeneration in burned areas near small wood pieces, fallen trees and branches. Even in non-burned areas in the current study, downed woody debris, logs and roots were microsites where a high percentage of whitebark pine regeneration occurred, with a major percentage of whitebark pine regeneration also occurring in sites under the protection of a low canopy or base of tree.

Future establishment of whitebark pine regeneration may be limited due to the current MPB outbreak in the Wind River Mountain Range. This will hinder the successful establishment of natural regeneration of whitebark pine in more recent fires, such as the Bridger-Teton and Shoshone National Forest Purdy fire in 2006. The MPB-induced mortality reduces potential seed source and may also deter the presence of the Clark's Nutcracker while it looks for food in other ecosystems (Tomback & Kendall 2001). Also, the genetic resource for potential resistance to WPBR will be greatly reduced due to the extensive mortality of mature, cone bearing trees from MPB infestation. It is not known if WPBR will stay at the present low incidence in mature and regenerating whitebark pine, or increase in incidence as it has done in stands to the southeast, also on the Wind River Range (Kearns & Jacobi, 2007).

Recommendations for future restoration of seral whitebark pine in previously burned areas include, planting on north facing slopes where there are more wet, cool, and sheltered conditions and in areas with vegetation that includes *Vaccinium scoparium*. Establishing whitebark pine regeneration under the protection of downed woody debris, logs or roots would mimic the natural placement of whitebark pine regeneration by Clark's Nutcrackers. Also, deterring competition by establishing seedlings in areas without grasses or thick turf corresponds to where whitebark pine regeneration occurs. These recommendations should be tested in stands recently opened up with extensive mortality due to MPB. The success of natural and artificial interplanting of whitebark pine in areas previously planted with other species should be researched.

References

Arno, S.F. 2001. Community types and natural disturbance processes. In: Tomback, D.F., Arno, S.F., and Keane, R.E. (eds.), Whitebark Pine Communities: Ecology and Restoration. Island Press, Washington, D.C., pp. 76-88.

Kearns, H.S.J., and Jacobi, W.R. 2007. The distribution and incidence of white pine blister rust in central and southeastern Wyoming and northern Colorado. Canadian Journal of Forest Research 37: 1-11.

Tomback, D.F. 2001. Clark’s nutcracker: agent of regeneration. In: Tomback, D.F., Arno, S.F., and Keane, R.E. (eds.), Whitebark Pine Communities: Ecology and Restoration. Island Press, Washington, D.C., pp. 89-107.

Tomback, D.F., and Kendall, K.C. 2001. Biodiversity losses: the downward spiral. In: Tomback, D.F., Arno, S.F., and Keane, R.E. (eds.), Whitebark Pine Communities: Ecology and Restoration. Island Press, Washington, D.C., pp. 243-262.

Tomback, D.F., Sund, S.K., and Hoffman, L.A. 1993. Post-fire regeneration of *Pinus albicaulis*: height-age relationships, age structure, and microsite characteristics. Canadian Journal of Forest Research 23: 113-119.

Table 1. Burned areas sampled in 2007 in the northern Wind River and southern Absaroka Mountain Ranges, WY.

		Shoshone NF/ Washakie District			Bridger-Teton NF/ Jackson District	Wind River Reservation	
Fire name		Geyser Creek	Unit 40	Moccasin Basin	Dry Cottonwood	Willow Creek	Crow Creek
Fire year		1975	1988	1999	1991	1988	1994
Area burned (ha)		114	556	12	2411	NA	NA
Average elevation (m)		2894	2673	2814	2722	2957	2809
Number of polygons[1]		2	4	1	4	1	2
	North facing	1	4	0	2	1	1
	South facing	1	0	1	2	0	1
Number of plots in burned area		48	76	16	65	15	36
Number of plots in non-burned area		20	40	10	40	10	20
Species composition trees with DBH/ha							
Whitebark Pine		177.1	55.0	19.3	443.4	224.5	352.3
Englemann Spruce		344.9	148.1	399.3	70.1	418.8	126.1
Subalpine Fir		114.6	538.7	884.8	214.2	0	1.6
Lodgepole Pine		57.6	65.7	9.1	71.5	4.1	366.6
% stems/ha of live WB infected with WPBR		3.5%	10.7%	0%	3.9%	4.2%	2.6%
Average WPBR severity of infected WB [2]		1	5	-	1.4	1	1
Post-fire MPB		22.5%	51.5%	42.5%	37.1%	17.1%	1.4%
Pre-fire MPB		18.8%	2.6%	0	9.7%	22.3%	0.2%

[1] Polygons are defined as being made up of a burned and non-burned area that have similar aspects, elevations, and forest type.
[2] White Pine Blister Rust (WPBR) severity: 0 to 9 with a rating of 0=0-9% affected, 1=10-19% affected… 9=90-100% affected.
Note: Whitebark pine is abbreviated as WB, mountain pine beetle as MPB, and diameter at breast height as DBH.

Table 2. Descriptive statistics for the density of live whitebark pine in height classes in burned and non-burned areas in the northern Wind River and southern Absaroka Mountain Ranges, WY. Trees potentially planted in the Geyser Creek and Unit 40 fires were not included.

	Live whitebark pine (stems/ha)				
	< 20cm	20-100cm	100-200cm	200-300cm	>300cm
mean	394.7	386.1	109.5	28.4	76.4
SE	44.9	33.7	12.7	5.6	12.1
maximum	7250.0	5625.0	1750.0	1500.0	2875.0
3rd quartile	375.0	500.0	125.0	0.0	0.0
median	0.0	125.0	0.0	0.0	0.0
1st quartile	0.0	0.0	0.0	0.0	0.0
minimum	0.0	0.0	0.0	0.0	0.0

Table 3. Adjusted mean density of live whitebark pine (back-transformed from $\log_{10}$) in burned and non-burned areas, and north and south aspects in the northern Wind River and southern Absaroka Mountain Ranges, WY. Trees potentially planted in the Geyser Creek and Unit 40 fires were not included.

	burned		non-burned	
	north aspect (n=157)	south aspect (n=99)	north aspect (n=90)	south aspect (n=50)
whitebark pine regeneration less than 200cm in height (+/- half LSD)	167.5 a (274.5, 104.0)	7.6 b (15.8, 5.1)	227.9 a (428.0, 148.7)	144.6 a (351.1, 102.4)

Note: Different letters denote significance at $p < 0.058$. Means adjusted for percent vegetation cover associated with wet site conditions.

Table 4. Percent of live whitebark pine ≤ 100cm in height and back-transformed (from $\log_{10}$) mean density by microsite classification in the northern Wind River and southern Absaroka Mountain Ranges, WY. Trees potentially planted in the Geyser Creek and Unit 40 fires were not included.

	Burned area (n=256)		Non-burned area (n=140)		
	% stems in burned area	stems/ha (+/- half LSD)	% stems in non-burned area	stems/ha (+/- half LSD)	p-value
Base of trees or under low tree canopy	9.5	1.7 (1.2, 0.7)	42.8	18.7 (14.4, 8.1)	0.0011
Under protection of downed woody debris, logs, or roots	63.9	11.5 (12.5, 6.0)	47.3	20.6 (23.8, 11.0)	0.2310
Open, no protection from wind or solar	12.3	2.2 (2.1, 1.1)	6.7	2.9 (2.9, 1.4)	0.5695
Under protection of rocks	8.0	1.4 (0.4, 0.3)	3.2	1.4 (0.5, 0.3)	0.8997
In cracks or holes in trees	6.2	1.1 (0.1, 0.1)	0.0	0.0	0.3485

Table 5. Mean number of whorls on live whitebark pine (back-transformed from $\log_{10}$) in burned areas and non-burned areas in the northern Wind River and southern Absaroka Mountain Ranges, WY. Trees potentially planted in the Geyser Creek and Unit 40 fires were not removed from analysis.

		Burned area (+/- half LSD)	Non-burned area (+/- half LSD)	p-value
Height of live whitebark pine	< 20cm	3.7 (0.8, 0.7)	5.6 (0.8, 0.7)	0.0522
	20-100cm	11.4 (1.3, 1.1)	18.0 (1.7, 1.5)	0.0028

Table 6. Density and percent affected of whitebark pine with damages (back-transformed from $\log_{10}$) in burned and non-burned areas on whitebark pine in the northern Wind River and southern Absaroka Mountain Ranges, WY. Trees potentially planted in the Geyser Creek and Unit 40 fires were not removed from analysis.

	Burned (n=256)			Non-burned (n=140)			
	Mean stems/ha	+/- half LSD	% of live WB	Mean stems/ha	+/- half LSD	% of live WB	p-value
Dead top	1.3	0.82, 0.50	7.3	9.2	6.23, 3.71	36.8	0.0007
Animal damage	1.4	0.60, 0.42	10.3	7.5	3.50, 2.39	33.4	0.0029
WPBR	1.1	0.16, 0.14	2.2	1.5	0.26, 0.22	6.4	0.0815
< 20*	0.0	-	0.0	0.0	-	0.0	-
20-100*	1.0	0.04, 0.04	1.0	1.1	0.06, 0.57	1.9	0.2935
100-200*	1.0	0.05, 0.05	3.7	1.1	0.07, 0.06	2.2	0.6402
200-300*	1.0	0.04, 0.03	0.8	1.0	0.05, 0.05	3.6	0.5227
>300*	0.0	0.0	0.0	1.3	0.18, 0.16	8.7	0.0687

* Stems/ha of damaged whitebark pine is divided by the density of live whitebark pine within the corresponding height class to obtain percent affected.

Figure 1. Burned areas sampled in 2007 in the northern Wind River and southern Absaroka Mountain Ranges, WY.

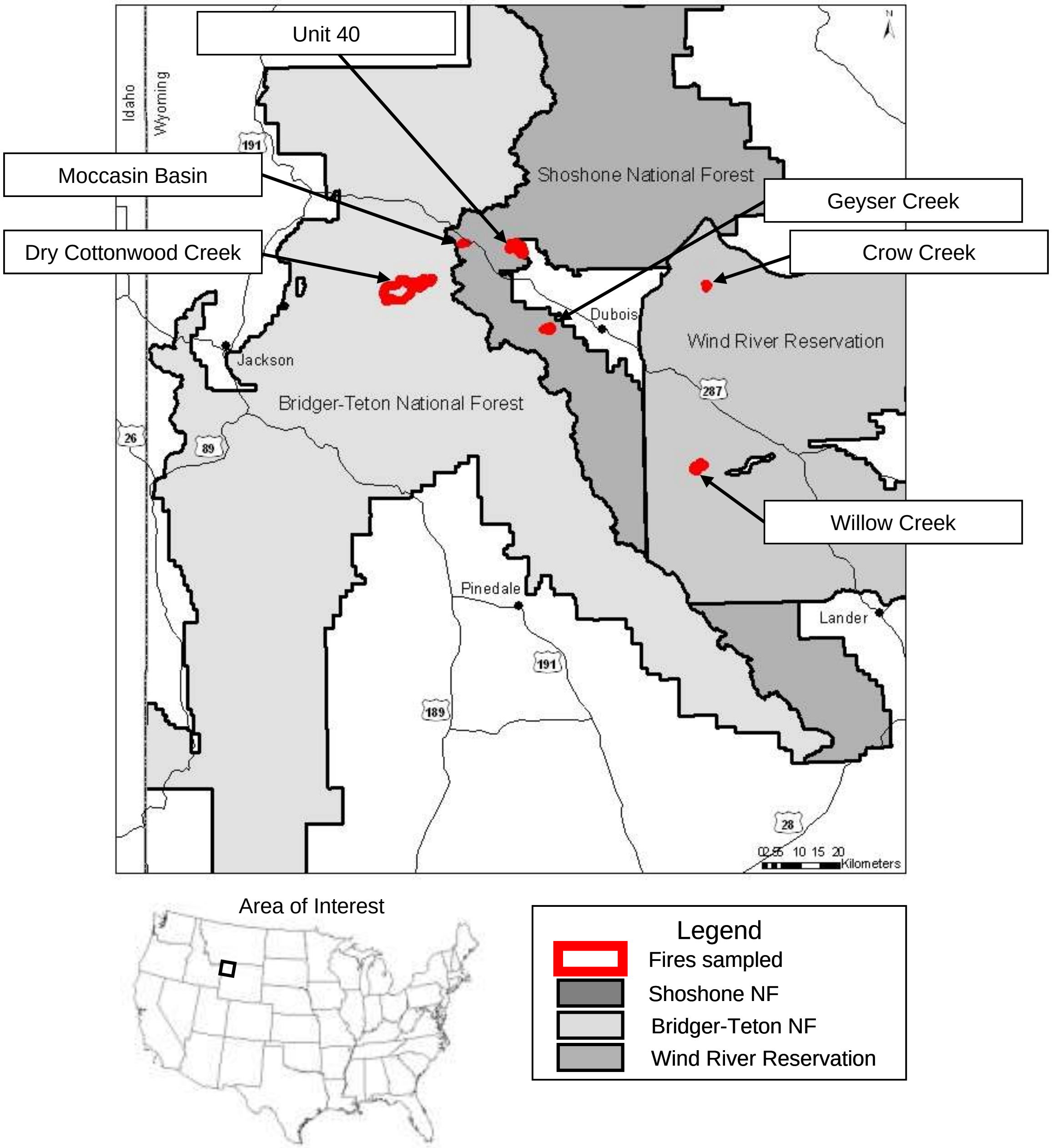
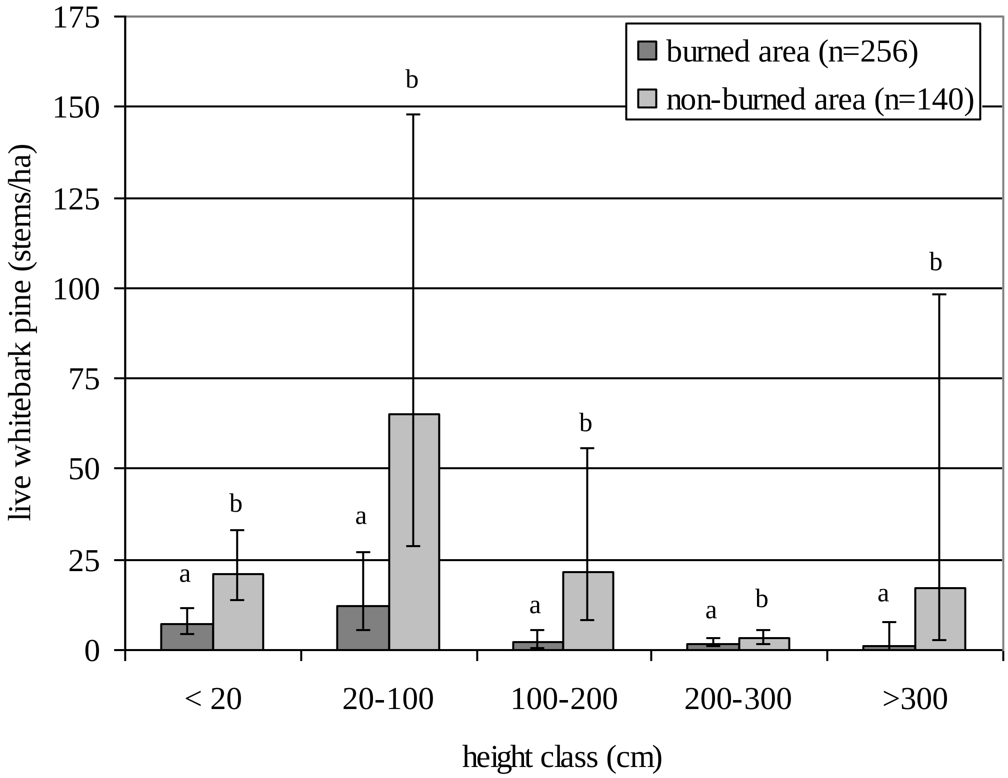
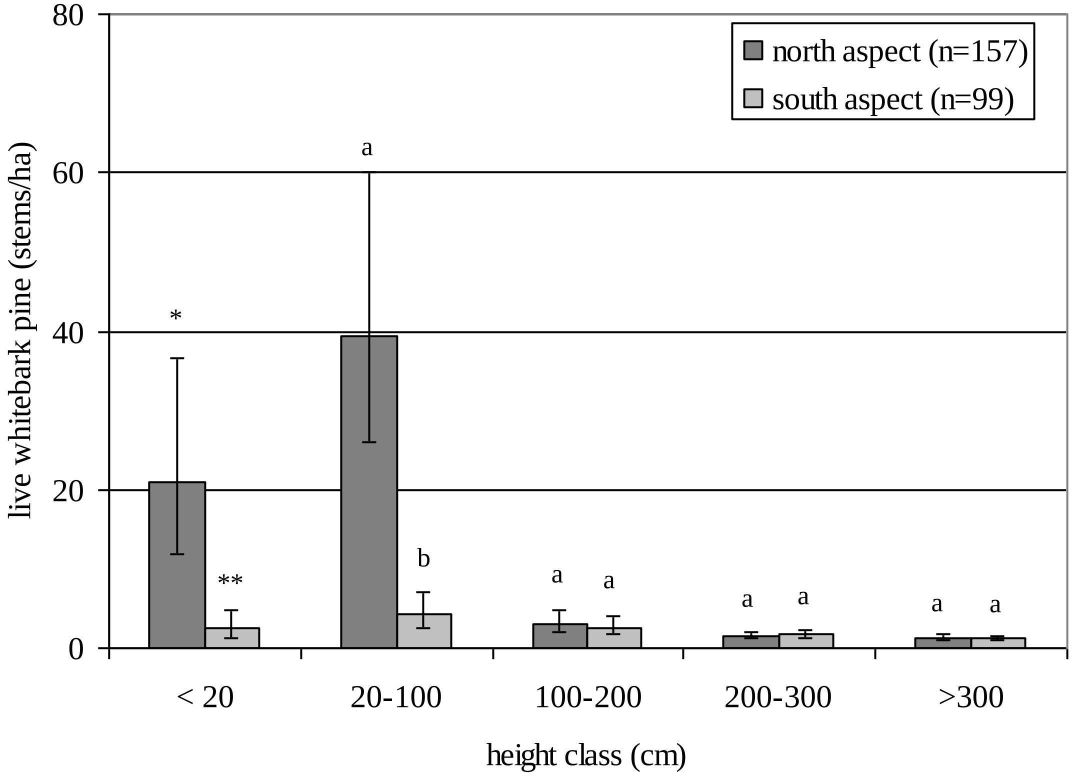


Figure 2. Adjusted mean density of live whitebark pine (back-transformed from $\log_{10}$), by height class in burned and non-burned areas in the northern Wind River and southern Absaroka Mountain Ranges, WY.



Note: Error bars are half LSD. Different letters denote significance at $p<0.05$ within height classes. Trees potentially planted in the Geyser Creek and Unit 40 fires were not included. Density of live whitebark pine in height class <20cm is adjusted for percent cover of vegetation associated with wet site conditions. Density of live whitebark pine in height class 20-100cm is adjusted for trees/ha of lodgepole pine (seedlings to mature trees). Density of live whitebark pine in height class 100-200cm is adjusted for trees/ha of all species (seedlings to mature trees) other than whitebark pine and percent cover of litter. Density of live whitebark pine in height class >300cm is adjusted for percent cover of vegetation that is associated with wet site conditions.

Figure 3. Adjusted mean density of live whitebark pine (back-transformed from $\log_{10}$) in burned areas in the northern Wind River and southern Absaroka Mountain Ranges, WY.



Note: Error bars are half LSD. * denotes significant difference from ** at $p<0.10$ within height class. Different letters denote significance at $p<0.05$ within height classes. Trees potentially planted in the Geyser Creek and Unit 40 fires were not included.

Density of live whitebark pine in height class <20cm is adjusted for trees/ha of all species (seedlings to mature trees) other than whitebark pine, basal area of nearest whitebark pine potential seed source, and percent cover of shrubs.

Density of live whitebark pine in height class 20-100cm is adjusted for time since fire, percent cover of grass, minimum distance to potential seed source, and trees/ha of lodgepole pine (seedlings to mature trees).

Density of live whitebark pine in height class 100-200cm is adjusted for time since fire. Density of live whitebark pine in height class 200-300cm is adjusted for time since fire, trees/ha of lodgepole pine (seedlings to mature trees), and percent cover of vegetation that is associated with dry site conditions.

Density of live whitebark pine in height class >300cm is adjusted for time since fire.

Figure 4. Density of subalpine fir, Engelmann spruce, and lodgepole pine (back-transformed from $\log_{10}$) by height class in burned and non-burned areas in the northern Wind River and southern Absaroka Mountain Ranges, WY. A. subalpine fir; B. Englemann spruce; C. lodgepole pine. Error bars are half LSD.

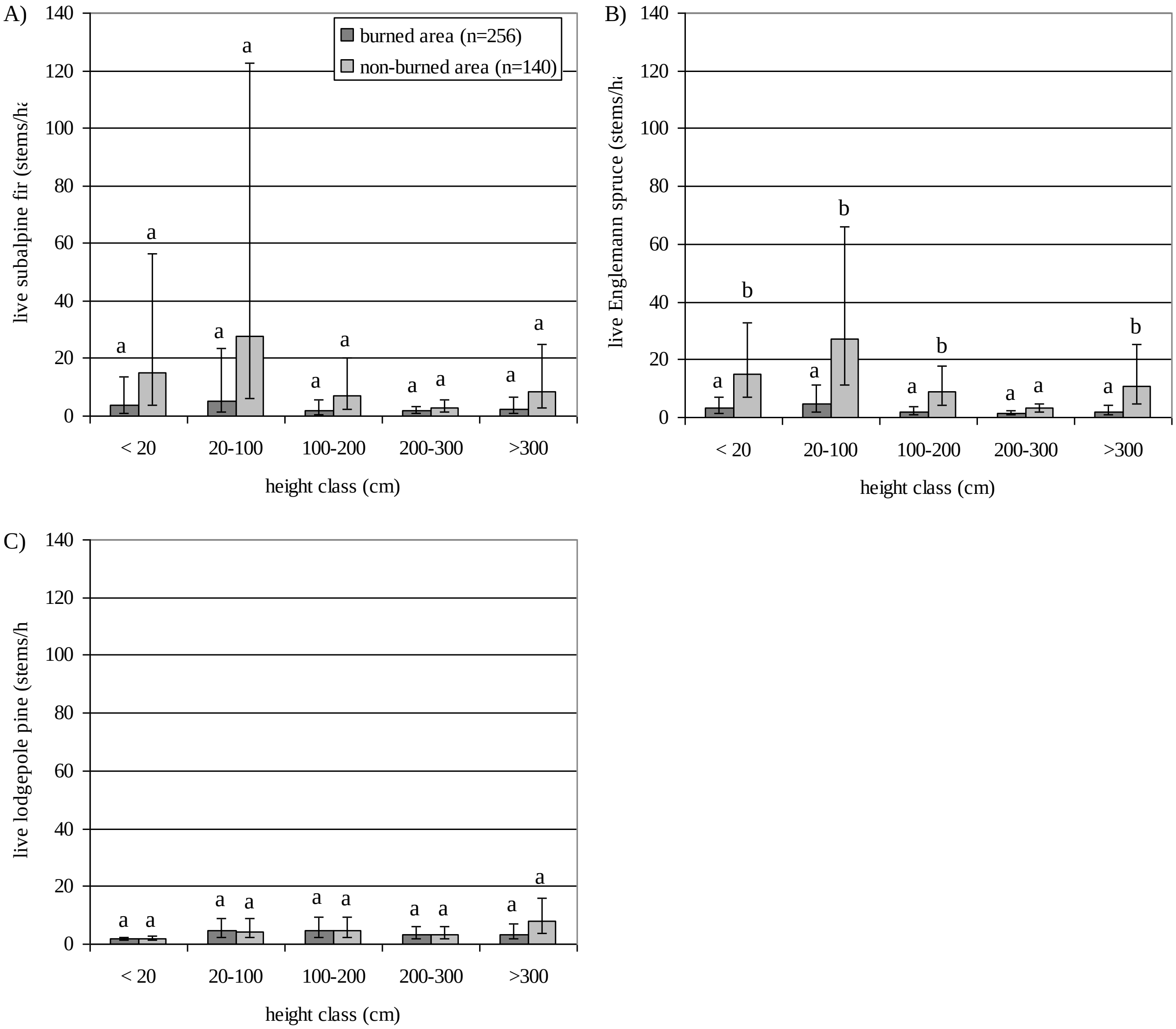
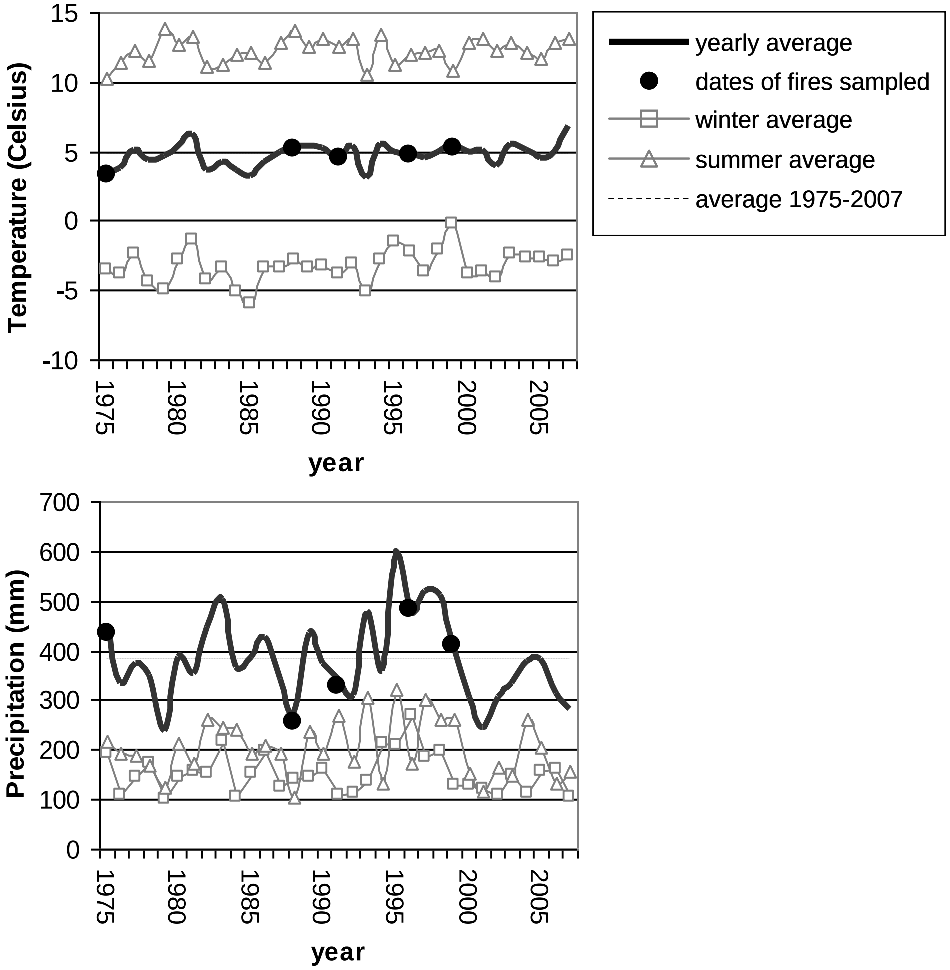
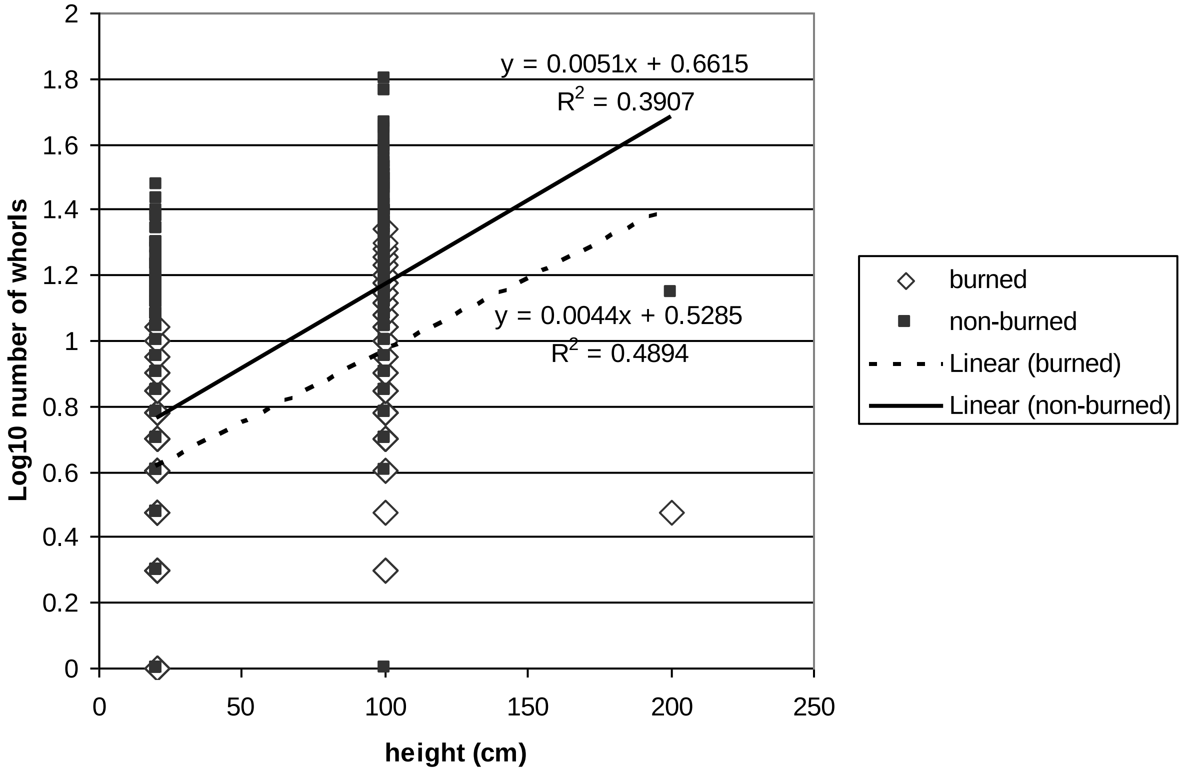


Figure 5. Average yearly, winter, and summer temperature (Celsius) and precipitation (mm) for 4 NOAA weather stations in the Wind River Mountain Range from 1975 to 2007.



Note: Averages of temperature and precipitation were calculated from National Oceanic and Atmospheric Administration weather stations surrounding the Wind River Range and obtained from the National Climatic Data Center: Lander (elevation 1694m), Jackson (elevation 1899m), Moran (elevation 2072m), and Dubois (elevation 2120m).

Figure 6. Regression models for height and log_{10} transformed number of whorls in burned and non-burned areas in the northern Wind River and southern Absaroka Mountain Ranges, WY.



Note: Burned area model: log_{10}(# of whorls)=0.0044(height)+0.5285; R^2=0.4894.
Non-burned area model: log_{10}(# of whorls)=0.0051(height)+0.6615; R^2=0.3907.