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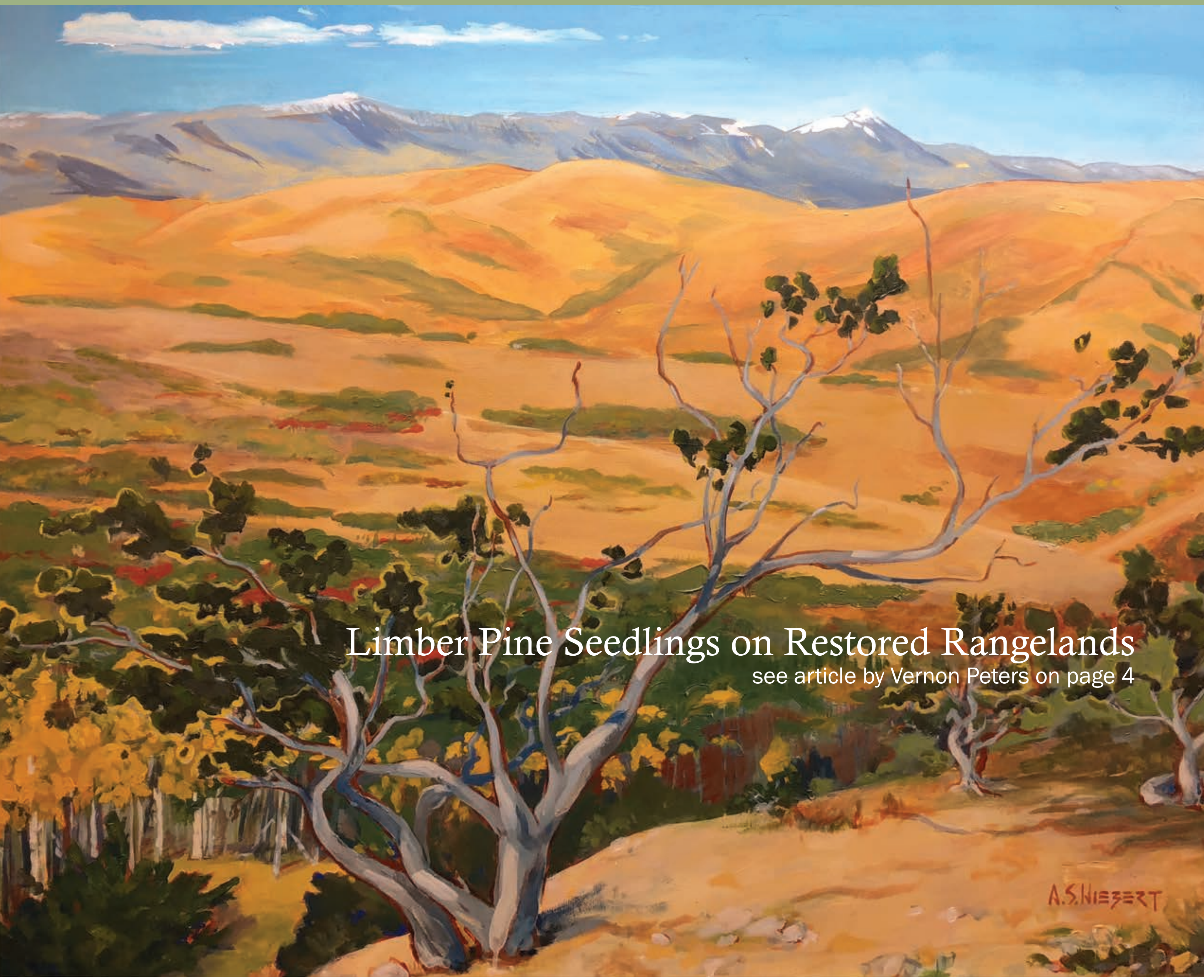

Limber Pine Seedlings on Restored Rangelands

see article by Vernon Peters on page 4

Painting by Andrew S Hiebert, titled "Gatekeeper," from the vantage point of a First Nation's dreambed, "Gatekeeper" overlooks the Livingston Range at the entrance to the Crowsnest Pass, Alberta.

OUR MISSION The Whitebark Pine Ecosystem Foundation is a science-based nonprofit organization dedicated to counteracting the decline of whitebark pine and enhancing knowledge of its ecosystems.

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Inside *Nutcracker Notes*

Robert D. Mangold

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DIRECTOR'S MESSAGE:

Greetings Everyone! I hope this issue of Nutcracker Notes finds you safe and sound in these times of covid-19. My heart goes out to people who have lost loved ones and others who have lost their jobs. But we continue to persevere.This issue is filled with the latest scientific information on whitebark pine and we thank the many authors for their submissions. It's also the last issue that our intrepid editor, Bob Keane, will complete before his retirement. Bob has had a wonderful career and has been a stalwart in the whitebark pine story. We wish him well in his next chapter.

Sadly, we had to postpone the international Symposium High-Five 2020 Conference (H5II) to October 5-7, 2021. This conference has been held every decade since 1989 and it is easily the most important conference for scientific and management information on the ecology and management of high elevation five needle pines. We will have a half day virtual conference on September 16, 2020, with nine talks and a virtual social that night. Should be lots of fun.

We will be holding elections for various offices and board memberships in the upcoming months. Please consider serving in an elected office on our board. Our all-volunteer board works very hard to run this organization and we can always use new ideas. So please let me know if you are interested in helping.

In addition, I want to thank the folks working hard on the National Restoration Plan for whitebark pine. We continue to make progress and when this plan is finished, it will provide a great road map in the years ahead to guide restoration efforts. I want to especially thank Diana Tomback for her unfailing efforts in leading the effort. Also, I want to acknowledge Eric Sprague of American Forests for his strong support.

Well, that's about it for now. Be safe and continue your efforts in these times of covid.

Robert D. Mangold
Director, WPEF

MORE on the Front Cover limber pine painting

Vernon Peters commissioned this painting in 2019 to commemorate the first limber pine community restoration planting he organized in 2013. The planting was completed with outreach and education funds from the Recovery Plan for limber pine, from Alberta Environment and Protection. Through the ongoing support of the Alberta Conservation Association, more than 200 students have monitored restoration efforts at this site, which summarized here in the paper "Effects of grazing, trampling, and site factors on limber pine seedlings on restored rangeland," on page 4.

"It is a great joy to paint emotionally emblematic commissions, like Gatekeeper," said the painter, Andrew Hiebert. "It's my way of standing behind and supporting those who are living out their values, of taking care of the ancient things".

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Randy Moody

CANADIAN PRESIDENT'S REPORT:

There has been a flurry of whitebark pine work being conducted at all levels in Canada; ranging from direct on the ground seedling work to higher level plans. The interest level in whitebark pine continues to grow and we anticipate this momentum to carry on and expect to see some great gains in recovery work down the road.

Following the recognition ceremony we had for Sorcerer Lodge becoming the first ski area in Canada to be certified as whitebark pine friendly, we have had five more in BC express interest to go along with two Alberta hills looking for certification. Hopefully we will soon be in a mad panic to get everyone certified, a good problem to have.

In November, Natalie Stafl of Parks Canada and Canadian board member hosted a seed orchard planning meeting in Revelstoke. This meeting was attended by many whitebark pine recovery practitioners but was also attended by many experts in seed orchard management and development. A task list was created at the event and work is ongoing to first identify suitable sites for orchard installation; a field tour is planned for this summer to visit proposed sites and hopefully several will meet orchard needs and we can proceed with orchard installation in the coming years. Notable sites for orchard locations were at the Calgary Zoo and on Teck Coal lands in the East Kootenay.

From the Canadian Foundation, we held a strategic planning session November 2019 to identify our strengths, weaknesses, and how we can better achieve our goals. We are presently in the throes of developing a strategic plan which will also include actions on internal structure, budgeting, potential partnerships, communication planning, and who knows – possibly hiring an executive director!

Long time board member Don Pigott attended the Association of BC Forest Professionals with a booth concerning whitebark pine. The booth consisted of educational panels on the importance of whitebark pine, the decline of the species, and suggestions for how foresters can assist with recovery efforts.

BC MFLNRORD (Forest Service) employee, Kendra Bennett has been tasked with writing the provincial Implementation Plan. This differs from other higher-level plans in that it directly provides actions and targets for the province and practitioners to meet, such as retaining all healthy whitebark pine during timber harvest and annual seedling planting targets.

In 2018, the largest whitebark pine seed collection to-date was conducted in BC, including some seed held by the Foundation. This large collection has resulted in a great influx of seed and seedling demand (who knew!); a typical planting year in BC is roughly 10,000 seedlings, the increase in seed has resulted in a planned planting in 2020 of ~20,000 seeds and for 2021 requests are around 100,000 seedlings. These are great gains in the recovery effort and it should be noted that the new plantings include work by a number of groups not previously involved in whitebark pine recovery; it's great to see the number of partners expanding like this.

Randy Moody

COVER STORY

Effects of grazing, trampling, and site factors on limber pine seedlings on restored rangeland

By Vernon Peters, Miriam Mahaffy, Nathan Oostenbrink, and Daniel Knop

Introduction

Effective restoration can be grounded in community action and utilize private land. This ensures community education, increases local buy-in, and allows for sustainability in restoration work. In Southern Alberta, the majority of limber pine habitat occurs on private or leased land, dedicated to ranching. Restoration in this context will likely co-occur with ranching, and with no prior studies on five-needle pine responses to grazing or trampling, it is crucial to better understand whether these factors will affect seedling survivorship and growth. Studies on other conifer species in managed forests suggest that cattle adversely affect survivorship through trampling rather than grazing (McLean and Clark 1980), and these effects are greatest in the first 6 months following planting (Lewis 1980).

We conducted a preliminary study on seedling survivorship to investigate the factors specific to restored ranchland. We explored the following factors: intensity of cattle stocking, exclusion from livestock, planting location relative to cattle trails, and site factors.

Methods

A community group planted 420 seedlings in the montane ecoregion near Lundbreck, Alberta, in early August 2013. Site elevation ranged from 1224 m to 1317 m, and slopes ranged from 6 – 19°, with a predominant NW aspect. Three-yr-old putatively resistant seedlings were planted in clusters of three (n = 120 clusters), with "nurse-objects" rocks placed 0.3 m away into prevailing winds. The study site spanned two fenced pastures, one representing a low stocking rate treatment of six horses and the other a high stocking rate treatment of 30 cow-calf pairs, respectively, per quarter for three months of the year. In May 2014, 9 months after planting, we randomly selected 60 seedling clusters for a fine-scale assessment of grazing effects. We randomly assigned 20 clusters as unprotected (open plots), 20 as protected in the high grazing treatment, and 20 as protected in the low grazing treatment.

Seedlings were protected by flexible steel grazing exclosures (1.5 m2, x 1.3 m tall) that prevented trampling and grazing (except at the edges, where they were staked to the ground). Exclosures were removed after the 26-month assessment. Seedlings were individually tagged, and monitored at 2, 14, and 26 months, at the end of the growth season, in late September of each year. In order to track seedling health, and assign mortality when seedlings were no longer able to recover, seedlings were categorized according to decreasing health as: 3 (vigorous, < 5% needles brown), 2 (healthy, 5 – 50% brown needles), 1 (stressed, > 50% needles brown), or 0 (dead, all needles brown). Sites variables including slope, elevation, vegetation cover, trampling exposure (on or off trails), and grazing pressure (high vs. low stocking, in exclosures vs. open plots) were recorded each year, and tested as explanatory variables for survivorship in a nonlinear logistic regression, using Aikeke's information criteria. Survivorship was analyzed at the level of seedling clusters, where the health of each seedling in the cluster was summed (cluster values ranged from 0-9), and transformed to a proportion ranging from zero to one. Analyses were performed in R, version i386 3.1.3.

Results and Discussion

There was a general decline in seedling health prior to mortality. Seedlings that survived between successive monitoring periods either maintained a similar health status (approximately 50% in each of health categories 3 and 2), or declined by one health category. Once seedlings were classified as category 1 (stressed, > 50% needles brown), seedlings invariable died by the next assessment period, 12 months later. By 26-months, survivorship had

Figure 1: From left, undergraduate students assessing seedling health (left picture), high school students participating in the 5th annual community-based rangeland planting (2019), and grazing exclosure with seedlings, showing site conditions.

stabilized, with an overall rate of 41.1% in exclosures. We anticipate that little further mortality occurred from the establishment process of seedlings, as only 11% of these survivors were in a stressed condition. Overall, these rates of establishment were much lower than the 72% reported at three years in research trials for limber pine in Waterton National Park, Alberta (Smith et al 2011), suggesting site, environmental conditions, and biotic interactions post-planting were harsher for establishment in our study site.

Grazing Pressure

The "fine scale", exclosure-level assessment showed that exclosures elevated health significantly (p = 0.009, Table 1b), with 52% fewer seedlings surviving in open plots in the high grazing treatment (horses) versus the low grazing treatment (cattle; Fig. 2a). Grazing pressure was evidenced by greater above ground forage biomass in the low versus high grazing treatment (35 g/m2 vs. 15.5 g/m2 in open plots, and 50 g/m2 vs. 25g/m2 , in exclosures). Duration of seedling protection from livestock further elevated seedling survivorship (Fig 2b). A model of this subset of plots identified protection by exclosures (p = 0.009), plus the duration of protection (p = 0.007) as factors that significantly increased survivorship (Table 1b).

Trampling

Seedling health declined with variables that indicate level of trampling. In the logistic regression, seedlings located on cattle trails had significantly lower health (p = 0.045) than seedlings located off trails (Table 1a). This is reflected in Fig. 4a, where seedlings on trails declined more rapidly in health. Additionally, when trampling was quantified during the 14 month period (3 categories were assigned reflecting degree of flattening, or seedling damage), seedling health declined with respect to the level of trampling (t = -1.992, p = 0.049, df = 118). Lewis (1980) reported decreased survival in slash pine seedlings when trampling injuries were sustained in the first two years post-planting.

Site Variables

Preliminary analyses suggest that site variables, namely elevation, and percent vegetation cover, adversely affected seedling survivorship and added information to the overall model (Table 1). Elevation indicative of exposure to wind, as tree cover declined closer to the ridgetop. Soils were also more xeric and rockier at the ridgetop. Overall, forage biomass was low, and many planting sites had greater than 75% bare ground. We suspect that planting sites with noticeably

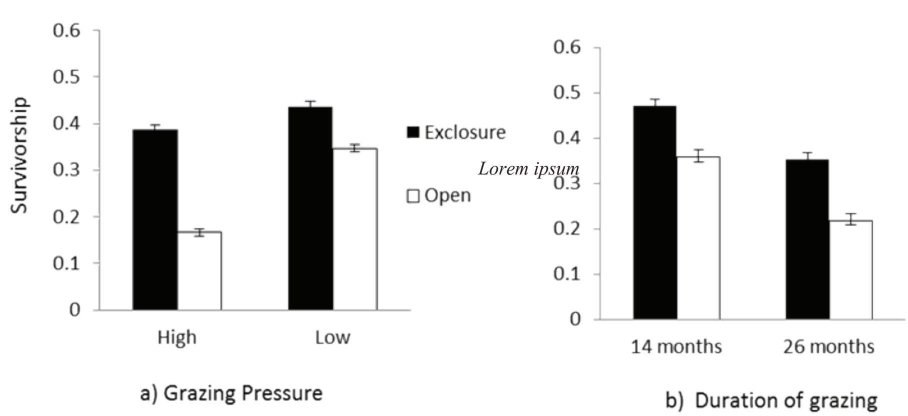

Figure 2: Cluster health relative to a) stocking rate (after 26 months) and b) duration of grazing, in exclosures versus open plots (n = 60 plots).

a) Variables	t value	Pr(>|t|)	b) Variables	t value	p value	c) Variables	t value	p value
Intercept	3.229	0.001	**Intercept**	5.913	<2.5e-08			
Months	-27.193	< 2e-16	**Months**	-2.745	0.007	**Trampling**	-1.992	0.049
Elevation	-2.032	0.043	**Exclosure**	2.644	0.009			
Cattle trail	-2.009	0.045						
Percent cover	-1.568	0.118						
r^2	0.611		**r^2**	0.096		**r^2**	-0.180	
AIC	7.13		**AIC**	39.49				

Table 1: Logistic regression of a) all seedling clusters, showing the five strongest explanatory variables (n = 140 clusters, and b) the subset clusters in exclosures versus open plots, (n = 60 clusters). In c), a correlation test of individual seedling health relative to trampling damage was performed (n = 118 seedlings). The t critical for all the models was 1.65 and an α value of 0.05 was used.

higher grass productivity contributed to lower cluster health and survivorship.

Interacting effects

Trampling combined with slope and aspect may collectively reduce seedling survivorship. Cattle trails on steep slopes have been shown to decrease the presence of soil stabilizing plants, increase soil erosion, and decrease substrate quality (Pimental et al. 1995). Slopes direct cattle movement, and with a windward aspect, slope may have exacerabated wind, rain, and trampling effects on substrate. Several indicators of range health, namely productivity, site stability, and moisture retention suggest that the high grazing treatment is adversely affecting range health scores.

Conclusions and Recommendations

Early assessments of limber pine restoration on rangelands shows potential for compatibility with traditional range use for livestock. While fewer animals appears better for seedling survivorship, our study suggests that livestock effects relate to rangeland use, and overall activity, as no direct effects of grazing were seen. Even under higher stocking rates of cattle, the selection of safe planting sites, largely by avoiding cattle trails, appears to reduce mortality during the establishment phase. Over time, compatibility with cattle use is important to justify restoration on these sites. For this reason we recommend longer term assessment of cattle effects on survivorship before planting seedlings with confirmed resistance to WPBR.

Community connections

Engaging restoration activities on private land have allowed us to educate a large number of participants with a vested interest in limber pine recovery, including two landowner couples, the 22 community members that planted the site in 2013, and six years of undergraduate ecology classes (180 students) that monitored seedlings until 2019. The accessibility of rangelands to roads facilitated community education, furthering the goals of the agencies funding this work, and enabling us to plant three more rangeland properties with local grade 10 science classes (200+ volunteers).

Acknowledgements

We thank Alberta Environment and Protection for financing the 2013 planting from Recovery Plan funds for outreach and education, and the Alberta Conservation Association for financial support through the Conservation, Community, and Education grants (2013-19), numerous undergraduate students (120 students) for data collection, and three students that wrote B.Sc. theses.

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A burning paradox: whitebark is easy to kill but also dependent on fire

Bob Keane, USFS Rocky Mountain Research Station, Missoula Fire Sciences Laboratory
Andrew Bower, USFS Olympic National Forest, Area Geneticist and PNW Region WBP Restoration Program Lead
Sharon Hood, USFS Rocky Mountain Research Station, Missoula Fire Sciences Laboratory

Many research studies and syntheses have suggested that prescribed fire (Rx fire) and wildland fire use fires (WFU) are perhaps the most effective tool for restoring whitebark pine ecosystems (Murray et al. 1995, Keane et al. 2012, Perkins 2015, Keane 2018). Rx and WFU fires can kill competing conifers; reduce surface and canopy fuels; and create attractive sites for nutcracker caching. They best mimic historical fire regimes, much better than mechanical thinnings and cuttings (Keane and Parsons 2010). However, the primary assumption of their application as a restoration tool is that the Rx and WFU fires are not so hot that they kill mature, cone-bearing whitebark pine. A little mortality is acceptable (>10%) due to the uncertainty with applying fire, especially in the understory where some whitebark pine saplings may be the same age as the overstory (Keane and Parsons 2010). But Rx and WFU fires that kill over 20-30% of healthy, mature whitebark pine in the overstory are undesirable or ineffective at successful restoration. This is especially true in areas with heavy blister rust mortality and there are limited seed sources for nutcracker dispersal.

Lately, there have been multiple reports of Rx fires killing healthy whitebark pine trees. A contingent of people from USFS R6 recently toured a stand of ~70 year old, pole-sized trees in southern Oregon that had been part of a burnout during management of a wildland fire that killed nearly all whitebark pine trees in the stand (Figure 1). Before the fire, the site had been mechanically thinned, leaving all whitebark pine and a few lodgepole pine individuals (Figure 2). Trees were pole-sized (6-12” DBH) and widely scattered on the site and it was assumed that they would withstand a low intensity backfire. The bark on most of the trees were relatively un-charred, yet all trees where fire burned completely around the tree were killed (Figure 3). The only trees that survived had some unburned grass and duff around the tree (Figure 4). It is unclear whether it was damage to the roots or to the cambium at the root collar that caused mortality, but it was very clear that

Figure 1

Figure 2

trees of this size and age class were unable to withstand even a low-intensity fire.

In fact, the Keane and Parsons (2010) restoration study found that there was well over 40% whitebark pine mortality on their Rx burns. This mortality was sometimes equal to the subalpine fir fire-caused mortality. One of their research sites burned in one of the Bitterroot fires of 2000 and fire-caused mortality in mature whitebark pine was over 80%. However, another sites burned in an Rx burn which caused less than 5% whitebark pine mortality.

Many silviculturalists and managers have also expressed other concerns about implementing Rx burns in areas that have been mechanically thinned or treated. Rightly, they ask the questions – why should I take the chance of losing valuable whitebark pine to Rx fire when these stands have just been treated, usually at great expense, specifically to prevent their loss? Won't Rx fire make them more susceptible to beetle and rust attack? Will the benefits outweigh the negatives for Rx fires?

What is going on? Obviously, fire scars on living whitebark pine trees attest to the species' ability to survive fires, but why are we seeing such high mortality in recent burns? Rx and WFU can still be important tools for whitebark restoration, but to be successful, we will have to put individual whitebark pine trees in the context of the forest environment. There are several things to consider with burning in whitebark pine forests. First and most important, the capacity of whitebark pine to survive a fire has been vastly overestimated. Hood et al. (2007) found that previous mortality equations for whitebark pine overestimated post-fire mortality, but these equations were limited because they only accounted for crown scorch. Hood and Lutes (2017) updated the mortality equations in the FOFEM model, and the new whitebark model showed outstanding accuracy in an updated evaluation (Cansler et al. In Review). Recently, Stevens et al. (2020) rated whitebark pine 27th of 29 western US species in fire resistance based on fire-adapted traits. While whitebark pine has a sparse crown and deep roots, it has thin bark making it especially susceptible to damage from even a low-intensity surface fire. Even with just light charring, there is a 60% percent chance that the cambium is dead, and the chance goes to almost 100% with moderate char (Hood et al. 2008).

The key to whitebark pine surviving fire is to not burn around the entire circumference of the bole. A blackened bole, even if it's just a thin sliver at the base, virtually guarantees the tree will die because the connections between the crown and roots are severed. Next, some sites may have too much fuel to support a successful Rx or WFU burn. Heavy loadings of litter, fine woody, and shrub fuels may foster fires that are too intense for mature whitebark pine to survive and even low-intensity fires may be too hot for younger whitebark pine to survive. Some sites may also have steep slopes and south aspects that often promote higher fire intensities. Whitebark can survive crown scorch levels less than 25% but again, only if the bole is not charred all around the circumference (Cansler et al. In Review). It also may be that the mature whitebark pine trees stressed by blister rust, competition, and climate change, have a lower capacity of surviving any fire. And last, perhaps there is a great genetic diversity in fire-adapted traits for the species across its range?

What's a practitioner to do? There is no doubt that Rx and WFU fires can be beneficial under the right circumstances. These fires perform many desirable tasks that are impractical with mechanical treatments, such as killing the carpet of subalpine fir seedlings and other competing trees, consuming fuels to

Figure 3

Figure 4

PARADOX continued on page 34

Survival of whitebark pine seedlings germinated from directly sown seeds

By Elizabeth R. Pansing and Diana F. Tomback
Department of Integrative Biology, University of Colorado Denver

Whitebark pine restoration strategies focus on speeding up natural selection for WPBR resistance and supplementing populations until natural regeneration can maintain viable populations and levels of resistance. These goals are accomplished by planting putative pathogen-resistant seedlings (Keane et al. 2012). However, planting is time and work intensive, costly, and logistically challenging. Time from seed collection to outplanting is a minimum of three years and costs roughly between $1980 to $2400 (USD) per ha (Tomback et al. 2011), a challenge for underfunded land-management agencies. Further, planting is restricted to accessible locations where agency guidelines allow restoration activities. In wilderness areas, which comprise 48% of whitebark pine habitat in the U.S., access is often difficult due to remoteness, regulations may prohibit planting, and use of mechanical equipment and motorized transport are prohibited (Keane et al. 2012).

Direct seeding is viewed as an alternative to planting to reduce costs and expand restoration into remote areas, because it reduces the equipment required and avoids some arguments against seedling planting in wilderness areas. Direct seeding germination rates have ranged from 0.13 to 0.85 over one to three years (e.g., DeMastus 2013, Pansing et al. 2017). However, there is limited information about survival of seedlings resulting from sown seeds or the conditions that favor survival. Here, we present results of five years of monitoring seedlings resulting from direct seeding, estimate annual whitebark pine seedling survival, estimate effects of site-specific characteristics, and suggest avenues for future research.

Methods

Study Area

Tibbs Butte, Shoshone National Forest, Wyoming (44°56′28″ N, 109°26′39″ W; Figure 1), is located within the Greater Yellowstone Ecosystem (GYE), east of the Continental Divide. Elevations within the study area range from 2980 to 3240 m, encompassing both upper subalpine and treeline forest. See a detailed description of the study area in Wagner et al. (2018). During the study, air temperatures at the Beartooth Lake SNOTEL station (2850 m), ~11 km west of Tibbs Butte, ranged from −36.3 to 26.5 °C. The growing season extended from ~30 May to 15 October each year. Median daily average temperature was 9.4 °C during the growing season and −4.5 °C during the non-growing season. Cumulative water year precipitation ranged from 68.1 cm to 124 cm during the 2015 and 2018 water years, respectively, and averaged 96.1 cm per water year.

Direct sowing and cache surveys

We collected seeds in September 2011 from Line Creek Research Natural Area, Custer Gallatin National Forest, Montana, ~11 km north-northeast of Tibbs Butte. We did not assess collection trees for WPBR-resistance or WPBR symptoms. In early August 2012, we created 372 whitebark pine seed caches, stratified by elevation zone and nurse object (rock, tree, or no object). Caches were created ~10 cm from the closest systematically assigned nurse object to a random point location. We sowed seeds ~2.5 cm below the soil surface, the average depth of nutcracker caches (Tomback 1982). The number of seeds per cache was drawn randomly from a distribution derived from cache size data (mean = 3, range = 1–7; Hutchins and Lanner 1982, Tomback 1982). Each August from 2013

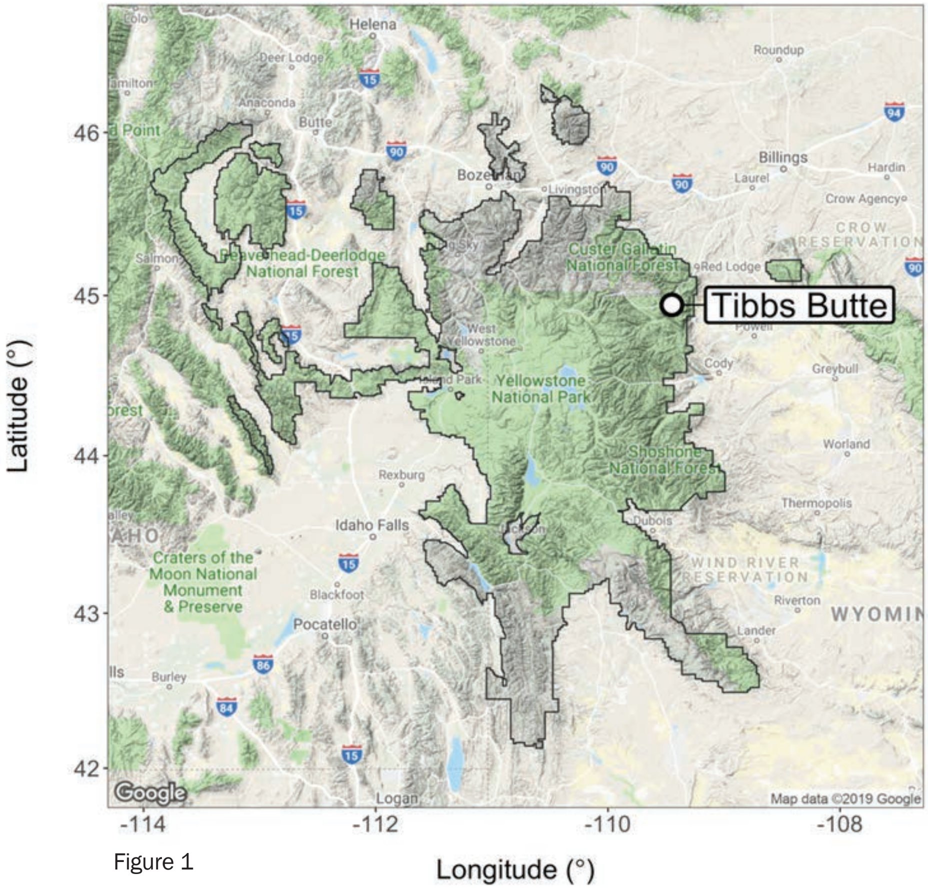


Figure 1

through 2018, we recorded the number of living seedlings in each cache. Here, we focus on 184 caches from which one or more seedlings germinated in either 2013 or 2014. Germination rates are presented in Pansing et al. (2017).

Data analysis

Using known fate models, we estimated the annual survival rate (ASR) of caches comprising one or more living seedlings and the effects of covariates including year, elevation zone, and nurse object on ASR. We tested four hypotheses determined a priori (Table 1) and compared relative support for each using AICc. We included year because seedling survival varies over time for many conifer species. Elevation zone can influence recruitment, and effects were detected previously for this sample of seedlings (Pansing et al. 2017). Lastly, nurse object presence and type can affect seedling survival and are often considered in restoration protocols.

Results

By 2014, 184 caches of 372 contained living seedlings, and 37.0% of these were still living in 2018 (Table 2). The additive effect of elevation zone and year was the most parsimonious model (ΔAICc = 0), followed by the additive effects of elevation zone, year, and object (Table 1). The top model indicated that odds of annual survival at treeline were 2.62 (95% CI: 1.60, 4.26) times higher than within subalpine forest, and that ASR increased relative to 2014 in all years but 2015. Relative to 2014, odds of survival were 36.2 (95% CI: 4.85, 269) times higher in 2016, 4.78 (95% CI: 2.02, 11.3) times higher in 2017, and 5.09 (95% CI: 2.03, 12.7) times higher in 2018. ASRs estimated using the top model ranged from 0.571 (95% CI: 0.470, 0.667) in subalpine forest in 2014 to 0.992 (95% CI: 0.945, 0.999) at treeline in 2016 (Figure 2). The probabilities of one or more recently germinated seedlings in a cache surviving from 2013 to 2018 were 0.273 and 0.571 in the subalpine forest and at treeline, respectively.

Discussion

Compared to seedling planting, direct seeding could reduce time between seed collection and planting, decrease costs, and increase area available for restoration. The ASRs estimated by our case study, which ranged from 0.571 to 0.992, fall within the range of published ASRs (e.g., DeMastus 2013), suggesting that direct seeding may be a viable restoration option for whitebark pine. Using the target restoration density of 247 established trees per ha recommended by the GYCC Whitebark Pine Subcommittee (GYCC 2011), we estimated that 1410 (95% CI: 1134, 2266) and 4229 (95% CI: 2772, 7609) caches would need to be planted to restore one hectare at treeline and in the subalpine forest, respectively. These estimates consider the proportion of caches pilfered by granivorous rodents, germinated, and survived as reported by Pansing et al. (2017). Nursery expense estimates for whitebark pine seedling

Model	Parameters	AICc	ΔAICc	Model Weight	Evidence Ratio
~ year + elevation zone	6	428.88	—	0.658	—
~ year + elevation zone + object	8	430.19	1.31	0.342	1.93
~ object × elevation zone	6	474.14	45.26	9.77×10^{-11}	6.73×10^{9}
~ 1	1	491.16	62.28	1.97×10^{-14}	3.35×10^{13}

Table 1. Diagnostic statistics for all fitted models describing the probability of one or more seedlings per cache surviving each year (ASR) as functions of covariates including elevation zone, year, and nurse object. ASR ~ 1 indicates constant ASR and represents the null

SURVIVAL continued on page 35

Why Do Grizzly Bears Kill Livestock on Public Lands?

By Smith Wells

Livestock depredations within the Greater Yellowstone Ecosystem (GYE) have increased with rising grizzly bear numbers and continued range expansion, including expansion into public lands with grazing allotments (DeBolt et al. 2017, Frey and Smith 2017). Public lands grazed by livestock in the GYE are characterized by large, relatively undisturbed expanses that provide ample foraging opportunities and security cover for grizzly bears but also are associated with livestock-bear conflicts (Northrup et al. 2012). Reducing human-bear conflicts, an integral part of effective grizzly bear conservation, requires information on the relationships between livestock depredations, allotment management, and grizzly bear habitat conditions. The objective of our study was to evaluate these relationships on public land grazing allotments in the GYE during 1992–2014.

Methods

We evaluated livestock management and grizzly bear habitat characteristics on 311 U.S. Forest Service (USFS) and 5 Grand Teton National Park (National Park Service [NPS]) grazing allotments for each year during 1992–2014. Allotments were within the grizzly bear Demographic Monitoring Area (DMA; 49,930 km2), which is deemed suitable habitat for the Yellowstone grizzly bear population (Fig. 1; U.S. Fish and Wildlife Service 2013). Allotments ranged in elevation from 1,300 m to 3,800 m, averaged 4,950 ± 6,150 (SD) hectares in size, and were grazed with cattle, sheep, and horses primarily from June to October.

We collated annual USFS and NPS grazing allotment stocking information including class and number of livestock stocked, grazing season length, presence of bulls or horses, and allotment size. Grizzly bear habitat characteristics previously reported to be related to grizzly bear space use or livestock-bear conflicts and used in our analysis included grizzly bear density index, terrain ruggedness, road density, vegetation cover and productivity (estimated with the normalized difference vegetation index [NDVI]), distance to forest edge, whitebark pine presence and cone production, and several other habitat metrics. We recorded the number of livestock depredation events per allotment per year using investigated and confirmed depredations from conflict data collected by the Wyoming Game and Fish Department, Montana Department of Fish, Wildlife and Parks, Idaho Department of Fish and Game, and Grand Teton National Park, and maintained by the Interagency Grizzly Bear Study Team. We used generalized linear mixed modelling to evaluate relationships of annual depredation events within each allotment with livestock stocking attributes and grizzly bear habitat conditions during 1992–2014.

Results & Discussion

As grizzly bear range expanded during the study period, the number of grazing

allotments within the DMA (n = 316) occupied by grizzly bears increased from 177 in the 1990s to 295 in the 2000s. The proportion of allotments experiencing depredation increased from 1% of grazed allotments in 1992 to 12% of grazed allotments in 2014. Cow-calf pairs were stocked exclusively on 71% of grazing allotments in the DMA, at an average of 300 cow-calf pairs/allotment, and experienced 70% of all recorded livestock depredation events. Ewe-lamb pairs were stocked exclusively on approximately 10% of allotments, at an average of 1,100 ewe-lamb pairs/allotment, and experienced 18% of livestock depredation events. Allotments stocked with other cattle classes, horses, or mixtures of livestock classes were less common and experienced less depredation, with bull cattle or horse-only allotments not experiencing any depredations.

Grazing allotment characteristics associated with depredation events included livestock number, allotment size, bull or horse presence, summer grazing, stocking mixed cattle versus cow-calf pairs, terrain ruggedness, road density, grizzly bear density index, distance to forest edge, relative NDVI, and the proportion of whitebark pine cover. Among these factors, the grizzly bear density index demonstrated one of the largest relative effects (Fig. 2A); an increase of 1 bear/196 km2 in this index was associated with a 20% increase in depredation events. This finding is consistent with higher documented cattle losses in pastures with greater numbers of predators in northwestern Alberta (Bjorge 1983) and supports the expected pattern of increased depredations as more grizzly bears are spatially associated with livestock.

Livestock numbers also showed a large relative association with the number of depredation events (Fig. 2B). Estimated depredation events increased by 1.2 times for every additional 100 head of cow-calf pairs stocked. On average, depredation events increased by approximately 10% for every 1,000-hectare increase in allotment size (Fig. 2C). Also, allotments where bulls or horses were stocked were estimated to average about half the number of depredations compared to allotments where they were not present. Allotments larger in size, with more livestock, and without intensively-managed livestock classes like bulls or horses may indicate reduced human presence and accessibility (per head or per acre). Our findings are consistent with higher documented cattle depredations by bears and wolves on forested pastures in northwestern Alberta with little human supervision compared to pastures with intensive human management (e.g., fencing and herd supervision; Bjorge 1983). Estimated depredation counts increased considerably for allotments with road

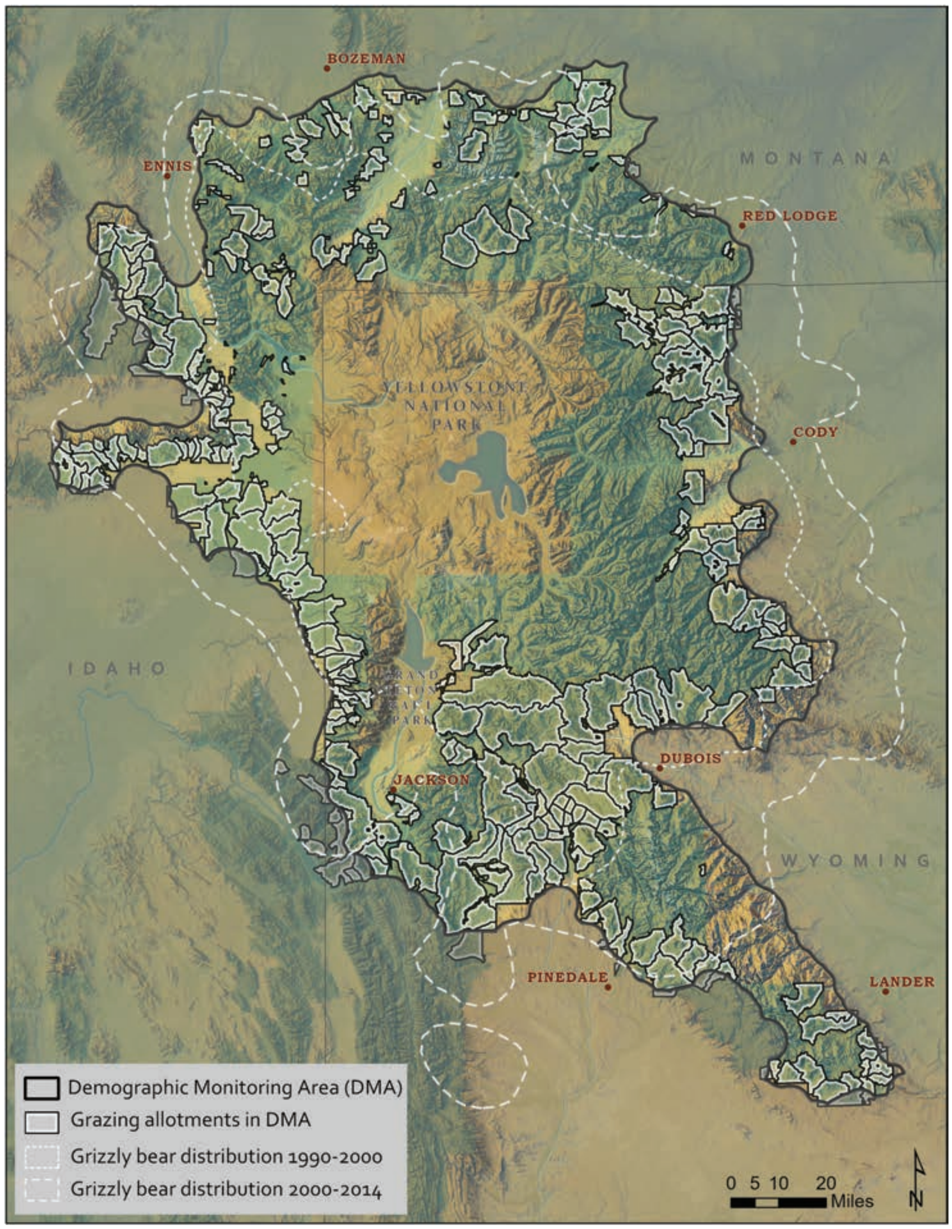
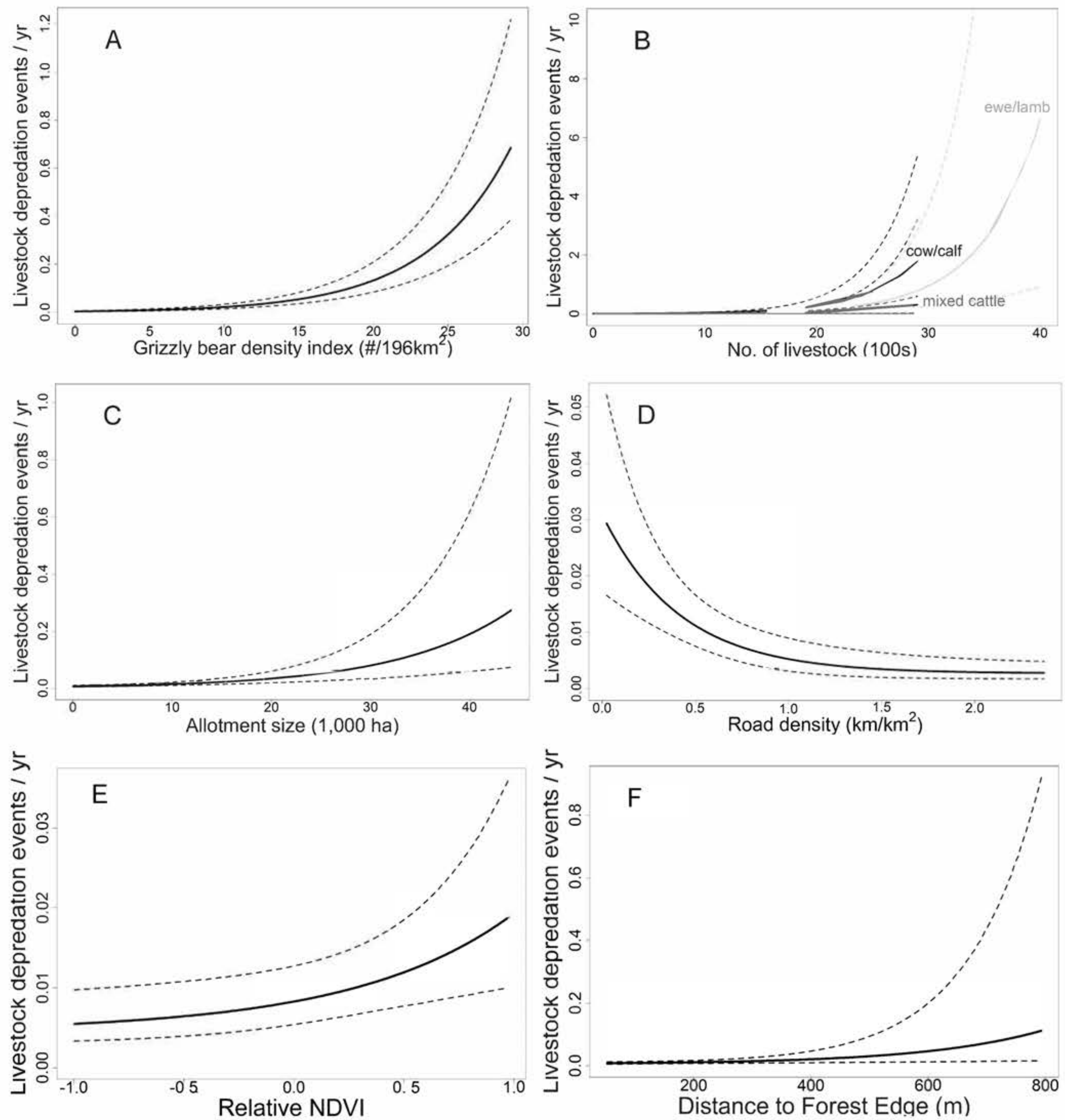


Figure 1. U.S. Forest Service (USFS) and National Park Service (NPS) grazing allotments within the grizzly bear Demographic Monitoring Area and occupied range, Greater Yellowstone Ecosystem, USA, 1992–2014. Data sources: Bjornlie et al. 2014, Interagency Grizzly Bear Study Team, Montana State Library, WyGISC, NPS, USFS, and ESRI.



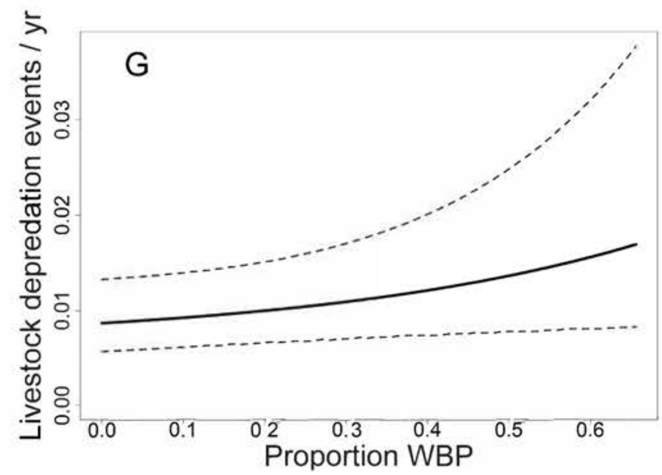


Figure 2. Effects of grizzly bear density index (A), livestock number and class (B), allotment size (C), road density (D), vegetative productivity (E), distance to forest edge (F), and proportion of whitebark pine (G) on the frequency of livestock depredation events by grizzly bears on U.S. Forest Service and National Park Service grazing allotments, Greater Yellowstone Ecosystem, USA, 1992–2014. Effects and 85% confidence intervals (dotted lines) are estimated as a weighted average of the predicted responses for the 5 best-fitting models. Yearling and mature cow classes are not shown because of indistinguishable effects within the plots.

densities below approximately 1 km/km2 (Fig. 2D), also possibly reflecting a reduced level of human presence or reduced access for bear managers to manage conflict bears.

Estimated depredation counts were greater for allotments with higher primary productivity (NDVI) and that were generally farther from forest edges. Allotments with a greater proportion of whitebark pine cover had a positive association with livestock depredation events, but annual cone production on allotments had less of an effect (Fig. 2E–G). Grazing allotments with these characteristics likely have greater grizzly bear use because they provide ample foraging opportunities and daytime cover, thus increasing the probability of grizzly bear-livestock interactions. Similar to our results, in Sweden the risk of an encounter between grizzly bears and free-ranging cattle was greater in areas with higher NDVI (Steyaert et al. 2011). Where whitebark pine is present, grizzly bears will select for whitebark pine habitats from approximately 15 August to 30 September, even in years of poor cone production (Costello et al. 2014). We note that our findings do not support the notion that cattle depredation provides an alternative food source in years of poor cone production. Rather, habitat conditions and general forage productivity in areas with whitebark pine are concurrent with potentially increased grizzly bear use and therefore a higher probability of depredation is expected where those habitats also have livestock grazing.

Management Implications

Our work provides context for long-term, landscape-level planning and carnivore conflict management to accommodate livestock production on public lands with increasing grizzly bear presence. Livestock producers and managers may focus herd supervision and carnivore conflict management efforts on allotments with a higher density of grizzly bears, fewer roads, and quality grizzly bear habitat. Our findings may be used to develop collaborative conflict management approaches among key stakeholders, including state and federal land and wildlife management agencies, livestock producers or grazing associations, and conservation organizations.

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Proactive Limber Pine Conservation Strategy for the Greater Rocky Mountain National Park Area

By Anna W. Schoettle[1], Kelly S. Burns[2], Christy M. Cleaver[3], Brian Verhulst[4], and J. Jeff Connor[4]

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Ecological condition and context determine the likelihood of success of management interventions to mitigate impacts of white pine blister rust (WPBR) (Schoettle et al. 2019a). In populations heavily impacted by WPBR, the remaining seed trees may be too few to support natural regeneration even with management intervention. Likewise, rust pressure can be so high that it will overcome the expression of WPBR-resistance, reducing the efficacy of planting with resistant stock. Management has a low probability of successfully rebuilding a population under these conditions (Keane and Schoettle 2011); focusing less on these areas in favor of managing areas with less rust pressure may be a better investment. In threatened or less impacted populations, regeneration management, whether it be planting genetically resistant seedling stock, maintaining and augmenting the size of the pine populations, or generating a diverse mosaic of stand ages across a landscape, can provide and position young seedlings to begin to mature to help offset mortality of the reproductive overstory trees as the disease intensifies over time (Schoettle and Sniezko 2007).

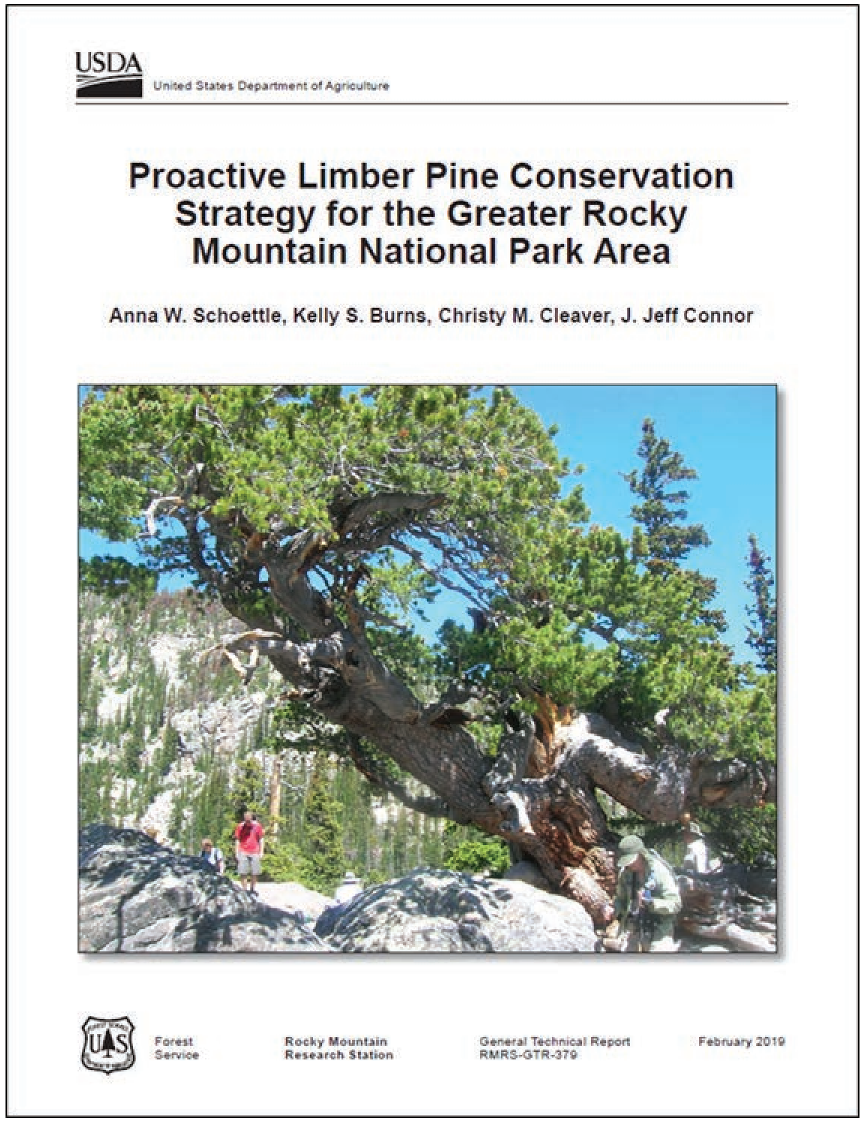
These concepts of highlighting opportunities across stand conditions and encouraging management in areas where management has a high probability of success have been applied in the development of the Proactive Limber Pine Conservation Strategy in the Greater Rocky Mountain National Park Area (Schoettle et al. 2015, 2019b).

Rocky Mountain National Park (RMNP) is at the infection front for *C. ribicola* in Northern Colorado and the park has a responsibility to prevent ecosystem impairment. The Proactive Limber Pine Conservation Strategy for the Greater Rocky Mountain National Park Area is an outcome of a partnership between RMNP and the USDA Forest Service. The Strategy focuses on timing specific research, monitoring and interventions efforts to inform management to sustain healthy limber pine populations and ecosystems during invasion and naturalization of WPBR, thereby helping to put limber pine on a trajectory that does not lead to ecosystem impairment in the future (Schoettle et al. 2015, 2019b, Cleaver et al. 2017). At the time of this collaboration, a high frequency of complete resistance to WPBR in limber pine populations in RMNP and surrounding areas was discovered revealing a unique feature of this area's ecology (Schoettle et al. 2014).

That we have this information and gained additional site-based genetic and disturbance ecology information from a network of plots installed before the limber pine populations have been invaded by WPBR is also unique. This situation justified developing a proactive conservation strategy specific to the greater RMNP area.

The management goals that the Strategy outlines includes (1) Promote ex situ and in situ conservation - continue and expand efforts to collect and archive limber pine genetic diversity through seed collections and protect limber pine trees from mountain pine beetle, WPBR, and fire to minimize mortality when and where land designations and management objectives permit; (2) Increase population size and sustain genetic diversity - increase the number of limber pine trees on the landscape through planting or seeding, or both, immediately to offset future mortality and to sustain viable self-sustaining populations; (3) Locate treatments to maintain durability of complete WPBR resistance - minimize selective pressure on the rust by planting trees with a range of susceptibilities, only in low-WPBR-risk areas, to reduce the probability of the proliferation of rust genotypes virulent to the complete resistance in limber pine; (4) Discover, develop, and deploy local quantitative WPBR-resistant sources - research quantitative (polygenic) WPBR resistance types in limber pine in the greater RMNP area; and (5) Monitor pines and rust - monitor for limber pine health, early detection of WPBR, and WPBR virulence.

The Strategy includes specific recommendations for the monitoring network and management actions to achieve these goals. The Proactive Limber Pine Conservation Strategy was adopted by the park in 2015 and was expanded to the larger area of northern Colorado and southern Wyoming in 2019 (Schoettle et al. 2019b). It has served as a model for ongoing proactive conservation efforts for Rocky Mountain bristlecone pine, Great Basin bristlecone pine, and southwestern white pine and healthy portions of foxtail pine and whitebark pine distributions. The approach to prioritize management actions by their probability of success (Schoettle et al. 2019a) has also been adapted and applied to prioritize treatments for a restoration strategy for whitebark pine in a pilot area within the Crown of the Continent Ecosystem (Jenkins et al. 2020).


USDA
United States Department of Agriculture

Proactive Limber Pine Conservation Strategy for the Greater Rocky Mountain National Park Area

Anna W. Schoettle, Kelly S. Burns, Christy M. Cleaver, J. Jeff Connor

Forest Service | Rocky Mountain Research Station | General Technical Report RMRS-GTR-379 | February 2019

Timely management approaches that incorporate both ecological context and an evolutionary perspective increase the likelihood of successfully sustaining high-mountain pine ecosystems into the future. In healthy but threatened ecosystems, acting now will increase forest resilience to position the ecosystems to develop fewer impacts, and need less restoration, in the future.

The Proactive Strategy encourages managers to not wait until an ecosystem is impaired to begin managing for increased resilience. This Strategy also offers insights for managing impacted ecosystems by suggesting that one look for management opportunities beyond the heavily impacted areas that often attract most attention but have a poor prognosis. Starting management before or early in the invasion of *Cronartium ribicola* and spreading treatments over a diversity of current stand conditions will increase the likelihood that some populations avoid impairment or extirpation and can sustain the high elevation five-needle pine species.

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PROACTIVE continued on page 30

Whitebark pine (*Pinus albicaulis*) growth and defense in response to mountain pine beetle outbreaks

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Introduction

Whitebark pine (WBP; *Pinus albicaulis*) is a critical keystone forest species of U.S. Northern Rocky Mountain subalpine ecosystems (Tomback et al. 2001). There is growing concern that WBP may be largely extirpated from its current habitat over the next century due to cumulative impacts of climate change, insect–related mortality, changing fire regimes, increased competition from shade–tolerant species, and the invasive exotic pathogen white pine blister rust (*Cronartium ribicola*). While insects, fire, disease, and drought have contributed to recent mortality of WBP, these processes are also thought to play an important role in the long–term establishment and persistence of Northern Rocky Mountain WBP forests. Historical records detailing patterns and characteristics of disturbance that promote or inhibit WBP establishment and persistence are poorly lacking, highlighting a critical research need.

Within conifers, resin–based defenses (direct expulsion of beetles from tree phloem/cambium via resin flow through ducts) have long been recognized as the primary mechanism by which trees respond to attack by bark beetles and pathogens. Resin ducts are permanent anatomical features within the secondary xylem and have been shown to correspond with resin flow, such that greater total area of resin ducts facilitates increased production, storage, and mobilization of oleoresin to sites of wounding. As resin ducts are produced regularly (typically every year to every few years), they can be measured, along with tree rings, to assess how trees allocate resources between growth and defense over time. Several researchers have linked physical properties of resin ducts to survivorship during periods of increased beetle activity (see Kichas et al. 2020 for key references).

In this study, we evaluated whether diameter growth and resin duct characteristics differed between residual live trees (hereafter "live trees") and trees that died (hereafter "dead trees") during recent disturbance episodes (e.g., mountain pine beetle outbreaks, drought, fire). Understanding resin defense systems is of particular importance as these structures represent the primary defense mechanism of WBP to biotic disturbance. Evaluating relationships between resin duct structures, oleoresin production, and disturbance can provide valuable insight into overall defensibility of these trees to stressors that are projected to increasingly impact this important species.

Methods

Data for this study were collected across two high–elevation WBP sites on the Flathead Indian Reservation as part of a larger fire history reconstruction for the Confederated Salish and Kootenai Tribes (Kichas et al. 2020). Both areas were affected by numerous large–scale bark beetle outbreaks, occurring in the 1930s, 1960s–1980s and most recently 2002–2009 (Harley et al. 2019, Jenne and Egan 2019). The majority of WBP mortality was due to cumulative impacts from mountain pine beetle and white pine blister rust, which was introduced to this region of the Northern Rocky Mountains circa 1950 (Geils et al. 2010). Of the 701 sampled WBP trees, 82% were dead, with the majority of dead trees (76%) showing evidence of beetle activity (J–shaped galleries along the tree stem and / or presence of blue–stain fungi (Grosmannia clavigera), which is introduced to WBP trees by bark beetles during colonization.

To assess the influence of disturbance on growth and defense characteristics, live trees and corresponding dead trees (hereafter "pairs") were identified from the larger suite of demography data. Suitable pairs were identified based on distance (< 20 m apart) and size (< 3 cm difference diameter) to control for potential microsite differences. Overall, we identified 144 trees (72 live and 72 dead). A more detailed description of the methods and analyses used can be found in Kichas et al. (2020).

Results

Whitebark pine trees that died grew 22% faster than living trees, primarily during the period of 1911–1975 (Figure 1a). In the 20–years preceding mortality, growth in whitebark that died declined by 26% relative to live trees, especially post–1975. Dead WBP also produced 20% more resin ducts compared to live trees (Figure 1b). This relationship declined (by 10%) in the 20–years preceding mortality, with the greatest difference occurring from 1990–2000. However, despite producing more resin ducts on average, the ducts were smaller for dead WBP (56% smaller on average) compared to live trees (Figure 1c). Similar to growth, duct size showed an increasing trend post–1975, where duct size in live trees continued to increase relative to dead trees.

Resin duct area was also greater in live trees (48% increase; Figure 1d) and duct area showed a similar post–1975 trend, with increasing duct area in live WBP relative to dead trees. In contrast, resin duct density was greater in dead trees (18% greater; Figure 1e) and post–1975, duct density continued to increase in dead WBP throughout the remainder of the record. Relative duct area (% of annual ring occupied by resin ducts) was significantly greater in live WBP (57% increase; Figure 1f). Unlike the other metrics, there was no clear temporal trend for relative duct area.

The two most significant metrics influencing tree survivorship were resin duct size, and relative duct area. WBP trees that are able to produce larger resin ducts (> 0.001 mm2) with greater overall duct area (> 10% annual ring) had a

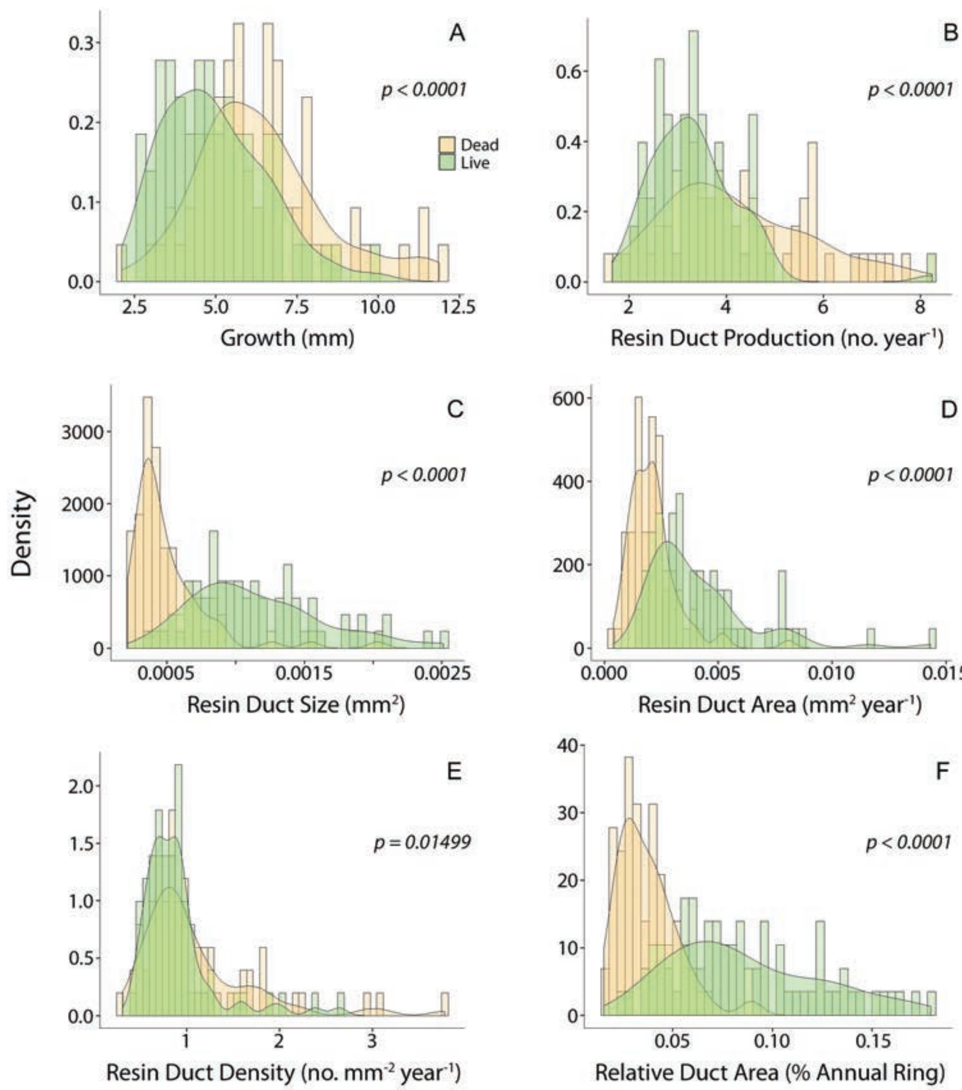

Figure 1. Kernel density plots for growth and defense metrics across pairs of live and dead WBP. These plots visualize the distribution of samples (depicted as vertical bars) over each continuous variable with a smoothing kernel (smooth lines with shading) applied to assist in visualization of the distributions.

significantly greater chance of survival (~80%; Figure 2).

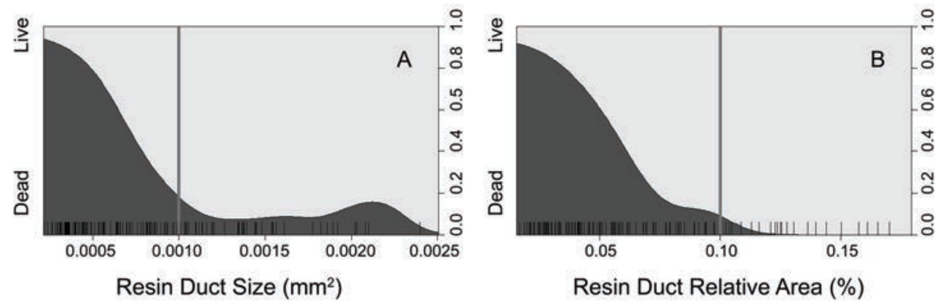

Figure 2. Conditional density plots describing the probability of mortality in relation to principle resin duct metrics (A) resin duct size [mm2] and (B) relative resin duct area [% annual ring]. Light shading reflects live trees while dark shading reflects dead trees. Vertical

Discussion

Whitebark pine trees that produced larger resin ducts were far more likely to survive disturbance events at each of our study sites. The presence of larger resin ducts and greater duct area in live trees could be associated with an increased capacity to mobilize oleoresin in response to attack or infection and may be a factor in the ability of live trees to endure numerous disturbance events over time. Although dead trees produced more resin ducts on average the ducts were smaller, which might have been insufficient in area to produce, store, and mobilize adequate amounts of oleoresin in response to wounding by bark beetles and blister rust infection. This reduced resin flow in dead trees could be linked to lowered defense and higher mortality despite increased density of ducts, particularly in the years leading up to death.

Importantly, our results suggest that WBP trees that invest a relatively greater amount of resources into the production of constitutive resin–based defenses have a higher probability of surviving disturbance events, which parallels previous research on other conifers (Kichas et al. 2020). Whitebark pine trees appear to exhibit different strategies in the allocation of resources toward growth and defense depending on their biophysical setting and climate and disturbance history. Live trees that persisted through 20th century disturbance events produced larger resin ducts with a greater overall annual duct area relative to growth. In contrast, those trees that died invested more into growth, at the expense of defense. Both strategies involve tradeoffs that can confer fitness benefits under different circumstances. For example, during relatively long disturbance-free intervals (decades to centuries) WBP trees that invest more resources into growth may thrive. As defensive features are energetically expensive to produce and maintain, the presence of these characteristics suggests there is strong selective pressure from disturbances to invest in these defenses. Our results lend insight into resin duct characteristics that may be beneficial to increasing WBP survivorship and highlight how variable physiological traits confer advantages under different circumstances.

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Using genetics to distinguish limber from whitebark pine

Science Summary of Alongi et al. (2019) An economical approach to distinguish genetically needles of limber from whitebark pine. Forests 10, 1060.

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The northern Rocky Mountains, the Great Basin, and the central Sierra Nevada are regions of North America where limber pine (*Pinus flexilis* James) and whitebark pine (*Pinus albicaulis* Engelm.) live in sympatry or close proximity. For those needing to distinguish between these two pine species in these areas of western North America, seed cones are the best visual identification aid. Limber pine has seed cones that measure 7–15 cm long and have persistent woody scales whereas whitebark pine has seed cones that measure 4–8 cm long and have tightly overlapping woody scales (Figure 1).

Figure 1. Cones of limber and whitebark pine. Seed cones of limber pine (upper left; ~10 cm long) and whitebark pine (upper right; ~7 cm long). Pollen cones of limber pine (lower left; ~2 cm long) and whitebark pine (lower right~1.5 cm long). Photos by M. Lavin.

Seed cones of limber pine often persist on the tree and on the ground beneath whereas seed cones of whitebark pine are soon removed by seed-harvesting birds and squirrels and often lie on the ground in a disintegrated state. Pollen cones sometimes aid visual identification but are less reliable. The color of limber pine pollen cones ranges from yellow to pale red, whereas that of whitebark pine pollen cones is usually scarlet (Figure 1). However, this distinction is blurred because the color of limber pine pollen cones is sometimes reddish and that of whitebark pollen cones can fade to pale red.

Because of either convergent evolution or retention of an ancestral white pine growth form, limber and whitebark pine are similar in vegetative form. Variations in needle dimensions, branching patterns, and canopy shapes are highly overlapping between the two and without cones, limber and whitebark pine are difficult if not impossible to tell apart. These two pines species can grow side-by-side or nearby in the same or similar habitats and then often lack their distinguishing cones. Fortunately, genetically distinguishing these two pine species when cones are absent is relatively easy. This is because the evolutionary history of limber and whitebark pine in North America is different and genetic information tracks these different histories. Genetic evidence reveals that limber pine has been in residence in western North America for millions of years and comes from an ancestry shared with close relatives mainly in the southwestern USA and in Mexico, such as Mexican white pine (*Pinus ayacahuite* Ehreng. ex Schlecht.) and southwestern white pine (*P. strobiformis* Engelm.). In contrast, genetic evidence reveals that whitebark pine is a Pleistocene immigrant into North America from a Eurasian source area and its closest relatives include the Swiss stone pine (*Pinus cembra* L.) and Siberian pine (*Pinus sibirica* Du Tour).

With these contrasting evolutionary histories revealed and well supported by many DNA studies, we set out to optimize a genetic identification tool that would most economically distinguish limber from whitebark pine. We ultimately determined that a tiny fragment of one green pine needle, 1 mm long, lacking discolored spots suggestive of infection, was sufficient to obtain good quality DNA. Our relatively inexpensive approach to extracting DNA from each needle fragment involved the Extract-N-Amp™ Plant Tissue PCR Kit from Millipore Sigma (Darmstadt, Germany). One of these extraction kits permits the analysis of about 200 pine needle fragments. The kit also permits polymerase chain reaction (PCR) amplification of a desired region or genetic locus from the DNA isolation of the needle fragment.

Using standard PCR protocols, we amplified DNA regions from the chloroplast genome from each leaf fragment. The reason for the focus on the chloroplast genome is that in the pine family (*Pinaceae*), the nuclear genome is complicated by its large size, which renders genetic analysis difficult because of extensively repeated DNA elements.

We ultimately identified two informative chloroplast DNA regions that readily distinguish limber from whitebark pine. These are the matK coding region and the non-coding psbA-trnH spacer, which is a span of DNA sequence between a gene encoding for a protein involved in photosynthesis (psbA) and one encoding a particular transfer RNA (trnH).

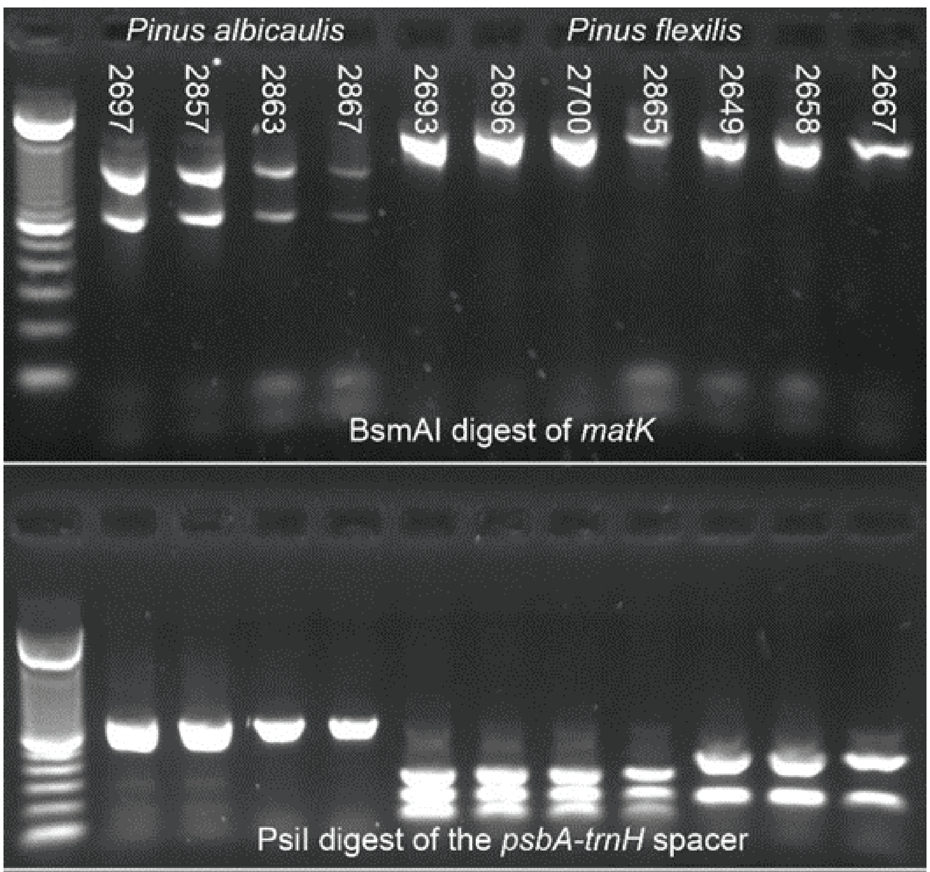

Figure 2. Restriction enzyme digests of whitebark (*Pinus albicaulis*, lanes 2697 to 2867) and limber pine (*Pinus flexilis*, lanes 2693 to 2667) PCR amplification of the chloroplast regions matK (top) and psbA-trnH (bottom). The 12 lanes in each of the three panels represent the same series of DNA samples (2697 to 2667). The left-hand lane in each panel represents a 100 base pair DNA ladder. Subsequent lanes are labeled by the DNA isolate number, from 2697 to 2667, details for which are in Alongi et al. (2019).

GENETICS continued on page 33

Simple yet effective testing of genetic resistance to white pine blister rust in whitebark pine (*Pinus albicaulis*)

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Introduction

Whitebark pine (*Pinus albicaulis*) mortality is increasing mainly due to *Cronartium ribicola*, the introduced pathogen causing white pine blister rust. Whitebark pine have little resistance to this disease (Schoettle and Sniezko 2007). The effects of this pathogen are compounded by the impacts of mountain pine beetle, altered fire regimes, and climate change (Environment and Climate Change Canada 2017). In some areas, white pine blister rust is present on over 90% of trees, with mortality exceeding 50% (Smith et al. 2008). Increasing the genetic resistance of whitebark pine to this pathogen remains the most promising conservation strategy for this endangered tree (Sniezko et al. 2014).

Rust-resistant genotypes of whitebark pine are typically identified through controlled inoculations (Sniezko et al. 2014). Seeds are collected from healthy trees, and seedlings are grown for two years, then inoculated in a controlled-environment chamber. *Ribes* leaves containing rust telia are suspended over the seedlings, leading to uniform rust infection. Then the seedlings are planted outside, and left to develop symptoms of infection. Seedlings are assessed multiple times for rust up to five years post-inoculation. Space, personnel, and equipment constraints render this process costly, time and labour intensive. Due to the urgency of whitebark pine decline, research into alternative screening methods for resistance to blister rust is necessary, and streamlining this process has the potential to increase the availability of material for restoration.

The British Columbia Ministry of Forests, Lands, Natural Resource Operations, and Rural Development (FLNRORD) undertook an alternative approach in 2015. They established a common garden experiment of whitebark pine seedlings at Skimikin Nursery near Salmon Arm, British Columbia. A western white pine (*Pinus monticola*) provenance trial, interplanted with *Ribes nigrum*, next to the whitebark pine trial provided a source of inoculum via wind-dispersed basidiospores, and resulted in blister rust infection of many of the whitebark pine seedlings. Here we evaluate the efficacy of this field inoculation by analyzing infection levels for 214 families from 44 provenances, and compare the relative genetic resistance for a subset of 81 of the same families subject to traditional controlled inoculations.

Methods

Data were collected in a common garden experiment located at the BC FLNRORD's Skimikin Nursery (50.79°N and -119.43°W), approximately 13 km northwest of Salmon Arm, British Columbia. Seed for the common garden was collected from 214 healthy seed parent trees in 44 locations across the species range, including some locations where rust infection was high. Seed was first stratified in November 2013. Thirty-two of the 44 provenances were represented by three or more families. The final dataset contained 4100 whitebark pine seedlings.

Seedlings were planted at Skimikin in 2015 beside a plantation of western white pine and *Ribes nigrum* infected with *Cronartium ribicola.* The experimental design included 8 columns and up to 595 rows per column, with seedlings planted approximately 11-14 cm apart. Seedlings were planted using an alpha design with 20 replications, each containing one seedling from every family.

Of the 214 families included, 81 were previously tested at the USDA Forest Service Dorena Genetic Resource Centre (hereafter referred to as "Dorena") for rust resistance using standard controlled inoculation procedures (Danchok et al. 2004). They were used to compare the effectiveness of natural inoculation methods used at Skimikin to control inoculations done at Dorena.

Data collection occurred in mid-May 2019. Each seedling was assessed for height (cm), severity of rust damage [from 0 (healthy) to 9 (dead from rust)], and the presence/absence of needle spots, bole infections, normal cankers (limb infections), and aecia. Resistance ratings were obtained from Dorena for the 81 families also present at Skimikin. This data contained grades for every family from A (most resistant) to F (most susceptible).

For the analyses, rust severity data were re-classified from 10 to 4 levels. These categories were then converted to "normal scores" before estimating breeding values for resistance based on methods used by Gianola and Norton (1981). Linear mixed models were fit using the R package ASReml-R (Butler 2019) to adjust for strong spatial correlation patterns of blister rust infection across the experiment between column and row.

Results

Overall, 73.4% of seedlings were cankered and 95.0% of seedlings showed signs of rust (needle spots or cankers). Average rust severity as well as seedling mortality was highest in seedlings planted closer to the *Ribes* and linearly decreased as distance increased (Table 1).

Column	Average Rust Severity	Distance from *Ribes* (m)	Mortality from Rust
1	6.65	3.0	56.4%
2	6.07	6.0	44.3%
3	5.43	8.0	30.9%
4	5.17	10.0	26.1%
5	4.45	12.0	15.1%
6	3.98	14.0	13.3%
7	3.65	16.0	5.9%
8	2.41	18.0	2.2%

Table 1: Rust severity and mortality of seedlings averaged by column prior to spatial correction at Skimikin Nursery, BC.

80 of the 194 tested families had positive breeding values for resistance, and values were normally distributed, ranging from -0.92 (family 232, from Wenatchee, WA) to 1.31 (275, Mt. Rainier, WA). After adjusting for the spatial pattern of infection with distance from *Ribes*, estimated breeding values had a strong relationship with mean percent stem symptoms per family of original data, with higher breeding values corresponding to lower infection (r2=0.87) (Figure 1).

Breeding values for rust resistance were highest in families from the Cascade Mountains of Washington and Oregon, as well as from the southern Columbia Mountains of BC, Kettle River Range of Washington, and Rocky Mountains of northern Idaho and northwest Montana (Figure 2). High susceptibility was found in provenances from further north in the North Cascades, Coast Ranges, and Rocky Mountains of British Columbia as well as in the far southeast of the range in Idaho and Wyoming.

Grades from Dorena for the previously control-screened families matched well with the estimated breeding values of the same families at Skimikin (Figure 3). All A and B grade families contained positive breeding values, while C grade families contained a range of positive and negative values. D, E, and F grade families contained mostly negative breeding values. Tukey HSD pairwise tests revealed significant differences between the most resistant

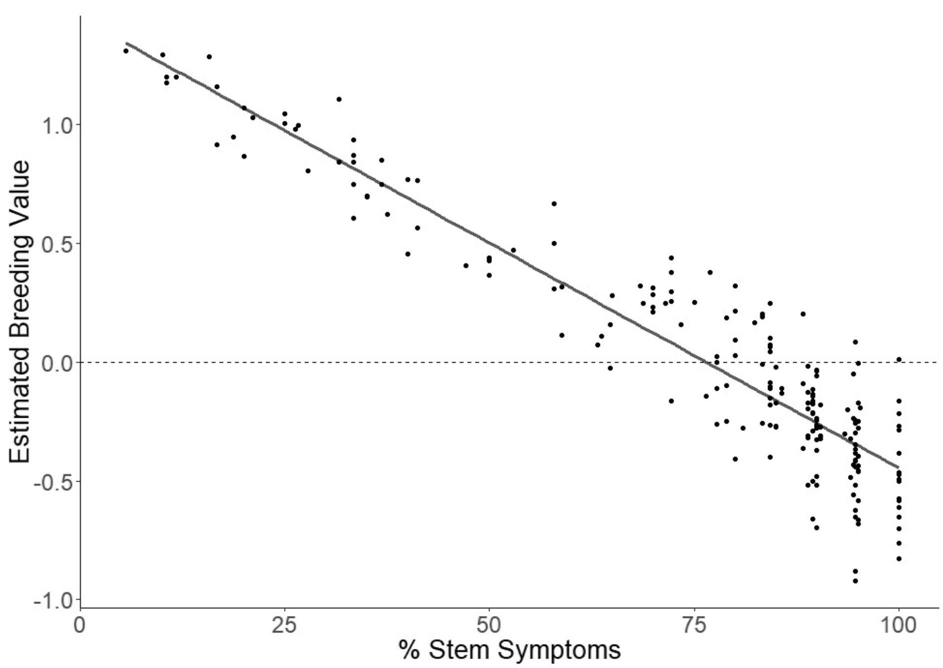

Figure 1: Linear relationship between spatially corrected family estimated breeding values and percent stem symptoms per family of original data (r2=0.87). Points above the dashed line represent families with positive breeding values for resistance.

classes (A and B) and the intermediate class (C); as well as between class C and the combined susceptible classes (D, E, and F).

Discussion & Conclusion

The Skimikin common garden trial demonstrates a simple yet effective alternative to controlled artificial inoculations for determining blister rust-resistant families of whitebark pine. This natural inoculation produced infections on 95% of seedlings, close to the nearly 100% rate typically achieved from controlled inoculations (Sniezko et al. 2014). Additionally, a clear negative relationship between distance from *Ribes* and rust severity was shown in this trial, so interplanting *Ribes* throughout a whitebark pine trial rather than only on one side would likely produce even better results.

Based on the comparison to Dorena resistance ratings, the Skimikin trial classified resistant, moderately susceptible, and very susceptible families well; however, it was not sufficiently sensitive to distinguish between some of the most resistant or among the most susceptible classes. Since the most resistant grades (A and B) of families were detected effectively with this method, it appears the sensitivity of this approach is sufficient for selection and nearly as effective as control inoculations. The families identified as resistant in this study will expand the genetic base of blister rust-resistant parent trees that can be used as seed sources for restoration purposes.

In this study, the distribution of resistant families was not strongly correlated with any climatic or geographic gradients. The observed distribution of resistance does not seem to follow any spatial pattern, but may be related to the spread of blister rust over time. Since its introduction to

TESTING continued on page 36

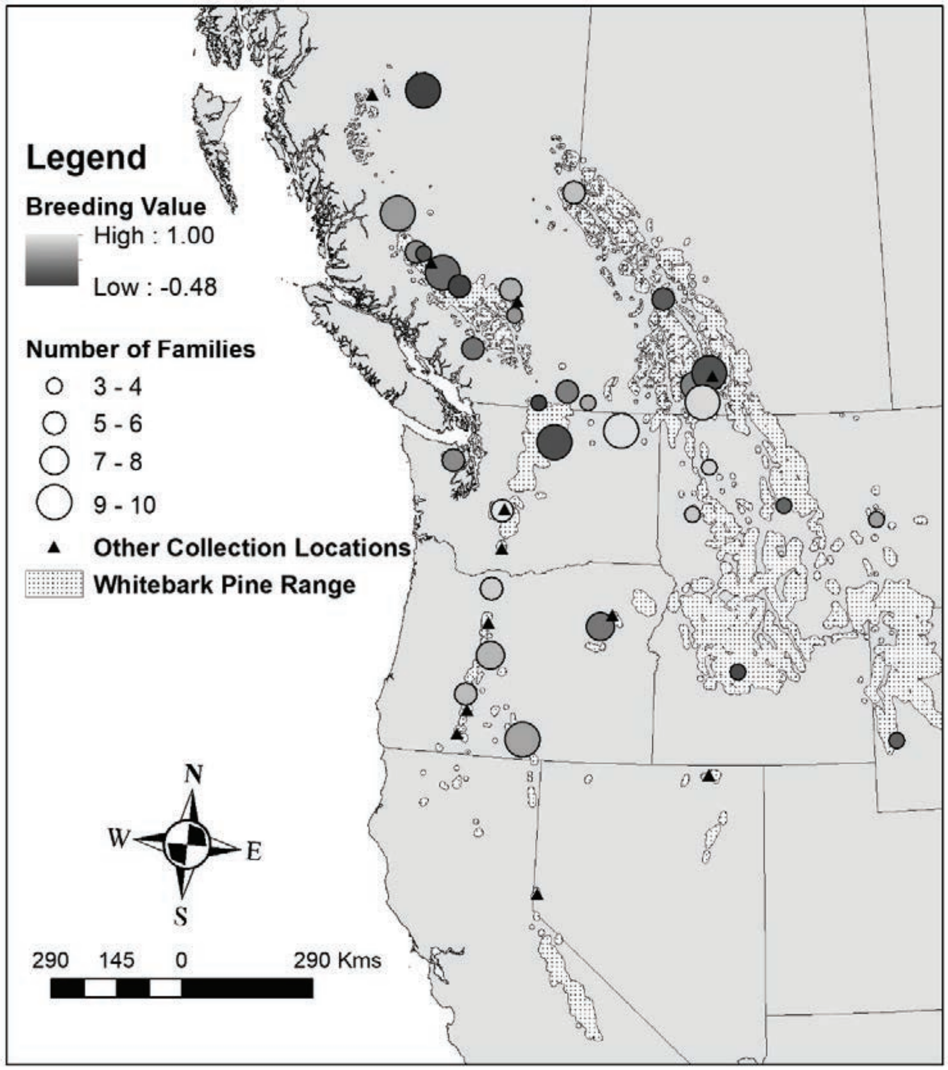

Figure 2: Map of spatially corrected breeding values by provenance. Circle size represents number of families tested per provenance. Provenances containing fewer than three families were removed from this analysis and are marked as black triangles on the map.

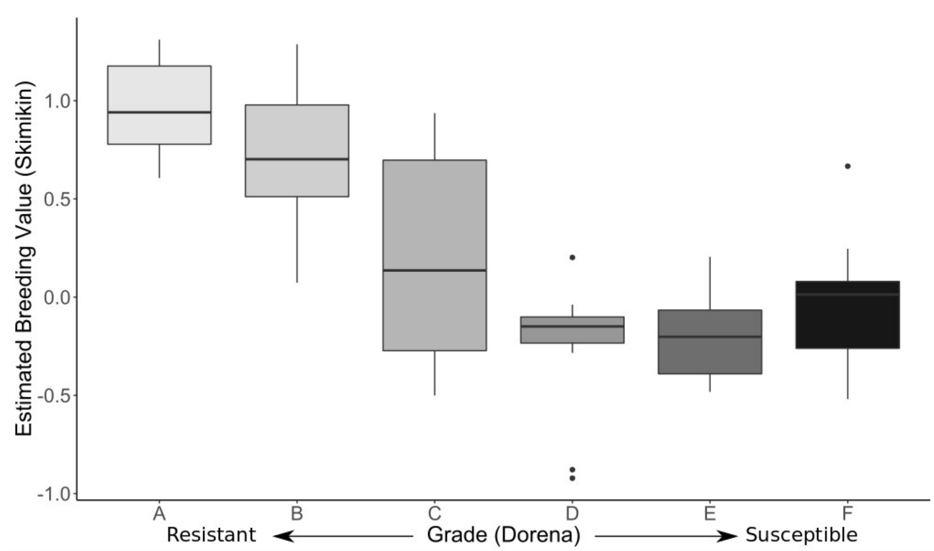

Figure 3: Comparison between spatially corrected family breeding values for rust resistance at Skimikin with A to F grades from control inoculations of the same families done at Dorena, OR.

Long term monitoring plots in Alberta: Update 2019

Jodie Krakowski, Forest Genetics Specialist, Agriculture & Forestry, Forest Health & Adaptation, Forest Stewardship and Trade Branch, Edmonton

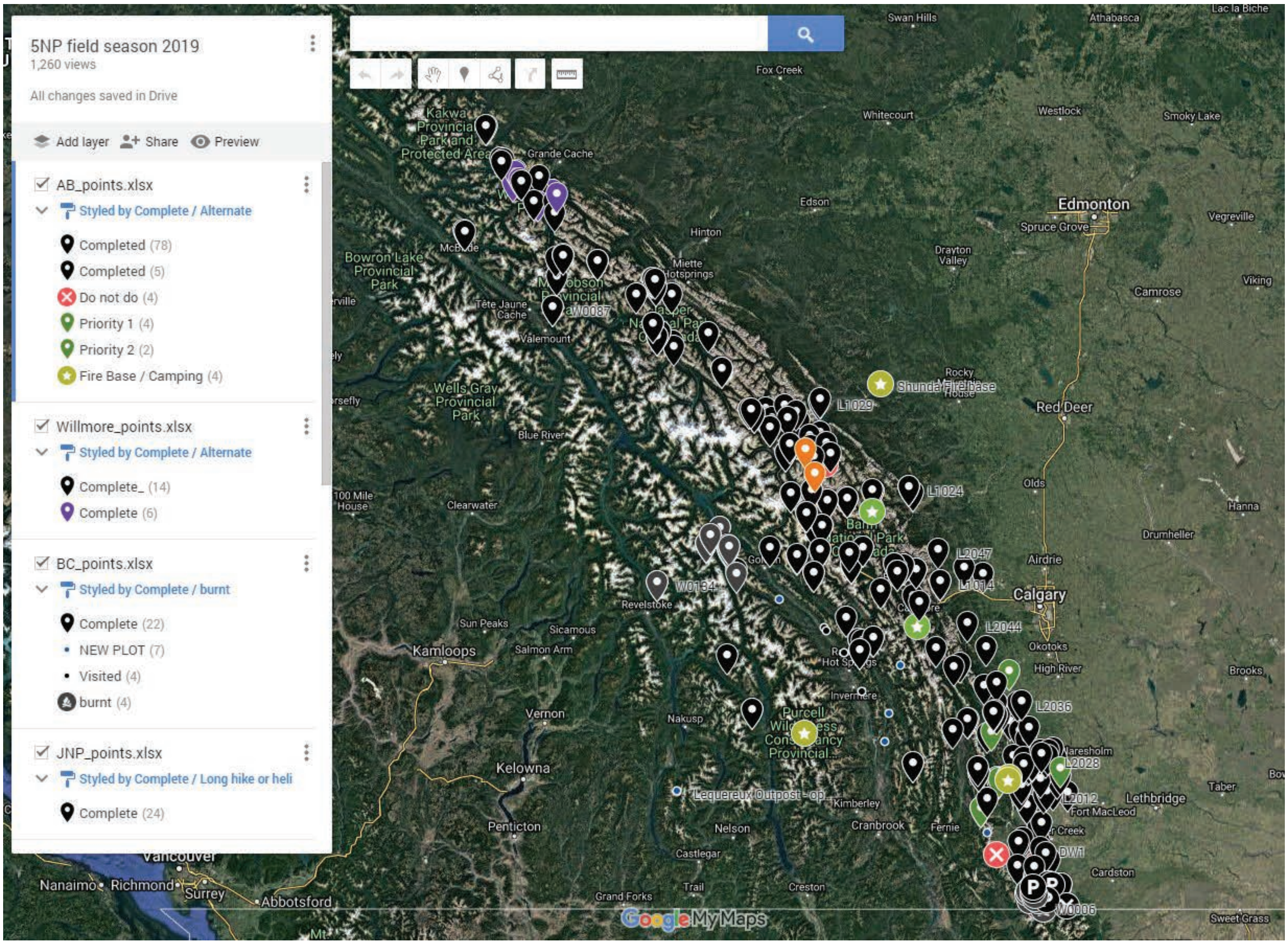

Figure 1. Monitoring plts in the Canadian interior.

Monitoring

While 2018 was a mast cone year for Canada, 2019 was a monitoring year. Crews from Alberta, Parks Canada, and BC teamed up to plan and train together to assess the interior network of around 250 long term monitoring plots following the Whitebark Pine Ecosystem Foundation protocols (Figure 1, Table 1). For most of these plots it was the fourth assessment, done every 5 years. New plots were established to expand the sample area into BC and to fill spatial gaps, and to replace burnt or inaccessible sites. Many staff from various agencies contributed time and logistical support to make this a success.

Brenda Shepherd of Jasper National Park was the lead coordinator and hired two crews, and all Rocky Mountain National Parks supported the work, especially Waterton Lakes National Park who had a dedicated crew. In Alberta, one crew was hired to support this program and to also collect data on fire history in stands in order to assess relationships between fire and regeneration at the northern ranges of whitebark and limber pine. Sites were also assessed for fire hazard based on fuel loads. Parks Canada teams also collected fire data across many sites.

A summary of transect monitoring data is being prepared. Below is a short synopsis of the fuels data. Regional studies and anecdotal evidence led us to wonder if fire is really as integral a component of limber and whitebark pine ecosystems as it is in more southern ecosystems. To test this, crews collected a streamlined data set indicating past fire history, severity, and fuel characteristics in plots and the surrounding stand. Not to anyone's great surprise, GIS layers missed a lot of fires in these remote areas that field sampling confirmed – highlighting the importance of field data collection. Without detailed time consuming studies fires could not be accurately dated, but we could generalize if they were recent, older (more than 20 years), or unburnt.

Regeneration density was compared to fire categories (Figure 1). Overall, there was more tall than short regeneration for each class, which might be due to declining recruitment, or to the longer time represented by the tall seedling class compared to the short seedling class. Whitebark pine stands had far more regeneration than limber pine stands. Short regeneration showed similar densities for whitebark pine stands that were unburnt and those that burnt recently; limber pine stands had a gradient of increasing regeneration from recent burns to unburnt to old burns. Tall regeneration showed no significant difference in regeneration between limber pine stands that were not burnt and those that were burnt over 20 years ago; stands that had burnt more recently had less regeneration. Whitebark pne stands showed a gradient of increasing regeneration from old burns to unburnt or recent burns, which were not significantly different.

Restoration

Over 7,000 plus tree limber pine seedlings were planted at priority sites for restoration in southwestern Alberta by Alberta staff from Agriculture and Forestry, Environment and Parks, Waterton Lakes National Park, and

ALBERTA continued on page 37

Fire Data Source	Total	Limber pine	Whitebark pine
Plots established	300	95	205
Veg transect 2019	244	80	164
Fuels assessed (at least partial data)	263	87	176

Table 1. Monitoring plots and data collection in 2019 in Canada.

Source	Unburnt	Burnt	Old (>20 yrs)	Recent (<20 yrs)
*GIS layer	153	35	7	28
Plot data (stand)	168	95	66	29
Plot data (plot only)	229	15		

Table 2. Fire evidence from different data sources.

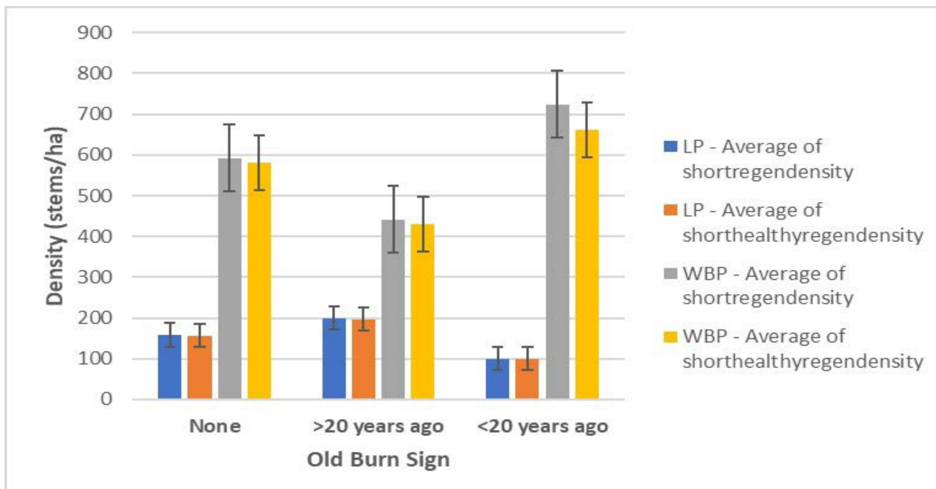

Figure 1A. Short (0-50 cm) regeneration density for limber and whitebark pine relative to burn class.

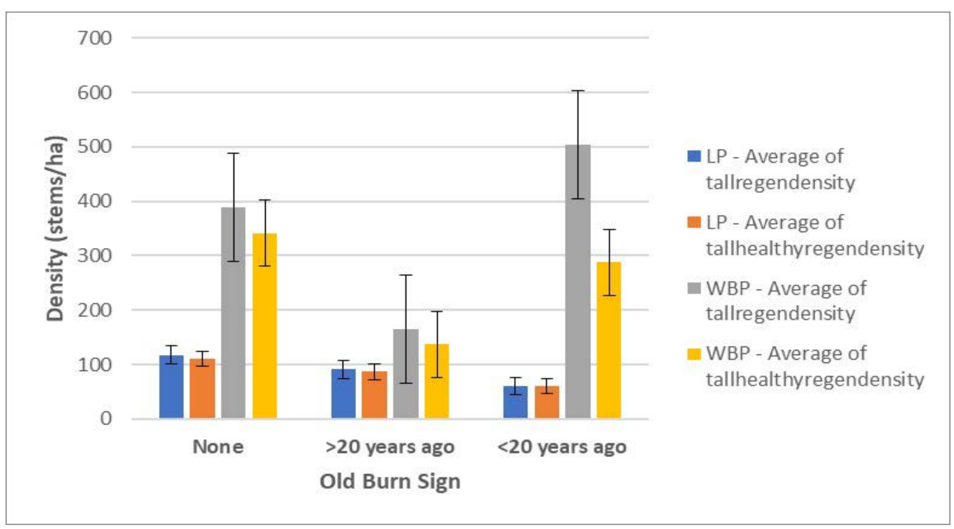

Figure 1B. Tall (50-140 cm) regeneration density for limber and whitebark pine relative to burn class.

New and Exciting Research papers

By Bob Keane, Editor Nutcracker Notes

This is a brand new column that we are adding for the next two years in Nutcracker Notes to get everyone caught up on the latest and greatest papers to be published over the last two years. In this issue, we highlight some interesting studies that were published in 2018.

1. J. Amberson, M. Kerville, C. Nelson, 2018, Effects of Disturbance on Tree Community Dynamics in Whitebark Pine (Pinus albicaulis Engelm.) Ecosystems, Forests, 2018, 9 (9), 566.

2. J. Cartwright, 2018, Landscape Topoedaphic Features Create Refugia from Drought and Insect Disturbance in a Lodgepole and Whitebark Pine Forest, Forests, 2018, 9 (11) 715.

3. Sarah Flanary, 2018, Demographics and Growth History of Whitebark Pine on Undisturbed Sites across the Northern US Rocky Mountains, MS Thesis, The University of Montana, Missoula, https://scholarworks.umt.edu/etd/11282

4. S. Goeking and D. Izlar, 2018, Pinus albicaulis Engelm. (Whitebark Pine) in Mixed-Species Stands throughout Its US Range: Broad-Scale Indicators of Extent and Recent Decline, Forests, 2018, 9 (3), 131.

5. J. S. Hooke, Whitebark Pine Conservation Program 2018 Annual Report. National Park Service. Crater Lake National Park, Crater Lake, Oregon. https://irma.nps.gov/DataStore/Reference/Profile/2259925

6. Kathryn Ireland, Andrew Hansen, Robert Keane, Kristin Legg and Robert Gump, 2018, Putting Climate Adaptation on the Map: Developing Spatial Management Strategies for Whitebark Pine in the Greater Yellowstone Ecosystem, Environmental Management 61 (6) pp 981-1001, http://www.montana.edu/hansenlab/documents/downloadables/Ireland_etal_2018_Spatial%20climate%20adaptation%20planning%20for%20whitebark%20pine.pdf

7. R. Keane, 2018, Managing Wildfire for Whitebark Pine Ecosystem Restoration in western North America, Forests 2018, 9(10), 648.

8. R. Keane, M.F. Mahalovich, B. Bollenbacher, M. Manning, R. Loehman, T. Jain, L. Holsinger, and A. Larson, 2018, Chapter 5 Effects of Climate Change on Forest Vegetation in the Northern Rockies, In "Climate Change and Rocky Mountain Ecosystems", edited by J.E. Halofsky and D.L. Peterson, Advances in Global Change Research 63, DOI 10.1007/978-3-319-56928-4_5 https://www.fs.fed.us/rm/pubs_journals/2018/rmrs_2018_keane_r001.pdf

9. R. Keane, R. Loehman, L. Holsinger, D. Falk, P. Higuera, S. Hood and P. Hessburg, 2018, Use of landscape simulation modeling to quantify resilience for ecological applications, Ecosphere, 9 (9), e02414. https://esajournals.onlinelibrary.wiley.com/doi/epdf/10.1002/ecs2.2414

10. Marian Lea, John Syring, Tara Jennings, Richard Cronn, Leo Bruederle, Jennifer Ramp Neale, and Diana Tomback, 2018, Development of nuclear microsatellite loci for Pinus albicaulis Engelm. (Pinaceae), a conifer of conservation concern, PLoS ONE 13(10): e0205423. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0205423

11. Colin Maher, Cara Nelson, Andrew Larson, and Anna Sala, 2018, Ecological effects and effectiveness of silvicultural restoration treatments in whitebark pine forests, Forest Ecology and Management, 429, 534-548

12. M. Murray and J. Siderius, 2018, Historic Frequency and Severity of Fire in Whitebark Pine Forests of the Cascade Mountain Range, USA , Forests, 2018, 9 (2), 78.

13. Erin Shanahan, K. Legg, R. Daley, K. M. Irvine, S. Wilmoth, and J. Jackson. 2018. Monitoring five-needle pine on Bureau of Land Management lands in Wyoming: Summary report for 2013, 2014, 2016, 2017. Natural Resource Report NPS/GRYN/NRR—2019/1931. National Park Service, Fort Collins, Colorado.

NEW PAPERS continued on page 37

The 2020 H5II Conference has been POSTPONED to October 5-7, 2021

By Bob Keane

The good news is that the Whitebark Pine Ecosystem Foundation is still planning to host the Second International symposium on high elevation, five needled pines (H5II) at the Hilton Garden Inn in Missoula, Montana. The bad news is that this conference will now be held a year from its original date: **October 5-7, 2021**. The dire consequences of the COVID-19 pandemic and our concern for our attendees and the Missoula community has forced us to postpone this important conference. We hope that this will only make the conference more exciting and relevant and gives another year for people to finish work to present at the conference.

The conference website (www.highfivepines.org) will still accept abstracts for posters and oral presentations. If people are reluctant to submit an abstract because it's too early, don't worry, our abstract submission system allows people to update any submissions. Also, people can still register for the conference. All registration funds are used by the WPEF to promote and restore high elevation five needle pine ecosystems. Registration costs may increase next year (2021) so if you want to attend the conference at the lowest prices, please register now. Government people might think about using end-of-year monies to register.

For those who are new to this conference, it is usually held every ten years since 1989. It convenes internationally renowned scientists and resource managers to present state-of-the-art information on the research and management of these valuable pines that may redefine the management of the keystone high elevation pine forests. Tragically, we are losing many high elevation five-needle pine forests throughout North America. Six high elevation five-needle pine species, whitebark (*Pinus albicaulis* Engelm.), limber (*P. flexilis* James), southwestern white (*P. strobiformis* Engelm.), foxtail (*P. balfouriana* Grev. & Balf.), Great Basin bristlecone (*P. longaeva* D.K. Bailey), and Rocky Mountain bristlecone pine (*P. aristata* Engelm.), are in great danger of rapidly declining in the upper subalpine forests of western North America.

Pro-active restoration is needed to ensure these species remain on the high elevation landscape. All scientists, ecologists, resource professionals, and managers interested in these iconic ecosystems are invited to learn new techniques, research results, and new information on the research and management of high elevation five needle pine ecosystems. Topics to be covered include (1) blister rust and mountain pine beetle interactions with H5 pines, (2) rust resistance testing and findings, (3) wildland fire dynamics, (4) restoration techniques and actions, (5) status of the National Whitebark Pine Restoration Plan, (6) ecology and ecophysiology, (7) genetic concerns, and (8) nutcracker-pine interactions.

The program contains three keynote and six plenary presentations from recognized experts in the field that will set the stage for the conference. There will also be over 150 invited and contributed presentations in four concurrent sessions over 2 ½ days that will cover ecology, restoration, and management of the six tree species. Featured will be the National Whitebark Pine Restoration Plan (NWPRP). This three-day conference will also feature a ½ day field trip day will visit a local whitebark pine restoration site to discuss the current issues in restoring high five tree species, especially under a future of changing climates.

We hope you can find the time to attend this exciting conference next year as it will be the most important meeting of resource professionals and researchers since the 2010 conference. Please put this one-of-a-kind event on your calendar.

H5II

The Second Conference on the Research and Management of High Elevation Five Needle Pines in Western North America

2021 High Five II Field Trip Overview

As is the tradition at all Whitebark Pine Ecosystem Foundation conferences, workshops, and annual meetings since our inception, there will be a field trip available to all participants at the High Five II Conference in Missoula in **October 2021**.

The Field Trip Subcommittee has selected the Smith Creek Whitebark Pine Research Project area on the Bitterroot National Forest west of Victor as our destination. This location was selected as an excellent example of the dynamic nature of whitebark pine ecosystems, particularly in the face of a changing climate. Many folks will recall this is the same location of the field trip conducted at the 1998 Whitebark Pine Conference 22 years ago. So much has changed at this site that the Subcommittee felt the lessons learned were too numerous to pass up.

Field trip participants will load up on buses at the hotel and travel down Highway 93 and through the beautiful Bitterroot Valley. We will then travel up National Forest roads to the field trip site, at which time the provided lunch will be enjoyed along with presentations from local dignitaries, including Dr. Steve Arno. We will then split up in six groups and rotate through presentations and discussions pertinent to the immediate surrounds. Subject matter presented by experts in the field will include restoration strategies, interacting disturbances, a Smith Creek research synopsis, high elevation wildland fire, management issues & challenges, and blister rust & resistance.

We will be high in the Bitterroot Mountains, which means you will need to come prepared for all manner of weather: sturdy shoes, warm clothing, raingear, sunblock, a hat, etc. The weather you observe when you are getting on the bus may not be the weather you get five hours later and 3000 feet higher. First aid and emergency services will be provided if needed.

After the presentation, participants will load back up on the buses and return to the hotel by 5:00 p.m. in time for the evening programs. We hope to see you there.

A Virtual WPEF Science and Management Meeting – September 16, 2020

In keeping with WPEF tradition, we have decided to hold our annual Science and Management Meeting in a virtual format on September 16, 2020. This virtual meeting will be in one of the same time slots as the H5II conference, which was postponed until **October 5-7, 2021**.

This virtual conference is free to all, but we will be asking for donations during the meeting to cover costs.

The science and management part of the conference starts at 1 pm on Wednesday, September 16, and ends at 4 pm. There is an hour break and then, starting at 5-7pm, we will have a virtual kegger hosted by Liz Davy when she will auction off items, conduct a very quick members meeting, and provide the WPEF community a chance to socialize in this time of pandemic. It should be loads of fun, and Liz guarantees huge whitebark smiles for all.

The program of this web-based conference includes three hours of science and management talks on three topics: status of the National Whitebark Pine Restoration Plan, and climate change in high elevation ecosystems, and post-fire dynamics in upper subalpine forests. Experts in these fields are preparing exciting talks for the High 5 community.

Please put this one-of-a-kind event on your calendar.

Sorcerer Lodge certified as first ‘Whitebark Pine Friendly Ski Area’ in Canada

The Whitebark Pine Ecosystem Foundation is pleased to announce that Golden-based Sorcerer Lodge is being recognized as the first Whitebark Pine Friendly Ski Area in Canada. Whitebark pine is an endangered high elevation tree species, commonly growing within ski areas; thus, ski areas have a unique management responsibility for the survival of the tree.

This program recognizes ski areas that have contributed to the recovery of whitebark pine through diligent management actions. The intent of this program is to: 1) Recognize ski areas that are leaders in whitebark pine recovery; 2) Increase awareness among ski areas; 3) Provide guidance to ski areas in conservation efforts; 4) Provide opportunities for ski areas and their patrons to be directly involved in whitebark pine recovery; and 5) Preserve whitebark pine to be enjoyed by future generation of recreationists.

Sorcerer Lodge has been supporting whitebark pine recovery for over a decade by providing a base for recovery specialists, educating guests, developing local mapping and recovery projects, and contributing financially to the recovery of the species.

Media and public are invited to a recognition ceremony and reception to be held on November 21st from 7-9 PM at the Mount Begbie Brewery Tasting Room, 2155 Oak Drive, Revelstoke BC.

For more information see: whitebarkfound.org/our-work/ski-area-certification/

Contact:
Randy Moody, President, Whitebark Pine Ecosystem Foundation of Canada: whitebarkrandy@gmail.com

Mike Giesey, Chair of Ski Area Partnership Committee: mike.giesey@whitebarkfound.org

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PROACTIVE continued from page 16

America. In: The Future of High-Elevation, Five-Needle White Pines in Western North America: Proceedings of the High Five Symposium. 28-30 June 2010, Missoula, MT. Edited by RE Keane, DF Tomback, MP Murray, CM Smith. USDA For. Serv. Proc. RMRS-P-63. pp 276-294 https://www.fs.usda.gov/treesearch/pubs/38240

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Schoettle AW, Cleaver CM, Burns KS, Connor JJ. 2015. Limber Pine Conservation Strategy for Rocky Mountain National Park. On file as an active management guide at Rocky Mountain National Park.

Schoettle AW, Jacobi WR, Waring KM, Burns KS. 2019a. Regeneration for Resilience Framework to Support Regeneration Decisions for Species with Populations at Risk of Extirpation by White Pine Blister Rust. New Forests 50: 89–114. https://doi.org/10.1007/s11056-018-9679-8

Schoettle AW, Sniezko RA. 2007. Proactive Intervention to Sustain High Elevation Pine Ecosystems Threatened by White Pine Blister Rust. Journal of Forest Research 12:327-336. https://www.fs.usda.gov/treesearch/pubs/29500

Schoettle AW, Sniezko RA, Kegley A, Burns KS. 2014. White Pine Blister Rust Resistance in Limber Pine: Evidence for a Major Gene. Phytopathology 104:163-173. https://www.fs.usda.gov/treesearch/pubs/44228

MEMBERSHIP REPORT

Michael Murray

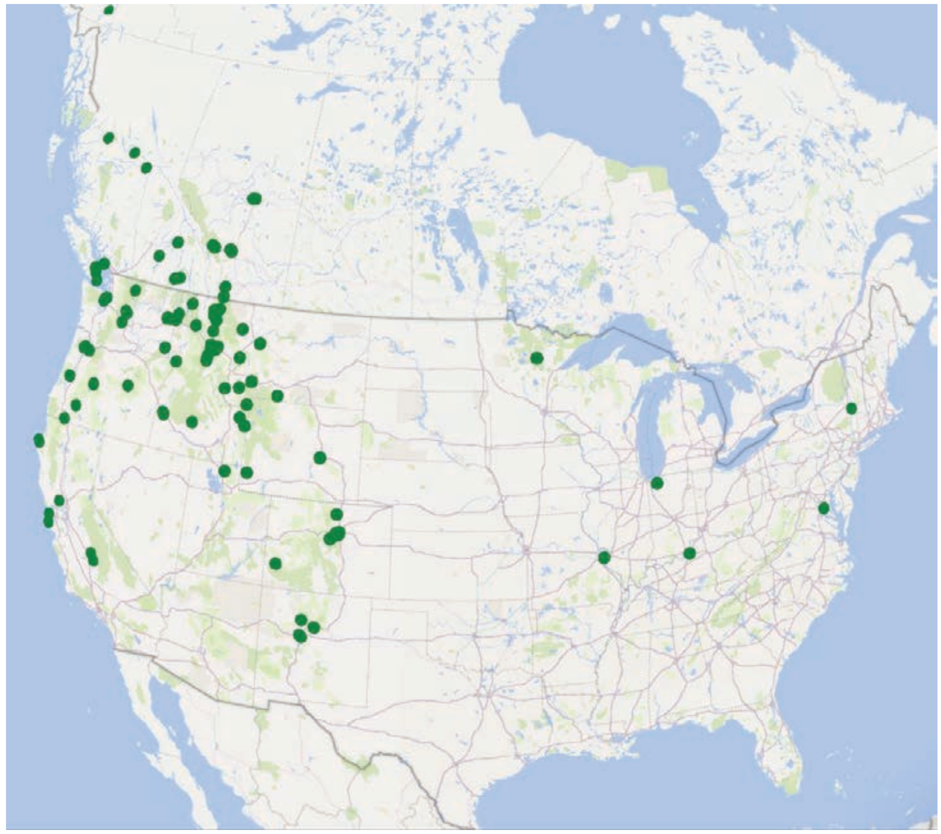
Have you renewed your membership for 2020? If not, this will be your last Nutcracker Notes. We recently switched our membership year to match the calendar year.

After reading the Directors' reports for both USA and Canada WPEF (in this issue of NN), you are surely inspired!

Can't remember if your membership is expiring? Please send an email to michael.murray@whitebarkfound.org

Like most non-profits, we depend on members for the support needed to meet our mission of restoration and education of high-elevation pine ecosystems. The funds received via your annual dues are the basis for the foundation's operations. With the proliferation of social media, perhaps you can follow our WPEF posts (Facebook, Twitter, Instagram, Youtube) so you can share our postings with your friends. Help spread our greatness and recruit members!

Membership is available in various categories. All categories are afforded the same level of membership benefits and differ in the amount of contribution. The Student level allows those enrolled in school to participate at a reduced rate. The Whitebark level is the standard category. The Nutcracker level allows for a greater level of contribution. The Institutional level allows for an entire organization to be enrolled with benefits available to all individuals at that location, including a hardcopy of Nutcracker Notes to share at the office. The Grizzly level is the one-time, lifetime membership category.



WPEF member locations around the U.S. and Canada.

Consider renewing as a sustaining member! This option is available at www.whitebarkfound.org/membership. By renewing with a recurring annual option, your membership will automatically renew (with a payment transaction and a personal email notification) one year from your personal subscription date. Why choose this option? It lessens the time and funds WPEF needs to spend on outreach/renewal efforts every year. This has been substantial. And these resources are better spent directly on conservation of high-elevation pines. Moreover, this is a convenient option for members who rather not try to remember when they need to renew….this is automatic!

Please Renew for 2020!

STUDENT RESEARCH GRANTS

WPEF student research grant awarded for 2020

A call for proposals for the annual WPEF student research grant was released in the Winter issue of Nutcracker Notes, on the website and through social media. The proposals were reviewed by the Evaluations Committee, composed of former board members Bryan Donner, Edie Dooley and Cyndi Smith, and Nutcracker Notes editor and interim associate director Bob Keane. ***HENRIETTE GELINK****, a PhD student in the Faculty of Applied Ecology and Biotechnology at Inland Norway University of Applied Sciences, was chosen as the grant recipient for 2020. Henriette is also associated with Dr. Scott Powell of Montana State University and Dr. Dan Tyers of the US Forest Service. Following is a description of Henriette's project:*

Grizzly bear habitat management in a changing world: the impact of blister rust, bark beetle and wildfire on whitebark pine, and its influence on grizzly bear habitat management in the Greater Yellowstone Ecosystem

Main topic and objectives

The main topic of my project is "Grizzly bear (*Ursus arctos horribilis*) habitat management in a changing world", and focuses on a complex and vulnerable ecosystem, driven by native species, and endangered by climate driven threats. I will study the health status of whitebark pine (WBP, *Pinus albicaulis*) as a foraging resource for grizzly bears in the Greater Yellowstone Ecosystem (GYE), and examine environmental variables that could explain the observed trends of WBP mortality, survival and regeneration. Findings will help managers understand how WPB responds to mountain pine beetle (*Dendroctonus ponderosae*) and white pine blister rust (*Cronartium ribicola*) epidemics across a wide landscape, at different elevations and changing environments.

Background

WBP is native to high-elevation forests in Canada and northwestern United States, predominantly above 2000 m (Kokaly et al. 2003), and needs 50 years to reach cone bearing age (Logan et al. 2010). WBP is an important snow and watershed facilitator, creates microenvironments, and produces large fat-rich seeds which several species depend on, including the Clark`s nutcracker (*Nucifraga columbiana*), red squirrel (*Tamiasciurus hudsonicus*), black bear (*U. americanus*), and grizzly bear (Logan and Powell 2001, Tomback et al. 2001, Arno and Allison-Bunnell 2002, Logan et al. 2010). The Clark`s nutcracker is native and almost exclusively forages on WBP seeds when available (Hutchins and Lanner 1982, Owens et al. 2008), and can cash up to 90,000 seeds annually (Tomback 2001). Unrecovered seeds are the most important contribution to WBP regeneration (Arno and Allison-Bunnell 2002). This entire high elevation ecosystem fully depends on the symbiotic relationship between the nutcracker and WBP, and any interference may cause cascading effects influencing essential ecosystem functions and endangered native species (Logan and Powell 2001). WBP seeds

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are one of the most important forage resources during the pre-hibernation hyperphagia period when grizzly bears fatten for their winter hibernation (Robbins et al. 2006), and a reduction in WBP cone production can alter grizzly bear behavior significantly (e.g., occupy areas closer to human settlements) (Mattson et al. 1992).

WBP populations are declining as a result of complex interactions, including white pine blister rust, mountain pine beetles, and climate change (Logan et al. 2009). The introduced blister rust attacks and kills WBP (McDonald and Hoff 2001, Logan et al. 2010), and trees already infected with blister rust are more susceptible to beetle attack (Bockino and Tinker 2012). The beetle is native, but climate change induced warm winters have enable more beetles to overwinter and reproduce in areas they previously only infrequently

occupied (Carroll et al. 2003, Logan et al. 2010). To promote the persistence and regeneration of WBP forests, managers are experimenting with a variety of techniques, including reducing competition with other conifers through selective cutting and prescribed fire (Keane 2000, Jenkins et al. 2008, Schwandt et al. 2010). There is still much to learn about the ecological interactions of blister rust, beetles, WBP and bears in high elevation ecosystems, which is why long-term and landscape level WBP surveys are so important (Shepherd et al. 2018).

Methods

The blister rust outbreak in Glacier National Park (GNP), in the 1990s killed an estimated 44-90% of the WBP forest (Kendall and Keane 2001). To investigate blister rust impact on WBP in the GYE, my main advisor, Dr. Dan Tyers, initiated several studies on WBP health status. One of the studies involved the establishment of 115 permanently marked belt transects (10 x 300 feet) across the northern portion of the GYE. In total, 3384 individually marked WBP trees have been surveyed from 2008-2019. Each tree (diameter > 2.5 cm) was measured at chest height and marked with a metal plate nailed to the bole. Trees were assessed by age class, health status, alive/dead, and damage codes. I have contributed to the surveys and data management, and am currently analyzing the data collected and drafting two manuscripts.

Preliminary results

Preliminary results suggest that blister rust has not been as detrimental in the GYE as in GNP. Beetles seem to be killing more WBP in the GYE, and beetle-caused WBP mortality seems to be related to a combination of elevation, precipitation, human disturbance and plant competition. Climate induced warmer and wetter winters in the GYE in the near future could facilitate more blister rust germination and enable more beetles to overwinter, potentially causing massive WBP mortality.

References available upon request.

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We determined these two chloroplast DNA regions as most informative because they readily PCR amplified from all our DNA isolations. In addition, and importantly from an economic perspective, the PCR products generated from these two chloroplast regions for each of our needle fragments are readily cleaved by inexpensive restriction enzymes. Cleaving our PCR products results in a set of DNA bands that distinguish limber from whitebark pine (Figure 2). The restriction enzyme BsmAI cuts the matK PCR product of whitebark pine into two bands (Figure 2; top panel). The restriction enzyme PsiI cuts the PCR product of psbA-trnH spacer in limber pine into two or three bands (Figure 2; bottom panel).

With our approach involving the Extract-N-Amp kit and restriction enzymes, we estimate the cost for an analysis of 200 pine needle fragments can be as low as $1200, which includes the labor of an experienced undergraduate student. This estimate also assumes access to basic equipment in a genetics lab, including a PCR machine, pipettes, and plastic disposable items such as tubes and pipette tips.

We predict that this approach to the genetic identification of limber and whitebark pine will reveal that whitebark pine is a bit more common at lower elevations, altitudes below about 2440 m (~8000 ft), than previously appreciated. Perhaps at such lower elevations whitebark pine will generally be found in a non-reproductive state and thus non-cone-bearing. The results of Alongi et al. (2019) may lead to studies that more accurately model species distributions of limber and whitebark pine and better estimate how climate change will affect the geographic distribution and climatic tolerances of these two ecologically important pine species.

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reduce intensities of future wildfires, recycling nutrients and minerals, and creating good caching sites for whitebark regeneration. But, the huge questions on everyone's lips is, of course, when is Rx or WFU appropriate?

We'll take a stab at possible conditions under which to burn:

1. Reduce fuels. Treat canopy and surface fuels to reduce the amount and subsequent fire intensities.

2. Protect mature trees. Pay special attention to fuels around the bases of trees that must survive. Light raking to remove the litter and duff from around trees can protect tree boles from charring and widen the prescription window for burning.

3. Burn under higher moisture prescriptions. It may be that burning under higher wind and higher fuel moistures will ensure higher survival and encourage patchy burns.

4. Apply fire sparingly. Unburned patches are good! If the majority of the forest floor is black, you've probably burned too much of the unit.

5. Use thinner strips. When lighting under strip headfire ignition patterns, try to use smaller distances between each strip and don't light continuous strips. If using aerial ignition techniques, use a lower intensity than in other forest types to achieve a patchy burn, especially under hot, dry, windy conditions.

Clearly, more research is needed here, but also there needs to be more Rx burning experience in these high elevation environments to fine-tune our burn techniques to minimize mortality in the valuable whitebark pine. The take-home message is that fire is still an important tool in the toolbox to restore whitebark pine forests. BUT, it's essential to make sure fires are patchy and do not burn all the way around the bases of the most important whitebark pines to retain.

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planting range from $2.28 to $2.35 USD per seedling, and planting costs range from $371 to $1236 USD per ha (Tomback et al. 2011). Assuming similar planting costs for seedling planting and direct seeding, direct seeding could save $563 USD per hectare, reducing costs by 41%. However, direct seeding costs have been estimated only for research purposes, not restoration, and more rigorous cost analysis is required to assess whether seeding would be more economical than seedling planting.

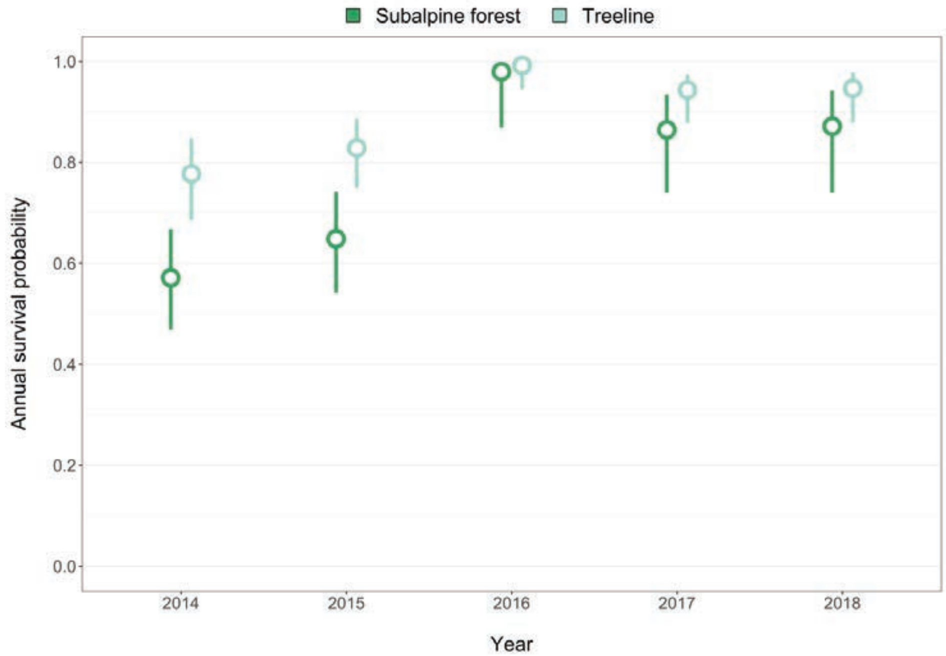

Figure 2. Annual survival probability of directly sown whitebark pine seeds on Tibbs Butte, Shoshone National Forest, Wyoming, USA as described by elevation zone and year. Points show annual survival estimates, and lines show 95% confidence intervals. The model selected includes the additive effects of elevation zone (subalpine forest vs. treeline) and year.

	No. Caches with 1+ Seedlings					
	2013	**2014**	**2015**	**2016**	**2017**	**2018**
Treeline	66	75	47	47	45	42
Subalpine	73	63	34	32	28	26
TOTAL	**139**	**138**	**81**	**79**	**73**	**68**

Table 2. Number of caches with one or more seedlings by year and elevation zone. Note that counts for 2014 represent both additional germination and mortality since 2013. One or more seedlings emerged from 45 caches in 2014 that had zero seedlings in 2013--21 at treeline and 24 in the subalpine forest.

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Vancouver in 1910, the rust first spread south into Washington and Oregon as well as directly east towards the Columbia and Rocky Mountains (McDonald and Hoff 2001). In this study, it appears places experiencing rust earlier (e.g. Washington) had more resistant families than places that were infected later (e.g. Coast Range, Wyoming), likely due to more natural selection for resistance. In high infection areas, phenotypic selection of seed parents may have resulted in collection of more seed from resistant individuals for this study.

Whitebark pine is federally listed as endangered in Canada (Environment and Climate Change Canada 2017). It is slow growing, inhabits difficult to access areas, and seed collection is onerous, making restoration efforts costly and both time and labour intensive. Finding ways to increase efficiency in the process of locating, growing, and planting rust-resistant trees is of the utmost importance for the long-term viability of the species. The nursery-based seedling-screening methods used in this study would help to speed up this process and provide another option for identifying rust-resistant seedlings. While this approach does have some drawbacks, including less control over the pathogen and environment, and these results are based on only a single test site, it is sufficiently promising that additional field trials are underway throughout British Columbia. Long term monitoring of these trials will help identify additional parent trees, determine the durability of resistance, and adjust seed transfer guidelines for restoration in a changing climate.

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Piikani Nation. About 500 seedlings were planted in a multi-species climate resilience trial at Star Creek. Elementary school kids from 6 classes in Crowsnest area each learned about the importance of and threats to limber pine, and planted a plus tree in Beauvais Lake Provincial Park, giving a much-needed boost to a declining stand with zero natural regeneration. Parks Canada also planted thousands of whitebark and limber pine seedlings in their parks – an early heavy snowfall cut some of the work short, but will continue next season.

Recovery planning

A revised, combined version of the Alberta recovery plans for whitebark and limber pine is complete and undergoing consultation. It reflects progress to date, and has updated objectives, targets, and actions based on the series of Open Standards recovery planning workshops hosted by Parks Canada to support consistent effective recovery planning and implementation across Canada for these species. The plan will be posted on the Alberta Species At Risk website.

There's more…

Like any great story, there is a lot more to be proud of that will be told in the next chapter. Stay tuned!

Fire Data Source Total Limber pine Whitebark pine
Plots established 300 95 205
Veg transect 2019 244 80 164
Fuels assessed (at least partial data) 263
87 176

Photo by Libby Pansing

NEW PAPERS continued from page 27

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The program of this web-based conference includes three hours of science and management talks on three topics followed by a virtual social.

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