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Clark's Nutcrackers: An investigation into population-wide failure to breed in the Greater Yellowstone Ecosystem

Clark's nutcracker nestlings in the Greater Yellowstone Ecosystem.

By Taza Schaming

Abstract

Clark's nutcrackers at my study site in the southern Greater Yellowstone Ecosystem exhibited population-wide failure to breed in two out of five years. The two nonbreeding years, 2009 and 2011, followed low whitebark pine cone crops the previous autumn (≤ an average of 8 ± 2 cones per tree versus ≥ an average of 20 ± 2 cones per tree during breeding years). The confounding factor was that both nonbreeding years also had a higher early spring snowpack (≥ 61.2 ± 5.5 cm versus ≤ 51.9 ± 4.4 cm during breeding years). The birds may not have attempted to breed because they predicted that breeding conditions would be poor, based on the low availability of cached whitebark pine seeds. Alternatively, the birds may have

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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.

WHITEBARK PINE ECOSYSTEM FOUNDATION

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DIRECTOR'S MESSAGE - CLIMATE CHANGE AND WHITEBARK PINE REVISITED

Diana F. Tomback

The climate change predictions for whitebark pine based on bioclimatic envelope models (aka species distribution models) are in general agreement, but will they be right? They indicate that warming temperatures will result in distributional shifts of whitebark pine to higher elevations and more northern latitudes, and, ultimately, the whitebark pine distribution will dwindle to a mere handful of locations in the western United States. These predictions are often portrayed as "whitebark pine moves upward and off the top of mountains, and marches across the Canada-U.S. border to more northern latitudes." (Then, WPEF-Canada takes over all our work!) This scenario does not encompass future mortality from white pine blister rust, future outbreak patterns for mountain pine beetles, plus predictions of larger, more severe wildfires occurring at shorter intervals, which could influence future whitebark pine distributions in complex ways.

In addition to altered disturbance regimes, there are many other reasons to be skeptical of this simplistic scenario, and these are discussed in the WPEF white paper by Keane et al. 2013, "Climate change and whitebark pine: compelling reasons for restoration," which is posted at www.whitebarkfound.org and addressed in my Fall/Winter 2013 Director's message. Factors, such as the great genetic diversity of whitebark pine associated with its broad geographic range; local variation in topography providing diverse microclimates; and the resilience of old growth, cone-bearing whitebark pine trees to climate change over centuries together argue that these predictions may exaggerate distributional changes.

Now, Keane et al. (2016) have a forthcoming U.S. Forest Service, Rocky Mountain Research Station, General Technical Report, "Restoring whitebark pine (*Pinus albicaulis*) ecosystems in the face of climate change." This publication builds on the tools and strategies previously described by Keane et al. (2012) in "A range-wide restoration strategy for whitebark pine (*Pinus ablicaulis*)," USDA Forest Service, RMRS-GTR-279. Keane et al.'s (2016) revisited recommendations are informed by a major simulation modeling effort using two geographic regions in Montana as case histories—the East Fork of the Bitterroot River, Bitterroot National Forest, and the Crown of the Continent, which is defined for this effort as comprising a portion of Glacier National Park and adjacent Flathead National Forest. The simulations were run with FireBGCv2, "a mechanistic, individual-tree gap model that is implemented in a spatial domain." The climate inputs for the model used projections from a global climate model with the best performance for the Northwestern U.S. The simulations projected landscapes to the year 2100.

The results indicated that whitebark pine was retained on the landscape over time, but at 10-30% lower basal areas depending on various conditions, such as fire, restoration treatments, and geographic region. First of all, increased fire in the Bitterroot favored whitebark pine. Restoration efforts including thinning and prescribed burning generated the highest whitebark pine basal areas for the Bitterroot study area, but these "treatments" had little effect on the Crown study area. When simulations were carried out to 500 years, the benefit of both restoration and planting blister rust-resistant whitebark pine seedling became apparent, increasing the number of cone-bearing whitebark pine, and reducing the impact of white pine blister rust.

The simulations indicated that the benefits of restoration treatments varied geographically. But in successional communities, the removal of competing shade-tolerant conifers through thinning and prescribed fire helped maintain whitebark pine communities, and planting rust-resistant seedlings spread resistance to blister rust. Given the long generation time of whitebark pine, the benefits may not be hugely apparent within our lifetimes, but these efforts may make the difference ultimately between whitebark pine survival and extirpation. More simulation exercises like these but based on different regional conditions may help us prioritize and allocate scarce resources for restoration projects.

WPEF business and thanks

On behalf of the Board of Directors, I would like to thank Gerry Gray for his service as a board member over the last three years. This position was one of the two that the board itself can fill, and Gerry was our first board member from the eastern U.S.

We are grateful to the organizing committee of the Ashland, Oregon, WPEF annual Science and Management Workshop at Southern Oregon University. Special thanks to Kristen Chadwick and Jen Beck for their work on the program, to Sean Smith for the venue, and to Jen Beck, Michael Kauffman, and Rich Sniezko for leading very successful and informative field trips throughout the week. We are indebted to Laura DeNitto for another enjoyable and successful silent auction.

I would also like to acknowledge the Lazar Foundation and Norcross Foundation for recent grants to the WPEF, and to Charles Bacon and Cynthia Dusel-Bacon for their generous donation in support of the Ashland meeting.

Whitebark pine in wilderness under a changing climate

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Introduction

Whitebark pine (*Pinus albicaulis*) is considered a foundation species of subalpine forests and woodlands across many mountainous regions of the western US (Ellison et al. 2005). In recent decades, whitebark pine has experienced widespread mortality from a non-native blister rust fungus (*Cronartium ribicola*), historical fire exclusion resulting in larger, stand-replacing fires , and climate change-facilitated colonization by mountain pine beetles (*Dendroctonus ponderosae*) (Tomback et al. 2001, Logan et al. 2010). Climate change impacts may exacerbate these stressors (Loehman et al. 2010, Jewett et al. 2011).

Restoration strategies have been developed that include mechanical thinning of other conifers and prescribed burning to reduce fuels and establish sites for regeneration and planting rust-resistant genotypes (Keane et al. 2012). It has been suggested, however, that whitebark pine occurs disproportionately in wilderness areas, presenting a philosophical dilemma regarding the choice between using all available management actions to restore whitebark pine and the ecosystem the species supports (preserving “natural ecological condition”) and showing restraint in intervention (preserving “untrammeled condition”).

To better understand the potential vulnerability of whitebark pine under various climate change scenarios, we used current and future modeled whitebark pine distributions to investigate forecasted range shifts. To better understand potential management limitations, we investigated what percentage of whitebark pine’s current and projected future range occurs in the US National Wilderness Preservation System.

Figure 1. US wilderness areas (grey polygons) in whitebark pine’s range

Methods

We used a geographic information system (GIS) to overlay models of predicted current and projected future distributions of whitebark pine and existing boundaries of the National Wilderness Preservation System (Figure 1). Whitebark pine distribution models

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A Decision Framework for Managing Whitebark Pine in Wilderness

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Whitebark pine and the wilderness dilemma

A large proportion of current whitebark pine (*Pinus albicaulis)* habitat is located in federally-designated wilderness areas, and it is estimated that an even greater proportion will be found in wilderness in a climate change-influenced future (Fig. 1; and see accompanying article by Belote et al., this issue). While being located in a wilderness area is beneficial for whitebark pine conservation in many respects (wilderness areas contain strict prohibitions on commercial logging, oil and gas drilling, mining, road building, and other developments; Keane 2000), a wilderness designation may also limit the amount and type of restoration that can occur there (see Sydoriak et al. 2000).

Whitebark pine has declined over most of its range in North America (Tomback et al. 2011; Keane et al. 2012). Three major proactive restoration strategies have been proposed and implemented to restore whitebark pine: 1) mechanical thinning to reduce competition from other conifers, reduce the likelihood of mountain pine beetle (*Dendroctonus ponderosae*) attacks, and control the spread of alternate blister rust fungus (*Cronartium ribicola*) hosts (mostly *Ribes* spp.); 2) planting of blister rust-resistant seedlings; and 3) using fire in late-successional whitebark pine stands to eliminate competition and promote regeneration (Keane and Parsons 2010).

Certain activities, which may be required to effectively and economically achieve restoration in wilderness areas, are, however, restricted by law. There can be no permanent roads or any commercial activity within any Congressionally-designated wilderness area. And, except as necessary "to meet minimum requirements for the administration of the area for the purpose of [the Wilderness Act]," the following are prohibited: temporary roads; use of motor vehicles, motorized equipment, or motorboats; landing of aircraft; other forms of mechanical transport; and structures or installations (The Wilderness Act, Section 4 (c)). In wilderness, therefore, some actions are always prohibited (permanent roads, commercial enterprises), some are prohibited unless necessary to meet "minimum requirements" for administration, and some are neither definitively nor conditionally prohibited but may adversely affect wilderness character. It is perhaps best to view all potential management activities in wilderness, whether conditionally prohibited or not, as a tradeoff between the ecological condition of the land and freedom from human control. In fact, the Arthur Carhart National Wilderness Training Center recommends that a "minimum requirements analysis" be conducted whenever an administrative action may adversely affect wilderness character, whether an otherwise prohibited use is considered or not (Arthur Carhart Center 2008).

Wilderness character has been described in two dimensions representing orthogonal qualities of land (Fig. 2). One quality is based on the land's degree of human control, from completely trammeled to "self-willed." The other quality represents the degree of ecological condition or integrity, from novel and degraded to pristine (Aplet 1999; Aplet and Cole 2010). The dilemma of wilderness management (Cole 1996) recognizes that there is now—in an era of rapid change—often a tradeoff between freedom from control and ecological condition, as benign neglect may lead to a loss of ecological integrity. With respect to whitebark pine, two questions arise from this dilemma: 1) how do managers effectively restore whitebark pine when the proportion of stands in wilderness is relatively high and increasing? and 2) if conducting restoration within wilderness areas, how can we best restore the natural ecological condition of the land while respecting self-willed nature within wilderness?

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Nominations Needed for FOUR Board Positions

By Cyndi Smith, Associate Director

This next year will see some major changes in the leadership of the WPEF, with two of our original board members (Diana Tomback and Bob Keane), and another long time board member (Michael Murray), finishing their final terms as per the foundation's bylaws. We are now seeking nominations to fill the following positions on the WPEF board of directors (BOD):

- Director
- Secretary
- General Board Member
- General Board Member

These new members would start serving on the BOD in September, 2016. Nomination forms are available in this issue of Nutcracker Notes and on the Foundation's website … www.whitebarkfound.org, along with a list of responsibilities for each of the positions. Nominations close on 1 February 2016. Please consider running for one of these positions, or nominating someone else – all nominees must be (or become) members of the Foundation. Your active participation is critical to keeping the Foundation relevant to the general membership.

If you have any questions about any of the positions or the nomination process, please contact me at cyndi.smith9@gmail.com. Or use the form on page 33.

STUDENT RESEARCH GRANT

The mission of the Whitebark Pine Ecosystem Foundation (WPEF) is to "promote the conservation of whitebark pine and other high elevation five needle white pine ecosystems through education, restoration, management, and research." In support of this mission, the WPEF will be offering a research grant of $1000 to an undergraduate who is writing an undergraduate thesis or graduate student (MS or PhD) conducting research on whitebark pine.1 Relevant areas of research include, but are not limited to: threats to whitebark pine, including mountain pine beetle, white pine blister rust, successional replacement, and climate change (only in whitebark ecosystems); interactions with wildlife, such as Clark's nutcracker or other birds, red squirrels and grizzly bears; restoration strategies for whitebark pine, including both field operations and nursery seedling production; ecosystem level impacts of whitebark pine die off; and, social or policy aspects of whitebark pine decline and restoration, including wilderness issues.

Monies will only be awarded for travel expenses for field work, or consumable research supplies. Grants shall not be used to buy equipment that will be used beyond the duration of the project (and thus would be retained by the lab in which the student works).

Please submit a short (two single-spaced pages at most, not including references) proposal covering:

1. The purpose and need for the research
2. A brief description of the study plan and methods, including expected dates of data collection and writing completion
3. Expected outcomes of the research
4. A brief explanation of how the money will be spent
5. Contact information and academic affiliation of the student

Grant recipients are encouraged to present their research findings at a subsequent WPEF annual science meeting and are expected to publish a research summary in our bi-annual journal Nutcracker Notes. In addition to the proposal, applications should include a CV as well as a letter of recommendation from the student's research advisor. All applicants are encouraged to join WPEF and the grant recipient will receive a free subscription to Nutcracker Notes for one year.

Please send application materials (electronic only) to <Cyndi.smith9@gmail.com> by February 1, 2016.

Giants in Peril:
Whitebark pine decline continues in the Bob Marshall Wilderness

Molly L. McClintock Retzlaff
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Whitebark pine (*Pinus albicaulis*) plays a prominent role throughout high elevation ecosystems of the northern Rocky Mountains. It is an important food source for many birds and mammals as well as essential to watershed stabilization. Whitebark pine is vanishing from the landscape due to three main factors – white pine blister rust (*Cronartium ribicola*), mountain pine beetle (*Dendroctonus ponderosae*) outbreaks, and successional replacement by more shade-tolerant species.

The purpose of this study was to use voluntary public participation or "citizen science" (Bonter and Hockachka 2009) to re-measure plots initially established between 1990 and 1994 and determine changes in the status of whitebark pine populations over the last 20 years across parts of the Bob Marshall Wilderness Complex (BMWC), a large wildland preserve in northwest Montana (Keane and others 1994). The Keane and others (1994) original study intensively inventoried high elevation forests to develop a spatial classification of upper subalpine cover types and forest decline using satellite imagery and extensive plot sampling. In the summers of 2013 and 2014, staff and volunteers of the Bob Marshall Wilderness Foundation (BMWF) used protocols established by Keane and others (1994) to locate the original plots and then sample tree characteristics.

Forest Service personnel from the Rocky Mountain Research Station trained both the director and staff crew leader of the BMWF in a simplified sampling protocol designed to accommodate the lack of experience by volunteer crews. The methods of Keane and others

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Figure 1: Examples of visual changes on whitebark pine stands. (A) Whitebark pine re-growing after a wildfire. (B) Shade tolerant species replacing whitebark pine

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Banding a nestling. Photo credit Taza Schaming

had such low body stores that they chose not to or were unable to breed. During the two years with data on the breeding season adult body condition index, the average index was significantly lower in 2011, the nonbreeding year (-1.5 ± 1.1), as compared to 2012, the breeding year (6.2 ± 2.0). Breeding plasticity would enable Clark's nutcrackers to exploit fluctuating resources. However, declining whitebark pines could lead to an increase in nonbreeding years. An increase in nonbreeding years could have serious consequences for Clark's nutcracker populations and the whitebark pine-Clark's nutcracker mutualism.

Introduction

Life-history theory suggests that individuals can better exploit variable environments by reducing reproduction in poor years to increase survival and lifetime reproductive success [1]. Population-wide failure to breed may occur because reliable cues indicate that the environment will negatively impact reproductive success [2]. Alternatively, unfavorable prebreeding food resources or weather could lead to individuals having such low body stores that they skip a year before attempting to breed [3]. Climate change and declining forest health may increase instances of such large-scale failure to breed, contributing to population declines or local extinctions.

Clark's nutcrackers are a keystone species in the western U.S. because they disperse seeds for at least ten conifer species (see references within [4]). Because they rely on cached seeds from masting conifers for overwinter survival and reproduction, they have unusually accurate information about spring food resources prior to breeding [5]. Nutcracker populations have been reported to irrupt when cone crops fail, and some studies have suggested that Clark's nutcrackers forego breeding in years with low food [6,7]. My objective in the paper is to evaluate conditions contributing to Clark's nutcracker population-wide failure to breed.

Methods

Study site. Between 2009 and 2013, I studied Clark's nutcrackers in Bridger-Teton and Shoshone National Forests, and Grand Teton National Park.

Determination of population breeding status. At all times in the field, while radio-tracking and conducting surveys, I documented breeding activity, nest building and attendance, of both radio-tagged and unbanded nutcrackers. I also recorded all observed fledglings. I examined captured Clark's nutcrackers to document presence or absence of a brood patch.

Results

My field assistants and I spent 967 person-days in the field during the breeding and post-breeding seasons. I trapped and banded 155 adult nutcrackers. Between 2010 and 2012, I fit radio transmitters to and regularly tracked 76 adults. In 2010, I primarily triangulated

Table 1. Annual indications of Clark's nutcracker breeding.

Year	Fledglings seen on study area	% Trapped adults with brood patches	# Radio tagged observed to attempt breeding	# Active nests observed	# Active nest building observations, final nest not found	Dates nesting activities observed
2009	**No**	**0% (0/38)**	**NA**	**0**	**0**	**NA**
2010	Yes	40% (6/15)	13% (2/13)	2	0	Mar 17-May 4
2011	**No**	**0% (0/67)**	**0% (0/29)**	**0**	**0**	**NA**
2012	Yes	6% (4/65)	88% (30/34)	31	6	Mar 5—Jun 15
2013	Yes	None trapped	NA	0	0	NA

Nonbreeding years are in bold.

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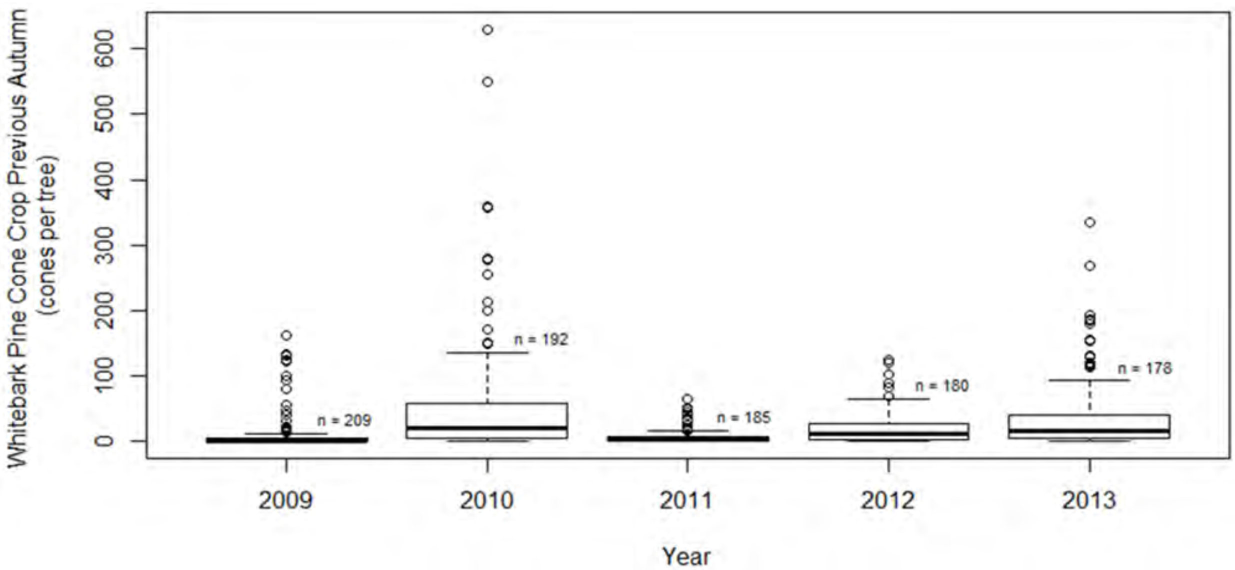

Figure 1. Whitebark pine cone crop in breeding (2010, 2012, 2013) vs nonbreeding years (2009, 2011).

radio-tagged individuals. In 2011 and 2012, I homed in on radio-tagged individuals an average of 19 ± 2 and 17 ± 1 days, respectively. In 2010 and 2012, I located a total of 33 active nests, and observed six additional building activities. Between 2009 and 2013, I conducted 1,066 thirty minute occupancy surveys at 247 point count locations. The study area was a mosaic of habitats, and I regularly worked in all six conifer habitats at the site.

During the five-year study, I did not observe any indications of Clark's nutcrackers breeding in the study area in two years, 2009 and 2011 (Table 1). The birds experienced large inter-annual variation in food availability and spring snowpack (Figures 1 and 2). The average whitebark pine cone crop was lower during the autumn prior to nonbreeding years. This is confounded by the fact that the average March snowpack was higher during the nonbreeding years.

The body condition index is considered the residuals of body mass regressed against tarsus, corrected for date. The adult prebreeding season body condition index did not differ significantly between breeding and nonbreeding years ($n = 43$; $t = 1.8$, $df = 29.7$, $p = 0.09$; Figure 3). In contrast, the adult breeding season body condition index was significantly higher in the breeding year ($n = 96$; $t = 3.4$, $df = 27.4$, $p = 0.002$).

Discussion

Strong evidence suggests that Clark's nutcracker did not breed population-wide within the study area in two of the five years of the study. The nonbreeding years followed autumns with low whitebark pine cone crops, and occurred during years with high spring snowpack. Low whitebark pine cone crops and/or lack of access to food caches due to high spring snowpack may have been cue(s) which allowed the birds to predict that breeding would be poor. As a result the birds skipped breeding. Alternatively, all individuals may have had such low body stores that they chose not to or were unable to breed.

Previous researchers suggested Clark's nutcrackers may skip breeding in years with widespread cone crop failure, but this is the first study to positively document it [7]. It is possible that the high snowpack caused nonbreeding. However, to my knowledge, there is no evidence which suggests that high snowpack would prevent Clark's nutcrackers from nesting in a given year. Instead, high snowpack seems more likely to influence when the birds can begin breeding [8]. Breeding plasticity could be an adaptive strategy for Clark's nutcrackers to maximize lifetime reproductive success while exploiting a variable environment.

The problem is that five-needled pines are rapidly decreasing, and this could lead to more years with poor food resources [9]. When there are fewer trees, even years with high numbers of cones per tree could be perceived as poor food years by Clark's nutcrackers. An increase in years with low cone crops could lead to an

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were obtained from the Moscow Forestry Science Laboratory (MFSL), Rocky Mountain Research Station (http://forest.moscowfsl.wsu.edu/climate/species/speciesDist/Whitebark-pine). MFSL provides current and future projections of predicted species' climate profiles as 'climate viability scores,' which range from 0 (climate inconsistent with species' presence) to 1 (climate consistent with species' presence). For data analysis we used a climate viability score ≥ 0.588 as our threshold for where whitebark pine presence is deemed likely (Crookston et al. 2010).

MFSL produced species viability scores for western North America tree species for future decades under various emissions scenarios and general circulation model predictions (Rehfeldt et al. 2006). MFSL provides projected viability distributions for 2030, 2060, and 2090; we focused on 2060 as a mid-range standard of comparison. Here, we compared shifts from predicted current distribution of whitebark pine to all seven projected distributions available from MFSL. Specifically, we used climate viability scores from the Canadian Center for Climate Modeling and Analysis (CGM) for scenarios A1B, A2, and B1; Geophysical Fluid Dynamics Laboratory (GFD) for scenarios A2 and B1; and Hadley Center/World Data Center (HAD) for scenarios A2 and B2. For one climate change scenario (CGM B1), we mapped "disappearing", "stable", and "novel" climate viability distributions with respect to wilderness.

Geographic distributions based on climate viability scores were imported into our GIS

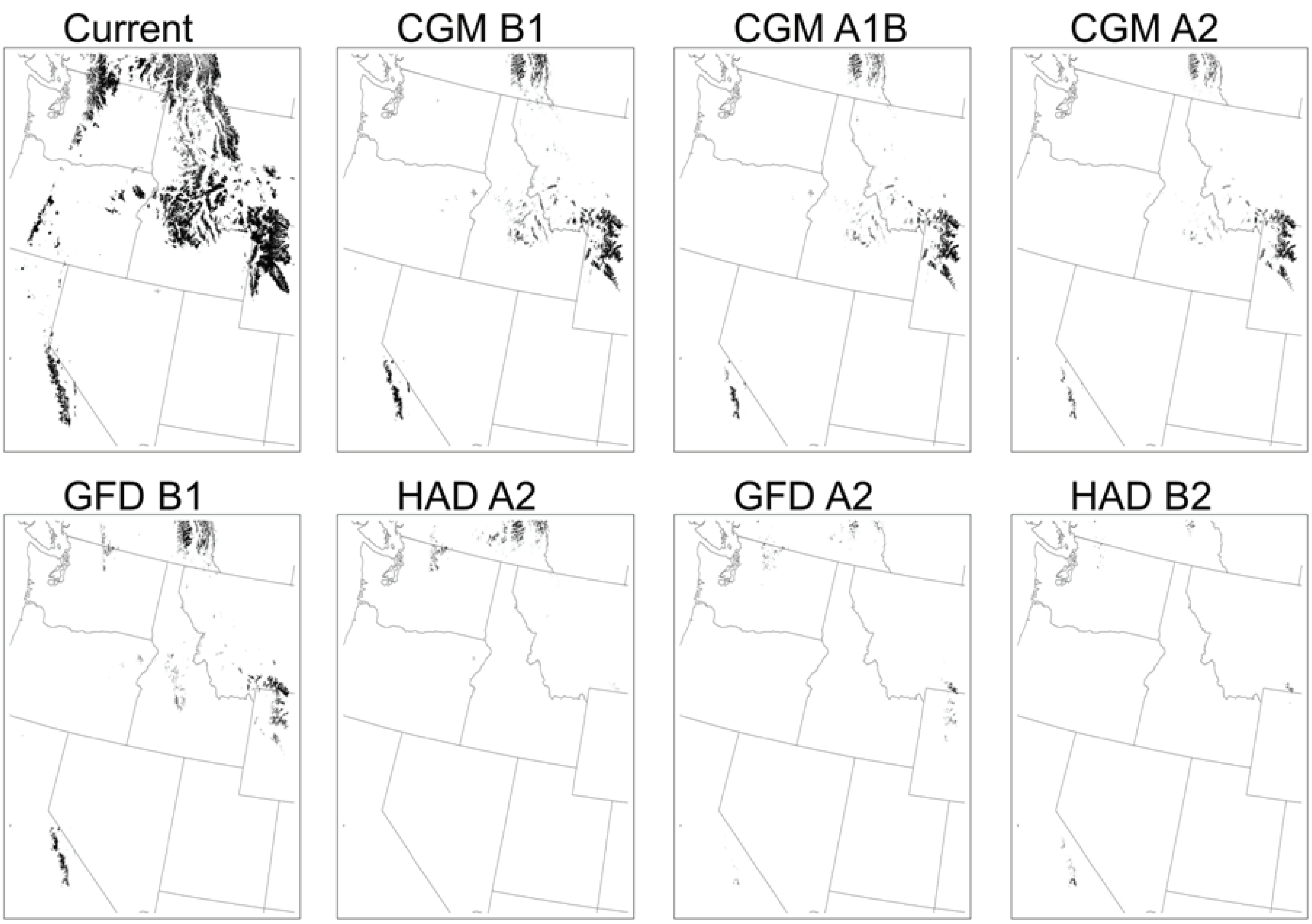

Figure 2. Predicting distribution of whitebark pine (black polygons) under current and projected future climate scenarios by 2060. See text for explanation.

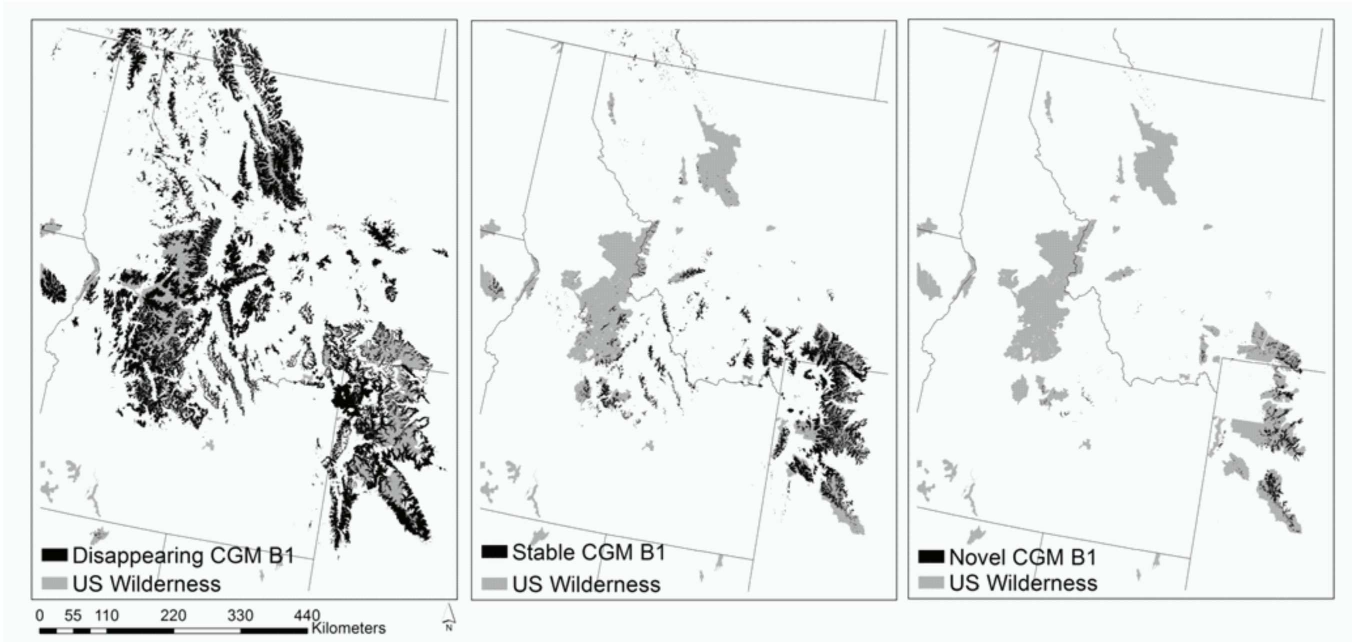

Figure 3. Disappearing ("here today, gone tomorrow" areas; left panel), stable ("here today, here tomorrow"; middle panel), and novel ("not here today, here tomorrow"; right panel) distributions of climate viability scores comparing current and future projections under the CGM B1 scenario mapped over existing wilderness areas. We focus on 'the best case scenario' (CGM B1) only as a demonstration of how considerations of disappearing, stable, and novel climate space can be evaluated.

and compared with "current" range maps of Little and Viereck (1971), which are digitally available through the USGS (1999). Climate viability scores predict presence of whitebark pine far outside the current range (e.g., in Colorado's San Juan Mountains). To reduce errors of commission, we buffered Little and Viereck's range maps by 100 km (to ensure we capture true presence along edges of the current range), and removed all predicted occurrences outside of this buffered range map.

Current and future climate viability scores of whitebark pine distributions were overlaid with land management records from the National Wilderness Preservation System (Wilderness Institute, 2015) to calculate the percent area in wilderness. We also overlaid these data with Environmental Protection Agency (EPA) Level III ecoregions (Omernik and Griffith 2014) to investigate patterns among broad ecological regions.

Results

The total area of predicted current distribution of whitebark pine's viable climate space (i.e., climate viability scores ≥ 0.588) in the U.S. is 11 million hectares, 39% of which occurs within 90 different wilderness areas. Whitebark pine's viable climate space is expected to contract by 2060, although the extent varies considerably among GCMs and emissions scenarios (Table 1; Figure 2). For example, the CGM model under a B1 emissions scenario predicts nearly an 80% reduction in the climate space for whitebark pine (from 11.0 to 2.2 million ha), whereas the HAD model under a B2 scenario predicts a 99% reduction (from 11.0 million to ~79,000 ha). While only 39% of the current whitebark pine distribution exists in wilderness, the projected reduction in climate space for whitebark pine results in an expected increase in the proportion of distribution within wilderness, ranging from 60% to 99% depending on GCM and emission scenario (Table 1).

The Middle Rockies, Central Basin and Range, and Sierra Nevada ecoregions to expect relatively less reduction in area of viable climate space for some GCMs and emission

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Climate projection	Outside Wilderness		Inside Wilderness		Total
Current	6,737,812	61%	4,301,303	39%	11,039,116
CGM B1	892,614	32%	1,354,436	68%	2,247,050
CGM A1B	568,964	40%	984,987	60%	1,553,951
CGM A2	356,925	37%	759,290	63%	1,116,215
GFD B1	255,513	28%	776,449	72%	1,031,962
HAD A2	16,883	25%	117,329	75%	134,213
GFD A2	24,912	13%	65,558	87%	90,469
HAD B2	1,101	1%	77,596	99%	78,696

Table 1. Total hectares and percent area in the contiguous US outside and within wilderness areas under predicted current climate space and seven global climate change models and emissions scenarios.

scenarios. All seven future climate models predict some whitebark pine distribution remaining in the Absaroka-Beartooth Wilderness, while six future models agree that that the range will persist in the John Muir, Sequoia-Kings Canyon, North Absaroka, Yosemite, Hoover, Ansel Adams, and Golden Trout Wilderness areas. In the worst case scenario (HAD B2), only 15 wilderness areas are expected to support climate space of whitebark pine, with most occurring in Sequoia-Kings Canyon, Absaroka-Beartooth, and the John Muir Wilderness.

Discussion

Climate change is expected to cause a reduction in viable climate space for whitebark pine across its range, resulting in significant declines in area of distribution irrespective of GCM or emissions scenario. This reduction in climate space might be associated with higher mortality and lower recruitment rates, but it might not result in the complete extirpation of whitebark pine implied by the maps in Figure 2. In other words, estimates of whitebark pine's distribution are based only on modeled climate space and might not reflect actual occupied habitat.

Our estimate of the current proportion of whitebark pine's distribution occurring in wilderness (39%), based on climate viability scores, nearly matches the 40% estimate made by Tomback (2014) and is slightly lower than estimates of Keane (2000) based on extant range. Keane et al. (2012) argue articulately for range-wide restoration of whitebark pine and stress the importance of management to its conservation, including the potential need for active manipulation of whitebark pine stands in wilderness to preserve the species and supported ecosystems. The relatively high proportion of whitebark pine's distribution in wilderness has – in some cases – left some managers feeling they have no choice but to compromise the untrammeled character of wilderness in order to sustain the species (e.g., USDA Forest Service, 2013).

Actively manipulating ecological structure, composition, or function in whitebark pine stands within wilderness presents potential tradeoffs between the untrammeled qualities of wilderness and ecological conditions (Tomback 2014), and climate projections suggest that as its range shrinks, whitebark pine will become progressively concentrated in wilderness areas, likely resulting in intensified calls for manipulation. Rather than stoking conflict throughout the range of whitebark pine, though, our projections may point to solutions for wise management. Rather than investing in whitebark restoration in areas where a suitable climate will disappear, management may be better focused where a viable climate will persist.

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By Ben Wilson

(1994) were streamlined so that only sapling and tree data (species, status, health) were remeasured to make it easier for BMWF crews to accurately assess rates of decline. The BMWF staff then trained and supervised volunteers in data collection throughout the two summers with help from the authors. The data were summarized by identifying the total number of both live and dead whitebark pine sampled at each plot in 1994 and again in 2014. These numbers were then used to calculate mortality estimates (number, density, percentages). Mortality by agent was determined from detailed notes recorded by field crews. A two-tailed T-test was used to determine if the changes were significant.

Only 25 of the original 116 plots were visited because of time and access challenges, but the BMWF crews measured characteristics of 570 mature trees, with over 180 being mature whitebark pine trees. Of the whitebark pine trees measured, 156 of the trees were dead and only 33 were still alive. The BMWF-sampled stands consisted of mature but scattered whitebark pine, subalpine fir, and occasional Engelmann spruce with an understory almost entirely of subalpine fir (Figure 1). A total of 411 whitebark pine trees (365 live, 197 dead) were measured by Keane and others (1994) on the same 25 plots, but in 2013-2014, BMWF crews measured only 265 by (46 live, 219 dead) (Table 1) It is assumed that 319 live trees died and 100 snags fell over the 20 years.

Whitebark pine attribute	1994	2014	% change
Live tree density (t ha^{-1})	365	46	-87*
Dead tree density (t ha^{-1})	197	219	+11
Percent mortality (%)	35	83	+137*
Healthy trees (t ha^{-1})	22	7	-68
Live but damaged trees (t ha^{-1})	343	39	-89*
Mortality by agent (%)			
Whitepine blister rust (t ha^{-1})	63	13	-79*
Mountain pine beetle (t ha^{-1})	3	10	+233**
Wildland fire (t ha^{-1})	5	12	+140**
Unknown (t ha^{-1})	29	65	+124*

*Indicates significance ($p \leq 0.05$)

Table 1: Summary and comparison between 1994 and 2014 of the proportion of live and dead whitebark pine trees affected by health and mortality factors on the 25 plots in the Bob Marshall Wilderness Complex. Only data from mature whitebark (>10 cm DBH) were used for the calculations. The total numbers of dead and live trees in 1994 and in 2014 do not match because of snagfall from fires, wind, and other factors. Healthy is defined as a tree with no crown damage from blister rust. Unknown mortality agents increased because BMWF crews were inexperienced at determining cause of dead of whitebark pine trees.

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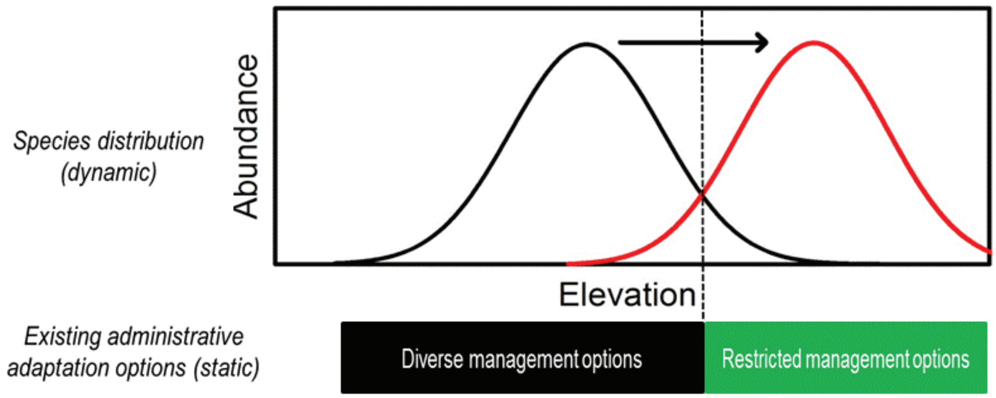

Figure 1. In the western United States, climate change may push many species' distributions higher in elevation as temperature rises and individuals shift to cooler, more suitable habitats. In many areas, this dynamic response to climate change will result in an increase in the overlap with management zones, such as wilderness, where climate adaptation and restoration options become more restricted. The curves represent current (left) and projected future (right) species' distributions that occur on lands with permissive and restrictive management options. The vertical dashed line represents the divide between management zones to illustrate how the distribution of a species occurring within each zone may shift with climate change.

Decision framework for restoring whitebark pine

Whether the stand is inside wilderness or not, the first step is to decide if restoration action is actually necessary. Do we have monitoring data to show that the condition of the stand in question is improving, stable, or deteriorating? Often, when faced with ambiguous situations, managers exercise "action bias" even though every effort to restore landscapes has an inherent impact, irrespective of its potential efficacy. If restoration is deemed to be necessary, then managers should determine if there is an acceptably high probability that restoration will increase the survival or regeneration of whitebark pine.

Next, managers should consider the potential effectiveness of passive, instead of active, restoration. Passive restoration has little impact on the land's self-willed nature and may, in some circumstances, actually increase untrammeled character. Are there stressors on the landscape that are negatively impacting whitebark pine? Managers should assess the full range of activities occurring on the landscape to determine if removing stressors will have a positive (and sufficient) impact on whitebark pine stands. Livestock grazing, off-highway vehicles, and natural resource extraction, for example, may be impeding regeneration or altering soil characteristics. Restoring natural fire to the landscape—through wildland fire use—may also be an effective passive restoration tool.

If it is determined that active restoration is, indeed, needed and will be effective, managers should consider starting with restoration of whitebark pine stands that are not in designated wilderness areas. Here, there is less concern with preserving untrammeled condition, and a greater array of restoration options will be available. Despite the large proportion of whitebark pine stands in wilderness, there are currently over 6.7 million hectares of potentially viable whitebark pine habitat outside of wilderness areas (Belote et al., this issue). Managers should ask if there is currently enough restoration funding to even conduct restoration in all non-wilderness areas? Restoration work in non-wilderness areas may also impact wilderness positively or negatively, and this should be considered in deciding where to work. For example, planting rust-resistant seedlings on the edge of wilderness will almost certainly impact the future genetic composition of the adjacent wilderness stand.

If all of these options are exhausted and/or if there is a compelling reason to conduct restoration locally in wilderness (the stand in wilderness is essential for the survival of an endangered species or there is a threat of local extirpation, for example), then managers should evaluate various restoration activities in light of the tradeoff between ecological condition and untrammeled condition. The goal should be to improve ecological condition to the greatest degree possible while simultaneously limiting human control as much as possible (Fig. 3).

The degree of management can be measured in terms of how intrusive the action is and the time (or number of treatments) it takes to complete the action. For example, passive restoration—such as wildland fire use (Fig. 3, point A) or removal of non-native ungulates—would occur only once and would actually increase freedom from control. A small number of treatments of prescribed fire, for example, would be considered a relatively non-invasive, acute (or "pulse") action (point B). Planting rust-resistant pines over several field seasons may also fall into a similar category (point C). Mechanical thinning with powered tools every year, for 20 years, would be considered a relatively intrusive, chronic (or "press") action (point D). And finally, building temporary roads for management access would be considered a highly intrusive management action (point E). On the ecological benefit axis, ecologists should agree upon consistent metrics to determine the relative benefit (or cost) to whitebark pine survival or regeneration. Actions in the upper right of the graph would be preferable to those in the lower left; that is, they are most "efficient" with respect to the tradeoff between freedom from control and ecological condition. The restoration action can then be viewed in terms of the original axes of wilderness to determine whether there is a net increase or decrease in wildness.

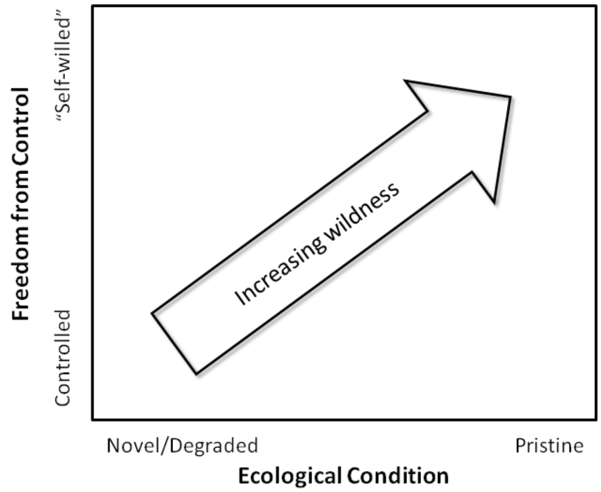

Figure 2. A conceptual model that arrays landscapes along two axes, from controlled to self-willed and from novel to pristine (modified from Aplet 1999). The wildest areas are in the upper right corner.

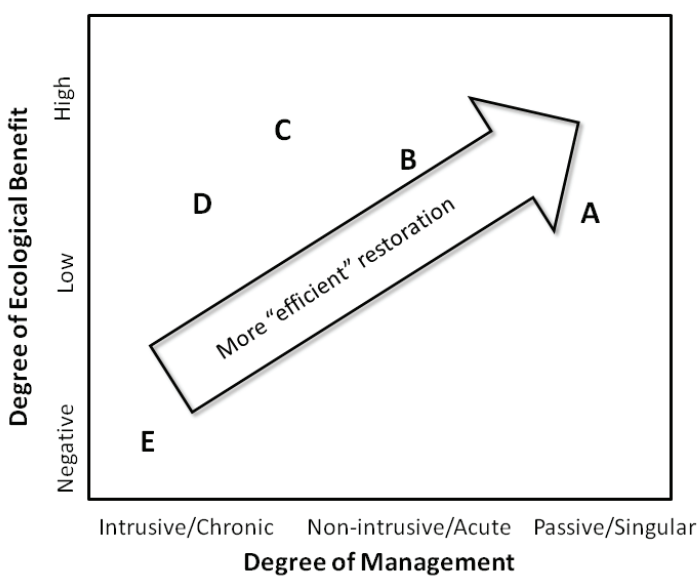

Figure 3. A conceptual model that illustrates the degree of management versus the degree of ecological benefit for various restoration projects. The degree of management is on a decreasing gradient of impact, from most intrusive and chronic to non-intrusive and acute to passive and singular. The degree of benefit is on an increasing gradient from negative benefit to low benefit to high benefit. Points A-E represent various theoretical restoration activities and their positions on the graph (A=single wildland fire use; B=prescribed fire over two seasons; C=planting rust-resistant pines over 3 seasons; D=mechanical thinning with powered tools over 20 years; E=building temporary roads for management access).

In conclusion, whitebark pine serves as an illuminating case study representative of conservation challenges in the era of climate change, especially in lands set aside to limit human control of nature. Whitebark pine and the ecosystems it supports face numerous challenges. We believe the conservation community should not stand idly by and watch species go extinct, but we also recognize the value in some places, especially in wilderness, of allowing nature to respond to environmental challenges without human intervention. We believe the framework presented here strikes a delicate balance in explicitly recognizing and addressing tradeoffs between values of ecological condition and self-willed nature. However we respond to climate change and declining abundance of key

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FRAMEWORK continued from previous page

species, we should intervene with humility and a commitment to actively learning as we attempt to minimize our intrusion in wilderness landscapes while maximizing our ability to keep all.

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On Vasiliki Ridge in the Methow River Drainage, North Cascades. By Cliff Schwab

An unexpected growth response in whitebark pine seedlings colonized with ectomycorrhizal fungi in the greenhouse

(and a mystery perhaps you can help us solve)

By Cathy Cripps and Marlee Jenkins

We have been examining how inoculation with native ectomycorrhizal fungi (ECF) in the greenhouse affects the survival of whitebark pine seedlings after out-planting. Native fungi, mostly *Suillus* species, are gathered in whitebark forests (Cripps & Antibus 2011, Mohatt et al. 2008) and fruiting bodies (mushrooms) are processed into spore slurries (Cripps & Grimme 2011). Spores are added to seedlings (3-5 million/seedling) in the greenhouse and several weeks are allowed for colonization to take place under a low nitrogen fertilizer regime (Lonergan & Cripps 2013). In a recent field study, out-planted seedlings inoculated with native fungi had a 15-18% higher survival rate after three years on burn sites compared to non-inoculated seedlings; this suggests that inoculation with native ECF has the potential to increase early seedling survival on certain sites (Cripps et al. 1014, Lonergan et al. 2014).

All of the seedlings are grown at the Forest Service nursery in Coeur d'Alene, Idaho. We also acquire seedlings from the same nursery for research to be conducted in the Plant Growth Center at Montana State University. In 2014 and 2015 we picked up nursery seedlings and brought them back to MSU for greenhouse experiments. During pre-screening, it was observed that over half of seedlings were already well colonized by ectomycorrhizal fungi. This level of infection is usually a warning signal that unwanted nursery fungus such as *Thelephora* are present, but these did not look like *Thelephora* ectomycorrhizae.

Seedlings were separated into two groups (colonized and uncolonized) and it appeared that seedlings colonized with EMF were larger and greener. An early growth response to colonization by EMF is not expected for this slow-growing pine species. Our research focuses on survival in the field, not on producing larger seedlings in the greenhouse. However, this unexpected response could not be dismissed. To confirm visual observations, total biomass and nitrogen content in needles were measured and compared for a sampling of colonized and uncolonized seedlings. Heavy colonization was noticed in two seed lots that arrived at MSU (2014, 2015); here we report results from a preliminary study of the 2014 seedlings. Morphological observation of the ectomycorrhizae on the roots and molecular analysis of their ITS region were used to determine the identity of the fungi---and this is where the mystery comes in.

Methods

The 190 cone-tainerized whitebark pine seedlings were approximately 1.5 years old when they were transferred from the Idaho nursery to the MSU Plant Growth Center in September 2014. At transfer, significant ectomycorrhizal colonization was noted by the Idaho nursery crew. Seedlings were not inoculated with EMF while at MSU and were not in contact with any colonized seedlings during this time. Twelve seedlings (6 colonized and 6 un-colonized) were selected for destructive analysis and assessed for: percent mycorrhizal colonization, total biomass/dry weight, and foliar nitrogen content. Foliar nitrogen was determined by combustion analysis using a LECO FP-528 Nitrogen/Protein Analyzer. Statistical analysis was performed using a non-parametric Wilcoxon Rank-Sum test in statistical program R.

Morphotypes of ectomycorrhizae were described in general terms. DNA was extracted from fresh and tissue-cultured mycorrhizae using a Qiagen DNeasy Plant Mini Kit; amplification and purification of the ITS region with PCR was performed using a Qiagen QIAquick Kit. Successful samples were sequenced at the Berkeley DNA Sequencing Facility, edited and aligned using SeqTrace software and results were blasted using NCBI Blast (blast.ncbi.nlm.nih.gov) for best species matches to identify the ECF.

Results

Seedlings in the un-colonized group were less than 1% colonized and seedlings in the colonized group were 10 – 30% colonized with EMF. On average, seedlings colonized with EMF had a 68% greater the biomass and 66 % higher total foliar nitrogen content (Figs. 1, 2). Wilcoxon Rank-Sum tests showed that colonized seedlings had a significantly higher biomass ($P = 0.015$)

MYSTERY continued on page 19

Pacific Coast States Host th

Fun on the bus en route to one of the field trips.

The workshop ended with a field trip to C
discuss the status of whitebark pine and the
with Park Botanist Jen Beck.

By Kristen Chadwick

The 2015 Whitebark Pine Ecosystem's Annual Science and Management Workshop was held in Ashland, Oregon September 17th-19th at Southern Oregon University in the Meese Auditorium. This was the first time the workshop has been held in the Pacific Coast States. The board of directors met on Thursday, September 17th at the Rogue River-Siskiyou National Forest Supervisor's office. The indoor session was kicked off by an evening session on the 17th which was open to the public with WPEF Director, Diana Tomback; US Forest Service Plant Pathologist, Kristen Chadwick; and Crater Lake National Park Botanist Jen Beck, highlighting ecology and threats to whitebark pine throughout its range, in Oregon and Washington, and at Crater Lake National Park.

The community welcomed the WPEF and highlighted the Foundation and whitebark pine with an interview on Jefferson Public Radio's Jefferson Exchange program with Diana Tomback, Jen Beck, and Kristen Chadwick. The interview can be found at: http://ijpr.org/post/why-whitebark-pines-are-so-important#stream/0

The main indoor session was September 18th with the workshop presenters highlighting all of the high elevation five needle pines in panels focused on Regional Updates and Status; Inventory and Monitoring; Ecology, Restoration, and Resistance; and Genomics and Landscapes. The workshop started with two keynote addresses. Diana Tomback provided the foundation on the unique ecology of the high elevation five needle pines, their geographic distributions, and the threats they face. Sam Friedman, Botanist with the US Fish and Wildlife Service, gave the second keynote focusing on the listing status and process with USFWS over the next few years.

A few highlights of the presentations that followed include: Anna Schoettle presented on a proactive strategy of integrating white pine blister rust resistance into an ecological context to inform management decisions for limber pine and Rocky Mountain bristle cone pine; Richard Sniezko presented on white pine blister rust resistance breeding programs and challenged people to know and understand the data behind the analysis and the types of resistance; Barbara Bentz presented results on the vulnerability of Great Basin bristlecone pine and foxtail pine to mountain pine beetle; and Danny Cluck presented on the California Warner Mountains and the status of whitebark pine post-mountain pine beetle outbreak.

e WPEF 2015 Annual Meeting

Crater Lake National Park to view and
e unique restoration program at the Park

Panel discussion at the indoor session.

Inventory and monitoring presentations were given by Erik Jules on modeling population dynamics in whitebark pine populations; Jonny Nesmith on white pine blister rust spread on high elevation five-needle pines in the southern Sierra Nevada mountains; Michael Kauffmann on the status and distribution of whitebark pine in Northern California; and Greg DiNitto on the High-5 Database

.

The indoor session wrapped up with a panel on genomics and landscapes. Andrew Eckert presented on the genomic landscape of water use efficiency for foxtail pine and on the genetic architecture of survival-related traits for whitebark pine at fine spatial scales-an example from the Lake Tahoe Basin. Uzay Sezen presented on comparative transcriptomics of four white pines. Zolton Bair presented on his work finding candidate genes associated with blister rust resistance in whitebark pine.

Overall, discussions following presentations and panels focused on the complexity of restoring these high elevation species in wilderness areas, challenging planning rules, understanding the genetic material available for restoration plantings, and a discussion on what is needed for the next steps in the genomics work. Robyn Darbyshire, Regional Silviculturist for Region Six, wrapped up the indoor session by summarizing the talks, discussions, and some insight on where to go from here.

The indoor session was followed by an evening social, silent auction, and poster viewing.

Presentations for the keynotes and the four panels can be viewed at:

Part 1: http://www.ustream.tv/recorded/73516216
Part 2: http://www.ustream.tv/recorded/73524273
Part 3: http://www.ustream.tv/recorded/73531584
Part 4: http://www.ustream.tv/recorded/73538089

Many presenters have also given permission for the Foundation to post their presentations on the website at http://whitebarkfound.org/.

Several field trips were available to those that attended. Tours of the Forest Service's Dorena Genetic Resource Center in Cottage Grove, Oregon were optional as people traveled to Ashland. 'Genetic resistance to blister rust in white pine species of North America'. Dorena GRC is a recognized world leader in developing populations of trees with genetic resistance to non-native pathogens such as *Cronartium ribicola* and *Phytophthora lateralis*. High

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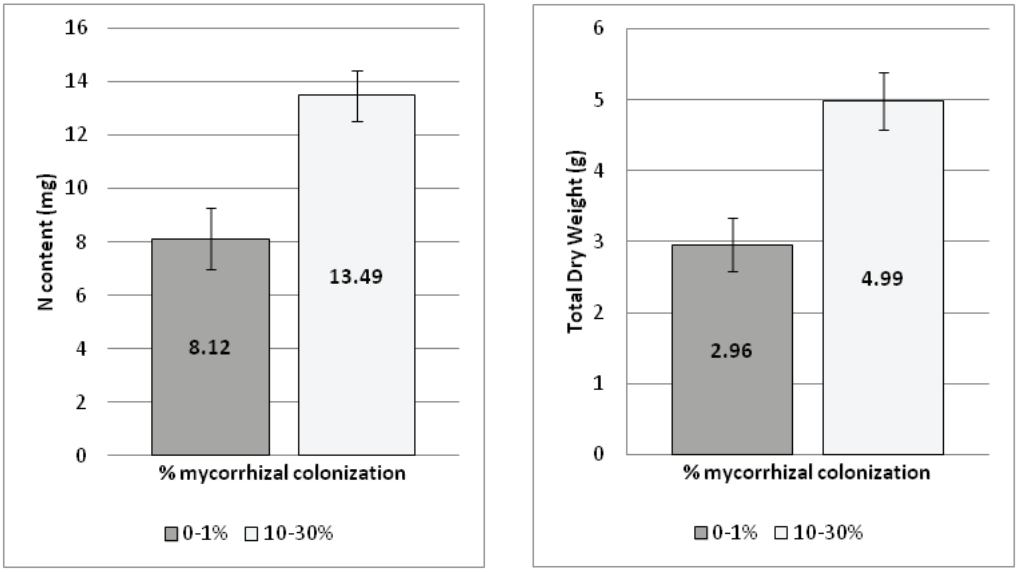

Figures 1 and 2 - On average, seedlings colonized with EMF had a 68% greater the biomass and 66 % higher total foliar nitrogen content.

and foliar nitrogen content (P= .0086, with one outlier excluded).

A majority of ectomycorrhizae possessed the *Suillus* 'hand-type' morphology, and very few were thelephoroid and *Cenococcum* types. Molecular analysis picked up *Suillus tomentosus* variety *discolor* in four blast matches, *Suillus sibiricus* in two, and *Thelephora terrestris* in one confirming that these species were present in the nursery seedlings. From morphology and molecular analysis, we conclude that almost all ectomycorrhizae were of the suilloid type, and were species native to whitebark pine forests (Fig. 3).

Discussion and the Mystery

Only a few seedlings were sampled in this preliminary study and a larger study is underway. However, we felt results were interesting enough to report quickly, and we also wanted to present a mystery to solve. Our results show a higher foliar nitrogen content and higher biomass in seedlings that were 10% to 30% colonized by ectomycorrhizal fungi, most of which were suilloid fungi, in comparison to non-colonized seedlings. This suggests that these colonization rates may be effective for enhanced N acquisition at least in the greenhouse. It also implies that seedlings colonized with ECF grew faster resulting in a lower foliar nitrogen concentration (dilution effect), but that they had a higher total nitrogen content overall per seedling due to higher biomass. An early growth response to ECF is not expected for this slow-growing pine; in fact, initial carbon drain to the fungus often retards early growth of seedlings being colonized by ECF. Results also suggest that colonized seedlings could have an advantage when out-planted in the field because of higher biomass and N content. Indeed, Heumader (1992) found that cembran pines (European stone pines) with ectomycorrhizae had more nitrogen than those lacking them.

Now for the mystery. We were stunned to find the same species of suilloid fungi on un-inoculated seedlings from the Idaho nursery that we collect in whitebark pine forests and use for inoculation of whitebark pine seedlings (Cripps and Grimme 201, Lonergan and Cripps 2013). These EMF are specific for five-needle pines. The seedlings were already colonized when we received them, and a growth response takes time, so we suspect seedlings were well colonized at the Idaho nursery. But where did they come from? We know the nursery is surrounded by western white pine which can host at least Suillus sibiricus --is it possible spores blew into the nursery? We know seedlings are tested in the field at the nursery and

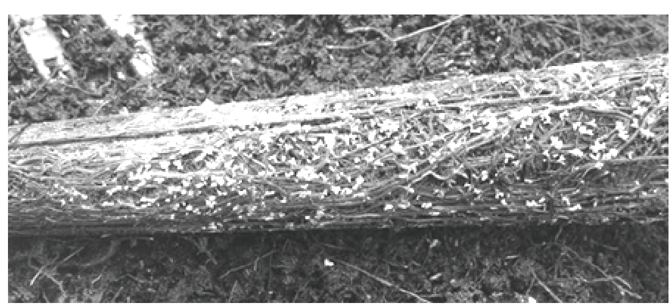

Figure 3 - Almost all ectomycorrhizae were of the sulloid type.

2016 Whitebark Pine Ecosystem Foundation Science and Management Conference

By Melissa Jenkins, 2016 Science Conference Committee

One of the biggest successes of the WPEF is the annual "Science Conference". In 2016, the conference will be held on September 16th and 17th in Whitefish, Montana. A committee of folks including Melissa Jenkins, Bryan Donner, Karl Anderson, Jen Asebrook and Vita Wright are organizing a great event.

The indoor presentations on Friday will be held at the world class O'Shaughnessy Center in downtown Whitefish, MT (www.whitefishtheatreco.org). There will be field trips on Saturday and Sunday to Whitefish Mountain Resort and Glacier National Park.

A presentation on the "Whitebark Friendly" ski area certification process, a tree climbing/cone collection demonstration and opportunities to view 5-needle pine trees in the stunning setting of Glacier National Park will make the 2016 WPEF Science and Management Conference an unforgettable event. We hope to see you there!!!

that they could pick up native fungi, but these would be unlikely to fruit and be a spore source. Could spores have been brought in with cones or other material from 5-needle pine forests (branches for grafting)? What about Insects or small mammals? We visited the Idaho nursery and found lots of Suillus sibiricus fruiting in the 'western white pine cone orchard' there---this could be another source of the unknown inoculum. Let us know your thoughts on this mystery!

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Touring in the field.

lights included seeing perhaps the largest inoculation chamber anywhere in action and took place during the 4 weeks of white pine blister rust inoculation trials. All 9 species of white pines native to the U.S. and Canada are involved in rust testing at the Center, including large scale screenings of whitebark pine, western white pine, southwestern white pine, sugar pine, and limber pine. Smaller efforts with foxtail pine, eastern white pine, and the two bristlecone pine species are ongoing.

Visitors were be able to see both the major gene resistance and the mainline multi-trait rust screening, and get detailed information on genetic resistance, including cautions about over-extrapolation of results and how inoculum level impacts resistance levels. Participants were also able to visit BLM's Tyrrell orchard complex where whitebark pine and western white pine (WWP) field trials for resistance are established with some of the most resistant seedlots known.

The WWP field trial is heavily infested with white pine blister rust, easily accessible from the road, and provides perhaps the most vivid contrast of a susceptible seedlot with those with either major gene resistance or partial resistance. This site provided is a unique opportunity look at and discuss resistance in the field, its utility, and its limitations as well as the relationship between seedling artificial inoculation trials and actual field results, including the question of durability of resistance.

A field trip was led by Michael Kauffmann of the California Native Plant Society to the Crater Creek Research Natural Area in Northern California to view foxtail, whitebark, and western white pine.

The workshop ended with a field trip to Crater Lake National Park to view and discuss the status of whitebark pine and the unique restoration program at the Park with Park Botanist Jen Beck. CLNP welcomed us by granting permission for the bus to drive the rim on a weekend which was closed to vehicles. Since 2002, Crater Lake National Park has been active in collecting cones, testing for resistance to white pine blister rust, applying verbenone treatments for mountain pine beetle prevention, and conducting restoration plantings. All the restoration plantings have genetic identities of the seedling families noted and will be monitored overtime. The planting at the Rim Village site is ADA accessible and seen by 100,000's of visitors a year. The seedlings there are growing well, and blister rust has now made an appearance. Attendees were able to see some of the impacts of mountain pine beetle, white pine blister rust, and dwarf mistletoe in whitebark pine, as well as whitebark pine restoration plantings.

Many thanks for additional support to make this meeting a success which was provided by the Klamath Inventory and Monitoring Network, Crater Lake Institute, USDA-FS Forest Health Protection, and Crater Lake National Park.

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Overall, live tree density (t ha-1) of whitebark pine trees decreased by 87% between 1994 and 2014 (Table 1). WPBR was responsible for the majority of the additional whitebark pine mortality; it was present in all of the BMWF plots that contained mature whitebark pine. In the original 1994 sample, 63% of live, mature whitebark pines were infected with blister rust. In 2014, only 13% of live mature whitebark pine trees were visibly infected with WPBR; rust-caused mortality decreased by 79% over the same time period. This suggests that many of the originally sampled whitebark pine trees died from blister rust between 1994 and 2013. It also suggests that there appears to be some level of rust-resistance in the living populations.

In 1994, only 1% of living whitebark pine trees showed insect damage. However, mountain pine beetle attacks were observed in eight of the plots measured in 2014, affecting over 50% of the mature remaining whitebark pine. Over the same time period, beetle-caused mortality increased from 3% to 10% (Table 1). Recent fires had burned parts of eight of the 25 BMWF plots and accounted for 12% of the total whitebark pine mortality. In the original 1994 study, only two of the 116 plots were affected by fire, accounting for only 5% of total mortality (Table 1).

The findings of this citizen-science re-measurement effort indicate that whitebark pine mortality has more than doubled across the BMWC over the last 20 years, primarily as a result of blister rust infection, and to a lesser extent from mountain pine beetle and wildfire. Regeneration of whitebark pine may be reduced as the number of mature cone-bearing trees continues to dwindle; this may lead to an overall change in stand structure throughout the BMWC as faster growing, more shade tolerant species become dominant.

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The effects of seed source health on whitebark pine (*Pinus albicaulis*) regeneration density after wildfire

Signe B. Leirfallom, Robert Keane, Diana F. Tomback, Solomon Dobrowski

Introduction

Invasive disease, native pest outbreaks, and fire suppression practices have resulted in major losses of whitebark pine across much of its range. Due to high levels of mortality in cone-bearing whitebark pine, managers are concerned that seed production may not support natural regeneration after disturbance such as wildfire. Several studies have explored factors that influence whitebark pine seed dispersal and seedling recruitment after fire (Tomback et al. 1993; Perkins 2004), but none have quantified the relationship between seed source health and whitebark pine regeneration density in burns. The objective of this study was to examine this relationship by evaluating natural whitebark pine regeneration in burns across Montana, given varying levels of damage and mortality in nearby seed sources.

Whitebark pine regeneration depends upon where Clark's nutcrackers cache seeds and the suitability of the cache site for seed germination and seedling establishment (Tomback 2001). Because nutcrackers often cache seeds several kilometers away from a seed source, whitebark pine is often one of the first trees to colonize large, stand-replacing burns (Tomback et al. 1990; 1993; 2001b). Burned areas tend to promote conditions favorable for whitebark pine germination and establishment. They provide ground features that protect young seedlings from environmental exposure (Tomback et al. 1993; Lonergan et al. 2014), reduced litter cover (McCaughey and Weaver 1990), higher levels of soil nutrients (Perkins 2004), and reduced competition from other conifer species that are physiologically less tolerant of exposure (Maher and Germino 2006; Bansal et al. 2011). Evidence suggests that whitebark pine seedlings experience higher growth and survival rates in burns as opposed to closed canopy forests (Perkins 2004; Izlar 2007; Tomback et al. 2011; Lonergan et al. 2014). Therefore, fire is often favorable and even necessary for the long-term development of whitebark pine forest communities (Keane et al. 2012).

Figure 1. Map of study region showing the location of 15 study areas across Montana, USA. Shaded areas indicate National Forest; the Continental Divide is shown for reference.

Recently, there has been concern among land managers that high-elevation burns are actually detrimental to certain populations of whitebark pine (Keane et al. 2012). If a seed source adjacent to a burn produces few cones because mature trees are damaged or dead, Clark's nutcrackers may not utilize the seed source, or much of the available seed could be consumed by birds and mammals, resulting in low whitebark pine regeneration densities (McKinney and Tomback 2007; McKinney et al. 2009; Barringer et al. 2012). Managers need to know whether or not sufficient natural regeneration in a burn will occur. This information can be used to refine restoration efforts and help managers make decisions about which high-elevation burns should be prioritized for planting rust-resistant seedlings.

In this study, we evaluate natural whitebark pine regeneration patterns following wildfire in the US northern Rocky Mountains. It builds upon preliminary work completed by Tomback et al. (2008) in four burns in or near the Bob Marshall Wilderness Complex, Montana. In 2010-2013, we sampled eleven additional burns. The central objective of the study was to examine the effect of seed source health (considering factors such as white pine blister rust infection and outbreaks of mountain pine beetle) on regeneration density in large burns of the northern Rocky Mountains. In addition, we evaluated site conditions within the burns that may have influenced whitebark pine seedling establishment; those results are described in Leirfallom et al. (in press).

Methods

Study areas

We sampled regeneration and seed source health in 15 burns, ranging from five to 23 years old. All study areas were located in Montana, and ranged geographically from the Flathead National Forest in the north to the Gallatin National Forest in the south (Figure 1; Table 1). Study areas were identified using GIS analysis and the expertise of local land managers and met the following criteria: (a) burned terrain within the elevational range of whitebark pine, (b) burns that were at least five years old to accommodate delayed germination, (c) terrain burned by a stand replacement fire greater than 100 ha, and (d) burned area adjacent to an unburned forest that contained seed-producing whitebark pine trees at the time of the fire. We attempted to sample across a broad range of seed source health conditions, from relatively intact stands to highly impacted stands. Each study area had two distinct sampling components. The “seed source” component refers to a patch or stand of mature trees adjacent to or within each sampled burn. The “burned area” component refers to the sampled portion of the burn, adjacent to the seed source(s), and meeting the criteria described above.

Seed Source Sampling

Sampling methods were tailored to the unique objectives of each sampling component. Seed source stands were sampled using fixed-area (0.04 ha), circular plots (11.28m radius). Seed source plots were located along a transect parallel to and approximately 100 m from the edge of the burn (Figure 2). We used FIREMON methods (Lutes et al.

Table 1. Summary of subalpine burns in Montana sampled for this study.

Burn Name	Year Burned	Size of Burn (ha)	Study location (Montana, USA)
Ann	1994	1,265	Bitterroot National Forest
Beaver Creek	2000	4,323	Gallatin National Forest
Bighorn Lake	1988	80,961	Scapegoat Wilderness Area, Helena National Forest
Challenge Creek	1998	3,846	Flathead National Forest
Charlotte Peak	1985	2,385	Bob Marshall Wilderness Area, Flathead National Forest
Fall Fork	2000	850	Anaconda – Pintler Wilderness Area, Beaverhead-Deerlodge NF
Gates Park	1988	22,093	Bob Marshall Wilderness Area, Lewis and Clark National Forest
Helen Creek	1994	2,846	Bob Marshall Wilderness Area, Flathead National Forest
Monitor Mtn	1988	80,961	Scapegoat Wilderness Area, Lewis and Clark National Forest
Monture	2000	9,624	Bob Marshall Wilderness Area, Flathead National Forest
Mussigbrod	2000	11,178	Anaconda - Pintler Wilderness Area, Beaverhead-Deerlodge NF
Pettengill	2007	6,192	Beaverhead-Deerlodge National Forest
Red Owl	1984	591	Flathead National Forest
Skalkaho	2000	3,027	Bitterroot National Forest
Wyman	2007	14,374	Beaverhead-Deerlodge National Forest

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Table 2. Summary of linear regression models for the mean whitebark pine regeneration density (seedling clusters ha^{-1} yr^{-1}) among 15 burn study areas in Montana, USA; WBP refers to whitebark pine, SAF refers to subalpine fir, BA refers to basal area (m^2 ha^{-1}). Final model is in bold; also shown are correlations between measures of seed source health.

Model Predictor Variable(s)	Coefficients	SE	R^2	*P*-value
Healthy WBP BA (m^2 ha^{-1})	1.397	0.60	0.25	0.037*
Healthy+unhealthy WBP BA (m^2 ha^{-1})	0.998	0.53	0.16	0.085
Dead WBP BA (m^2 ha^{-1})	-1.014	0.86	0.02	0.262
Mean WBP crown kill (%)	-0.889	0.23	0.48	0.002**
Ratio of live SAF BA to live WBP BA (m^2 ha^{-1})	-9.789	7.39	0.07	0.218
%healthy WBP	0.850	0.20	0.54	0.001***
(%healthy WBP)²	0.013	0.002	0.69	0.0001***
%healthy+unhealthy WBP	0.634	0.23	0.33	0.015*
%dead WBP	-0.520	0.25	0.19	0.060
%healthy WBP+(%healthy WBP)²	**-0.957+0.026**	**0.66, 0.01**	**0.70**	**<0.001*** **
Correlation Between Measures of Seed Source Health				
%healthy WBP | healthy WBP BA (m^2 ha^{-1})	1.708	0.41	0.56	0.001**
%healthyWBP | mean WBP crown kill (%)	-1.001	0.13	0.81	<0.001***
Healthy WBP BA (m^2 ha^{-1}) | mean WBP crown kill (%)	-0.352	0.10	0.47	0.004**

* = P-value significant at 0.05, ** = P-value significant at 0.01, ***= P-value significant at 0.001

2006) for measuring plot and tree characteristics including the diameter at breast height (DBH), height, height to live crown base, and health status (healthy, unhealthy, sick, dead) for each tree over 11.5 cm DBH in the plot boundary. For each living whitebark pine tree we recorded the percent of crown killed by white pine blister rust, abiotic, or unknown factors. We also tallied live saplings (trees smaller than 11.5 cm DBH) by DBH class and recorded average height and crown base height. Finally, we tallied seedlings by species and height class in a nested fixed area (0.004 ha), circular plot (3.64 m radius).

Burned Area Sampling

Within a burn, we established fixed area (15 m2) circular plots (2.18 m radius) along a set of parallel transects that ran from the seed source stand toward the center of the burn (Figure 2). We sampled between 22 and 80 plots at each burn with a grid resolution at or near 100 m between both plots and transects. We measured whitebark pine seedlings individually and tallied all other conifer seedlings and saplings by species and height class. For each whitebark pine seedling or sapling, we sampled the additional variables of microsite (distance in meters to any major ground feature), presence or absence of blister rust symptoms, and seedling age (estimated from branch whorls).

Data Analysis

For our purposes, each cluster of whitebark pine seedlings was counted as one regeneration site. Because whitebark pine regeneration increases over time following fire (Tomback et al. 2011), we normalized the overall mean regeneration density at each site by the number of years since fire at the time of sampling. Regeneration densities among burns were compared using simple, multiple and piecewise linear regression. Numerous measures of seed source health were tested as potential predictors of seedling density in the burn (see Table 2). Predictor variables and interaction terms were eliminated using t-tests; nested models were compared using F-tests in an analysis of variance.

Results

In sampled burns, the basal area of live mature whitebark in the seed source ranged from 2.8 to 44 m² ha-1. Whitebark pine seedling densities in the burns were highly variable across and within sites (Figure 3). When normalized by number of years since fire, mean study area-level seedling densities ranged from 0 to 86 seedling clusters ha-1year-1. The Charlotte Peak burn on the Flathead National Forest had the highest overall seedling density, but was also one of the oldest burns. When normalized by years since fire, the Pettengill Fire on the Beaverhead-Deerlodge National Forest had the highest seedling density, followed by the Mussigbrod burn, also on the Beaverhead-Deerlodge. Two sites had no regeneration at the time of sampling, Challenge and Wyman, but these were relatively recent burns (seven and five years old respectively). Overall, only 3% of seedlings showed signs of blister rust infection.

Effects of seed source health on regeneration density

The greater the proportion of healthy whitebark pines in the seed source, the greater the mean seedling density in the burn (Figure 4). While several measures of seed source health were statistically significant predictors of seedling density in individual models (Table 2), these variables were often redundant; the best model included only the proportion of mature whitebark pine in the seed source that were healthy (%healthy). Seedling density increased among burns in relation to %healthy (R^2 = 0.54, P = 0.001, Figure 4a), but the R^2 and the residuals were improved by adding a quadratic term, $\%healthy^2$ (R^2 = 0.70, P =0.0002, Figure 4b). In a piecewise regression model, we identified a threshold of approximately 50% healthy trees, above which, seedling density increased at a higher rate (Figure 4c). However, there were too few data points at high values of %healthy to determine the robustness of this threshold.

Discussion

The strongest relationship that we found between regeneration density and seed source health indicated that if at least 50% of the mature whitebark pine are healthy, seedling density in the adjacent burn will increase (Figure 4, Table 2). This effect is likely an indication of greater nutcracker visitation and reliable seed-caching. For burned areas where more than 50% of the seed source whitebark pine are damaged or dead, rates of natural regeneration are likely to be limited (< 40 seedling clusters ha-1 yr-1). Given that older, taller seedlings are more susceptible to blister rust infection, seedling mortality is likely to increase over time in these areas. Therefore, while natural whitebark pine regeneration was present throughout most of the burned stands that we sampled, future seedling and sapling mortality may prevent these stands from becoming productive, cone-producing forests. It is important to note that regeneration rates are but one of the key vital rates which influence population growth rates following wildfire. While regeneration density and mortality are important indicators of potential forest structure, managers should also consider long-term adult growth rates, fecundity, and mortality rates as blister rust infection levels stabilize or increase. Regardless, long-term monitoring of natural regeneration characteristics, planted seedling survivorship and seed source health is critical in developing effective restoration plans (Keane et al. 2012).

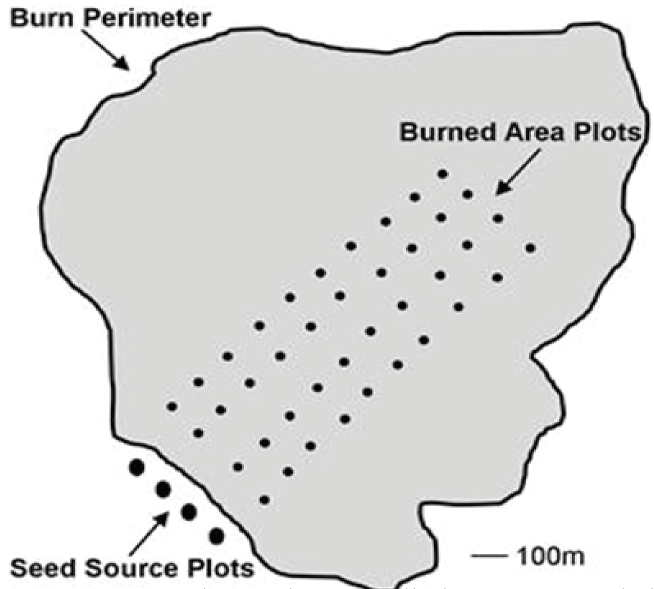

Figure 2. Study area layout. All plots were sampled at or above the lower elevational limit of whitebark pine.

Fire managers are often faced with conflicting values in determining whether or not to suppress high elevation fire. Given that burned areas provide the conditions most favorable for whitebark pine seedling establishment and growth to reproductive maturity, suppressing high elevation fire for the benefit of whitebark pine could be counter-productive. While many of the burns we sampled may not meet seedling density objectives for future desired forest structure, natural regeneration can be supplemented with planted rust-resistant seedlings where appropriate (Keane

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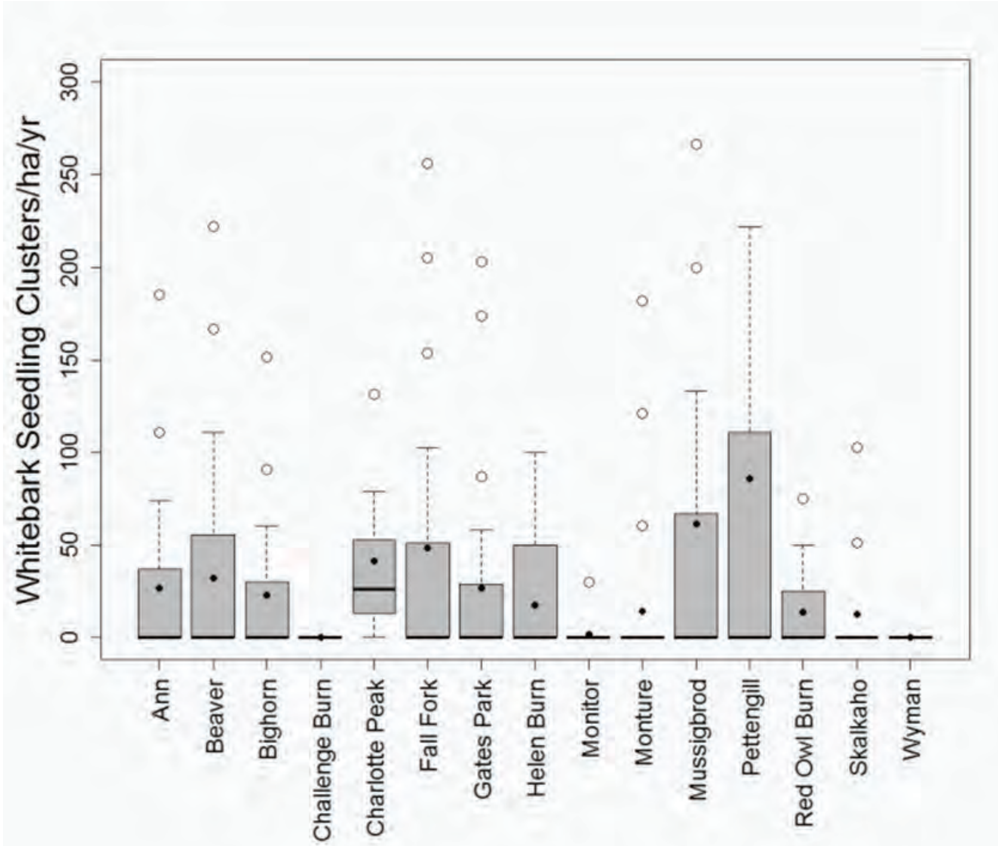

Figure 3. Boxplots of whitebark pine seedling density by study area, where the median is shown by the solid black line and the mean is shown by the solid black circle. Seedling density is normalized by number of years since fire.

and Parsons 2010; Keane et al. 2012). Fire suppression on a small scale that leads to the protection of healthy seed source stands and "plus" trees (trees that have been identified as sources for rust-resistant seeds, see Mahalovich and Dickerson (2004)) or small islands of subalpine habitat that hold special recreational or wildlife value comprises the best fire management response in whitebark pine forests.

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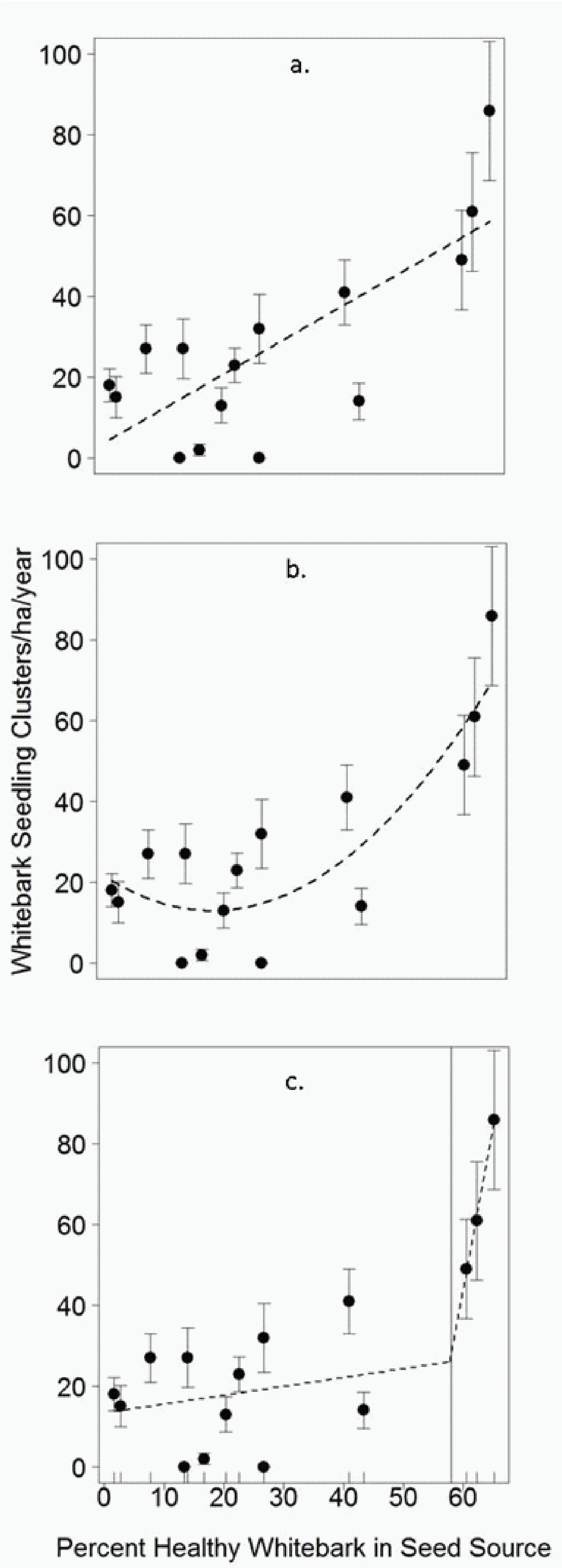

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Figure 4. Simple linear (4a), multiple linear (4b) and piecewise (4c) models reflecting the relationship between seed source health (percent of mature trees in the seed source that are healthy) and seedling density (seedlings ha-1 year-1) in the adjacent burn. Standard error bars are shown. Potential threshold shown as solid vertical line in 4c.

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Clark's continued from page 8

increase in population-wide nonbreeding years. Such an increase could lead to population declines, negatively affecting the stability of regional nutcracker populations. Without enough good resource years to maintain populations, certain regions could become ecological traps [10]. A decrease in Clark's nutcracker populations, and hence their seed dispersal function, could have serious ecosystem-wide consequences.

Taza Schaming taking notes. Photo Credit Pocholo Martinez.

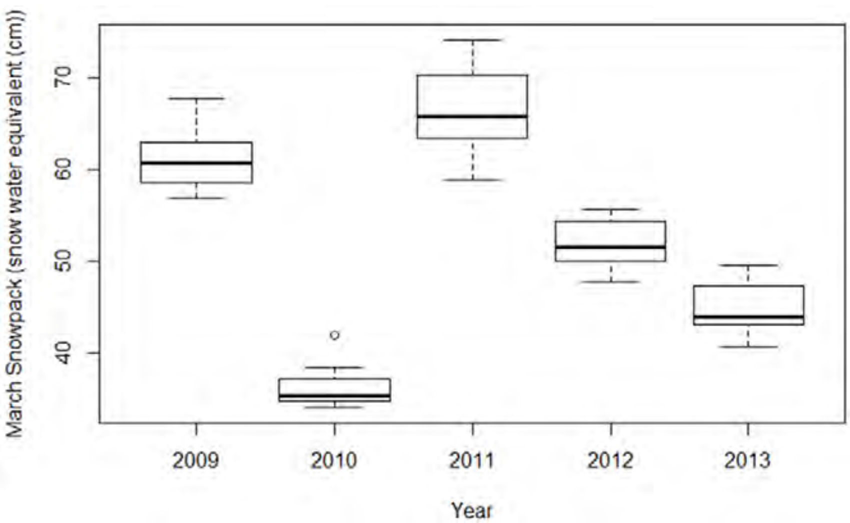

Figure 2. Snowpack in breeding (2010, 2012, 2013) versus nonbreeding years (2009, 2011; n = 31 for all years).

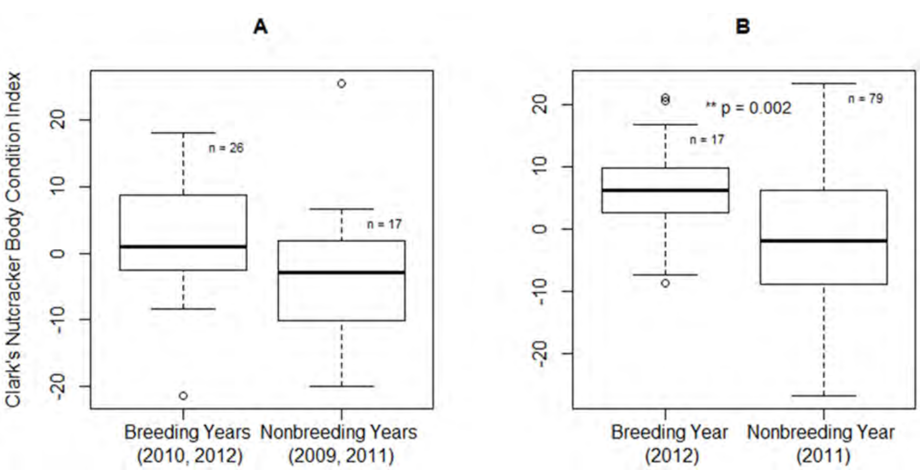

Figure 3. The Clark's nutcracker prebreeding (A) and breeding season (B) body condition indices in breeding versus nonbreeding years.

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In places like the Absaroka Mountains and the southern Sierra Nevada, a case may be made for intervention to preserve the “natural” quality of wilderness (Landres et al. 2008). Alternatively, sites in these locales may be sought outside of wilderness where restoration experiments may be undertaken (e.g., ca. 60% of its current range). Indeed, where climate projections suggest the opening of new climate space to whitebark pine in the future (Fig. 3), it may be appropriate to aggressively pursue cultivation outside wilderness in anticipation of the arrival of suitable climate. In such cases, we suggest projects be designed as rigorous experiments where treatments – including untreated controls – are replicated across the landscape (sensu Larson et al. 2014). Monitoring and understanding the ways ecological systems re-organize without intervention following the loss of a foundational species, such as whitebark pine, and under a changing climate should be considered an important goal of future management. Lessons learned from these experiments can help inform future decisions about whether and how to intervene in wilderness to protect its natural character and save this keystone species.

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Whitebark pine seedlings

Nominations for 2016 Whitebark Pine Ecosystem Foundation Board Elections

Our bylaws dictate that elections are to be held every year for various positions – this way there is always a rotation of experienced Board Members and Executive Committee officers and we would never face a complete turnover of officers and the chaos that could ensue. Please consider running for one of these positions!

Board members and officers commit to working collectively to advance the business of the WPEF and the conservation and restoration of high elevation pines. This includes attending two board meetings per year, one of which is usually in March or April in Missoula, MT, and the second is in conjunction with the annual WPEF science meeting and field trip in mid-to-late September somewhere within the range of whitebark pine. To find out more about the duties of these positions, please refer to the back of this form, consult the WPEF Executive Handbook on the website www.whitebarkfound.org, or contact one of us.

Diana F. Tomback, Ph.D.
Director: diana.tomback@ucdenver.edu

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Nomination Form – Whitebark Pine Ecosystem Foundation

Nominations are being sought for the following four (4) positions, to begin serving on the Board of Directors in September, 2016. All positions are for a 3-year term:

- Director
- Secretary
- Board Member (2 positions)

RULES:

- All board members can serve up to 3 terms consecutively [Bylaw E(h), E(i) and F(a)].
- All nominees must be members of the WPEF in good standing [Bylaw F(b)(iv)].
- Any nomination must be made by 2 members in good standing [Bylaw F(b)(i)]; signatures can be on one form, or on separate forms.
- Any nomination must be validated by the signature of the nominee [Bylaw F(b)(i)]; this signature can be on the same form as a nominator, or on a separate form.
- Only one nomination per form. If you need more forms, please copy this one, or download another one from our website <www.whitebarkfound.org>.
- Nominations may be sent by mail [Box 17943, Missoula, MT, 59808], E-mail melissa.jenkins@whitebarkfound.org or fax (406-758-5379), and must be postmarked/dated no later than 01 Feb 2016.

We, the undersigned, nominate ________________________________ for the position of
DIRECTOR ___ SECRETARY ___ BOARD MEMBER ___
[please check the one that applies].

Nominator #1: ______________________ ______________________ ______________________
Signature Print Name E-mail address

Nominator #2: ______________________ ______________________ ______________________
Signature Print Name E-mail address

Nominee: ______________________ ______________________ ______________________
Signature Print Name E-mail address

The purpose of the Board of Directors (BOD) is to make decisions affecting the general membership of the WPEF. This includes making policy, deciding on major spending, or solving major problems concerning the organization.

1. Responsibilities of the Director:

General

- Oversight of all WPEF activities
- Interface with external constituencies on matters relating to WPEF & whitebark pine
- Oversee fund raising and public relations
- Participate in meetings, make presentations at important events relative to WPEF mission
- WPEF will provide reimbursement for activities that are of impact to WPEF and not funded by external sources, upon authorization by Board of Directors

Specific

- Call board meetings twice a year
- Develop agendas for board and annual members meeting
- Call for host/location for annual science and members meeting
- Propose and call for initiatives meeting WPEF mission
- Follow potential leads for fund raising and WPEF mission

2. Responsibilities of the Secretary:

- Record all activities of the Executive Committee and BOD
  - Attend BOD meetings and record minutes
  - Record e-mail votes and notify Director of outcomes
  - Compile a record of all e-mails, letters, and web postings
  - Distribute draft copies of minutes within 4-6 weeks following BOD meetings
- Serve as the Election Official for all voting activities
  - Print and mail each ballot in cooperation with Membership/Outreach Coordinator
  - Collect and organize all completed ballots
  - Report to the BOD on election results
  - Store all ballots and results
  - Compile a report on voting activities for newsletter
- Maintain WPEF bylaws and executive handbook
  - Record any changes as approved by the BOD
  - Update the bylaws or handbook
  - Post changes to website and newsletter
  - Create a ballot if changes to bylaws are warranted

3. Responsibilities of a general board member:

- Attend all BOD meetings (in person or via conference call)
- Attend all WPEF annual meetings
- Chair at least one Committee or Working Group
- Organize annual meetings as appropriate
- Perform fundraising as needed
- Participate in other WPEF tasks and activities when appropriate

WHITEBARK PINE
ECOSYSTEM FOUNDATION

PO Box 17943
Missoula, MT 59808
www.whitebarkfound.org

SAVE THE DATE

Whitebark Pine Ecosystem Foundation's Annual Science & Management Meeting

Sep 16-18, 2016 - O'Shaughnessy Center, Whitefish, Montana

Workshop Topics:
Whitebark Friendly Ski Areas
Inventory and Monitoring

Field Trips:
Glacier National Park
Whitefish Mountain Resort
Tree climbing/cone collection demo

Plus:
Evening Social
Silent Auction
& Poster Session

Look for more information on the web: www.whitebarkfound.org

Show your support for Whitebark Pine & shop our new online store

HATS - T SHIRTS - CALENDARS

www.whitebarkfound.org