Conference Abtracts

Whitebark Pine Ecosystem Foundation

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Differential Spring Budburst Phenology Across Western Five-Needled Pine Species

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Keywords: Great Basin Bristlecone pine, Limber pine, Whitebark pine, budburst, greenhouse, phenology

With conservation efforts of high-elevation pine species underway, understanding the mechanisms of spring growth initiation could optimize restoration efforts. We tracked the progression of seedling spring budburst in greenhouse-grown whitebark, limber, and Great Basin bristlecone pine seedlings of varying ages and from different source populations. We identified six stages of budburst phenology and assessed each seedling weekly starting from the end of February 2021 to present. Although the stages of spring budburst are still progressing, preliminary data show intriguing species, population, and age-level patterns. Limber pine advanced through budburst stages the fastest, followed by whitebark, with GB bristlecone pine advancing the slowest among the eldest age class. Limber pine exhibited strong within-species variation with one population largely responsible for the quick budburst progression. Interestingly, younger populations of whitebark pine show both the earliest and most rapid spring development progression. This study will improve restoration efforts and seedling establishment through improved selection of seedling populations to outplant based on budburst phenology. These improved selection criteria could help optimize the growing seasons and ultimate fitness of outplanted populations.

Soil Moisture Regime and Canopy Closure Structure Subalpine Understory Development Over 30 Years Following Stand-Replacing Fire

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Keywords: 1988 Yellowstone fires, succession, understory community

Western subalpine forests, critical habitat for many species of five-needle white pines, have experienced some of the most severe wildfires in recent decades due to climate change. Of particular concern is the potential for increasing soil moisture deficits to alter successional dynamics in post-fire communities. Recent studies indicate that conifer regeneration may be limited in some burns, but the cascading impacts on understory (forbs, graminoids, shrubs) community composition and microclimate remain unexplored. We investigated the long-term (30 years) associations among understory plant succession, soil moisture regime, and conifer regeneration in two study areas that burned during the 1988 Yellowstone fires. Permanent plots (n=275) were

established in mixed whitebark pine (*Pinus albicaulis*) stands and classified by site type (mesic-burned, mesic-unburned, xeric-burned, xeric-unburned). Over the first decade of succession, species richness was lower in xeric-burned than in mesic-burned plots across study areas; however, conifer regeneration density was markedly higher at one study area. Nearly 30 years after fire at the study area where regeneration density was lower, soil temperatures and photosynthetically active radiation remained higher in burned than in unburned communities. There, understory community composition diverged by soil moisture regime, with the odds of graminoid cover 23-fold higher, and the odds of forb cover 3-fold lower, in xeric-burned than in mesic-burned plots. In contrast, at the study area where regeneration density was higher, microclimatic conditions converged between burned and unburned communities. Additionally, understory community composition did not diverge by differences in soil moisture regime but became more similar to unburned communities. Our results suggest that soil moisture regime structures the early trajectory of post-fire understory recovery, but the relationship diminishes as tree canopy closure alters microclimatic conditions. Under a warming climate, sparse tree canopy development may compound increasing aridity, with the potential for altered successional development of the understory.

Restoration Planting Options for Limber Pines (*Pinus flexilis* James) – 10 Years Later

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Keywords: Cronartium ribicola, Limber pine, Pinus flexilis, artificial regeneration, bark beetles, facilitation,five-needle pines, planting, restoration

In 2018, 58.5% of seedlings were healthy, 7% higher than in 2012, as some seedlings with lower health ratings recovered. There continued to be significant differences in survival by planting site (75.2% to 30.3% living; X_2=274.96, df=5, p<0.0001). For the establishment period ('09-'12), seedlings performed best on the west and north sides of an object, and under denser canopy cover. For the growth period ('12-'18), seedlings performed best with a nurse object, regardless of orientation or percent canopy cover. These findings will be used to refine planting guidelines needed for management, conservation, and restoration efforts, including deploying WPBR-resistant seedlings. Importantly, our results indicate that unlike *P. albicaulis*, *P. flexilis* seedlings can be planted in at-risk stands, prior to overstory tree mortality. Therefore, planting methods are not universal for five-needle pine species.

My Introduction to Whitebark Pine

by Steve Arno | USFS, retired

Keywords: history, whitebark pine

I first saw whitebark pine while hiking in the Northeastern Olympic Mountains in 1960. By 1965 I had seen it in many more places, including the Washington Cascades, Oregon's Wallowa Mountains, the Sierra Nevada, and the Northern Rockies. Except in California and Oregon, it was already besieged by the introduced disease, white pine blister rust, and to some extent by mountain pine beetles. In 1970, while working as a forester on Northern Idaho's Kaniksu National Forest, forest ecologist Earle

Layser and I commiserated about whitebark's fate. Then while working on Bob Pfister's Habitat project, and later at Missoula's Fire Sciences Lab, I realized that whitebark is a fire-dependent species, unable to compete with other conifers, without periodic fires. At this time other forest fire ecologists had reached similar conclusions, but whitebark' cone crops were being recognized as a critical food source for the Clarks Nutcracker, squirrels and both black and grizzly bears. By the 1990s, biologists Diana Tomback, Kate Kendall, and ecologists Tad Weaver, Ward Maughey, and Ron Lanner, and young fire ecologist Bob Keane saw the need to form a Whitebark Pine Ecological Foundation (WPEF), to promote research and on-the ground activities, such as planting rust- resistant seedlings, being grown at the Coeur d' Alene by Mary Frances Maholovich. Under the leadership of Tomback, Keane and WPEF Canada, the organization has piled up accomplishments in recent years.

Managing High-Elevation Pines at Great Basin National Park

by Gretchen M. Baker | Great Basin National Park

Keywords: bristlecone, management, national park, threats

Great Basin National Park, located in east-central Nevada, contains over 10,000 acres of limber pine-bristlecone pine woodlands. Tens of thousands of visitors come each year to see ancient bristlecone pines (*Pinus longaeva*). Part of a visitor center exhibit is dedicated to them, as well as an interpretive walk through an ancient bristlecone grove. Current threats to bristlecone and limber pines are climate change, wildfire, mountain pine beetles, and the eventual arrival of white pine blister rust. The Park partners with the National Park Service Inventory and Monitoring Program to conduct surveys to characterize and study plots for long-term changes. In addition, the Park works with Anna Schoettle's Proactive Strategy. Seeds from bristlecone and limber pines are being tested for their resistance to white pine blister rust so that future trees can be grown from resistant trees.

Defense Characteristics Among High-Elevation Pines and Vulnerability to Native Bark Beetles

by Barbara Bentz | Rocky Mountain Research Station

Keywords: bristlecone pine, climate, mountain pine beetle

Changing climate has increased awareness of the native bark beetle mountain pine beetle (*Dendroctonus ponderosae*) in high-elevation five needle pine ecosystems. True to its name, mountain pine beetle has adapted to high-elevation mountain climates, with the capacity for population growth during warm periods. Warming in recent decades at high-elevations has facilitated mountain pine beetle population success and associated pine mortality in some forests. Although the majority of pine species are susceptible to mountain pine beetle attack and associated tree death, vulnerability varies among high-elevation pine species. We describe and compare defense capacity and attack vulnerability among Great Basin bristlecone (*Pinus longaeva*), foxtail (*P. balfouriana*), Rocky Mountain bristlecone (*P. aristata*) and limber (*P. flexilis*) pines. We also evaluate causal agents of recent mortality in Great Basin bristlecone pine, a species considered the least susceptible to mountain pine beetle attack and reproduction. Understanding the role of native insects and climate in mortality of iconic high-elevation pines is vital for protecting and projecting the future of these foundational ecosystems.

Divergent, Age-Associated Fungal Communities of *Pinus Flexilis* And *Pinus Longaeva*

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Keywords: Great Basin bristlecone pine, Limber pine, belowground ecology, dendroecology, ectomycorrhizal, facilitation, symbiotic

The long-lived five-needle pines, *Pinus flexilis* (limber pine) and *Pinus longaeva* (Great Basin bristlecone pine) can co-occur and may form symbiotic partnerships with the same species of ectomycorrhizal fungi. These shared symbiotic relationships may facilitate the persistence of these pine species. Throughout their lives, *P. flexilis* and *P. longaeva* may also assemble unique belowground fungal communities, adding to the conservation value of ancient trees. We used MiSeq sequencing of fungal rDNA to compare fungal community similarity for co-occurring *P. flexilis* and *P. longaeva* roots and soils in an old-growth forest at the Utah Forest Dynamics Plot, Utah, USA. We cored trees to measure their age and determine whether fungal communities change with advanced tree age. We found 720 amplicon sequence variants associated with *P. flexilis* roots, 736 with P. longaeva roots, and 199 that were shared between the two pines. Root-associated fungal communities were significantly different between *P. flexilis* and *P. longaeva* despite similar soil communities. The fungal community composition on *P. flexilis* roots and around *P. longaeva* soil was associated with advanced tree age up to 1340 years. The root-associated fungal community of *P. flexilis* and the soil community of *P. longaeva* increased in dissimilarity with tree age, indicating that age heterogeneity within old-growth stands promotes fungal diversity. The significant differences in root-associated fungal communities between the two pine species highlights that they are likely engaged in different bi-directional selection with fungal communities.

Limber Pine Restoration in the Black Hills National Forest, South Dakota

by James T Blodgett | Cheryl Mayer | USDA Forest Service | USDA Forest Service

Keywords: branch pruning, Cronartium ribicola, limber pine, management, monitoring, planting, restoration, seed collection, white pine blister rust

As part of the Limber Pine Restoration Project, a new limber pine population was established in 2017 in the Norbeck Wildlife Preserve, Black Hills National Forest. In South Dakota, limber pine (*Pinus flexilis* E James), a Black Hills National Forest species of local concern, occurs in isolated areas scattered over a small geographic area of about 518 ha in the Black Elk Wilderness of the forest and adjacent Custer State Park. Recently many of these pines were killed by mountain pine beetle and white pine blister rust. An integrated management plan has been implemented in the forest including planting two-year-old limber pine seedlings. Four hundred and fifty-five seedlings from local seed were planted in the spring of 2017, 2018, and 2021 at seven areas with the help of several volunteers. Vexar tubes (i.e., animal protectors) were staked around seedlings to protect them from herbivory. Seedling survival was better than expected (97%) and we are seeing good exponential growth (average 6.1 cm/yr). Most of the seedlings are growing well and the Vexar tubes appear to be protecting seedlings. These sites will be monitored over the next few years.

Mechanisms of Vegetation Change in High-Elevation Forests of the Greater Yellowstone Ecosystem

by Erika Blomdahl | James H. Speer | Margot Kaye | Nicole E. Zampieri | Maegen Rochner | Bryce Currey | Denise Alving | Cahalan | Ben Hagedorn | Hang Li | Rose Oelkers | Lissa Pelletier | Ichchha Thapa | Kevin Willson | Brian D. Woodward | R. Justin DeRose | Utah State University | Indiana State University | Penn State University | Florida State University | University of Louisville | Montana State University | Penn State University | The Nature Conservancy | Western Washington University | Indiana State University | Lamont-Doherty Earth Observatory | SUNY-ESF | Indiana State University | University of New Mexico | Colorado State University | Utah State University

Keywords: Greater Yellowstone Ecosystem, dendrochronology, drought, ecotone shift, global change, high-elevation, whitebark pine

Global climate change is predicted to cause widespread changes in the distribution of forest vegetation, particularly in mountain environments where climate exerts strong controls on community arrangement. The upslope movement of vegetation communities has been observed in association with warming temperatures, especially evident in ecotones, or transition zones between vegetation types. We explored the role of drought and tree mortality on recent change in high-elevation forests of the Greater Yellowstone Ecosystem (GYE). We established 20 forest demography plots along an elevational gradient spanning the dominant high-elevation vegetation types in the GYE. Establishment dates indicated ecotone shift from meadow to forest, where *Pinus albicaulis* and *Pinus contorta* moved into the highest elevations following the 1950s. Among forest types, comparisons between live overstory and understory compositions suggested an upslope movement of *Abies lasiocarpa*, stability in *Pinus contorta*, and counterintuitively, downslope movement of *Pinus albicaulis*. Tree mortality was concentrated in the *Pinus* spp., largely due to *Dendroctonus ponderosae* activity from 2008-2012 that was exacerbated by drought conditions. Interestingly, the primary driver of growth variability in both *Pinus* spp. shifted from temperature in spring and winter to drought relatively rapidly during the 1950s. It appears that increased sensitivity to drought during the mid-20th century, in combination with increasing stand density associated with aging forests, created conditions of increased susceptibility to drought-related beetle-caused mortality during the most recent drought, the largest in the last millennia. While the species in these high-elevation forests of the GYE responded individually to expected successional processes, global change stressors (i.e., drought) acted on these forests in a complex way, and provided evidence for both ecotone shifts and stability.

Conservation and Restoration of Whitebark Pine by the USFS in Oregon and Washington

by Andrew Bower | USDA Forest Service

Keywords: USFS Pacific Northwest Region, conservation, restoration, restoration strategy, rust resistance

There are over 1.1 million acres of whitebark pine habitat in Oregon and Washington, over 90% of which is on U.S. Forest Service land. The US Forest Service Pacific Northwest Region (OR and WA) has allocated substantial financial and human resources in efforts for conservation and restoration of whitebark pine. These efforts have followed a plan outlined in a

document titled the "Whitebark Pine Restoration Strategy for the Pacific Northwest Region" which presents a comprehensive plan to reach the goal of "a network of viable populations of whitebark pine throughout the Pacific Northwest". The key actions prescribed include:

- collect seed for rust resistance screening, reforestation, and gene conservation refine species habitat mapping and assess stand conditions
- planting seedlings in areas where natural regeneration is lacking
- thin or remove competing vegetation to release whitebark pine and reduce fuel loads treat for mountain pine beetle in areas experiencing outbreaks
- continue a rust screening program

Highlights of some of the activities that have been undertaken as prescribed in this strategy as well as future direction, including how the Pacific Northwest Regional Restoration Strategy will tie in with the National Whitebark Pine Restoration Plan will be discussed.

Does High Severity Fire Facilitate Species Transition in California Subalpine Forests?

by Emily Brodie | Hugh Safford | Joseph Stewart | Andrew Latimer | Jesse Miller | UC Davis, Department of Environmental Science and Policy | USDA Forest Service | UC Davis, Department of Environmental Science and Policy | UC Davis, Department of Plant Sciences | Stanford, Biology Department

Keywords: Fire severity, species transition, subalpine forest, tree regeneration

Many montane tree species distributions are likely to move upslope in the coming decades due to predicted changes in precipitation and temperature. However, long-lived species such as trees might lag in colonizing climatically suitable habitat because adult trees can persist for long periods in stressful environments. By removing adult trees and reducing the "biological inertia" of an intact forest, disturbances such as fire are predicted to facilitate changes in species composition. In this study we asked whether high severity fire facilitates regeneration of non-dominant lower elevation tree species in subalpine forest in California. California subalpine forest is of particular interest because climate-driven changes in stand density and annual burned area are already occurring in this forest type. Preliminary analysis of tree regeneration in 248 plots across 13 fires suggests that high severity fire does not facilitate regeneration of lower elevation species over higher elevation species. In fact, while white pine regeneration generally increased with fire severity, lower elevation species (predominantly red fir) regeneration decreased with fire severity. In the Sierra Nevada, where shade-tolerant red firs dominate just downslope from subalpine forest, the existence of appropriate regeneration microsites seems to be having more of an effect on species regeneration patterns than broad-scale shifts in temperature. While red fir may be gaining a foothold in shadier, unburned subalpine forest understories, white pines do better in exposed post-fire sites with high canopy mortality. Our results suggest that small patches of high severity fire such as those sampled in this study might help to maintain white pine stands in the face of upward movement of lower elevation species that are shade tolerant.

Can We Improve Western White Pine Microbiomes to Promote Resistance to Blister Rust Disease?

by Lorinda Bullington | Emily Martin | Nadir Erbilgin | Peter Kennedy | Richard Sniezko | Department of Ecosystem and Conservation Sciences, University of Montana, Missoula, MT, USA | MPG Ranch, Missoula, MT 59801, USA 598801, USA | Department of Renewable Resources, University of Alberta, Edmonton. Alberta, Canada | Department of Plant and Microbial Biology, University of Minnesota, St. Paul, MN, USA | USDA Forest Service, Dorena Genetic Resource Center, Cottage Grove, OR 97424, USA

Keywords: Cronartium ribicola, Endophytes, ectomycorrhizal fungi, terpenes

Hundreds of asymptomatic fungal taxa live inside healthy white pine tissues. Recent studies suggest that these fungi can influence the frequency and severity of infections by fungal pathogens such as *Cronartium ribicola*, the causal agent of white pine blister rust. In a full- factorial experiment, we inoculated western white pine (*Pinus monticola*) seedlings from six seed families with foliar fungal endophytes (FFE) or ectomycorrhizal fungi (EMF, genus: *Suillus*), as well as a combined fungal treatment (FFE+EMF), and a control treatment (no inoculation). The six seed families consisted of half-siblings and full-sib progeny, with both high and low levels of known disease resistance. Four months post-inoculations, we infected a subset of seedlings from all four treatments with the rust to determine the individual and shared effects of FFE and EMF on resistance to white pine blister rust as well as seedling performance. We measured tree defensive chemistry (terpenes) for all treatments immediately before, and four months after infection, as disease symptoms began to appear. Seed family influenced both initial disease severity and terpene composition in all seedlings. We observed a strong treatment effect on tree defensive terpenes after pathogen infection ($p < 0.005$), indicating that fungal inoculations altered seedlings' induced defense responses. EMF inoculations had the greatest influence, while EMF+FFE treated seedlings were more similar to untreated control seedlings, suggesting an interaction between above and belowground fungi. How these differences in induced defensive responses translate to disease resistance will be assessed with ongoing monitoring of disease progression.

Efficacy of Pruning Limber Pine to Mitigate White Pine Blister Rust Impacts

by Kelly Burns | USDA Forest Service, R2-FHP

Keywords: disease management, limber pine, pruning, white pine blister rust

White pine blister rust is a disease that damages and kills white pines in the Southern Rocky Mountains. The purpose of this study was to determine if various pruning treatments could prevent crown dieback and increase the longevity of high-value limber pines in two recreation areas with high disease pressure. Four treatments were applied to infected trees:
(1) do nothing (control); (2) preventive pruning of branches and needles up to 7 ft (2.1 m) or 60% of the crown, whichever was less; (3) preventive and sanitation pruning (removing cankers throughout the crown); or (4) sanitation pruning only. Treatments for uninfected trees included control or preventive pruning. Trees were assessed and treated three times over the course of the study (2005-2006, 2010-2011, 2015). The same treatments were reapplied if new cankers were detected during subsequent assessments. Data collected included tree health status; branch and stem canker counts; type (stem or branch), number, and crown/stem location for canker removals; and branch canker lengths (to infer infections periodicity). Percent crown dieback

was quantified in the last two assessments. Significantly less crown dieback occurred on trees that received both preventive and sanitation pruning than on controls. Sanitation pruning removed the most cankers. New cankers occurred annually on 47–52% of originally infected trees and 10% of originally uninfected trees, suggesting that a 5-year pruning rotation is needed on sites with high disease pressure. A longer rotation could be used in areas with lower disease pressure. Management guidelines are provided.

Verbenone and Green-Leaf Volatiles Reduce Whitebark Pine Mortality in a Northern Range-Expanding Mountain Pine Beetle Outbreak

by Etienne Cardinal | Brenda Shepherd | Jodie Krakowski | Parks Canada | Parks Canada | Independent Consultant

Keywords: mountain pine beetle, verbenone, whitebark

This is the first study testing effectiveness of pheromone treatments to protect individual trees from a range-expanding mountain pine beetle (MPB, *Dendroctonus ponderosae* Hopkins) attack into newly exposed host populations of endangered whitebark pine (*Pinus albicaulis* Engelmann). We investigated the effectiveness of a combination of verbenone and Green-Leaf Volatiles (GLV) to protect rare and valuable disease-resistant trees during a MPB epidemic from 2015 to 2018 in Jasper National Park, Canada. Treatments reduced the proportion of trees attacked by MPB for all diameter classes, across all stands, from 46 to 60%. We also evaluated the effect of the exotic disease white pine blister rust, the species' other main regional threat. MPB were less likely to attack large, infected trees than healthy trees, emphasizing the value of the pheromone treatment. Protecting large, cone-bearing disease-resistant whitebark pine trees is fundamental to whitebark pine recovery. Maintaining reproductive trees on the landscape increases the frequency and diversity of rust-resistant genotypes more effectively than just planting seedlings to replace MPB-killed trees, because this slow-growing species takes over 80 years to reproduce. Our study confirmed protecting large rust-resistant trees with verbenone and GLV is a proactive and effective treatment against MPB for whitebark pine in naïve populations.

Early Results from Whitebark Pine Genecology Field Trials in British Columbia

by Charles V Cartwright | Richard A Sniezko | Michael P Murray | Iain R Reid | BC Ministry of Forests | USDA Forest Service | BC Ministry of Forests | Parks Canada

Keywords: genecology, genotype by environment interaction, whitebark pine

Whitebark pine (*Pinus albicaulus* Englm.) is listed as endangered in Canada, chiefly due to decimation by white pine blister rust (*Cronartium ribicola* J. C. Fisher), and mountain pine beetle (Drendroctonus ponderosae Hopkins). In response to the federal listing of the species, it is incumbent on the Province of British Columbia (BC) to take steps towards restoration. Multi-environment genecology field trials were established with the intent of screening for blister rust resistance trees, quantifying genotype by environment interactions, providing a basis for developing climate-based seed transfer guidelines, and eventually evidence concerning trait durability. Test sites were established in most of the climate types where whitebark grows in BC using

seed sources from across much of the range. The same provenances were also deployed in a farm field setting and some were scored in controlled inoculation screening. Effects of seed source latitude, elevation, and several climate variables on survival and growth are reported. As well, correlation of rust resistance scores across some of the sites is described. Implications for restoration using rust resistant planting stock in BC are considered.

Predicted Impacts of Climate Change on the Northern Range Limit of Whitebark Pine

by Alana J Clason | Eliot J.B. McIntire | Philip J. Burton | Bulkley Valley Research Centre | Natural Resources Canada | University of Northern BC

Keywords: Clark's nutcrackers, Climate change, dispersal, latitudinal range limit, suitable habitat

A common expectation for tree adaptation to climate change involves elevational or latitudinal migration to track suitable climate. Whitebark pine reaches its northern range limit in north-central BC, with many bioclimatic species distribution models predicting currently suitable climate further north than this range limit. We tested the role of climate across scales on the occurrence and abundance of whitebark pine at its northern limit and found it is commonly associated with cold habitats throughout this northern range. These results suggest cold is not limiting the species, and migration north with climate change is unlikely with increasing temperatures alone. The biotic interaction between whitebark pine and Clark's nutcrackers, and between the nutcracker and its alternative food sources such as Douglas-fir, drive current northern range dynamics, and these interactions will also determine range shifts with climate change. While cold temperatures are not currently limiting, climate change will reduce suitable habitat throughout the range of whitebark pine, with much of future suitable climate habitats occurring further north than the current range. Blister rust, mountain pine beetle and fire all result in whitebark pine mortality throughout its northern range, suggesting restoration of these northern ecosystems to sustain the pine-nutcracker interaction will be required to facilitate future dispersal north.

Clark's Nutcrackers Influence on the Northern Range of Whitebark Pine

by Alana J. Clason | Eliot J.B. McIntire | Philip J. Burton | Bulkley Valley Research Centre | Natural Resources Canada | University of Northern BC

Keywords: Clark's nutcrackers, Northern range limit, biotic interactions, dispersal, disturbance, whitebark pine distribution

The co-evolved positive biotic interaction between whitebark pine and Clark's nutcrackers influences the occurrence and abundance of whitebark pine across scales. The pine- nutcracker interaction may drive the current northern limit of whitebark pine in north- central BC, influenced by the distribution of alternative food sources (Douglas-fir). Whitebark pine is suffering ongoing mortality throughout its northern range from blister rust, mountain pine beetle, and fire. On top of these multiple stressors, maintaining habitat for Clark's nutcrackers will be required to sustain whitebark pine dispersal within this range and to facilitate migration into habitats that will be less vulnerable to climate change. Here, we will present evidence for the role of nutcrackers in limiting the northern range of whitebark pine. We also suggest potential impacts to future whitebark pine distributions across the northern range through cumulative disturbances that could disrupt pine- nutcracker interactions.

Limber Pine Condition on Montana's Rocky Mountain Front

by Christy M. Cleaver | Katie M. McKeever| Amy M. Gannon | August C. Kramer | Dave Hanna | USDA Forest Service, Forest Health Protection | USDA Forest Service, Forest Health Protection | Montana Department of Natural Resources | Montana Department of Natural Resources | The Nature Conservancy

Keywords: limber pine, white pine blister rust, mountain pine beetle, Montana

White pine blister rust (WPBR) has caused extensive crown dieback and mortality along Montana's Rocky Mountain Front since its introduction to eastside limber pine in the 1930's. The combined impacts of WPBR, mountain pine beetle, and changing climate patterns are suspected to be contributing to mortality and the alteration of limber pine stands occupying the grassland-montane ecotone throughout this region. Information on stand conditions is needed to inform management and restoration efforts. Our study objectives were to: (1) assess site and stand characteristics that describe limber pine along Montana's Rocky Mountain Front (2) determine the status and health of limber pine trees and regeneration, and (3) characterize the major damage agents on limber pine trees and regeneration and determine the occurrence, incidence, and severity of WPBR on limber pine.

In 2017 and 2018, we assessed 4,427 limber pine on 74 plots in limber pine-dominated stands along a 50-mile latitudinal gradient west of Choteau, Montana. Mean density of live limber pine was 150 trees per acre. Thirty-seven percent of limber pines were classified as healthy, 21% were declining or dying, and 43% were dead. White pine blister rust was the primary damage agent, occurring in 100% of plots with a mean incidence of 36%. Bark beetle-caused mortality was low at less than 5%. Live limber pine seedling density averaged 251 trees per acre. Of all limber pine seedlings 69% were alive, 31% were dead, and WPBR occurred on 5% of live seedlings. Competing Douglas-fir trees and seedlings were common. This establishment of baseline conditions for Montana's Rocky Mountain Front limber pine stands will help to monitor effects of future climate change, assist resource managers in forecasting WBPR impacts in areas more recently invaded by the disease, and inform future restoration activities for limber pine.

Evaluating Spectroscopy as a Tool For Rapid Identification of Wpbr-Resistant Whitebark Pine Trees

by Anna O. Conrad | Caterina Villari | Richard Sniezko | Pierluigi Bonello | USDA Forest Service | University of Georgia | USDA Forest Service | The Ohio State University

Keywords: Pinus albicaulis, machine learning, predictive models, rapid phenotyping, resistance chemotypes, support vector machine, white pine blister rust

One of the major challenges in selecting and breeding for white pine blister rust (WPBR) - resistant whitebark pine trees lies in the initial phenotyping phase. Currently available methods require time consuming and resource intensive inoculations of progeny, followed by months or years of observation to determine which individuals are resistant and which susceptible. Here we show that predictive models based on machine learning (ML, AKA artificial intelligence) applied to Fourier-transform

infrared (FT-IR) and Raman spectra of plant tissues, or their extracts, can be useful to streamline and greatly accelerate this all- important initial phase of the process. The best ML model we produced, based on support vector machine (SVM), correctly classified 76.7% of the FT-IR spectra as coming from either resistant or susceptible trees. With Raman spectra, the accuracy of the best SVM model was 67.9%. Both accuracies are significantly better than chance alone.

In conclusion, SVM appears to hold great promise as a rapid predictive tool for WPBR resistance when combined with FT-IR or Raman spectroscopy. Our results are already encouraging, but the inclusion of spectra from additional WBP with known ratings would likely strengthen the predictive power of ML models even further, and allow for additional validation and refinement, ultimately leading to a more robust and reliable, yet fast and non- destructive, predictive tool. Further investments in these areas of phenotyping technology, as well as in the very promising area of near infrared (NIR) spectroscopy, could result in field deployable, user-friendly hand-held sensors in the near future, and are strongly encouraged.

Post-Fire Regeneration of Endangered Limber Pine (*Pinus Flexilis*) at the Northern Extent of Its Range

by Denyse A. Dawe | Vernon S. Peters | Mike D. Flannigan | Natural Resources Canada | King's University| University of Alberta

Keywords: Limber pine; Pinus flexilis, fire ecology, post-fire regeneration

Limber pine (*Pinus flexilis*), an understudied tree species important to montane and subalpine ecosystems, is listed as endangered in Alberta. Prescribed burning is a proposed tool to stimulate natural regeneration via dispersal by Clark's nutcracker (*Nucifraga columbiana*). Extensive burns are suggested as a way to provide limber pine with a competitive advantage, due to long-distance dispersal. However, no studies had surveyed limber pine's immediate post-fire regenerative response at the northernmost extent of its range. We examined post-fire regeneration in one 16-year-old prescribed burn and one 8- year-old wildfire at the northern edge of limber pine's distribution. We then compared this to a regeneration baseline of plots in nearby unburned limber pine acting as seed sources to the burns.

Overall, we found only six post-fire limber pine seedlings within the burns compared to one hundred twenty-four similarly aged seedlings found in unburned plots. Statistical modelling suggests that distance to a seed source and microclimate effects, due to lack of canopy cover, may have influenced these low seedling numbers in our burned plots. Our findings suggest that extensive prescribed burns and stand-replacing wildfire events at the northern extent of limber pine's range may have limited seedling regeneration in the immediate post- fire period. Conservation efforts may be well-served by focusing on fire mitigation practices, such as thinning and other fuel treatments, in areas surrounding established limber pine stands. Finally, post-disturbance stands could benefit from supplementary seedling plantings to achieve recovery plan restoration goals for this endangered species.

Variable Demographic Patterns Interact with Disturbance to Shape Limber Pine Population Viability

by R. Justin DeRose | Utah State University

Keywords: climate change adaptation, generalist, mountain pine beetle, nutcrackers, surrogate species

Limber pine is an important western tree species having the largest ecological amplitude of any of the five needle pines. Its presence in western forests is equally likely irrespective of elevation, aspect or slope. Recent, severe, and widespread decline of a closely related species, whitebark pine, is suggestive of a similar fate for limber pine. Indeed, recent work has indicated that range-wide mortality in limber pine is approaching similar levels as was seen in whitebark pine two decades ago. Mountain pine beetle outbreaks are likely responsible for the vast majority of limber pine mortality. Whether the recent mountain pine beetle outbreaks are novel, or a normal part of disturbance dynamics in limber pine forests is unknown. In this study, we examine the long-term persistence of a limber pine woodland located in the Greater Yellowstone Ecosystem. Dendroecological methods were employed to reconstruct establishment dates, death dates, and cause of death for 78 total (n=28 live, and n=50 dead) limber pines. Over the past ~800 years, limber pine recruitment was characterized as pulsed, with peaks occurring in the 13th and 17th century consistent with multi-decadal pluvial periods. Over the past ~700 years limber pine mortality was much more continuous, but with pulses centered on the 1880s, 1960s, and early 2000s. Death of over half the limber pine since ~1860 can be attributed to mountain pine beetle. Because continuous propagule pressure for limber pine is driven by nutcracker, the pulses of successful establishment we saw appear to have been driven by relatively wet periods. In contrast, background mortality rates were very low, and pulses of mortality driven by the mountain pine beetle. The balance between continuous and episodic demographic processes in the face of mounting disturbance pressure over time is likely to further bottleneck limber pine population viability.

Special Session: The North American Dendroecological Fieldweek (NADEF): Educational and Research Opportunities to Better Understanding 5-Needle Pines

Organizer: Maegen Rochner

The Importance of Energy-Water Limitation Threshold in Drought Impact Studies

by Joan C. Dudney | University of California, Santa Barbara

Keywords: climate change, drought, tree-rings, whitebark pine

Forest diebacks have increased in magnitude in many regions in response to greater water limitation. “Hotter droughts” are predicted to increase under climate change and result in significant restructuring of forest composition and ecosystems services. Many drought- related studies, however, focus on water limited systems, where water—not energy—poses the greatest constraint on photosynthesis. Contrary to expectation, hotter, drier conditions in energy limited systems may cause greater growth, as the growing season is extended. Thus, identifying the location of the energy-water limitation threshold is critical to predict

forest mortality under climate change. Here we assess the impacts of the recent extreme drought in California (~2012-2015) on subalpine whitebark pines across the central and southern Sierra Nevada. We use a combination of over 700 tree-rings and over 1,000 stable isotope samples to test whether extreme drought led to greater growth or greater physiological stress. We show that during extreme drought, the energy-water limitation threshold shifted upslope into higher elevation whitebark pine. Trees growing near this threshold experienced some physiological stress, but trees far from this threshold experienced positive growth. These results suggest that extreme drought has a more nuanced effect on average productivity for forests that occur across strong climatic gradients.

Nonlinear Shifts in White Pine Blister Rust Due to Climate Change

by Joan C. Dudney | John Battles | Adrian Das | Jonathan Nesmith | Claire Willing | Andrew Latimer | University of California, Santa Barbara | UC Berkeley | USGS | US Forest Service | Stanford University | UC Davis

Keywords: White pine blister rust, climate change, foxtail pine, range expansions, sugar pine, western white, whitebark pine

Though climate change is predicted to cause major shifts in infectious disease risk, definitive evidence is often elusive due to data limitations and confounding factors. Thus, disease outbreaks are often interpreted as stochastic events, rather than a response to changing environmental conditions. Nonlinearities in climate change patterns can also complicate inference of mechanistic drivers. Nonlinear stochastic events, such as droughts, are also predicted to increase in frequency and severity throughout various parts of the globe and negatively affect fungal pathogens. Here we take advantage of a unique long-term dataset (two survey periods spanning ~19 years; over 8,000 individual hosts) of the fungal tree disease, white pine blister rust (*Cronartium ribicola* Fisch., blister rust) in Sequoia and Kings Canyon National Parks. We find that climate change between 1996 and 2016 moved the climate optimum of the disease into higher elevations. The nonlinear climate change- disease relationship contributed to an estimated 5.5 (4.4-6.6) percentage points (p.p.) decline in disease prevalence in arid regions and an estimated 6.8 (5.8-7.9) p.p. increase in colder regions. Though climate change likely expanded the suitable area for blister rust by 777.9 (1.0-1392.9) km2 into previously inhospitable regions, the combination of host- pathogen and drought-disease interactions contributed to a substantial decrease (32.79%) in mean prevalence between surveys. Specifically, declining alternate host abundance suppressed infection probabilities at high-elevations, even as climatic conditions became more suitable. Further, drought-disease interactions varied in strength and direction across an aridity gradient—likely decreasing infection risk at low elevations while simultaneously increasing infection risk at high-elevations. These results highlight the critical role of aridity in modifying host-pathogen-drought interactions. Variation in aridity across topographic gradients can strongly mediate plant disease range shifts in response to climate change.

Compounding Effects of White Pine Blister Rust, Mountain Pine Beetle, and Fire on White Pines in Sequoia and Kings Canyon National Parks

by Joan Dudney | Jonathan Nesmith | Matt Cahill | Jennifer Cribbs | Dan Duriscoe | Adrian Das | Nathan Stephenson | John Battles | UC Davis | USFS PNWRS | The Nature Conservancy | UC Davis | NPS Night Sky Program | USGS WERC | USGS WERC | UC Berkeley

Keywords: I&M, NPS, Sierra Nevada, white pines

Invasive pathogens and bark beetles have caused precipitous declines of white pines in North America. We characterized long-term patterns of mountain pine beetle (*Dendroctonus ponderosae*; MPB) attacks and white pine blister rust (WPBR; *Cronartium ribicola*). We focused on four dominant white pine host species in Sequoia and Kings Canyon National Parks (SEKI), including sugar pine (*Pinus lambertiana*), western white pine (*P. monticola*), whitebark pine (*P. albicaulis*), and foxtail pine (*P. balfouriana*). Between 2013 and 2017, we resurveyed 152 long-term monitoring plots that were first established between 1995 and 1999. Overall extent (plots with at least one infected tree) of WPBR increased from 20% to 33%. However, the infection rate across all species decreased from 5.3% to 4.2%. WPBR dynamics varied greatly by species, as infection rate decreased from 19.1% to 6.4% in sugar pine, but increased in western white pine from 3.0% to 8.7%. For the first time, WPBR was recorded in whitebark pine in SEKI, but foxtail pine remained uninfected. MPB attacks were highest in sugar pines and decreased in the higher elevation white pine species, whitebark and foxtail pine. Both WPBR and MPB were important factors associated with elevated mortality in sugar pines. In addition, multiple mortality agents, including WPBR, MPB, fire, and drought contributed to major declines in sugar pine and western white pine; recruitment rates were much lower than mortality rates for both species. Our results highlighted that sugar pine has been declining much faster in SEKI than previously documented. Given current spread patterns, blister rust will likely continue to increase in higher elevations, threatening subalpine white pines in the southern Sierra Nevada. More frequent long-term monitoring efforts could inform ongoing restoration and policy focused on threats to these highly valuable and diverse white pines.

Special session title: White pines in NPS. Special session organizer: Kristin Legg

Climatic Factors Affecting White Pine Blister Rust Incidence on Whitebark Pine in Washington National Parks

by Sebastian Espinosa Novoa | Beth Fallon | John Boetsch | Northern Arizona University, Department of Earth and Sustainability; National Park Service, North Coast and Cascades Inventory and Monitoring | National Park Service, Mount Rainier National Park | National Park Service, North Coast and Cascades Inventory & Monitoring Network

Keywords: National Park Service, blister rust, climate drivers, whitebark pine

Whitebark pine, *Pinus albicaulis*, is a low-cover but critically important tree in the subalpine ecosystems of national parks

within western Washington state, in the North Coast and Cascades Inventory & Monitoring Network (NCCN). Trees within North Cascades (NOCA) and Mount Rainier National Parks (MORA) have experienced mortality rates ranging from 9-45% and 21-50%, respectively. Mountain pine beetle attacks are rare and mortality is attributed primarily to white pine blister rust (WPBR). The interpark differences in mortality may be partially attributable to different climates between NOCA, at a higher latitude, and MORA; past analysis of monitoring data has demonstrated a correlation of increasing latitude with declining mortality (Rochefort et al. 2018). In the present study we explore how environmental factors are driving WPBR rates within the remaining living tree populations at MORA and NOCA and assess intrapark climatic differences that are correlated with particularly vulnerable populations and/or areas ripe for restoration work (e.g., refugia). As in other locations, seasonal variation in moisture and temperature may increase disease presence in whitebark pine. Analyses of NCCN monitoring plots show that while Park is a significant factor in mortality rates, vapor pressure deficits in August are another significant predictor ($P < 0.05$), but simple models of vapor pressure, location, temperature and precipitation only explain 32% of the variation in mortality. WPBR infection rates of live trees are not significantly predicted by the same models. Misidentification of blister rust, field crew turnover, and coarse environmental data may be reducing our ability to model environmental variables affecting rust in these parks. In 2021, we will complete establishment of new monitoring plots and catalog tree disease status in all existing plots, and b) model disease incidence with higher resolution climate data to evaluate the abiotic conditions contributing to current WPBR presence and decline in NCCN parks.

Comparative Species Assessments of Five-Needle Pines Throughout the Western United States

by Sara A. Goeking | Marcella A. Windmuller-Campione | US Forest Service | University of Minnesota

Keywords: Great Basin bristlecone, Pinus albicaulis, Pinus aristata, Pinus balfouriana, Pinus flexilis, Pinus longaeva, Pinus strobiformis, Rocky Mountain bristlecone pine, forest inventory, foxtail, limber, southwestern white, whitebark

Five-needle white pine species provide important ecosystem services throughout the western U.S., and many of these species have become susceptible to stressors including warmer temperatures, insect epidemics, nonnative disease, and altered disturbance regimes. The objective of this study was to characterize recent broad-scale demographic patterns, including species abundance (i.e., numbers of individuals, tree density, size-class distributions, recruitment, growth rates, mortality rates, and causes of mortality, for the six species of five-needle pine that occur in the western US. We used the U.S. Forest Service's Forest Inventory and Analysis (FIA) dataset, spanning >10 years, to quantify demographic status and trends for each species. FIA data were compiled from a probabilistic sample design and consistent analysis framework that included not only the dominant community types of five-needle pines, but also all other forest community types, which have previously been demonstrated to encompass abundant regeneration of five-needle pine species. Our analysis revealed similar trends for whitebark and limber pines: both species exhibited increased levels of mortality that are occurring faster than growth of surviving trees, as well as abundant regeneration in forest types that are not dominated by five-needle pines. Although limber pine has experienced lower mortality rates than whitebark pine, it nonetheless showed signs of decline that are comparable to broad-scale indicators exhibited by whitebark pine 10 years prior. Great Basin bristlecone and foxtail pine mortality rates were relatively low, and their populations exhibited flat diameter distributions except for low recruitment from seedling to sapling size-classes. Our findings suggest that five-needle white pine species would benefit not only from increased seedling recruitment, but also from enhanced recruitment among older and larger age and size classes, both in stands dominated by conspecifics and in stands dominated by species other than white pines.

Whitebark Pine Restoration in BLM Montana's Core Areas

by Emily Guiberson | Rich Byron | Bureau of Land Management | Bureau of Land Management

Keywords: , cone collection, daylighting, monitoring, planting, prescribed fire

Bureau of Land Management Montana/Dakotas State Forester, Rich Byron, and Dillon Field Office Forester, Emily Guiberson, highlight the restoration actions being implemented in Montana's whitebark pine core areas. They will discuss ongoing projects, agreements, and plans to establish a statewide monitoring protocol, with the intent of making it standardized within the agency. In addition, future conservation strategies and objectives will be outlined throughout the presentation.

Assisted Migration of Whitebark Pine to Higher Latitudes and Elevations near its Northern Limits

by Sybille Haeussler | Linda Tackaberry | Hugues Massicotte | UNBC | UNBC (retired) | UNBC (retired)

Keywords: assisted migration, mycorrhizae, northern BC, planting trials, whitebark pine

Here, we report 5- to 10-year results of three assisted migration field trials established from 2011 to 2013 near whitebark pine's northern limits in British Columbia. These trials (1) tested whether absence of compatible mycorrhizal fungi could inhibit whitebark pine migration beyond its current range, and (2) compared performance of provenances from northwest Washington to northern BC and Alberta, outplanted at 848 - 1934 m elevation across a range of minimally to severely disturbed sites.

Although we did not examine mycorrhizae after seedlings left the nursery, we found no evidence that mycorrhizal colonization level inhibited field performance. In our 2011 field trial, adding 250 ml of soil collected beneath mature whitebark trees to planting holes had no effect on 10-year field performance of seedlings grown in standard nursery potting mix and outplanted on moderately to severely disturbed sites (all $P > 0.10$). In our 2012 and 2013 trials, mycorrhizal development in the nursery was excellent in soils collected from alpine (above current whitebark elevation range) and subalpine (within current elevation range) habitats. Seedlings grown in alpine soils had larger diameters than seedlings grown in subalpine soils when they left the nursery *(*$P = 0.001$) and retained this advantage for at least 5 years in the field ($P = 0.05$).

ANOVA results indicated that effects of provenance on field performance of whitebark pine seedlings were either non-significant or subtle (diameter growth of one southern BC provenance was ~2 mm less than that of other provenances). Detailed statistical modeling incorporating climate parameters and seed weight is warranted once 10-yr data are available from all sites.

Environmental conditions at local planting sites (a disturbance severity gradient in the 2011 trial; an elevation gradient in 2012-13 trials) substantially affected seedling performance. (1) Seedling growth rates increased with disturbance severity with growth on severe wildfire and burned clearcut sites exceeding that on unburned clearcuts or beneath mountain pine beetle snags. (2) Blister rust infection rates (60% on the severe wildfire site) also increased with disturbance severity, creating a difficult trade-off between growth performance and infection risk. (3) Seedlings suffered more damage from extreme weather at alpine or montane elevations than at subalpine elevations. (4) Seedlings in thin soils over bedrock or moist productive soils had lower survival and more damage than those in submesic soils.

These early results support current BC guidelines allowing whitebark pine seed transfer over broad geographic and elevation ranges. They suggest that, in an uncertain climate, selecting genotypes with high rust resistance should be prioritized over fine-

tuning provenances. Longer evaluation is needed to determine how provenance affects seed crops and the other ecosystem services provided by whitebark pine. Planting above treeline and over a broader spectrum of microsites must proceed cautiously. Research to support enhanced seedling resistance to disease and climate stress (e.g., through fungal inoculation in the nursery, or by planting trees where they can form fungal linkages with mature trees) should be explored further at these northern whitebark pine limits.

High-Elevation Five-Needle Pine Seedling Traits Vary According to Climatic Gradients

by Lacey Hankin | Sarah Bisbing | Elizabeth Leger | Department of Natural Resources, University of Nevada - Reno | Department of Natural Resources, University of Nevada - Reno | Department of Biology, University of Nevada - Reno

Keywords: Great Basin bristlecone pine, adaptive traits, climate change, limber pine, restoration, whitebark pine

Tree species' persistence potential under rapid, ongoing climate change will depend on their capacity to adapt, migrate, or acclimate via phenotypic plasticity. The variation in and distribution of seedling traits conferring early success is a key knowledge gap for restoration and conservation of forest ecosystems. We quantified variation in seedling traits and evaluated evidence for local adaptation and plasticity in five-needle pine populations across the Great Basin using paired greenhouse and field common gardens. We specifically asked: a) how do seedling traits vary within- and among-populations across environmental gradients? and b) to what extent do populations exhibit local adaptation and/or plasticity to growing conditions? We planted seeds from three whitebark, four limber, and four Great Basin bristlecone pine populations in all source locations and in field-collected soils in the greenhouse and assessed germination, growth, and survival. We used linear mixed effects models to evaluate trait variation and quantified plasticity to soils using a plasticity index.

Our findings highlight interspecific seedling strategies for allocating biomass, yet high intraspecific trait variation across broad climatic gradients. Bristlecone showed significantly higher specific leaf area and root length but lower growth rates and total biomass. Whitebark invested relatively more in root mass when sourced from drier conditions, while limber reduced fine root production but limber and bristlecone produced faster and more growth when sourced from warmer and drier conditions, consistent with interspecific niche differentiation. Notably, limber populations germinated at significantly higher rates in both the greenhouse and field gardens regardless of conditions, suggesting potential advantages of this generalist species over co-occurring bristlecone pine under increasingly stressful environmental conditions. Significant population- and species-level differences in trait responses across climatic gradients and plasticity to soils suggest that successful restoration of climate change-impacted forests may hinge upon species-soils interactions and selection of climate-informed seed sources.

Potential Changes in Climate Suitable Habitat of Whitebark Pine in Greater Yellowstone Under Climate Scenarios

by Andrew J Hansen | Montana State University

Keywords: climate change, environmental tolerances, whitebark pine

Whitebark pine (*Pinus albicaulis*) (PIAL) is a proposed threatened species that plays a keystone ecological role in the Greater Yellowstone Ecosystem (GYE). Its population response to climate change is of high interest to managers because climate-induced declines may adversely affect critical ecosystem services that this species provides. While previous studies of reproductive size classes of the species have projected dramatic reductions in area of suitable habitat under climate warming scenarios, it has been suggested that the species can tolerate warmer and drier conditions if seedlings and saplings are not competitively excluded by other conifer species. Thus, we asked if juvenile-sized PIAL are found in warmer and drier locations than larger individuals, under the assumption that competitive exclusion would require several years to decades to influence the distribution of regenerating PIAL. We used a new genetic technique to distinguish non-cone bearing PIAL from the more warm-dry tolerant limber pine (P. flexilis) among samples collected along transects extending from lower treeline to the subalpine around the GYE. We discovered that smaller diameter PIAL were not proportionally more abundant at lower elevations, suggesting that competitive exclusion may not be the primary mechanism limiting this species' low elevation distribution. In contrast, the small size class PIAL was slightly less warm-dry tolerant than larger individuals. This suggests that the zone of regeneration of PIAL has shifted upwards in elevation in recent decades, perhaps associated with the observed warming in the GYE. In comparison to a previous study of reproductive-sized trees (>20 cm dbh) from a coarser (1.6 km) sampling frame, however, the predicted zone of suitable habitat of PIAL (<1 cm dbh) was 122 m lower in elevation. We conclude that consideration of the fine-scale distribution of PIAL near lower treeline suggests that the tree species is slightly less sensitive to climate warming than found by previous studies of reproductive-sized trees, but, nonetheless, large range contractions of PIAL in GYE are likely under projected future climates.

Summer Air Temperature for the Greater Yellowstone Ecoregion (770–2019 CE) Over 1,250 Years

by Karen Heeter | Maegen Rochner | Grant Harley | University of Idaho | University of Louisville | University of Idaho

Keywords: blue intensity, climate change, paleotemperature, tree rings

Annual surface air temperatures across the western United States (US) have increased by more than 1°C since ca. 1900. Continued warming will likely lead to increased drought conditions and exacerbated fire regimes, threatening to push ecosystems past their natural tolerance limits and potentially lead to a major demographic shifts, especially in subalpine ecosystems. Millennial-length paleo-temperature proxies derived from tree ring data in North America are rare, but extremely important because they enable comparisons between the modern warming trend and conditions that existed during the Medieval Climate Anomaly (MCA; ca. 950–1250 CE). We use latewood blue intensity from high-elevation *Picea engelmannii* to reconstruct late-summer maximum air temperature for the Greater Yellowstone Ecoregion (GYE) spanning 770–2019 CE. Using a robust regression model ($r^2 = 0.60$), the 1,250-year reconstruction documents regional expression of past warm and cool events, such as an anomalously warm periods spanning several decades of the MCA (1050-1070 CE), a prolonged warm period spanning the fifteenth to sixteenth centuries, and the Maunder and Dalton minima of the Little Ice Age. We demonstrate that historical temperature trends during key periods across the region—such as the MCA, the sixteenth century, and the LIA—were more variable as compared to those presented at hemispheric- global scales. Summer temperature variability across the GYE shows multi-centennial agreement with trends in solar irradiance, volcanic activity, snowpack, and other regional- to-hemispheric temperature records. Further, we emphasize the need for more millennial- length paleo-temperature records to better understand historical variability of climatic change in subalpine ecosystems of North America.

Fire-Caused Mortality of Whitebark Pine

by Sharon Hood | Alina Cansler | US Forest Service | University of Washington

Keywords: prescribed fire, tree mortality, wildfire

Whitebark pine forests are dependent on fire, yet the individual trees are susceptible to mortality from fire. This can make it difficult to minimize whitebark pine mortality when implementing prescribed burns and managing wildfires for resource benefit. The Fire and Tree Mortality Database contains approximately 1300 whitebark pine tree records collected from Wyoming, Montana, Idaho, and Oregon. We use the database to examine the likelihood of whitebark pine mortality after fire based on tree size and fire injury level, as well to evaluate the accuracy of whitebark pine mortality models in fire effects and behavior software systems. We also tracked mortality for 20 years after wildfire for a subset of the whitebark pines and report on long-term mortality from both fire and mountain pine beetle. This talk will present data on fire-caused tree injury levels that are likely to cause mortality, model accuracy, as well as discuss ways to mitigate mortality when burning.

Whitebark Pine Conservation Program at Crater Lake National Park: 2003-2021

by Jen Hooke | Crater Lake National Park

Keywords: High-elevation white pine communities in the Pacific West Region

Crater Lake National Park has maintained an active Whitebark Pine Conservation Program since 2003 that supports the Park's goals and objectives for conserving and restoring whitebark pine. Major elements of the program include identification of rust-resistant individuals; annual monitoring and protection of rust-resistant trees; sampling long-term monitoring plots to track trends in health and disease incidence; and conducting restoration plantings and monitoring the efficacy of those plantings. Out of 126 whitebark pines that have undergone screening trials, 41 have shown genetic resistance to blister rust although 7 of those "resistant" trees have since died. The Park's long-term monitoring plots show large whitebark pine continuing to decline from blister rust- and mountain pine beetle-caused mortality. The Park has conducted six restoration outplantings with more plantings planned for the future.

Whitebark Pine Restoration at Crater Lake National Park: The First Ten Years

by Jen Hooke | Richard Sniezko | Crater Lake National Park | USFS Dorena Genetic Resource Center

Keywords: Special session led by Richard Sniezko on resistance/genetics

Six whitebark pine restoration plantings have been established at Crater Lake National Park from 2009-2016 and monitored on an almost-annual basis. These plantings serve a dual purpose as: 1) restoration plantings including seedlings from rust-resistant 'parent' trees to reestablish whitebark pine in areas suffering from high mortality rates; and 2) these plantings also

include seedlings from parent trees deemed 'susceptible' to blister rust and therefore double as genetic trials to confirm field resistance to blister rust and to monitor genetic variation to other biotic and abiotic influences. The current plantings serve as focal restoration populations, laying the foundation for further future natural regeneration and spread of resistance. In addition, the current living rust-resistant parent trees identified in Crater Lake National Park will also help spread resistance. The Crater Lake National Park plantings provide one model of the potential use of genetic resistance to begin the restoration of a non-commercial forest tree species. They also provide a conservation education tool to raise public awareness of the potential for restoration using genetic resistance.

Physiological Responses of Whitebark, Limber and Great Basin Bristlecone Pines to Environmental Stress

by Sean Hoy-Skubik | Danielle Ulrich | Montana State University | Montana State University

Keywords: climate, drought, heat, physiology, seedlings, stress

High-elevation five-needle pines are currently facing grave threats as a result of global change. Warming and drying trends are expected to increase the physiological stress these trees face, leading to future increases in the already widely prevalent mortality events. A primary conservation strategy for mitigating these threats is the outplanting of seedlings. However, the success of this strategy is dependent on the selected seedlings' level of resistance, response to, and ability to recover from future climate-type stressors. To investigate these themes, we used a greenhouse-based study to impose heat and drought treatments, followed by a recovery period, on Whitebark Pine (*Pinus albicaulis*), Limber Pine (*Pinus flexilis*) and Great Basin Bristlecone Pine (*Pinus longaeva*) seedlings, using 3-, 4- and 6-year-old individuals from 17 populations from climatically distinct seed sources. We regularly measured leaf gas exchange and predawn and midday leaf water potentials, and we sampled needles, stems, and roots for non-structural carbohydrate concentrations regularly throughout the experiment. These measurements were used to elucidate patterns of stress resistance across species and populations, including different carbon allocation strategies. Historic climate variables from each population's seed source were compared to measures of heat and drought response. The experiment is ongoing and results will be available by September 2021. Our findings serve to improve our understanding of future responses of these trees to climate change induced stress, as well as the viability of conservation strategies such as outplanting.

Great Basin Bristlecone and Limber Pine in Great Basin National Park: First Look into the Long-Term White Pine Monitoring Efforts

by Nicole Hupp | Devin Stucki | Jeff Galvin | Bureau of Land Management | National Park Service, UCBN| National Park Service, MOJN

Keywords: NPS, bristlecone, limber pine, long-term monitoring

Great Basin National Park (GRBA) in north-central Nevada contains two white pine species, Great Basin bristlecone pine (*Pinus longaeva*) and limber pine (*P. flexilis*) forests. Together, these two species occupy over 3,000 ha within the Park. Like all white pines, these treasured forests are at risk of infestation by many threats including white pine blister rust (*Cronartium ribicola*), mountain pine beetle (*Dendroctonus ponderosae*), and dwarf mistletoe (genus Arceuthobium). To understand these risks, ecologists at GRBA, the Upper Columbia Basin Network Inventory & Monitoring Program (UCBN), and Mojave Desert Network Inventory & Monitoring Program created a white pine monitoring protocol. While GRBA specific, this protocol is a rendition of Mckinney et al (2013), which is implemented in three NPS long-term monitoring programs. The purpose of this monitoring project is to document and interpret changes in community dynamics in forests containing *P. longaeva* and *P. flexilis*. To do this, the protocol measures the following variables: Tree species composition and structure; Forest birth, death, and growth rates; Incidence of WBPR and level of associated crown kill; Incidence of mountain pine beetle and severity of tree damage; Incidence of dwarf mistletoe and severity of tree damage; Cone production of white pine species.

This program began in 2018 with a three-year rotating panel design. In 2020, all plots were established and measured once (n=30). Here we present some background on the details of this monitoring program and an initial assessment of the population. The results we share focus on status of white pines in GRBA; we do not yet have enough data to understand trends. We did find encouraging results of the initial sample: white pine blister rust was not present on any species in GRBA. Together, UCBN, GRBA, and MOJN provide an example of a collaborative long-term monitoring program that is designed to provide both short term and long-term information about white pines in GRBA.

Integrating Restoration Practices for Whitebark Pine with Climate Change Distributional Shifts

by Katie Ireland | Andrew Hansen | Robert Keane | Kristin Legg | MTDNRC, Sage Grouse Habitat Conservation Program | Montana State University, Department of Ecology | USDA Forest Service, Missoula Fire Sciences Laboratory | Inventory and Monitoring Division, Greater Yellowstone Network, National Park Service

Keywords: adaptive management, conservation, planning, status

Whitebark pine (*Pinus albicaulis*), a keystone species in subalpine forests of the northern Rocky Mountains, is expected to be vulnerable to climate-mediated shifts in suitable habitat, pests, pathogens, and fire. Adapting whitebark pine restoration practices to changing climates is a critical need for management of these forests. However, few existing climate adaptation frameworks prescribe where to place management actions to be most effective under anticipated future climate conditions. We developed three spatially-explicit management alternatives for whitebark pine in the Greater Yellowstone Ecosystem, including: (1) no active management, (2) current management, and (3) climate-informed management which used projected climate suitability for WBP and competing tree species to place management actions. Using a landscape simulation model, we evaluated the effect of these management alternatives on whitebark pine population under projected future climate conditions on two landscape within the Greater Yellowstone ecosystem. Using the FireBGCv2 simulation model, we evaluated the effect of these management alternatives on whitebark pine populations under projected future climate conditions on two landscapes within the Greater Yellowstone Ecosystem. Climate change impacts on whitebark pine differed amongst the two landscapes. Management actions had little impact on whitebark pine abundance in the Wind River Range of northeastern Wyoming, where increased fire frequency led to loss of competing tree species and large classes of trees, resulting in establishment of whitebark pine seedlings but an inability to mature due to frequent burns. In the Beartooth Mountains of Montana, white pine blister rust was the primary driver of whitebark pine mortality under future climate, so planting blister-rust resistant seedlings has the potential to mitigate some climate-driven loss of whitebark pine forests. These results suggest that climate change impacts on whitebark pine forests will be context- dependent and require restoration strategies customized to local conditions.

Restoring the Crown: A Plan for Whitebark Pine Restoration in the Crown of the Continent Ecosystem

by Melissa B. Jenkins | Anna W. Schoettle | Jessica W. Wright | US Forest Service (retired) | USFS, Rocky Mountain Research Station | USFS, Pacific Southwest Research Station

Keywords: Ecosystem services; range mapping; restoration plan; whitebark pine; Pinus albicaulis; effective population size; Crown of the Continent Ecosystem; reforestation

The Crown of the Continent Ecosystem (CCE) has experienced the highest levels of whitebark pine (*Pinus albicaulis*; WBP) mortality anywhere in the species range with >90% losses in some locations. This dramatic decline is due to a combination of mountain pine beetle (*Dendroctonus ponderosae*), effects of fire suppression, and the nonnative pathogen *Cronartium ribicola*, all of which have the potential to be exacerbated by climate change. The CCE spans 18-million acres in parts of Montana, British Columbia, and Alberta. While internationally recognized for its biodiversity and ecological integrity, the CCE is also very jurisdictionally fragmented which presents challenges when coordinating restoration efforts. This presentation describes a pilot approach done on three jurisdictions within the CCE to: 1) Assess the relative conservation value of WBP habitat with consideration of the individual jurisdiction's mission and mandates, and 2) Prioritize actions needed to ensure the persistence of functional, evolutionarily stable, WBP populations. An example from one national forest is provided where land managers have completed the final step of developing a long-term restoration plan that assigns site-specific restoration treatments. The original pilot approach has been modified based on lessons learned and has recently been used to guide a restoration strategy for both WBP and limber pine (*Pinus flexilis*) across the full CCE; preliminary results of that analysis will be covered briefly.

Whitebark & Worldview-2 - Looking into the Possibilities of Using Satellite Imagery to Distinguish Subalpine Tree Species

by Stephanie Jouvet | Brendan Wilson | Selkirk College | Selkirk College

Keywords: Whitebark, WorldView-2, remote sensing

Whitebark pine has the largest distribution of all the five-needle white pines in North America and can be found throughout western Canada and the United States. The pine is listed as endangered under the Canadian Species at Risk Act due to comprehensive impacts such as white pine blister rust, pine beetle, fire suppression and climate change. Understanding the species' distribution and occurrence will aid in establishing localized recovery strategies to help conserve this keystone species. Remote sensing has streamlined traditional field-based data collection methods, reducing the time and resources needed to map detailed forest information over large spatial extents. The objective of this research was to explore the use of multispectral satellite imagery (WorldView-2) to distinguish between whitebark pine and other two main subalpine species (Engelmann spruce and subalpine fir) within the Darkwoods Conservation Area in British Columbia. An Object-Based Image Analysis and the maximum likelihood classification algorithm was used to classify the WorldView-2 imagery. The mean spectral signatures of the three tree species had similar values across the eight bands available in the imagery, but Engelmann spruce has slightly lower

reflectance values in the Red Edge, NIR 1 & 2 bands. The overall producer's accuracy was 68.75% and the Kappa coefficient was 64.29%. Whitebark pine's individual accuracy was disappointingly low at 21%, compared to that of the spruce (68%) and fir (63%). The overall classification accuracies were relatively low compared to other studies conducting tree species classification. This could have been due to several factors including a smaller sample size of geo-referenced trees, the quality of reference data, and classification algorithm used. Future work will include collecting a more extensive dataset and exploring the combination of LiDAR and multispectral imagery, as well as other classification algorithms.

An Assessment of Whitebark Pine Populations in National Parks of the Pacific States

by Erik S. Jules | Phillip J. van Mantgem | Benjamin G. Iberle | Jonathan C.B. Nesmith | Regina M. Rochefort | Humboldt State University | U.S. Geological Survey | Humboldt State University | National Park Service | North Cascades National Park Service Complex

Keywords: Inventory & Monitoring Program, National Parks, Pinus albicaulis, matrix model, mountain pine beetle, white pine blister rust

Whitebark pine (*Pinus albicaulis*) is a long-lived tree found in high-elevation forests of western North America that is currently experiencing population declines across its range. We evaluated monitoring data from seven national parks in the USA, including Sequoia & Kings Canyon, Yosemite, Lassen Volcanic, Crater Lake, Mount Rainier, Olympic, and North Cascades national parks. We first summarized stand structure, presence of blister rust, and mountain pine beetle prevalence for each park. Next, we used a stochastic, size-structured population model constructed using separate, detailed demographic data from Crater Lake to forecast future trends in the parks under conditions of increased beetle activity and ongoing blister rust infection. Blister rust infected 29-54% of whitebark pine in all the parks except the two southernmost parks, Sequoia & Kings Canyon and Yosemite, where infections rates were 0.3% and 0.2%, respectively. Similarly, the proportion of dead trees in the two southernmost parks was low (0-1%), while they ranged from 10-43% in the other parks. Assuming Crater Lake conditions, model projections suggested an average population decline of 27% in the parks over the next century, though we do not expect these declines unless the parks experience marked increases in beetle prevalence and blister rust. Overall, blister rust was a common stressor in most parks we studied, while beetles appear to have impacted whitebark pine mortality most at Crater Lake. If climate change increases future beetle prevalence, then our study also illustrates the potential rates of whitebark pine decline given a scenario of increased pest outbreaks with simultaneous blister rust infections.

Overview of Whitebark Pine Restoration Efforts in U.S. Forest Service Regions 1, 2, and 4

by Ellen Jungck | USFS Northern & Intermountain Regions

Keywords: whitebark, management, planting, cone collection, relase & weed, mountain pine beetle protection

Individual and cooperative efforts with cone collection, planting and survival trends, release & weed and mountain beetle protection treatments, and gene conservation actions will be discussed. The evolution of cone collection and nursery techniques will be discussed, as will the development of sub-regional cooperative groups and associated conservation strategies.

Anatomy Measurements from Whitebark Pine (Pinus Albicaulis) In the Beartooth Mountains, WY Show Strong Seasonality Signal

by April L. Kaiser | Grant Harley | Georg von Arx | Maegen Rochner | University of Idaho | University of Idaho | Swiss Federal Institute WSL | University of Louisville

Keywords: dendroclimatology, paleoclimate, quantitative wood anatomy, whitebark pine

Whitebark pine (*Pinus albicaulis*) populations are declining across southern Canada and northwestern United States. In the Greater Yellowstone Ecosystem (GYE), whitebark pine populations are negatively impacted by increased temperatures, decreased snowpack, and increased disease occurrence. The nutrient-dense seeds from whitebark pine support grizzly bear *(Ursus arctos horribilis)*, Clark's nutcracker *(Nucifraga columbiana)*, and Douglas squirrel *(Tamiasciurus douglasii)* survival and reproductive health. Understanding how whitebark pine respond to variable climate conditions is critical for the continued legacy of the whitebark pine ecosystem and its dependent species. Quantitative wood anatomy (QWA) is a novel dendrochronological method such that anatomical and cellular features are quantified and analyzed in micro-resolution quality. Our study uses QWA methods to measure cellular parameters in whitebark pine from the GYE such as maximum radial cell wall thickness (CWT_{Rad}), hydraulic conductivity (Kh), and lumen area (LA). Whitebark pine CWT_{Rad} has a strong relationship ($p < 0.01$) with maximum temperature both spatially and temporally (1910-2017). Future climatic changes will likely continue to negatively impact whitebark pine populations unless climate mitigation strategies and continued whitebark pine recovery efforts are implemented.

Special Session: The North American Dendroecological Fieldweek (NADEF): Educational and Research Opportunities to Better Understanding 5-Needle Pines

Organizer: Maegen Rochner

Ecology and Distribution of Klamath Foxtail Pine

by Michael Edward Kauffmann | Ecologist

Keywords: Klamath foxtail pine, Pinus balfouriana subsp. balfouriana

California's endemic foxtail pines have established two esoteric populations abscinded by nearly 500 miles of rolling mountains and deep valleys. The species was first described by John Jeffrey in the Klamath Mountains near Mount Shasta in 1852. Later, this species was discovered in the high-elevations (9,000'-12,000') of the southern Sierra Nevada. The ecological context of Klamath foxtail pines (*Pinus balfouriana* subsp. *balfouriana*) in the Klamath Mountains differs drastically from that in the Sierra Nevada due to the divergence of these populations in the mid-Pleistocene (Bailey 1970). Michael Kauffmann has been working to understand the ecology and distribution of this species for nearly 20 years and will provide and update of his work.

Managing Wildfire for Whitebark Pine Ecosystem Restoration in Western North America

by Robert Keane | USFS RMRS Missoula Fire Sciences Lab

Keywords: wilfire, whitebark pine, suppression, fuel treatment, prescribed burning, partial suppression

Wildfire in declining whitebark pine forests can be a tool for ecosystem restoration or an ecologically harmful event. This presentation will detail a set of possible wildfire management practices for facilitating the restoration of whitebark pine across its range in Western North America. These management actions are designed to enhance whitebark pine resilience and health, while also being effective wildfire management measures. The actions are presented by the three phases of the wildfire continuum: Before, during, and after a wildfire. Current pre-wildfire restoration actions, such as mechanical thinning's, prescribed burning, and fuel treatments, can also be designed to be fuel treatment activities that allow more effective suppression of wildfires when needed. Three wildfire strategies can be implemented while the wildfire is burning—full suppression, partial suppression, and wildland fire use (letting some fires burn under acceptable conditions)—for protecting valuable whitebark pine trees and for ecosystem restoration. Finally, post-wildfire activities include planting rust-resistant seedlings and monitoring effects of the wildfires. Recommended wildfire management practices for the wildfire continuum are provided in this presentation.

Effective Actions for Managing Resilient High-elevation Five-Needle White Pine Forests in Western North America under Changing Climates at Multiple Scales

by Bob Keane | USFS Missoula Fire Sciences Lab

Keywords: landscape ecology, Clark's nutcracker, management strategy, whitebark pine, limber pine, restoration treatments, planting

Many ecologically important high-elevation five-needle white pine (HEFNP) forests that historically dominated the high-elevation landscapes of western North America are now being impacted by mountain pine beetle (*Dendroctonus* spp.) outbreaks, the exotic disease white pine blister rust (*Cronartium ribicola*), and altered high-elevation fire regimes. Management intervention using specially designed strategic tactics designed at both range- wide, landscape and stand levels are needed to conserve these keystone species. The goal of this intervention is to promote self-sustaining five-needle white pine ecosystems that have both resilience to disturbances and genetic resistance to white pine blister rust in the face of climate change. Many tools and methods are available for land managers, and in this paper, we summarize possible multi-scaled actions that might be taken as steps toward restoration of these valuable HEFNP forests. Long-term programs, such as inventory, mapping, planning, seed collection, nursery, education, and research provide the materials for effective restoration at finer scales. Stand- and landscape-level passive and active treatments, such as silvicultural cuttings and prescribed fires, in both healthy and declining forests are the foundation of HEFNP restoration and they are described in detail and grouped by objectives, methods, and tactics. And last, there are the proactive tree-level actions of planting and protection that may be used alone or to enhance success of other restoration actions. As with any range-wide restoration effort, the administrative, policy, legislative, and societal barriers to implementation of an effective restoration effort will also be discussed.

The Grizzly-Squirrel-Pine Nut Connection

by Kate Kendall | Ursine Ecological

Keywords: Tamiasciurus hudsonicus, Ursus americanus, Ursus arctos, black bears, caching behavior, feeding ecology, grizzly bears, red squirrels, whitebark pine seeds

In 1977, we knew that whitebark pine seeds were one of many grizzly bear foods in the intermountain west of North America. What we didn't know was the significance of this food source, how grizzlies were able to obtain cones or seeds, and if red squirrels played a role in making them available to bears. In this talk I provide a glimpse into my research and other's that answered these and other questions about the grizzly-squirrel-whitebark pine connection. Highlights include grizzlies digging through 3 m of snow to feed on cones in the spring, black bears with resin-encased club feet from harvesting sticky cones, feeding bears pine nuts in the zoo, and the Boone and Crocket record size squirrel cache of whitebark pine cones.

Whitebark Pine (Pinus Albicaulis) Growth and Defense in Response to Mountain Pine Beetle Outbreaks

by Nickolas Kichas | Sharon Hood | Gregory Pederson | Richard Everett | David McWethy | Montana State University | U.S. Forest Service | U.S. Geological Survey | Salish Kootenai College | Montana State University

Keywords: defense, growth, mortality, mountain pine beetle, resin ducts, whitebark pine

Whitebark pine (*Pinus albicaulis*) is a critical forest species of Northern Rocky Mountain upper subalpine ecosystems, yet little is known about the physiological response of whitebark pine to disturbance (e.g. fire, bark beetles, and pathogens) across a range of diverse environmental gradients. Resin–based defenses have long been recognized as the primary mechanism by which conifers respond to attack by bark beetles and pathogens and several studies have linked resin duct properties to survivorship during periods of increased beetle activity. However, to our knowledge, no studies have compared axial resin ducts in the secondary xylem of whitebark pine across pairs of living and dead whitebark pine trees to better understand survivorship following multiple disturbances including mountain pine beetle and white pine blister rust. We found a clear distinction in growth and defense characteristics between live and dead whitebark pine. Across our study sites on the Flathead Indian Reservation in northwestern Montana, live whitebark pine produced larger resin ducts with a greater annual investment in resin–based defenses than whitebark pine that died. Resin duct size, duct area, and relative duct area were all greater in live whitebark pine (by 56%, 48%, and 57%, respectively) and these were the most important variables influencing whitebark pine survivorship. In contrast, whitebark pine that had died grew faster over time (22% larger ring widths) than their live counterparts and also produced more resin duct structures (20% more ducts on average). Whitebark pine at our study sites exhibit differing strategies in the allocation of resources toward growth and defense, with the majority of survivors of recent disturbance investing more in defensive structures than growth. Our results support the idea that maintaining genetic variability and the associated suite of differing physiological traits promotes diverse response strategies to a complex array of biophysical and biological stressors that might leave a species vulnerable to extinction across its range.

Clark's Nutcracker Habitat Use and Breeding Ecology in a Heavily Impacted Whitebark Pine Ecosystem

by Vladimir Kovalenko | Diana L. Six | Lisa J. Bate | University of Montana | University of Montana | Glacier National Park

Keywords: Clark's nutcracker, Glacier National Park, breeding ecology, foraging ecology, habitat use, migration

This presentation outlines ongoing research in Glacier National Park, focusing on environmental and temporal drivers of Clark's nutcracker occupancy, use of the landscape, migration, and breeding behavior. With high rates of white pine mortality due to white pine blister rust, it is of interest whether the extant whitebark population in the park remains functional at a level that supports a breeding nutcracker population, as a declining bird population is unlikely to sustain natural whitebark regeneration.

The first objective of this study is to inventory whitebark stands throughout Glacier and provide an update on blister rust infection and mortality, as well as live basal area and cone production. Following the findings of previous research, the second objective is to relate these forest characteristics to nutcracker occupancy at the stand level, as well as migration and breeding ecology at the landscape level. We are also interested in whether higher nutcracker occupancy correlates with greater seedling density.

Previous research proposes that there is a threshold level of whitebark cone density below which nutcracker occupancy becomes highly unlikely. Additionally, research in the Greater Yellowstone Ecosystem suggests that in years of low whitebark cone production, birds are more likely to leave the ecosystem in winter and less likely to breed. Due to high white pine mortality, we seek to learn if nutcracker breeding still occurs in Glacier, even in a relatively good cone year. We are also interested in whether nutcrackers are caching sufficient quantities of seeds to remain in the ecosystem year-round; and if not, where they migrate to and whether they return.

Hold Your Fire: Whitebark and Limber Pine Regeneration Is Not Fire-Dependent in the Canadian Rocky Mountains

by Jodie Krakowski | Joyce Gould | Margriet Berkhout | Robin Gutsell | independent consultant | Office of the Chief Scientist, Alberta Environment and Parks, Government of Alberta | Rocky Mountain House Forest Area, Alberta Agriculture and Forestry, Government of Alberta | Species at Risk Stewardship, Alberta Environment and Parks, Government of Alberta

Keywords: fire, forest health, limber pine, regeneration, whitebark pine

Whitebark (WBP) and limber pine (LP) habitats in Canada's Rocky Mountains are moister and cooler than in the USA, with only limited regeneration-fire studies. We examined whether relationships between fire and regeneration in the USA held in Canada. Alberta Wildfire fuel and fire history assessment methods were streamlined to quickly collect key data while monitoring ~250 long-term WBP and LP plots in 2019. Around half (54% of 82 LP and 47% of 106 WBP) stands had no visible fire evidence. Neither latitude nor elevation significantly influenced regeneration density. Regeneration density weakly increased with LP tree density (LP: $R_2 = 0.22$, $p < 0.05$; WBP $R_2 = 0.07$, $p > 0.05$). Fire (presence/absence) did not significantly affect regeneration abundance or health in either species. However, recently burnt (< 20 years) LP stands had significantly less

total regeneration (181 sph) compared to unburnt stands (266 sph) or those with older (>20 years) burns (283 sph). In contrast, recently burnt WBP stands had more regeneration (504 sph) than unburnt stands (389 sph) or stands with old burns (165 sph), and also had significantly more rust infection in tall (50 – 140 cm) regeneration than in stands with no or old burns. This may reflect post- fire increases in understory vegetation, including blister rust hosts, especially in wetter sites that support WBP stands, whereas LP is more restricted to dry sites with sparse fuels. Our frequency and presence estimates for older fires are conservative and may have missed historical, unrecorded burns that require dendrochronology to confirm.

Walking the Talk: Alberta's Whitebark and Limber Pine Recovery Program

by Jodie Krakowski | Robin Gutsell | independent consultant | Species at Risk Stewardship, Alberta Environment and Parks, Government of Alberta

Keywords: disease resistance, endangered species, gene conservation, limber pine, recovery, seed orchard,seedlings, seeds, whitebark pine

Alberta established a multi-agency team in 2006 for recovery of whitebark (WBP) and limber pine (LP), listed as Endangered in 2008. The recovery team led data collection and developed recovery plans for WBP (2013) and LP (2014). The team refocused on provincial implementation, submitting a unified plan in 2019 reflecting recent progress. New external team members expand capacity and continue successful cross-jurisdiction information and resource sharing. Core to status and trends assessment is the network of ~250 long-term monitoring plots spanning the Canadian Rocky Mountain region. Spatial inventory and habitat models are published. Gene conservation seed collections include seed from over 200 LP and nearly 50 WBP putatively disease-resistant trees to date, with many in genetic screening. Their seeds produce seedlings for restoration planting of over 15,250 seedlings in over 78 hectares since 2018. Monitoring tracks success to adapt practices. A replicated WBP daylighting project was established in 2018. Rust-resistant WBP and LP seed orchards are in development and species-specific seed zones are established with supporting provenance trials through partnerships. Grafted scion from 30 resistant LP parents are planted in a seed orchard at Waterton Lakes National Park, with more pending to enhance genetic diversity and future seed production. Guidelines and best practices are shared with industry and agency staff for impact avoidance and mitigation, especially for irreplaceable disease-resistant trees and restoration projects. The slow growth, irregular cone crops, and extensive, remote ranges of these species necessitate a long-term commitment among diverse partners to for effective recovery.

Opportunities and Challenges for Uav/Drone Surveys of High-elevation Pine Forest

by Andrew Latimer | UC Davis

Keywords: drone photogrammetry, neural networks, tree mortality

Rates of disturbance, including fire and disease, have been increasing in many high- elevation forests. The effects at stand scale are often detectable from Landsat and other satellite time series of images, yet the effects on individual trees and the dynamics of local spread are too fine to be seen in this imagery. Drone imagery coupled with neural networks for image

segmentation and classification is becoming a powerful tool for surveying forest overstories at high resolution and may offer an intermediate-scale solution for surveying disturbance in these forests. We present results from surveys of lower-elevation conifer forests to demonstrate the method and show how accurate these surveys currently are. In mid-elevation mixed conifer forest, we can survey about 40 hectares/day, which corresponds to on the order of 10,000 individual tree crowns. Tree mortality is easy to evaluate from a distance with near-perfect accuracy, while species identification is more challenging. These methods promise to allow rapid surveys of forest composition and structure, and tree disease and mortality in high-elevation forests as well. Challenges, however, include more difficulty identifying individual trees, and morphological similarity between some growth forms the high five pines, as well as access for flights in wilderness areas.

What Have We Learned in 20 Years of Whitebark Pine Restoration in Glacier National Park?

by Rebecca Lawrence | Jennifer Hintz Guse | Glacier National Park | Glacier National Park

Keywords: Glacier National Park, monitoring, restoration

Glacier National Park has been dedicated to restoring five needle pine trees including limber and whitebark pine across the park landscape since 1998. In the ensuing decades we have been studying how to do this successfully and efficiently. Have we been effective in this and what have we learned? Since the start of the 20th century five needle pines in Glacier have been dying from white pine blister rust. Due to their importance as a keystone and foundation species, restoration efforts are critical to their continued survival in the park and for the hundreds of species that rely on the trees. From 2000 to 2020 crews have planted 23,608 whitebark seedlings throughout the park and approximately 21% of those trees have been monitored. 7071 limber seedlings have been planted from 2002 to 2017 on the east side of the park of which 25% were monitored. The data from early monitoring results have influenced subsequent plantings.

The overall survival of monitored whitebark seedlings is 48% and 17% for limber seedlings. This includes plantings in burned and unburned sites, as well as spring, late summer and fall plantings. The most successful plantings are generally in burned areas with success in both spring and fall plantings. Preliminary results suggest inoculation with a mycorrhizal slurry increases survival and growth, particularly when planted in a burn. As summers are getting warmer and drier continued attention to planting locations, exposure, elevation and weather conditions are increasingly important to the survival of planted five needle pine seedlings.

Special Session Organizer: Kristin Legg, kristin_legg@nps.gov

Special Session Title: Five Needle Pine Research, Monitoring, and Restoration in National Parks

Convergence and Conservation of Major Gene Resistance to White Pine Blister Rust in White Pines

by Jun-Jun Liu, Anna W. Schoettle, Richard Sniezko | 1. Canadian Forest Service – Pacific Forestry Centre, Natural Resources Canada, Victoria, BC, Canada. 2. USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO, USA. 3. USDA Forest Service, Dorena Genetic Resource Center, Cottage Grove, OR, USA.

Keywords: association study, comparative genetic mapping, major gene resistance (MGR), resistanceevolution, southwestern white pine

Major gene resistance (MGR) to white pine blister rust (WPBR) is found in four species of North American native white pines, including *Cr1-Cr4* in sugar pine (*Pinus lambertiana*), western white pine (*P. monticola*), southwestern white pine (*P. strobiformis*), and limber pine (*P. flexilis*), respectively. Their R loci determine phenotypic expression of MGR after infections by corresponding avirulent races of *Cronartium ribicola*. Understanding the molecular basis of phenotypic convergence would assist utilization of resistance resources in conservation and breeding. Previous genetic mapping works compared R loci from sugar pine (*Cr1*), western white pine (*Cr2*), and limber pine (*Cr4*) and mapped them on different *Pinus* consensus linkage groups (LGs). We performed phylogenetic analysis of their positional candidates of nucleotide binding site leucine-rich repeat (NLR) genes, demonstrating that they are not orthologous. Thus, convergence through independently parallel evolution appears to be responsible for the generation of R genes in these three species. In contrast, southwestern white pine has overlapping geographical ranges with limber pine, and hybrid zones between the two species allow gene flow. Using genotyping arrays with *Cr4*-linked SNPs, association mapping of southwestern white pine *Cr3* was performed to examine if MGR trait convergence with limber pine is caused by a shared orthologous locus. Our evidence suggests that conservation of an ancient MGR specificity may be present and shared between the two species, which may reflect an ancient mechanism, presumably without coevolved interaction with *C. ribicola*, through either descent from an ancestral progenitor, or relatively recent introgression from one to another.

Assessment of Cumulative Whitebark Pine Mortality in the Greater Yellowstone Ecosystem

by William W. Macfarlane | Brian Howell | Jesse A. Logan | Chad Garlick | Gabe Henry | Robert E. Spangler | Utah State University | USDA Forest Service | Retired: USDA Forest Service | Utah State University | Utah State University | U. S. Fish and Wildlife Service

Keywords: Cronartium ribicola, Dendroctonus ponderosae, GIS, Greater Yellowstone Ecosystem (GYE), Landscape Assessment System (LAS), Mountain pine beetle, Pinus albicaulis, aerial survey method, climate change impacts, pest monitoring, white pine blister rust, whitebark pine

An aerial survey method called the Landscape Assessment System (LAS) was used to assess mountain pine beetle (Dendroctonus ponderosae; MPB) - caused mortality of whitebark pine (*Pinus albicaulis*) across the Greater Yellowstone Ecosystem (10,232 km2; GYE). This large- scale implementation of the LAS method consisted of 12,300 km of flightlines, along which 4,434 geo-tagged, oblique aerial photos were captured and processed. The Mountain Pine Beetle-caused Mortality Rating System, a landscape-scale classification system designed specifically to measure the cumulative effects of recent and older MPB attacks on

whitebark pine, was used to classify mortality. A rating of none to severe (0-4.0 recent attack or 5.0-5.4 old attack) was assigned to each photo based on the amount of red (recent attack) and gray (old attack) trees visible. The approach produced a photo inventory of 74 percent of the GYE whitebark pine distribution by area. For the remaining 26 percent of the distribution, mortality levels were estimated based on an interpolated mortality surface. Catchment level results that combine the photo-inventoried and interpolated mortality indicate that 44 percent of the GYE whitebark pine distribution showed severe old attack mortality (5.3-5.4 rating), 37 percent showed moderate old attack mortality (5.2 to 5.29 rating), 19 percent showed low old attack mortality (5.1-5.19 rating) and less than 1 percent showed trace levels of old attack mortality (5.0-5.09). No catchment was dominated by recent attacks indicating that the outbreak of the early 2000's has ended and that current MPB populations are likely low, but not eliminated. As weather once again becomes favorable for MPB, these endemic populations are once again capable of explosive population growth and if there are available whitebark pine to serve as food future MPB outbreaks in are possible. Spatially explicit mortality information produced from this assessment is efficient for targeting restoration and conservation management at a landscape scale. Given the level of mortality and whitebark pine's important role as a foundation and keystone species, future research aimed at monitoring mortality and understanding the cascading effects of widespread decline of this species on wildlife, hydrology, and forest structure and function is warranted.

Alpine Treeline Ecotones Are Potential Refugia for a Montane Pine Species Threatened by Bark Beetle Outbreaks

by Colin Maher | University of Alaska Anchorage

Keywords: Pinus albicaulis, boundary, climate change refugia, edge, mountain pine beetle, tree mortality, whitebark pine

Warming-induced mountain pine beetle (*Dendroctonus ponderosae*; MPB) outbreaks have caused extensive mortality of whitebark pine (*Pinus albicaulis*; WBP) throughout the species' range. In the highest mountains where WBP occur, they cross alpine treeline ecotones (ATEs) where growth forms transition from trees to shrub-like krummholz – some of which survived recent MPB outbreaks. This observation motivated the hypothesis that ATEs are refugia for WBP because krummholz growth forms escape MPB attack and have the potential to produce viable seed. To test this hypothesis, we surveyed WBP mortality along transects from the ATE edge (locally highest krummholz WBP) downslope into the forest and – to distinguish if survival mechanisms are unique to ATEs – across other forest ecotones (OFEs) from the edge of WBP occurrence into the forest. We replicated this design at 10 randomly selected sites in the US Northern Rocky Mountains. We also surveyed reproduction in a subset of ATE sites. Mortality was nearly absent in upper ATEs (mean ± 1 s.e. % dead across all sites of 0.03 ± 0.03% 0-100 m from the edge and 14.1 ± 1.7% 100-500 m from the edge) but was above 20% along OFEs (21.4 ± 5.2% 0-100 m and 32.4 ± 2.7% 100-500 m from the edge). We observed lower reproduction in upper ATEs (16 ± 9.9 cones·ha^{-1} and 12.9 ± 5.3 viable seeds·cone^{-1} 0-100 m from the edge) compared to forests below (317.1 ± 64.4 cones·ha^{-1} and 32.5 ± 2.5 viable seeds·cone^{-1} 100-500 m from the edge). Uniquely high WBP survival supports the hypothesis that ATEs serve as refugia because krummholz growth forms escape MPB attack. However, low reproduction suggests ATE refugia function over longer time periods. Beyond our WBP system, we propose that plant populations in marginal environments are candidate refugia if distinct phenotypes result in reduced disturbance impacts.

Winter Damage Is More Important than Summer Temperature for Maintaining the Krummholz Growth Form above Alpine Treeline

by Colin Maher | University of Alaska Anchorage

Keywords: Pinus albicaulis, growth limitation, krummholz flags, plant-climate interactions, snow transport, treeline ecotone, whitebark pine, wind

Understanding the processes that control alpine treelines, the elevational limits of tree growth forms, has been a central question in ecology and is growing in importance with concern over climate change. Cool summer air temperatures are currently thought to be the ultimate limiter of upright tree growth at alpine treelines globally. However, winter damage has long been recognized as a shaping force near alpine treelines. Low-growing krummholz growth forms provide an opportunity to test hypotheses about the controls of upright growth in environments above current treelines.

To distinguish between effects of growing season temperature, winter damage and their interaction on preventing upright growth in krummholz, we conducted a field experiment on krummholz growth forms of *Pinus albicaulis* over the summer and winter of 2015-2016 at 10 mountain top sites in the Tobacco Root Mountains, Montana, USA. We experimentally manipulated four factors using a fully crossed design: shoot position (natural low position in the krummholz mat vs. propped up above the krummholz mat), summer warming (warming chamber vs. ambient), winter exposure (shelter cage vs. exposed), and elevation position (local high vs. low krummholz limits). We also conducted an observational study of the climatic conditions associated with recent natural emergent stem establishment from krummholz.

Experimentally propped shoots that were exposed in winter experienced the highest mortality (10-50%), while propped shoots in shelter cages and shoots located within the krummholz mat, whether caged or not, had low mortality (0-10%). Summer warming had little influence on shoot mortality. Surviving mat shoots had marginally higher growth rates than surviving propped shoots during the early growing season after treatments were established. Natural emergent stem establishment was associated with warmer than average summer temperatures, but also warmer winter temperatures, lower winter wind speeds, and lower snowpack.

Synthesis. Our results suggest winter damage plays a more important role than does growing season temperature in maintaining the krummholz growth form. While warming may increase opportunities for emergent shoot establishment above krummholz mats, establishment of upright trees in the krummholz zone will also

Long-Term Assessment of the Efficacy of Prescribed Burning and Mechanical Thinning for Restoration of Whitebark Pine

by Enzo Martelli | Cara R. Nelson | Robert E. Keane | Andrew Larson | Department of Ecosystem and Conservation Sciences, W.A. Franke College of Forestry and Conservation, University of Montana, 32 Campus Drive, Missoula, MT, USA | Department of Ecosystem and Conservation Sciences, W.A. Franke College of Forestry and Conservation, University of Montana, 32 Campus Drive, Missoula, MT, USA | USDA Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory, Missoula, MT | Wilderness Institute and Department of Forest Management, University of Montana, 32 Campus Drive, Missoula, MT, USA

Keywords: ecological succession, mechanical thinning, natural regeneration, prescribed burning, restoration, tree mortality

Whitebark pine (*Pinus albicaulis*), an ecologically important tree of high-elevation ecosystems of western North America, is declining across most of its range due to the combined effects of an invasive pathogen, episodic native insect outbreaks, climate-change- induced increases in wildfire frequency and severity as well as successional replacement due to fire suppression. Concern over these threats has led to the listing of whitebark pine as an at-risk species under both the US and Canadian Endangered Species Acts and an increase in restoration and conservation activities. Prescribed burning and thinning have been proposed as primary strategies for restoration. However, there is only limited available information on the efficacy and effects of these treatments, and projects that have been evaluated have shown highly variable results, suggesting that monitoring is a priority need. We used a 20-year, replicated before-after-control-impact (BACI) study to assess the effects of prescribed burns and mechanical cuttings on rates of whitebark pine mortality, natural regeneration, and successional replacement by shade-tolerant conifers in the northern Rocky Mountains of the United States. Rates of whitebark pine mortality (plot percentage) were 9% lower and 4% higher than control plots for thinned and burned plots, respectively. Natural regeneration (ind./acre) was 25% lower and 30% higher than control plots for thinned and burned plots, respectively. Basal area (sq. m./ha) reduction of competing conifers was of 22% and 25% higher than control plots for thinned and burned plots, respectively. Since the implementation of this experiment in the mid-90's, whitebark pine communities have shown a significant increment in mortality of mature trees and reduced natural regeneration in addition to the treatments effect. These results indicate that active management is an effective strategy to mitigate the effect of current threats, where trade-off's includes promoting natural regeneration at the cost of greater tree mortality.

Clark's Nutcracker Conifer Resource Use in Yellowstone National Park: A Hierarchical Distance Sampling Approach

by Thomas McLaren | Diana Tomback | Nels Grevstad | Walter Wehtje | Doug Smith | Lauren Walker | University of Colorado Denver | University of Colorado Denver | Metropolitan State University Denver | Ricketts Conservation Foundation | Yellowstone Center for Resources | Yellowstone Center for Resources

Keywords: Clark's nutcracker, Yellowstone National Park, foraging ecology

Clark's nutcrackers (*Nucifraga columbiana*) harvest and cache seeds from many western conifer species, contributing to tree regeneration. Multiple seed resources within a region are required to sustain nutcracker populations but especially seeds of whitebark pine (*Pinus albicaulis*), a preferred but declining species. Many conifer species are known to display high variability in annual cone production, resulting in variable food resources for seed foraging species. These variations in seed resource availability are thought to be an important factor in nutcracker habitat use, in part, due to their energy sensitive foraging behavior.

In this study, we examined how nutcrackers use conifer forest community types within Yellowstone National Park to determine all potential seed resources. In 2019 and 2020, we established eleven transects in five different forest community types including whitebark pine, lodgepole pine, Engelmann spruce, limber pine and Douglas-fir. Each transect consisted of five point-count stations, and used distance sampling methods, relative cone abundance indices, and behavioral observations to determine habitat and seed resource use. Using annual cone abundance indices collected along our transects, we analyzed how cone production varies between conifer species and across years. To determine which forest community types in the park are used by nutcrackers within a season and how variation in cone production influences their use within and across years, we applied a hierarchical approach to habitat use modeling using distance observations to estimate detectability within each forest community type in a regression modeling framework.

Ecological Integrity of Whitebark Pine on National Forests in California

by Marc Meyer | Michele Slaton | Shana Gross | Ramona Butz | Carol Clark | USDA Forest Service, Region 5 Ecology Program | USDA Forest Service, Region 5 Remote Sensing Laboratory | USDA Forest Service, Region 5 Ecology Program | USDA Forest Service, Region 5 Ecology Program | USDA Forest Service, Region 5 Remote Sensing Laboratory

Keywords: California, ecological integrity, national forests, whitebark pine

Whitebark pine (*Pinus albicaulis*) forest ecosystems in California are diverse and unique, yet their current status and condition are uncertain. Using a combination of geospatial and monitoring plot data, we assessed the ecological integrity of whitebark pine ecosystems primarily on national forests throughout the state of California. We found whitebark pine ecosystems to be structurally, compositionally, and functionally distinct among subregions of California, and all subregions displayed some evidence of declining ecological integrity. Whitebark pine forests in northern California exhibited signs of greater stand densification (Cascade-Klamath), potential encroachment by shade-tolerant conifer species (Cascade- Klamath and Warner Mountains), and increased tree mortality

associated with mountain pine beetle outbreaks (Warner Mountains) than elsewhere in California. Whitebark pine stands in the Sierra Nevada showed signs of stand densification (central Sierra) and localized mountain pine beetle outbreaks (southern Sierra east). Notwithstanding these negative signs, much of the state's whitebark pine ecosystems on national forestlands appear to be relatively healthy and intact compared to more northern latitudes. Active management may be required to restore and build adaptive capacity in California's whitebark pine ecosystems with declining integrity.

Special Session title: High-elevation white pine communities in the Pacific West Region Special Session organizer: Jonny Nesmith

Population Structure and Genotype-Environment Associations of Whitebark Pine in the Sierra Nevada

by Elizabeth R Milano | Amy G. Vandergast | Phillip van Mantgem | Joan Dudney | Jonathan Nesmith | Harold Zald | U.S. Geological Survey | U.S. Geological Survey | U.S. Geological Survey | UC Berkeley | USDA Forest Service | USDA Forest Service

Keywords: Sierra Nevada, drought response, genomic population structure, genotype environment association, whitebark pine

Whitebark pine is a long-lived keystone species in subalpine ecosystems of western North America. Though the species has experienced rapid decline due to threats associated with a changing climate, whitebark pine in the Sierra Nevada has shown a less dramatic overall decline. The Sierra Nevada is the southern range limit of the species distribution and whitebark pine in this region show a variable response to specific biotic stressors, making these populations worthy of further investigation. Our genomic study is part of a multidisciplinary effort to investigate the response of whitebark pine in the Sierra Nevada to a major abiotic threat, extreme drought. Specifically, our aim was to measure genomic diversity and characterize the neutral and selective forces that contribute to that variation. We estimated population structure to identify the pattern of neutral variation within and between occurrences. We then used redundancy analysis, a genotype-environment association analysis, to identify specific genetic loci associated with drought indicative climatic predictors. We found whitebark pine occurrences to be well connected in the Sierra Nevada with a moderate trend of isolation-by-distance and slightly elevated diversity in the south. We also found that 1% of the total genetic variation was significantly associated with a select set of climate variables. Of the 1,270 outlier loci identified, 39% were most associated with climate water deficit, 22% with minimum temperature, 20.5% with actual evapotranspiration, and 18% with annual precipitation. These results lay a groundwork for further investigation into genotype-phenotype associations and genotype-by-environment interactions and provide a set of climate associated loci for future monitoring efforts.

Whitebark Pine Recruitment Following Timber Harvest

by Randy Moody | Ken Wright | Moody Tree | Moody Tree

Keywords: Whitebark pine, silviculture, timber harvest

On many sites whitebark pine (*Pinus albicaulis*) recruitment is closely linked with disturbance, which provides suitable conditions for early seral species, such as whitebark pine, to establish and gain a competitive advantage on late seral species which are often more rapidly growing, and more shade and competition tolerant. Fire is the most frequent stand initiating disturbance resulting in whitebark pine stand initiation, and prescribed fire is commonly applied across the landscape to restore whitebark pine ecosystems.

Like fire, timber harvest presents an opportunity to re-initiate whitebark pine on the landscape as it creates early seral conditions suitable for whitebark pine recruitment. The openings created by timber harvest are often viewed as a potential restoration opportunity; however, the post harvest objective is typically to reforest a site with commercial species to support future timber harvest. The objective of this study was to identify the levels of whitebark pine recruitment into harvest areas and determine if recovery gains were present. We surveyed regeneration levels of all species in five harvest areas ranging in age from five to 26-years. Whitebark pine was present in at all sites with densities ranging from 15 to 1435 stems/ha; rust levels were generally low ranging from 0-18% infection. Although whitebark pine densities were high and rust levels low, at no site was whitebark pine common in the tallest cohort and generally only represented up to 26% of the stems on a site. Although harvest areas provide good sites for whitebark pine recruitment, the trajectory to taller size classes appears unlikely. We recommend reduced commercial species planting in areas with advanced whitebark pine regeneration or thinning activities to improve site conditions and to improve the probability of advancing trees to mature size classes.

Whitebark Pine Tree Improvement and Operational Management on the Helena-Lewis and Clark National Forest

by Tanya E Murphy | Matthew O Voigt | USDA Forest Service | USDA Forest Service

Keywords: cone collection, daylight thinning, management, planting, restoration, scion, seed orchard, test plantation, tree improvement, whitebark pine

Whitebark pine (*Pinus albicaulis*) is present in a pure or mixed conifer stand condition on approximately 4 percent of the Helena-Lewis and Clark National Forest. Although relatively small in quantity, management of whitebark pine has been at the forefront of the silviculture program of work for the last 25 years. The Forest actively participates in whitebark pine tree improvement as part of the Northern Region Genetic Resource Program and Intermountain Whitebark Pine Restoration Program with the objective of producing seed with improved white pine blister rust resistance. The Forest manages the Adams Creek Central Montana seed zone whitebark pine seed orchard, two performance test plantations, and 88 plus trees. Operational management, such as whitebark pine planting, daylight thinning and prescribed fire, has also been implemented to assist with restoration of this valuable species. The Northern Region, State and Private Forestry Forest Health Protection, and the National Forest Foundation have funded the Forest's restoration efforts. Find out what it takes to manage a seed orchard and 88 plus trees, establish and monitor performance test plantations, and collect cones, scion, and aeciospores to fulfill Northern Region's tree improvement mission, as well as implement restoration activities across a 2.9-million-acre land base.

How to Log Whitebark Pine Stands

by Michael Murray | BC Forest Service

Keywords: Harvest retention, silviculture, windthrow

Knowledge of post-harvest survivorship and factors that promote successful retention of whitebark pine in mixed-conifer forests is lacking. The objective is to describe the temporal attrition of retained mature whitebark pine trees and to identify factors that likely influence survivorship during the critical initial post-harvest period. Five separate harvest units in southeastern British

Columbia were assessed. Dendrochronological investigation revealed that retained trees experienced high annual mortality rates (3-16%) across harvest sites during the initial five-year post-harvest interval. By eight years post-harvest, retention survivorship ranged 17-80%. After eight years post-harvest, mortality rates became low. The preponderance of fallen stems oriented towards the northeast suggests that storm system events arriving from the Pacific Ocean are the most significant drivers of blowdown. Survivorship is positively associated with shorter tree heights and longer crown lengths, lower frequencies of disease cankers, greater presence of rodent wounding, and higher numbers of surrounding retained trees. There was little effect based on slope and aspect or distance to forest edge. As an endangered species, harvest operations should practice cautiously when in associated forests. I recommend carefully selecting retention trees, ensuring an adequate number of neighbor trees, and positioning retention patches to avoid predominant storm wind directions.

The Whitebark Pine Genome Project

by David Neale | WPEF

Keywords: reference genome

The primary goal of the Whitebark Pine Genome Project is to develop genetic marker technology that can be used to measure and monitor genetic diversity in whitebark pine populations undergoing restoration. Genetic markers of several types have been used in whitebark pine for many years, but for the most part these markers interrogate non-coding, and thus selectively neutral, regions of the genome. Genetic markers are urgently needed to measure white pine blister rust resistance and adaptation to the environment. For this requirement, genetic markers from protein-coding regions of the genome are needed. Such genetic markers can only be developed following deep transcriptome or full genome sequencing. Transcriptome resources do exist for whitebark pine, but a complete genome sequence has not been produced. The specific objectives of the Whitebark Pine Genome Project are:

1. Sequence, assemble and annotate a complete genome sequence.
2. Identify genes determining white pine blister rust resistance and genes determining adaptation to the environment. This will be done through a combination of genome wide association studies (GWAS) and environmental association analysis (EAA).

Once objectives 1 and 2 are completed, there will be a set of genetic markers that can be used in applied programs to measure and monitor white pine blister rust and adaptation to the environment in populations undergoing restoration.

Effective Monitoring and Evaluation of Whitebark Pine Restoration Treatments—Key to Adaptive Management and Future Applications

by Cara R Nelson | Diana Tomback | Bob Keane | University of Montana | University of Colorado | US Forest Service

Keywords: adaptive management, evaluation, monitoring, restoration, success

Whitebark pine restoration remains, to a large extent, experimental, and we are still exploring the methods to achieve desired conditions. This is especially true with respect to the effectiveness of prescribed burning and silvicultural treatments in meeting treatment goals. To date there is only limited information on outcomes from these treatments and results indicate mixed success. Although monitoring project success and applying outcomes to improve future project implementation are essential aspects of the restoration process, monitoring is often not included in projects or is not done with a sampling design that allows inference. Here, we cover basic approaches to evaluating project success including implementation, efficacy, and effects monitoring, as well as design considerations for each category. Specifically, we discuss when the use of reference stands or models is required, and why sampling both treated and control stands before and after treatment is necessary to determine whether the treatment had an effect. We will also discuss how to determine required replication of monitoring plots and methods for evaluate the efficacy of a monitoring design to avoid over- or under-sampling. Finally, we propose to establish a monitoring network to assist managers with developing and implementing monitoring programs for whitebark pine restoration and for sharing lessons learned. The overall objective is to motivate managers and scientists to increase their engagement in monitoring activities and to provide some tools to improve monitoring practice.

Monitoring the Effects of Prescribed Burning on Whitebark Pine

by Cara R. Nelson | University of Montana

Keywords: burning, mortality, prescribed fire, restoration

Whitebark pine (*Pinus albicaulis* Engelm.) is a keystone species of high-elevation ecosystems that provides hydrologic regulation, nutrient-rich food for wildlife, and unrivaled scenery for wilderness enthusiasts. However, this important tree and the goods and services it provides is in decline, due to the combined effects of altered fire regimes, climate change, white pine blister rust (Cronartium ribicola) and mountain pine beetle (Dendroctonus ponderosae). Despite widespread interest in using prescribed burning as a restoration tool, there is little information on the ecological effects of these treatments at the stand or individual tree level. We were awarded funding through the FHP program to assess the effects of prescribed burning on whitebark pine ecosystems by sampling understory plant dynamics, seedling density, tree growth and mortality, and rates of insect and disease infection at two 5-ha sites in the Mission Mountains of Montana using a before-after-control-impact design. Trees in both the control and treated stands had high rates of blister rust infection prior to treatment (ca. 50%). Pre-treatment sampling occurred during summer 2013 and 2014, the burn was implemented in fall 2014, and post-treatment sampling occurred in summer 2015 and 2016. During the two-year period after burning, 40% of mature whitebark pine trees in the treated stand died (31% in year 1 and 7% in year 2). Nearly 20% of the mature whitebark in the treated stand were scorched up into their canopies; all of these trees died. Another 20% of mature trees in the treated stand had bole scorch up to two meters in height; 60% of these trees died. Three trees that did not have any evidence of scorch also died; two of these showed evidence of blister rust infection prior to the burn. In comparison, there was no mortality of whitebark trees in the control stand. We plan to continue to monitor the Mission Mountain sites, and hope to adaptively add additional prescribed fire sites, in order allow for broader spatial and temporal inference about the effects of prescribed fire on whitebark ecosystems.

Whitebark Pine in Yosemite, Sequoia, and Kings Canyon National Parks: Assessment of Stand Structure and Condition

by Jonathan Nesmith | Micah Wright | Erik Jules | Shawn McKinney | USFS PNWRS | Humboldt State University | Humblodt State University | Fire Sciences Laboratory, Rocky Mountain Research Station

Keywords: Inventory & Monitoring, Sierra Nevada, mountain pine beetle, white pine blister rust, whitebark pine

Whitebark pine is a foundational species in many subalpine ecosystems and has experienced severe population declines. Here we present results on the status of whitebark in the southern Sierra Nevada of California, collected as part of the National Park Service Inventory and Monitoring Program. We selected random plot locations in Yosemite, Sequoia, and Kings Canyon national parks using an equal probability spatially-balanced approach. Tree- and plot-level data were collected on forest structure, composition, demography, cone production, crown mortality, and incidence of white pine blister rust and mountain pine beetle. We measured 7,899 whitebark pine, 1,112 foxtail pine, and 6,085 other trees from 2012–2017. Whitebark pine occurred in nearly-pure krummholz stands at or near treeline and as a minor component of mixed species forests. Less than 1% of whitebark pine were infected with white pine blister rust and <1% of whitebark pine displayed symptoms of mountain pine beetle attack. Whitebark pines in the southern Sierra Nevada are relatively healthy compared to other portions of their range where population declines have been significant and well documented. However, increasing white pine blister rust and mountain pine beetle occurrence, coupled with climate change projections, portend future declines for this species, underscoring the need for broad-scale collaborative monitoring.

Special session title: From genes to tree-rings: characterizing long-term climate drivers and extreme drought effects on Sierra Nevada whitebark pine

Special session organizer: Joan Dudney & Elizabeth Milano

Status of Whitebark Pine: Where We Go from Here

by Amy Nicholas | Sean Sweeney | Lisa Solberg Schwab | Ben Solvesky | Julie Reeves | Doug Keinath | USFWS | USFWS | USFWS | USFWS | USFWS | USFWS

Keywords: endangered species act, proposed rule

On December 2, 2020, the U.S. Fish and Wildlife Service (Service) published a proposed rule (85 FR 77408) to list the whitebark pine (*Pinus albicaulis*) as a threatened species under the Endangered Species Act of 1973, as amended (16 U.S.C. 1531 et seq.) (Act). Included in the proposed rule is a special rule pursuant to section 4(d) of the Act that identifies actions necessary to conserve and recover the whitebark pine, as well as a limited number of prohibited acts (85 FR 77408). While the proposed 4(d) rule would not relieve federal agencies of their consultation obligations under section 7 of the Act, it includes exceptions that allow for optimal, flexible, and adaptive forest management activities conducted by Federal agencies that can advance whitebark pine conservation. Designation of critical habitat (CH) was deemed not prudent for the whitebark pine, hence CH was not proposed. Should the proposed listing become finalized in early 2022, the Service will

take further steps including but not limited to: 1) Initiation of recovery planning in concert with external partners currently developing a range-wide Restoration Plan and 2) Development of a programmatic consultation(s) for the species in order to streamline the consultation process for project-related actions that may affect whitebark pine.

Whitebark Pine Regeneration Densities, Niche, and Dynamics Three Decades after the 1988 Yellowstone Fires

by Elizabeth Pansing | Diana Tomback | American Forests | University of Colorado Denver

Keywords: microsite, regeneration, wildfire

Although wildfires provide whitebark pine regeneration opportunities and prevent successional replacement by faster growing conifers, increasing fire frequency and severity threaten the persistence of this imperiled species. The 1988 Yellowstone fires, harbinger of future fire regimes under climate warming, provided an opportunity to characterize the post-fire whitebark pine regeneration niche and timeline to canopy closure. In 1990, 275 permanent plots (20m2), stratified by relative moisture availability (xeric, mesic), were established at two study areas, Henderson Mountain (HM) and Mount Washburn (MW), in areas that experienced stand-replacing fire during the 1988 Yellowstone fires and in adjacent unburned forest. We surveyed for whitebark pine regeneration during seven remeasurements between 1990 and 2017 and determined recent stand age-structure, annual regeneration density, growth rates, common microsites, and annual survival rates.

Whitebark pine regeneration density increased with time and differed with moisture availability. Although regeneration densities were similar over time at HM, densities increased more quickly in mesic than xeric sites at MW. Most recent regeneration densities ranged from 0.05 to 0.4 and 0.05 to 1.0 stem/m2 at HM and MW, respectively. At MW, median density was higher in mesic (0.45 stems/m2, IQR: 0.25, 0.65) than xeric (0.10 stems/m2, IQR: 0.05, 0.1) sites, whereas median densities were similar across sites on HM (~0.10 stems/m2). Stand age structure in xeric sites was uniform, whereas mesic sites were dominated by individuals that germinated 5-10 years after fire. Higher seedling growth rates were more likely in mesic than xeric and burned than unburned sites. Regeneration occurred in microsite types including open sites, vegetation, near deadfall, and near other regenerating conifers; common substrates included duff, woody debris, and ash/soot. Differences in regeneration density, growth rates, and microsite types potentially may be explained by topography, microclimate, and increasing water deficits caused by increasing temperature.

Does Drought Response Change with Parental Ancestry across a White Pine Hybrid Zone?

by Lulu Peach | Northern Arizona University / Washington State University

Keywords: adaptation, genetics, hybridization, models, pines

Hybrids of *Pinus strobiformis* (PIST) and *P. flexilis* (PIFL), two high-elevation, five-needle white pine species, have genetic variation associated with climatic gradients across the southwestern U.S. Our goal was to explore the relationship between hybrid index (percentage of ancestry conferred to a hybrid offspring by PIST) and tree-ring-based growth responses to

historical drought (or, dendrophenotypes) in order to (1) draw connections between hybrid index, climate-related variables, and tree-ring sensitivity, (2) test for a relationship between four selected dendrophenotypes and hybrid index, and (3) develop multivariate models to predict dendrophenotype based on hybrid index and a variety of environmental covariates. To develop dendrophenotypes, we dated and measured tree rings on cores from 104 trees at 9 geographic sites from Texas to Colorado. We used transformed raw ring measurements to calculate and used these calculations, hybrid indices, and environmental covariates to address our three objectives We found (1) strong, positive correlations between monsoon index (defined as the percentage of annual precipitation received in summer) and hybrid index and between monsoon index and tree-ring sensitivity, as well as significant correlation between hybrid index and other water-availability gradients in the hybrid zone. In addition, we observed (2) weak, positive, but non-significant relationships between two dendrophenotypes (Rc and W:D) and hybrid index and (3) no strong predictive relationships from our final multivariate models. Future research on the effects of hybrid inheritance on growth during drought periods should consider using a larger sample size including more hybrids with greater PIFL ancestry and available single- nucleotide polymorphism (SNP) data in a genotype-phenotype analysis (GPA) in order to improve understanding of future drought responses and management options.

Whitebark Pine Restoration on the Flathead Indian Reservation: Tribal Cultural Benefits Reaped from New Management Strategies

by ShiNaasha Pete | Confederated Salish and Kootenai Tribal Forestry

Keywords: Confederated Salish and Kootenai Tribal Forestry, Whitebark Pine

Today on the Confederated Salish and Kootenai Indian Reservation in Northwest Montana, a conifer species called Whitebark pine is suffering from ramifications of insect and disease, fire suppression, and climate change. Whitebark pine is a keystone species that grows in the upper subalpine and timberline forests of their surrounding mountains. Losing this tree will have a negative effect on animal and plant habitats, contributing an imbalance to different ecosystems below. The Tribe will lose not only a "First Food" of the people (a plant species with a long tradition in the diet and culture), but the Reservation's land and water quality will alter from the loss of different species, mountain snowpack, and erosion. This study explores how the Confederated Salish and Kootenai Tribal Forestry have been restoring the proposed endangered species Whitebark pine across the suitable habitats on their reservation. The Tribes' efforts include scouting appropriate locations for collecting cones, harvesting seeds for planting, and testing for genetic resistance against the fungus called White pine blister rust; which is annihilating Whitebark pine stands in the northwest. The Tribe collaborates with researching groups, and other tribal natural resource entities, applying silviculture practices, and helping create healthy sustainable forest. The findings show that the Whitebark Pine Restoration is successfully moving forward, but more importantly the Confederated Salish and Kootenai Tribes are reconnecting to a part of their ancestral teachings and history by restoring this first food. The results show with continued focus in conserving Whitebark pine across the Reservation and sharing the cultural history between plant, animal, and man; it protects a future for this threatened species, the Salish and Kootenai culture, and the future generations to come.

Does Interannual Availability of Cones Affect Clark's Nutcracker Caching in Burns and Habitat Selection

by Vernon S. Peters | Darren s. Proppe | Janae L. Vriend | Evan K. Buist | Kaleigh S. Greidanus | The King\'s University | St. Edward\'s University | The King\'s University | The King\'s University | The King\'s Univesity

Keywords: Burns, Caching, Limber, Nutcrackers, Whitebark, acoustic analyses

Whitebark pine (*Pinus albicaulis*) and limber pine (*Pinus flexilis*) are endangered species that rely on fire for regeneration to varying degrees at their northern range limit. Despite the crucial role that Clark's nutcrackers (*Nucifraga columbiana)* play in 5-needle pine ecology, no direct assessment of their presence and caching activity has been made in Canada. We tested whether nutcracker activity differed between mast (2018) and non-mast years (2019), on a 2009 fire with burned whitebark and limber pine habitat. We examined three sites for each species, at varying distances into the fire to determine whether nutcracker activity varied between unburned seed sources and burned sites. We used Ravenpro and Kaleidoscope acoustic analysis software to quantify nutcracker calls manually via spectrogram analysis, and to build advanced classifiers to automate detection, respectively. Fall caching activity was 27% higher in mast years based on call bursts/hour, and evenly distributed between both limber and whitebark pine habitat. Interestingly, nutcrackers shifted habitat in the nonmast year, and spent disproportionately more time in burned and unburned whitebark pine habitat (190% more than limber pine habitat). During spring seed retrieval, nutcrackers spend disproportionately more time in whitebark pine habitat, regardless of interannual availability of cones. Manual estimates of nutcracker activity were far more conservative than automated detections with classifiers, which had high levels of false-positive detections due to wind and rain. Our findings suggest that nutcrackers cache more seed in mast years, and cache in both habitats, however they use whitebark pine habitat preferentially during seed retrieval periods, regardless of fall caching activity. More surprisingly, nutcrackers are quite active in both habitats in non mast years, despite the apparent lack of 5-needled pine cones for caching. This suggests that nutcrackers populations are maintained interannually at the northern limits of 5-needled pines, despite the lack of other key conifer food sources. A proper understanding of nutcracker use of burned habitat is important to applying fire management in recovery actions for each of these endangered pines.

Assessing Vulnerabilities in the Mutualism between Whitebark Pine and Clark's Nutcracker in Sierra-Cascade Parks

by Chris Ray | Regina Rochefort | Jason Ransom | Jonathan Nesmith | Sylvia Haultain | Taza Schaming | John Boetsch | Mandy Holmgren | Robert Wilkerson | Rodney Siegel | The Institute for Bird Populations | National Park Service | National Park Service | National Park Service | National Park Service | Northern Rockies Conservation Cooperative | National Park Service | The Institute for Bird Populations | The Institute for Bird Populations | The Institute for Bird Populations

Keywords: Clark's nutcracker, N-mixture model, Vital Signs monitoring, foxtail pine, whitebark pine

Dispersal of whitebark pine, a keystone species at high-elevations in western North America, depends on Clark's nutcracker, a seed-caching bird with an affinity for whitebark pine seeds. To the extent that this dependence is mutual, declines in whitebark

seed production could cause declines in nutcracker abundance. Whitebark pine is in decline across much of its range due to interacting stressors, including the non-native pathogen white pine blister rust. We combined avian and tree monitoring data from four national parks to investigate whether spatial or temporal trends in Clark's nutcracker corresponded with trends in whitebark pine. We allowed for trophic dependence of nutcrackers on whitebark in temporal models by linking models of nutcracker density and whitebark trend in a Bayesian framework. Spatial models suggested that nutcracker density responded to resources other than whitebark in at least one park. Temporal models showed strong evidence for dramatic decline or fluctuation in nutcracker density concurrent with significant increases in whitebark crown mortality and trees infected with white pine blister rust. Our results suggest that the mutualism between whitebark pine and Clark's nutcracker is vulnerable to disruption in areas where an introduced pathogen threatens these species.

Field-Testing Whitebark Pine Resistance to White Pine Blister Rust: A Cost-Effective Approach to Progeny Testing

by Iain R. Reid | Charlie Cartwright | Richard A. Sniezko | Richard C. Hamelin | Sally N. Aitken | Parks Canada, Jasper National Park, Jasper, Alberta, T0E 1E0, Canada | British Columbia Ministry of Forests, Lands, Natural Resource Operations, and Rural Development, Cowichan Lake Research Station, Tree Improvement Branch, Mesachie Lake, British Columbia, Canada | Dorena Genetic Resource Centre, USDA Forest Service, 34963 Shoreview Road, Cottage Grove, OR, 97424, USA | Department of Forest and Conservation Sciences, University of British Columbia, Vancouver, British Columbia, V6T 1Z4, Canada | Department of Forest and Conservation Sciences, University of British Columbia, Vancouver, British Columbia, V6T 1Z4, Canada

Keywords: common garden, inoculation, resistance, white pine blister rust, whitebark pine

The endangered species whitebark pine (*Pinus albicaulis* Engelm.) is declining mainly due to the introduced pathogen *Cronartium ribicola* J.C. Fisch, causing the disease white pine blister rust. Low levels of genetic resistance to blister rust are present in whitebark pine. Traditional methods of inoculating seedlings to determine rust-resistance have been effective, but are costly and time intensive. Due to the need for resistant material for planting, this presents a bottleneck in the process of restoring heavily infected stands. Here we test an alternative approach to controlled inoculations that could screen large numbers of families. We screened 214 open-pollinated families from 44 provenances from British Columbia (BC), Washington (WA), Oregon (OR), Idaho (ID), Montana (MT), and Nevada (NV) to determine: (1) the effectiveness of natural rust inoculation from *Ribes nigrum* L. in a common garden; (2) family and provenance level resistance to blister rust; and (3) climate variables related to height and rust resistance. Eighty-one of these families were previously screened in Dorena, Oregon using standard artificial inoculation methods. The natural inoculation was effective, with 73% of seedlings displaying stem symptoms of the disease, and 95% showing rust infection. A clear relationship was found between distance from the nearest *Ribes nigrum* plant and severity of blister rust. Linear mixed models were fitted to height and rust data using *ASReml-R* to estimate breeding values, heritability, and among- population differentiation (QST) for rust-resistance. Population differentiation for rust- resistance was moderate, with the highest resistance in provenances from the Cascade Mountains of Washington, and the most susceptible families from the BC Chilcotin and Okanagan regions. Heritability of rust resistance was moderate (0.23). This method of screening could be used at a broader scale to determine families resistant to white pine blister rust without specialized testing facilities and increase the availability of resistant seedlings for restoration.

Special Session Organizer: Richard Sniezko/ Genetics and Rust Resistance

Whitebark Pine Production at the USFS Coeur d'Alene Forest Nursery

by Emily Rhoades | Molly Retzlaff | Aram Eramian | USDA Forest Service | USDA Forest Service | USDA Forest Service

Keywords: greenhouse, production, seedling, whitebark

Whitebark pine (*Pinus albicaulus* Engelm.) is a high-elevation foundation species that acts as a critical food source for many species. Populations are rapidly declining due to White pine blister rust (*Cronartium ribicola* Fischer*)*, Mountain pine beetle (*Dendroctonus ponderosae* Hopkins*)*, wildfire, and successional replacement by more shade-tolerant species. Restoration efforts are key to ensuring that this species does not vanish from the landscape. The USFS Coeur d'Alene Forest Nursery has grown whitebark pine, for restoration purposes, for almost 30 years. In 2021, the nursery will ship 179,000 whitebark seedlings and continues to see an increase in whitebark orders. To meet this growing demand, the CDA nursery is continually modifying the propagation protocol for whitebark to streamline the seed preparation process and maximize production. Each year, small improvements lead to a more efficient use of labor and growing space, and a more uniform crop.

Whitebark Pine as Natural Archive: The Dendrochronological Value of Whitebark Pine and a Call to Action

by Maegen Rochner | Matthew Bekker | Sally Horn | University of Louisville | Brigham Young University | University of Tennessee Knoxville

Keywords: dendrochronology, tree ring, whitebark pine

Long-lived, montane tree species like whitebark pine and Engelmann spruce may eventually cease to exist due to the combination of climate change and exacerbated native and invasive threats. While this loss would entail dramatic circumstances for mountain ecosystems, it would also result in the irreversible loss of valuable climatological and ecological data. The objective of this research is to develop extended whitebark pine and Engelmann spruce tree-ring chronologies with the potential for use in regional analyses of climate and disturbance but also to serve as an example of the potential of these tree species and the need for increased tree-ring based work. From a high-elevation site in the Beartooth Mountains of Wyoming, we collected hundreds of samples from both living and remnant whitebark pine and Engelmann spruce and, using dendrochronological methods, developed two millennial-length, tree-ring chronologies for the species. The final whitebark pine chronology covered the period 765–2016 CE, and the final Engelmann spruce chronology covered the period 754–2017 CE. While further analyses are needed to fully evaluate the climatological and ecological value of these chronologies, results indicate a strong common signal in both chronologies, along with evidence of possible synchronous disturbances, including fire and insects. In addition to these results, we also provide observations gathered over four years of work at the same study site, which we believe may assist efforts to identify and collect remnant samples with the ability to considerably extend tree-ring chronologies. We hope that our work may serve as a guide for future efforts to collect and analyze data from whitebark pine and other species that are, and may be, threatened with extinction. We call for increased contribution of tree-ring data, from whitebark pine especially, but also from other subalpine species, to accessible archives, such as the International Tree-Ring Data Bank (ITRDB), which will make tree-ring data available for current and future scientists.

High Altitude Abies Religiosa Reciprocal-Transplant Test to Estimate Climatic Change Impacts in Monarch Butterfly Reserve

by Cuauhtémoc Sáenz-Romero | Ana Laura Cruzado-Vargas | Roberto Lindig- Cisneros | Arnulfo Blanco-García | Mariela Gómez-Romero | Leonel Lopez-Toledo | Erick de la Barrera-Montpellier | Universidad Michoacana de San Nicolás de Hidalgo | Universidad Michoacana de San Nicolás de Hidalgo | Universidad Nacional Autónoma de México | Universidad Michoacana de San Nicolás de Hidalgo | Universidad Michoacana de San Nicolás de Hidalgo | Universidad Michoacana de San Nicolás de Hidalgo | Universidad Nacional Autónoma de México

Keywords: Abies religiosa, high altitude conifers, climatic change, provenances, frost damage, drought stress, Monarch Butterfly, conservation

Sacred fir *Abies religiosa* distribute at high-elevations (2800 to 3550 m of altitude) at the Mexican Transvolcanic Belt. Some of their best stands host the Monarch Butterfly overwintering populations at the Monarch Butterfly Biosphere Reserve (MBBR), at the border between Michoacán and México state, central-west México. We established a field/common garden provenance reciprocal-transplant tests at three sites at contrasting altitudes (3400 m, 3000 m, and 2600 m). Planted seedlings originated from seed collected in natural stands along an altitudinal gradient (3000 to 3550 m; eleven provenances, one every 50 m of altitudinal difference), inside the MBBR. The objective is to estimate the phenotypic plasticity (growth and survival in response to be growing on a climate different than their origin) of *A. religiosa* seedlings that might enable them to cope either with warmer climates (by translocating to warmer planting sites, at lower altitudes than their seed origin; site at 2600 m) or with colder climates at assisted migration sites (by translocating to planting sites colder to their seed origin, at 3400 m). Preliminary results indicate heavier mortality at the low altitudinal site, during the dry season, apparently due to exceptionally warm winter temperatures and low winter precipitations. That is consistent with our field observations of a deficit of natural regeneration seedlings recruitment. Results support the proposal of shifting altitudinally upwards Sacred fir populations by assisted migration, to maintain healthy trees, as long as possible, by re-coupling them with the climate for which they are adapted, when such climate will occur at higher altitude, due to climatic change.

High-elevation Chilgoza Pine Forests in the Western Himalayas: Survival Threats & Conservation Exigencies

by Rinki Sarkar | Independent Researcher, Himalayan Studies

Keywords: Himalayan ecology, Chilgoza pine, Edible pine nut, Natural regeneration, Nutcracker, Forest conservation

This research endeavor traces the outcomes of an interdisciplinary field study conceived for tracking the socio ecological trajectory of a high-elevation Himalayan pine. The researcher encountered this species accidentally during her exploratory hiking trails in the Kinnaur Himalayas of India. She gathered that the global distribution of these forests, known as Chilgoza (*Pinus gerardiana*), is extremely sparse posing grave biodiversity concerns. This three-needle pine, which has a soft white-

pine lineage, is restricted to stressful montane environments occurring sporadically in patches across the Western Hindukush Himalayas. Native inhabitants in the surrounding vicinity access these forests for pine seeds which are consumed as pine nuts. The fury of cone collection for pine nuts, which caught the researcher's eye, was the main motivation behind this study as she pondered over the repercussions for natural regeneration.

Topographical constraints secluded Kinnaur for a long spell. During this period, pine nuts were collected mainly for self-consumption with meagre threats to Chilgoza forests. Speedy development of a highway through the region in the post-sixties, for strategic defence purposes, dismantled barriers to market access triggering the sale of pine nuts on an unprecedented scale. The rare resource tapped from the wild started fetching a high value in national and international markets causing a vicious cycle of destructive and near total harvesting of cones, declining yield and spiralling prices. 90% of the forest plots evaluated post-extraction had no cones on the branches.

With seeds all sold off as pine nuts, threats to natural regeneration seemed intuitively tenable. The researcher's forest surveys corroborated these untoward consequences. Excessive lopping of branches for cones was all-pervasive and the poor status of natural regeneration was evident from the survey data analysis which reflected an unstable community structure characterized by low seedling and sapling counts, grossly insufficient to sustain the existing forest stock. Native perceptions of the resource, captured during field work, invariably projected a sense of myopia and nonchalance about the ecological implications of ruthless resource extraction. The endemic nature of the resource was not even common knowledge. The urgency of conservation action seemed inevitable for reversing these unsustainable trends.

Unfortunately, a concerted conservation drive is yet to kick off and artificial propagation strategies have not produced the expected results due to poor field initiatives. However, the researcher's inadvertent discovery of the large spotted nutcracker (*Nucifrga multipunctata*) in these forest tracts and its presumed ability to disperse seeds of this Strobus pine, nurtured the possibility of managing forests to enhance nutcracker visitations as an immediate, cost-effective strategy for restoring the depleting forest stock. Towards this end, incentives can be designed for leaving cones behind for the nutcracker besides curtailing cone collection altogether on a rotational basis from a few areas to facilitate recovery and regeneration. Managing grazing is also crucial for preventing browsing or trampling of juvenile recruits. The efficacy of these management strategies can be strengthened if forest restoration efforts are pursued with more scientific rigor preferably through community engagement fostered by awareness programs that pillar sustainable extraction techniques as well.

Satellite-Tracking Clark's Nutcrackers to Investigate Space Use In Declining Whitebark Pine Habitats

by Taza Schaming | Teresa Lorenz | Peter Singleton | Jason Ransom | Diana Tomback | Thomas McLaren | Lauren Walker | Northern Rockies Conservation Cooperative | USFS | USFS | North Cascades National Park | University of Colorado, Denver | University of Colorado, Denver | Yellowstone National Park

Keywords: Clark's nutcrackers, whitebark pine, mutualism, space use, habitat use, habitat selection, movement, dispersal, satellite-tracking, management

Managers need information on Clark's nutcracker habitat use and selection, foraging and seed dispersal movement patterns, and long-distance movements, to inform whitebark pine management plans, and to identify and prioritize areas for whitebark pine conservation or restoration, including best locations to plant blister rust resistant seedlings. Our primary objectives are to evaluate (1) What are nutcrackers' seasonal range sizes, habitat use and selection, and emigration patterns relative to habitat type and health? (2) How does nutcracker space use vary between years and regions? (3) How do nutcrackers connect habitats and ecosystems? Evaluating space use by satellite-tracking nutcrackers in both the Greater Yellowstone Ecosystem (GYE) and Washington's Cascades allows for better inference range-wide. Additionally, comparing data over a large habitat gradient in

Washington – in the eastern, central, and western Cascades; high, moderate, and low whitebark pine density, respectively – best allows for accurate regional management recommendations. We began the first ever study to satellite-track Clark's nutcrackers in 2014, and by spring 2020, will have tagged 20 nutcrackers, including four birds in a new collaborative study in Yellowstone National Park. The seven GYE birds transmitted an average of 713 days, and the Cascades nutcrackers continue to transmit. Preliminary results reveal that, both GYE and Cascades nutcrackers, when separately analyzed, moved over an annual home range of approximately 18,500 ha, a significantly larger area than previously documented via radio-tracking. To date, the Cascades' nutcrackers have remained in the same general area, but in one year, the majority of GYE nutcrackers flew to non-whitebark pine habitat in Utah to overwinter. We will continue to analyze our data in 2020, and will develop resource selection function maps, to inform whitebark pine restoration efforts, including best locations to plant seedlings, and to define which habitat qualities are important for nutcracker population stability and resilience under environmental change.

Taking the Long View: Ecology, Condition, and Outlook for the High-Elevation Five-Needle Pines

by Anna W. Schoettle | Kelly S. Burns | Jodie Krakowski | Shawn T. McKinney | Kristen M. Waring | Diana F. Tomback |Marianne Davenport | USDA Forest Service, Rocky Mountain Research Station, Ft. Collins, CO | USDA Forest Service, Rocky Mountain Region Forest Health Protection, Lakewood, CO | Whitebark Pine Ecosystem Foundation of Canada, Edmonton, AB | USDA Forest Service, Rocky Mountain Research Station, Missoula, MT | Northern Arizona University, School of Forestry, Flagstaff, AZ | University of Colorado Denver, Department of Integrative Biology, Denver, CO | University of Colorado Denver, Department of Integrative Biology, Denver, CO

Keywords: whitebark pine (Pinus albicaulis), limber pine (Pinus flexilis), Rocky Mountain bristlecone pine (Pinus aristata), Great Basin bristlecone pine (Pinus longaeva), foxtail pine (Pinus balfouriana), and Southwestern white pine (Pinus strobiformis), compounding stresses, white pine blister rust, regeneration, climate change, forest health, adaptive capacity

Mountain regions are facing seasonal warming rates that are greater than the global land average putting many of the subalpine forest communities of western North America at risk. The high-elevation five-needle pine species, including whitebark pine (*Pinus albicaulis* Engelm.), limber pine (*P. flexilis* James), Rocky Mountain bristlecone pine (*P. aristata* Engelm.), Great Basin bristlecone pine (*P. longaeva* D.K. Bailey), foxtail pine (*P. balfouriana* Grev. & Balf.), and Southwestern white pine (*P. strobiformis* Engelm.) are often keystone or foundation species in these forests and frequently defined the forest-alpine tree line. In addition to direct climate change impacts (e.g. heat, drought), the high-elevation five-needle pine species are threatened by the compounding stresses of the non-native pathogen that causes white pine blister rust, climate-driven bark beetle impacts, and other pests and pathogens as well as altered largescale disturbance dynamics. The novel suite of stressors and their interactions threaten the sustainability and adaptive capacity of the high-elevation five-needle pines and the resilience of the subalpine ecosystems. Each of the high-elevation five-needle pine species differ in their ecological context, population dynamics, life-history traits, and exposure and sensitivity to the stressors that challenge them. We applied an evolutionary ecology perspective to review the ecology, genetics, and forest health condition of the high-elevation five-needle pine species to identify key vulnerabilities of each species to infer possible future outcomes.

Adaptive Monitoring in Action: Reconsidering Design-based Estimators Reveals Underestimation of Whitebark Pine Disease Prevalence in the Greater Yellowstone Ecosystem

by Erin Shanahan/Kathi Irvine | GRYN-NPS/USGS

Keywords: Bayesian hierarchical model, Cronartium ribicola, Pinus albicaulis, imperfect detection, multiple observer, occupancy models, sampling, trend estimation

Identifying and understanding status and trends in dynamic ecological processes requires continual monitoring over a prolonged time period. A reality of field-based, long-term monitoring efforts is the inevitable turnover of field crew members which may affect consistency and accuracy in data collection over time. Thus far, there has been little effort to quantitatively investigate imperfect detection of tree diseases as compared to wildlife and plant community surveys. Here we evaluate observation error when detecting white pine blister rust (*Cronartium ribicola*) infection in whitebark pine tree (*Pinus albicaulis*) populations in the Greater Yellowstone Ecosystem. We rigorously assess the prescribed analytical approach in the original long-term Greater Yellowstone Interagency Whitebark Pine Monitoring protocol. We consider the design-based ratio estimator initially proposed for estimating white pine blister rust prevalence versus a model-based approach that accounts for the sampling design and imperfect detection and allows for infection probabilities to vary over time and space. Specifically, we found that ignoring observation errors led to lower estimated prevalence of white pine blister rust in the general population. We determined that infection probability has increased since 2004 when monitoring was initiated. However, overall prevalence likely has not changed because of the shift towards smaller diameter trees because of the mountain pine beetle outbreak that spanned over a decade starting in the early 2000s. In addition, we highlight the use of Bayesian hierarchical modeling which offers an alternative method for analyzing data for more practical applications in conservation biology. Our assessment underscores the need for continued evaluation of a long-term monitoring program's analytical procedures as statistical methods improve and new tools become available for estimating and explaining patterns in status and trend of ecological indicators.

Application of High-Resolution (1.2 M) Worldview-3 Satellite Imagery to Resolve Treeline Species Composition: Case Study Using Limber Pine in Rocky Mountain National Park

by Laurel Sindewald | University of Colorado Denver

Keywords: Alpine Treeline Ecotone, Limber Pine, Remote Sensing, Satellite Imagery, Treeline, WorldView-3

Limber pine *(Pinus flexilis)* is an ecologically important conifer in Rocky Mountain National Park (RMNP) and elsewhere in Colorado that is of management concern. Limber pine occurs in scattered subalpine stands in RMNP, but its treeline distribution is unknown. Here, we propose to adapt remote sensing methodology recently developed by coauthor Cross for

identifying rainforest tree species to conifers in treeline communities. Our goals are to (1) pioneer the application of high-resolution (1.2 m) satellite imagery from MAXAR's WorldView-3 commercial satellite to distinguish conifer species at treeline, and (2) create a library of spectral profiles for treeline vegetation in RMNP. We will collect spectral reflectance data with a field backpack spectroradiometer and use known GIS locations of tree species to do object-based, rule-based classification of WorldView-3 imagery to estimate park-wide treeline distribution of each conifer species. We conducted a preliminary analysis with ENVI's Example-Based Classification workflow to demonstrate that the three treeline conifer species can be distinguished—limber pine, Engelmann spruce *(Picea engelmannii)*, and subalpine fir *(Abies lasiocarpa)*. The K Nearest Neighbors algorithm was used for the classification with 2/3 of the training samples for each species. The remaining 1/3 of samples was used to do a confusion/error matrix in ENVI. A 70.16% overall accuracy with this simplified method demonstrates that the species can indeed be discriminated. We will continue to refine data inputs and classification approach and to determine if a rule- based classification will improve differentiation in treeline conifers. We will also develop a library of spectral profiles for dominant vegetation species, including willows and birch, to validate our classification results and to facilitate future classifications. The proposed remote sensing approach will pilot cost-effective methodology for community surveys at a fine scale and broad extent, particularly useful for regions that are difficult or hazardous to access.

Mapping and Monitoring California's High-elevation Forests: A State-Wide Field and Remote Sensing Campaign

by Michele Slaton | Alexander Koltunov | Shana Gross | US Forest Service Pacific Southwest Region Remote Sensing Lab | UC Davis Center for Spatial Technologies and Remote Sensing (CSTARS); US Forest Service Pacific Southwest Region Remote Sensing Lab | US Forest Service Pacific Southwest Region Ecology Program

Keywords: California, distribution mapping, disturbance detection, health monitoring, remote sensing

High-elevation white pine forests dominate upper treelines of California's Sierra Nevada, Cascade, Klamath, and Great Basin mountain ranges. These forests include whitebark pine, limber pine, western white pine, foxtail pine, and Great Basin bristlecone pine (*Pinus albicaulis, P. flexilis, P. monticola, P. balfouriana, and P. longaeva*, respectively). The US Forest Service Pacific Southwest Region recently published a state-wide distribution map for whitebark pine, based upon field and aerial survey data, and this map serves as a much- needed input for management and research applications. We report on the development of this map and on the accompanying long-term monitoring strategy stratified across different climate zones and topographic settings, and for which the US Forest Service completed the first round of baseline monitoring in 2019.

Secondly, we report on the implementation of a remote-sensing based disturbance detection system to monitor high-elevation forests in California. Because the remote and rough terrain and short growing season of these forests make traditional field or airborne monitoring difficult to implement with the frequency required to track rapid changes at broad scales, such operational remote sensing methods are in great demand. The Ecosystem Disturbance and Recovery Tracker (eDaRT) is a highly automated, broadly applicable disturbance mapping system that processes all available Landsat imagery, detecting change at 8-16 day timestep, and is operated by the US Forest Service Pacific Southwest Region to generate disturbance map products for science and land management applications. We report results for years 2010-2021 of a newly developed method to estimate canopy cover loss using time series of spectral change associated with eDaRT disturbances. We provide an overview of plans for continued implementation of this tool and its potential to improve the accuracy and efficiency of delivery of high-elevation forest change products for researchers and managers.

Genetic Resistance to White Pine Blister Rust, Restoration Options, and Potential Use of Biotechnology

by Richard A. Sniezko | USDA Forest Service, Dorena Genetic Resource Center

Keywords: genetic resistance, durability, stability, usability, restoration, white pine blister rust, biotechnology, Cronartium ribicola

All white pine species in North America are highly susceptible to the white pine blister rust (WPBR), caused by the non-native fungal pathogen *Cronartium ribicola*. WPBR is present within the geographic range of eight of the nine species in the U.S. (and the four species present in Canada), but has not yet been documented in Mexico. WPBR has led to extirpation of white pines in some areas and drastically reduced the incidence of some species in portions of their range. A low frequency of genetic resistance has been documented in eight of our white pine species, with extensive work on foxtail pine (*P. balfouriana*) now underway. The development of populations of trees with genetic resistance, while retaining genetic diversity and adaptability is seen as a fundamental step in restoring white pine species. Will resistance work? Since trees are long-lived organisms and any use for restoration will serve as the progenitors for future generations, it will be key to establish the durability, stability and usability of resistance in each species. Fortunately, we are able to draw on the many decades of experience with western white pine resistance program which provides a guide to answering such questions. Can biotechnology help? Conventional resistance breeding and tree improvement programs are the key to success in finding and deploying resistance to WPBR. However, biotechnology has the potential to aid resistance programs, but only if used in the context of a holistic resistance program. Biotechnology tools may aid in the initial search for candidate trees or may provide avenues to speed up the development of resistance or incorporate unique resistance not currently found in North American white pines. The strategic use of resistance will vary by species and some options will be discussed.

Range-Wide Testing of White Pine Blister Rust Resistance in Foxtail Pine (Pinus Balfouriana)

by Richard A. Sniezko | Angelia Kegley | John Gleason | Robert Danchok | Brianna McTeague | USDA Forest Service, Dorena Genetic Resource Center | USDA Forest Service, Dorena Genetic Resource Center, Oregon, U.S.A. | USDA Forest Service, El Dorado National Forest, Placerville Nursery, California, U.S.A | USDA Forest Service, Dorena Genetic Resource Center, Oregon, U.S.A. | Weyerhaeuser, Centralia, Washington, USA

Keywords: Pinus balfouriana, foxtail pine, genetic resistance, white pine blister rust

Foxtail pine (*Pinus balfouriana*) is a high-elevation white pine species endemic to California. Due to foxtail pine's small and disjunct range and concerns about the potential impacts of a changing climate and air pollution, the IUCN Red List has listed this species as "Near Threatened." Like all white pine species native to the U.S., foxtail pine is very susceptible to the non-native fungal pathogen *Cronartium ribicola* (causal agent of the white pine blister rust disease, WPBR). A trial inoculated in 2015 suggested that foxtail pine may be the most susceptible of all native U.S white pines. New trials sown in 2018 and 2019 at two USDA Forest Service facilities, Dorena Genetic Resource Center (Oregon) and Placerville Nursery (California) will sample

much of the range of this species. In addition, subsets of the seedling families will be tested (1) at differing inoculation densities to characterize resistances that may be expressed at different (low to moderate) densities and (2) included in field trials in CA and OR to validate the seedling inoculation results. These trials will provide the first baseline data on WPBR resistance in this species, critical information for foxtail pine conservation efforts. Early results from the 2018 trial indicate foxtail pine is very susceptible, but there is some variation with inoculum density, with some families showing higher or faster mortality at the higher inoculation levels. Germination data for this range-wide collection will provide an update on the potential for ex situ conservation using seed storage.

White Pine Blister Rust Resistance Programs for Alberta Limber and Whitebark Pine Recovery

by Richard Sniezko | Angelia Kegley | Jodie Krakowski | Genoa Alger | Jun-Jun Liu | Center Geneticist/Tree Breeder, USDA Forest Service, Dorena Genetic Resource Center, Cottage Grove, OR | Geneticist/5-needle Pines & Seed Orchards, USDA Forest Service, Dorena Genetic Resource Center, Cottage Grove, OR | Consultant, Edmonton, AB | Resource Management Officer, Waterton Lakes National Park, Parks Canada, Waterton AB | Molecular Forest Pathologist, Canadian Forest Service – Pacific Forestry Centre, Natural Resources Canada, Victoria, BC

Keywords: disease resistance, limber pine, restoration, seed orchard, white pine blister rust, whitebark pine

Significant advances continue in Alberta to develop rust-resistant populations that support restoration of impacted limber and whitebark pine habitat. Putatively resistant trees from heavily infected stands have been identified. Parks Canada and Alberta are screening 201 limber pine and over 120 whitebark pine parents at facilities in the USA and Canada. Seed collections from more plus trees will add to the parents being tested in future years. Final results are pending for most parents. Multiple Alberta limber pine populations have dominant single-gene (MGR) resistance; tests are underway to confirm the existence of a second putative major gene in one parent from Waterton Lakes National Park. Interim results indicate low to moderate levels of quantitative resistance in Alberta populations of both species; final results are pending. Preliminary results are used to guide establishment of grafted seed orchards with partners. Provisional whitebark pine seed zones are established, and seed orchards are under development among Canadian partners. One limber pine orchard established in 2020 has 111 grafts from 30 selected parents, with planned expansion up to 1000 from 50-100 genotypes to provide diverse restoration material adapted to the southwest Alberta-USA Northern Rockies seed zone. Another orchard and/or clone bank is planned. As seed zones overlap both provinces, Alberta material is incorporated in whitebark pine seed orchard planning in BC, with planting grafts beginning in 2021 at 2 to 3 sites. MGR limber pine seedlings tested at Dorena were planted at 2 southwest Alberta sites in 2018; long-term observation will determine the durability of this resistance.

A Fungal Focus: Ectomycorrhizal Fungi of Whitebark Pine in Interior British Columbia

by Hanno Southam | Natalie Stafl | Shannon H. A. Guichon | Suzanne W. Simard | Department of Forest and Conservation Sciences, Faculty of Forestry, The University of British Columbia, Vancouver, BC, Canada | Ecologist Team Lead, Parks Canada Agency, Mount Revelstoke and Glacier National Parks, Revelstoke, BC, Canada | Department of Forest and Conservation Sciences, Faculty of Forestry, The University of British Columbia, Vancouver, BC, Canada | Department of Forest and Conservation Sciences, Faculty of Forestry, The University of British Columbia, Vancouver, BC, Canada

Keywords: Suilloid fungi, ectomycorrhizal fungi, plant-fungal interactions, whitebark pine

Whitebark pine is entangled in a mutualistic partnership with an assemblage of ectomycorrhizal fungi (ECMF). This relationship is like sunlight (exaggeration?) – whitebark would not grow and survive without these fungi. We need to start digging, to start paying more attention to these fungi – they are major players in whitebark pine ecology, some with a particular affinity to whitebark pine may be endangered by the loss of their host and they may well impact the success of management and restoration. Here we report on a project in the Columbia Mountains of British Columbia that used next-generation sequencing to identify ECMF on the roots of whitebark pine and in the adjacent soils. At the level of genus, the community of fungi in this region shares the same culprits that have been identified elsewhere (e.g. *Suillus, Rhizopogon, Piloderma, Cenococcum, Meliniomyces* (=*Hyaloscypha*) and *Cortinarius*) but below that level it is completely distinct and appears endemic and adapted to a mixed forest type. ECMF on planted seedlings in our study looked like strangers compared to naturally occurring seedlings and this is expected to influence future survival. The composition of ECMF on mature trees was related to tree health and this may have impacts on a tree's resistance to insects and pathogens. This fungal focus is important not just because of the direct links to whitebark pine ecology but also because it expands our frame of reference to understand trees and their functions as systems.

Education and Research through the North American Dendroecological Fieldweek

by James H. Speer | Margot Kaye | Bryan Black | Grant Harley | R. Stockton Maxwell | Christopher Gentry| Indiana State University | Penn State | University of Arizona | University of Idaho | Radford University | Austin Peay State University

Keywords: Greater Yellowstone Ecosystem, dendrochronology, whitebark pine

Forests are changing around the world due to stress from global change. We examined multiple forest sites in the Shoshone National Forest, during North American Dendroecological Fieldweek events in 2014, 2017, 2018, and 2019. We sampled over a thousand trees from 14 sites to reconstruct temperature, streamflow, spruce budworm outbreaks, fire, mortality dates, and regeneration patterns. We used innovative techniques such as blue intensity, stable isotopes, and quantitative wood anatomy, combined with traditional tree-ring research. We were able to reconstruct over 1,000 years of snowpack, stream flow, and temperature. Mountain pine beetle caused massive mortality in whitebark pine between 2008 and 2012 while spruce budworm outbreaks occurred five times from 1751-2017 CE. Outbreaks have been increasing in duration and the current outbreak is the most severe on record. Whitebark pine is establishing further upslope than was previously recorded, resulting in the conversion

of high-elevation meadows to young forests. Whitebark pine from above and subalpine fir from below are regenerating underneath lodgepole pine forests, suggesting a contraction of the lodgepole pine zone in the future. We documented a switch from temperature minimum as the dominant climatic parameter in high-elevation tree growth to drought stress around the 1950s and insect outbreaks may be speeding the conversion to new vegetation types. Overall, the long-term perspective from tree rings shows that recent climate, disturbance, and forest regeneration are outside the natural range of variability in the Greater Yellowstone Ecosystem.

Challenges to Limber Pine at Craters of the Moon National Monument and Preserve

by Devin Stucki | National Park Service, Upper Columbia Basin Network

Keywords: Craters of the Moon, dwarf mistletoe, limber pine, national park service

Limber pine (*Pinus flexilis*) is a foundational and pioneer species and an integral part of the sparse woodlands found at Craters of the Moon National Monument and Preserve (CRMO), located in southern Idaho. Limber pine at CRMO can be found growing near the lower elevational limit of the species' range and tree densities across the rugged lava flows are characteristically low with few exceptions. Limber pine trees at CRMO are facing ongoing threats from native and non-native pests and pathogens, as well as drought. Here we present findings from 9 years of monitoring limber pine woodland dynamics within 2500$_2$ m plots (n=93) at CRMO including stand composition and structure, cone production and seedling regeneration, and incidence of white pine blister rust (*Cronartium ribicola*), mountain pine beetle (*Dendroctonus ponderosae*), and dwarf mistletoe (*Arceuthobium cyanocarpum*). Rates of mountain pine beetle and white pine blister rust infection remain low, but rates of dwarf mistletoe infection have increased over the course of monitoring with over 40% of limber pine trees currently infected. Dwarf mistletoe is the most commonly recorded cause of mortality within monitoring plots, though rates of mortality remain low for limber pine. The rate of limber pine regeneration has increased while the proportion of living limber pine trees has decreased. Rocky mountain juniper (*Juniperus scopulorum*) stem density is low but increasing at a rate about three times that of limber pine. Long-term monitoring at CRMO is part of a broader collaborative white pine monitoring effort shared by four National Park Service Inventory and Monitoring Networks within the Pacific West Region.

Using Audio Recording Devices and Multiseason Occupancy Modelling to Evaluate Clark's Nutcracker Occurrence in Whitebark Pine Habitats

by Lauren Taracka | Dr. Taza Schaming | Dr. Alison Scoville | Dr. Teresa Lorenz | Central Washington University | Northern Rockies Conservation Cooperative | Central Washington University | U.S. Forest Service

Keywords: Clark's nutcracker, Clark's nutcracker ecology and seed dispersal, acoustic monitoring, whitebark pine

Clark's nutcrackers (*Nucifraga columbiana*) and whitebark pine (*Pinus albicaulis*), both native to the subalpine habitat of Washington's Cascade Mountains, are part of a fascinating mutualism: whitebark pine, a keystone species which is declining,

provides high energy seeds, which nutcrackers eat and cache. The goal of this pilot project was to survey nutcrackers in whitebark pine habitat with acoustic recording units, to assess how multiple habitat variables impacted nutcracker occurrence, colonization (likelihood of moving into an unoccupied site), extinction (likelihood of moving out of an occupied site), and detectability. We deployed monitors at twelve sites in the Cascades from June through October 2020 to gather audio data (n = 781 days of data collected), then determined daily presence or absence of nutcrackers with Raven Pro software. In addition, we conducted habitat surveys, cone counts, and in-person occupancy surveys. In our model set, we included weather as a predictor of detectability; and date, local-level whitebark pine density and cone presence/absence, and landscape-level ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*) density, as predictors of colonization and extinction. Additional analyses include determining whether whitebark pine germination rate is associated with nutcracker occupancy, and comparing in-person surveys to monitor detection. Final results are pending. Our project has strong links to restoration goals and management planning efforts. Understanding how nutcracker occupancy relates to whitebark pine cone, stand and landscape metrics is important for managers because whitebark pine persistence on the landscape depends on presence of birds to disperse seeds. Information on nutcracker habitat use, and foraging and seed dispersal movements will help inform whitebark pine management plans by aiding in identifying and prioritizing areas for whitebark pine restoration.

Climate-Smart Conservation: Putting Adaptation Principles into Practice for Whitebark Pine Conservation and Other Management Challenges

by David Thoma | GRYN-NPS

Keywords: adaptive capacity, climate change, climate impacts, exposure, integration, sensitivity, vulnerabilities

Climate-Smart Conservation was developed by the National Wildlife Federation in partnership with multiple government agencies including the NPS, USFWS, and USFS. The Climate-Smart Conservation (CSC) is a guidance tool for natural resource managers challenged with integrating climate considerations into climate adaptation practices. The CSC framework emphasizes four overarching themes: Act with intentionality through linking actions to impacts; Manage for change, not just persistence; Reconsider goals, not just strategies, and; Integrate adaption into existing work. Using whitebark pine conservation as an example, David Thoma and Erin Shanahan will shepherd participants through the key steps and nuances in the CSC cycle. Components of the cycle include identification of the issue, assessment vulnerabilities further divided into exposure, sensitivity, potential impacts, and adaptive capacity, determining management actions and window of management opportunity, and implementing management actions according to policy and law. The CSC structure is applicable throughout the discipline of natural resource management and simplifies a wicked problem into digestible parts.

The National Whitebark Pine Restoration Plan: Restoration Model for the High Five Pines

by Diana F. Tomback | Eric Sprague | University of Colorado Denver | American Forests

Keywords: High Five pines, National Whitebark Pine Restoration Plan, whitebark pine

Federal land management agencies and non-profit organizations have been aware of the decline of whitebark pine (*Pinus albicaulis*) for more than 30 years, culminating in its recent proposed listing as threatened under the Endangered Species Act. In 2016, the Whitebark Pine Ecosystem Foundation and American Forests jointly proposed the development of the National Whitebark Pine Restoration Plan (NWPRP) to the leadership of the U.S. Forest Service, who would oversee and help support the effort. The plan includes as collaborators other principal land management agencies across whitebark pine's U.S. distribution, including the National Park Service, Bureau of Land Management, several Native American tribal governments, and the U.S. Fish and Wildlife Service. The NWPRP is a geographic plan entailing the identification of essential core or high priority areas in need of restoration, representing 20 to 30% of whitebark pine's range within agency units or tribal lands. The underlying premise is that seed dispersal by Clark's nutcracker will, over time, disseminate blister-rust-resistant genotypes beyond the core areas. The selection of priority areas for restoration is based on the biological and ecological criteria used by the U.S. Fish and Wildlife Service to guide their species status assessments and for assessing species recovery. The steps in the NWPRP development included a National Whitebark Pine Summit in 2017, formation of a Liaison Committee in 2018 to provide feedback and guidance to the organizers, and a series of data calls between 2018 and the present to acquire new distributional information, nominated core areas, and proposed restoration projects for these core areas. The nominated core areas and proposed restoration projects will serve to focus agency resources and support NGO fund-raising to restore a critical number of whitebark pine populations to insure the future survival of the species. Several related high-elevation five-needle white pines are also in decline and may require federal listing in the future, unless there is timely strategic management intervention. Here, we propose that the procedure followed in the National Whitebark Pine Restoration Plan could be applied to develop effective restoration plans for other "High Five" pines.

Do Whitebark Pine Regeneration Trends Support Predicted Distributional Shifts under Climate Change? Examples from the GYE

by Diana F. Tomback | Elizabeth R. Pansing | Tony Chang | University of Colorado Denver | American Forests | Conservation Science Partners

Keywords: climate change predictions, post-fire regeneration, whitebark pine

Whitebark pine (*Pinus albicaulis*) is an ecologically important species of upper subalpine and treeline communities in the Greater Yellowstone Area (GYA) and of conservation concern in the region. Studies of climate change impacts to the GYA concur that whitebark pine is highly climate sensitive and will decline at its lower boundary and eventually throughout most of the GYA. We have monitored subalpine forest recovery after the 1988 fires at the lower boundary of the whitebark pine zone in two study areas (2680 m and 2560m) in both mesic and xeric burned study sites per area, tracking mapped whitebark pine individuals through seven remeasurements of 200 plots. Given that the regeneration niche is expected to be more restrictive than the climate niche for mature trees, we asked whether early signs of climate change impact are apparent in patterns of whitebark pine regeneration. PRISM data since 1989 for the Henderson Mtn., Custer Gallatin National Forest, and Mt. Washburn, Yellowstone National Park, study areas show that average annual air temperature increased significantly during this time in both study areas (by 0.09– 0.10 °C yr^{-1}), but average annual precipitation has not changed, indicating a growing moisture deficit. As of our 2016/2017 plot remeasurements, whitebark pine regeneration density across three burned study sites in two study areas has reached 0.005 sites/m^2, but the whitebark pine regeneration density on the fourth (northwest-facing Mt. Washburn mesic, burned) study site is four times greater at 0.023 sites/m^2. Climatic niche modeling based on AR5 RCP 4.5 and 8.5 GCMs indicate that the Henderson Mtn. study sites have a higher probability (~0.115-0.162) of retaining whitebark

pine through 2099 than Mt. Washburn (0.006-0.016), but observed regeneration patterns hint at a different future outcome than the niche models predict. The high regeneration density on the Mt. Washburn mesic, burned study site suggests that local conditions may lead to higher germination rates, greater seedling survival, or facilitation by fast-growing conifers, and possibly alter predictions on a local scale.

Seminal Research: Foraging Strategies of Clark's Nutcracker. 1978. The Living Bird 16, 123-161

by Diana F. Tomback | University of Colorado Denver

Keywords: Clark's nutcracker, seminal paper, whitebark pine

As recently as the 1980s, foresters in North America were confused as to how whitebark pine (*Pinus albicaulis*) seeds were disseminated. For example, in *Forest Trees of the Pacific Slope*, 1908, George Sudworth wrote that whitebark pines shed their seeds in September, and "the cones dry out and open slowly in the high, cold situations where this pine grows." My doctoral dissertation, *The behavioral ecology of Clark's Nutcracker (Nucifraga columbiana) in the eastern Sierra Nevada*, 207 pages, was completed in 1977 at the University of California at Santa Barbara. Until this time, little was known about the role of Clark's nutcracker as a seed disperser, and virtually nothing was published about its relationship with whitebark pine. I presented the first chapter "Ecological strategies for year-round utilization of pine seed by the Clark's nutcracker in the eastern Sierra Nevada" at a major ornithological conference and received an invitation to submit the work to *The Living Bird*, the distinguished journal of the Cornell Laboratory of Ornithology. With a simplified title "Foraging strategies of Clark's Nutcracker," the 1978 paper detailed the annual cycle of family group interactions, seed harvesting, and seed caching. Based on five research field seasons, it clearly documented nutcracker caching and seed recovery principally of whitebark pine but also of Jeffrey pine (*P. jeffreyi*), thus showing how additional seed sources within a region are important to support nutcracker populations. The second chapter of my dissertation, which has been more frequently cited, was published in 1982 as "Dispersal of whitebark pine seeds by Clark's Nutcracker: a mutualism hypothesis" in the Journal of Animal Ecology. This paper demonstrated that nutcracker caches led to whitebark pine regeneration, nutcrackers buried more seeds than they required, and no other animal that cached seeds was likely to be as effective a seed disperser. This latter theme was explored in the 1982 *Oecologia* paper by Hutchins and Lanner. The nutcracker-whitebark pine interaction literally became a textbook example of a coevolved mutualism, and citations to our papers appeared in several ecology textbooks in the 1980s and 1990s.

A Tale of Two Pines: Comparing Seedling Morphological and Stomatal Traits between Whitebark Pine and Limber Pine

by Danielle Ulrich | Montana State University

Keywords: ecophysiology, limber pine, seedlings, whitebark pine

Investigating the ecophysiological mechanisms that determine seedling establishment, such as traits that determine how seedlings acquire light, water, and CO_2, can improve our understanding of current forest boundaries and our ability to predict

future ones. Whitebark pine (*Pinus albicaulis*) and limber pine (*Pinus flexilis*) are two species with similar growth habit and dispersal mechanism yet contrasting geographic distributions by elevation. Based on current distributions in the Greater Yellowstone Ecosystem, limber pine has been more associated with warm, dry conditions at lower elevations (870-3810m), while whitebark pine has been more associated with cool, wet conditions at higher elevations (1600-3660 m). Comparing this pair of species enables us to isolate ecophysiological traits that may influence seedling establishment and underlie their contrasting distributions. Here, we quantified crown morphological and stomatal traits in greenhouse-grown 5-year old seedlings of whitebark and limber pine. Specifically, we measured needle length, needle width, stomatal density, stomatal length, stomatal area, fascicle density, the ratio of sunlit leaf area to total leaf area (STAR), and leaf mass per area (LMA).

Preliminary results demonstrated that needle length and needle width did not significantly differ between species ($p>0.05$). Limber pine exhibited significantly greater stomatal density and stomatal length than whitebark pine ($p<0.05$). Limber pine exhibited significantly greater fascicle density, lower STAR, and greater LMA ($p<0.05$). Together, these results suggest that limber pine may have greater stomatal control over the uptake of CO_2 and loss of water, and may be more adapted to high light conditions than whitebark pine.

Growth, Drought Response, and Climate-Associated Genomic Structure in Whitebark Pine in the Sierra Nevada of California

by Phillip van Mantgem | Joan Dudney | Elizabeth Milano | Jonathan Nesmith | Amy G. Vandergast | Harold Zald | U.S. Geological Survey | Department of Environmental Science, Policy, & Management, UC Berkeley | U.S. Geological Survey | National Park Service, Sierra Nevada Network | U.S. Geological Survey | USDA Forest Service, Pacific Northwest Research Station

Keywords: Pinus albicaulis, climate change, dendrochronology, stable isotopes, subalpine forests

Whitebark pine (*Pinus albicaulis* Engelm.) has experienced rapid declines and has recently been proposed as threatened under the Endangered Species Act in the United States. Whitebark pine in the Sierra Nevada of California may be faring better compared to other portions of its range, although biotic and abiotic stressors may still affect populations. We present patterns of stem and needle growth in large, disease-free whitebark pine before and during a recent extreme drought across the Sierra Nevada. We interpret growth patterns considering additional data collected on needle isotope discrimination and population genomic diversity and structure. Whitebark pine had positive to neutral growth trends prior to drought, correlated with increasing minimum temperatures. Growth responses to drought measured in terms of basal area increment and needle length remained positive to neutral during the drought. Stem and needle growth patterns were consistent with interannual patterns in needle δ13C, which did not generally suggest moisture stress during the drought years. Individual tree growth response phenotypes appear to be linked to genotypic variation in climate-associated loci, suggesting that growth is not only controlled by site level climate differences, but that some genotypes can take better advantage of local climatic conditions than others. We did not find strong geographical differences in drought growth responses, which was congruent with low levels of observed among site genetic variability. We speculate that snowpack losses during the drought may have lengthened the growing season while retaining sufficient moisture to permit growth for most individuals. While sampled whitebark pine may have responded with neutral to increasing growth during the recent drought in the Sierra Nevada, future conditions may be different, with growth declining in response to increased moisture stress or pest and pathogen activity.

Special Session title: High-elevation white pine communities in the Pacific West Region Special Session organizer: Jonny Nesmith

Fire, Restoration and Climate Change in Southwestern Mixed Conifer Forests: Implications for P. Strobiformis

by Kristen M. Waring | Nicholas Wilhelmi | Northern Arizona University | USDA Forest Service Forest Health Protection

Keywords: southwestern white pine; wildfire; white pine blister rust; gene conservation

Southwestern white pine (SWWP; *Pinus strobiformis*) is an important component of mixed conifer forests of the US Southwest and Sierre Madre Occidental of Mexico. In the US Southwest, the range consists primarily of disjunct populations at higher elevations. Density of SWWP has increased in many locations since the late 1800's due to fire suppression and exclusion. However, the incidence of stand-replacing high severity fire has been increasing amid severe drought conditions across the Southwest. Between 2010-2015, we installed 79 permanent plots to monitor the spread of white pine blister rust (WPBR) in Arizona and New Mexico. Wildfires have since burned 21 of these plots, in 2011, 2014 and 2017. Most plots burned at high severity, and conifer regeneration was limited to moderate and low severity burned areas. In addition, individual trees being assessed for genetic resistance to WPBR, including those which have shown resistance, have succumbed to these fires. Updated results from 2021, 10-year plot remeasurements will be presented. Managers will need to balance silviculture objectives such as fire hazard reduction and restoration to historic conditions with projected losses to WPBR to sustain the species through sufficient regeneration.

Interdisciplinary Research in Southwestern White Pine: Results and Management Implications

by Kristen M. Waring | Samuel Cushman | Andrew Eckert | Lluvia Flores-Renteria | Richard Sniezko | Christopher Still | Christian Wehenkel | Any Whipple | Michael Wing | Justin Bagley | Ethan Bucholz | Marja Haagsma | Jessica Hartsell | Cory Garms | Jeremy Johnson | Erin Landguth | Alejandro Leal Sáenz | Mitra Menon | Ehren Moler | Gerald Page | Andrew Shirk | Jared Swenson | Northern Arizona University | USDA Forest Service Rocky Mountain Research Station | Virginia Commonwealth University | San Diego State University | USDA Forest Service Dorena Genetic Resource Center | Oregon State University | 7. Universidad Juárez del Estado de Durango | Northern Arizona University | Oregon State University | Virginia Commonwealth University | Northern Arizona University | Oregon State University | Northern Arizona University | Oregon State University | Northern Arizona 5. USDA Forest Service Dorena Genetic Resource Center University, | University of Montana | 7. Universidad Juárez del Estado de Durango | Virginia Commonwealth University, 10. University of California-Davis | Northern Arizona University | Oregon State University | University of Washington | Northern Arizona University

Keywords: Pinus strobiformis, adaptive traits, climate change, ecophysiology, genetics, white pine blister rust

Southwestern white pine (SWWP; *Pinus strobiformis*) is an important tree species of the southwestern US and Mexico. Southwestern white pine populations are threatened by climate change and an invasive tree disease, white pine blister rust (caused by the fungal pathogen, *Cronartium ribicola*). Rapid climate change is negatively affecting SWWP by increasing heat and drought stress, and thus challenging its ability to adapt. White pine blister rust causes extensive tree decline and mortality in SWWP. The dual threats of climate change and invasive species make forecasting future tree distributions at continental scales an urgent challenge. The goal of our project is to determine how gene movement among populations, adaptation to disease and drought, heritable changes beyond DNA mutations, and a changing environment interact to govern the success of SWWP. We are utilizing and developing tools to help forecast and manage the future of the species, including those from genomics, ecophysiology, common gardens, tree disease resistance testing, and remote sensing to measure drought tolerance, disease resistance and presence and physiological response. Results will be synthesized and included in cutting-edge landscape genomics models to meet our overarching goal. We will present our framework and current project status, including results and management implications. Completed products include landscape genomic models, a species distribution model incorporating climate change, and analyses of adaptive traits, ecophysiological traits, phenotypic plasticity, genomic variation, and genotype-phenotype associations.

Within and between Species Physiological Traits and Stress Resistances of Three High-Elevation Pines

by Chloe Wasteneys | Danielle Ulrich | Montana State University | Montana State University

Keywords: Great Basin bristlecone pine, Pinus albicaulis, Pinus flexilis, Pinus longaeva, high-elevation pine, limber pine, pine ecophysiology, pine physiological traits, pine stress tolerance, whitebark pine

High-elevation pines inhabit exposed mountain tops, providing habitat for other organisms. However, high-elevation pines are declining rapidly due to a suite of factors exacerbated by climate change including white pine blister rust, bark beetle, and competition with faster growing conifers. The primary restoration strategy is outplanting rust-resistant seedlings. The seedling is the most vulnerable developmental stage and seedling establishment can drive species distributions. Understanding the physiological mechanisms underlying seedling establishment, such as physiological traits and stress resistances, is critical for successful restoration and conservation. Here, in greenhouse-grown 5-year old seedlings, we quantified physiological traits and stress resistances in populations from varying climates of three high-elevation pine species: whitebark pine (WBP, *Pinus albicaulis*), limber pine (LP, *Pinus flexilis*), and Great Basin bristlecone pine (GBBP, *Pinus longaeva*). We also measured physiological traits in WBP seedlings of three ages: 2, 3, and 5 years old. We quantified photosynthetic capacity from photosynthetic-CO2 response curves (maximum photosynthetic capacity (Amax), RuBisCO efficiency (Vcmax)), high light tolerance from photosynthetic-light response curves (maximum photosynthetic rate in saturating light conditions (Asat), light saturation point (Qsat)), drought tolerance from pressure-volume curves (water potential at full turgor and turgor loss point), and thermotolerance from chlorophyll fluorescence and electrolyte leakage curves.

Preliminary data show that the three species do not significantly differ in any of the physiological traits measured at this point. However, marginally significant differences in traits were observed between LP populations from contrasting climates and between WBP seedling ages. The LP population from a lower elevation site (1,645 m) exhibited greater mean Asat (11.35 $\mu mol\ m^{-2}\ s^{-1}$) than that from a higher elevation (2225 m, 6.63 $\mu mol\ m^{-2}\ s^{-1}$) (two-way ANOVA, p-value=0.055), suggesting that the low elevation population exhibited greater high light resistance. Two-year old WBP exhibited greater mean Qsat (1385 $\mu mol\ m^{-2}\ s^{-1}$) than both 3- and 5-year olds (870 $\mu mol\ m^{-2}\ s^{-1}$ and 1130 $\mu mol\ m^{-2}\ s^{-1}$, respectively) but was only marginally significantly different from the 3-year olds (p-value=0.054).

Discovery of WBP, MSU,1974-2001: WBP Environment, Stand Establishment/Development, Physiology, and Follow-Up

by Theodore Weaver | MSU Emeritus

Keywords: and follow-up., physiology, stand establishment/development, wbp environment

The presence of Rocky Mountain WBP forests and their qualities was/were essentially unknown in 1970. Exploration of their nature and processes was an exciting activity of the MSU ecology lab and its USFS associates. I list twenty-five resultant papers, 1974-2001. And suggest important extensions/derivatives.

1. We described open woodlands of multi-stemmed trees based on a sample of ten Montana mountain ranges.
2. We described their environments: Their climates in the northern Rockies and throughout the west - -and compared them with those of their Asian cohorts: eg with respect to temperature, moisture, frosts. Their geologic substrates (lime/hard rock/volcanics). Their soils, including the seasonal dynamics of water and nutrients which influence forest physiology more directly than anything remotely sensible. Wind, vapor pressure deficit, fire and logging were neglected.
3. We observed the establishment and development of WBP forests. We measured seed production and its variability among sites and years and reflected on thier establishment. Once established, stand densities fell through time while cover increased. Total standing crops were followed over 500 years and partitioned, for various applications, among leaf, branch, bole, bark (unique), and roots.
4. Tree performance was related to temperature and light. Stand production was related to structure and resource availability. Decomposition rates are contemplated.
5. Human influences from feeding, though trampling, weed introduction and vegetation recovery from human impacts were recorded. We suggest a solution to the blister-rust problem. Soils recover slowly from compaction, rates over 30 years are still measurable.

Clark's Nutcracker Seed Resource Use and Limber Pine Metapopulation Structure in Rocky Mountain National Park

by Tyler J. Williams | Diana F. Tomback | Community College of Denver | University of Colorado Denver

Keywords: Clark's nutcracker, Rocky Mountain National Park, connectivity, foraging ecology, habitat use, limber pine, metapopulation, seed dispersal

This presentation explores the dynamics of two versatile mutualists, Clark's nutcracker and limber pine, in a northern Colorado landscape mostly unaffected by extreme fire events and white pine blister rust infections during and prior to the study period of 2014 to 2016. We first discuss seed resource use by nutcrackers in Rocky Mountain National Park. What are the drivers that cause nutcrackers to use their preferred seed resource of limber pine as well as the alternative seed resources of ponderosa pine and Douglas-fir? Will these alternative seed resources sustain nutcracker populations in the face of future limber pine mortality

from blister rust? Secondly, we explore limber pine's metapopulation structure in Rocky Mountain National Park. We examine the distribution and size of limber pine stands as well as how many stands could be connected by the seed-dispersal flights of nutcrackers. We also examine how historical fire regimes may have impacted local extinction events and how larger fires, such as the 2020 Cameron Peak and East Troublesome fires (the largest in Colorado history) may impact extinction rates.

Nutcrackers foraged on limber pine seeds each year of the study. However, limber pine alone did not provide sufficient energy resources for foraging and caching, and nutcrackers used an additional conifer seed resource each year. Temporal variation in patterns of cone production and maturation among the three conifers as well as temporal changes in habitat use by nutcrackers appear to be the best drivers of conifer use. Limber pine and ponderosa pine stands were utilized primarily as seed resources, whereas Douglas-fir was more frequently used as habitat. With potential future limber pine losses, these other seed resources may be essential to sustain a nutcracker population.

Limber pine component populations ranged from 1 - 400 ha in size with inter-population distances of 1 - 36 km. Nutcracker flight distances indicate potentially high limber pine metapopulation connectivity, even with a smaller nutcracker population. Historically, the limber pine metapopulation likely experienced infrequent extinction events. However, large- scale fires (such as the East Troublesome fire) appear to cause significantly higher extinction rates, potentially complicating metapopulation processes.

Forest Structure Twenty Years after the First Whitebark Pine Prescribed Burn in Banff Nation Park

by Brendan Wilson | Stephanie Jouvet | Rob Walker | Jon Stuart-Smith | Selkirk College | Selkirk College | Parks Canada, retired | Parks Canada

Keywords: long-term, monitoring, prescribed fire, recruitment, succession, whitebark

Following a reconnaissance level survey of whitebark pine stands and blister rust infection in the Canadian Rockies, Parks Canada started a conservation program for the pine species in 1998. With the recognition that fire suppression had reduced the amount of available early serial subalpine forest in the Parks system, the initial action was to assess the use of prescribed fire in creating suitable recruitment habitat for this species. Permanent monitoring plots were established in control and burn treatment units on the southern flank of Observation Peak in Banff National Park. After the initial pre-burn measurement of the treatment units, a high intensity fire was applied to the burn treatment in late August of 1998. The treatments were remeasured the following summer and the results confirmed that the fire had achieved almost 100% mortality of all size classes of the tree and shrub species. Twenty years later, we have remeasured the treatment plots and found substantial recruitment of whitebark pine, compared to the spruce and fir species that previously dominated the burn treatment area. The density of all species combined was 2200 stems/hectare, with whitebark accounting for just under half of this value. Greater that 99% of all these different tree species were seedlings or samplings less than 1.5m tall. No blister rust was evident on whitebark pine in either treatment. Understory shrub layers were dominated by huckleberry and grouseberry in the burn treatment, whereas, the control was dominated by a more diverse mixture subalpine fir, common juniper, Engelmann spruce, and grouseberry. Future burns elsewhere and continued monitoring will provide more insights as to the apparent early success of increasing whitebark regeneration on this northern Rockies landscape.