Project Title: Developing management guidelines for creating resilient whitebark pine ecosystems in the northern Rocky Mountains using spatial simulation modeling

Project Coordinator: Bob Keane, Missoula Fire Sciences Laboratory, US Forest Service Rocky Mountain Research Station, 5775 Highway 10 West, Missoula, MT 59808, 406-329-4846, email: rkeane@fs.fed.us

Project PI(s): Rachel Loehman, Missoula Fire Sciences Laboratory, US Forest Service Rocky Mountain Research Station, 5775 Highway 10 West, Missoula, MT 59808, 406-829-7386, email: rloehman@fs.fed.us and Bob Keane.

Partners: Whitebark Pine Ecosystem Foundation (www.whitebarkfound.org); Barry Bollenbacher (bbollenbacher@fs.fed.us), Regional Silviculturist, and Steve Shelly (sshelly@fs.fed.us), Regional Botanist and Research Natural Areas Coordinator, USFS Northern Region; Daniel Reinhart (Dan_Reinhart@nps.gov), Branch Chief, Vegetation and Resource Operations, National Park Service (Yellowstone National Park); Tara Carolin (tara_carolin@nps.gov), Director, Crown of the Continent Research Learning Center, National Park Service (Glacier National Park); Cyndi Smith (Smith9@gmail.com), Parks Canada, Waterton Lakes National Park

Project Summary: Landscape simulation modeling will be used to develop detailed management guidelines for restoring and sustaining whitebark pine under future climates, accounting for the principal stressors that threaten its persistence (exotic disease infections, mountain pine beetles, and fire exclusion policies). We will build on existing work, including the 2012 publication *A Range-Wide Restoration Strategy for Whitebark Pine Forests* and existing simulation areas within critical whitebark pine habitat. This project will create a robust and trans-boundary set of management tools for creating resistant and resilient whitebark pine forests within the Rocky Mountains, USA and Canada.

Need: Whitebark pine (*Pinus albicaulis*), an important component of western North America high-elevation forests, has been declining in both the United States and Canada since the early 20th century from the combined effects of native mountain pine beetle (*Dendroctonus ponderosae*) outbreaks, contemporary fire exclusion policies, and the spread of the exotic disease white pine blister rust (Tomback et al. 2001). The Great Northern LCC (GNLCC) area contains over 90% of whitebark pine's range where its decline is especially precipitous, and, within the GNLCC, over 95% of whitebark pine forests occur on public lands (Keane 2006). The species is now listed under the Endangered Species Act but precluded due to administrative backlogs (http://www.fws.gov/mountain-prairie/species/plants/whitebarkpine). Whitebark pine is considered a keystone species because of its various roles in supporting community diversity (Tomback et al. 2001), and is also a foundation species that promotes community development and stability (Ellison et al. 2005). Within the last decade there have been major mountain pine beetle outbreaks and increasing damage and mortality from blister rust across the Rocky Mountains, causing cumulative whitebark pine losses that have altered high-elevation communities, shifted ecosystem functions, and fragmented landscapes. Under current management strategies, further loss of whitebark pine communities is assured and local extirpations probable due to expected of climate change interactions with other critical landscape stressors such as species encroachment, invasions, shifting fire regimes, and increased pressure from blister rust and mountain pine beetles.

Observed and predicted losses of whitebark pine directly challenge two of the conservation goals described in the GNLCC Strategic Conservation Framework: **Goal 1 - Maintain large, intact landscapes of naturally functioning terrestrial community assemblages; Goal 4 - Promote landscape-scale disturbance regimes that operate within a future range of variability and sustain ecological integrity.** Recent declines in species abundance have spurred government agencies to implement pro-active efforts designed to restore whitebark pine forests to their historical prominence through restoration activities (e.g., removing tree competition through prescribed burning and mechanical thinning, followed by planting seedlings). Keane et al. (2012) published *A Range-Wide Restoration Strategy for Whitebark Pine Forests*, presenting a trans-boundary approach for restoring whitebark pine across its entire range including the Rocky Mountains and Canada. Although this report provides extensive guidelines, information, and strategies for restoring whitebark pine from the regional to landscape to stand scales, it lacks is a comprehensive description of how managers can modify restoration activities to account for potential climate change impacts.

Most climate change effects, especially those in fire-dominated ecosystems of the western US, will be mediated by disturbance and disturbance impacts will probably overwhelm most direct vegetation responses to climate (Dale et al. 2001). Unique among most high elevation tree species, whitebark pine may respond favorably to increased fire because it has bird-mediated (Clark's nutcracker) seed dispersal mechanisms that disseminate seed vast distances into the large, severe fire patches predicted for the future, well before wind can disperse the seeds of its competitors (Tomback 1982, Lorenz et al. 2008). In addition, whitebark pine has morphological characteristics to survive low to mixed severity fires (Ryan and Reinhardt 1988). Paleoecological data indicate that whitebark pine was maintained and even increased under past warmer and drier climates in many parts of its range (Tausch et al. 1993). On the other hand, whitebark pines are vulnerable to both direct effects of climate changes, such as shifts in temperature isotherms that alter species distributions, and indirect effects such as increased mountain pine beetle activity. ***Persistence of whitebark pines under future climate and fire regimes and blister rust presence requires that we maintain and promote communities on today's landscapes, and mitigate effects of other stressors.***

The goal of today's restoration efforts, as detailed in the *Rangewide Strategy*, should be to create whitebark pine forests that are resistant and resilient in the face of future climate and disturbance regimes (Keane et al. 2012). This can be done by facilitating rust-resistance and fire adaptations by (1) saving all putative rust-resistant trees to provide seeds for natural rust-resistant regeneration, (2) collecting seed from rust-resistant trees and outplanting rust-resistant seedlings, and (3) allowing natural disturbances, especially mixed severity wildfires, to create competition-free growing spaces or creating the effects of these disturbances using prescribed burning and/or mechanical cuttings. However, the strategy is critically lacking validation of these directives and consideration of the impacts of interacting stressors possible under future climates. Further, the strategy does not include important details that can guide how to select the best areas to plant, burn, and treat; and the amount of the landscape that needs to be treated to ensure the sustainability of resilient whitebark pine forests.

Most studies that predict the effect of climate change on whitebark pine use Species Distributional Models (SDMs) to project future geographical ranges (Koteen 1999, Warwell et al. 2007). SDMs, also called Bioclimatic Envelope models, niche models, or species envelope models, are developed by correlating current species distribution with current climate; predictions of climate-caused distribution shifts are made by remapping species to changing climatic zones (Warwell 2007). SDMs are inherently limited because they do not represent key ecological processes that define species abundance and distribution: reproduction, growth, and mortality; interactions among species (e.g., competition, mutualism); and disturbance interactions (e.g., wildfires, pests, pathogens, invasives), and therefore should not be used to design management strategies and treatments. For example, although whitebark pines can establish at most elevations within western forests (Arno et al. 1995), they grow best at high elevations where there is little competition from other species. However, warming temperatures may drive distributional limits of competing species upslope, altering fire regimes, ecosystem water and energy balance and further reducing whitebark pine abundance. Understanding dynamics of complex interactions requires a commensurately complex modeling approach.

For the last 20 years we have been developing, updating, and refining a model called FireBGCv2 that is an ideal tool for simulating complex and dynamic interactions among climate, individual species, and ecosystem stressors and disturbance processes on forested landscapes of the Rocky Mountains

(Keane et al. 1996; Keane et al. 2011). Specific to whitebark pine modeling, FireBGCV2 includes explicit routines for Clark's nutcracker seed dispersal, mountain pine beetle activity, blister rust, and a genetics feedback to rust resistance. It has successfully been used in over 20 projects to simulate climate change impacts on landscape dynamics (e.g., Loehman et al. 2011a). In fact, Loehman et al. (2011b) used FireBGCv2 to explore effects of restoration treatments on whitebark pine population levels under three climate change scenarios and found that allowing wildfires to burn maintained whitebark pine forests under a warming climate, albeit at lower levels. What is greatly needed is to expand Co-PI Loehman's study to test the effects of proposed restoration treatments under the range of climates and emergent and interacting ecosystem stressors projected for landscapes of the GNLCC, and to use these results to enhance and expand restoration guidelines developed by PI Keane and others. *The direct management application of this work is an updated and robust set of guidelines to help managers most effectively promote and restore whitebark pine forests in the northern Rocky Mountains (USA and Canada).*

Objective: We propose to use FireBGCv2 simulation modeling to develop effective restoration strategies, treatments and detailed management guidelines for creating resilient and persistent whitebark pine forests in the Rocky Mountains (USA and Canada). These recommendations will provide critical information to incorporate into decision support tools for the conservation of endangered whitebark pine forests in perpetuity. We will develop a guide that will answer the often asked management questions of *(1) What stands should I restore? (2) When and where should I plant rust-resistant seedlings? (3) How can I ensure that restoration efforts will be effective under projected climate changes?*

Methods: Our simulation framework uses FireBGCv2, a mechanistic, spatially-explicit individual tree succession model that simulates ecological processes (e.g., tree growth, organic matter decomposition, and litterfall) using detailed physical and biogeochemical relationships, and explicitly spatially simulates landscape fire dynamics and fire's effects on ecosystem components, including interactions with climate, insects (mountain pine beetle), diseases (rust), and land management practices (see Keane et al. 2011 for complete model documentation, also http://www.firelab.org/research-projects/fire-ecology/139-fi). We will assess resilience and persistence of whitebark pine under future climates and landscape stressors on three landscapes that are broadly representative of a wide range of climate, vegetation, and fire regime types for whitebark pine in the northern Rocky Mountains. These landscapes have already been prepared for FireBGCv2 execution, a considerable investment (it requires 3-6 months of intensive sampling by a two person crew to collect data to initialize and parameterize FireBGCv2and another 6-8 months to prepare the input maps and files):

- **Crown of the Continent, including portions of Glacier National Park and the Flathead National Forest:** A 100,000 ha high-elevation mesic mixed-conifer ecosystem with low- to moderate-frequency, mixed severity fire regimes historically containing 12-16% whitebark pine forests,
- **East Fork Bitterroot River, Bitterroot National Forest:** A 128,000 ha dry mixed-conifer ecosystem with a mixed frequency, mixed severity fire regime currently containing 8-12% whitebark pine,
- **Central Plateau, Yellowstone National Park:** A 120,000 ha high-elevation Lodgepole pine dominated ecosystem with a low-frequency, high-severity fire regime with >10% whitebark pine

We will implement a multifactorial simulation experimental design with five factors: Fire Management (FM), Restoration Treatment (RT), Treatment Level (LL), Whitebark Planting (WP), and climate change (CC). Within each factor are a set of levels that span the range of possible outcomes. For FM, we will simulate three levels of fire suppression: zero suppression (natural fire regime), 50% suppression (wildland fire use), and 90% suppression (full fire suppression). For RT, we will simulate two restoration treatments –prescribed burning and mechanical cuttings that remove whitebark pine competitors using harvesting. The five factor levels under TL represent the percent of a landscape that is treated each year using the two RT treatments (0.0, 0.5, 2.0, 10, and 25 percent of the landscape per year). The WP factor has two treatments – planting rust-resistant seedlings and no planting. We will evaluate a suite of response variables that describe ecological dynamics under combinations of factors described above, including vegetation (basal area and tree density by species, LAI, structure, cover type), fuels (canopy bulk density, duff loading, surface fuel loading), fire (fireline intensity, average annual area burned, landscape fire rotation), fire effects (tree mortality, fuel consumption, fire severity), and carbon (aboveground, total, carbon smoke emissions). We will further quantify ecological resilience as an index that integrates fire-caused tree mortality, change in vegetation type after disturbance, and longevity of vegetation types on the landscape. We will assess whether modeled ecological trajectories represent threshold shifts and important tipping points using statistical change point detection methods, and quantify the sensitivity of each landscape to climate changes and ecosystem stressors. We will analyze our results using nested repeated ANOVA statistics to detect major differences across factors and levels and to explore possible interactions among factors. We will also use the range and variability of the response metrics to set quantitative thresholds and sideboards for each management guideline. Because whitebark pine is a keystone and foundation species and its distribution overlaps with other forest types that provide important habitat for key conservation targets, our management guidelines and results will also benefit other species of concern within the Rocky Mountains, such as grizzly bears, wolverines, and Canada lynx.

Deliverables: *Two publications, webinars, a conference presentation, and a formal workshop.* We will author a scientific journal article summarizing restoration treatments needed to keep whitebark pine on the landscape under changing climate and interacting ecosystem stressors, and produce an authoritative Restoration Guide and Toolkit for managers (published as an RMRS General Technical Report), a decision support instrument that presents protocols, guidelines, and considerations to plan, design, and implement successful whitebark pine restoration treatments. We will develop webinar presentations to introduce the Restoration Guide and Toolkit: these will be hosted and archived by the Northern Rockies Fire Science Network, USFS Region 1 Environmental Monitoring Program, and Rocky Mountain Research Station, as well as the GNLC if interested. We will also hold a one day Restoration Workshop to share project results during the 2014 Whitebark Pine Ecosystem Foundation annual science meeting, and will present project results at one national conference.

Key Cooperators: Our cooperators (see p. 1) are recognized authorities on whitebark pine ecosystems and are actively engaged in managing high-elevation forests within the Rocky Mountains (USA and Canada). Each of our cooperators will provide in-kind contributions on all phases of the project. The Whitebark Pine Ecosystem Foundation (PI Keane is a founding member and current board member) will also serve as a cooperator in broadly disseminating project results.

Statement of compliance: Both PIs (Keane, Loehman) have read the Great Northern Landscape Conservation Cooperative Information, Management, Delivery, and Sharing Standards and agree to comply with those standards if the proposal is selected. We will archive and share the data for the GNLCC and also provide the model and the inputs.

Schedule: Assuming an award date of 9/2013:
Sept-Oct 2013: Develop simulation framework in collaboration with cooperators
Nov-Feb 2014: Execute simulations on Cray supercomputing cluster, Missoula Fire Lab
Mar-May 2014: Analyze results; produce figures and tables; draft publications internally reviewed
June-Sept 2014: Journal paper and Restoration Guide submitted for publication; Projects results available for dissemination via web sites (GNLCC and others); Webinars and conference presentation delivered, present Restoration Workshop at 2014 Whitebark Pine Ecosystem Foundation annual science meeting

References

Arno, S. F., J. H. Scott, and M. G. Hartwell. 1995. Age-class structure of old growth ponderosa pine/Douglas-fir stands and its relationship to fire history. Research Paper INT-RP-481, Intermountain Research Station, Forest Service, USDA.

Dale, V. H., L. A. Joyce, S. McNulty, R. P. Neilson, M. P. Ayres, M. D. Flannigan, P. J. Hanson, L. C. Irland, A. E. Lugo, C. J. Peterson, D. Simberloff, F. J. Swanson, B. J. Stocks, and B. Michael Wotton. 2001. Climate Change and Forest Disturbances. BioScience **51**:723-734.

Ellison, A. M., M. S. Bank, B. D. Clinton, E. A. Colburn, K. Elliott, C. R. Ford, D. R. Foster, B. D. Kloeppel, J. D. Knoepp, G. M. Lovett, J. Mohan, D. A. Orwig, N. L. Rodenhouse, W. V. Sobczak, K. A. Stinson, J. K. Stone, C. M. Swan, J. Thompson, B. Von Holle, and J. R. Webster. 2005. Loss of foundation species: consequences for the structure and dynamics of forested ecosystems. Frontiers in Ecology and the Environment **3**:479-486.

Keane, R. E., R. A. Loehman, and L. M. Holsinger. 2011. The FireBGCv2 landscape fire and succession model: A research simulation platform for exploring fire and vegetation dynamics U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO.

Keane, R. E., D. F. Tomback, C. A. Aubry, A. D. Bower, E. M. Campbell, C. L. Cripps, M. B. Jenkins, M. F. Mahalovich, M. Manning, S. T. McKinney, M. P. Murray, D. L. Perkins, D. P. Reinhart, C. Ryan, A. W. Schoettle, and C. M. Smith. 2012. A range-wide restoration strategy for whitebark pine forests. General Techical Report RMRS-GTR-279, USDA Forest Service Rocky Mountain Research Station, Fort Collins, Colorado.

Keane, R. E., K. C. Ryan, and S. W. Running. 1996. Simulating effects of fire on northern Rocky Mountain landscapes with the ecological process model FIRE-BGC. Tree Physiology **16**:319-331.

Koteen, L. 1999. Climate change, whitebark pine, and grizzly bears in the greater Yellowstone ecosystem. Pages 343-364 *in* S. H. Schneider and T. L. Root, editors. Wildlife responses to climate change. Island Press, Washington DC USA.

Loehman, Rachel A.; Corrow, Allissa; Keane, Robert E. 2011. Modeling climate changes and wildfire Interactions: Effects on whitebark Pine (Pinus albicaulis) and implications for restoration, Glacier National Park, Montana, USA. Pages 176-188 In: Keane, Robert E.; Tomback, Diana F.; Murray, Michael P.; and Smith, Cyndi M., eds. 2011. The future of high-elevation, five-needle white pines in Western North America: Proceedings of the High Five Symposium. 28-30 June 2010; Missoula, MT. Proceedings RMRS-P-63. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 376 p. Online http://www.fs.fed.us/rm/pubs/rmrs_p063.html

Loehman, R. A., J. A. Clark, and R. E. Keane. 2011. Modeling Effects of Climate Change and Fire Management on Western White Pine (Pinus monticola) in the Northern Rocky Mountains, USA. Forests **2**:832-860.

Lorenz, T. J., C. Aubry, and R. Shoal. 2008. A review of the literature on seed fate in whitebark pine and the life history traits of Clark's Nutcracker and pine squirrels. General Technical Report PNW-GTR-742, USDA Forest Service Pacific Northwest Research Station, Portland, OR.

Ryan, K. C., and E. D. Reinhardt. 1988. Predicting postfire mortality of seven western conifers. Canadian Journal of Forest Research **18**:1291-1297.

Tausch, R. J., P. E. Wigand, and J. W. Burkhardt. 1993. Viewpoint: Plant Community Thresholds, Multiple Steady States, and Multiple Successional Pathways: Legacy of the Quaternary? Journal of Range Management **46**:439-447.

Tomback, D., S. F. Arno, and R. E. Keane. 2001. Whitebark pine communities: Ecology and Restoration. Island Press, Washington DC, USA.

Tomback, D. F. 1982. Dispersal of Whitebark Pine Seeds by Clark's Nutcracker: A Mutualism Hypothesis. Journal of Animal Ecology **51**:451-467.

Warwell, M. V., G. E. Rehfeldt, and N. L. Crookston. 2007. Modeling contemporary climate profiles of whitebark pine (Pinus albicaulis) and predicting responses to global warming. Pages 139-142 *in* Proceedings of the conference whitebark pine: a Pacific Coast perspective. Ashland, OR, Ashland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region., 2006 August 27-31; Ashland, OR.