Whitebark Pine Encroachment into Lower Elevation Sagebrush Grasslands in Southwest Montana, USA

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Introduction

The collective impacts of fire exclusion polices, mountain pine beetle (*Dendroctonus ponderosae* Hopkins) outbreaks, and white pine blister rust (*Cronartium ribicola* J.C. Fisch) infections have resulted in a rapid decline of whitebark pine (*Pinus albicaulis* Engelm.) forests in western North America over the last several decades (Arno 1986, Kendall and Keane 2001, Goeking and Izlar 2018). Especially distressing are the projected declines in these iconic forests because of future changes in climate (Warwell et al. 2007, Chang et al. 2014). Future warmer and drier climates could result in increases in the frequency of wildland fire (Flannigan et al. 2009, Abatzoglou and Williams 2016, Schoennagel et al. 2017) and mountain pine beetle outbreaks (Carroll et al. 2003, Wong and Daniels 2016), but it is also speculated that it will also increase white pine blister rust infections (Landguth et al. 2017, Wyka et al. 2018). However, more alarming is that many statistical modeling studies have shown significant reduction in the biophysical conditions that define suitable whitebark pine habitat over the next century (Warwell et al. 2007, Chang et al. 2014). Historically, whitebark pine forests composed about 10-15% of the upper subalpine zone of the northern Rocky Mountains (Arno and Weaver 1990) with around 48% of that in wilderness landscapes, but future projections for these iconic forests suggest that they may inhabit as little as 0.5-7.0% by 2070-2100 (Hansen and Phillips 2015).

In general, there are modes of response to climate change for most tree species in western North America: modification, contraction, and expansion (synonymous with encroachment in this study; Keane et al. 2018). A species may increase or decrease in productivity or abundance *in situ* within its current range due to climate change (Ashton 2010; *modification*). The species could also potentially decline in parts of its range where conditions change enough to become inhospitable to that species (Allen et al. 2010; *contraction*). And last, the species could migrate to new areas that are now more conducive for establishment and growth (Johnstone and Chapin 2003; *expansion*). In reality, many tree species may respond to future climates via all three modes. Conventional wisdom and statistical modeling have predicted that whitebark pine will probably contract in range over the next century with warmer, drier climates, but may perhaps expand into high elevation timberline environments (Koteen 2002, Warwell et al. 2007, Chang et al. 2014). However, expert opinion and empirical analyses rarely address the complex feedbacks and interactions between climate, biophysical environment, disturbance, and the tree species. The challenge then is to determine the validity of these predictions by measuring early responses of whitebark pine to changing climates. We feel that field detection of migration patterns of tree species into new environments may provide potential information on the impacts of climate change on species response and validate existing empirical and simulation modeling study results.

The objective of this case study was to document the encroachment (local expansion of species into new habitats) of whitebark pine (Fig. 1) into both lower elevation sagebrush grassland areas and upper elevation subalpine meadows that were

a. b.

c. d.

Figure 1. Examples of whitebark pine trees encroaching into sagebrush grasslands for the three sites in this study. a) Photo from Morrison site. Edge of mature seed source stand showing whitebark pine encroachment into sagebrush landscape b) Photo from Morrison site. Mature cone bearing whitebark pine interspersed on sagebrush habitat c) Photo from potential site in southwestern Montana. Downward encroachment of whitebark pine into open sagebrush d) Photo from Morrison site. Seedling and sapling sized whitebark pine mixing in with sagebrush. All photos by Sarah Flanary.

directly adjacent to mature, cone-bearing whitebark pine stands, which might provide seeds for dispersal into the two non-forest settings. We sampled seedling, sapling, and mature tree densities by species on three study sites in southwestern Montana, USA where we found evidence of encroachment either into the upper subalpine meadow or lower sagebrush grasslands. This limited field assessment only documents whitebark pine encroachment into the two non-forest areas, but we speculate on possible reasons as to why this encroachment occurred.

Methods

The Tendoy and Beaverhead mountain ranges of southwestern Montana USA served as the study area in this project (Fig. 2). Lower elevational lands within this area contain mountain big sagebrush (*Artemisia tridentata* ssp. *Vasseyana* Rydb.) grasslands intermixed with dry Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and lodgepole pine (*Pinus contorta* Douglas) forests (Pfister et al. 1977, Larson 2009), while the upper elevation lands contain subalpine meadows and grasslands with forest patches of whitebark pine, limber pine (*Pinus flexilis* James), subalpine fir (*Abies lasiocarpa* (Hook) Nutt.), Engelmann spruce (*Picea engelmannii* (Parry) Engelm.), lodgepole pine, and Douglas-fir. Mountain big sagebrush lands had a mean pre-settlement fire interval between 25 to 40 years, but fire suppression, elimination of Native American burning, and livestock grazing in these areas have decreased the fire frequencies and increased the amount of dense-canopy mountain big sagebrush.

Sites in this study were chosen opportunistically by driving and hiking throughout the study area and finding those areas that displayed possible whitebark pine encroachment either uphill into

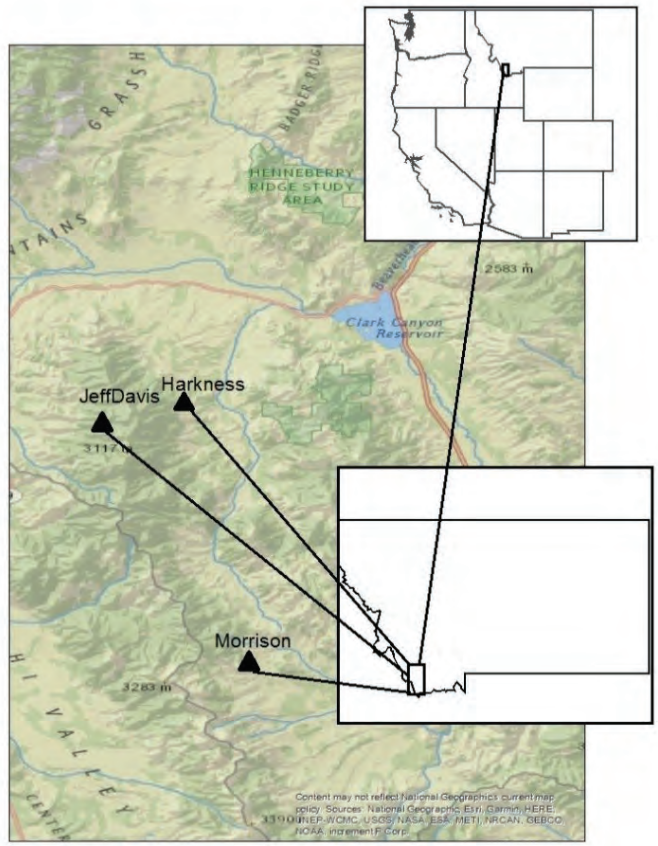


Figure 2. Locations of the three sites sampled in this field study in the southwest Montana, USA study area: a) Harkness, b) Jeff Davis, and c) Morrison sites.

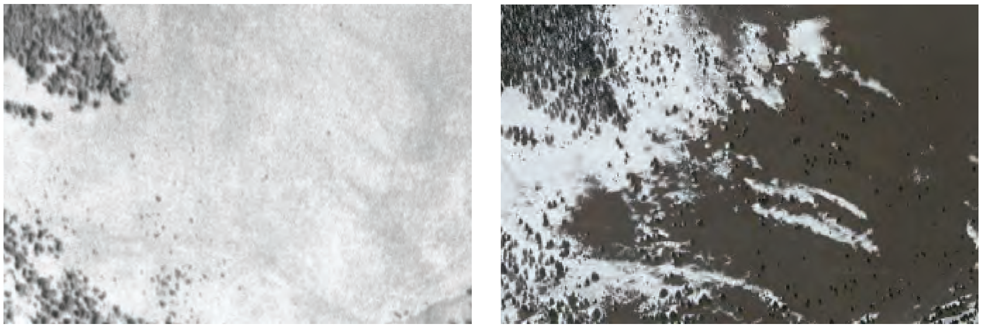
subalpine grasslands or downhill into sagebrush grasslands. We also used aerial survey imagery from the 1950's and compared it to current aerial products for provide further confirmation of encroachment (Fig. 3). At each sampling site, we established plots in the mature seed source stands to quantify seed source trees. At the lower and upper edge of the seed source stand, we also installed one 100 m belt transect running downhill into the sagebrush grassland and uphill into the subalpine meadow. Each belt transect was 100 meters wide and at least 100 meters long following the shape of the stand. Within these belt transects, we tallied and measured diameter, height, and age of all whitebark pine trees (seedlings, saplings, and mature trees).

Results

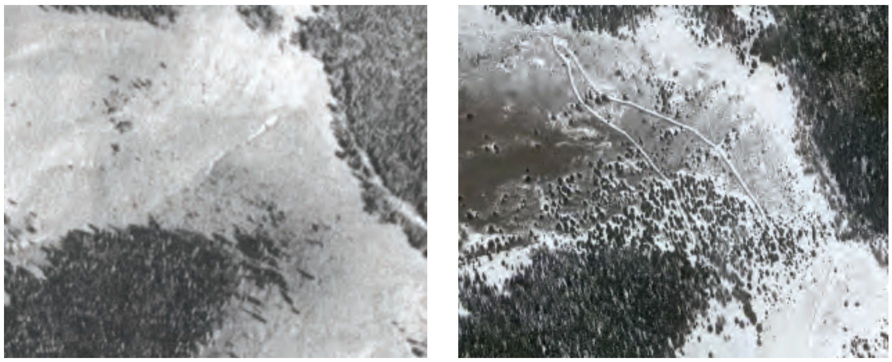
In this limited case study, we found whitebark pine encroachment into non-forested areas only occurred downslope into the drier, warmer sagebrush grasslands rather than upslope into the cooler, moister subalpine meadows. This finding suggests that conventional wisdom and the findings of some statistical modeling studies may be incorrect in their future projections within our study area. We found that not only were substantial amounts of whitebark pine regenerating downslope in the sagebrush grasslands, but the sampled individual trees were healthy and thriving as evidenced by the large height growth increments, pitch exudations from growth cracks at branch origins near the bole, and large diameters in the young trees. Some of the young trees were producing numerous cones at an early age (<50 yr), which is in contrast to the first cone production ages of 60 years documented by Arno and Hoff (1990). Moreover, we found that this encroachment occurred over the last 100 years and did not occur as a pulse but rather as a gradual increase as evidenced by the wide span in ages (Fig. 4). We did not observe any subalpine fir or Engelmann spruce encroachment into either the sagebrush grasslands or the subalpine meadows. We also found abundant non-serotinous lodgepole pine and Douglas-fir seed source stands adjacent or near (<500 m) the sagebrush grassland belt transects on all three sites but found few of these tree species within the belt transects (we found five Douglas-fir trees within the Harkness sagebrush grassland belt transect). The only tree species successfully populating and thriving in the sampled sagebrush grasslands was whitebark pine. While we did not sample additional sites because of time and funding issues, we are sure there are other sites in this expansive area where whitebark pine encroachment is occurring. We also observed many areas in the study region where whitebark pine forests bordered sagebrush grasslands and there was no detectable encroachment. Moreover, we failed to detect this phenomenon outside of southwest Montana.

The explanation for this limited downward migration of whitebark pine remains a mystery. We speculate that the lack of fire in the southwestern Montana sagebrush grasslands over the fire exclusion era, perhaps since 1860 (Heyerdahl et al. 2006), has allowed whitebark pine to expand its range downward in elevation, as has been documented by Arno et al. (1993) for the Bitterroot Valley in Montana, but this doesn't explain why other tree species in the area failed to migrate into the non-forested areas. Whitebark pine seeds are dispersed by a bird, the Clark's nutcracker (Tomback 1998), which can disperse seeds great distances (>10 km) allowing whitebark pine a dispersal advantage over wind-dispersed species. However, 90 years is more than sufficient to allow wind to disperse seeds of whitebark pine's competitors into sagebrush grasslands. Still more compelling is that few studies have identified sagebrush grasslands as reliable or common nutcracker caching habitat or suitable whitebark pine regeneration environments. Sagebrush has been known to facilitate some pines (Callaway et al. 1996), and many whitebark pine sites have a sagebrush component (Arno 2001), but this encroachment facilitation has never been

a. Harkness



b. Jeff Davis



c. Morrison

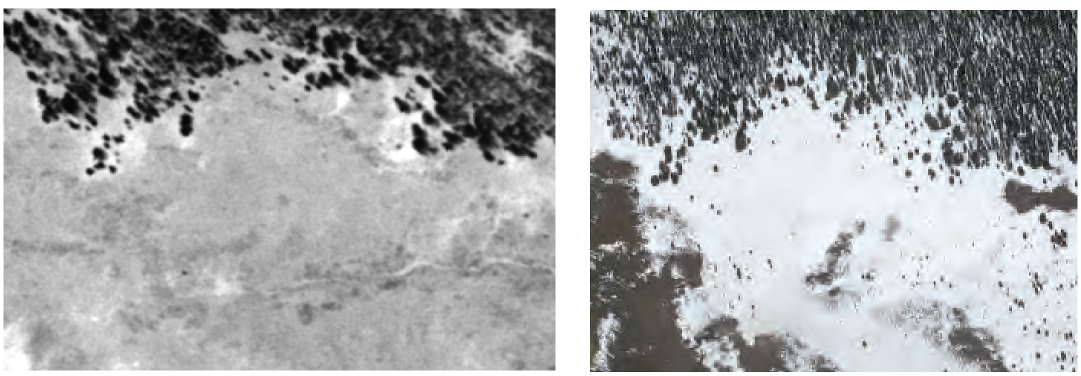


Figure 3. Aerial photographs showing each of the sampled sites in this study, showing both upper and lower forest margins for the three sampling sites: a) Harkness, b) Jeff Davis, and c) Morrison. Photos on left were taken between 1953-1954 while photos on right are a 2018 visual of the same spot. Encroachment is evident in the 2018 visual. Data available from the U.S. Geological Society, USGS Aerial Single Frame Archive at earthexploter.usgs.gov

documented in whitebark pine communities. Mycorrhizae may also play a role in the regeneration of whitebark pine in this arid area by allowing access to more soil water (Lonergan et al. 2013), but many of the other tree species in the area often share the same beneficial mycorrhizae (Mohatt et al. 2008).

Results from this limited case study of three sites in western Montana USA indicate that we still have an incomplete understanding of what will drive tree regeneration and growth dynamics into our uncertain future. We can anticipate possible responses of tree species such as whitebark pine to a warming climate, but it will always be difficult to determine the primary change agents or factors that influence future species populations because of the complex interactions among changes in disturbance, climate, vegetation, and land management. Further investigation is needed in other areas within whitebark pine's range to determine if our measured trend is widespread and if other species follow this same expansion downward in elevation (Harsch and Hille Ris Lambers 2014). Caution should be used when applying climate change projections into land management decisions by fully recognizing the uncertainty of future climate projections and the great complexity of forested ecosystems. This case study serves as evidence of that uncertainty in climate change vegetation response projections.

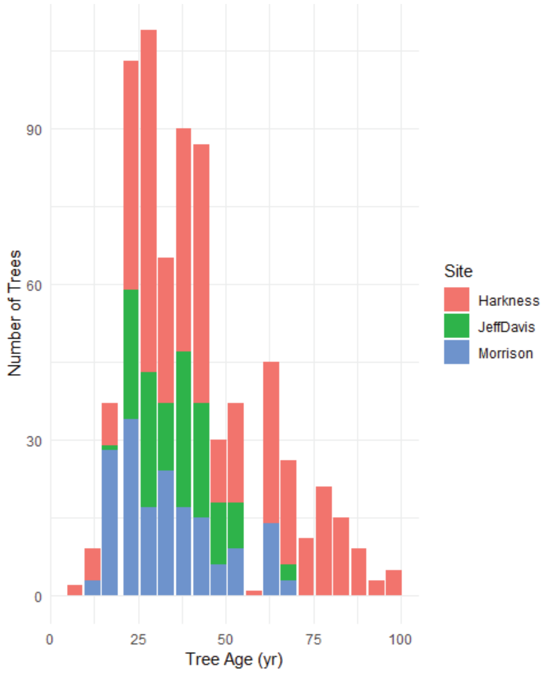


Figure 4. Count data and field estimated ages for sapling (<10 cm DBH) and mature (>10 cm DBH) whitebark pine trees sampled on the lower sagebrush grassland belt transects in the potential encroachment areas across all sites.

References

Abatzoglou, J. T., and A. P. Williams. 2016. Impact of anthropogenic climate change on wildfire across western US forests. Proceedings of the National Academy of Sciences 113:11770-11775.

Allen, C. D., A. K. Macalady, H. Chenchouni, D. Bachelet, N. McDowell, M. Vennetier, T. Kitzberger, A. Rigling, D. D. Breshears, and E. T. Hogg. 2010. A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. Forest Ecology and Management 259:660-684.

Arno, S. A. 2001. Community types and natural disturbance processes. Pages 74-89 in D. F. Tomback, S. A. Arno, and R. E. Keane, editors. Whitebark pine communities: ecology and restoration. Island Press, Washington, DC USA.

Arno, S. F. 1986. Whitebark pine cone crops—a diminishing source of wildlife food? Western Journal of Applied Forestry 1:92-94.

Arno, S. F., and T. Weaver. 1990. Whitebark pine community types and their patterns on the landscape. General technical report INT (USA).

Ashton, I. W. 2010. Observed and projected ecological response to climate change in the Rocky Mountains and Upper Columbia Basin: A synthesis of current scientific literature.

Callaway, R. M., E. H. DeLucia, D. Moore, R. Nowak, and W. H. Schlesinger. 1996. Competition and Facilitation: Contrasting Effects of *Artemisia tridentata* on Desert vs. Montane Pines. Ecology 77:2130-2141.

Carroll, A. L., S. W. Taylor, J. Régnière, and L. Safranyik. 2003. Effect of climate change on range expansion by the mountain pine beetle in British Columbia. In Pages 223-232 in TL Shore et al. (eds) Mountain Pine Beetle Symposium: Challenges and Solutions, Oct. 30-31, 2003. Kelowna BC. Natural Resources Canada, Infromation Report BC-X-399, Victoria.

Chang, T., A. J. Hansen, and N. Piekielek. 2014. Patterns and variability of projected bioclimatic habitat for *Pinus albicaulis* in the Greater Yellowstone Area. PLoS One 9:e111669.

Flannigan, M. D., M. A. Krawchuk, W. J. de Groot, B. M. Wotton, and L. M. Gowman. 2009. Implications of changing climate for global wildland fire. International Journal of Wildland Fire 18:483-507.

Goeking, S. A., and D. K. Izlar. 2018. *Pinus albicaulis* Engelm. (Whitebark Pine) in mixed-species stands throughout its US range: broad-scale indicators of extent and recent decline. Forests 9:131.

Hansen, A. J., and L. B. Phillips. 2015. Which tree species and biome types are most vulnerable to climate change in the US Northern Rocky Mountains? Forest Ecology and Management 338:68-83.

Harsch, M. A., and J. Hille Ris Lambers. 2014. Species distributions shift downward across western North America. Global Change Biology:n/a-n/a.

Heyerdahl, E. K., R. F. Miller, and R. A. Parsons. 2006. History of fire and Douglas-fir establishment in a savanna and sagebrush–grassland mosaic, southwestern Montana, USA. Forest Ecology and Management 230:107-118.

Johnstone, J. F., and F. S. Chapin. 2003. Non-equilibrium succession dynamics indicate continued northern migration of lodgepole pine. Global Change Biology 9:1401-1409.

Keane, R. E., M. F. Mahalovich, B. L. Bollenbacher, M. E. Manning, R. A. Loehman, T. B. Jain, L. M. Holsinger, and A. J. Larson. 2018. Effects of climate change on forest vegetation in the Northern Rockies. Pages 59-95 Climate Change and Rocky Mountain Ecosystems. Springer.

Kendall, K. C., and R. E. Keane. 2001. Whitebark pine decline: infection, mortality, and population trends. Whitebark pine communities: ecology and restoration. Edited by DF Tomback, SF Arno, and RE Keane. Island Press, Washington, DC:221-242.

Koteen, L. 2002. Climate change, whitebark pine, and grizzly bears in the Greater Yellowstone Ecosystem. Wildlife responses to climate change: North American case studies. Edited by SH Schneider and TL Root. Island Press, Washington, DC:343-414.

Landguth E. L.; Holden, Z. A. M., M. F.; Cushman, S. A. 2017. Using landscape genetics simulations for planting blister rust resistant whitebark pine in the US northern Rocky Mountains. Frontiers in Genetics 8.

Larson, E. R. 2009. Status and dynamics of whitebark pine (*Pinus albicaulis* Engelm.) forests in southwest Montana, central Idaho, and Oregon, USA. University of Minnesota.

Lonergan, E. R., C. L. Cripps, and C. M. Smith. 2013. Influence of site conditions, shelter objects, and ectomycorrhizal inoculation on the early survival of whitebark pine seedlings planted in Waterton Lakes National Park. Forest Science 60:603-612.

Mohatt, K. R., C. L. Cripps, and M. Lavin. 2008. Ectomycorrhizal fungi of whitebark pine (a tree in peril) revealed by sporocarps and molecular analysis of mycorrhizae from treeline forests in the Greater Yellowstone Ecosystem. Botany 86:14-25.

Pfister, R. D., B. L. Kovalchik, S. F. Arno, and R. C. Presby. 1977. Forest habitat types of Montana. USDA Forest Service, Intermountain Forest and Range Experiment Station Gen. Tech. Rep. INT-GTR-34. 174p.

Schoennagel, T., J. K. Balch, H. Brenkert-Smith, P. E. Dennison, B. J. Harvey, M. A. Krawchuk, N. Mietkiewicz, P. Morgan, M. A. Moritz, and R. Rasker. 2017. Adapt to more wildfire in western North American forests as climate changes. Proceedings of the National Academy of Sciences 114:4582-4590.

Tomback, D. F. 1998. Clark's nutcracker (*Nucifraga columbiana*). The Birds of North America 331:1-23.

Warwell, M. V., G. E. Rehfeldt, and N. 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. Citeseer.

Wong, C. M., and L. D. Daniels. 2016. Novel forest decline triggered by multiple interactions among climate, an introduced pathogen and bark beetles. Global Change Biology:n/a-n/a.

Wyka, S. A., I. A. Munck, N. J. Brazee, and K. D. Broders. 2018. Response of eastern white pine and associated foliar, blister rust, canker and root rot pathogens to climate change. Forest Ecology and Management 423:18-26.