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Whitebark Pine Diameter Growth Response to Removal of Competition

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Abstract—Silvicultural cutting treatments may be needed to restore whitebark pine (*Pinus albicaulis*) forests, but little is known of the response of this species to removal of competition through prescribed burning or silvicultural cuttings. We analyzed stem cross-sections from 48 whitebark pine trees in Montana around which most of the competing vegetation was removed by timber harvest treatments. We compared tree ring growth rates before and after the harvest treatment using intervention analysis to determine 1) the potential of release for this little-studied tree species and 2) whether the release is related to tree and stand characteristics. We defined release as a statistically significant increase in radial growth after competing trees were removed. All but one of our 48 sampled trees increased in diameter growth after competition was removed, while 40 trees showed a statistically significant ($p<0.05$) increase in growth. Diameter release was greatest in stands that were dense prior to tree cutting and greatest in old trees with large diameters. Recommendations for appropriate silvicultural cutting are included to aid managers in designing effective restoration treatments.

Key words: Whitebark pine, diameter release, logging, restoration treatments, intervention analysis, advance regeneration

Introduction

It is well known that whitebark pine (*Pinus albicaulis*) is declining rapidly across many parts of its range in the United States and Canada due to the combined effects of the exotic white pine blister rust (*Cronartium ribicola)*, the native mountain pine beetle (*Dendroctonus ponderosae*), and the exclusion of fires (Arno 1986; Kendall and Keane 2000; Tomback and others 2000). Recent research efforts are attempting to restore whitebark pine forests using prescribed fire and silvicultural cuttings (Keane and Arno 1996, 2001). These treatments could be implemented in stands with significant amounts of advance whitebark pine regeneration in the understory or slow-growing saplings or pole-sized whitebark pine trees in the overstory. These suppressed trees can be quite old since the species is moderately shade tolerant having the ability to survive under partial shade for many decades (Minore 1979, Arno and Hoff 1989). Since other high elevation trees appear to respond to harvest cuttings (Crossley 1976; Helms and Standiford 1985; McCaughey and Schmidt 1982), managers need to know if suppressed whitebark pine trees have the ability to release (increase in growth as a response to the elimination of competition) after silvicultural cuttings and eventually grow into cone-bearing trees.

Few studies have explored the ability of crowded whitebark pine trees to respond to a sudden decrease in competition after overstory removal. Eggers (1990) observed that "whitebark pine … responded little to release," but recognized that additional data was needed in this area. However, Kiper and others (1994) evaluated crown response in whitebark pine using a distance dependent competition index in three Montana logged stands and found many trees increased crown dimensions after release. Since the success of some restoration treatments depends on the ability of understory whitebark pine to respond to overstory removal, managers need to know the circumstances under which whitebark pine seedlings and saplings will release so that cutting prescriptions can be designed to maximize the success of restorative treatments.

In this study, we sampled 1-3 whitebark pine trees in 21 logged stands where most of the competing vegetation was removed by recent timber harvest activities. We compared tree ring growth rates before and after the harvest treatment to determine 1) the thresholds

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of diameter release for this little-studied tree species and 2) the relationship of the magnitude of release to tree and stand characteristics. We defined release as a statistically significant increase in radial growth after logging. Recommendations for appropriate silvicultural cutting are included in this paper to aid managers in designing effective restoration treatments.

Methods

Field Sampling

During the summers of 2003 and 2004, we opportunistically searched for high elevation harvest areas across Montana where surviving whitebark pine trees remained in good health. We attempted to sample across a wide range of tree diameters, heights, and ages. Only previously logged areas where healthy, surviving whitebark pine trees were in the pre-harvest understory or overstory were sampled. We did not sample trees with observable signs and symptoms of insects or diseases, especially those with blister rust or mountain pine beetle. We sampled only those trees where all competing trees were removed within an area surrounding the tree (defined by a circle with a radius greater than the surviving tree's height). Smaller whitebark pine trees found within this surrounding area were sometimes sampled, up to three trees per plot, to obtain a full range of diameters in our sample. All the sampled trees were individuals and did not occur as a cluster, either before or after the cutting. We determined the cutting dates from stand records filed in National Forest District offices and we verified these dates from diameter release dates estimated from increment cores taken at each site from surviving trees of any species taken outside the plot.

We gathered additional site and vegetation information within a 0.1-acre circular plot surrounding the tree(s) using FIREMON sampling techniques (Lutes and others 2006, www.fire.org/firemon). The site variables measured were slope, aspect, elevation, geo-referenced location, habitat type (Pfister and others 1977), ground cover, and landform. We measured the tree diameter at breast height (DBH), height, live crown base height, and crown position of all living trees above 4.5 feet (1.37 meters) tall. To estimate pre-harvest stand densities and basal areas by species, we measured cut diameter and determined the species of all stumps >4 inches (10 cm) in diameter. We also recorded detailed notes on the 1) pre-harvest and current stand conditions, 2) tree species compositional changes in the plot, and 3) silvicultural treatment paying special attention to past disturbances and evidence of disease.

We felled each sample tree and cut a cross-sectional disk at three heights along the bole of the tree: 1) 4-5 feet (1.37 meters) from the base of tree, 2) at bottom of crown, and 3) at 1 foot (0.3 meters) down from the top of crown. Each disk was about 0.5 to 1.5 inch (1-3 cm) in thickness. These disks were transported to the laboratory in burlap sacks where they were air-dried and mounted on a board using wood glue. The top of the disk was smoothed using progressively finer sand paper until all growth rings were visible with the naked eye. We then measured the annual ring widths along four radii of the pith: two radii along the widest diameter of the cross section and two radii that were perpendicular to this longitudinal diameter. We measured ring width using a tree ring chronometer and associated software specifically designed to measure within 0.01 mm tolerance. Assuming circuit uniformity across diameters, we calculated average annual growth for each core as an average across the four radii for each year since the tree's origin.

Data Analysis

We used a statistical technique called "intervention analysis" (Sridharan and others 2003) to test for significant release or change in tree ring growth for the years following logging and to estimate the magnitude and significance of the release. Intervention analysis is a time series tool developed by Box and Tiao (1975) used to detect a change over the time that the data were collected. Time series analysis is a statistical tool that uses autocorrelation in data collected sequentially in time to predict future observations (Brockwell and Davis 2002). Once stationarity has been achieved (in other words, when the trend and drift in temporal data has been removed), an ARIMA (Autoregressive, Integrated, and Moving Average) model is fit to the time series data before the intervention (harvest) has occurred (pre-harvest).

We calculated the first difference of the ring width time series before performing the intervention analysis to achieve stationarity. We then used the ARIMA model to make forecast predictions for the post-intervention period. If the forecasted values were significantly different than the observed values for the post-intervention period, we concluded that the intervention (release of competition) had an effect (Box and Tiao 1976). We used a chi-square test statistic compared to a chi-square distribution with degrees of freedom equal to the number of forecasted values to determine the significance of the effect (SPLUS 2001). The intervention analysis was performed using the ITSM 2000 software developed by Brockwell and Davis (2002).

To quantify the magnitude of the change, a regression model with a time series component was fit to each tree ring series by modeling both the pre-harvest and the post-harvest periods. We analyzed the magnitude of ring width change because we found evidence that some trees appeared to have a gradual increase in growth rate for a few years after logging and then a gradual decrease. We estimated the magnitude using only the pre-intervention period (25 years prior to release) and the post-intervention period (at least 20 years after release or until growth rate started to decrease). The following regression model was fit to each tree:

$X_t=bg_t+N_t$ where $t=2,3,\ldots n$

and $X_t=Y_t-Y_{t-1}$

where X_t is the change in growth at time t, Y_t is the tree ring growth at time t, g_t equals 1 from the time of observed release to the time of the observed decline in growth, and g_t equals 0 before the release. N_t is the stationary sequence to which an appropriate ARIMA model was fit (Brockwell and Davis 2002). The above model is similar to a regression model with a correlated error structure. The slope coefficient, b, is a measure of the magnitude of the release for a given tree. We used ring widths in this analysis instead of basal area increment because the differences in diameter across the 45+ years of analysis were relatively small (1 to 8 cm) and the variable transformation would favor post-harvest response.

We used average tree ring growth across the four radii measured for the cross-section taken at DBH for our analysis because we found that the other two height sections either contained nearly the same information as the DBH core or there was not the required ring count (40 years) for the higher cross-sections. We did not perform the intervention analysis on trees that did not have enough pre-intervention years (<40 years) because the limited record did not provide statistically valid comparisons ($p<0.05$). This reduced the number of valid trees for some of the sites. The intervention or release date was determined from stand records. There were no stand records for two trees, so we used release dates determined from increment cores of subalpine-fir trees taken on-site but off the plot.

Three measures of release were developed from the results of the time series analysis. Once the ARIMA model was fit, the estimate of b (slope) was estimated to quantify the magnitude of the release (Sridharan and others 2003). The number of years that the release lasted (length) was estimated by visual inspection of time series graphs for individual trees. And the total release (product of length and slope coefficient) was also estimated. We then calculated Pearson's Correlation coefficient between each of the three release variables (magnitude, length, and total release) (SPSS 1999) and each of the following tree and stand variables that were calculated from collected field data:

1. Diameter of tree (outside bark at breast height 1.37 m; DBH) at the time of sampling (summer of 2003 or 2004)
2. Age of tree at breast height at time of sampling (summer of 2003 or 2004)
3. DBH of tree (inside bark) at time of release
4. Age of tree at breast height at time of release
5. Stand density at time of release
6. Stand density at time of sampling
7. Change in stand density from release to sampling
8. Stand basal area at time of release
9. Stand basal area at time of sampling
10. Change in basal area from release to sampling
11. Mean growth for the 25 years prior to intervention

The age of the tree at the time of release and at the time of sampling was estimated from the cross section taken at breast height with no adjustments to estimate true age. To determine the influence of the tree and stand variables on the magnitude and length of release, we performed extensive regression analyses using the tree and stand variables as independent variables and the three release variables as dependent variables (SPSS 1999).

Results

We sampled 59 trees from 21 stands on 10 sites across the northern Rocky Mountains in Montana, USA (fig. 1). These sites had a wide variety of pre-harvest densities and stand ages (table 1). It was difficult to find suitable sites that contained healthy, residual trees after logging because there are very few harvest activities in the high elevation whitebark pine stands due to a lack of roads and valuable timber. Moreover, many trees in the western portion of Montana were infected with blister rust or dying because of mountain pine beetle (Kendall and Keane 2001). The sampled trees had a wide range of diameters (1 to 63 cm DBH) and ages (51 to 395 years) (table 1). A total of 14 trees had to be removed from the statistical analysis because they did not contain a sufficient number of tree rings (<40 rings prior to harvest date) to adequately perform the time series analysis.

Tree ring growth rates for all trees in the study are shown in table 2 for 25 years prior to release and for 5-year time intervals after release (post-logging). Most trees (>80 percent) showed a statistically significant increase

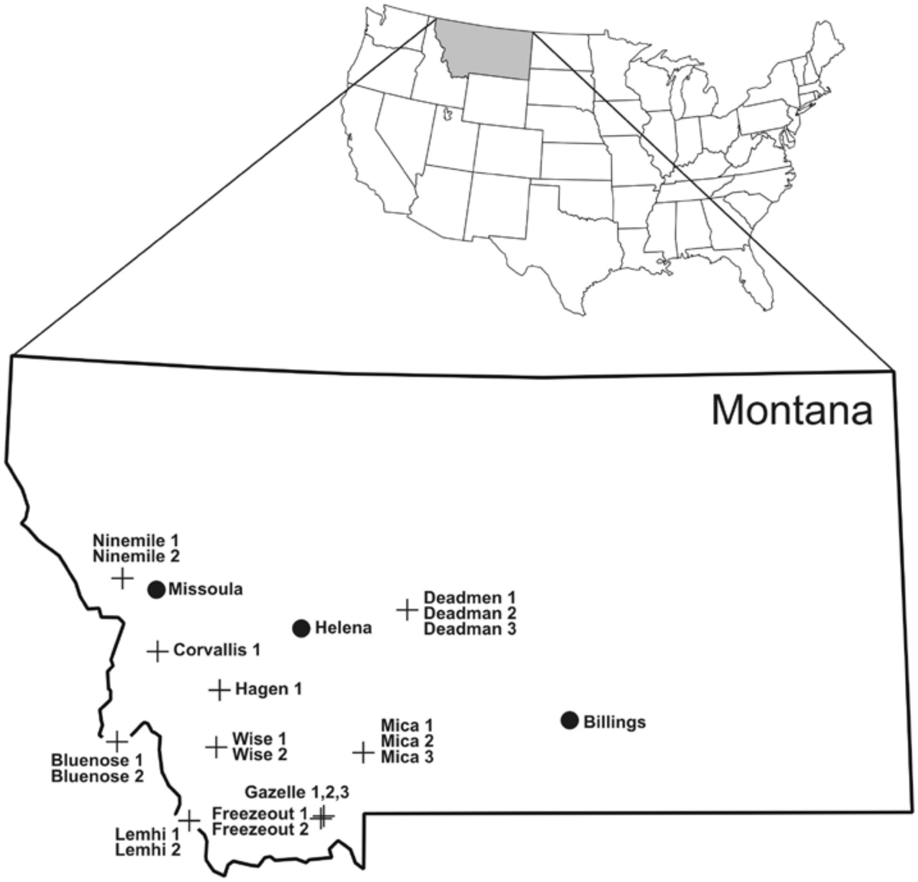

Figure 1—Distribution of sample sites across Montana.

Table 1—General description of the study sites sampled and the 45 trees sampled at those sites. We sampled 59 trees, but only 45 met our criteria for analysis.

Site	Number sample trees	Year of harvest	Pre-harvest density[a]	Pre-harvest basal area[b]	Tree DBH(s)	Tree age(s)[c]
			(trees ha^{-1})	*(m^2 ha^{-1})*	*(cm)*	*(years)*
Ninemile 1	1	1970	790	42.5	19	242
Ninemile 2	1	1992	741	52.3	22	257
Bluenose 1	2	1973	444	16.1	5, 36	115, 135
Bluenose 2	2	1973	593	28.6	3, 36	61, 304
Corvalis	2	1968	395	21.5	5, 23	93, 122
Deadman 1	3	1993	543	28.1	3, 7, 25	102, 145, 225
Deadman 2	1	1963	370	64.7	26	216
Deadman 3	1	1978	593	22.5	20	214
Freezeout 1	3	1996	1,259	52.4	8, 10, 31	51, 74, 240
Freezeout 2	2	1996	1,309	66.8	3, 23	63, 251
Gazelle 1	3	1997	741	54.6	5, 8, 25	110, 190, 252
Gazelle 2	3	1992	469	22.4	1, 5, 20	49, 185, 228
Gazelle 3	3	1973	1,259	34.8	13, 16, 24	149, 213, 237
Hagen 1	2	1992	642	28.5	5, 28	61, 93
Lemhi 1	1	1963	519	38.7	43	172
Lemhi 2	2	1978	765	34.3	23, 36	95, 120
Mica 1	3	1963	1,235	43.0	3, 11, 17	70, 119, 115
Mica 2	3	1978	1,086	34.7	9, 9, 18	117, 128, 132
Mica 3	3	1992	543	22.9	5, 12, 25	99, 113, 123
Wise 1	2	1967	444	30.2	10, 19	159, 179
Wise 2	2	1953	444	34.6	9, 61	67, 395

[a]Density includes all trees greater than 1 cm in diameter at stump height.
[b]Basal area was measured at stump height.
[c]Tree ages were estimated from a ring count at DBH.

Table 2—Summary of tree ring growth (mm year^{-1}) before the release date and tree ring growth for 5-year growth periods up to 20 years past the release date. Numbers in parentheses indicate the standard deviation. Numbers in bold and italics indicate statistical significance ($p<0.01$). An asterisk (*) indicates a statistically significant decrease in growth after release.

			Average annual growth (mm year^{-1})				
Plot	**Tree number**	**Release year (AD)**	**25 years prior to release**	**1-5 yrs post-release**	**6-10 yrs post-release**	**10-15 yrs post-release**	**16-20 yrs post-release**
Ninemile 1	1	1970	0.90 (0.24)	***1.12***	***1.46***	***1.73***	***1.76***
Ninemile 2	1	1992	0.71 (.26)	***1.98***	***3.89***		
Bluenose 1	1	1973	1.32 (.24)	***1.68***	***2.37***	***1.96***	***2.25***
	2	1973	0.25 (.07)	***0.41***	***0.39***	***0.63***	***0.59***
Bluenose 2	1	1973	1.57 (.38)	***1.65***	***1.64***	***1.39***	***1.54***
	2	1973	0.13 (.03)	***0.19***	***0.20***	***0.19***	***0.29***
Corvallis	1	1968	0.66 (.18)	***1.39***	***2.81***	***3.22***	***3.05***
	2	1968	0.12 (.03)	0.11	0.18	***0.30***	***0.25***
Deadman 1	1	1993	0.66 (.25)	***1.08***	***1.07***		
	2	1993	0.62 (.31)	***0.74***	***1.72***		
	3	1993	0.41 (.21)	0.53	***0.78***		
Deadman 2	1	1963	0.34 (.10)	0.19	***0.33***	***0.79***	***0.90***
Deadman 3	1	1978	0.14 (.07)	0.19	***0.74***	***0.83***	***0.89***
Freezeout 1	1	1996	0.15 (.04)	0.23			
	2	1996	0.31 (.11)	***0.72***			
	3	1996	0.21 (.15)	***0.86***			
Freezeout 2	1	1996	0.56 (.17)	***2.95***			
	2	1996	0.16 (.07)	***0.53***			
Gazelle 1	1	1997	0.56 (.11)	0.47			
	2	1997	0.48 (.13)	***1.04***			
	3	1997	0.08 (.03)	0.09			
Gazelle 2	1	1992	0.67 (.43)	***1.09***	***0.66***		
	2	1992	0.66 (.18)	***0.83***	***1.12***		
	3	1992	0.011 (.05)	***0.48***	***0.80***		
Gazelle 3	1	1973	0.30 (.14)	***0.99***	***1.55***	***1.30***	***1.23***
	2	1973	0.76 (.37)	***1.55***	***2.37***	***2.55***	***2.12***
	3	1973	0.54 (.11)	0.55	0.95	1.01	0.76
Hagen 1	1	1992	1.47 (.39)	***2.37***	***3.72***		
	2	1992	0.23 (.07)	***0.60***	***0.55***		
Lemhi 1	1	1963	2.56 (.30)	2.23	***2.41****	***2.04****	***2.37****
Lemhi 2	1	1978	1.98 (.40)	***2.04***	***1.62***	***2.60***	***3.90***
	3	1978	1.27 (.22)	***2.05***	***1.77***	***2.72***	***3.19***
Mica 1	1	1963	0.58 (.15)	0.65	***1.61***	***1.20***	***0.49***
	2	1963	0.13 (.03)	***0.25***	***0.90***	***0.70***	***0.36***
	3	1963	0.06 (.03)	***0.25***	***0.33***	***0.26***	***0.13***
Mica 2	1	1978	0.19 (.09)	***0.93***			
	2	1978	0.11 (.06)	0.09			
	3	1978	0.68 (.21)	0.86			
Mica 3	1	1992	0.61 (.37)	***1.48***	***1.62***		
	2	1992	1.18 (.63)	***2.49***	***1.65***		
	3	1992	0.33 (.35)	***1.43***	***1.33***		
Wise 1	1	1967	0.62 (.12)	***0.72***	***0.67***	***0.83***	***1.38***
	2	1967	0.29 (.07)	0.15	0.12	0.15	***0.39***
Wise 2	1	1953	0.73 (.25)	***0.97***	***1.15***	***1.42***	***2.24***
	2	1953	0.17 (.06)	0.21	0.17	0.16	0.23

in ring growth after the harvest treatments while only one tree (2 percent) showed a significant decrease in ring growth—a small suppressed sapling. The increase in ring growth for some trees was dramatic (fig. 2a, 2c; Mica 3 Tree 3 table 2) while for others it was difficult to detect (fig. 2b; Gazelle 1 Tree 1 table 2). Most trees (67 percent) showed an increase in ring growth immediately after release, but some trees did not increase diameter growth until 10 to 15 years had elapsed (Corvallis Tree 2 in table 2). The delay in release may be due the shock of the sudden removal of competition (Crossley 1976; McCaughey and Schmidt 1982). The period of significantly higher post-release ring growth rates was over 20 years for 30 percent of the sampled trees. Some sampled trees had limited post-intervention data because logging had occurred fairly recently. It is doubtful that the increase in ring growth is related to climate factors because the release years do not seem to correlate with average springtime temperature or precipitation, which are important climate variables for upper subalpine ecosystems (fig. 3) (Arno and Hoff 1989; Perkins and Swetnam 1996).

Results of the regression and correlation analyses of ring growth release with stand and tree variables revealed that the stand variable describing the change in density was significantly related to the magnitude of ring growth release, while the tree variables of age and DBH were significantly related to length of release and total release (table 3). DBH and mean ring growth were significantly related to the total release of a tree (table 3). The change in stand density from release to

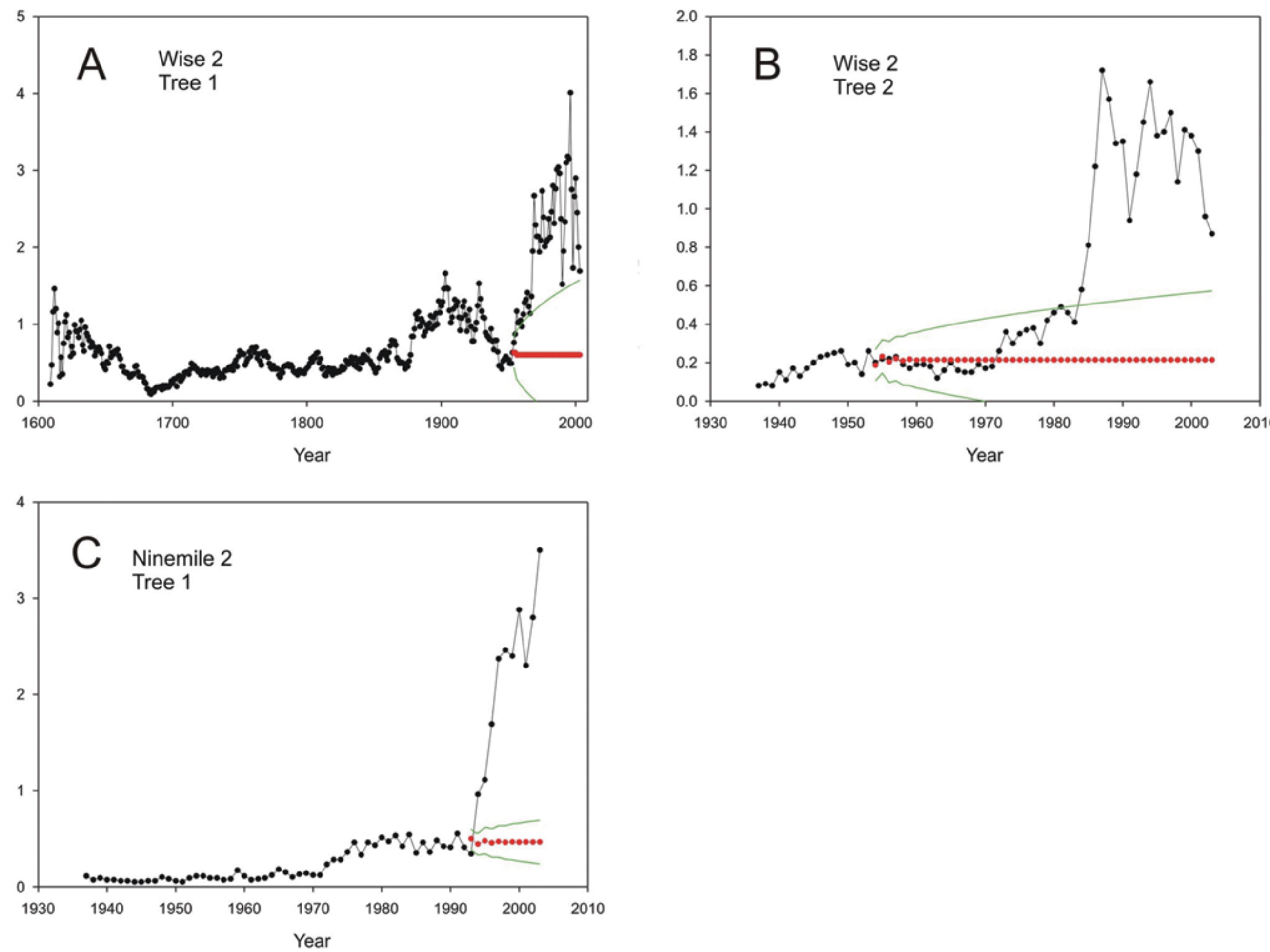

Figure 2—Tree ring growth rates for three trees sampled in this study to illustrate the magnitude of release. The forecasted ring growth (horizontal bar) after intervention is plotted along with 95% confidence intervals (green parabaloid). A) Tree 1 at the Wise 2 site experienced a large increase in ring growth after release, but, at the same time, B) Tree 2 at the same site did not experience an increase in growth for over 20 years, while C) Tree 1 at the Ninemile site experienced the greatest increase in ring growth after release.

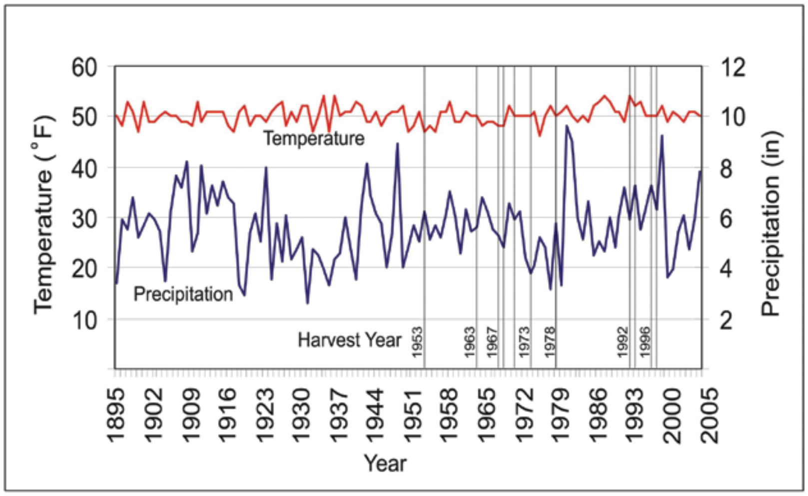

Figure 3—Long term springtime (May to June) average temperature and precipitation from 1895 to 2005 and each of the release dates used in this study (shown by the vertical bars). No apparent trends between climate and ring release were found.

Table 3—Results of the correlation analyses where tree and stand variables were correlated to the slope coefficient from the time series analysis (magnitude), the number of years that the release lasted (length), and the total release (product of slope coefficient and length) (total release). Numbers in bold indicate that the variable was significant (p-value<.05) in regression using tree and stand variables as predictor variables.

Tree or stand variable	Magnitude	Length	Total release
	(mm year^{-1})	*(years)*	*(mm)*
DBH at time of sampling (cm)	0.121	**0.535**	**0.555**
Age at time of sampling (years)	–0.067	**0.584**	0.304
DBH at time of release (cm)	0.172	**0.391**	**0.494**
Age at time of release (years)	0.013	**0.481**	0.317
Density at release (t ha^{-1})	**0.639**	**–0.377**	0.198
Density at sampling (t ha^{-1})	–0.252	0.199	–0.309
Density change (%)	**–0.401**	**0.406**	–0.230
Basal area at release (m^2 ha^{-1})	0.287	–0.079	0.142
Basal area at sampling (m^2 ha^{-1})	–0.118	–0.017	–0.176
Basal area change (%)	–0.245	0.130	–0.209
Mean ring growth before release (mm)	0.193	0.150	**0.399**

sampling had the highest correlation to the magnitude and length of release (table 3) and the tree DBH at the time of sampling had the highest correlation to total release (table 3). Stand density and basal area at time of release were some of the best predictors of the magnitude of release (r=–0.28). Most of the stand variables measured at the time of release had the greatest potential to predict ring growth release but the same variables measured at time of sampling had little predictive ability (r<0.20; table 3).

Discussion

The large magnitude of release and long length of release for most sampled trees were somewhat surprising for a high elevation, shade intolerant tree species (table 2) considering Eggers (1990) observations. Some trees experienced four- or five-fold short-term increases in ring growth after logging (fig. 2), while other trees sustained high ring growth rates for several decades (Wise 2 Tree 1 growth increase lasted 52 years). Young trees and smaller trees did not release as well as the older and larger trees, probably because the younger trees grew in lower light conditions and did not have the morphology to take advantage of the increase in light and resources directly after release.

Many factors can contribute to the ability of whitebark pine trees to increase in growth after a thinning treatment. As measured in this study, it appears that the basal area and density at the time of release may be important for predicting the magnitude and length of release (in other words, greater ring growth will occur after harvest in denser stands; table 3). It also seems that the increases in ring growths for trees in dense, pre-harvest stands usually were short-lived (table 3). The stand and tree variables measured at the time of harvest seem to be more predictive of the potential for release. An interesting result was that the larger diameter whitebark pine trees tend to have a higher total release and older trees seem to maintain the release for longer time periods (table 3). This may mean that the release of older individuals might result in healthier trees that have the ability to produce more frequent and abundant cone crops. The low number of observations in the correlation analysis (n=48) may have limited the results in this study.

The low number of sample trees (48) reflects the difficulty of finding suitable trees to sample across the large study area. There are few harvest operations occurring in high elevation whitebark pine stands because the timber is of low quality and harvestable areas are remote and often roadless. Finding un-cut whitebark pine trees is also challenging because the species' timber value is higher than most of its competitors in upper subalpine settings. The most limiting factor, however, is the extensive blister-rust infection and beetle mortality in the northern and western parts of whitebark pine's range in Montana (Keane and Arno 1993). Most cutover stands visited in western Montana did not have any surviving whitebark pine trees that met our stringent sampling criteria of no rust and insect damage. The opportunistic sampling approach used in this study to find sample trees was obviously inadequate and more conventional, but more costly, controlled experiments might be needed to create more robust data sets. These controlled experiments might selectively remove all trees in small sample stands or plots and leave the healthy mature whitebark pine.

Management Recommendations

Results from this study indicate that release cuttings can increase whitebark pine diameter growth across a wide variety of diameters and ages. This increase in growth could also suggest larger and more frequent cone crops. Seeds from these cones can be widely dispersed by the Clark's nutcracker and thereby improve whitebark pine regeneration success. Cutting guidelines for whitebark pine restoration efforts should consider the following:

- Slow growing, old sapling (<10 cm DBH) whitebark pine trees may not release.
- Any whitebark pine tree larger than a sapling will probably release after thinning.
- The thinning of dense stands with mature whitebark pine trees will probably result in the greatest increases in tree ring growth rate.

Author Profiles

Robert E. Keane is a Research Ecologist with the USDA Forest Service, Rocky Mountain Research Station at the Missoula Fire Sciences Laboratory, Missoula, MT. Since 1985, Keane has developed various ecological computer models for the Fire Ecology and Fuels Research Project for research and management applications. His most recent research includes the synthesis of a First Order Fire Effects Model; construction of mechanistic ecosystem process models that integrate fire behavior and fire effects into succession simulation; restoration of whitebark pine in the Northern Rocky Mountains; spatial simulation of successional communities on the landscape using GIS and satellite imagery; and the mapping of fuels and fire regimes for fire behavior prediction and hazard analysis. He received his B.S. degree in forest engineering in 1978 from the University of Maine, Orono; his M.S. degree in forest ecology from the University of Montana, Missoula, in 1985; and his Ph.D. degree in forest ecology from the University of Idaho, Moscow, in 1994.

Kathy Gray is currently working for Systems for Environmental Management as a statistician. She also teaches statistics at the University of Montana and will be completing her Ph.D. degree in Mathematics in May of 2007. Her research interests are in statistical ecology and she has worked for the Missou;a Fire Science Lab and the Aldo Leopold Wilderness Research Institute as a statistician.

Laura J. Dickinson has been a Biological Science Technician since 2002 with the USDA Forest Service Rocky Mountain Research Station at the Missoula Fire Sciences Laboratory, Missoula, MT. She has contributed to several projects within the Fire Ecology and Fuels Research Project including data collection and analysis for studies on whitebark pine, relict ponderosa pine mortality in the Bob Marshall Wilderness Area, fuels, and fuel sampling techniques. She received her B.S. degree in Aquatic Wildlife Biology in 2003 from the University of Montana, Missoula.

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