Evaluating climate sensitivity of red pine (*Pinus resinosa*) in managed forests of northern Minnesota: stand and management factors influencing responses

Sawyer S. Scherer[1], Anthony W. D'Amato[2]

1. Undergraduate, Department of Forest Resources, University of Minnesota.
2. Associate Professor of Silviculture, Department of Forest Resources, University of Minnesota.

Introduction

Forest tree species are expected to endure significant population changes in response to warmer temperatures across the United States. Red pine (*Pinus resinosa)* being ecologically important and commercially valuable, is of particular concern. In order to anticipate and minimize negative impacts of climate change on growth of this valuable resource, an evaluation of the effects of climate on this species is needed.

Recent studies have shown that drought and high temperatures can depress growth in temperate conifers (Aakala et al. 2011, D'Amato et al. 2013). By reducing competition for moisture and altering micro-site conditions (Nyland 2002), thinning may be an effective strategy for mitigating these concerns. This study attempts to quantify the efficacy of stand structure modifications at reducing climate impacts on red pine forests by investigating the relative impacts of past climate on growth of thinned and un-thinned forest stands.

Figure 1.
A recently thinned stand on the University of Minnesota's Cloquet Forestry Center. Thinnings and other partial harvests are effective ways to alter forest structure and significantly reduce competition among trees. Notice the recently cut stumps, wide spacing of trees and open canopy.

Methods

Study Area & Sample Collection:

All stands were located within the Cloquet Forestry Center in Carlton County Minnesota. For each stand, a single 0.04 ha circular plot was established. Diameter at breast height (DBH, 1.37m), species, and crown class were recorded for all trees on the plot. Within each plot, all red pine greater than 10 cm DBH were cored using an increment borer. Ring widths were measured to the nearest 0.05-millimeter and then crossdated to ensure proper dating of individual rings.

Analysis:

Individual tree chronologies from each individual stand were standardized to create a single residual chronology representing each stand. Annual variation of the residual chronology for each stand was compared to various stand level measures for the study period (1960-2012).

In addition a response function analysis was used to identify monthly weather parameters that contribute to growth indices in tree ring data within the study period, followed by a boot strapping (n=1000) to compute confidence intervals and significance levels. Chronologies from individual stands were combined based on two criteria: management history (thinned vs. control), and average tree age (old vs. young). For the thinned treatment, a stand was considered old if its mean age exceeded 75 years, for control treatments a mean age of 100 years was used. Each new pooled chronology was standardized before analysis. Climate data used in the analysis included mean maximum monthly temperature, mean minimum monthly temperature, and precipitation.

Forest Description

Stand	Treatment	Average Age (years)	Quadratic Mean Diameter (cm)	Coefficient of Variation-Tree Diameter	Basal Area (M^2/Hectare)	% basal area comprised of red pine	Stand Density Index (Reineke's)	Relative density %
A	control	95	46.87	0.56	49.53	79	819.02	69.03
B	control	177	58.99	0.07	47.05	87	785.92	71.39
C	control	75	35.33	0.27	33.55	88	615.04	51.39
D	control	174	41.02	0.14	63.64	93	1131.68	90.93
F	thin	78	38.23	0.16	53.67	91	971.57	80.70
G	thin	53	30.94	0.19	30.05	100	563.05	47.04
H	thin	89	38.96	0.25	43.14	97	778.65	65.54

Table 1. Stand level characteristics of sampled stands. Control treatments have no known history of management/thinning. Thin treatments represent stands with at least one management/thinning entry. Average age, quadratic mean diameter, and coefficient of variation for diameter represent only red pine within the stand.

Results

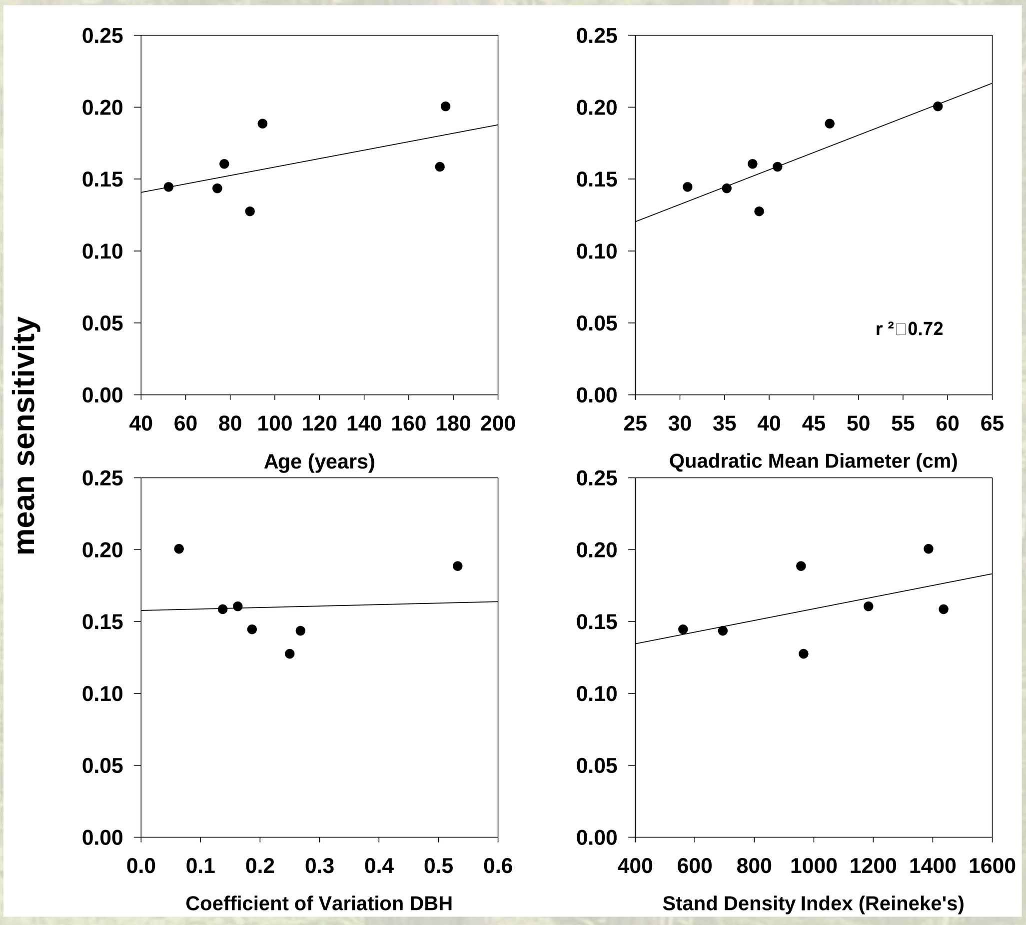

Figure 2. Relationship of mean sensitivity to stand level characteristics: average tree age of stand (top left), quadratic mean diameter in centimeters (top right), coefficient of variation of sampled trees (bottom left), and Reineke's stand density index (bottom right). Significant results (α *= 0.05)* displayed with associated coefficient of determination.

Stand Level Characteristics:

Mean sensitivity was used as a measure of climate sensitivity for each stand in the study. This statistic measures the average percentage change of tree ring indices from one year to the next and can be calculated as:

$$ms_x = \frac{1}{n-1}\sum_{t=1}^{t=n-1}\left|\frac{2(x_{t+1}-x_t)}{(x_{t+1}+x_t)}\right|$$

Where n represents the number of rings in the chronology, t represents year, and x defines the ring indices within the chronology of interest.

Our results show a trend of increasing climatic sensitivity in stands that display older age trends, higher stocking, and larger average diameter (Fig. 2). The positive trend with quadratic mean diameter was found to be significant (α=0.05). Little or no relationship was found for the coefficient of variation in DBH, a simple measure of structural complexity.

Climate Response:

In general our response function analysis showed that across all treatments relationships between temperature, precipitation, and radial growth exist for red pine. Warm temperature extremes in the late summer (July and August) tended to negatively impact growth and precipitation from the previous year increased growth (Table 2). Between blocks we found that the number of significant results was higher in the control blocks that received no thinning treatment. Managed stands, on the other hand, displayed less significant results. Within the control stands, we see increased positive trends within younger stands compared to their older counterparts. Interestingly, within managed stands we found increased responses within the younger treatment block, with significant results for summer temperature extremes in the current year and no significant responses in the older treatment block.

	Maximum Temperature		Minimum Temperature		Precipitation
Treatment	PAUG	JUL	JUL	AUG	PJUL
Old Control	-0.28*	-0.09	-0.04	-0.20*	-0.08
Young Control	-0.17	-0.22*	-0.11	-0.12	0.22*
Old Managed	-0.18	-0.05	-0.07	-0.02	0.14
Young Managed	0.09	-0.31*	-0.23*	0.02	-0.01

Table 2. Relationship between mean stand age/management combinations and mean monthly maximum temperature, mean minimum temperature, and precipitation for *Pinus resinosa* stands based on response function analysis for the years 1960-2012. Months preceded by "P" represent climate averages from previous growing season. Significant responses (α < 0.05) denoted with asterisk (*). Treatments pool stands as: Old Control (stands B & D), Young Control (stands A & C), Old Managed (stands F & H), Young Managed (stand G).

Results Continued

Results suggest that thinning may be an effective method for mitigating negative growth impacts within red pine forests caused by a warming climate. Response function analysis revealed that thinning altered the climatic response of trees over the 52 years observed (table 2). All control treatments contained significant negative coefficients for late summer heat and a heightened response to precipitation. In thinned treatments this response was less uniform with no significant coefficients for summer heat within the older treatment block, and a negative response to July heat for the younger treatment block. This response in the younger managed stands was not expected given the results shown in Figure 2 depicting lower sensitivity in small diameter and younger trees. One possible explanation for this response may be the timing of thinning. This stand was thinned within a year of sampling and had minimal thinning in the previous to that year. This would suggest that the annual rings within trees in that stand reflected predominantly pre-treatment growth.

Conclusions

Overall, thinning results in reduced negative impacts associated with warmer temperatures. However, given the positive relationships between increasing tree size (quadratic mean diameter) and mean sensitivity, thinning should be viewed as a short term strategy as it may push trees into larger, more sensitive size classes. Management implications include:

◆Red pine forests are negatively impacted by extreme summer heat, especially those that have not been thinned.

◆Thinning over a 52 year period reduced negative responses to extreme heat, and altered precipitation responses.

◆Age and tree size play a role in this response, and should be considered in mitigation strategies.

◆While thinning reduced the negative response to heat, increased sensitivity in larger trees may counteract those impacts given increased growth following thinnings suggesting this may be a short term solution for individual stands.

Fig 3. Thinned stand in St. Louis County Minnesota displaying typical structure following partial harvest.

References

Aakala, T., Kuuluvainen, T., 2011. Summer droughts depress radial growth of *Picea abies* in pristine taiga of the Arkhangelsk province, northwestern Russia. Dendrochronologia 29, 67-75.

D'Amato, A., Bradford, J., Fraver, S., Palik, B., 2013. Effects of thinning on drought vulnerability and climate response in north temperate forest ecosystems. Ecological Applications 23(8):1735-1742.

Nyland, R. 2002. Silviculture: Concepts and Applications 2nd edition. Waveland Press.

Acknowledgements

Special thanks to Henry Rodman for assistance in the field, Frank Falzone and Mike Reinikainen for assistance and expertise in sample preparation and measurement, and to Kyle Gill for guidance in statistical analysis.

Funding which made this project possible was provided by the University of Minnesota's Undergraduate Research Opportunities Program.