Effects of Climate Change on Growth, Productivity, and Wood Properties of White Pine in Northern Forest Ecosystems

PI:
Ronald S. Zalesny Jr.
USDA Forest Service, Northern Research Station
Institute for Applied Ecosystem Studies
5985 Highway K, Rhinelander, WI 54501, USA
Phone: (715) 362-1132; Email: rzalesny@fs.fed.us

Co-PIs:
John Brissette, USDA Forest Service, Northern Research Station
Sophan Chhin, Michigan State University, Department of Forestry
Steve Colombo, Ontario Ministry of Natural Resources and Forestry
Pengxin Lu, Ontario Ministry of Natural Resources and Forestry
Bill Parker, Ontario Ministry of Natural Resources and Forestry
Michael Ter-Mikaelian, Ontario Ministry of Natural Resources and Forestry

Cooperators:
Les Groom, USDA Forest Service, Southern Research Station

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Project Summary

Eastern white pine is a valuable species, both in terms of wood for everything from masts for sailing ships to millwork for the interiors of modest to stately homes, to a range of ecological values including mine reclamation, wildlife habitat, and aesthetics. While adaptable and valuable, eastern white pine is threatened by a number of biotic and abiotic factors (Wendel and Smith 1990). White pine weevil and white pine blister rust are serious insect and disease pests. Eastern white pine is vulnerable to a range of pollutants, such as acidic deposition and road salt. The shifts in suitable habitats predicted by climate change models represent a serious threat to white pine throughout much of eastern North America, especially as changes in the climate will likely interact with other stressors (Millar et al. 2007).

White pine provenance trial in Manistique, Michigan. Photo by Ron Zalesny, US Forest Service.

The primary goal of the project was to identify eastern white pine (*Pinus strobus* L.) provenances with enhanced adaptation to climate change pressures and carbon (C) sequestration potential throughout the portion of its native distribution from Wisconsin to Maine, USA, and including Ontario and Quebec, Canada (**Figure 1**). Selection of climatically-adapted provenances for planting will help promote biologically and economically sustainable reforestation, afforestation, and gene conservation throughout the region.

Using climate models and data collected from provenances grown in long-term trials established in the 1960s, our objectives were to:

1. Predict the effects of climate change on growth, productivity, and wood properties of existing white pine forests;
2. Estimate C sequestration potential of white pine under new climate regimes;
3. Quantify range of genetic variation in climatic response and adaptive traits of white pine;
4. Develop seed transfer models from historic climate data and provenance trial data from a subset of test locations;
5. Use validated models from (4) and future climate projections to: a) predict radial and stem growth response of white pine in the northeastern U.S., and b) contribute to provisional seed transfer recommendations for assisted migration of white pine seed sources to help adapt northern forests to future climate.

Figure 1. Seven proposed provenance trials for the current study. All sites with green trees were part of an original range-wide IUFRO white pine study established in the early 1960's in the eastern United States and Canada. Trees with an "X" indicate trials that no longer exist, while the status of those marked "?" is uncertain.

Background and Justification

There is a need for long-term forest management strategies that optimize C sequestration and feedstock production potential of plantations and natural forests. The success of such programs depends upon development of adaptation strategies for enhanced ecosystem sustainability under changing climates (Millar et al. 2007, Alexander and Perschel 2009). Data from long-term provenance trials have substantial potential to improve our understanding of species responses and adaptability to rapidly changing climate (Rehfeldt et al. 1999). Dramatic increases in atmospheric concentrations of CO_2 and other greenhouse gases will occur if fossil fuel intensive energy generation continues to grow at current rates. The resulting growth in emissions over the next century would raise mean annual global surface temperature by 2.5 to 6.5 °C by 2100 (IPCC 2007). The resulting climatic change threatens to alter the distribution, structure, function, and productivity of northern forests through spatial and temporal change in regional temperature and precipitation regimes, increased frequency of natural disturbance events, and atmospheric CO_2 enrichment (Mickler et al. 2000, Parmesan and Yohe 2003).

White pine is one of the most commercially- and ecologically-important forest tree species of the northeastern United States and other regions of the eastern United States and Canada. Further reductions in the range and abundance of white pine dominated forests are projected to result from climate change (McKenney et al. 2007, Iverson et al. 2008).

White pine typically exhibits significant adaptive genetic variation in response to broad climatic gradients that exist over this range, the product of natural selection and genetic processes (Genys 1987). This has resulted in the existence of tree species populations that are genetically adapted to local and regional environmental conditions. However, as the climate begins to change, species populations will become increasingly unsynchronized with and maladapted to their prevailing climatic habitat, resulting in decreased vigor, productivity, and wood quality. The projected unprecedented rates of climate change will exceed the natural ability of tree species and tree species populations to adapt to this new climate or to migrate to keep pace with the climate to which they are genetically adapted (McLachlan et al. 2005).

Human intervention to help forests adapt to the climate change will be required to minimize the loss of many ecological, economic and social values of forests (Millar et al. 2007, Alexander and Perschel 2009). There exists a unique series of old (>50 yr since establishment) white pine provenance trials established across the range of this species (Genys 1987). This resource has renewed value as a long-term study that can help us understand the impact of climate change on white pine populations growing outside the climatic envelope to which they are naturally adapted (Wang et al. 2006).

Methods

The proposed project was conducted at seven sites belonging to a range-wide International Union of Forestry Research Organizations (IUFRO) white pine study established in the early 1960s in the eastern United States and Canada (**Figure 1**). In total, 13 white pine provenances were evaluated at each site, with the exception of the Orono trial that has 12 of the 13 (**Table 1**). Field protocols for tree measurement and sample collection were developed at the Ganaraska Forest, Ontario, Canada during October 2009. In addition, historic data from sites such as the Orono trial and those in Wisconsin and Michigan were assembled and used.

Table 1. Seed sources (provenances) to be tested in the proposed study that belong to a range-wide IUFRO white pine study established in the early 1960's in the eastern United States and Canada.

Seed Source Number				
Canada	United States	Location of Origin	Latitude	Longitude
1	1633	Union County, Georgia	34°5´	84°0´
2	1634	Greene County, Tennessee	36°0´	82°5´
3	1640	Monroe County, Pennsylvania	41°1´	75°3´
4	1639	Franklin County, New York	44°3´	74°2´
5	1638	Penobscot County, Maine	44°5´	68°4´
6	1632	Ashland County, Ohio	40°5´	82°2´
7	1624	Allamakee County, Iowa	43°2´	91°2´
8	1622	Cass County, Minnesota	47°2´	94°3´
9	1623	Forest County, Wisconsin	45°5´	88°5´
10	1637	Luneborg County, Nova Scotia	44°3´	64°4´
11	1635	Pontiac District, Quebec	47°3´	77°0´
12	1636	Algoma District, Ontario	46°1´	82°4´
13[a]	1670	Newaygo County, Michigan	43°3´	85°4´

[a] Seed source was not established at Orono, Maine.

- Height, diameter at breast height (dbh), and survival were recorded for each experimental tree located at each of seven sites (Wabeno, WI; Manistique, MI; Pine River, MI; Newaygo, MI; Turkey Point, ON; Ganaraska Forest, ON; Orono, ME).
- Two wood cores were collected from each tree and permanently mounted and sanded to prepare them for radial growth trend analysis using standard dendrochronology procedures and x-ray densitometry (see below).
- Scanned images of individual cores were processed with cross-dating (COFECHA) and tree ring analysis (WinDENDRO, Regent Instruments, Quebec) software.
- Mean tree ring width, mean annual basal area increment, and total tree ring basal area increment over the period 1980 to 2004 were estimated for each provenance.
- Quantitative genetic and dendrochronological analyses were used to develop the universal response functions.
- X-ray densitometry was used to measure intra and inter tree-ring density.

Key Findings and Accomplishments

- The universal response function for white pine height growth performed very well and indicated that it was sensitive to trial site and seed source temperature and precipitation and (**Table 2**).
- The universal response function for white pine diameter growth indicated that it was affected both by trial site and seed source temperature and precipitation (**Table 3**).
- Dendroclimatic analysis indicated that natural populations of white pine in Michigan were more responsive to the Climate Moisture Index (CMI) than temperature. In Wisconsin and in Canada (Turkey Point), white pine radial growth was more responsive to temperature than to CMI.
- Under the temperature regression models, projected change in growth of natural populations of white pine was significantly reduced for Wabeno (WI), Manistique (MI), and Pine River (MI). Under the CMI regression model, projected growth was significantly reduced for the Newaygo (MI) site.

Table 2. Multiple regression analysis predicting mean height growth of white pine from site and provenance climate in the form of a universal response function.

Independent Variable	Parameter Estimate	Partial R^2	Model R^2	F	P
Intercept	59.1307				
T_B11_TCOL_2	-0.0028	0.417	0.417	302.8	<0.0001
T_B13_PWP_2	0.0004	0.277	0.694	176.1	<0.0001
T_B15_PSCV	-0.1378	0.050	0.744	48.6	<0.0001
T_B07_TAR	-0.3388	0.051	0.795	25.0	<0.0001
P_B02_MDR_2	-0.2466	0.018	0.813	19.3	<0.0001
P_B18_PWAR_2	-0.0001	0.024	0.837	11.8	0.0009

Note: The prefix "T_" and "P_" refer to test sites and provenances, respectively.
The next within variable name abbreviation refers a bioclimatic parameter which is defined in detail at this web-link: https://cfs.nrcan.gc.ca/projects/3/8

Test site variables: B11 = Mean temperature of coldest quarter; B13 = Precipitation of wettest period; B15 = Precipitation seasonality; B07 = Temperature annual range

Provenance variables: B02 = Mean diurnal range (Mean(period max-min)); B18 = Precipitation of warmest quarter

The variable name with a "_2" suffix refers to quadratic forms of the variable.

Table 3. Multiple regression analysis predicting mean DBH growth of white pine from site and provenance climate in the form of a universal response function.

Independent Variable	**Parameter Estimate**	**Partial R^2**	**Model R^2**	**F**	**P**
Intercept	-22.024				
T_B11_TCOL_2	-0.0022	0.320	0.320	13.1948	0.0005
T_B05_MTWP_2	0.0095	0.147	0.467	17.3814	0.0001
T_B14_PDP_2	0.0006	0.049	0.516	27.0387	<0.0001
T_B06_MTCP_2	0.0817	0.056	0.572	18.3056	0.0001
P_B07_TAR_2	-0.0216	0.039	0.611	16.6202	0.0001
T_B07_TAR	-0.9792	0.026	0.637	7.0393	0.0097
P_B11_TCOL	0.2934	0.021	0.658	7.6373	0.0071
P_B15_PSCV_2	-0.0001	0.028	0.686	10.5731	0.0017
P_B13_PWP_2	-0.0001	0.014	0.700	3.45	0.0671

Note: The prefix "T_" and "P_" refer to test sites and provenances, respectively.
The next within variable name abbreviation refers a bioclimatic parameter which is defined in detail at this web-link: https://cfs.nrcan.gc.ca/projects/3/8

Test site variables: B11 = Mean temperature of coldest quarter; B05 = Max temperature of warmest period; B14 = Precipitation of driest period; B06 = Min temperature of coldest period; B07 = Temperature annual range

Provenance variables: B07 = Temperature annual range; B11 = Mean temperature of coldest quarter; B15 = Precipitation seasonality; B13 = Precipitation of wettest period

The variable name with a "_2" suffix refers to quadratic forms of the variable.

Implications and Applications in the Northern Forest Region

- For the dendroclimatic analysis of seed sources at each trial site location, the first principal component explained the most significant variation in growth which indicates that the regional climatic conditions exerts a generally uniform response in the seed sources at each trial site (**Table 4**). While the amount of variation in PC2 was not statistically significant, the explained variance is geographically and biologically meaningful (**Table 4**, **Figure 2**).
- In the Wabeno (WI) trial site location, PC1 was significantly associated with seed source elevation and PC2 was related to seed source longitude. For both Turkey Point (ON) and Orono (ME), PC1 and PC2 were associated with seed source latitude and longitude, respectively (**Table 4**).
- In terms of responses to temperature, PC1 of seed sources was generally affected by cold temperature stress in the fall or early winter (**Figure 2a**). PC2 of seed sources was also affect by cold temperatures including cool summer temperatures.
- PC1 of seed sources at all site locations (except Orono, ME) was more responsive to CMI (**Figure 2b**) compared to the response to temperature (**Figure 2a**). PC2 of seed sources at Pine River (MI), Turkey Point (ON), and Orono (ME) was more associated with CMI compared to temperature. PC2 of seed sources in Wabeno (WI) and Manistique (MI) were more responsive to temperature compared to a weaker or no response to CMI.

Table 4. Amount of explained variance and associated geographical variables (seed source location) for the principal component axes of the seed sources at each trial site location.

Trial Site Location	Explained Variance PC1 (%)	Explained Variance PC2 (%)	Variables Associated with PC1	Variables Associated with PC2
Wabeno, WI	70.2	11.0	Elevation	Longitude
Manistique, MI	84.5	5.6	NS	NS
Pine River, MI	80.8	7.0	NS	NS
Turkey Point, ON	84.0	5.1	Latitude and elevation	Longitude and elevation
Orono, ME	88.5	3.8	Latitude	Longitude

Note: NS = no siginificant associated variables.

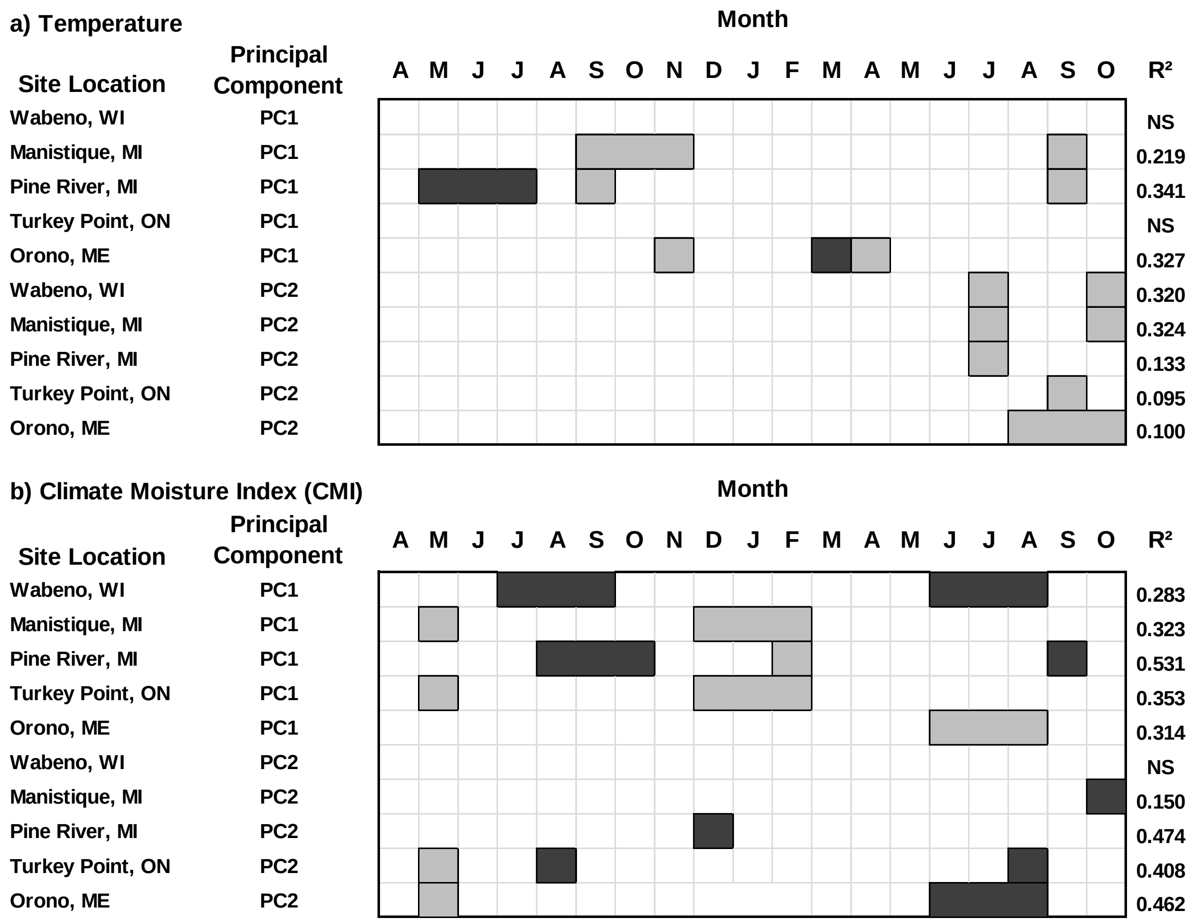

Figure 2. Relationships between the first (PC1) and second (PC2) principal component axis of white pine radial growth of seed sources at each trial site location and monthly and seasonal a) mean temperature and b) Climate Moisture Index examined via multiple regression analysis. For each regression model, predictor climate variables having a positive relationship with growth are denoted by light gray boxes, and predictor climate variables having a negative relationship with growth are denoted by darker gray boxes.

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Products

Papers in Progress

Growth response functions of provenance trials under past and future climate.

Dendroclimatic analysis of white pine natural forests under past and future climate.

Dendroclimatic analysis of white pine provenance trials under past and future climate.

Refereed Journal Publications

Zalesny, R.S. Jr., and Headlee, W.L. 2015. Developing woody crops for the enhancement of ecosystem services under changing climates in the North Central United States. Journal of Forest and Experimental Science 31:78-90.

Invited Papers and Presentations

Zalesny, R.S. Jr., and Headlee, W.L. 2014. Developing woody crops for the enhancement of ecosystem services under changing climates in the North Central United States. In: International Symposium on Tree Breeding Strategies to Cope with Climate Change; September 15-19, 2014; Suwon, Republic of Korea. (Invited Oral Presentation with Refereed Proceedings)

Offered Papers and Presentations

Parker, W.C. 2014. Forest ecosystem vulnerability in the Great Lakes basin of Ontario. Ontario Ministry of Natural Resources and Forestry Climate Change Symposium, November 24, 2014, Peterborough, Ontario. (Oral Presentation)

Parker, W.C. 2014. Pre-symposium field tour of the Ganaraska, ON white pine provenance trial site, November 23, 2014. Ontario Ministry of Natural Resources and Forestry Climate Change Symposium, November 24, 2014, Peterborough, Ontario. (Oral Presentation)

Zalesny, R.S. Jr., and Headlee, W.L. 2014. Comparing aboveground, stand-level carbon storage potential of intensively-managed poplar with plantation-grown eastern white pine in the North Central United States. In: International Poplar Symposium VI; July 20-23, 2014; Vancouver, British Columbia, Canada. (Poster Presentation and Published Abstract)   Also presented as: Zalesny, R.S. Jr., Headlee, W.L., Bauer, E.O., Birr, B.A., Hall, R.B., Parker, B., and Wiese, A.H. 2014. Contrasting ecosystem services of hybrid poplar and white pine in the upper-Midwest, USA. In: 10th Biennial Conference of the Short Rotation Woody Crops Operations Working Group; July 17-19, 2014; Seattle, WA, USA. (Poster Presentation and Published Abstract)

Zalesny, R.S. Jr., Bauer, E.O., Birr, B.A., Brissette, J., Colombo, S., Froese,, R.E., Groom, L., Hall, R.B., Headlee WL, et al. 2012. Assessing the environmental sustainability of plantation

Populus and *Pinus* in North America. In: 9th Biennial Conference of the Short Rotation Woody Crops Operations Group; November 5-8, 2012; Oak Ridge, TN, USA. pp 33-34. (Poster Presentation and Published Abstract)

Zalesny, R.S. Jr., Bauer, E.O., Birr, B.A., Brissette, J., Colombo, S., et al. 2012. Ecosystem services associated with purpose-grown *Populus* and *Pinus* in North America. In: 9th Conference of the International Phytotechnology Society: Phytotechnologies – Plant-based Strategies to Clean Water, Soil, Air and Provide Ecosystem Services; September 11-14, 2012; Hasselt, University, Diepenbeek, Belgium. (Poster Presentation and Published Abstract)

Web Page

http://www.nrs.fs.fed.us/disturbance/climate_change/longterm_genetics/

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