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An Analysis of the Growth of Fire-Damaged *Pinus koraiensis* Trees in a Northern Temperate Forest

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ABSTRACT—**This paper evaluates the effects of a groundfire on the radial growth of fire tolerance species Korean pine (*Pinus koraiensis*) trees growing in the Changbai Mountain Nature Reserve which occurred more than 90 years.. The study material includes damaged and undamaged sample trees approximately with the same age. The trees are growing in close vicinity to each other and are subject to the same climatic conditions. The study material is rather homogenous and allowing analysis of the long-term effects of ground fire on the growth of important tree species. Two tree-ring chronologies from 25 fire-damaged and 24 undamaged trees were analyzed. The results showed that temperature and precipitation during the previous winter had a significant effect on the mean annual radial growth of both groups. Trees which had been damaged by an old fire were more sensitive to the negative effect of high summer temperatures and to the positive effect of high spring temperatures than the undamaged group. In contrast to previous studies, their growth was also considerably more affected by competition than the growth of the undamaged individuals. The study material is rather homogenous and probably unique, allowing such a temporal and spatial analysis of the long-term effects of a ground fire on the growth of an important tree species in a northern temperate forest.**

Keywords-Groundfire, Tree ring analysis, Radial growth, competition, climate

I. INTRODUCTION

Many studies have shown the considerable impact of fire on a forest ecosystem（Heyerdahl et al., 2008b) A high fire frequency limits the species replacement in the canopy and favors fire tolerant individuals (Johnson, 1992; Lesieur et al, 2002). The longer interval between two consecutive fire events, the more likely it is for the forest to reach an advanced stage of succession (Brown, 2006). The effects of fire on forest ecosystems monitoring are manifold. A variety of processes operate at spatial scales (Beaty & Taylor, 2008) causing structural changes which are difficult to predict (Sakulich & Taylor, 2007). The results may be a great variety of possible distribution and diversity patterns which are caused by species-specific responses, in particular fire events . The study of such responses is essential for understanding forest dynamics, especially if management attempts to emulate natural disturbance regimes (Falk et al, 2008).

Dendroecological methods for quantifying and dating historical canopy fire events have been widely applied in temperate forests (Py, 2006). However, the effect of a ground fire in northern temperate forests, especially in the Changbai Mountain area, is still poorly understood. Improved knowledge of the fire history, including the intensity and frequency, will help to understand the natural succession and would permit predictions of future forests composition and age structure. Such knowledge, in turn, would facilitate the development of new "near-natural" forest management practices that emulate natural processes (Bergeron et al. 1999a).

This study aims to evaluate the potential effect of fire in the Changbai Mountain forest, especially in view of future management options. One basic requirement for achieving this objective is a better understanding of how the tree growth is controlled by fire, on temporal and spatial scales. Compared with other dominant tree species, Korean pine (*P. koraiensis*) is fire-tolerant and can live for several centuries. Therefore, in this initial research project, tree-ring data on fire-damaged and undamaged Korean pine trees of more or less the same in age were monitored. More precisely, the following two objectives were set (i) to determine whether differences in radial activities of pines are caused by fire; and (ii) to evaluate response patterns following an old fire in the study area. In contrast with previous studies, increment cores were collected at the same sites from trees of almost the same age. This makes it easier to analyze the effect of fire on the Korean pine trees.

II. MATERIAL AND METHODS

A. Selecting trees on the study area

The study area is located approximately at 784 m of altitude above sea level (N42°20′211″，E128°05′705″）in the Changbai Mountain Nature Reserve. The climate of the region is continental with cold winters and warm summers. The mean annual temperature is 3.7 ℃. The mean total annual precipitation for the region is 707 mm. In the study area, some *P.* koraiensis and *F. mandshurica* trees showed old fire-damage with visible scars on the bark. All the fire-damaged *P. koraiensis* trees had corrupted ring sections in the core. Then two increment cores were taken from all the fire-damaged Korean pine trees with a dbh at least 30 cm in the damaged area. Approximately the same number of cores was taken from undamaged trees with dbh's greater than 30 cm in the area at a distance of 100 m from the damaged area. The year of the fire was determined by counting the number of annual rings from the year of sampling to the beginning of the scar. In addition, the dbh's of the four nearest neighboring trees and their distances to the sample tree were measured.

Cores were surface-sanded and cross-dated according to standard techniques (Stokes and Smiley, 1968). The ring widths were measured with an accuracy of 0.001 mm using a *Lintab5* measuring system. All the cores of the damaged trees were analyzed starting after the injured section. The dating accuracy was checked statistically and visually using the programs *COFECHA* (Grissino-Mayer, 2001) and *TSAP-Win Professional*, version 0.59 (Rinntech, Heidelberg, Germany). 25 fire-damaged and 24 unburned trees were reserved for the subsequent analysis. The ring-width chronologies were developed using the program *ARSTAN* (Cook, 1985). Tree-ring chronologies were constructed using conventional analytical techniques. Individual ring-width measurement series were first detrended to remove the biological effect in ring width using modified negative exponential detrending (Tardif et al., 2001). Residual chronologies that contained only high-frequency variation were developed by autoregressive modeling to eliminate autocorrelation.

B. Statistical analysis

The competition status of each sample tree as affected by the nearest four neighboring trees was assessed using Hegyi's competition index (Daniels, 1976).

$$CI_i = \sum_{i=1}^{4} \frac{dbh_j}{dbh_i} \cdot \frac{1}{dist_{ij}}$$

where CI_i is the competition index for the sample i, dbh_i represents the dbh of the sample tree and dbh_j the dbh of the *j'th neighbor* (cm); $dist_{ij}$ is the distance between the sample tree i and the neighbor j. The correlations between the average radial growth during the past five years (mm) and the competition index were calculated.

The response of tree-ring widths to climate was assessed by correlation and response analysis. 1000 bootstrapped samples were used to compute correlation coefficients, and to test their significance at the 0.05 level. Tree-ring chronologies were related to climate variables covering the period 1982-2007. The climate variables correspond to the monthly mean, minimum and maximum temperatures and the precipitation values from August of the previous year to August of the year of growth.

III. RESULTS

A. Relationships with meteorological data

One possible explanation for the higher growth rates since the early 20th century, are changes in the climate. Mean annual air temperature and average precipitation records for the study area are only available since 1960. Higher temperatures during the growing season are very likely to have a positive effect on the radial growth in the study area. The results of our analysis show that during the years of increasing temperature, the mean annual radial increment of the undamaged trees was significantly higher than that of the fire-damaged ones (Paired-T test, $p<0.05$). This result may indicate that the two groups respond differently to climate. The results of the response analysis are shown in Tab. 1. Fire-damaged and undamaged trees show a significantly positive response to the minimum temperature in September of the previous year. However, the response to the mean and maximum (*) temperature as well as the precipitation in that month is negative.

The ring width of fire-damaged trees responds positively to the April minimum temperature in current growing season. The undamaged trees responded negatively to the maximum of June temperature of the current year. There is also a significantly positive relationship between the ring width and the November precipitation of the previous year and the June precipitation of the current year for both damaged and undamaged tree. The ring widths of fire-damaged trees are negatively correlated with the April precipitation, but the corresponding correlation is not significant for undamaged trees. The tree-ring widths of only the undamaged trees are significantly and positively correlated with the February and July precipitation and negatively with the precipitation in January. In addition, undamaged trees significantly relate with the mean temperature in May. However, there is no significant correlation between the ring widths of fire-damaged trees and the mean temperature.

Table.1.Annual negative (-) and positive (+) ring width response to monthly mean, maximum, and minimum temperatures and precipitation from the previous August (P-Aug) to current August (Aug). Asterisks * in highlighted squares show a statistically significant response at the 0.05 level.

Month	Mean temperature		Minimum temperature		Maximum temperature		Precipitation	
	Fire damaged	Un damaged	Fire damaged	Un damaged	Fire damaged	Un damaged	Fire damaged	Un damaged
P-Aug	+	-	+	+	-	-	+	+
P-Sep	-	-	+*	+*	-*	-*	-	-

P-Oct	+	+	+	+	+	-	-	-
P-Nov	+	+	+	+	+	+	+*	+*
P-Dec	-	-	+	-	-	-	+	+
Jan	-	-	+	+	+	-	-	-*
Feb	-	-	-	-	-	-	+	+*
Mar	+	+	+	-	+	-	+	+
Apr	+	+	+*	+	+	+	-*	-
May	+	+*	+	+	-	-	+	+
Jun	-	+	+	+	-*	-	+*	+*
Jul	-	-	+	+	-	-	+	+*
Aug	+	+	+	+	+	-	-	-

These results indicate that certain climate factors in the previous winter do significantly affect the radial growth of both fire-damaged and undamaged trees. In the previous winter, both of the highest and the lowest temperature have a negative effect on the tree-ring widths whereas high precipitation improves the grow rate during the following growing season. Fire-damaged trees seem to be more sensitive to the monthly minimum and maximum temperatures as well as to the monthly precipitation in the current growing season. The monthly precipitation had the greatest effect on the radial growth of the undamaged pines.

Higher precipitation values during the preceding winter and the associated increase in soil moisture at the beginning of the next growing season are particularly beneficial and conducive to higher growth rates. In contrast, higher temperatures in winter may increase the rate of respiration with associated loss of biomass. Very low winter temperatures may cause root freezing and injury to the root system, resulting in reduced radial growth during the next growing season.

B. Effect of recent competition

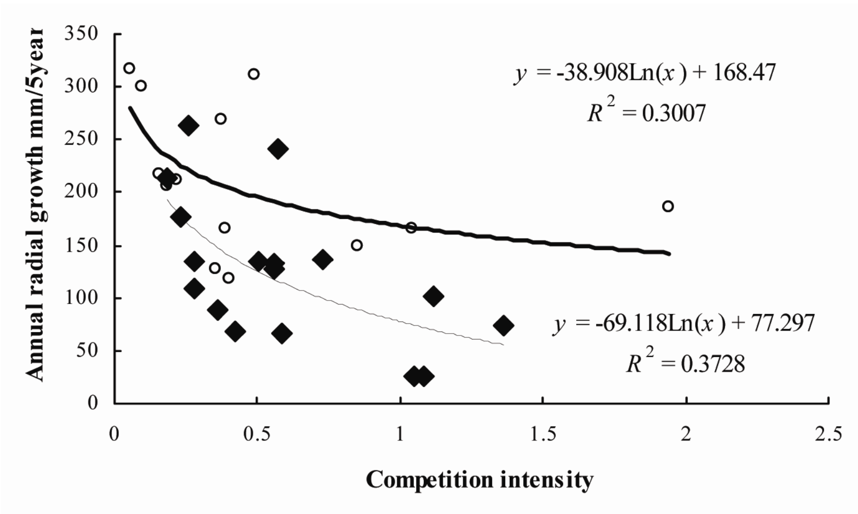

Figure.1. Relationships between growth rate and competition index for damaged (triangles) and undamaged (circles) trees

Competition from neighboring trees is important for explaining tree radial growth. Unfortunately, the immediate past neighbors of the sample trees and their attributes are not known much for the 142-year observation period. Therefore, it is not possible to use current competition to explain historical growth. However, it is possible to relate competition to the average radial growth during the past five years (mm). The results are shown in Fig. 1 for damaged and undamaged trees.

As expected, the radial growth rate was reduced by increasing competition from neighboring trees. This effect can be observed for both, fire-damaged and undamaged trees. The damaged individuals were affected more severely by competition than the undamaged ($p<0.05$). The correlation between competition and annual radial growth rate during the past 5 five years ($r=-0.586$, $p=0.013$) is only significant for the fire-damaged trees, but not significant for the undamaged ones ($r=-0.35$, $p=0.242$).

IV. DISCUSSION

Many studies have shown the considerable immediate and even long-term impact of a fire on the succession and species composition in a forest ecosystem (Johnson, 1992). Our paper supports the assumption made by Lesieur (2002) that in long fire-free periods, previously fire-damaged trees are more sensitive to disturbances. High winter temperatures had a negative, high winter precipitation a positive effect for both groups of trees. Fire-damaged trees seem to be more sensitive to the beneficial effect of high spring temperatures than undamaged individuals. They are also more sensitive to the negative effect of very high summer temperature than the undamaged trees.

The results also show that the correlation between competition and annual radial growth during the past five years ($r=-0.586$, $p=0.013$) is only significant for the fire-damaged trees. This finding is inconsistent with previous studies, which have shown that spatial factors do not explain the variation in radial growth after fire-damage (Bergeron et al, 2001).

Numerous studies have shown that the long-term interactions between climate, fire, and tree radial growth are complex. Climate has a direct influence on growth through the control of moisture and radiation, and fire is often caused by specific climatic conditions (Villalba and Veblen, 1997b). Previous studies have also revealed differential growth rates resulting from climatic conditions rather than from the direct influence of fire (Mutch, 1994). However, the samples in this study are from the same species with approximately the same age. The trees are growing in the same location under common climatic conditions. Thus the signal is not garbled and the samples provide good evidence about the effect of an old fire on tree radial growth.

This study confirms that the effect of a fire on tree growth may persist for a long time. This effect became evident in evaluation of the neighborhood competition which influenced damaged trees considerably more than the undamaged ones. The changes in the climate during the past three decades, especially the higher temperatures in the growing season, showed also significantly different effects on the damaged and undamaged trees.

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