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THE IMPACT OF ICE STORMS ON TREE-RING WIDTHS OF LOBLOLLY PINE IN NORTHERN GEORGIA

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1. INTRODUCTION

The central and northern portions of the southeastern United States of Louisiana, Mississippi, Alabama, Georgia and South Carolina erratically experience ice storms which can cause considerable damage to southern pines (Lemon, 1961; Williston, 1974). These storms usually occur when a winter warm front moves over the area and mixes with air that is below freezing near the surface. As liquid precipitation strikes the cold surface, freezing occurs upon contact forming a glaze of ice on vegetation. If sufficient ice builds up, considerable damage, especially to long-needled coniferous trees can occur as the weight of the ice causes branches to break.

The cultivation of various southern pine species is a significant component of the forest industry in the southeastern United States. Williston (1974) has shown that slash pines are very susceptible to ice-storm damage and that the widely cultivated loblolly pine (Pinus taeda L.) can also experience significant damage. Because loblolly pine is a commercially important species, several studies of the relationship between this species and ice storms have been undertaken (Brender and Romancier, 1965; Shepard, 1975).

Damage to a tree from an ice storm can be temporary whereby the negative impact influences the tree for less than a year, or the damage can be more permanent affecting the growth of the tree for the remainder of its life. Temporary damage usually occurs from the breakage of limbs and branches from the crown of the tree. Two limitations are placed upon the growth of the tree as a result of breakage. First, an opening for disease to penetrate the tree is created (Manion, 1971). Secondly, the decreased crown area results in the production of fewer photosynthates. A more compact crown and reduced rates of photosynthesis cause a reduction in the growth rate of the tree for the following summer (Lemon, 1961). Such a reduction in growth will result in a narrower tree ring for that year.

Trees can also be permanently deformed by ice storms. The weight of the ice can cause a tree to bend to a point in which it is unable to regain its original form after the ice has melted. In addition, a few large branches on one side may break, producing asymmetry. Both of these processes result in uneven growth which should be apparent in the tree rings.

The purpose of the present study is to determine if the occurrence of ice storms has an important impact on growth rates and, therefore, tree-ring widths for loblolly pines in northern Georgia. Because only healthy trees were used in the dendrochronological analysis, this study will focus only on the temporary damage of ice storms, whereby it is hypothesized that the occurrence of an ice storm will cause less growth and, therefore, a narrower tree ring for the subsequent growing season.

2. TREE-RING CHRONOLOGY AND CLIMATE RELATIONSHIPS

The tree-ring chronology incorporated into this study was developed near the northern Georgia city of Athens. Twenty loblolly pines were sampled providing data for the period 1921 to 1986. The tree-ring chronology was developed using well-established crossdating and standardization techniques (Douglass, 1941; Fritts, 1976; Graybill, 1982). For the latter, the traditional standardization method was employed by fitting the growth series of each tree with a linear, negative exponential, or low-order polynomial regression model with tree age as the independent variable. Dimensionless ring-width indices were then calculated for each tree and averaged together by year to produce the final master chronology. Full details of the development of this chronology are given in Grissino-Mayer et al. (1988).

As an extension to the Grissino-Mayer et al. (1988) study, a simple model relating tree-ring widths to growing season average temperature (June-September) and total precipitation (May-September) was developed utilizing data from the Climatological Data publications of the National Climatic Data Center for the north-central Georgia climate division. Regionally-averaged data were used rather than single station values because previous studies have shown that regional data provide better results in regression analyses with tree-ring data (Lawson et al., 1980; Blasing et al., 1981). The model obtained was:

$$\hat{R}_i = 2.08 + 0.015 P_i - 0.019 T_i \quad (1)$$

where $\hat{R}_i$ is the predicted index for year i, P_i is the May-September precipitation total (cm), and T_i is the June-September average temperature (°C). Both regression coefficients in equation 1 were significant at the .05 level. This simple model explained 39% of the variance in ring-width indices which compares favorably with other eastern U.S. dendroclimatic studies (Cook and Jacoby, 1977; Conkey, 1986).

Using equation 1, residuals were obtained by subtracting the predicted ring-width indices from the actual values (Figure 1). Several climatic and biological factors may account for the residual variance displayed in Figure 1. One such factor is the periodic occurrence of ice storms in northern Georgia.

3. ICE STORM/TREE RING RELATIONSHIP

In order to identify important ice storm events in the study area, several sources of information were consulted. Examination of National Weather Service (NWS) summary climate publications and local newspaper articles was undertaken. Because ice storms often disrupt electrical power service, personal interviews with longterm Georgia Power officials in the Athens area were also conducted. Through this effort, 16 significant ice storm events were identified (Table 1). An ice storm was considered significant if ice accumulation on surface objects was at least 12.5 mm based on estimates from written descriptions contained in the NWS summaries and newspaper reports. The 16 years in which ice storms occurred are highlighted by solid dots in the diagram of tree ring-width index residuals given in Figure 1. Note that December ice storms are plotted for the growing season of the subsequent year. The occurrence of 16 significant ice storms in the 66 year record agrees closely with the statement of McKellar (1942) that an important ice storm occurs about once in five years for the study area.

In addition to simply having an ice storm event, events with greater accumulations of ice were assumed to have a greater negative impact upon the trees. Storms were classified based on the ice accumulation estimates as (1) minor (12.5-25 mm of ice), (2) moderate (25-37.5 mm of ice), (3) major (37.5-50 mm of ice), and (4) severe (over 50 mm of ice).

Figure 1 indicates that six of the 16 ice storms had positive residuals while the other 10 had negative residuals. Of the six with positive, four occurred in December, i.e., early in the winter. Compared to early winter storms, storms occurring later in the winter may have a greater impact given that the trees have ceased dormancy and started to bud. The resulting damage may, therefore, have a greater impact on total growth during the subsequent growing season. In order to account for the time of season, an additional variable was calculated for each storm, i.e. the day number of the winter season beginning with 1 for December 1 through 121 for March 31 (assuming non-leap year).

In order to relate ice storms to the residuals plotted in Figure 1, multivariate models were utilized to determine the amount of variance that could be explained by the occurrence of an ice storm, the severity classification of the storm, and the day number of the year when the storm occurred. The significance of F-values associated with each model was noted, as well as the incorporation of Student's t-tests to determine if regression

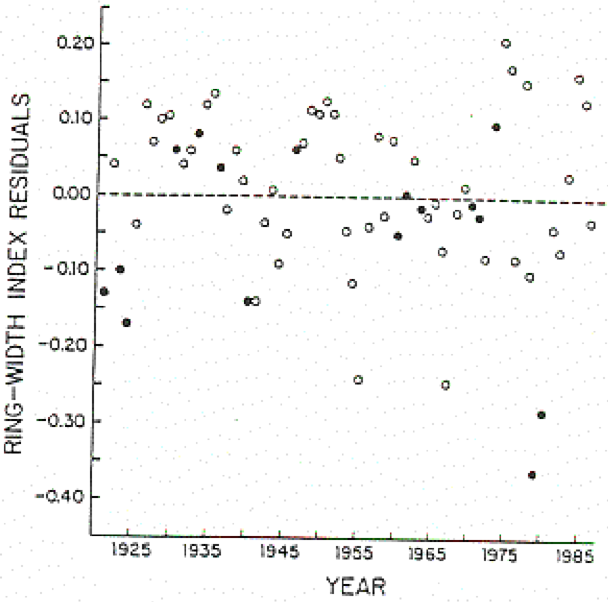

Figure 1. Ring-width index residuals (derived from equation 1) for each year. Years during which an ice storm occurred in the winter prior to the growing season are highlighted with solid dots.

Table 1: Ice Storms for Athens, Georgia During the Period 1921-1986

Date	Severity Classification*
Mar. 3 1921	1 - minor
Jan. 16 1923	1 - minor
Jan. 23 1924	1 - minor
Dec. 22 1929	1 - minor
Dec. 16 1932	1 - minor
Dec. 28 1935	4 - severe
Jan. 7 1940	3 - major
Dec. 24 1945	2 - moderate
Mar. 2 1960	3 - major
Jan. 26 1961	1 - minor
Dec. 25 1962	1 - minor
Jan. 11 1970	1 - minor
Mar. 25 1971	2 - moderate
Jan. 7 1973	1 - minor
Feb. 7 1979	4 - severe
Jan. 31 1980	2 - moderate

* minor (12.5-25 mm of ice), moderate (25-37.5 mm of ice), major (37.5-50 mm of ice), severe (over 50 mm of ice)

coefficients were significantly different from zero. Studentized residuals were also calculated for each observation in the model as a means of determining significant outliers (Freund and Littell, 1986). The best overall relationship relating the ring-width index residuals for year i (RES_i) to ice storms was:

$$RES_i = 0.019 + 0.126\ O_i - 0.039\ C_i - 0.003\ D_i \qquad (2).$$

where O_i is a binary expression of "0" for no storm during the winter before the growing season for year i, and "1" when an ice storm did occur during the winter, C_i is the severity classification (0 for non-occurrence, and 1 for minor to 4 for severe given in Table 1), and D_i is the day number of the winter season for the storm (0 for no storm). The regression coefficients for all terms were significant at the .10 level. The F-value for the model in equation 2 was indeed significant ($F = 5.7$, $p > 0.002$), with a model $R^2 = 0.22$. Recall that 39% of the original variance in ring-width indices was explained by the simple climate model incorporating growing season precipitation and temperature presented in equation 1. The relationship given in equation 2 accounts for 22% of the variance in the residuals from the growing season precipitation and temperature model. This implies that over 10% of the total variance in the tree-ring chronology can be accounted for by ice storms.

A review of the studentized residuals indicated that the observations for 1955 and 1967 were significant outliers (both are negative residuals in Figure 1). An in-depth analysis of the climatic conditions for these two years led to significant findings that may explain these negative outliers. During March of both these years, a severe late winter freeze occurred. This freeze was preceded on both occasions by a very warm period which induced many trees to break dormancy early. As a result, damage was severe resulting in a significant reduction of earlywood growth.

4. CONCLUSION

This study has involved the dendroclimatic analysis of loblolly pine in northern Georgia. A simple model incorporating growing season precipitation and temperature explained 39% of the variance in ring-width indices. Of the residual variance, 22% was accounted for by a relationship involving ice storms implying that at least 10% of the total variance in the tree-ring chronology can be accounted for by ice storms. This latter relationship incorporated the following terms: a binary representation of the occurrence of a storm, a severity classification of a storm from minor (1) to severe (4), and an expression of the timing during the winter for the storm (utilizing day numbers beginning with December 1 as day 1). Therefore, the occurrence of winter ice storms in northern Georgia has a significant impact on loblolly pine by retarding growth during the subsequent growing season, and this reduction in growth is evident in the tree-ring widths.

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