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Temporal Stability and Dendroclimatology in Silver Fir and Red Spruce

By

Kevin T. SMITH[1], Katarina ČUFAR[2] & Tom LEVANIČ[2]

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S u m m a r y

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Dendroclimatology uses precisely dated tree-ring series and climate measurements to reconstruct climate for periods prior to instrumented records. Dendroclimatology requires a predictable, relationship between growth and climate. Tree-ring series from silver fir in Slovenia and red spruce in the northeastern US were calibrated to monthly climate variables for two periods, corresponding approximately to the first and second halves of the 20th Century. Bootstrapped response function analysis indicated that growth during the two periods was associated with markedly different variables of monthly mean temperature and monthly total precipitation. These findings suggest caution in dendroclimatic reconstruction and are interpretable as indications that the relationship of tree growth to climate may have changed during the 20th Century.

I n t r o d u c t i o n

Dendroclimatology reconstructs past climate patterns through mathematical models that relate precisely dated tree-ring records to climate measurements (FRITTS 1976). The mathematical relationship is then extrapolated to tree-ring series formed prior to climate measurement. Such dendroclimatological reconstructions depend on a predictable linkage of growth to climate. Recent research questioned the stability of the dendroclimatic relationship for trees at high elevations and far-northern latitudes across the northern hemisphere (BRIFFA & al. 1998). In this research we examine the temporal stability of the dendroclimatic

[1] US Forest Service, P.O. Box 640, Durham, New Hampshire, 03824, USA. Fax: +1 603-868-7604, e-mail: kts@hopper.unh.edu
[2] Biotechnical Faculty, University of Ljubljana, Rozna dolina c. VIII/34, 1001 Ljubljana, P.O.Box 95, Slovenia. Fax: +386 (0) 61 123-50-35.

(2)

relationship at lower elevations and lower latitudes for silver fir (*Abies alba* Mill.) in Slovenia and red spruce (*Picea rubens* Sarg.) in the northeastern United States.

Material and Methods

Locations representative of silver fir in Slovenia (forests in Bistra (550 m elevation), Javornik (950 m), and Ravnik (600 m) at ca. 46° N lat., 14° E lon.) and red spruce in the northeastern US (forests in Big Moose Lake, New York (550 m); Groton, Vermont (510 m); Cone Pond and Bartlett, New Hampshire (585 and 480 m, respectively); Kossuth, Maine (150 m) at ca. 44-45° N lat., 68-75° W lon.) were selected for dendroclimatological analysis (Fig. 1). Slovenian locations consisted of mixed silver fir and beech forests with some spruce and maple, growing on brown and rendzina soils overlaying dolomitic parent material. US locations consisted of mixed red spruce, birch, and maple forests with some balsam fir, growing on acidic, primarily podsolic soils overlaying granitic parent material.

Increment cores were taken from canopy dominant or subdominant trees at approximately 1.4 m aboveground. Using standard dendrochronological techniques (STOKES & SMILEY 1996), ring-width series were measured and crossdated. Trees varied in age within each location; the majority of trees were mature (non-juvenile) by the beginning of the modeling period.

Each ring-width series was fitted with a cubic spline (50% frequency cutoff of 30 years) to represent the growth trend. Index series were calculated by dividing ring-width by the spline value. Following autoregressive modeling of the index series, a tree-ring chronology (type RES) was constructed for each location using the computer program ARSTAN (HOLMES & al. 1986). Each chronology was based on a minimum of 6 to 34 and a maximum of 37 to 67 index series. Monthly mean temperature and monthly total precipitation data were obtained from weather stations located near the forest locations in Slovenia and the northeastern US.

The climate records and tree-ring chronologies were divided into two segments, approximating the first and second halves of the 20th Century. Slight differences in the endpoints of the time segments between the Slovenian (1897-1946, 1947-1988) and US (1900-1949, 1950-1990) locations were dictated by the available climate records. Tree-ring chronologies were related to the principal components of the climate variables with bootstrapped response function analysis (GUIOT 1991) using the computer program PRECON (FRITTS & al. 1991). Potential predictor variables were drawn from May of the year preceding ring formation (pMay as indicated in Fig. 1) to August of the year of ring formation (Aug). As variation in precipitation had no significant effect on variation in the red spruce chronologies ($P = 0.05$, data not shown), precipitation data was not included in the subsequent analysis of red spruce growth. Principal component analysis reduced the number of predictor climate variables and reduced the likelihood of model over-fitting. The time course of the change in the dendroclimatic relationship was illustrated using correlation coefficients of significant climate variables and tree-ring chronologies for running 25-year periods.

Results

Tree-ring growth was significantly related to monthly mean temperature and monthly total precipitation (fir in Slovenia) or to monthly mean temperature alone (spruce in the northeastern US) ($P = 0.05$, Fig. 1). The proportion of variability in the tree-ring chronology accounted for by the climate variables is shown (r^2). For a given forest location, monthly climate variables with a significant effect on growth during the first half of the 20th Century were not the same as the significant climate variables for the second half of the 20th Century. This lack of

temporal stability in the statistical relationship occurred for silver fir in Slovenia and red spruce in the northeastern United States.
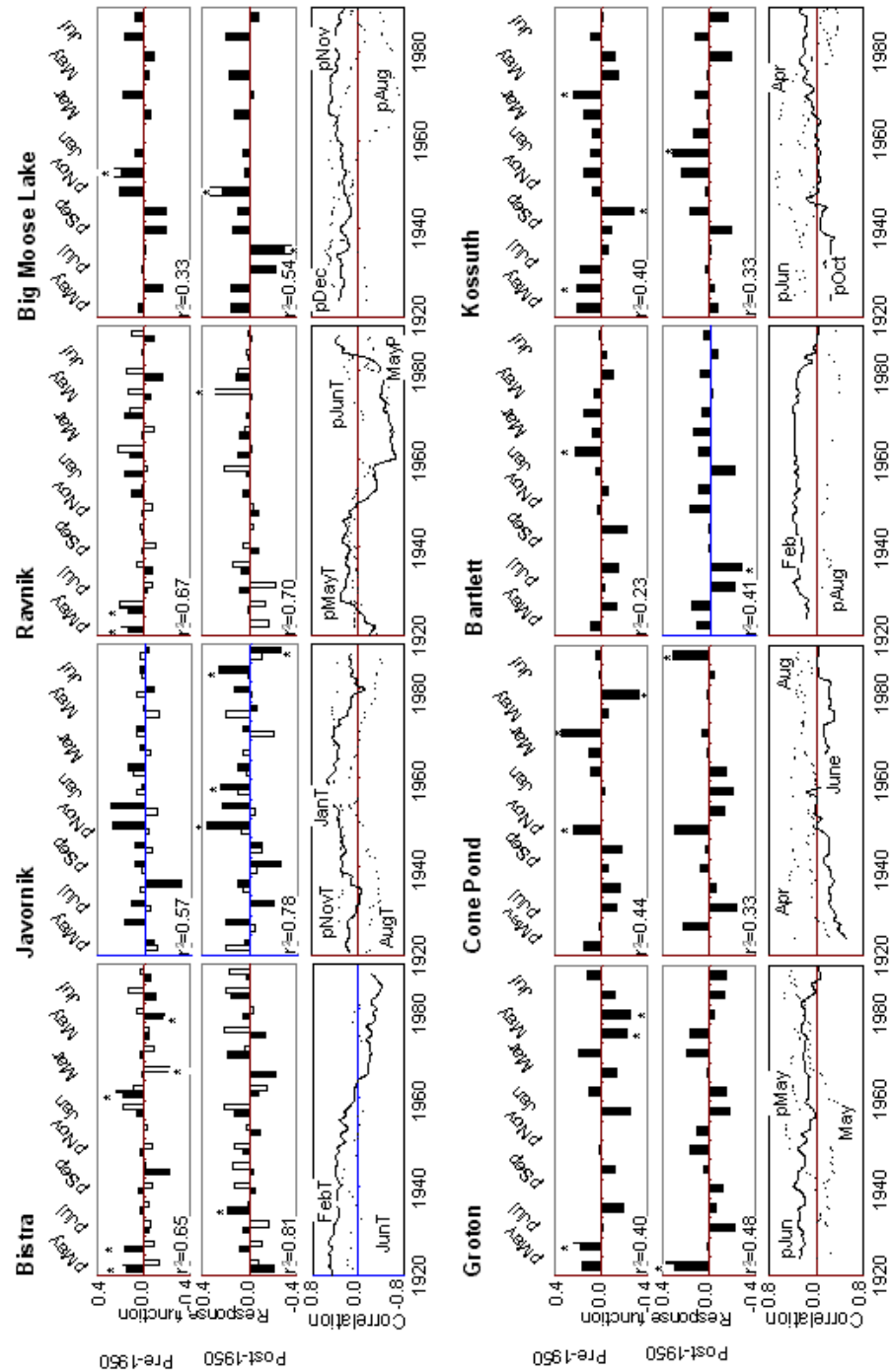

Fig. 1. Response function and correlation analysis of tree-ring chronologies with monthly mean temperature (filled bars) and monthly total precipitation (open bars).

(4)

Differences in the statistical relationship to climate were dramatic and not due to slight differences. For example, for fir in Ravnik, growth from 1897-1946 was significantly associated with warm May and June temperatures in the year prior to ring formation (response function coefficients (rfc) for pMay and pJun of 0.20 and 0.21, respectively). No significant relationship was evident in the 1947-1988 period, rfc=0.01 and <0.01, respectively). However, June precipitation was significantly related to growth for the later period (rfc=0.38) yet not related to growth in the earlier period (rfc=0.13). Similar lack of consistency of the statistical relationship of growth to climate was evident at all eight forest locations reported here (Fig. 1).

The correlation of tree-ring chronologies with significant climate variables (as identified by the bootstrapped response functions) over 25-year moving intervals also suggest that a statistically significant relationship was temporally dependent (critical correlation coefficient = 0.40 for P=0.05, 23 degrees of freedom).

D i s c u s s i o n

Tree growth is affected by climate through the processes of energy capture and storage, cell division and maturation, and defense. The statistical relationship of fir and spruce growth to climate changed through the 20th Century. This change could be due to statistical artifact, changes in temperature or precipitation patterns, or changes in tree sensitivity to climate.

The consistency of these results and earlier observations of the dendroclimatic response of red spruce (JOHNSON & al. 1988) argue against statistical error as an explanation. Although changes in temperature and precipitation patterns do occur within some span of time, there is no visibly apparent indication of a trend in the climate data used in this research (not shown). Although not investigated in this research, changes in tree sensitivity could arguably be due to cellular aging, changes in the extent or proportion of roots and crowns, or to other predisposing or injurious factors. Such factors could include elevated atmospheric CO_2, nitrogen deposition, and ultraviolet radiation (BRIFFA & al. 1998), base cation mobilization (SHORTLE & al. 1997), and ozone exposure (BARTHOLOMAY & al. 1997). In addition to providing a cautionary note for dendroclimatic reconstructions, these results may provoke a closer examination of the factors that affect tree growth and how those factors may be changing.

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