Tree-Ring–Drought Relationships in the Hudson Valley, New York

Abstract. *Annual tree-ring chronologies from certain well-drained sites in the Hudson Valley of New York record past changes in temperature and precipitation. This information accounts for much of the July variation in Palmer drought severity indices during the period 1931 to 1970 and is used to develop a preliminary reconstruction of drought as long ago as 1728.*

Analyses of ring-width variation in four different species of trees from well-drained sites in the Hudson Valley have shown that annual growth is correlated with precipitation and temperature (*1*). The relationship between these climatic variables and ring widths is strong enough that the ring-width data can explain more than 60 percent of the variation in drought intensity in the Hudson Valley. For a severe drought, such as that of the mid-1960's, the effect on growth rates of moisture-sensitive trees is large enough that all plots of the ring-width index show a sharp decrease (Fig. 1).

The use of tree-ring widths for developing proxy climatic and hydrologic series has proven successful in the western United States (*2, 3*). Stockton and Meko (*4*) reconstructed spatial patterns of drought west of the Mississippi River from anomalous patterns of tree growth. If tree growth in the northeastern United States proves to be sufficiently correlated with drought, an improved long-term estimate of frequency and duration should be feasible. Such information would prove valuable in planning for water resources. To test the feasibility of reconstructing past droughts in the northeast from tree rings, we performed correlation analyses between Palmer drought severity indices (PDSI's) (*5*) and tree-growth indices in the Hudson Valley of New York. The tree-ring data were then used in actual drought reconstruction.

In the mid-1960's, a drought of extreme severity reduced water supplies to dangerously low levels, particularly for heavily urbanized areas like New York City. For example, in 1965 New York City reservoir levels fell to 40.6 percent of capacity, and in 1966 the Potomac River flow dropped perilously close to the water consumption demand of the Washington, D.C., area (*6*). Since then, the region has experienced several years of adequate precipitation, but the specter of another drought remains. In order to plan more accurately, it would be valuable to know the frequency and intensity of droughts in the past.

Future estimates are based on the past record and hampered by the shortness of the available climatic and hydrologic data. Although some reasonably long climatic series exist (for example, the temperature and precipitation series of New York City and Albany, New York), they are relatively scarce and poorly distributed geographically. Tree rings offer a potential for lengthening the data base in areas without long climatic series.

Lyon (*7*) first recognized that past drought in the northeastern United States could be reliably inferred from tree rings. He characterized the small ring widths from these trees as indices of "physiological dryness." These narrow rings integrated the effects of internal water stress produced by low precipitation and high evapotranspiration. Lyon made only qualitative comparisons between narrow rings and descriptions of past drought. Palmer (*5*) developed the PDSI, which considers the interaction of temperature and precipitation in producing drought. The PDSI values range from ≤ -4.0 for extremely dry to $\geq +4.0$ for extreme wet; -1.0 to $+1.0$ is considered normal.

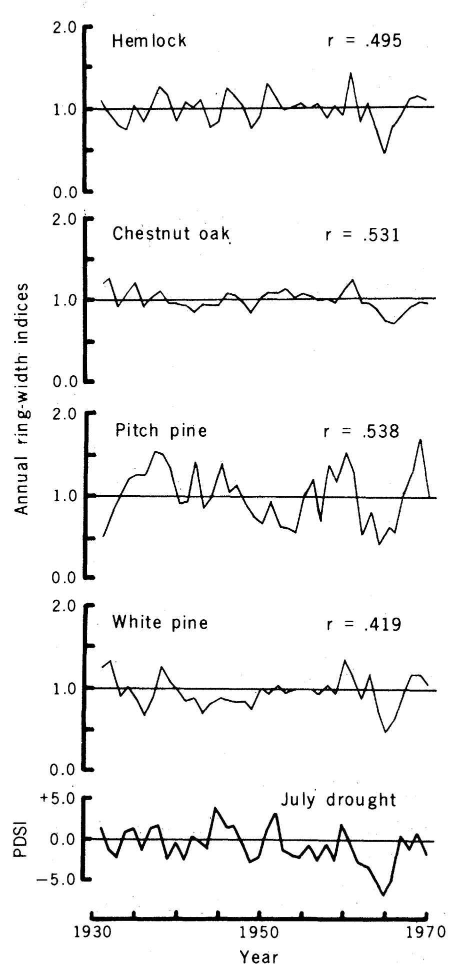


Fig. 1. Ring-width indices for four tree species for the period 1930 through 1970 compared with Palmer drought severity indices (*PDSI*). The product-moment correlation coefficient (r) of the tree-ring series and the PDSI is shown. The ring-width indices and the PDSI are dimensionless numbers.

Our analysis compares the PDSI's for the Hudson Valley climatic division in New York with annual tree growth for the period 1931 to 1970. Four annual tree-ring chronologies (*8*) were developed by Cook (*1*) from sites in the Shawangunk Mountains in the southern Hudson River Valley according to standard techniques (*9*). Trees were sampled on rocky, well-drained sites where moisture supply was felt to be the factor most limiting tree growth. Each chronology is represented by a single tree species and is a composite of at least 15 trees (two cores per tree). The four species are eastern hemlock [*Tsuga canadensis* (L.) Carr.], pitch pine (*Pinus rigida* Mill.), eastern white pine (*Pinus strobus* L.), and chestnut oak (*Quercus prinus* L.). An additional pitch pine chronology was developed later at Schunemunk Mountain, south of the Shawangunks. Because the method used to calculate PDSI's includes the conditions from prior months, July drought indices were chosen as best representing the cumulative effect of moisture stress at the trees' environs during a typical May through July growth season. Figure 1 illustrates the relationships between four of the tree-growth indices and the July PDSI's of the same year for the common period 1931 to 1970.

The correlation coefficients (Fig. 1) indicate a fairly high covariation between tree growth and drought. As a precaution, significance tests of the coefficients were made only after the degrees of freedom were corrected because of persistence in the time series (*10*). All correlations were significant ($P < .05$).

The physical phenomena corresponding to these relationships are depicted in the response functions of the tree-growth climatic relationships for each species chronology (Fig. 2). The derivation of response functions has been described by Fritts *et al.* (*11*). Such functions are interpreted as expressing the way in which monthly precipitation and temperature during and preceding the current growing season are related to increases in radial growth. In this case, 16 months beginning in May of the prior growing sea-

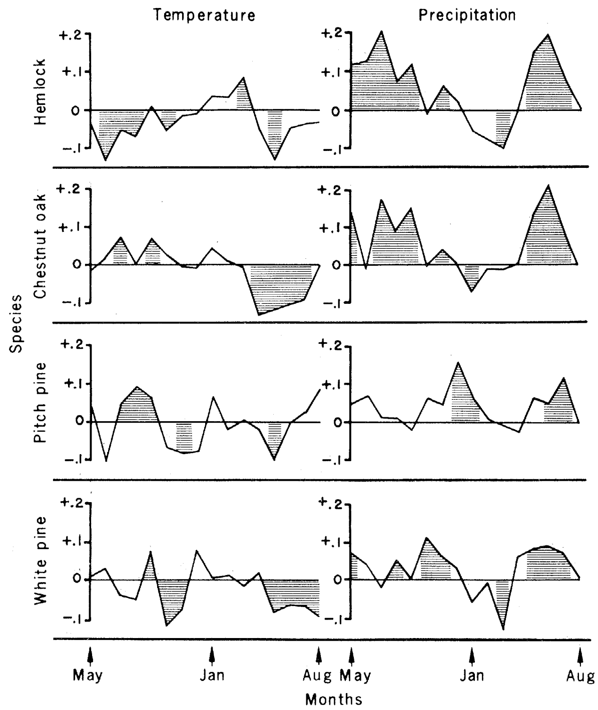


Fig. 2. Response functions for annual tree-ring growth in response to monthly mean temperature and total monthly precipitation for 16 months until the end of the growing seasons. The shaded areas are those months of temperature and precipitation that are related to tree growth ($P < .05$) (*15*). Vertical scales are dimensionless standardized units.

son and ending in August of the current season are used. The prior months are included because climatic events during that time interval can physiologically precondition a tree's potential for growth the next year (*12*).

The response functions indicate that each species responds to above-average rainfall and below-average temperature at times during any given growing season. This result explains the significant correlations of Fig. 1. Additionally, hemlock and chestnut oak are preconditioned by climate during and shortly after the prior growth season (Fig. 2), which suggests (i) that a more complex model relating tree rings to drought should be considered and (ii) that prior or subsequent tree-ring indices (or both) should be used as additional predictors of drought.

Models incorporating prior and subsequent tree-ring indices were used in stepwise regression analyses with July PDSI's as the dependent variable (*13*). Only significant variables ($P \leq .05$) were used as predictors in each regression problem. Hemlock growth can account for as much as 54.6 percent (50.4 percent adjusted for degrees of freedom) of the July PDSI variance. From the hemlock and PDSI plots in Fig. 1 it can be seen in several instances (for example, 1933–34, 1945–46, and 1955 through 1961) that the effects of July PDSI's are not recorded in hemlock growth until the following year. This phenomenon is also strongly manifest in the hemlock response function. Therefore, the first variable entered is the next year's growth.

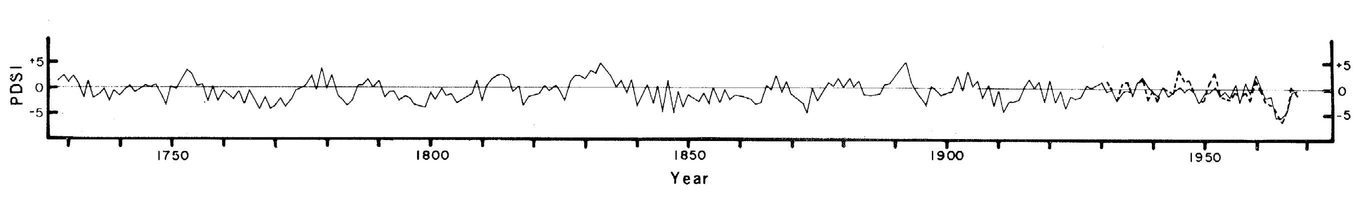
Chestnut oak growth can account for more than 52 percent (48 percent adjusted) of the July PDSI. A close scrutiny of the chestnut oak and PDSI plots, as with the hemlock, reveals that growth during years of drought is sometimes indicated by the indices of the next year (for example, 1931–32, 1941–42, and 1960–61). The oak response function also suggests that it is physically reasonable to include the following year's growth because of the dependence on rainfall during the prior May and July.

Pitch pine can account for a maximum of only 35.5 percent (33.7 percent adjusted) of the PDSI variance, although it has one of the higher simple correlations with drought. In each model, only the growth-year index is a significant predictor. Apparently there is no significant carry-over of July drought information in this chronology.

White pine accounts for a maximum of 19.7 percent (17.4 percent adjusted) of the PDSI variance. Again, only the growth-year index is significant in any model and no carry-over of the drought effect is present. This result is less surprising than for pitch pine since white pine has the poorest correlation with the drought indices in Fig. 1.

The results provide additional insight into the tree-growth–drought relationship and show that drought reconstructions are feasible in the Northeast. However, they must be approached cautiously. For example, the selection of variables according to the stepwise regression procedure can be adversely influenced by intercorrelations among the predictor variables, as was the case with the tree-ring indices. Thus, the PDSI variance explained by tree growth may be inflated. Additionally, the regression coefficients derived from such intercorrelated variables are somewhat unstable. Since multicolinearity is generally a problem when tree-ring series are used as predictors, orthogonalization of these variables is appropriate.

Each species chronology was shifted backward on itself 3 years for the period from 1730 to 1970 and subjected to principal-component analysis according to a technique developed by Stockton (*14*). Four sets of orthogonal amplitudes, or factor scores, were derived through this procedure. Of the four, the first three factor scores accounting for 85 to 90 percent of the original variances were chosen as potential predictor variables of



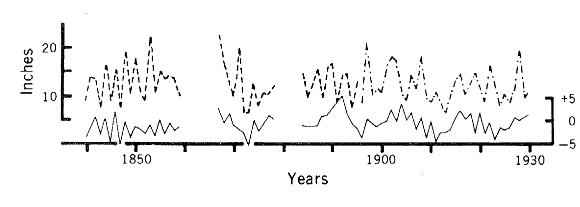


Fig. 3 (left). Reconstructed July PDSI series for the Hudson Valley. The actual drought indices (dashed lines) of the calibration period are superimposed on the regression estimates (solid lines) for comparison. Fig. 4 (right). Reconstructed July PDSI series (1840 to 1859, 1867 to 1878, and 1884 to 1930) (solid lines) versus May through July total rainfall in inches for West Point, New York (dashed lines) and Mohonk Lake, New York (dash-dot lines). The rainfall values were independently calculated from Weather Bureau records.

drought in a series of stepwise regression analyses corresponding to the same models used before; the period from 1931 to 1970 was used for calibration. Again, only significant variables ($P \leq .05$) were allowed into the equations.

In general, a little explained variance is lost when factor scores instead of tree-ring indices are used as predictors. This loss is to be expected since 10 to 15 percent of the information is discarded with the fourth factor score. However, hemlock and chestnut oak factor scores still explain as much as 50.8 percent (47.9 percent adjusted) and 52.6 percent (49.8 percent adjusted), respectively, of the July PDSI variance. These values are approximately equal to the best results of the earlier regressions. Given the stability of the regression estimates made from factor scores, these newest results appear superior.

The result of one reconstruction is shown in Fig. 3. The predictors were factor scores extracted from a combined matrix of the four Shawangunk Mountain tree-ring chronologies plus the Schunemunk Mountain pitch-pine chronology. The prediction equation, developed according to stepwise regression, explained 66 percent (60 percent adjusted for degrees of freedom) of the PDSI variance for the calibration period from 1931 to 1970. In this figure, the actual drought indices are superimposed on the regression estimates for comparison.

The estimates for the calibration period are unbiased in that the number of over- and under-predictions of the actual data are virtually equal. However, the poorest estimates are almost always for the wetter years. This is not a serious drawback since in this study we are primarily concerned with occurrences of past drought, not of past wet intervals. In the latter case, different modeling techniques might be used.

Verification of the reconstructed drought indices is shown in Fig. 4. The independent data are the total precipitation from May through July for West Point, New York (1840 to 1859, 1867 to 1878, 1884 to 1895) and Mohonk Lake, New York (1896 to 1930). Both stations are near the tree-ring sites. This rainfall summation was used as a drought indicator because (i) the tree species respond directly to rainfall (Fig. 2), and (ii) the July drought indices reflect, in part, moisture conditions of the preceding months. There is generally good agreement between the two series, particularly for the drier years. Also, the low-frequency signal in the reconstructed drought indices corresponds well to that signal in the precipitation series. This comparison verifies that the reconstruction is a reasonable indicator of past July drought in the Hudson Valley.

On the basis of this initial reconstruction, the drought during the 1960's appears to be the most severe episode in terms of both intensity and duration for the past 241 years. Episodes of more persistent, but less severe, drought were apparently more common in the past. The 1766 to 1774 and 1794 to 1799 intervals stand out in this regard.

This study demonstrates the feasibility and usefulness of dendroclimatic analysis in the northeastern United States. Drought and other climatic reconstructions will be developed and improved upon as additional tree-ring chronologies are generated from the region and the biological and statistical models are refined.

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10. Before the significance of correlation coefficients can be determined, the number of degrees of freedom must be corrected downward to account for persistence in each time series. If we assume that a first-order Markov process is operating in each series, an approximate correction can be calculated as:

$$N' = (N - 2)\frac{(1 - r_1 r_2)}{(1 + r_1 r_2)}$$

where N is the number of observations, r_1 and r_2 are the first-order serial correlation coefficients for series 1 and 2, and N' is the corrected degrees of freedom. In this case, $N = 40$ and each r is assigned a value of .5, which is actually slightly greater than that present in any of the series. After this correction degrees of freedom drops from 38 to 23 [D. R. Dawdy and N. C. Matalas, in *Handbook of Applied Hydrology*, V. T. Chow, Ed. (McGraw-Hill, New York, 1964), p. 87].
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13. The details of the modeling techniques and results will be described in greater detail (E. R. Cook, in preparation). The types of models have been described (*2*). The significance test for entering and deleting variables in stepwise regression is the partial F test. It determines whether or not the reduction in the variation of the dependent variable with the addition of an independent variable is sufficient for inclusion in the regression. The stepwise procedure terminates when the calculated partial F value falls below a predetermined significance level. [J. Neter and W. Wasserman, *Applied Linear Statistical Models* (Irwin, Homewood, Ill., 1974), pp. 382–383].
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15. The 95 percent confidence intervals identify those months when climate is significantly correlated with tree growth. For the actual derivation of the confidence limits, see H. C. Fritts, *Tree Rings and Climate* (Academic Press, London, 1976), p. 365.
16. Supported by grant ATM 75-21226 from the Climate Dynamics Research Section of the National Science Foundation. Four of the tree-ring chronologies used were developed by E.R.C. under the supervision of M. A. Stokes at the Laboratory of Tree-Ring Research in Tucson. Lamont-Doherty Geological Observatory Contribution No. 2585.

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Peptidoglycan in the Cell Wall of the Primary Intracellular Symbiote of the Pea Aphid

Abstract. *Primary intracellular symbiotes of the pea aphid,* Acyrthosiphon pisum *(Harris), when fixed with potassium permanganate, revealed a distinctly staining area between the cytoplasmic membrane and the outer cell-wall envelope. This area is thought to be analogous to the peptidoglycan complex of the Eubacteriales. In addition, the diagnostic bacterial peptidoglycan amino compounds, muramic acid and diaminopimelic acid, were detected in a hydrochloric acid hydrolyzate of isolated symbiotes.*

Insect intracellular symbiotes are of interest both to insect physiologists and to microbiologists, to whom the evolutionary ancestry of the symbiotes presents a challenging question. Several aphid species have two distinct types of symbiotes, a rod-shaped secondary symbiote that is, morphologically, clearly bacteria-like and an oval, primary symbiote that is more difficult to categorize with existing groups of microorganisms. Whereas many early workers disputed the microbial nature of the primary symbiotes (*1*), most recent students agree that they are microorganisms although they have classified them in groups ranging from the Eubacteriales (*2–4*) to the rickettsia (*5, 6*) and mycoplasma (*7, 8*).