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# VALMORE C. LaMARCHE, JR. 1937-1988

Valmore C. LaMarche, Jr. died of heart failure at age 50 in Tucson, Arizona, on March 23, 1988. Val was Professor of Dendrochronology at The University of Arizona's Laboratory of Tree-Ring Research and was widely known for his innovative use of tree-ring data in Quaternary studies.

Born in Hurley, Wisconsin, on August 27, 1937, Val moved with his family at an early age to Springfield, Oregon, where he attended local schools. While majoring in geology at the University of California, Berkeley, he first conceived the idea of directly establishing rates of slope erosion in California's White Mountains by dating the exposed roots of the long-lived bristlecone pines. After graduating with honors from Berkeley in 1960 he continued his White Mountain research at Harvard University (M.A. 1962, Ph.D. 1964) as an NSF Graduate Fellow. His Harvard dissertation stimulated his life-long interest in applying dendrochronological principles to the study of geological processes and events. He had joined the U. S. Geological Survey while still a graduate student at Harvard and was later to continue this association as a Research Project Chief at Menlo Park in California. In 1967 he left the Survey to become a member of the faculty of the Laboratory of Tree-Ring Research where he was advanced to full professor in 1974.

Over the course of his research career Val employed tree-ring techniques to investigate a variety of natural phenomena including floods, volcanic eruptions, earthquakes, land form changes, glacial advances, solar variability, insect infestations, radiocarbon variations, river runoff, and most notably, past climatic changes. A number of his papers - for example, his creative use of dated tree line fluctuations to infer Holocene climatic variations and his recognition of a possible direct $CO_2$ fertilization of high-altitude trees - were considered seminal contributions to the field. To carry out these studies Val constructed scores of long tree-ring chronologies. Although he concentrated primarily on old age species of the western U. S., he also pioneered the development of tree-ring series throughout the Southern hemisphere in New Zealand, Australia, South Africa, and South America. He maintained an interest in other parts of the world as well, conducting limited field work in India and editing three volumes of translations of selected Soviet publications in dendrochronology.

At the time of his death Val was serving as Editor of the *Tree-Ring Bulletin* and was an active participant in the International Project in Dendroclimatology. He was developing the study of bristlecone pine frost rings as records of climatically effective volcanic eruptions by the analysis of a greatly expanded sample set. His uniquely broad grasp of Quaternary science, his special contributions to dendrochronology, and his friendship will be sorely missed by his colleagues throughout the world.

# EFFECTS OF DEFOLIATION BY THE WESTERN FALSE HEMLOCK LOOPER ON DOUGLAS-FIR TREE-RING CHRONOLOGIES

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ABSTRACT

Annual rings of Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, which sustained 1 year of defoliation by the western false hemlock looper, *Nepytia freemanii* Munroe (Lepidoptera: Geometridae), showed a period of decrease in breast height ring width starting in the year that followed the damage. The magnitude of the decrease was related to the degree of defoliation: there was no ring width decrease on trees that were 0-10% defoliated; the decrease became progressively more noticeable in trees which sustained increasingly higher defoliation; and it was maximum in trees which sustained 91-100% defoliation. This period of reduction lasted 1 to 5 years and was followed by a period of above-normal growth which was related to defoliation in a similar manner: it was absent in trees 0-10% defoliated and maximum in the 91-100% tree defoliation class. Increase in defoliation caused a significant increase in index standard deviation, autocorrelation and mean sensitivity.

## INTRODUCTION

Sound forest pest management requires the preparation of hazard maps that describe areas of past insect activity. Such maps can be used to determine areas with a high probability of infestations and to prepare protection plans accordingly. It has long been recognized that the occurrence of past defoliator infestations can be established by studying the pattern of ring widths (Blais 1958, 1962; Alfaro et al 1982). However, relatively few studies have described in detail the pattern of ring reduction and recovery caused by different insect species (Koerber and Wickman 1970, Kulman 1971, Wickman et al. 1980, Alfaro et al. 1982). Blais (1958, 1962, 1983) studied the tree ring pattern in balsam fir, *Abies balsamea* (L.) Mill., and white spruce, *Picea glauca* (Moench) Voss, under defoliation by the spruce budworm, *Choristoneura fumiferana* (Clements). Brubaker (1978) and Brubaker and Greene (1979) described and compared the effects of western spruce budworm, *Choristoneura occidentalis* (Freeman), and Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough), on growth of Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, and grand fir, *Abies grandis* (Dougl.) Lindl., in the western United States. Swetnam et al. (1985) described a procedure to date and quantify the effects of western spruce budworm on the growth of New Mexico Douglas-fir trees. Alfaro et al. (1982) and Alfaro (1985) demonstrated that the reduction in ring width of Douglas-fir trees was related to the severity and duration of defoliation by the western spruce budworm. Morrow and LaMarche (1978) quantified the impacts of insect feeding on growth rates of two species of *Eucalyptus* in Australia.

In this paper we describe the effects of defoliation by the western false hemlock looper, *Nepytia freemanii* Munroe (Lepidoptera: Geometridae), on Douglas-fir tree rings in a locality of British Columbia. Populations of the western false hemlock looper periodically increase to outbreak levels for periods of 1 to 4 years (Harris et al. 1985), causing localized defoliation and tree mortality. In British Columbia, the western false hemlock looper feeds primarily on Douglas-fir and has one generation per year. Eggs are laid in late summer and early fall and hatch in the next spring. The larvae consume the new foliage preferentially and then the old foliage if necessary (Furniss and Carolin 1977).

## MATERIALS AND METHODS

An infestation of western false hemlock looper was detected near Chase, British Columbia in the summer of 1973 (Cottrell and Adams 1974). In the fall of 1974, one research plot, consisting of 100 randomly selected trees, was established in each of two stands within an area of new defoliation. Both stands were of pure Douglas-fir, multi-aged, and were located less than 1 km apart, on medium, well-drained sites. Average tree age was 60 years (range 22-109) and average diameter at breast height was 26 cm (range 7-75). Defoliation of every plot tree was ocularly estimated to the nearest 10% by dividing the living crown into one-third height sections and assessing the amount of foliage missing (all foliage age classes) from each section. A defoliation estimate for the tree was developed by averaging the estimates for the three crown sections. In the fall of every year until 1980, the plot was revisited and defoliation of each tree recorded.

A survey in the fall of 1985 (12 years after the defoliation) indicated that 188 of the original 200 trees were still alive and that the death of only two trees could be attributed to feeding by western false hemlock looper; the rest died of other causes (wind damage, etc). All surviving plot trees were sampled for annual ring growth as follows: one core was collected at breast height with an increment corer from each of 154 trees; in addition, 34 trees were felled and discs obtained at several points along the stem, including one at breast height (1.37 m). The analysis that follows is concerned only with the pattern of ring width at breast height, and for this reason, the breast height disc and the core samples were pooled. Several samples were discarded because of difficulties in crossdating or because of damage. Thus, the combined number of samples available for analysis was 172. Ring width variation along the stem due to defoliation will be reported separately.

Annual ring widths in discs and cores were measured to the nearest 0.01 mm, using a DIGIMIC measuring instrument, and the software described by Alfaro et al. (1984). Discs were measured along two average radii (Chapman and Meyer 1949) which were averaged into a single series per disc. Both sample types were crossdated (Stokes and Smiley 1968) with missing rings accounted for when detected.

In order to separate any reduction caused by defoliation from the confounding effects of the natural reduction in growth which occurs as the tree ages, the techniques developed by dendroclimatologists were used (Fritts 1976). A mathematical model is fitted to each tree ring series in order to describe its long-term trend. Annual ring widths are then divided by the corresponding model values. The resulting series of ratios is called an index series and is said to be standardized because it has a mean that approximates the value of one and a homogeneous variance. Standardized series from several trees in a locality can then be averaged into a site chronology.

In this study, the ring series of every tree was standardized by fitting a linear function to the annual rings from the center of the tree to the year of peak growth (determined visually) and a negative exponential for the remainder of the series (Figure 1). Both curves were fitted using the least squares method. For each tree index series, mean ring index and index standard deviation, as well as the series first order autocorrelation and mean sensitivity (a measurement of the average annual change in index value (Fritts 1976)), were calculated. Regression analysis was used to study the effects of defoliation on each of these measurements. Trees were sorted into six defoliation classes: 0-10, 11-30, 31-50, 51-70, 71-90 and 91-100%, and an average chronology was produced for each class. Also, a site chronology (average index series of all trees in both plots) was produced.

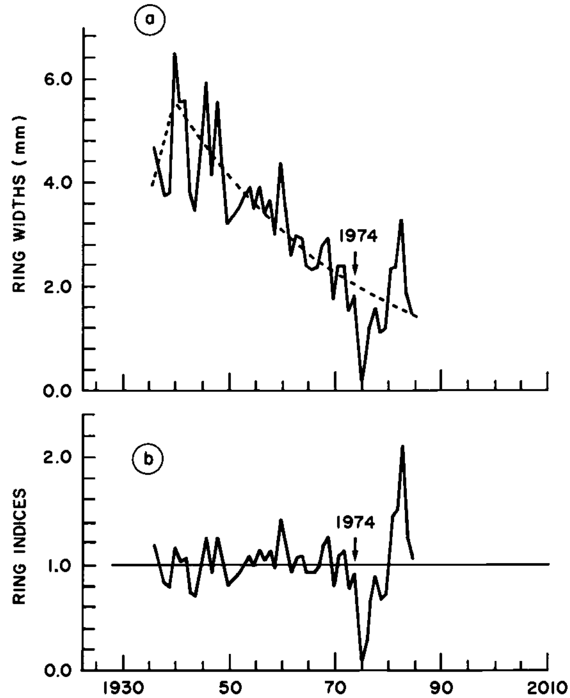


**Figure 1.** Example of the standardization procedure used to remove the growth trend from ring width series of Douglas-fir trees defoliated by the western false hemlock looper. a) annual ring widths (————) and fitted linear and negative exponential curves (———). b) Annual ring indices. Defoliation occurred in 1974.

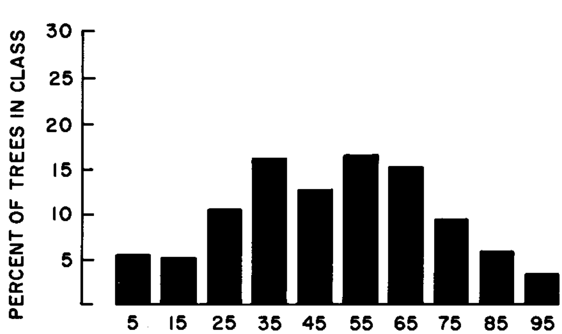


**Figure 2.** Frequency distribution of the percentage of trees sorted by defoliation class in 1974. Class width was 10% defoliation. N=172, Mean=50.6%.

## RESULTS

The infestation remained active in the Kamloops Region of British Columbia from 1973 to 1975. Although no population estimates are available, field observations indicated that the population reached maximum numbers in 1974 and collapsed in 1975 (Cottrell and Koot 1976).

No estimates of defoliation for the plot trees were available for 1973; however, since the Forest Insect and Disease Survey of the Canadian Forestry Service did not detect any defoliation in this particular area, defoliation was probably nil or light on the study plot trees in 1973.

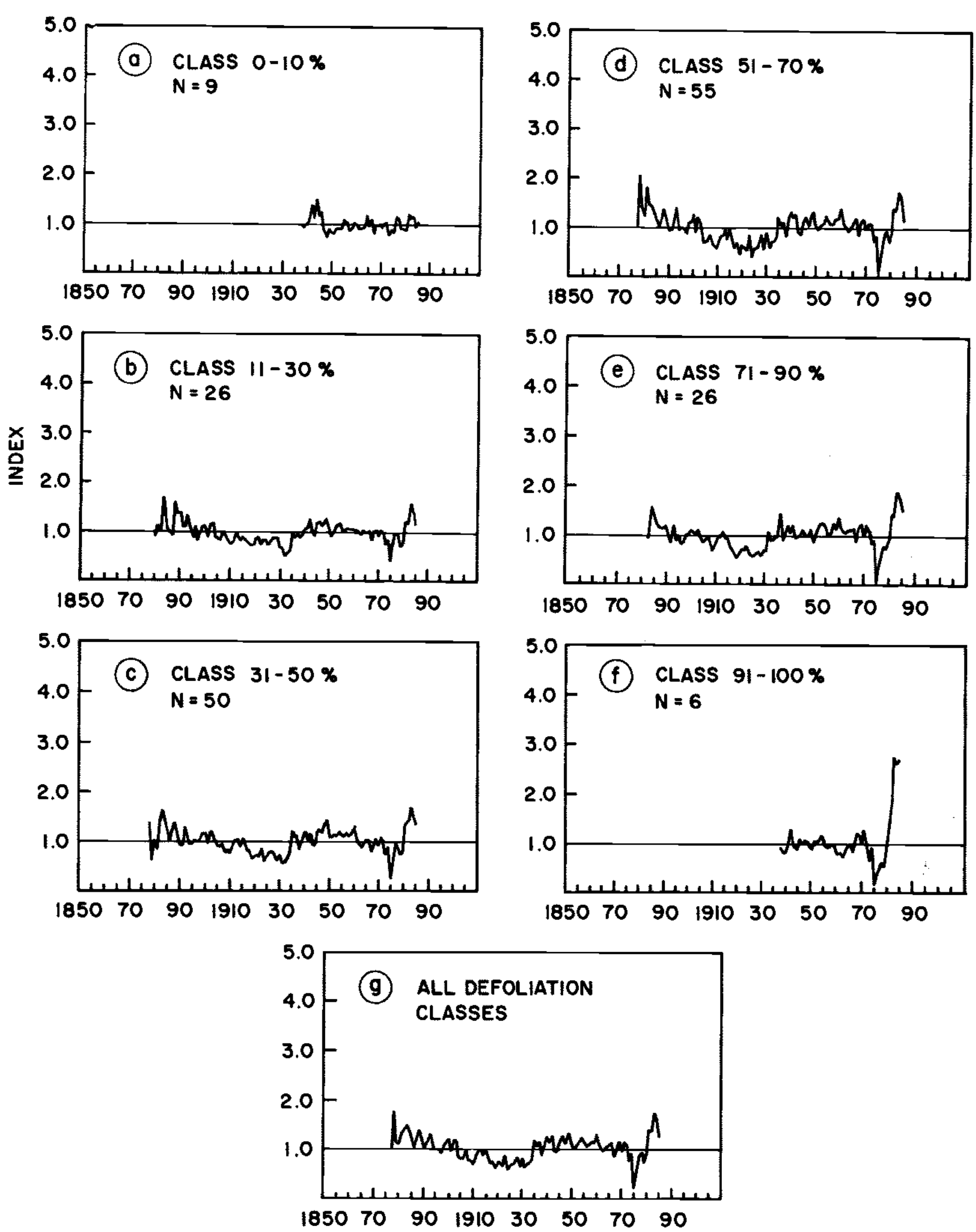


**Figure 3.** Ring index chronologies of Douglas-fir trees defoliated by the western false hemlock looper near Chase, British Columbia. a) to f) average chronologies in trees sorted by defoliation class; g) site chronology, i.e. average ring chronology for all trees in the locality, in all defoliation classes.

Therefore, it is assumed that any growth reduction incurred by the trees is the result of only one feeding season (1974). Tree defoliation averaged 50.6% in 1974 but varied widely from tree to tree in a distribution that approximated the normal (Figure 2). Only two trees remained undefoliated and only one tree sustained 100% defoliation and survived. Tree crowns began to grow new foliage in 1975 and had normal appearance by 1979, five years after defoliation.

The combination of linear and exponential curve fitting produced ring indices that eliminated the growth trend of the tree but displayed the variation induced by the 1974 defoliation. Examination of the chronology for the trees in the 0-10% defoliation class (Figures 3a, 4) showed no marked evidence of defoliation effects, either on the 1974 index or thereafter. Departures of indices in this chronology from the expected index value of one (the long-term trend represented by the fitted curve) were assumed to be caused by random or environmental variation.

The site chronology and the chronologies by defoliation class (Figures 3, 4) clearly showed the effects of increasing levels of defoliation in 1974. Growth declined sharply in 1975; the effect had a lag of one year. The index for year 1975 was progressively reduced with increasing defoliation, from 0.85 among the trees in the 0-10% defoliation class to 0.00 (no growth) among the trees in the 91-100% defoliation class (Figures 3, 4).

After 1975, ring indices began to increase rapidly. The number of years the trees took to reach annual growth rates that were within 10% of the trend was proportionally longer in the higher defoliation classes: trees in the 0-10% class already had an index value above one in 1976; trees in the 11-30% and 31-50% classes took 1 year to reach the annual trend (back to a value of approximately one by 1977); trees in the higher defoliation classes took 5 years to return to that level. After recovery from defoliation, many trees displayed above-normal growth rates. The magnitude of the increase was related to the degree of defoliation; the increase was absent in the trees that sustained 0-10% defoliation and maximum in the trees in the 91-100% defoliation class (Figure 4).

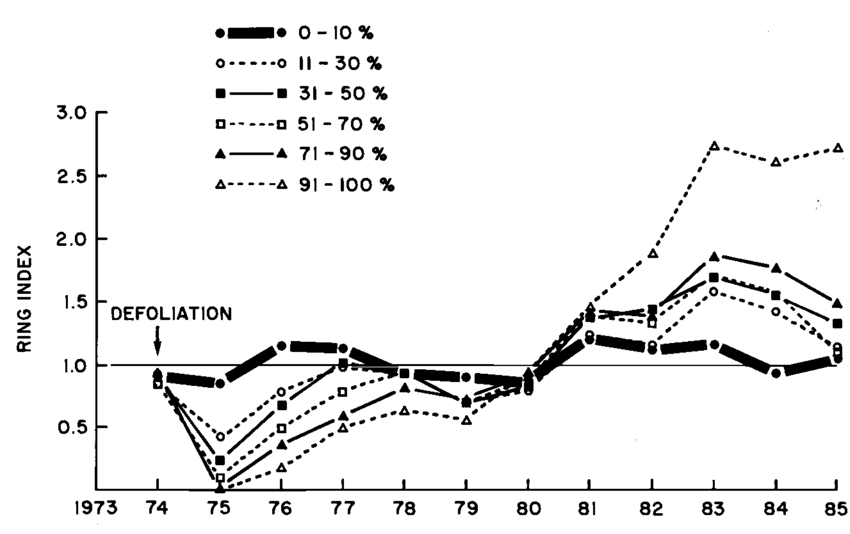


**Figure 4.** Last 12 years of the average annual ring index chronologies of Douglas-fir trees sorted by defoliation class. Defoliation is by the western false hemlock looper. Indices represented by the thicker line are those of the 0-10% defoliation class.

Regression analysis indicated a significant positive correlation of mean tree ring index, index standard deviation, first order autocorrelation and mean sensitivity with degree of tree defoliation (Figure 5, Table 1). All regressions had statistically significant intercept and slope. However, the regression of mean tree index on defoliation was barely significant ($F=5.7$, $P<0.05$), and was probably a consequence of the standardization method used.

Variability in mean tree index was strongly correlated with defoliation as evident from the scattergram of mean index versus defoliation (Figure 5a) and by the highly significant regression between index standard deviation and defoliation ($F=38.4$, $P<0.001$) (Figure). This increase in variability was caused by the severe reduction of the 1975 index and the period of vigorous growth increase that followed severe defoliation. The significant regression between mean tree sensitivity and defoliation ($F=41.1$, $P<0.001$) (Figure) is another indication of the increased index variability with defoliation as this parameter measures the average change in ring index from year to year (Fritts 1976). The significant increase of index autocorrelation with defoliation ($F=27.9$, $P<0.001$) was caused by the period of increasing growth that followed defoliation, which created a consistent and lasting upwards trend in the indices after 1975. This trend lasted for about 8 years (1976-1983).

## DISCUSSION

The pattern of growth decline in Douglas-fir caused by western false hemlock looper was similar to that described by Brubaker (1978) for the impact of the Douglas-fir tussock moth on Douglas-fir ring widths. The impact consisted of a sharp decline followed by a recovery over a number of years (according to Brubaker (1978), a "check mark" pattern). This similarity is to be expected since both insects are very similar in their feeding habits — they feed voraciously and wastefully — and both are able to totally defoliate a tree of its foliage in a single season. This feeding habit causes the sharp decline in growth rates.

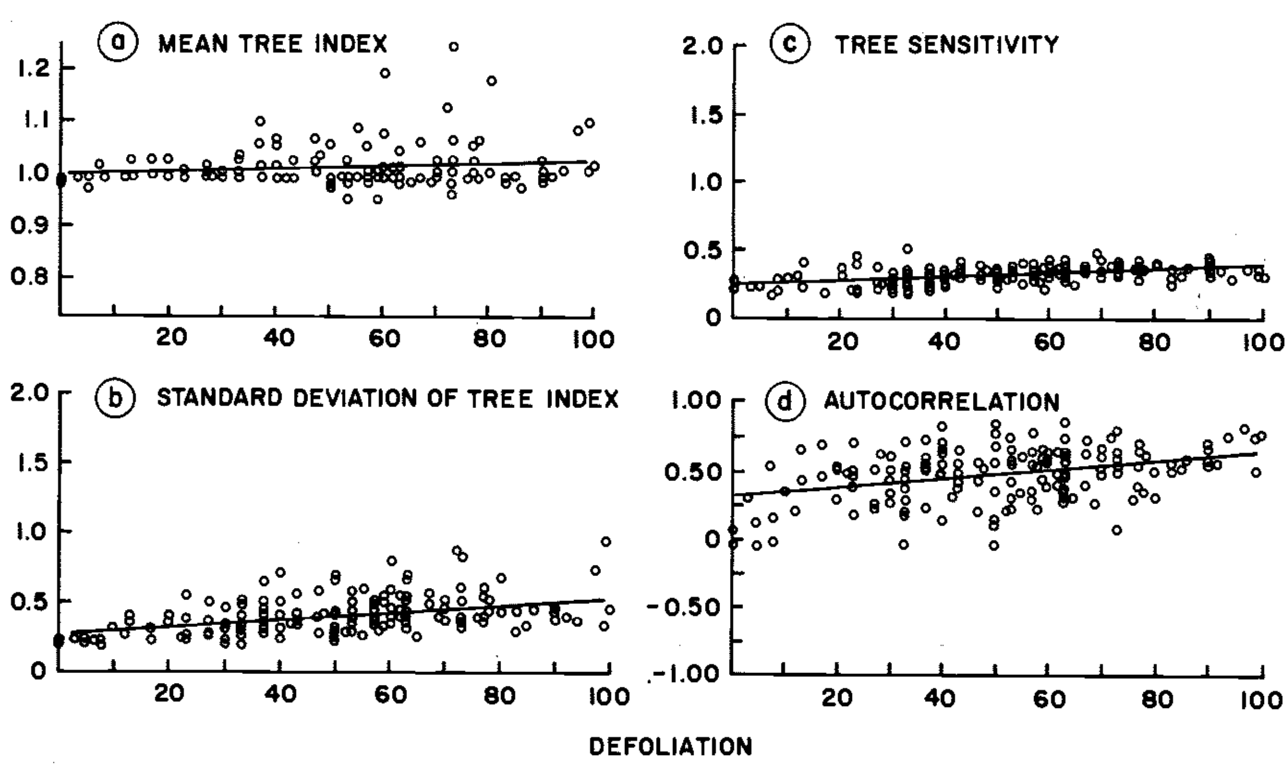


**Figure 5.** Relationship between a) mean tree ring index, b) Ring index standard deviation, c) mean sensitivity, and d) first order autocorrelation versus individual tree defoliation. Data are from 172 Douglas-fir trees defoliated by the western false hemlock looper, near Chase, British Columbia.

**Table 1.** Summary statistics for ring index chronologies for Douglas-fir trees tabulated by degree of defoliation caused by the western false hemlock looper, *Nepytia freemanii.*

| Defoliation class(%) | Trees # | Mean defoliation | Mean index | Index SD | Index autocorr. | Mean sens. |
|---|---|---|---|---|---|---|
| 0-19 | 9 | 5.1 | 1.00 | 0.24 | 0.16 | 0.24 |
| 11-30 | 26 | 23.6 | 1.01 | 0.33 | 0.44 | 0.28 |
| 31-50 | 50 | 41.2 | 1.01 | 0.39 | 0.47 | 0.31 |
| 51-70 | 55 | 60.3 | 1.01 | 0.42 | 0.50 | 0.35 |
| 71-90 | 26 | 80.0 | 1.03 | 0.47 | 0.54 | 0.36 |
| 91-100 | 6 | 96.8 | 1.04 | 0.54 | 0.70 | 0.38 |
| All classes | 172 | 50.6 | 1.01 | 0.40 | 0.48 | 0.32 |

The decline lags 1 year behind the defoliation presumably because the tree has food reserves to complete growth in the year of defoliation. In addition, in this year, the tree is capable of producing some photosynthate in the early part of the season, before total foliage destruction. A normal Douglas-fir tree usually carries foliage grown over the last five or six years. It therefore takes several years for ring width to recover because the tree needs several years to accumulate its full complement of foliage.

Increase in growth rate after defoliation has been reported by Wickman (1980) who found that, after defoliation by the Douglas-fir tussock moth, the growth of white fir, *Abies concolor* Lindl. ex Hildebr., was significantly higher than nondefoliated host trees nearby. This researcher hypothesized that the increased growth was due to a thinning effect caused by within-stand mortality due to defoliation and to increased nutrients in the form of insect frass. In our study, a thinning effect due to tree mortality was not a factor because the two stands had little mortality, and because the increase was absent from the less defoliated trees (0-10% class). A study of the overall productivity of the tree stem (which is now in progress) will indicate whether the observed growth increase at breast height also occurred at other levels. Such a study will also indicate what was the net effect of 1 year of defoliation, after any growth increase is balanced against earlier losses.

Construction of chronologies of past insect infestations (entomochronologies) requires a different sampling approach from that used for climatic chronologies. Trees selected for studies of past climate are collected preferably on "sensitive" sites, i.e., sites where precipitation or some other climatic variable is a limiting factor. Sampling to detect past insect infestations should be conducted based on the known feeding patterns of the insect. Some insects such as the western spruce budworm develop into infestations which extend over extensive areas. Therefore, sampling the known distribution of the insect will likely yield chronologies of past infestations. Other insects, however, are very patchy in their defoliation habits; therefore, sampling in areas where the insect is known to occur will not necessarily reflect the outbreak history for that general locality. This is the case of the western false hemlock looper. Infestations of this insect are highly variable both within and between stands. Therefore, whether increment core sampling will detect past infestations in a stand will depend on the extent of the past infestation in the stand and on its severity.

## ACKNOWLEDGEMENTS

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## RESEARCH REPORT

# A MODEL FOR TREE-RING TIME SERIES TO DETECT REGIONAL GROWTH CHANGES IN YOUNG, EVENAGED FOREST STANDS

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ABSTRACT

Time-related region-wide growth declines or increases due to environmental impacts are not readily detected in rings of young trees because the intrinsic age-related decrease in ring widths is too prominent. Standardization techniques often obscure gradual growth changes due to exogenous factors such as regional atmospheric deposition. The model presented here uses a linear aggregate analysis of ring widths that permits age to be held constant while time varies. Rigorous testing requires tree-ring observations from evenaged stands exhibiting a range of current ages normal for the species and region. With age held constant, the key variable is simply the calendar year to which given rings are dated, a measure of the passage of time. An application of the model is given in which a 36-year growth decline is identified in 20- to 40- year-old *Pinus taeda* L. in the southeastern United States.

## INTRODUCTION

Tree-ring models that establish growth changes related to changes in the environment must always account for the intrinsic effect of ring width decreasing with age due to increasing girth. In old trees this age-related trend has often long stabilized, so that long term chronologies may permit comparison of ring widths between two time periods without serious distortion due to increasing girth. Using "standardization" techniques (Fritts 1976), a calibration period can establish the expected growth trend in older trees and is statistically tested against a measured trend associated with an environmental change, or post-perturbation growth, all recorded in the rings of the same trees (Fritts and Swetnam 1986).

Younger stands of trees, however, may not predate suspected environmental changes, and the age-associated decrease in ring widths is often the most significant growth trend in these short chronologies. Moreover, regional environmental changes, such as non-point source atmospheric deposition, may accumulate gradually over time and may not be detected as date-related events that trigger sudden changes in ring widths of the same trees. A method is needed that holds age constant while time varies, comparing ring widths of equal aged trees at different periods of time. This report suggests a model in which tree rings of a given age in young, evenaged forest stands are tested for the impact of suspected time-related environmental changes on ring width.

## METHODS

The model requires absolutely-dated tree-ring measurements from many forest stands, located randomly throughout the region of interest, exhibiting as broad a range of current ages as normally occurs for the species and stand type. For example, most commercially important forest types in eastern North America, the southern and northern pines, the upland oaks, the cove hardwoods, and the northern hardwoods, occur commonly in evenaged stands currently aged from early regeneration to commercial rotations of 40 to 60 years. Short-term tree-ring chronologies from such stands must obtain replication for statistical testing from a large number of field plots. Cook et al. (1982) suggest that tree-ring studies in young forests typical of eastern North America utilize limited numbers of increment cores from each of a large number of field locations. Each evenaged stand becomes a separate observation for a given stand age.

Because juvenile trees younger than 10 to 15 years may contain a large proportion of reaction wood, sample stands should be sufficiently old to support closed canopies with stabilized dominant and codominant crown classes. This minimum age varies with species, site, and geographic location and can generally be determined from the tree-ring measurements. An adequate number of field plots, each representing a definable evenaged stand on a specific site, might be no more than 50, sampling the full range of age classes that is normal for the forest type and region.

Increment cores are extracted from dominant and codominant trees in each stand, prepared for measurement, crossdated and measured, all by standard techniques (Fritts 1976, Phipps 1985). Ring widths from all cores in each stand are averaged by collating the absolutely-dated ring measurements for all calendar years represented in the series. Stand, site, and climate data (for example, stand basal area, site index, and Palmer drought severity index) are collated for each stand by each calendar year for which there is an average ring-width measurement.

Graybill (1982) and Cook (1986) have presented aggregate models to express the potential components of tree-ring variation. For the short-term chronologies of young evenaged stands, such a model must include a term for calendar year to express the effect of the passage of time. The dependent variable in this aggregate model is RW, representing a ring-width measurement accurately dated to the calendar year t:

$$RW_t = f[Age_t, B_t, C_t, S_t, YR_t, E_t]$$

where:

Age = The age-related growth trend value in year t that is shared by all sampled trees of a given species on a given site.

B = The endogenous growth pulse within the given stand, originating from changes in competition, stand structure, and stocking levels or other forces acting on sampled trees in year t.

C = The climatically-related growth variations common to a stand of trees in year t, including current weather, lagged accumulative preconditioning climate, and the interaction of climate with a given site.

S = Independent site-related growth variation, usually ongoing over the life of the stand, often constant for all t years.

YR = A measure of the independent effect on growth of the passage of time, in year t, unrelated to the age of the stand, originating as an on- going exogenous pulse from outside the stand.

E = The more or less random variations representing growth- influencing factors in year t unique tó each stand and sample trees.

Each component must be identified, measured, and collated with each average annual ring width of each stand. Functions for the various components may take linear or exponential forms, and may interact with one another. This paper will not discuss such procedures, as they are complex and different for each forest type and region of interest. Many previous publications discuss these procedures in detail, presenting methodology for quantifying and testing the many components of tree-ring variation (Fritts 1976, Graybill 1982, Cook 1986, Fox et al. 1986, Fritts and Swetnam 1986, Zahner et al. in press).

In the present model, beginning with the current age of each stand when sampled, a time series for average annual ring widths is established by age classes. Ages are assigned to each ring width for each calendar year back as far as the post-juvenile chronology extends for a given stand. Five years constitute a satisfactory age class interval; thus five-year moving averages are calculated for each stand to establish the ring width trends over calendar years (Figure 1). For example, if stand 2 is 38 years old in 1984 when sampled, it will be represented in the model by average ring widths at four age classes: age 20 in 1966, age 25 in 1971, age 30 in 1976, and age 35 in 1981. In a field sample, if current ages of all stands are well distributed between 15 and 50 years, and the current year is 1988, then

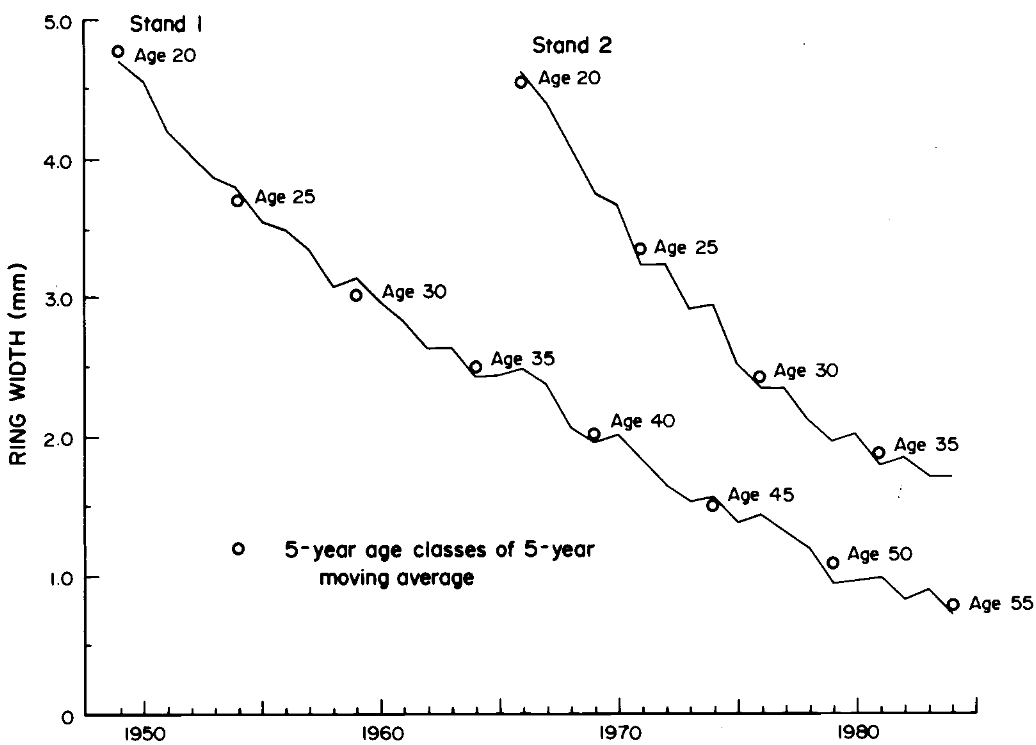


**Figure 1.** Examples of annual 5-year moving averages calculated for ring widths in two stands with chronologies ending in 1984. Ring widths previously adjusted for annual variance due to climate. The plotted age classes are 5-year averages of the annual 5-year moving averages. The age classes establish the ring-width trend that includes both the intrinsic age-related decay curve and any long-term changes in growth related to region-wide environmental impacts.

stands in the 20-year-old class occur dispersed throughout the 30 years from 1959 through 1988. Stands in the 25- and 30-year age classes are dispersed through shorter time periods, 1964-1988 and 1969-1988, respectively.

The independent components $B_t$ and $C_t$ in the aggregate model must also be averaged for those years comprising each 5-year age class. Establishing a relative stand density index is helpful for assigning the endogenous growth pulse by 5-year classes where annual measures are not available for averaging. The normally large variation in tree rings associated with annual weather variation can be reduced first on a year-to-year basis, before averaging ring widths by age classes (Zahner and Grier in press).

Multiple regression is employed as an appropriate technique to fit the field and laboratory data to a time trend (Draper and Smith 1966), such as the following ring-width (RW) model:

$$RW = b_0 + b_1(1/Age) + b_2(B) + b_3(C) + b_4(S) + b_5(YR) \\ + b_6(YR^2) + b_7(Age \times YR) + b_8(B \times YR) + b_9(C \times YR).$$

The independent variables are tested for their contributions to ring-width variance, the non-significant variables eliminated, and the coefficients calculated for significant variables.

The key variable in this model is YR, the effect of the passage of time on ring width variation. If the coefficient for this variable, or any of its interactions, is not significant within any age class, the ring widths have not changed with the passage of time for the data set tested. A data set that has significant coefficients for YR and for any of the other non-interactive variables in the above equation, i.e., $b_1$ through $b_5$, provides a ring-width time series that quantifies lineal growth changes over time.

Figure 2 illustrates two hypothetical possibilities, when both the YR and Age x YR variables are significant, with time series calculated for stands aged 15 years old in each of 1957, 1967, and 1977. These stands are simulated to be aged 25, 35, and 45 years old, respectively, when sampled in 1987. In these examples, the endogenous growth pulse (variable B) is held constant over time within each age class, climate (C) held at the long-term normal, and site (S) held at the average for the region. In example A, lines connecting the corresponding age classes show a ring width decline for stands older than 20 years but not for younger stands. In example B, there is an increase in ring widths for stands younger than 30 years but not for older stands. Many other possibilities exist for combinations of significant coefficients.

## AN APPLICATION OF THE MODEL

In a recent dendroecological analysis of natural stands of loblolly pine (*Pinus taeda* L.) in the Piedmont region of southeastern United States, Zahner et al. (in press) applied this time series model to tree rings from 131 stands between the ages of 25 and 80 years when sampled in 1985. Ring measurements in these young stands provided sufficient data to extend the absolutely-dated chronology back 36 years to 1949. These were USDA Forest Service inventory plots that had been remeasured for endogenous stand conditions four times at 10-year intervals since the early 1950's decade. Six 5-year age classes from 20 to 45 years were established, the endogenous pulse was entered as an index of basal area and number of trees per hectare for each age class in each stand extending back through the 36-year period, climate was modeled from weather data provided from NOAA data files (Zahner and Grier in press), and site quality was obtained from soil and site descriptions of each stand.

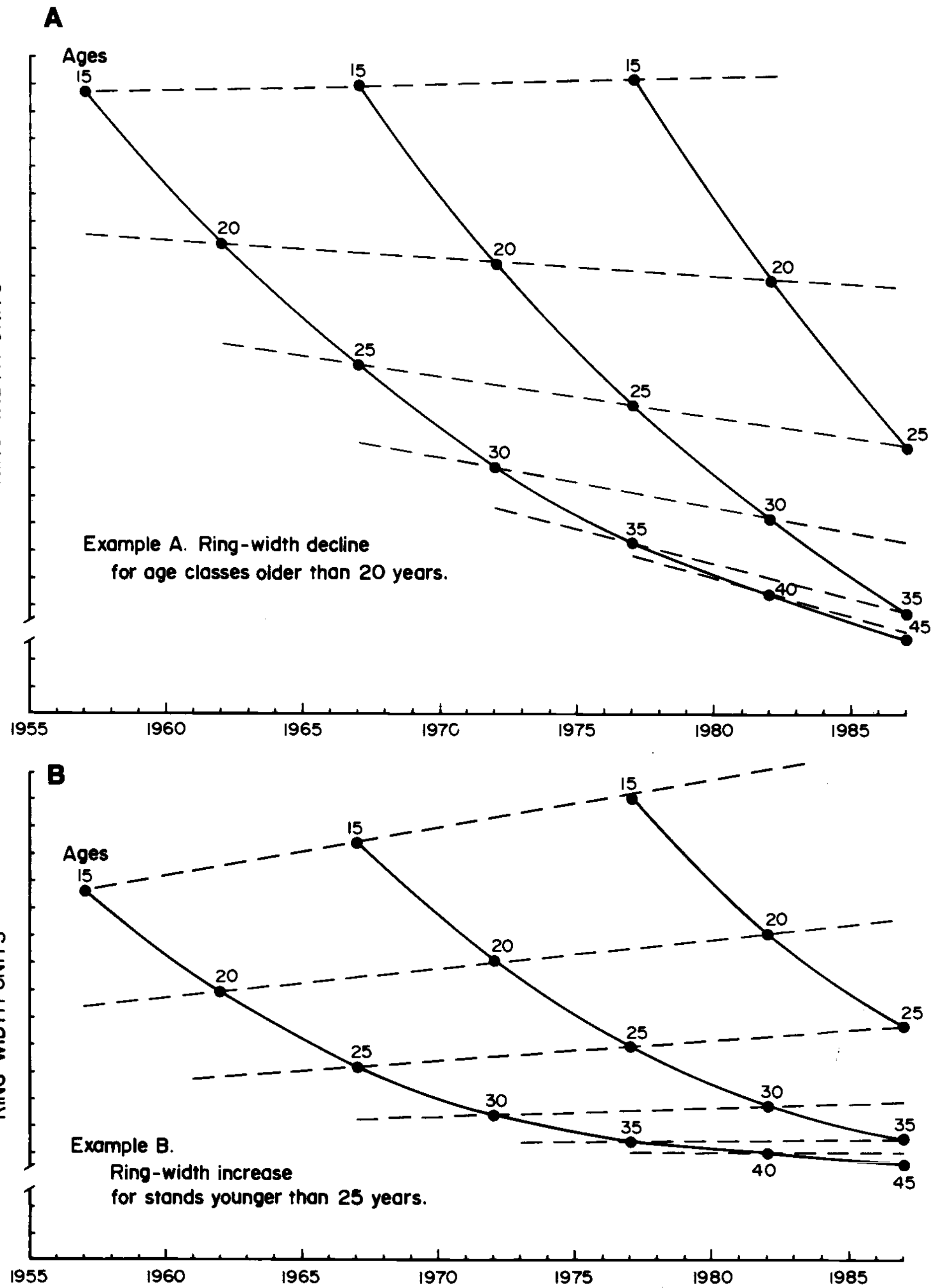


**Figure 2.** Two hypothetical solutions for the ring-width model. Both examples simulate time series for stands aged 15 years old in each of 1957, 1967, and 1977, with chronologies extending to the end of 1987, the assumed sampling date for the observations from which the model is calculated. The YR coefficient is negative in example A and positive in example B; the YR x Age coefficient is negative in both examples.

Tree rings were adjusted for all of the above components to test for the residual effect of the passage of time. For average loblolly pine stand conditions on average Piedmont region sites with trees growing under constant normal climate, the following linear relationship was found highly significant ($R^2$ = .62):

$$\text{Ring width (mm)} = 4.487 + 30.0\ (1/\text{Age}) - 0.0395\ (\text{YR})$$

where:

YR = Calendar year between 1949 and 1984 (i.e., 49-84).

This relationship is illustrated in Figure 3, (above) the time series and (below) the ring-width decline by age classes. The Age x YR variable was not significant in this analysis; therefore, the calculated decline is parallel for all age classes. The linear decrease in ring widths is about 1% per year over the 36-year period for average age stands.

In all such applications the impact of the YR component cannot be quantitatively established if there remains a large variation in ring widths unaccounted for by other factors. Success of the model, therefore, requires for each stand adequate endogenous, site, and climatic relationships over sufficient time spans to match the tree-ring record. Site, once measured, is constant for a given stand. Climate variables, although not measured on site at each stand, are always available regionally in the United States from the National Weather Service and are often available within reasonable distances from individual stands. Endogenous stand data are more difficult to acquire, even for short time spans, for reconstructing the development of young stands to maturity. Continuous or periodic forest inventories can provide such data and are available from government agencies such as the USDA Forest Service or the TVA in the United States, as well as from many industry, military, state, and university forest management offices.

The choice of environmental variables to represent the components of tree-ring variation is extensive and often dependent on the experience and interpretation of the investigator in tree growth-environment relationships. Environmental impact interpretation must be consistent with intrinsic responses of forest types, tree species, and geographic location. Such models must be based on adequate replication to reduce ring width variance attributable to the measurable environment sufficiently to detect growth changes attributable to the unmeasured environment, or the passage of time

## ACKNOWLEDGEMENTS

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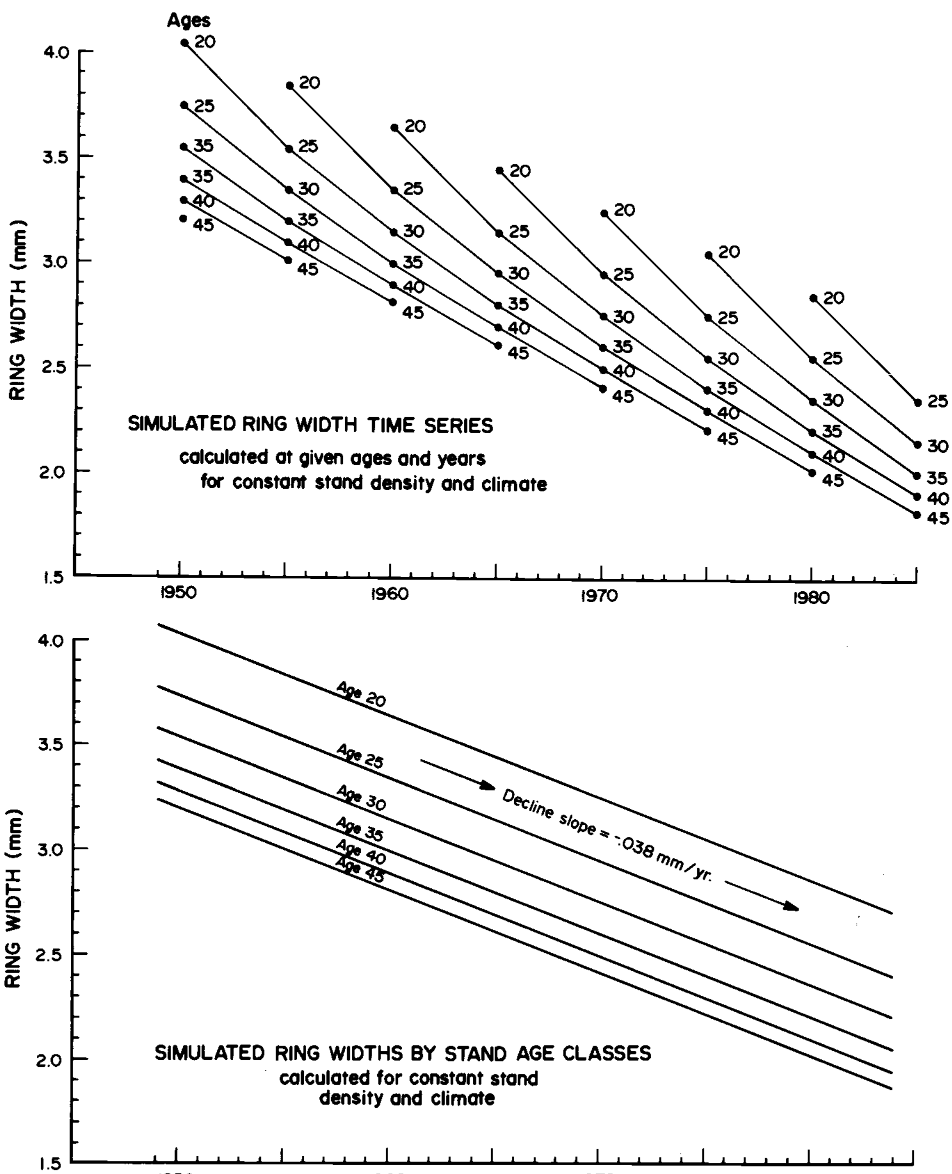


**Figure 3.** Solution for the treering model calculated from 131 loblolly pine stands in the Piedmont region of southeastern United States. (Above) Time series for stands aged 20 years old in each of 1950, 1955, 1960, 1965, 1970, 1975, and 1980, and for stands aged 25, 30, 35, 40, and 45 years old 1950. (Below) The ring-width decline identified from the solution above.

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## RESEARCH REPORT

# DENDROCHRONOLOGICAL RECONNAISSANCE OF THE CONIFERS OF NORTHWEST INDIA

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ABSTRACT

Tree-ring samples were collected from six coniferous species in the western Himalayan ranges during the summer of 1984 in order to evaluate their potential for use in dendroclimatic reconstructions. *Picea*, *Abies*, and *Pinus* spp. had previously been collected for ring widths and densitometric analysis by Hughes and co-workers on relatively mesic subalpine sites near the Vale of Kashmir. Our results support this earlier work in that ring-width series from these habitats are relatively complacent and contain little dendroclimatic information. Density and ring widths are largely temperature-dependent. However, our sampling included *Cedrus deodara* and *Pinus gerardiana* from lower altitudes in the dry inner valleys of the Pir Panjal Range, south of Kashmir. Both species exhibit great age, high mean sensitivity and good intra- and inter-specific crossdating, and yielded chronology statistics suggestive of a drought response. We strongly recommend that they receive high priority in future tree-ring research in northwest India.

## INTRODUCTION

Early botanists and foresters of India were well aware of the formation of annual growth rings in many Indian trees and their broad relationship with climate, and potential application in determination of age, growth rates and for identification of many taxa (Gamble 1982; Chowdury 1934, 1939, 1940a, 1940b and 1964). However, little tree-ring research has been carried out in the subcontinent of India. Modern tree-ring research began only toward the end of the 1970's based on annual ring-width data (Pant 1979, 1983), on stable isotope variations (Ramesh et al. 1985), and both annual ring-width and x-ray densitometric data (Hughes and Davies 1987). The Himalayan region presents the greatest immediate potential for tree-ring research because it contains many conifers with close affinities to species from Europe and North America that are already familiar to western dendrochronologists. Subhumid plant communities are comparable to some of the drier sites of the southwestern United States which have yielded drought-sensitive tree-ring series for climatic reconstruction. High priority must be given to the sampling of drought-sensitive trees from drier sites of the Himalayan region. The use of tree rings as proxy climate indicators would provide data for long-term climatic reconstruction could be applied to the study of climatic variability and, in particular, the behavior of the summer monsoon during the last few hundred years. In 1980 and 1982, M. K. Hughes (then Liverpool Polytechnic, now Laboratory of Tree-Ring

Research) in collaboration with R. Ramash (Physical Research Laboratory, Ahmedabad, India) made exploratory collections in the western Himalaya. Their intensive sampling was conducted at 14 sites in the subalpine forests around the Vale of Kashmir and from sites in Uttar Pradesh Himalaya and Himachal Pradesh. Hughes and Davies (1987) made well replicated site chronologies based on both densitometric properties and ring widths of *Abies pindrow* and *Picea smithiana* from the Vale of Kashmir.

## CLIMATE

The climate of the northwest Himalaya region is diversified due to the great range in elevation and aspect. It varies from dry-hot to subhumid tropical conditions in the southern foothill region to temperate-cold and alpine in the northern and eastern mountains. The highest monthly temperatures generally occur in June over large areas, except in the Kashmir region where they occur during July. After this, temperature generally declines and minimum temperatures are recorded during January. The available temperature records from some meteorological stations of this region show that the minimum January temperatures range from 17°C at Drass in the Ladakh region to 14°C in Jammu (both are in Jammu and Kashmir State) and 1°C in Simla, the capital of Himachal Pradesh. Precipitation occurs both in the form of snow and rain brought by the summer monsoon as well as by the western disturbances. In general the rainfall increases within northwest India because of the orographic effect of the foothills and outer Himalayan ranges. Many sites receive very little precipitation due to the rain shadow effect of the mountain ranges. The rainfall distribution in the region varies from 5 cm at Gilgit, 8 cm in Ladakh, 50 cm in Lahul Spiti, 115 cm in Jammu to over 340 cm in Dharam Shala in Himachal Pradesh. Most of the region receives maximum annual precipitation brought by the summer monsoon (generally from the first week of July to the middle of September). Kashmir, Ladakh, and Lahul Spiti receive precipitation mainly due to western disturbances during December to March.

## TOPOGRAPHY

In the south, this region is veiled from the Punjab plains by the Siwalik hills and to the north by the Great Karakorum Range (Figure 1). Between these two lie, successively, the Lesser Himalaya, Great Himalayan Range, the Zanskar Range and the Ladakh Range of the Tibetan Himalayan. These ranges extend in a northwest-southeast direction and are characterized by rugged terrains, lofty peaks, and deep canyons. The Great Himalaya runs unbroken from about 35°N, 74°E, southeastwards to 28°N, 87°E and then eastward to 25.5°N and 95°E. The peaks of this range often reach above 6000 meters. To the south, the Lesser Himalaya ranges range in height between 2000 m and 4000 m while even farther south, the Siwaliks are not more than 2000 m in height. The Pir Pangal, the largest of the lesser Himalayan ranges, bifurcates from the Greater Himalayan region. The Vale of Kashmir lies between the Pir Panjal and the Greater Himalayan Range. The Zanskar Range occupies the area between Chandra River in the south and the Indus River in the north. The range, with a succession of peaks above 6000 m, extends southeastwards to the great peak of Kamet (7634 m) in the vicinity of Badrinath. The Ladakh Range or the Trans-Himalayan Range situated north of the Zanskar Range and across the Indus River forms the principal geographic feature of Ladakh, which extends from the Nanga Parbat area. The Great Karakorum Range is situated across the river Shyok which forms the northern boundary of the Ladakh and Pangong Ranges. It culminates at the right angle bend of the Shyok

River near the Shyok village. This range includes some of the world's highest peaks (K-2, Sushorbram, Masharbram, SaserKangri) and has some of the world's most extensive nonpolar glaciers (Siachen, Biafo, Baltoro, and Rimo).

## VEGETATION

The northwest Himalaya exhibits greatly diversified vegetation types due to its great diversity in physiography, altitude, climate, and bedrock geology. The region is also affected by increasing anthropogenic activity. The vegetation ranges from alpine, subalpine, to temperate, grading from higher elevations to the subtropical and tropical at lower elevations. The vegetation (especially in terms of local flora) of this region has been studied by many workers. The present brief account on vegetation from our study area is based on information from Champion and Seth (1968).

*The subtropical pine forests* (*Pinus roxburghii*) generally occur up to 1220 m, but at some sites it extends to over 2000 m on exposed, dry south-facing slopes and well drained areas. At some sites the upper limit of these forests merges into *oak-rhododendron* plant communities which extend up to 1500 meters with the increasing availability of moisture on north-facing slopes. *Subtropical forest* merges with *temperate forests* at its upper limit. The distribution of taxa in the temperate forest mainly depends on altitude, aspect and precipitation. The moist temperate forest occurs at some sites at an elevation of about 1500 to 3000 m with rainfall about 1000-2500 mm. Most of this precipitation is brought by the southwest monsoon during July through September. Little is due to northwest disturbances during winter. Minimum temperatures occur in January, ranging from -3 to 2°C whereas maximum temperatures during August is 22 to 31°C. Conifers are the major elements but they are associated with some broad-leaf taxa. They generally prefer northern aspects whereas the broad-leaf vegetation is mainly confined to southern aspects. *Pinus wallichiana*, *Cedrus deodara*, *Taxus baccata*, *Picea smithiana*, *Abies spectabilis*, and *Abies pindrow* are

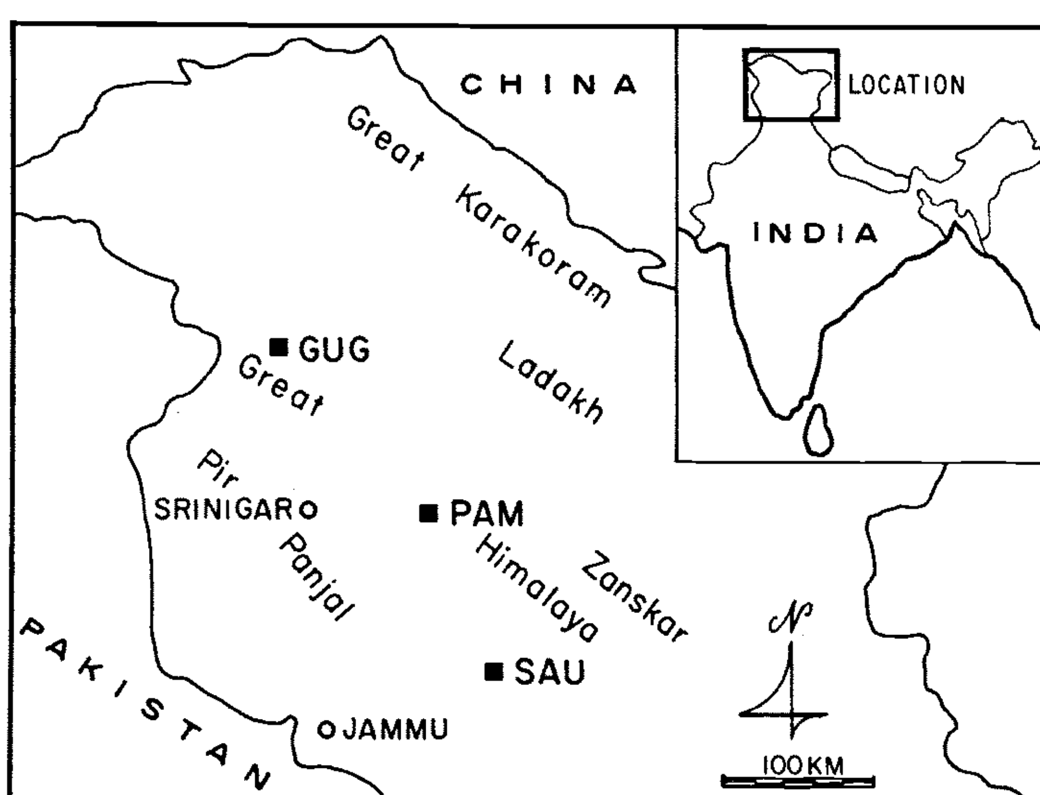


**Figure 1.** Location of tree-ring sites in relation to major mountain ranges, Jammu and Kashmir province, India.

conifer species associated with broad-leaf taxa represented by *Quercus, Rhododendron, Acer, Corylus, Aesculus,* and *Beluta.* Generally *Abies spectabilis, Quercus semecarpifolia,* and *Betula utilis* form the upper limit of this forest. *Dry temperate forest* occurs in the inner ranges, where most of the precipitation comes in the form of snow during winter and the effect of summer monsoon is limited. The mean annual precipitation is generally below 1000 mm. *Pinus gerardiana* and *Cedrus deodara,* with *Quercus ilex* and *Juniperus macropoda,* occur here at lower elevation and *Abies pindrow* with *Pinus wallichiana* grows at the upper elevation.

## STUDY AREA

Our study sites represent three types of forests described above which occur over pronounced mesoclimatic gradients. They comprise subalpine humid conifer forests of *Picea smithiana* at Pahlgam (3402 m) and *Pinus wallichiana* with *Abies pindrow* at Gulmarg (3505 m), both in the vale of Kashmir, to the lower elevation of subhumid mixed temperate conifer forests of *Pinus wallichiana, Abies pindrow, Picea smithiana,* and *Cedrus deodara* at Kistwar (1500 m) and with increasing aridity gradually merges into 'subtropical *Pinus roxburghii* and ultimately to *Pinus gerardiana, Cedrus deodara,* and *Quercus ilex* plant community at Sashu (1800 m) (Figure 2). We emphasised collection of tree cores from *Pinus gerardiana* and *Cedrus deodara* growing in inner dry valleys of the northwest Himalaya. The potential exists for longevity in these trees based on published information. These trees generally attain a great girth (*Pinus gerardiana* 2-4 m and *Cedrus deodara* 9-11 m) with a moderate rate of growth (5 rings/cm). For example, a *Cedrus* tree growing at Kunwar has

**Figure 2.** *Pinus gerardiana* woodland, Sashu site.

**Table 1.** Sample statistics. Values in brackets are considered unreliable because of small sample size.

| Chronology Identification | Number Trees | Number Radii | Period | Analysis of Variance |
|---|---|---|---|---|
| | | | | %Y |
| PAMBC9 | 3 | 6 | 1900-1983 | (8) |
| GUG9 | 6 | 12 | 1880-1983 | 11 |
| SAU9 | 6 | 12 | 1904-1974 | 28 |

Average Cross-Correlation Coefficients

| | Radii Within Trees | Radii Between Trees | Between Tree Means |
|---|---|---|---|
| PAMBC9 | 0.46 | 0.21 | 0.18 |
| GUG9 | 0.50 | 0.14 | 0.19 |
| SAU9 | 0.49 | 0.28 | 0.39 |

900 growth rings and a section of wood kept in the Forest Research Institute at Dehra Dun has 665 annual rings (Gamble 1902). Both *Pinus gerardiana* and *Cedrus deodara* are suitable for preparing long drought sensitive tree-ring chronologies from this region. Cores were collected from 10 trees of which three were *Cedrus deodara* and the rest from *Pinus gerardiana* growing around Sashu. Long cores could not be obtained from three trees of *Pinus gerardiana* due to the presence of heart rot. *Pinus wallichiana, Picea smithiana, Abies pindrow,* and *Cedrus deodara* from Kishtwar, and from the subalpine forests of Gulmarg (*Pinus wallichiana* and *Abies pindrow*) and Pahlgam (*Picea smithiana*) were also sampled for preliminary comparative analysis of tree-ring chronologies from trees growing under diversified habitat (Table 2). In this paper the dendrochronological potential of two species (*Cedrus deodara* and *Pinus gerardiana*) growing in inner valleys of the northwest Himalaya will be discussed at greater length.

## SAMPLING AND DATING

Tree cores analyzed in this study were collected during our visit to India from 30 June to 30 July 1984 in connection with the Indo-USA monsoon research program. The amount of time for field collection was limited by the nature of the trip. However, we were able to obtain at least reconnaissance tree-ring collections from several coniferous species in two contrasting areas in Jammu-Kashmir, including the first collection from *Pinus gerardiana*. This is a first attempt to develop a long chronology from a new species growing under stress conditions. Tree-ring sequences of both *Cedrus deodara* and *Pinus gerardiana* were crossdated through the skeleton plot method (Stokes and Smiley 1968). Crossdating was noticed among all cores of individual species and between these two species. Both species contain some locally missing rings, but double rings are rare. The occurrence of missing rings is more prevalent in *Pinus gerardiana* than *Cedrus deodara.* Some cores collected from *Pinus gerardiana* were impossible to date due to the apparent absence of many rings.

## ANALYSIS

After dating was completed, the ring widths in each dated core were measured to the nearest 0.01 mm using standard procedures followed in the Laboratory of Tree-Ring Research in Tucson, Arizona. The ring-width series of each core was then transformed to indices using the standard program INDEX developed by the Tree-Ring Laboratory (Graybill 1979). Most of the cores were standardized by using negative exponential or straight-line curves. Negative exponential curves were used where visible growth trend was seen in early part of the cores, whereas a horizontal line fitted through the mean of a series was used in the outer parts of *Cedrus deodara* where no visible growth trend is present. After standardization, the indices of each species were averaged for the cores from each tree and then averaged for all trees in the site to make a chronology for the species (Figure 3). We have combined the chronologies from *Cedrus deodara* and *Pinus gerardiana* to make a composite chronology for this site. This was done because the individual sample number for both species was small. The combining of chronologies of these two species was also justified as tree-ring sequences in both species show a good crossdating and also have more or less common chronology statistics. The chronology statistics for both species is shown in Table 3. In the subsequent steps, the analysis of variance and cross correlation analysis were obtained using computer program SUMAC (Graybill 1979) to judge the suitability and potential of average and individual tree-ring indices.

## DISCUSSION AND CONCLUSIONS

In the analysis of variance (Table 1) the observed common variance among all trees considered to be due to climatic signal is about 28% (%Y), the remaining 72% is considered 'noise.' The climatic signal observed in our pine-Himalayan cedar chronology is much lower in comparison to the climatic signal present in trees growing in semiarid sites of western United States which may be due in part to the small sample size. The present pine-cedar chronology from Sashu showed a high climatic signal in comparison to other tree-ring chronologies so far studied from the Indian Subcontinent using tree-ring width data. A cross correlation analysis (Table 1) among tree-ring indices using common period 1904 to 1974 shows that there is a moderate correlation among all trees used in the site chronology. We hope by increasing our sample size it would be possible to enhance correlation among cores and the common climatic signal.

The potential exists to develop long chronologies from both *Cedrus* and *Pinus gerardiana.* In this study, one *Cedrus* tree was dated over 500 years without reaching the pith. We observed many stumps of logged *Cedrus* of about one foot height still *in situ.* These stumps may provide samples to develop a longer chronology from this site. A long chronology from *Pinus gerardiana* can also be made from this site. The trees were dated between 300 to 400 years, despite the presence of butt rot. Our present study shows that a drought sensitive chronology over 500 years could be developed from both *Cedrus deodara* and *Pinus gerardiana* in this region.

Dry temperate or subtropical forests of *Pinus gerardiana* and *Cedrus deodara* in many inner arid valleys of the western Himalaya would be suitable sites to collect samples. Besides

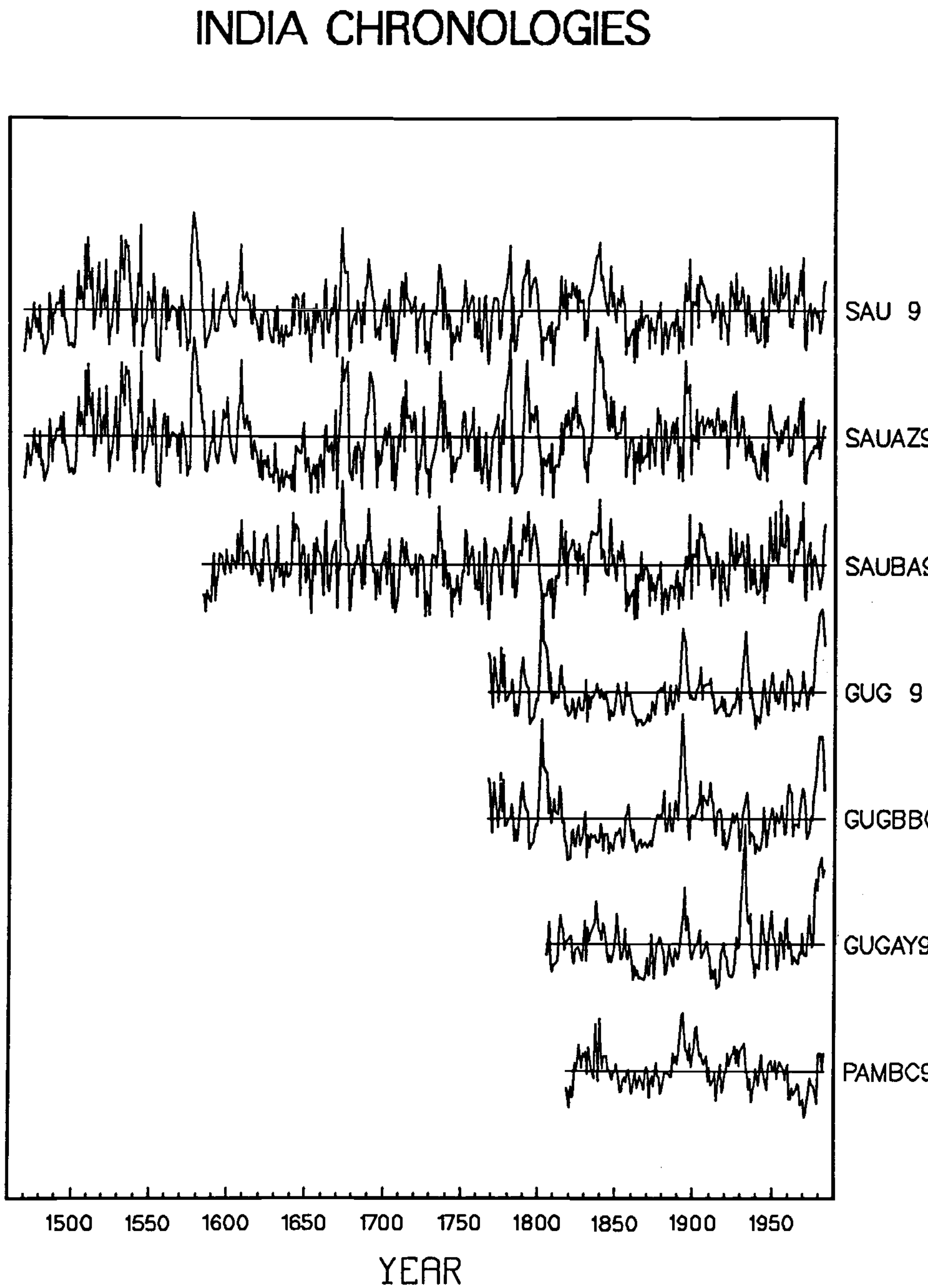


**Figure 3.** Ring-width index chronologies from India; SAU9 is a composite of SAUAZ9 and SAUBA9, GUG9 is a composite of GUGBBO and GUGAY9.

**Table 2.** Site Characteristics

| Location | Species | Altitude (meters) | Latitude | Longitude | Slope (degrees) | Aspect | No. of Trees | Number of Radii | Abbreviation |
|---|---|---|---|---|---|---|---|---|---|
| Pahlgam | *Picea smithiana* | 2620 | 34°42'E | 75°42'N | 3 | N | 3 | 7 | PAM |
| Gulmarg | *Abies pindrow* | 2740 | 35°05'E | 74°18'N | 25 | S | 3 | 8 | GUG |
| | *Pinus wallichiana* | " | " | " | " | " | 4 | 8 | GUG |
| Sashu | *Pinus gerardiana* | 1680 | 33°15'E | 76°10'N | 35 | N | 5 | 16 | SAU |
| (Bagnic) | | to | to | to | to | to | to | | |
| | *Cedrus deodara* | 1800 | 33°20'E | 76°05'N | 40 | NE | 3 | 10 | SAU |

**Table 3.** Chronology Characteristics

| Chronology Identification | Species | Period (A.D.) | Mean Sensitivity | Standard Deviation | First Order Auto correlation | Percent Absent Rings |
|---|---|---|---|---|---|---|
| PAMBC9 | *Picea smithiana* | 1819-1983 | 0.19 | 0.29 | 0.64 | 0.22 |
| GUGAY9 | *Abies pindrow* | 1805-1983 | 0.21 | 0.40 | 0.73 | 0.00 |
| GUGBB0 | *Pinus wallichiana* | 1767-1983 | 0.22 | 0.41 | 0.74 | 0.00 |
| GUG9 | *Abies* plus *Pinus* | 1767-1983 | 0.18 | 0.36 | 0.74 | 0.00 |
| SAUBA9 | *Pinus gerardiana* | 1583-1983 | 0.37 | 0.39 | 0.42 | 2.66 |
| SAUAZ9 | *Cedrus deodar* | 1469-1983 | 0.41 | 0.49 | 0.57 | 0.97 |
| SAU9 | *Pinus* plus *Cedrus* | 1469-1983 | 0.36 | 0.42 | 0.49 | 2.05 |

Sashu and its adjoining region around Kishtwar in Jammu and Kashmir State, this pine-Himalayan cedar plant community also grows in inner valleys of Kinnaur and Panji division of Himachal Pradesh and extends to the adjoining region of Pakistan and Afghanistan. *Pinus roxburghii*, another promising dendroclimatological tree, is also found in this region. It grows in the areas which are comparatively less arid than sites growing with *Pinus gerardiana* and *Cedrus deodara*. Furthermore it occurs in a region where the main source of precipitation is the summer monsoon rather than winter precipitation. The potential of this species for dendroclimatological studies from the Indian subcontinent has already been proved from some sites in the western and central Himalaya. It has clear growth rings that can be easily crossdated, moderate mean sensitivity, a good percentage of common variance among trees and low first order of correlation (Pant 1983). However, the problem of finding old trees in most of the stands decreases the potential for long chronology development. The careful selection of sites, especially from the areas where this tree is growing under stress conditions and exhibits stunted growth and heavy old branches, may provide trees with sufficient age.

All the other conifers we sampled (*Abies Pindrow, Abies spectabilis, Juniperus communis, Picea smithiana, Taxus baccata, Pinus wallichiana*, and also *Cedrus deodara*) at higher elevations in temperate and subalpine forests provide datable annual ring sequences. As different species respond to the seasonal variability of climate in different ways, the growth-climate relationship from these species would be very useful to provide proxy climatic data to reconstruct various aspects of past climatic variability. So far, tree-ring chronologies have been developed from *Abies pindrow, Picea smithiana*, and *Pinus wallichiana* growing around Kashmir Valley (Hughes and Davies 1987, Ramesh et al. 1985) and around Kishtwar in Jammu and Kashmir State. A temperature reconstruction from 1890 to 1980 has been made for the Vale of Kashmir using densitometry and ring widths from *Abies pindrow* (Hughes and Davies 1987). Earlier Ramesh et al. (1985) also found that *Abies pindrow* and *Pinus wallichiana* would be suitable for dendroclimatological analysis using isotopic properties of tree rings. However, most of the tree-ring series are not long enough to make long replicated chronologies from this region.

Our present study consisted of a few trees of Himalayan cedar (*Cedrus deodara*) and Chilgoza pine (*Pinus gerardiana*) growing at Sashu near Kishtwar in Jammu and Kashmir State. It reveals that these trees are suitable for tree-ring analysis which will provide dendroclimatological information in India. They exhibit comparatively higher mean sensitivity, higher common variances among trees, and lower first order autocorrelation than other conifer species so far studied from the Indian subcontinent. However, this could be an artifact of sample size. A preliminary matching between tree-ring indices from these species with historical drought years from India, and mean precipitation from this region shows that low indices match drought years and low precipitation years indicating the potential of this site for reconstruction of past climatic variability.

Climatic reconstructions for the recent past from this region will be significant in developing an understanding of climatic variability in Southeast Asia. The bordering Tibetan Plateau has a great effect on the weather regimes of the Indian subcontinent in different months. It is now known that the Tibetan Plateau with an elevation of about 5 kilometers plays a significant role in changing the pressure gradient which regulates the monsoon climatic regime in Indian subcontinent. Climate oriented tree-ring research for the Tibetan Plateau is also now in progress at the Institute of Geography, Academia Sinica, Peking (Wu Xiangding, personal communication 1986). A large network of tree-ring climatic studies from both regions would help us better understand the variability in summer monsoon as well as precipitation brought by the western disturbances to the vast area of the northwestern part of the Indian subcontinent during winter.


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## RESEARCH REPORT

# THE DEVELOPMENT AND STATE OF DENDROCHRONOLOGY IN THE USSR

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ABSTRACT

The first dendrochronological investigation in the USSR was carried out at the end of the past century. Systematic study of tree rings for the purpose of dating different events and reconstruction of natural conditions began in 1950-1960's. Tree-ring analysis is most intensively used in the studies of forest ecosystem dynamics, timing and frequency assessment of catastrophic phenomena, reconstruction of radiocarbon content in the Earth atmosphere, and dating of historical wood. Much attention is given to the development of long-term prognoses of tree growth and forest environments.

The first dendrochronological investigation in the USSR, which has not been recognized so far, was carried out by Professor Shvedov in 1882 on two trees of black locust (*Robinia pseudoacacia* L.) growing in the streets of Odessa (Shvedov 1892). He discovered that there is a close relation between ring widths and precipitation of the hydrological year (from September to August) and that the narrowest wood layers form in very dry years, which are regularly repeated in three and nine years. On the basis of this periodicity, he predicted a drought for 1891. This prognosis proved to be accurate and Shvedov subsequently published the results of the investigations. He demonstrated the possibility of "dendrometric method" for reconstruction of climatic conditions of the past. Shvedov should be rightfully considered as one of the founders of dendrochronology.

Unfortunately these investigations, which began so successfully, were not continued over a long period of time. Only in the 1930's dendrochronological papers began to be published. These articles were basically methodological (Zaozersky 1934; Tolsky 1936) and only the work by Kostin (1940) was devoted to the reconstruction of droughts in the European part of the Soviet Union. At the same time abstracts of the research of American dendrochronologists (A. Douglass, W. Glock) were published (Jashnov 1925; Krishtofovitsh 1934; Chrgian 1938) and these were valued very highly.

Systematic investigations in the field of dendrochronology began only from the 1950's. Rudakov (1951, 1958, 1961) popularized the dendroclimatological method. In particular, he made popular the moving average method for determination of the age trend and the calculation of growth indices. Some investigations were carried out to discover the effects of climatic factors on tree-ring growth: in the Latvian SSR (Zwiedris and Sacinieks 1960; Zwiedries and Matuzanis 1962), in the Karelian Neck (Dmitrieva 1959), in the Eastern part of the European territory of the USSR (Liseev 1962; Rudakov 1958, 1961), and in the Lithuanian SSR (Bitvinskas 1965). Interesting work on qualitative reconstruction of humidity in the Middle Asia highlands during the last millenium on the basis of the ring-widths study of Turkestan juniper (*Juniperus turkestanica* Kom.) was carried out by Gursky et al. (1953). Tree rings were extensively used by Galazy (1954) for reconstruction of climatic conditions and the upper timberline dynamics in the Zabaikalie and for estimation of the dates of high water levels in Lake Baikal (Galazy 1955, 1967). Kostin (1960, 1963) has studied ring-width variability for the purpose of reconstruction of severe droughts in the last 200-300 years in the steppe zone. Shiyatov (1965) has made a qualitative reconstruction of the thermal conditions in summer months in the Polar Urals.

At the end of the 1950's dendrochronological methods began to be used for dating historical and archaeological monuments and relics. Zamotorin (1959, 1963) carried out relative dating of the Altai-Sajan Barrows. In 1959 the first Dendrochronological Laboratory at the Institute of Archaeology of the USSR Academy of Sciences (Moscow) under the leadership of Professor Kolchin was organized (Kolchin 1963). The Laboratory was engaged in absolute dating of medieval buildings, churches, and paved wood roadways in the northwestern part of the Soviet Union, in Novgorod in particular.

From 1968 until the present, there has been a period of broad application of dendrochronology in the study of variability of various natural and anthropogenic processes and dating of various events. That year the First All-Union Conference on Dendrochronology and Dendroclimatology (in Vilnius) was held and the Dendroclimatochronological Group at the Institute of Botany of the Lithuanian Academy of Sciences (in Kaunas) was organized. In 1976 this Group was reorganized into the Dendroclimatochronological Laboratory and at present this Laboratory is the largest scientific subdivision in the Soviet Union that specializes in dendrochronology (Bitvinskas 1978).

In the Soviet Union during the last two decades, tree-ring analysis has been most intensively used for the study of forest ecosystem dynamics. First of all this is related to the fact that the majority of Soviet dendrochronologists are foresters and they work in Forestry and Ecological Institutes.

The work of Soviet dendrochronologists is based on a form of forest ecosystem dynamics called the cyclic form. Within the cold and temperate zones, annual fluctuations and long-term changes in climatic conditions significantly affect the composition and structure of forest ecosystems. Changes of forest environments caused by climatic variations (moisture and heat supply, droughts, fires, floods, snow avalanches, and other catastrophic phenomena) are the main reasons of the cyclic forest dynamics. The duration and amplitude of processes which are not strictly periodic, but change to some extent, allowing the estimate of the oscillation parameters by statistical methods are called cyclic. Not only short-term fluctuations (daily, seasonal, annual, intrasecular), but long-term and essential ones (secular and oversecular) should be attributed to cyclic forest dynamics, including forest vegetation succession into woodless vegetation and back.

The cyclic processes can be observed in the changes of almost all components of forest ecosystems. Most of all they are expressed in tree growth. There are various length cycles in the dynamics of separate components of forest ecosystems (polycyclicity). But there are usually only a few dominant cycles, which bring about the highest contribution in the variability of the process.

The presence of certain cycles are characteristic of various forest ecosystem components and processes. For example, seed crop dynamics are characterized by short-term cycles, less than 10 years. Forest successions are determined by long-term climatic cycles (secular and oversecular). The cyclic processes are expressed primarily in regions which unfavorable for tree growth (arid and cold regions and sites). The greatest contribution to the study of forest dynamics was made by the following research: Komin (1963, 1970); Bitvinskas (1964, 1974); Kolishchuk (1966, 1979); Shiyatov (1972, 1975, 1986); Gortinsky (1968); Malokvasov (1974); Olenin (1976, 1977); Polyushkin (1979); Mazepa (1986); and Dyrenkov et al. (1987).

Frequently dendrochronology is used for estimation of the effectiveness of various forest measures (melioration, fertilization and so on). The comparison of the growth of trees which are or are not subject to the effects of the studied factors are used most of all (Bitvinskas 1965, 1974; Buzikin 1978; Evdokimov 1979; Pshenichnikova 1987).

In the coniferous boreal and broad-leaf forests of the Soviet Union severe insect outbreaks are often observed. As the result of the full defoliation large massives of forests are dried out. Therefore an important task is estimation of the timing and intensity of insect outbreaks. For reconstruction of outbreaks such indicators as growth of host and non-host species and trees, the width and index of summer wood, dimension and number of cells in the annual rings, and histograms of indices for each calendar year are used (Litvinenko 1972; Vaganov et al. 1972; Isaev and Kiselev 1987; Kucherov 1987).

Several investigations regarding the influence of seed crops on the annual growth of trees have been carried out. The dark-needled trees (*Picea, Abies*) grow at a reduced rate of about 50 percent during the harvest year in comparison with non-seedbearing trees. Reduction of the summer wood percentage in annual rings and a sharp decrease of apical growth were observed (Danilov 1953; Kolishchuk et al. 1975; Voronin 1986).

The influence on the tree growth of such anthropogenic factors as pollution and recreation are studied intensively at present. More frequently comparison of tree growth, which is influenced or not by the examined factor is conducted (Lairand et al. 1979; Lovelius 1979; Laletin 1987; Yuknees 1987; Sabirov 1987). In studies of forest decline, climatic response models have not yet been used.

For estimating pollution effects on forest ecosystems, a determination of chemical elements, especially heavy metals in the annual wood layers, has been determined (Chetverikov 1986; Adamenko et al. 1987). It is interesting that the ratio of potassium in the annual wood layers was determined (Chetverikov 1986).

Soviet dendrochronologists also pay much attention to reconstruction of the timing and frequency of such catastrophic phenomena as snow avalanches, mud slides, land slides, fires, and windthrows (Melechov 1948; Karpenko and Medvedev 1963; Turmanina 1971, 1979; Zabelin 1979; Gorchakovsky and Shiyatov 1985; Nesvetailo 1986; Shiyatov and Uljanov 1987). For dating these phenomena the following indicators are used: evidence of mechanical damages on trees, reaction wood, new vertical shoots, and appearance and determination of when the trees sprouted and died. The greatest contribution to this research was made by scientific workers of the Problem Laboratory of the Geographical Faculty of the Moscow State University (Turmanina 1971, 1972, 1979; Akifieva and Turmanina 1970; Lukjanova and Mjagkov 1979).

Presently intensive investigations dating past forest fires are being carried out in Siberian forests (Furyaev 1987; Valendic and Ivanova 1987; Evdokimenko and Koptsev 1987).

Although dendroclimatic reconstructions are being carried out by many researcher (Glebov and Pogodina 1972; Bitvinskas 1974; Muchamedshin 1974; Bitvinskas and Kairaitis 1975; Lovelius 1979; Borshova 1981; Shiyatov 1986; Adamenko 1986), only simple linear and non-linear regressive models are being used. There are no spatial reconstructions because the network of dendrochronological stations is not yet fully developed in many regions of the USSR.

Dating of historical and archaeological wood is being conducted mainly in the European territory of the Soviet Union (Kolchin and Chernich 1977; Kolischchuk et al. 1984; Brukstus 1986). In the eastern and southern regions, such dating has been performed rarely (Shiyatov 1980; Komin 1980). This is because of the absence of specialists and laboratories in these regions.

In the Soviet Union, research on the problem "Astrophysical Phenomena and Radiocarbon" have been carried out for the past 20 years. The purpose of these researches is the annual reconstruction of the radiocarbon content in the Earth atmosphere on the basis of estimation of its contents in annual wood layers (Dergachev and Kocharov 1981). The Dendroclimatochronological Laboratory (Kaunas), the Ioffe Physico-Technical Institute (Leningrad) and many Radiocarbon Laboratories participate in this research (Bitvinskas 1981). The annual reconstruction of radiocarbon contents for the last 200-300 years has been calculated. The close relation of radiocarbon content in the annual layers of trees growing in various regions of the country has been demonstrated. The relation between solar activity, especially in 11-, 22- and 80-year cycles and radiocarbon content in wood has been suggested (Bitvinskas 1984).

Dendrochronological methods are used for determining the time and place of criminal actions, especially regarding the illegal cutting and selling of timbers (Rosanov 1965, 1968).

Soviet dendrochronologists give much attention to the development of the long-term prognoses of tree growth and forest environments. Such prognoses are of a great importance, especially in regions of insufficient moisture and warmth. Economic effects of prognoses may lead redistribution and more effective utilization of investment, as well as due to the increase of forest productivity and forest protective functions. The polyharmonic models are most frequently used (Komin 1972; Polyushkin 1979; Shiyatov 1986; Mazepa 1986; Kairiukstis and Dubinskaite 1986). They are based on establishment, approximation, and extrapolation of the most important cyclic components in dendrochronological series. To determine the necessary parameters of cycles (length, amplitude and phase), Mazepa (1986) used data of spectral density and narrow-band filtration. The approximation of the cycles was conducted by sinusoids. Usually from 11 to 20 cycles are used in approximation and extrapolation of each chronology. The correlation coefficient between the original and approximated chronologies ranges from 0.5 to 0.8 (Shiyatov and Mazepa 1986).

For prognoses of growth indices, predicted data of solar activity (Bitvinskas 1984) and calculated data of distribution of the maxima atmospheric tides of the Moon and of the Sun (Javorsky 1975) are also used.

In many regions of the Soviet Union, seasonal growth of trees and factors which determine the duration and rate of growth are studied. The microscopic method is used most frequently in studying seasonal growth (Kairiukstis and Yuodvalkis 1970; Lobzhanidze 1975; Kishenko 1978; Goryachev 1987). Presently the most intensive research of seasonal and cell growth are carried out at the Biophysical Institute of the Siberian Division of the USSR Academy of Sciences (Krasnoyarsk). At this Institute, a special device "Ring Structure Measurer" which semiautomatically registers the number and dimension of cells in the annual rings is constructed (Vaganov et al. 1985).

Up to the present, about 370 tree-ring chronologies have been published in the form of indices. From these chronologies, only 115 are from the eastern and southern regions of the USSR (including the Urals). Most of the chronologies have been obtained from coniferous species (*Larix, Pinus, Picea, Abies*), while only about 60 chronologies are from broadleaf-bearing species (mainly from *Quercus*). Very few chronologies have been developed in Siberia, the Far East, Middle Asia, or the Caucasus. The longest published chronologies are the following: for *Juniperus turkestanica* Kom., Middle Asia, 1224 years (Kolchin and Chernich 1977), for *Pinus sylvestris* L., Novgorod, 1200 years (Kolchin and Chernich 1977), for *Larix sibirica* Ldb., Polar Urals, 1010 years (Shiyatov 1986), for *Larix siririca* Ldb., North of Western Siberia, 867 years (Shiyatov 1975), and for *Larix sibirica* Ldb., Altai Mountains, 677 years (M. F. Adamenko 1978).

Dendrochronological investigations in the USSR are coordinated by the Commission for Dendroclimatology of the USSR Academy of Sciences. This Commission sponsors all the All-Union Conferences on problems of dendrochronology and dendroclimatology (1968 - Vilnius, 1972 - Kaunas, 1978 - Archangelsk, 1983 - Irkutsk). On the initiative of the Commission in 1980 the Dendrochronological Bank of the Soviet Union (DBSU) at the Dendroclimatochronological Laboratory and the Lithuanian Forest Research Institute (Kaunas) was organized. With the Commission assistance, three volumes of "Dendroclimatological Scales of the Soviet Union" (1978, 1981, 1984) and the bibliographic reference "Dendroclimatochronology, 1900-1970" (Vilnius 1978) were published.

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# CORRIGENDUM

A number of errors occurred in "Climatic Response of Densitometric Properties in Semiarid Site Tree Rings" by Malcolm K. Cleaveland (*Tree-Ring Bulletin*, Volume 46, pp. 13-29). The most serious of these was the omission of half of each of Figures 3, 4, and 5, making relations between text and figures impossible. The Editor sincerely regrets these omissions and offers Dr. Cleaveland his apologies.

ERRATA;

| | |
|---|---|
| page 13, line 8 - | "anlyzed" and "definest" should read "analyzed" and "defines", respectively. |
| page 13, line 11- | "response" should read "Response". |
| page 20, line 5 - paragraph 2 | "(46.$^{a}$° F)" should read "(46.3° F)". |

Figures 3, 4, and 5 are reprinted in their intended form with the original captions.

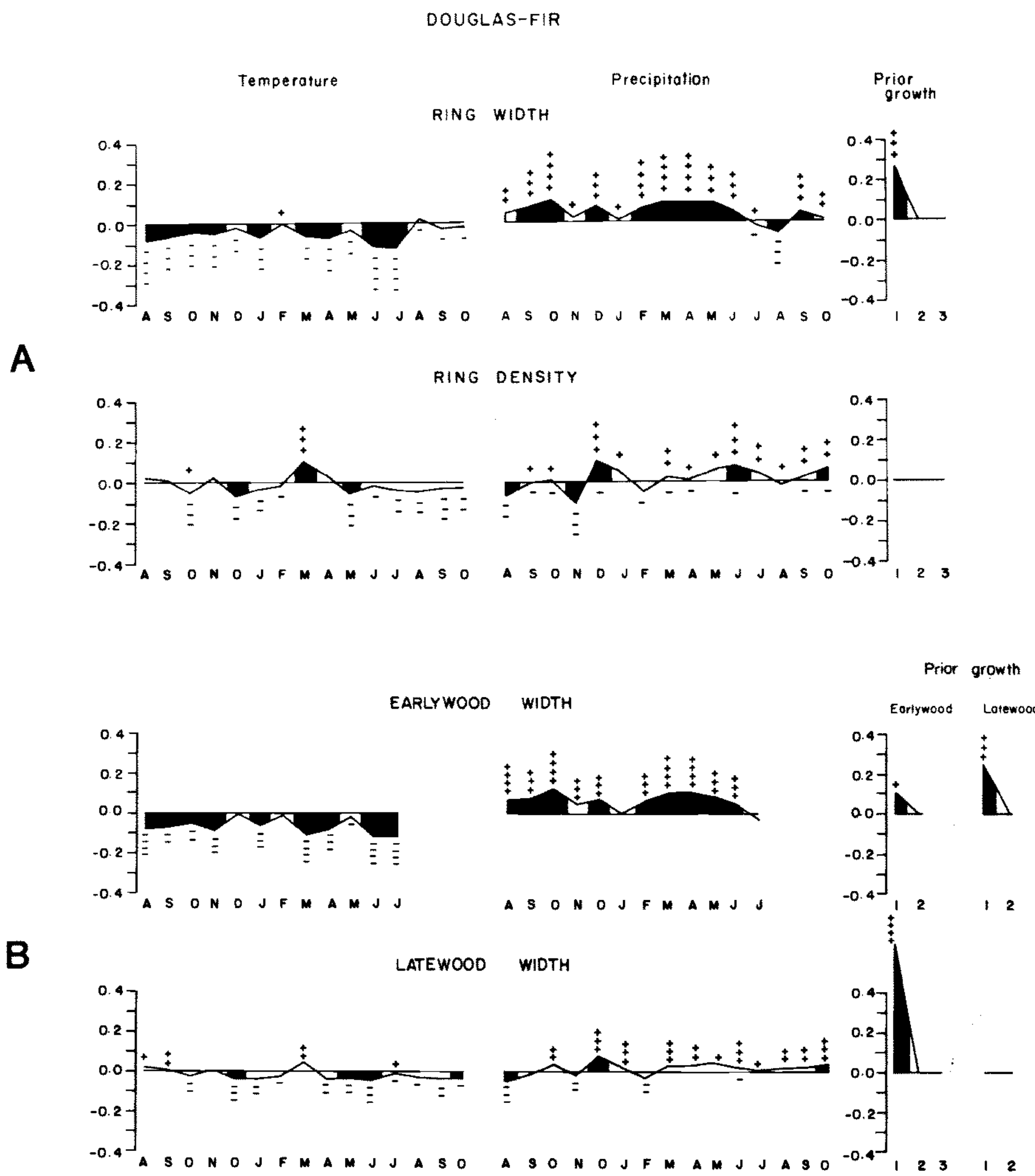


**Figure 3.** Douglas-fir response functions averaged from three collection sites (Spruce Canyon, Pueblito Canyon, Crystal). Separate Pueblito Canyon response functions were computed with north and south regional climatic data. Shaded months and prior growth or density lags are mean weights significantly different from zero at P <.95 level. The signs accompanying the months indicate in how many of the individual response functions the weights are significant or close to significant.

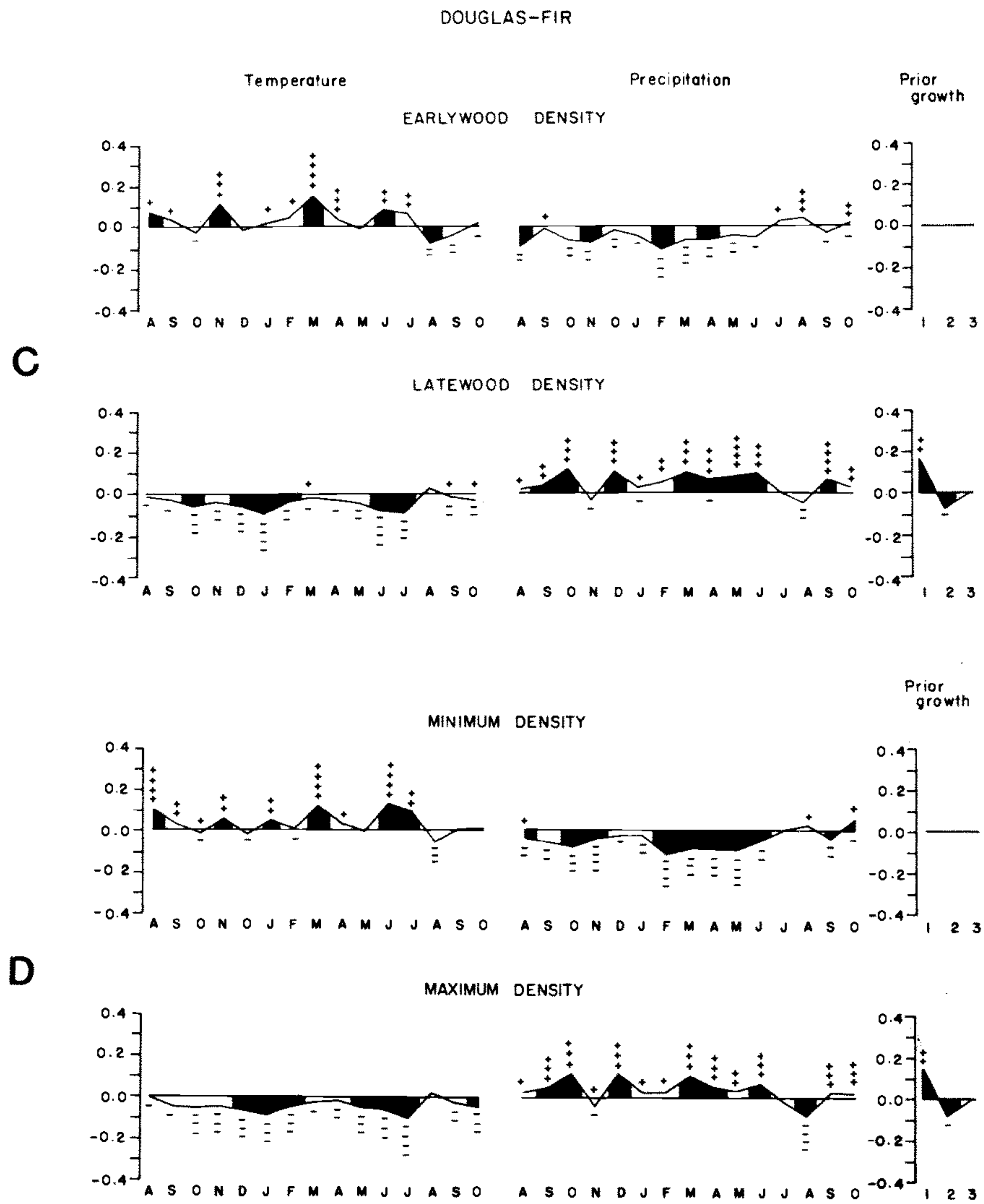


**Figure 3,** continued.

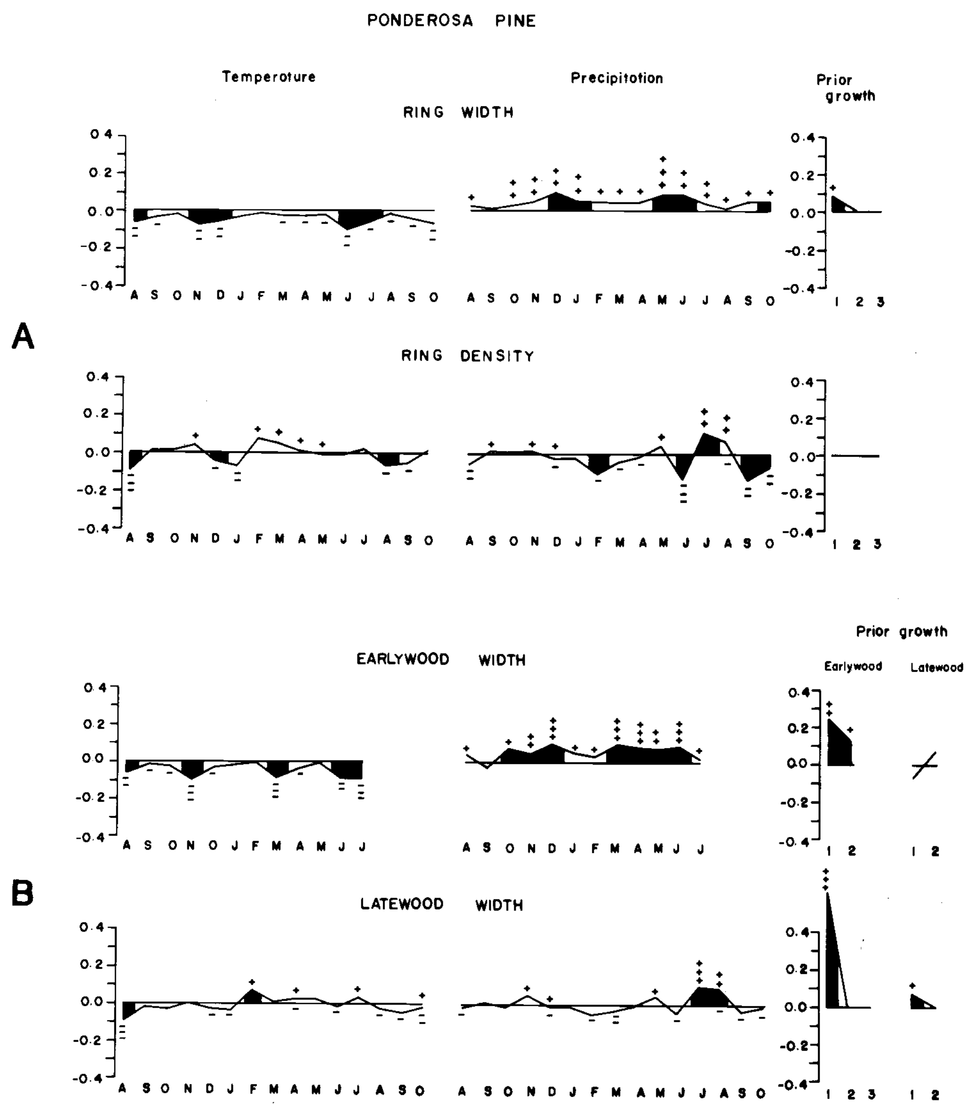


**Figure 4.** Ponderosa pine response functions averaged from two collection sites (Ditch Canyon, Crystal). Separate Ditch Canyon response functions were computed with north and south regional climatic data. Interpretation is the same as in Figure 3.

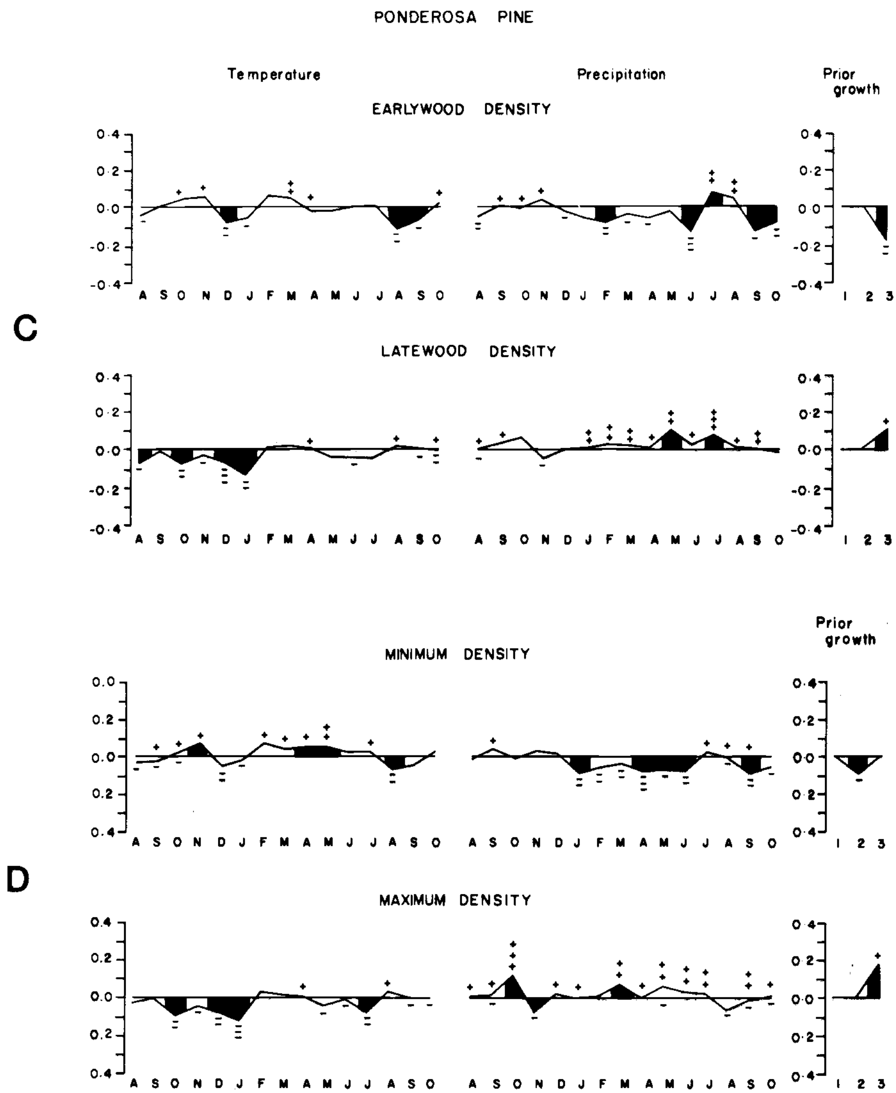


**Figure 4,** continued.

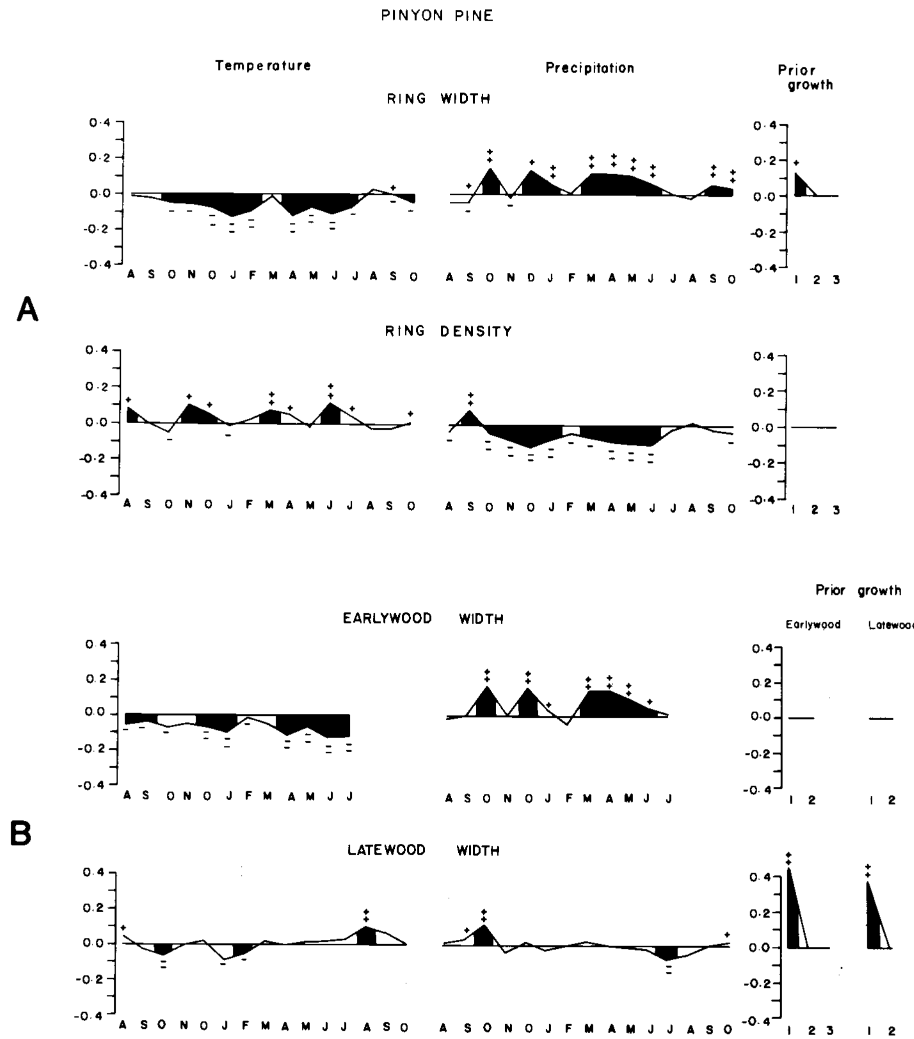


**Figure 5.** Pinyon response functions from Pueblito Canyon. Separate response functions were computed with north and south regional climatic data, then averaged. Interpretation is the same as in Figure 3.

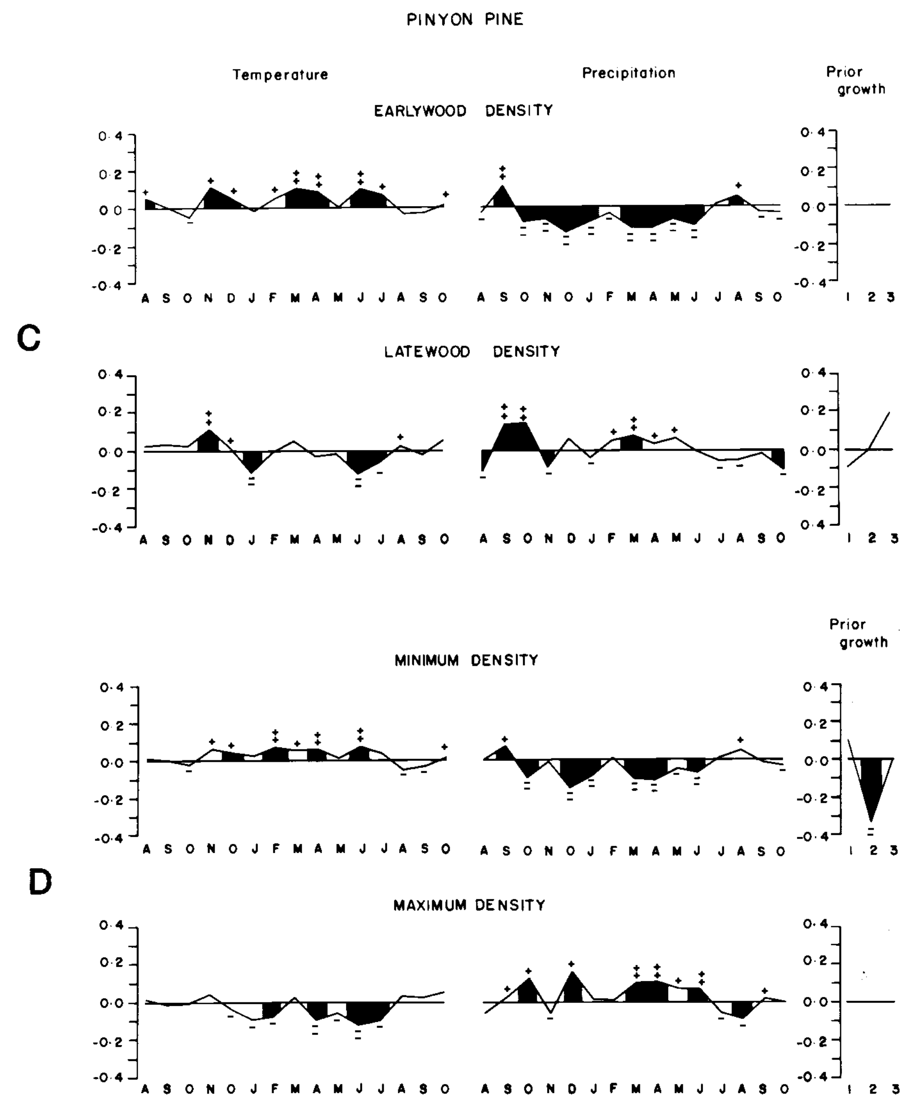


**Figure 5,** continued.

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