TREE-RING GROWTH IN HIGH-ALTITUDE BRISTLECONE PINE

AS RELATED TO METEOROLOGICAL FACTORS

A Research Proposal Submitted To

The National Science Foundation

by

The Laboratory of Tree-Ring Research

of

The University of Arizona

Name and Address of Institution

The Laboratory of Tree-Ring Research,

The University of Arizona, Tucson, Arizona

Title of Proposed Research

Tree-Ring Growth in High-Altitude Bristlecone Pine

as Related to Meteorological Factors

Desired Starting Date of the Research

July 1, 1968

Time Period for Which Support is Requested

Two years

Total Amount Requested

$59,460

Approval

Principal Investigator________________________
Valmore C. LaMarche, Jr.
Research Associate

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Bryant Bannister, Director
Laboratory of Tree-Ring Research

Approved for the
University by________________________
David L. Patrick
Coordinator of Research
The University of Arizona

ABSTRACT

Important climatic information may be contained in long tree-ring records from the upper treeline of mid-latitude mountains. Preliminary work and the results of related research suggest that the variation in annual ring-width series from bristlecone pine (*P. aristata*) at the upper treeline is related to year-to-year differences in the temperature regime, in contrast to the "drought sensitivity" of this species near the lower forest border. Therefore, the establishment of a quantitative relationship between meteorological factors and tree-ring growth at the upper treeline may permit the extension of temperature records, and would provide an additional tool for evaluating certain environmental characteristics of remote, high-mountain regions. Direct comparison of tree-ring chronologies from "drought-sensitive" conifers at the lower forest border with those from "cold-sensitive" trees at the nearby upper treeline might also lead to the separation of precipitation and temperature effects in paleoclimatic reconstruction.

The basic approach involves the empirical comparison of tree-ring chronologies with concurrent meteorological time series in a few areas in the western United States, selected for the proximity of a bristlecone pine treeline to one or more high altitude weather stations. A number of replicated tree-ring samples will be dated, measured, standardized, and evaluated to form the basic tree-ring chronologies. Testing the association between the ring-widths and meteorological factors will proceed through the development of progressively refined empirical models. Consistency with available biological data will serve as a general guide in the development of a meaningful model.

BACKGROUND

The best correlations between tree-ring records and meteorological data have generally been obtained near climatically determined forest limits, such as the arid lower forest border and the sub-Arctic treeline. In these extreme environments, even small departures from the climatic norm may directly or indirectly limit growth processes within a tree. Another important forest boundary is the alpine treeline of the mountains of temperate regions. The climatic information that may be contained in long tree-ring records from this environment is little known, and is the subject of the proposed research.

In arid regions, decreasing precipitation and increasing temperatures cause a rapid drop in soil moisture available for growth at progressively lower altitudes, and thus are major factors in determining the lower limit of distribution of a given tree species (Shreve, 1915). There are changes in tree-ring characteristics that parallel these environmental changes along a gradient from the forest interior to the lower forest border (Fritts, Smith, Cardis, and Budelsky, 1965). Trees closest to their lower limits show the greatest year-to-year differences and the highest common variation in ring widths. Furthermore, their growth records yield the highest correlations with concurrent meteorological records. In this environment, narrow rings are associated with low precipitation and high temperatures.

In the sub-Arctic, the northern forest limits are determined mainly by the length of the warm season and by the daily maximum temperatures, both of which decrease with increasing latitude. Here, as in the arid regions, the trees nearest the forest border are most responsive to year-to-year departures from the climatic norm (Mikola, 1962). However, the meteorological element most strongly influencing tree-ring growth is low temperature rather than low precipitation. At the northern treeline, the mean temperature of the warmest months, or some measure of the heat sum for the warm period, are the only factors significantly correlated with tree-ring growth (Eklund, 1957; Giddings, 1943; Hustich, 1945, 1948; Mikola, 1962).

The possibility of relating ring-widths in trees at the alpine treeline to high altitude meteorological records is suggested by several lines of evidence. The role of temperature in setting the upper altitudinal limits for tree growth has been described (Daubenmire, 1954) as "a major autoecological principle." Of particular significance are the results of physiological experiments involving high-altitude pines (Tranquillini, 1964, 1967; Schulze, Mooney, and Dunn, 1968). These results indicate that the upper treeline marks a critical altitude, above which annual net photosynthesis is insufficient for tree growth because of the short warm season and the low daily maximum temperatures. An important corollary is that at the treeline, successive annual rings would be expected to differ in width as a result of year-to-year differences in the temperature regime. The few studies that have been made, relating high-altitude tree growth to climate, lend support to this conclusion (Artmann, 1948; Brehme, 1951; Leopold, 1953).

BASIS FOR THE PROPOSED STUDY

The subalpine bristlecone pine (*Pinus aristata* Engelm.) was studied in two localities to test the hypothesis that climate strongly influences tree-ring growth in this species at the alpine treeline.

In the Snake Range of eastern Nevada, bristlecone pine grows over a wide altitudinal range and locally defines the treeline (LaMarche and Mooney, 1967). Tree-ring samples were collected from the lower, middle, and extreme upper parts of the bristlecone pine forest. Sampling error was reduced by collecting large replicated samples from each of the three sites. After dating and measurement, established procedures (Fritts, 1963) were used to standardize and statistically analyze the resulting tree-ring series. The results of cross-correlation and analysis-of-variance tests showed that the trees in the two lower altitude samples constitute one homogeneous group. The sample from the upper treeline proved to be quite different. Although the correlation of the annual index series between trees within the treeline group was high, there was little similarity between the treeline chronology (a time series of indices of average annual ring growth) and the chronology for the two lower altitude samples. To learn if these results represented only a local phenomenon, a collection of tree-ring material from the bristlecone pine treeline in the White Mountains, California, was also examined. Comparative data for a number of lower altitude sites were already available for this area (Fritts, *in preparation*). Again, the growth record at treeline proved to have distinctive characteristics that set it apart from the chronology common to the trees on all of the lower altitude sites.

These preliminary results show that there is a major change in the nature of the response of tree-ring growth to meteorological factors between the lower and upper limits of the subalpine bristlecone pine forest. The ring-growth-climatic model for bristlecone pine near the lower forest border is known from studies in two areas (Fritts, 1967). There, the growth response is similar to that of other arid-site conifers. Relatively narrow rings are formed during years of low springtime moisture availability, mainly reflecting low precipitation and high temperatures during the current spring and previous fall. The great differences between concurrent tree-ring series from the lower forest border and the upper treeline in the same area lend strong support to the idea that low temperature may be the dominant factor limiting ring growth at treeline.

Some general considerations suggest that the ring-growth-climatic model at the mid-altitude alpine treeline will incorporate features associated with the arid forest border as well as with the northern treeline. The evidence reviewed earlier indicates a similar strong dependence of growth on favorable temperatures in both the alpine and sub-Arctic environments. However, there may be some important differences. In the sub-Arctic, where daylength changes markedly from winter to summer, a longer winter period of photosynthetic inactivity may occur, while the length of the warm summer days would permit more rapid net photosynthesis in a shorter period of time. Thus the influence of temperature on ring growth at high latitudes is concentrated in a short period immediately prior to and during the first half of the growing season. This is illustrated by Eklund's (1957) results, which showed that the number of days with maximum temperatures over 16° C during the period 15 May to

31 July to be highly correlated with ring growth. Extending the time period considered or increasing the threshold temperature did not significantly improve the correlations. In the temperate latitudes, where seasonal changes in daylength are less extreme, the photosynthetic season may begin earlier and end later than in the sub-Arctic. Coupled with the possibility of high respiration rates on mild winter days--a period of low photosynthetic capacity in the high altitude pines--the effect would be to greatly extend the period during which temperature can affect growth processes.

OBJECTIVES

The main purpose of the proposed research is to quantitatively relate meteorological factors to tree-ring growth near the mid-latitude treeline. A second goal is to test the feasibility of extending meteorological records in time, using high-altitude tree-ring records.

POTENTIAL SIGNIFICANCE

Even in many developed countries, high altitude meteorological stations are scattered, and the available records are often short. Tree-ring data may be very useful in comparing a brief period of meteorological record with the long-term climatic norm for that locality (Gatewood et al, 1964; Stockton and Fritts, 1968). This approach can also be extended to the study of regional temperature patterns over long periods of time.

Study of plant communities in an area having no instrumental records may permit only general statements regarding the probable range of values of important climatic elements (Major, 1967). Under certain conditions, tree-ring characteristics can provide the basis for more precise evaluation of the environment. Furthermore, tree-ring series may contain information on the variation of conditions through time as well as through space.

Preliminary study indicates that temperature controls tree-ring growth at the mid-latitude upper treeline, and that ring-width series from upper forest-border trees can make important contributions to paleoclimatic analysis. High altitude ring-width series which are directly related to temperature could be combined with lower forest-border series which are directly related to precipitation and inversely related to temperature. The result would be a third series related to precipitation alone.

The great length of the tree-ring records available for certain subalpine species adds greatly to the potential usefulness of a new tree growth-climatic relationship, as proposed here. Historically, tree-ring studies in the western United States involved conifers of the woodland and montane forest zones. Interest in higher altitude species has developed since the 1950's, when Edmund Schulman discovered that certain subalpine conifers, notably the bristlecone pine and limber pine (*Pinus flexilis* James) can provide annual ring series thousands of years long (Schulman, 1956; Schulman and Ferguson, 1956). C. W. Ferguson, who has continued the bristlecone pine work at the Laboratory of Tree-Ring Research since Schulman's death in 1958, has been highly successful in locating very old "drought-sensitive" trees near the lower border of the subalpine forest in the White Mountains of California. The bristlecone pine chronology in this area is now more than 7000 years in length. The use of overlapping series from long-dead trees, stumps, and logs has greatly extended the record available from living trees, few of which attain ages of more than 4000 years (Ferguson, Huber, and Suess, 1966). Although maximum ages of living trees appear to be somewhat lower near the treeline (LaMarche, *in preparation*), ages of over 2000 years are not uncommon there. Furthermore, abundant remains of long-dead trees are available at and above the present treeline in at least two localities (LaMarche and Mooney, 1967), which will permit the construction of very long treeline chronologies paralleling those already developed for lower forest border sites.

PROCEDURE

The basic approach involves the empirical comparison of tree-ring chronologies with meteorological time series in a few selected localities. The bristlecone pine treeline in the White Mountains of California will receive the main emphasis because nearby high-altitude weather records are available (Pace, 1963) and the climatic model for ring-growth in low altitude bristlecone pine is already known (Fritts, 1967). Another principal site will be selected near the extreme eastern limits of the 6-state range of the bristlecone pine (Critchfield and Little, 1966). A suitable combination of high-altitude weather records and nearby stands of bristlecone pine at treeline may be found in the Mt. Evans or Pikes Peak areas of Colorado. The basic model--quantitatively relating annual tree-ring growth to current and antecedent meteorological conditions--will be independently derived in each of the two areas. The great contrast in mean annual precipitation between these areas will greatly aid in the evaluation of soil moisture as a growth factor at upper treeline.

Inadequate moisture for growth processes is likely to be a limiting factor more frequently in the arid western Great Basin than in the Colorado Rockies.

Some aspects of the resulting relationship can then be tested in other treeline areas using longer, but lower altitude, weather records. Survey sampling of bristlecone pine near treeline in several high mountain ranges in the western United States is planned. The Sangre de Cristo range of southern Colorado or northern New Mexico, the Snake Range of eastern Nevada, and the San Francisco Peaks of northern Arizona have been tentatively selected for this aspect of the proposed study.

Increment cores from at least two radii on each of at least 10 trees from each of several sites will provide the basic tree-ring data for an area. Sampling of trees from a variety of local microenvironments and ranging widely in ages will permit the selection of tree-ring series containing the maximum amount of climatic information.

After cross-identification and dating of the annual rings in each sample (Bannister, 1963) the ring widths will be measured. Then, computer processing will convert the resulting ring-width series to time-stationary series of growth indices (Fritts, 1963). Digital filtering of each index series, followed by cross-correlation, will then be used to evaluate the record from each core sample, each tree, and each site, for possible non-climatic trends (due to the affects of suppression, release, fires, etc. [Julian and Fritts, 1967]). Selected series will then be combined to form one or more tree-ring chronologies for each treeline area, for comparison with meteorological records.

Testing the association between tree-ring widths and meteorological factors in the two principal study areas will proceed through the development of progressively refined empirical models. First, a preliminary screening of mean monthly temperature and precipitation data in relation to tree-ring indices will be performed. Appropriate statistical and stochastic procedures include stepwise linear multiple regression (Fritts, 1962), probability analysis of joint occurrences (Stockton and Fritts, 1968) and principal component analysis (Mitchell, 1967). The results should indicate the relative importance of heat and moisture availability as factors in tree-ring growth in the treeline environment, and any broad changes in their importance from season to season. If indicated by the preliminary results, the next step would be the division of the daily meteorological data for the calendar year into what appear to be the most biologically meaningful periods. Studies elsewhere (Primault, 1953; Eklund, 1957) indicate that this can improve tree ring-climatic correlations.

Another refinement in the model would be achieved by testing the significance of meteorological variables other than, or in addition to, the simple mean values for temperature and precipitation. For example, during a period (such as early summer) in which a significant positive correlation between the tree-growth and mean temperatures might be established, expression of the temperature regime in terms of number of days with a maximum above a certain threshold temperature, or the calculated degree-hours for the period, could yield even better relationships. The results of growth studies (Fritts, _in preparation_) and physiological experiments (Tranquillini, 1964; Mooney, West, and Brayton, 1966; Wright and Mooney, 1965; Schulze, Mooney, and Dunn, 1968) involving high-altitude pines will serve as a general guide to the development of an empirical model that is consistent with known biological relationships.

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FACILITIES

The Laboratory of Tree-Ring Research is a leading center in the field of dendroclimatology. Two semi-automatic measuring instruments and a large computer library facilitate rapid handling and analysis of large numbers of tree-ring specimens. The data processing and programming section, supported by all grants, is available for the development of the new programs required for the proposed study. A new CDC 6400 computing facility, now in operation, will increase capacity and speed of operation.

PERSONNEL

Principal Investigator: Valmore C. LaMarche, Jr., Research Associate, Laboratory of Tree-Ring Research (see Appendix).

Advisory Associate: Harold C. Fritts, Associate Professor of Dendrochronology, Laboratory of Tree-Ring Research.

The study will be carried out with the full participation of the principal investigator. The field exploration and sampling will be performed jointly with the graduate research associate. The graduate research associate aided by the research assistant will have primary responsibility for dating and measurement of the sample collections. The principal investigator will supervise this work, and will direct the project activities of the programming and data processing section.

CURRENT SUPPORT AND PENDING APPLICATIONS

Valmore C. LaMarche, Jr., is currently carrying out research under the terms of NASA Grant NGR 03-002-101, "An Evaluation of Possible Relationships Between Solar Activities and Tree-Ring Growth in Western North America." This investigation will be completed by June 30, 1968. He is also listed as Principal Investigator (on the basis of one-half time for the calendar year) on another proposal, entitled "History of the Bristlecone Pine Treeline," which is now being reviewed for possible submission to the U. S. Atomic Energy Commission.

OTHER SPONSORS

This proposal is being submitted simultaneously to the National Science Foundation and to the Army Research Office, Durham.

SCHEDULE

The proposed study should be completed within 2 years of the starting date. The outline of activities is as follows:

July 1-Aug. 10, 1968 - Organization and personnel recruitment.

Aug. 10-Sept. 10, 1968 - Tree-ring sample collection in White Mountains, California.

Sept. 10, 1968-June 15, 1969 - Sample processing and evaluation, preparation of meteorological data, development of tree-ring climatic model for White Mountains area, preparation for following summer's field work.

June 15-Aug. 15, 1969 - Sample collection in other treeline areas in Arizona, Colorado, New Mexico, and Nevada.

Aug. 15, 1969-Jan. 1, 1970 - Sample processing, evaluation, development of model for Colorado Rockies; test of tree-ring climatic association in other areas.

Jan. 1-June 30, 1970 - Data synthesis, final analysis, and manuscript preparation.

BUDGET

Proposed Budget for the Period July 1, 1968 to June 30, 1970.

	1968-69	Agency Request	University Contribution	Project Cost
A.	Salaries and Wages			
	Valmore C. LaMarche, Jr. Principal Investigator 1/2 time, fiscal year	5500	1000	6500
	Graduate Research Associate 1/2 time, fiscal year	2800	--	2800
	Additional 1/2 time, 3 summer months	700	--	700
	Graduate Research Assistant 1/2 time, fiscal year	2400	--	2400
	Computer Programmer 1/4 time, fiscal year	2100	--	2100
	Data Processor 1/4 time, fiscal year	1250	--	1250
	Part-time Student Help 400 hours @ $1.40/hour	560	--	560
	Total Salaries and Wages	15,310	1,000	16,310
B.	Indirect Costs			
	42.02% of Salaries and Wages	6433	420	6853
C.	Payroll Taxes and Insurance			
	9% of Salaries and Wages	1378	90	1468
D.	Equipment	--	--	--
E.	Materials and Operating Expenses			
	Photographic supplies	100	--	100

1968-69	Agency Request	University Contribution	Project Cost
Increment borers and replacement bits	300	--	300
Miscellaneous supplies (sanding belts, razor blades, etc.)	200	--	200
Office supplies, data processing forms, IBM cards	300	--	300
Operating expenses	200	--	200
Total Materials and Operating Expenses	1,100	--	1,100
F. Technical Services			
Computer time (4 hrs. @ $450/hr.)	1800	--	1800
Programming Consultant	300	--	300
Total Technical Services	2,100	--	2,100
G. Travel			
Field Investigations			
Subsistence	1350	--	1350
Transportation	750	--	750
Total Travel	2,100	--	2,100
H. Publication Cost	--	--	--
GRAND TOTAL, 1968-1969	28,421	1,510	29,931

BUDGET

1969-70	Agency Request	University Contribution	Project Cost
A. Salaries and Wages			
Valmore C. LaMarche, Jr. Principal Investigator 1/2 time, fiscal year	5500	1250	6750

1969-70	Agency Request	University Contribution	Project Cost
Graduate Research Associate 1/2 time, fiscal year	2940	--	2940
Additional 1/2 time, 3 summer months	735	--	735
Graduate Research Assistant	2520	--	2520
Computer Programmer, 1/4 time, fiscal year	2205	--	2205
Data Processor, 1/4 time, fiscal year	1325	--	1325
Part-time Student Help 400 hours @ $1.40/hour	560	--	560
Total Salaries and Wages	15,785	1,250	17,035
B. Indirect Costs			
42.02% of Salaries and Wages	6633	525	7158
C. Payroll Taxes and Insurance			
9% of Salaries and Wages	1421	113	1534
D. Equipment	--	--	--
E. Materials and Operating Expenses			
Photographic supplies	150	--	150
Miscellaneous supplies	200	--	200
Office supplies, data processing forms, IBM cards	400	--	400
Operating expenses	250	--	250
Total materials and Operating Expenses	1,000	--	1,000

1969-70	Agency Request	University Contribution	Project Cost
F. Technical Services			
Computer time (5 hrs. @ $450/hr.)	2250	--	2250
G. Travel			
Field Investigations			
Subsistence	1800	--	1800
Transportation	1350	--	1350
Scientific Meetings	400	--	400
Total Travel	3,550	--	3,550
H. Publication Cost	400	--	400
GRAND TOTAL, 1969-1970	31,039	1,888	32,927

SUMMARY OF TOTAL PROJECT COST

	Agency Request	University Contribution	Project Cost
1968-1969	$ 28,421	$ 1,510	$ 29,931
1969-1970	31,039	1,888	32,927
Total Requested Support	59,460	3,398	62,858

Comments:

1. Salaries. The proposed salary schedules for the Research Associate and Research Assistant have been determined on the basis of project responsibilities and on the necessary experience and ability levels. Annual increments are subject to review following the first year and may be modified consistent with University of Arizona policy.

2. Travel. The Principal Investigator and the Graduate Research Associate will make several trips to the various mountain areas to collect tree-ring specimens in the late summer of 1968 and during the summer of 1969. It is expected that the Principal Investigator will present the research results at one or more scientific meetings near the end of the investigation.

APPENDIX

Biography and Bibliography of Principal Investigator.

Biography

Born in Hurley, Wisconsin, August 27, 1937. Graduated from Springfield High School, Springfield, Oregon, in 1955. Received B.S. degree in Geology from the University of California, Berkeley, in 1960. Attended Harvard University from 1960 to 1964, receiving M.A. and Ph.D. degrees in Geology in 1962 and 1964, respectively.

Experience includes over 5 years as Research Project Chief with the U. S. Geological Survey, Water Resources Division, in Cambridge, Massachusetts, and Menlo Park, California, 1962-1967; Research Associate, Laboratory of Tree-Ring Research, 1967-. Professional Societies are A.A.A.S., Geological Society of America, and Sigma Xi.

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