The Role of Dendrochronology in Natural Resource Management

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Abstract.—The discipline of dendrochronology, that is, development and use of time series of annual growth rings of trees, is a set of techniques by which the annual growth layers of trees may be assigned to definite calendar years. The history of changes in the trees' environment may be reconstructed using various properties of tree rings. In this paper we will discuss how tree- ring measurement series can be used to reconstruct past river flow, precipitation, and forest fires over time spans of several centuries and occasionally over millennia. With an understanding of these variables, land and water resource managers will be able to reduce the risk of failure in planning.

Introduction

Dendrochronology is a name derived from the Greek words for "tree" and "knowing the time." Dendrochronology is a highly specialized field by which the annual growth layers of trees may be assigned to the specific years of their formation. Dendrochronology can be used in a broad array of applications, such as dendroclimatology (Fritts, 1976; D'Arrigo et al, 1996; Touchan et al, 1999; Hughes et al, 1994, Hughes et al, 1999), dendrohydrology (Stockton and Jacoby, 1976; Smith and Stockton, 1982; Meko and Graybill, 1995), forest ecology (Fritts and Swetnam, 1989; Touchan et al, 1996; Swetnam and Baisan, 1996), and many other applications. In this paper we will discuss three applications of dendrochronology, focusing on reconstructions of Colorado River flow in the Southwestern United States (dendrohydrology), precipitation of southern Jordan in the Near East (dendroclimatology), and forest fires in northern New Mexico (dendroecology). The results of these studies should be employed as guidance and direction to mitigate the risks in managing water and other natural resources on a sustainable basis.

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Applications of Dendrochronology

Dendrohydrology: Streamflow Levels in the Upper Colorado River Basin

In the past, it has been unusual for studies and management plans of water and other natural resources to use tree rings as a tool for reconstructing long-term means and variability in precipitation and streamflow. One of the most outstanding examples of a problem where the lack of historical information caused severe water resource overallocation is the case of the Colorado River Water Compact in the Southwestern United States. Around 1922, when tree-ring studies were limited, planners for the Colorado River Basin met to agree on the distribution of rights to the water coming down the Colorado River. The 2,667-kilometer river flows through some of the most arid lands in North America, including parts of seven states in the U.S. and a small portion of two states in Mexico. From existing instrumental records, planners estimated that the Colorado River had an average annual flow of 19,985 billion cubic meters. This estimate was based on the 17 years of precipitation and streamflow data that were available (1906 to 1922). In 1976 at the Laboratory of Tree-Ring Research of the University of Arizona, Stockton and Jacoby (1976) reconstructed the flow of the Colorado River back to A.D. 1564 (450 years) using time series derived from tree-ring studies. Their reconstruction indicated that the period from 1906 to 1930 was the longest period of sustained high streamflow during the past 450 years. The short period of the instrumental record was simply not representative of the long-term flow of the river. Therefore, the allocation of water among states of the United States and Mexico was based on an anomalously high value, which resulted in shortages when all of the entities involved demanded their share of the available water.

Dendroclimatology: Reconstruction of Precipitation in Southern Jordan

Water is the most limiting factor for agricultural production in the Near East. Careful planning and management of water resources in dry land regions requires sufficient information on what frequency and severity of extreme events to anticipate, such as prolonged drought. One needs to know the variability of the climate of the area on time scales of decades to centuries to understand drought conditions and the resultant probability of increased desertification. Dendrochronology is a valuable tool for the study of past climate variability and increases our knowledge of climate variability beyond the short period covered by the instrumental data. Touchan et al. (1999) developed the first dendroclimatic reconstruction in the Near East for southern Jordan, a 396-year-long reconstruction of October-May precipitation based on two chronologies of *Juniperus phoenicia* (figures 1 and 2). They showed that the longest reconstructed drought, as defined by consecutive years below a threshold of 80% of the 1946-1995 mean observed October-May precipitation, lasted four years. The longest drought recorded in the 1946-95 instrumental data lasted three years. Based on the results of the reconstruction, seven droughts of three or more years have occurred during the past 400 years. A Monte Carlo analysis designed to account for uncertainty in the reconstruction indicates a lower than 50% chance that southern Jordan has experienced drought longer than five years in the past 400 years (figure 3). The chronology from southern Jordan covers 527 years (1469-1995).

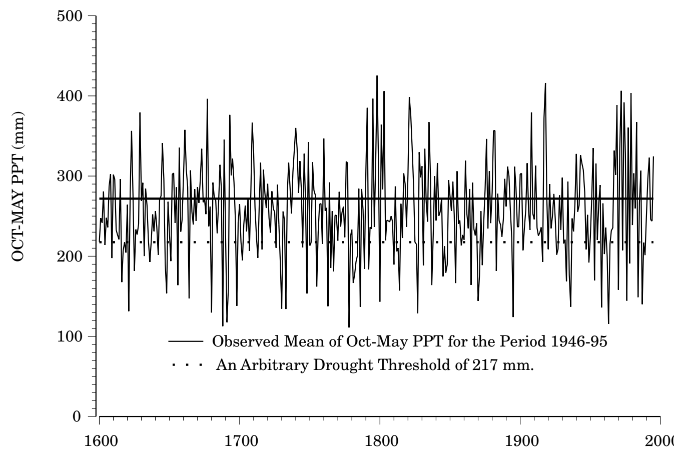

Figure 2. Annual values of the reconstruction for October-May precipitation for the period from 1600-1995.

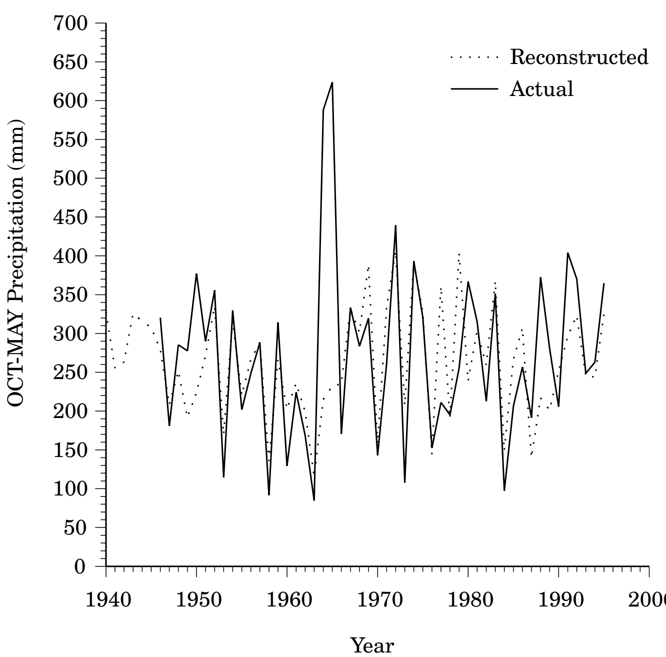

Figure 1. Comparison between actual and estimated October-May precipitation for southern Jordan, A.D. 1946-1995. Calibration R^2 is 0.44. Corresponding values for cross-validation is 0.41 (Touchan et al. 1999).

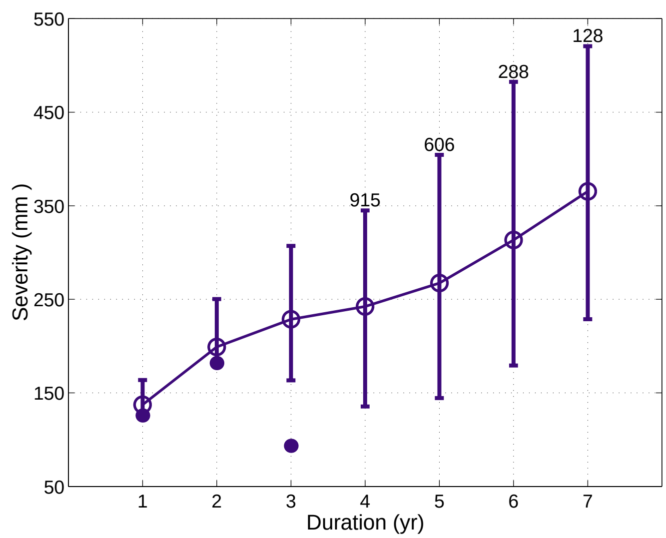

Figure 3. Median, 5th, and 95th percentiles of severity of most severe *n*-year droughts in noise-added reconstructions, 1600-1995. Black dots mark most severe *n*-year droughts in the observed precipitation series, 1946-95. Severity defined as run-sum below an arbitrary drought threshold of 80% of the mean observed October-May precipitation (217 mm). Results based on 1000 simulations. Number of simulations having at least one n-year drought annotated unless all simulations have a n-year drought (Touchan et al. 1999).

Dendroecology: Fire History and Climatic Patterns in Forests of Northern New Mexico

Fire has played a major role in shaping ecosystems of North America. In many areas, the presence or absence of fire controls vegetation succession, wildlife habitat, and nutrient cycles, as well as regulating biotic productivity, diversity, and stability. Fire is widely recognized as an integral and nearly ubiquitous element of forested landscapes in the western United States. Recognition of the importance of fire as a natural agent of change in the west has brought a corresponding interest in learning about the frequency, character, and impact of prehistoric and historic fires in this region. Touchan et al. (1996) reconstructed fire history in ponderosa pine and mixed-conifer forests in the Jemez Mountains in northern New Mexico. They found that prior to 1900, ponderosa pine forests were characterized by a high frequency, low intensity surface fire regime (figure 4). The mixed-conifer forests sustained somewhat less frequent surface fires, along with patchy crown fires (figure 5). They also examined the interaction between fires and winter-spring precipitation, finding

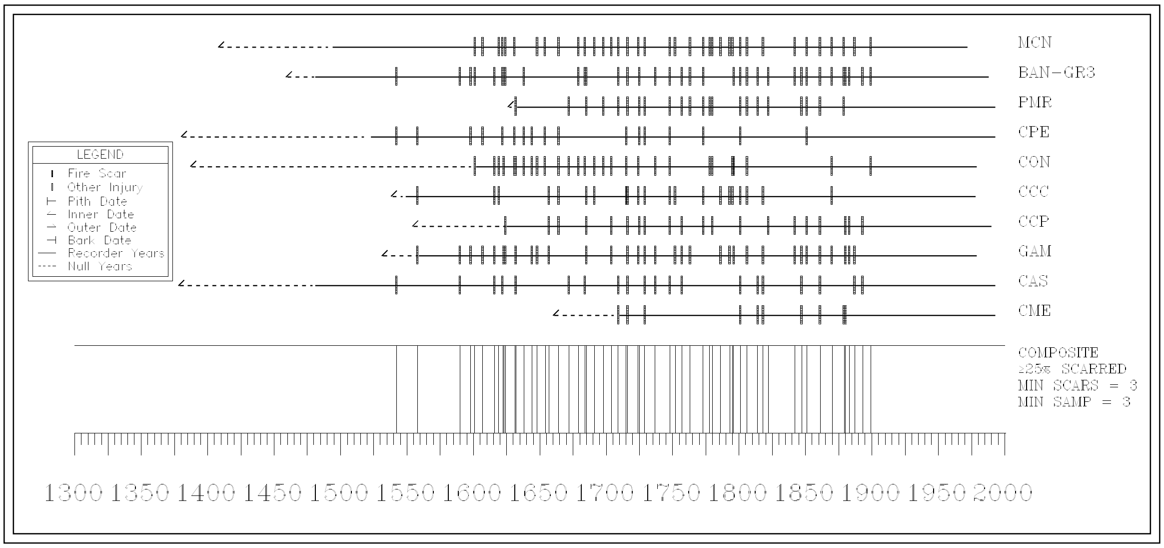

Figure 4. Composite fire history chart for the ponderosa pine forests. Horizontal lines are maximum life span of trees within each site. Vertical lines are composite fire dates recorded by 25% or more of the trees within each site (Touchan et al. 1996).

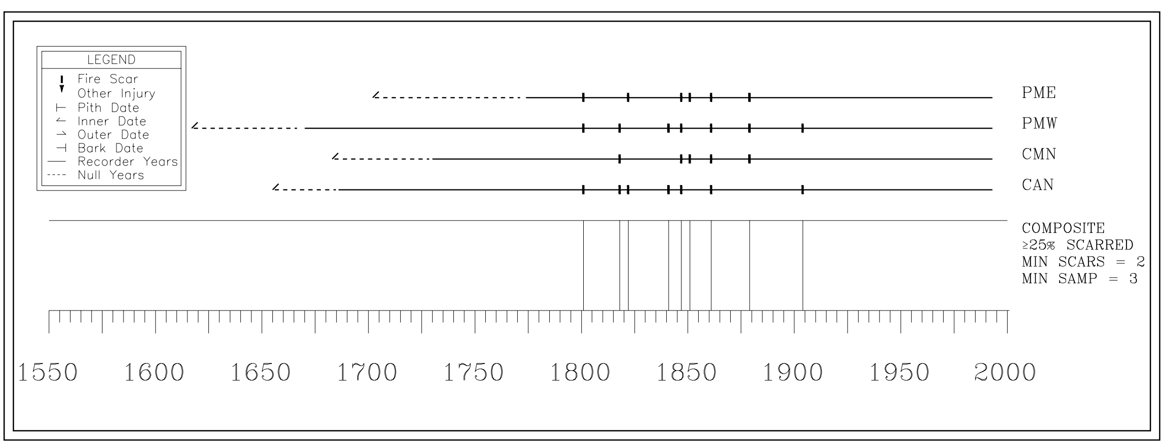

Figure 5. Composite fire history chart for the mixed-conifer forests. Horizontal lines are maximum life span of trees within each site. Vertical lines are composite fire dates recorded by 25% or more of the trees within each site (Touchan et al. 1996).

that in both forest types, precipitation was significantly reduced in the winter-spring period immediately prior to fire occurrence (figure 6). In the ponderosa pine forests, the winter-spring precipitation during the second year preceding major fire years was significantly greater. This study provided baseline knowledge concerning the ecological role of fire in both forest types. Results of the study are considered vital to support ongoing ecosystem management efforts in the Jemez Mountains.

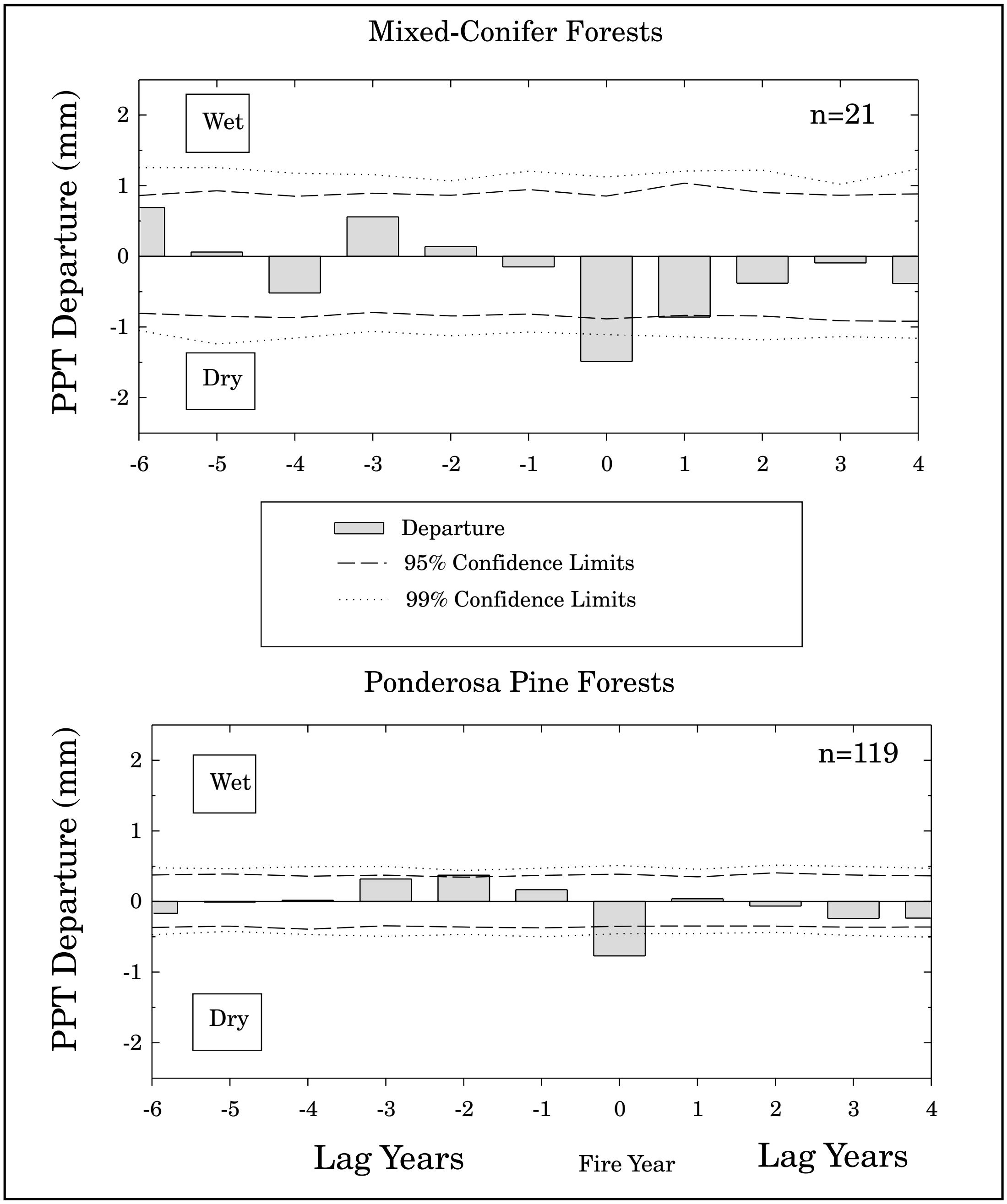

Figure 6. The superposed-epoch analysis for both the mixed-conifer (all fire dates) and the ponderosa pine forests (fire dates based on at least 10% trees scarred) for the period 1653-1986. The precipitation time series used was based on a tree-ring reconstruction of December-June precipitation. Departures were computed as the difference between the long-term mean precipitation level (1653-1986) and the observed mean precipitation during the fire years and lagged years (Touchan et al. 1996).

Conclusion

Tree-ring reconstruction of river flow, precipitation, and forest fires will help natural resource managers and decision makers understand these variables and execute low-risk, long-term action plans to accomplish desired conservation and sustainable use of natural resources. Such understanding can lead to a more realistic evaluation than is possible from direct observations of the nature and implications of environmental variability on timescales of decades to centuries. Understanding these variables will thus place managers in a better position to mitigate the risks affecting conservation and sustainable development of natural resources.

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