The Dendrochronological Potential of East-central California

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Abstract

Although Bristlecone Pine (*Pinus longaeva*) has been intensively studied in the White Mountains, this species has a high potential for further dendrochronological study. Tree-ring chronologies also need to be developed for other woody shrub and tree populations in the eastern Sierra Nevada, the White-Inyo Range, Glass Mountain, and other areas of east-central California. These chronologies and analyses of the wood will yield valuable ecological, climatological, hydrological and geological information that can increase the understanding of the dynamics of these environments. New analytical techniques, such as multi-elemental and stable isotope analyses, could add new information to standard ring-width measurements and aid in Holocene paleoclimatologic and paleoecologic reconstructions. In addition to ten species of *Pinus*, we believe that *Abies, Artemisia, Juniperus,* and *Cercocarpus* species analyzed by such techniques are particularly useful in developing environmental histories for both the Sierra Nevada and White-Inyo Range.

Introduction

East-central California is a region with high environmental diversity. Local relief exceeds 3,000 m. Annual precipitation varies from over 500 cm near the Sierra crest to less than 20 cm in desert basins. Lithology is variable, as a result of the transitional position of this region between the Great Basin, Mojave Desert, and Sierra Nevada crest. Geologic formations include Precambrian clastic and carbonate sedimentary units, Mesozoic intrusive and metamorphic units, and late Cenozoic volcanic and unconsolidated geomorphic deposits of various origins. A wide array of substrates are thus available for plant colonization. Several unique edaphic-floristic associations have developed as a result of this [Elliott-Fisk, 1986b]. In addition, tectonic activity in this region, including (1) the continuing uplift of the ranges bordering Owens Valley and elsewhere since the middle Miocene and (2) the Holocene volcanism of the Inyo and Mono craters, has amplified Late Cenozoic climate change [Elliott-Fisk, 1986a, 1987a, 1987b]. The flora and vegetation of the region today is thus the result of long-term environmental change interacting with floras of diverse Tertiary origins [Lloyd and Mitchell, 1973].

The more mesic Sierra Nevada has a higher floristic diversity (including numbers of tree and woody-shrub taxa) than the xeric Great Basin. The basins and ranges of the western Great Basin (including the Sweetwater Range and White-Inyo Range), however, have a more diverse flora than the central Great Basin, due to the proximity of the Sierra Nevada. Environmental change over the last several million years has resulted in an exchange of species between the California Floristic Province (with its Sierra Floristic Region) and the Transmontane Floristic Province (with its Great Basin, Inyo, and Mojave floristic regions) [Raven, 1977]. As a result of this transitional position, many populations of woody species occur throughout the region, and could yield important ecological information on the history and dynamics of east-central California environments.

The White Mountains have been the site of many "pioneering" studies in dendrochronology. Dendrochronology is the study of datable annual growth layers (*i.e.*, tree-rings) in woody plants and the construction of chronologies (*i.e.*, time series) from these ring sequences [Fritts, 1976]. Tree-rings can provide annual (and occasionally seasonal) information on plant growth for each calendar year of the individual's life. Through various methods of comparative statistical analyses, variation in ring-widths or indices (*i.e.*, corrected or standardized ring-widths) may be related to changes in the plant's environment. Plant establishment, maintenance, and reproduction are controlled by the genome of the plant and abiotic and biotic environmental variables, such as moisture, radiation, and interaction with neighboring individuals through competition for resources. Hence, much ecological information can be extracted from dated tree-ring series from sensitive sites.

The science of dendrochronology began at the University of Arizona under the direction of A. E. Douglass. Douglass founded the Laboratory of Tree-Ring Research in 1937 [Fritts, 1976]. Faculty and students at the lab continue his pioneering efforts. Important research has been done by Schulman [1958], Ferguson [1968, 1970], Fritts [1969], LaMarche [1968, 1973], LaMarche and Harlan [1973], and LaMarche, *et al.*, [1984] on Bristlecone Pine (*Pinus longaeva*) in the White Mountains. This species, the longest-lived of the conifers, is a co-dominant in subalpine woodlands of the Great Basin, and generally reaches its greatest age at its lower limits in the White Mountains [LaMarche, 1969]. By cross-dating ring-series between samples from living and dead individuals, long chronologies can be constructed [Ferguson, 1969, 1970]. The Bristlecone Pine chronology currently extends to 6,700 BC, with "floating" remnants beyond this [Ferguson, *et al.*, 1985].

Early dendrochronological studies emphasized the construction of long, well-verified chronologies from the semi-arid southwestern United States. This chronology construction had important implications for (1) the dating of archeological structures [Bannister, 1969], and (2) the calibration (*i.e.*, correction) of the radiocarbon time scale [Suess, 1970; Ferguson *et al.*, 1985]. Regional reconstructions of climate (including synoptic conditions, precipitation and temperature histories, etc.) were also done by establishing a grid or network of sites across western North America. Along with this, ecophysiological studies of the growth of Bristlecone Pine and other pine species were done to allow calibration of the ring-series, extracting a response "signal" or function from the trees [LaMarche, 1974].

Dendrochronologists are now working around the world constructing long tree-ring series from a variety of species on several continents. Climatic reconstructions through the last few thousand years are still a focus of research, especially those at the regional, continental or hemispheric scale. In addition to this type of dendroclimatological research, intensive work is being done within the realm of dendrohydrology, dendroecology, and dendrogeomorphology [Fritts, 1976]. In North America, attention has focused on the use of tree-rings for detecting air pollution [Fox, 1980; Gemmill *et al.*, 1982; Peterson, 1985; Cook, 1986], slope instability [Shroder, 1978, 1980], fire history [Madany *et al.*, 1982; Swetnam and Dieterich, 1985], drought frequency [Stockton and Meko, 1975, 1983], volcanic eruptions [Yamaguchi, 1983; LaMarche and Hirschboeck, 1984], forest infestation [Koerber and Wickman, 1970], forest decline [Cogbill, 1977], and atmospheric CO_2 increase [LaMarche *et al.*, 1984]. East-central California, with its high diversity of tree species and environments, is well suited for such studies. In addition, stable isotope analysis (*e.g.*, determination of D/H ratios) of wood cellulose from tree-ring samples may yield information on air mass origin and hence temperature, humidity and precipitation departures from the present [Epstein and Yapp, 1976; Yapp and Epstein, 1977]. Multi-elemental analysis of similar samples, using proton-induced X-ray emission analysis [Hall, 1984; Hall *et al.*, 1984; Elliott-Fisk, 1985], also provides information on chronological changes in the biogeochemical environment.

Species Suitable for Dendrochronologic Studies

Numerous tree species from the Pinaceae, Cupressaceae, Fagaceae, Salicaceae, Betulaceae, Aceraceae, and Oleaceae occur in east-central California [Elliott-Fisk and Peterson, 1988]. In addition, several shrub genera from the Asteraceae, Rosaceae, and Salicaceae families possess species that are long lived and sensitive to annual and inter-annual changes in the environment. All of these families have taxa that yield datable growth-ring series.

Some of the more important taxa for dendrochronological reconstructions in east-central California are shown in Table 1. Species are listed along with (1) the general geographical region in which they occur, (2) their minimum and maximum elevational ranges within the region, and (3) the estimated maximum age of individuals located for the species in this region. Composite chronologies may be longer than those from individual trees. The most accurate of these estimated ages are compiled from dated tree-ring series from select sites [Drew, 1972; Stokes *et al.*, 1973; Holmes *et al.*, 1986; and our observations]. At these sites, the individuals are frequently older than the ring count implies; and, where possible, we have estimated the age of these individuals by correcting core ring counts to basal age using diameter measurements. Other ages are from various scientific papers and books, preliminary coring of trees, and personal communications.

All of the species listed in Table 1, with the exception of *Pinus longaeva,* occur in the eastern Sierra Nevada. Several species, such as

Table 1

Dendrochronology of East-Central California

SPECIES	GEOGRAPHIC LOCATION	MIN.-MAX. ELEVATION(m)	ESTIMATED MAX. AGE (YRS)
Abies concolor	Sierra	2300-3050	400
Abies magnifica	Sierra	1900-3000	600
Artemisia tridentata	Sierra, Sweetwaters, White-Inyo, Panamints	1800-3100	800
Calocedrus decurrens	Sierra	2150-2750	500
Cercocarpus ledifolius	Sierra, Sweetwaters, White-Inyo, Panamints	2500-3200	3000(?)
Juniperus occidentalis	Sierra, Sweetwaters, White-Inyo, Panamints	2760-3220	1000 (3000?)
Juniperus osteosperma	Sierra, Sweetwaters, White-Inyo, Panamints	2000-3150	500(?)
Quercus kelloggii	Sierra	2250-2740	600(?)
Pinus albicaulis	Sierra	2250-3650	1000
Pinus balfouriana	Sierra	2800-3650	3300
Pinus flexilis	Sierra, White-Inyo, Glass Mtn.	2100-3500	2500
Pinus jeffreyi	Sierra, White-Inyo, Mono Craters, Glass Mtn.	2065-2350	850
Pinus lambertiana	Sierra	1800-2200	600
Pinus longaeva	White-Inyo, Panamints	2600-3550	4900
Pinus murrayana	Sierra, Whites, Sweetwaters, Glass Mtn.	2400-3100	1000
Pinus monophylla	Sierra, Sweetwaters, White-Inyo, Panamints	1700-3000	900
Pinus monticola	Sierra, Glass Mtn.	2430-3200	1400
Pinus ponderosa	Sierra, White-Inyo	1830-2300	950
Tsuga mertensiana	Sierra	2600-3200	800

Artemisia tridentata, Cercocarpus ledifolius, Juniperus occidentalis, J. osteosperma, and *Pinus monophylla*, also occur in the Sweetwater Range, White-Inyo Range and Panamint Range, and are as such widely distributed in the mountainous areas of the region. *Quercus kelloggii, Pinus balfouriana, P. longaeva,* and *P. ponderosa* have the most restricted distributions in the region. In addition, tree and shrub communities in the Great Basin ranges tend to be more depauperate than the "species-rich" communities of the more mesic Sierra Nevada. This is an important consideration when a research project calls for the use of multiple populations with different response functions. However, most of these species are evergreen conifers, and not deciduous and broadleaf taxa which yield different types of environmental information and thus can further provide additional data for environmental reconstruction.

Six species are restricted to the lower montane woodlands and forests, including *Juniperus osteosperma, Quercus kelloggii, Pinus jeffreyi, P. lambertiana, P. monophylla,* and *P. ponderosa.* These species are, in a general sense, drought-sensitive and perhaps prone to winter damage through dessication as well. *Pinus monophylla* and *P. ponderosa* have been widely used in the southwestern United States for archeological dating and studies of fire history. Dendrochronological reconstructions for east-central California for these two species are somewhat limited due to the high percentage of missing rings in Pinyon Pine and the sparse distribution of Ponderosa Pine in the area. Riparian stands of Ponderosa Pine between Tom's Place and Independence along the eastern Sierra front and an isolated population in Lone Tree Canyon in the White Mountains have long, sensitive ring series and should yield important hydrological and geomorphological information (Elliott-Fisk, in progress).

Alpine timberline species have been widely used for Holocene dendroclimatic reconstructions in western North America, with *Pinus longaeva* the best known of these [LaMarche and Mooney, 1972; LaMarche, 1973; LaMarche and Stockton, 1974]. Dendroclimatology requires long ring-width records, and few of the existing chronologies are longer than 500 years [Brubaker, 1982]. In east-central California only two upper timberline chronologies greater than 100 years in length are available. A chronology has been developed for *P. balfouriana* by Scuderi [1984, 1987] from the Cirque Peak and Cottonwood Basin area of the southern Sierra Nevada. This chronology has allowed the detection and dating of periods of late Holocene glacial advance. However, this site is west of the Sierra crest. *P. flexilis* is very similar in its response to *P. longaeva,* and has been used to a limited extent for dendroclimatic reconstructions in the western Great Basin [LaMarche, *et al.,* 1984]. Other high-altitude species that prefer more mesic habitats and can tolerate late-lying snow, such as *Tsuga mertensiana, Abies concolor* and *A. magnifica, Pinus lambertiana,* and *P. albicaulis* tend to be shorter lived with less sensitive ring series.

Many populations of the species listed above occur in the rugged, relatively inaccessible mountains of east-central California and have not been cored for dendrochronological study. Thus, although their potential is not fully known, inferences about the application of these tree-ring data to various environmental problems can be made through a knowledge of species' ecological requirements.

Applications of Dendrochronology

As tree-ring sequences are truly time-series of the variables that regulate tree growth, they yield an unlimited suite of environmental information, which through an understanding of the tolerance ranges and limiting factors of the populations allows the reconstruction of the tree's (and thus the region's) environmental history. Careful selection of individuals to be sampled in the field, coupled with accurate laboratory analyses, allow for inferences to be made about uni-or multi-variate statistical relationships between ring-width and environment. A contemporary, short (usually a minimum of 20 years) record of the environmental parameter in question (*e.g.,* precipitation, temperature, streamflow) is necessary for calibration of the tree-ring--environment relationship. For a lengthy description of statistical reconstructions of the environment from tree-ring materials, Fritts [1976] serves as a good reference. Acquiring these data, especially near the tree sampling site, can be difficult in east-central California, where the network of meteorological and hydrological recording stations is sparse.

In Table 2, we have listed potential dendrochronological applications of various taxa in east-central California. As noted here, all species will provide a climatic signal, as one or more aspects of climate limit tree growth in woodlands of the region. In a general sense, lower tree-line species are most frequently limited by low moisture levels and upper tree line species by low temperatures. Thus, collections from the same species at different sites may allow the reconstruction of several environmental parameters; LaMarche [1974]

Table 2
Dendrochronological Applications for East-central California

SPECIES	APPLICATIONS
Abies concolor	Climate (temp.)
Abies magnifica	Climate (temp. & moisture), ecol. (*e.g.*, air pollution)
Artemisia tridentata	Climate (temp. & moisture), archaeology
Calocedrus decurrens	Climate (moisture)
Cercocarpus ledifolius	Climate (temp. & moisture), geomorphology
Juniperus occidentalis	Climate (moisture & temp.)
Juniperus osteosperma	Climate (moisture), archaeology (?)
Quercus kelloggii	Climate (moisture & temp.)
Pinus albicaulis	Climate (temp.; moisture)
Pinus balfouriana	Climate (temp.)
Pinus flexilis	Climate (temp.)
Pinus jeffreyi	Climate (temp. & moisture), hydrology
Pinus lambertiana	Climate (temp. & moisture), ecol. (*e.g.*, air pollution)
Pinus longaeva	Climate (temp. & moisture), tephrochronology
Pinus murrayana	Climate (temp.), ecology (meadow invasion)
Pinus monophylla	Climate (moisture & temp.), archaeology
Pinus monticola	Climate (moisture & temp.)
Pinus ponderosa	Climate (temp. & moisture), hydrology, geomorph.
Tsuga mertensiana	Climate (moisture)

has done this using *P. longaeva* in the White Mountains. However, the best statistical relationship between ring-width and climate is commonly a function of two or more climatic parameters, such as spring moisture and summer temperature. Thus, multivariate techniques, such as the construction of response functions and subsequent multiple regression, canonical correlation, factor and principle components analyses, can yield the most accurate statistical functions with which to reconstruct environmental dynamics. It should also be noted that within the more central parts of the species range and on climatically optimal sites, ring series may not be sensitive and thus not datable.

The east flank of the Sierra has the potential for sensitive sites since it contains the distribution range boundaries and climatically suboptimal portions of the ranges of two relatively long-lived conifers, *Pinus balfouriana* and *P. flexilis.* Because these two species have roughly parallel distributions along the eastern Sierra and overlapping elevational ranges, they may profitably be used in conjunction. Foxtail Pine extends to higher elevations than Limber Pine, forming the treeline south of Mt. Whitney, and thus should provide a good temperature signal. Limber Pine extends to lower elevations where moisture is the dominant factor affecting ring-width and could yield precipitation information. Cores from Foxtail Pines (randomly selected for an age-structure study) growing near the species upper elevational limit in the vicinities of Onion Valley and Split Mountain, indicate that adequate sample size can be obtained with ring counts ranging from 300 to 1,048 years and actual or estimated age ranges from 300 to 3,325 years [Ryerson, 1983]. The average growth rates range from 0.31-0.85 mm yr^{-1}, and visual inspection indicates adequate ring-width sensitivity. Dead snags at these sites can be cross-dated and increase the chronology length. Although the upper elevational limit of Foxtail Pine in the eastern Sierra is near the limits of Neoglaciation, this area has less potential for a combination of dendrochronologic, dendroclimatological and dendrogeomorphological study, such as done by Scuderi [1984] for the Cirque Peak area. The area is highly dissected by relatively narrow, steep-sided canyons resulting in poorly distinguished moraines of multiple ages and considerable erosion of the deposits.

Species with potential archaeological application have been chosen as a function of their existence at archeological sites. This is largely the result of "permanent" inhabitation of only lower elevation sites in the region, hence the listing of *Artemisia tridentata, Juniperus osteosperma,* and *Pinus monophylla* as potentially important species. R. Bettinger's (U. C. Davis, unpublished information) excavations of high-altitude archaeological sites in the White Mountains may yield additional materials from *Pinus flexilis* and *P. longaeva* with dendrochronological dating control.

Tree stands on steep, unstable slopes can also provide geomorphological information. Trees can be injured by rockfalls, resulting in an aberration in growth. Soil creep or other mass movement can cause the formation of tension and compression wood as well. Trees in these habitats can have erratic growth patterns and are therefore unsuitable for cross-dating and the establishment of a chronology. A stand of *Pinus ponderosa* in Lone Tree Canyon in the White Mountains has been heavily impacted by slope processes [Elliott-Fisk, 1986b], and cross-dating of this long ring series has been difficult. Small stands of *Pinus jeffreyi* within the population at Jeffrey Mine Canyon in the White Mountains have less erratic ring series and are proving to be more suitable for tree-ring analysis (Elliott-Fisk, in progress). *Cercocarpus ledifolius* may attain large sizes and old ages on certain sites, and thus it is suitable for tree-ring studies. This species is a nitrogen-fixer and can easily colonize recent geomorphic surfaces. Therefore, by determining its age, the approximate age of the surface can be determined.

Hydrological reconstructions of streamflow, drought, and lake-levels have been done using tree-ring series, but not within this geographic region. Work is in progress on drought and lake-level reconstruction for the Mono Basin using ring series from *Pinus jeffreyi* [Bale *et al.*, in press]. *Pinus ponderosa* could also yield information on streamflow fluctuations for Rock Creek and Independence Creek along the eastern Sierra escarpment (Elliott-Fisk, in progress).

In southern California, *Pinus ponderosa* and *P. jeffreyi* are known to be susceptible to foliage damage by air pollutants. Limited dendroecological work has been done to date to detect damage by increased levels of ozone and other pollutants [Gemmill *et al.*, 1982]. A recent study on *P. jeffreyi* populations in Sequoia and Kings Canyon National Park shows ozone damage to local populations after 1965 [Peterson *et al.*, in press]. However, the impact of air pollutants has not been assessed using dendroecological techniques in east-central California.

The introduction of anthropogenic and "natural" pollutants to a tree's environment influences the biogeochemistry of the environment and could result in change in the elemental composition of the tree-rings (*i.e.*, woody tissues). Proton-induced X-ray emission analysis (PIXE: Cahill [1980]) has been used to detect the impact of air pollution on local populations [Hall, 1984] in eastern North America. Work is in progress in the White Mountains and Inyo-Mono Craters region to detect the uptake of exotic elements introduced with tephra deposition [Elliott-Fisk, 1985; King, 1985]. If these elements are fixed in the wood as the ring is formed, they should allow accurate dendrochronological dating of Holocene volcanic activity in the region.

Conclusions

The woodlands of east-central California include a minimum of nineteen species with long, sensitive tree-ring series. Chronologies and elemental analyses of the wood of these species should yield important climatological, ecological, hydrological, geomorphological and archeological time-series data on the environmental history of the region. In addition to detecting natural fluctuations in various environmental parameters, anthropogenic disturbance, whether by the introduction of air or water pollutants or by more direct physical damage to the tree, may be detected.

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