DEVELOPMENT OF TREE-RING CHRONOLOGIES IN AN OZONE AIR POLLUTION-STRESSED FOREST IN SOUTHERN CALIFORNIA

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ABSTRACT

The utilization of radial growth responses of trees to diagnose air pollution injury, and problems of growth defects interfering with the establishment of growth chronologies, is discussed. Cores from trees in an air pollution-stressed forest are examined for their potential to crossdate. Less than half, and usually less than a third of the trees on all plots can be crossdated, and number appears to be associated with changing conditions along a transect of elevational and pollution levels. Chronologies developed along this transect are presented.

Es wird die Anwendung der Wachstumsreaktionen von Bäumen zur Rauchschadensdiagnose diskutiert. Ferner werden die Probleme besprochen, die von Wachstumsschäden auf den Aufbau von Jahrringchronologien ausgehen. Bohrkerne von Bäumen aus einem Rauchschadensgebiet werden bezüglich ihrer Synchronisierbarkeit geprüft. Weniger als die Hälfte und gewöhnlich weniger als ein Drittel der Bäume von allen Versuchsflächen konnten synchronisiert werden. Diese Zahl scheint mit den veränderlichen Bedingungen entlang eines Höhen- und Immissionsgradienten zusammenzuhängen. Die entlang dieses Gradienten entstandenen Chronologien werden dargestellt.

L'utilisation de la réponse de la croissance radiale pour identifier les lésions dues à la pollution atmosphérique et les problèmes de défauts de croissance interférant avec l'établissement d'une chronologie est discutée. Des échantillons provenant d'une forêt atteinte par la pollution de l'air sont examinés et leur potentiel de synchronisation a été étudié. Moins de la moitié, et souvent moins d'un tiers des arbres analysés dans chaque station peut être synchronisé. Un certain nombre paraît être associé avec des conditions variant le long d'un transect de niveau d'altitude et de pollution. Les chronologies développées le long de ce transect sont présentées.

INTRODUCTION

Since at least the beginning of this century, researchers have been examining the radial growth of trees to diagnose and assess air pollution injury to forests. High concentrations of pollutants may directly affect the physiology of woody growth as seen in alterations of cell structure (Vins 1965; Parker et al. 1974) and reduced photosynthetic rate (Coyne and Bingham 1980; Noble and Jensen 1980). Many studies have focused on radial growth ring magnitudes and patterns as evidence of secondary impact due to reduced photosynthetic capacity. Marked changes in the patterns of the radial growth chronology have been used to diagnose air pollution injury (Bakke 1915; Clevenger 1913; Vins 1965, 1970; Skelly 1980). Several studies, many from Europe, have used growth-ring analysis to demonstrate the onset of diameter growth reductions of conifers corresponding to their exposure to SO_2 emissions (reviewed in Scurfield 1960). McBride et al. (1975) and Benoit (1980) have studied the impact of ozone on radial and height growth of forest trees in the United States. A major limitation of most earlier studies and even many contemporary ones, however, is that the tree cores used in analysis have not been crossdated according to dendrochronological procedures. Without definite dating of radial growth rings, analysis can only diagnose injury and must stop short of assessing actual year-by-year effects on growth.

Unfortunately, several difficulties are associated with dating ring series affected by air pollution. Where local site conditions, such as ambient air pollution, predominate and override climatic factors, crossdating is often impeded (Fritts 1976). A requirement for crossdating is that sample trees be limited by the same or similar climatic conditions. The inherent susceptibility of different trees to pollution stress, even within a species, will tend to produce considerable variation in growth response, obscuring any clear patterns. Charton and Harmon (1973), for instance, found that chronologies dated satisfactorily prior to the beginning of pollution exposure, and then began to lose agreement once within a known pollution period.

The preponderance of missing or partial rings in pollution-stressed chronologies presents a further difficulty in assigning correct dates. Vins and Mrkva (1972) found defects in formations of annual rings to characterize the chronologies of trees in the flume path of a smelter. As distance from the pollution source increased, the proportion of trees exhibiting defects decreased.

The potential for examining the effect of air pollution on radial growth is not entirely pessimistic. In those studies where crossdating of trees exposed to ambient air pollution has been possible, results have indicated that the growth rates of the trees appear to be more controlled and limited by variable(s) (presumably related to the presence of pollution) other than precipitation and temperature, and that this variable depresses growth (Ashby and Fritts 1972; M. Thompson, pers. comm.). Difficulties notwithstanding, dendrochronology appears to provide the only feasible avenue for both establishing time periods of pollution impacts on radial growth, and quantifying the consequent effects on growth.

Air pollution poses a serious threat to the coniferous forests of California. Symptoms of air pollution damage to coniferous species have been observed in forests located to the north and east of the Los Angeles basin, to the east of major cities in the Central Valley, and to the east of San Diego. This damage is especially severe in the San Bernardino mountains located at the east of the 130-km-long South Coast Air Basin where the last four decades of extensive urban and industrial development have created a severe air pollution problem.

As part of a multidisciplinary investigation of air pollution effects on the mixed conifer forest of the San Bernardino National Forest, a tree growth study was initiated in 1976. The tree growth study, as an integral part of a larger ecosystem investigation, has had the following constraints and requirements: (1) Sample trees had to be chosen from tagged trees on previously selected vegetation plots, forming a transect across the San Bernardino mountains. These trees had several years of data gathered from them concerning foliar injury, soil moisture usage, etc., and formed the focus of the entire study. Thus, (2) it was desirable to examine large quantities of trees, to characterize the entire forest, rather than a few highly responsive trees. And, (3) if at all possible, the actual magnitude of growth reductions should be evaluated, in view of the potential use of this study as baseline data for air quality policy-making. Thus, crossdating of trees to account for missing rings was essential.

MATERIALS AND METHODS

Five coniferous tree species were examined on six vegetation plots forming a portion of the study area of the Environmental Protection Agency/San Bernardino National Forest Ecosystem Project. All plots occurred in the coniferous forest zone and were dominated by either ponderosa pine (*Pinus ponderosa* Laws.) or jeffrey pine (*Pinus jeffreyi* Grev. and Balf.). Plots were 30 m wide and extended in length until 80 ponderosa and/or jeffrey pines of dbh (diameter at breast height) greater than 10 cm were included. The plots occurred along a 65 km long transect from the lower western end of the San Bernardino mountains with a heavy smog impact, to the eastern end (with lower pollution, higher elevation, and a drier climate (Fig. 1). Distances between sampling sites ranged from 14 to 22 km, the variation determined by the steepness of the air pollution gradient. At the high end of this gradient total June through October oxidant concentration in 1974 was 7.0 g/m^3-$hrX10^5$, while the lower end totaled 2.4 g/m^3-$hrX10^{-5}$ (Kickert et al. 1977). These data were collected at six locations along the gradient where continuous monitoring occurred from June 1 through October 1, 1974.

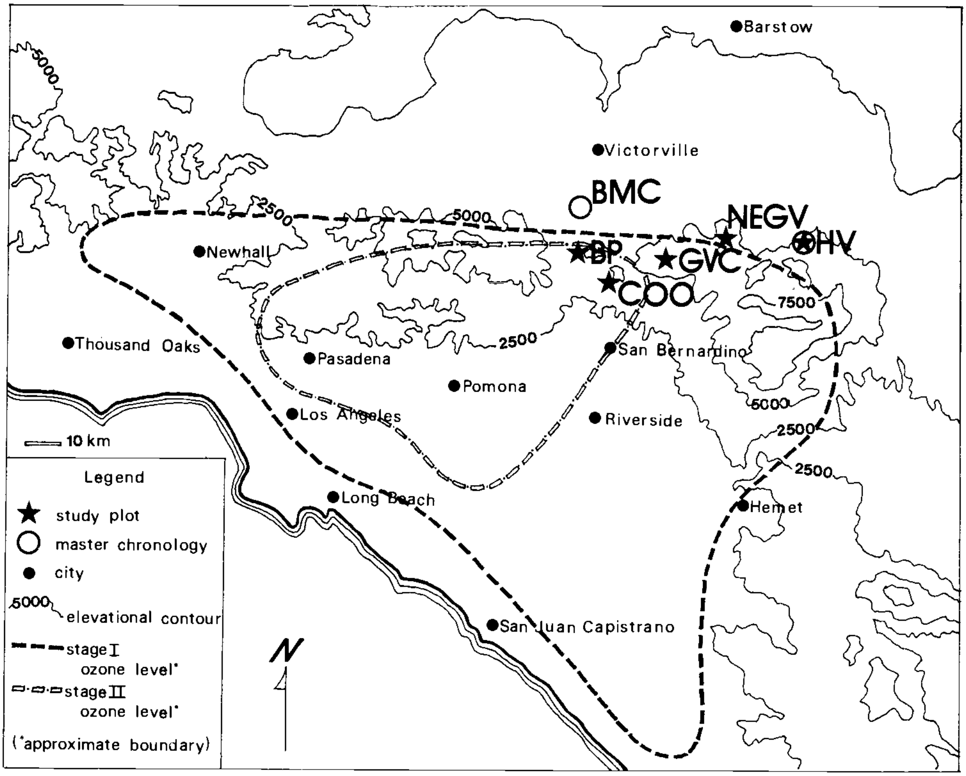

Figure 1. Location of tree growth study plots and master chronologies in relation to a severe ozone episode occurring September 7-14, 1979. Stage I ozone level is from 20 to 35 pphm (parts of pollutant per hundred million parts of air); Stage II ozone level is greater than 33 pphm. Plot abbreviations represent Burnt Mill Canyon chronology as BMC; Breezy Point as BP; Camp O-ongco as COO; Green Valley Creek as GVC; Northeast Green Valley as NEGV; and Holcomb Valley as HV (Deer Lick not shown). Map of ozone episode reproduced by permission of the California Air Resources Board.

Mast KI oxidant meters were used.

In the late summer of 1976, conifers greater than 10 cm dbh on the six study plots were cored at breast height with an increment borer. Cores were returned to the laboratory, dried, and mounted in wooden holders. Cores were surfaced with sandpaper and growth rings were measured using a Henson dendrochronometer, to the nearest 0.01 mm back to and including the year 1920.

A preliminary investigation was conducted of possible growth anomalies to provide some early indication of what might be expected from a tree-ring analysis. A sample of 50 trees in an area subject to severe pollution doses were cored at both ground level and breast height. Number of internodes were counted between these two coring heights, and number of rings were recorded from each core. Number of rings of the core at ground level was added to the number of internodes, and this total compared against number of rings at breast height. Seventy-eight percent of trees examined revealed over 10 missing rings on the average between breast height and ground level. Even allowing for the possibility of error in counting internodes, these results indicated a major anomaly in growth. Air pollution alone may not be responsible for this difference as it has been observed in situations where trees have been stressed by ground fires (Zackrisson 1980).

An attempt was made to crossdate each plot using a reference chronology, a sequence developed by the Laboratory of Tree-Ring Research at The University of Arizona for Baldwin Lake South, 4.8 km east of Big Bear City (Stokes et al. 1973). Only the two plots on the easternmost end of the transect (Northeast Green Valley and Holcomb Valley) could be crossdated successfully. Holcomb Valley exhibited particularly clear, consistent responses to climatic signals, and it was possible to establish a master chronology from this plot, based on 15 of the most responsive trees. This master chronology was then used to examine and crossdate the remainder of the trees on the Holcomb Valley plot and the trees on Northeast Green Valley.

Trees on the western and central portions of the transect did not crossdate satisfactorily with the Holcomb Valley chronology. In order to successfully crossdate these plots, a master chronology was needed. We concluded that this would only be possible by searching away from the tree growth plots on the western end for the types of trees more typically used in dendrochronological studies: at the forest border, on rocky slopes, severely limited by climate (Fritts 1976). Big Cone Douglas fir (*Pseudotsuga macrocarpa* Mayr.), a species which is known to often crossdate well, and which occurs in canyons at lower treeline in the San Bernardino mountains, was selected for search. Further, to reduce influences due to air pollution, we determined that specimen trees should ideally be found away from intensive exposure to ozone. Fortunately, just such a sample of Big Cone Douglas fir was located near Burnt Mill Canyon on the north aspect of the Crestline Ridge. Figure 2 shows the location of the sample trees gathered for forming a master chronology in relation to the heavily smog-impacted Breezy Point study plot on top of the ridge.

A master chronology developed from these sample trees permitted the crossdating of three plots on the western and central portions of the transect: Breezy Point, Camp O-ongo and Green Valley Creek. In a fourth plot, Deer Lick, still no consistent pattern could be discerned and as a result the entire plot had to be discarded from the sample.

RESULTS AND DISCUSSION

In Table 1, numbers of successfully crossdated trees by species and total number of trees per plot are tabulated. As these figures suggest, crossdating has been considerably more difficult on the western end of the transect, whether because precipitation and temperature regimes have been less growth-limiting in this area, or because air pollution impacts have been confounded or have affected individual trees in a more variable manner than have other environmental variables, it is not possible to speculate.

When this tree growth project was initially formulated, our goals were undoubtedly ambitious and somewhat naive in terms of the constraints on a tree-ring study. To expect that trees from a plot on typical terrain in the forest interior will crossdate to the degree of being able to pinpoint all years of missing rings has proven to be unrealizable. In fact, few of our successfully crossdated trees exhibit missing rings; those trees with severe growth defects did not crossdate. Consequently, our subsequent growth loss estimates will be conservative.

However, with the development of master chronologies showing strong local patterns of ring widths, we have been able to locate crossdatable trees on five of our six growth plots, and establish both chronologies for each plot from the most highly responsive trees (Fig. 3) and a data bank of dated trees to analyze against other data pertaining to air pollution effects.

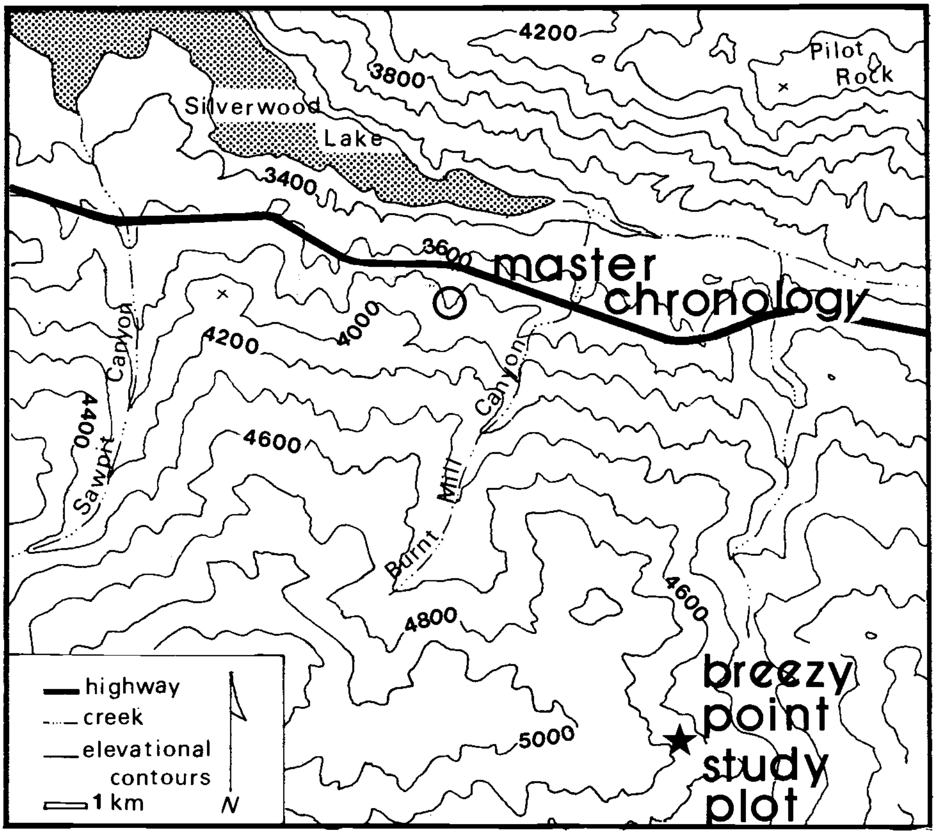

Figure 2. Location of Burnt Mill Canyon chronology in relation to local topography and the Breezy Point study plot.

Table 1. Numbers of crossdated trees on study plots.

Plot	Species	Total number of trees on plot	Number of trees crossdated	% of trees crossdated
Breezy Point				
	PP	65	21	
	IC	29	10	
	all spp	94	31	32.9
Camp O-Ongo				
	PP	44	15	
	WF	19	8	
	IC	3	0	
	SP	1	1	
	all spp	66	23	34.3
Green Valley Creek				
	JP	37	7	
	SP	11	2	
	WF	52	22	
	IC	8	1	
	all spp	108	32	29.6
Northeast Green Valley				
	JP	59	22	
	WF	8	3	
	all spp	67	25	37.3
Holcomb Valley				
	JP	132	74	
	WF	21	9	
	all spp	153	83	48.0

Species abbreviations: PP = *Pinus ponderosa* Laws.; JP = *Pinus jeffreyi* Grev. & Balf; IC = *Calocedrus decurrens* (Torr.) Florin; WF = *Abies concolor* Lindl.; SP = *Pinus lambertiana* Dougl.

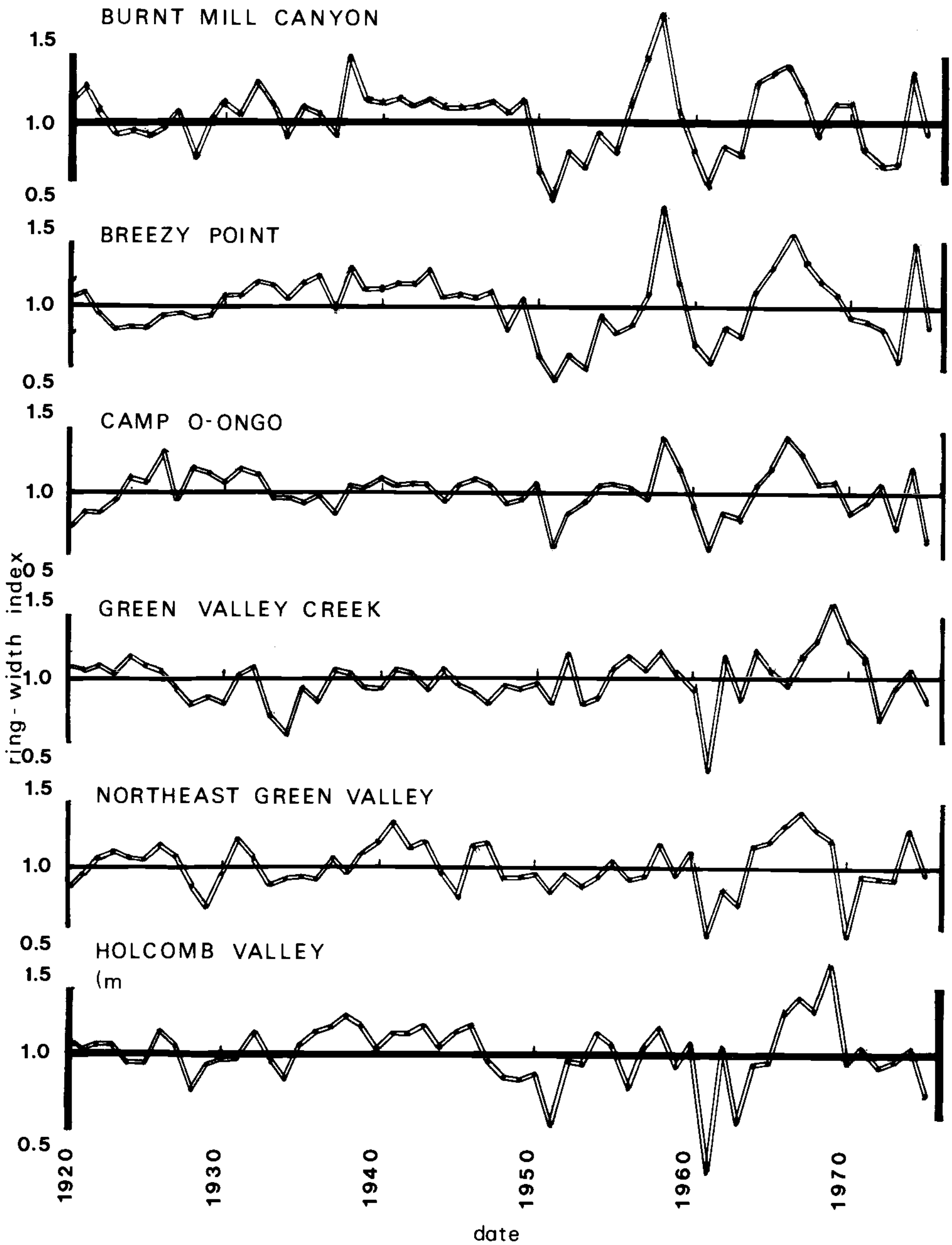

Figure 3. Master chronologies for study plots.

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