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Comparison of Two Approaches for Determining Fire Dates From Tree Scars

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ABSTRACT. Knowledge regarding the historic role of fire in forest ecosystems is often derived by dating fire scars. Fire history studies in boreal and western coniferous forests have used either complete or partial cross sections cut from fire-scarred trees. The occurrence of missing or false rings presents an obstacle to the accurate dating of individual fires. Two different techniques of dating partial cross sections of fire-scarred ponderosa pine (*Pinus ponderosa* Laws) were compared using the same samples. Method I involves the tabulation of "raw" dates followed by a subsequent adjustment based on synchronization with fire dates from adjacent trees. Method II uses correlations with master chronologies based on analysis of increment cores taken in the same region as the sampled fire scar sections. Method I is prone to error since the assumption that fire dates differing by a few years may actually be from the same year cannot be independently verified. Method II provides a higher degree of certainty with regard to the accuracy of individual dates because the cross dating of local patterns of ring widths circumvents the problem of absent or false rings. Eight samples from the Horse Pasture Plateau in Zion National Park, Utah, were dated by both methods. Agreement on dates derived by the two methods for 39 separate fire years was limited to only 26 percent. The average error of Method I was 1.0 year. Fire history studies using Method I are accurate enough for most managerial recommendations and some ecological interpretations, but they may lack the precision necessary to correctly identify fire years or differentiate small changes in fire frequency. The dendrochronological approach of Method II is preferable because of its greater reliability, especially in ecosystems where short fire intervals are common or where fires occur in consecutive years. FOREST SCI. 28:856–861.

ADDITIONAL KEY WORDS. *Pinus ponderosa,* dendrochronology, fire frequency, fire history, rings missing.

THE PROBLEM OF ACCURATELY DATING FIRES recorded on fire-scarred trees has vexed researchers for many years. Assuming that the number of rings between the cambium and the healing ring are counted with precision, error can still be present due to anomalous growth patterns in the tree itself (Zackrisson 1980). Wagener (1961) reviewed the various factors that contribute to the unreliability of tree ring counts. Traumatic events that can cause a partial or complete absence of a growth ring include fire, insect defoliation, drought, and lightning strikes. In describing his procedure for consolidating fire history data from various studies in the Sierra Nevada, Wagener indicated that the lumping of fire dates (by assigning dates from low incidence years to the nearest year of high incidence) was the best approach to cope with the problem of intrinsic inaccuracy.

Later Arno and Sneck (1977) advocated a similar scheme of correlating fire dates within a sample pool of trees. Following Wagener's approach, they stressed the need for careful adjustment of dates for trees that are consistently out of synchronization with dates for adjacent trees. Problems with this type of cross dating become acute when fires are so frequent that they occur in consecutive years. Arno and Sneck emphasized the need to base dates on records from trees with clear, nonsuppressed growth rings.

Another approach can be used to date fire scar sections more accurately. By applying basic dendrochronological techniques (Stokes and Smiley 1968, Stokes 1980), several re-

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searchers have been able to date their samples more confidently (Weaver 1951, Ahlstrand 1980, Dieterich 1980). Essentially, the approach uses a master tree-ring chronology as a dating control. The master chronology is developed through a process of cross dating and ring-width measurement of increment cores taken from a minimum of ten trees, two cores per tree. The "raw" tree ring-width data are "standardized" by computer techniques into ring-width indices, from which a plot can be constructed for cross dating purposes or for other analyses (Stokes and Smiley 1968, Fritts 1976). With the cross dating procedure, which is a correlation of distinctive patterns of narrow and wide rings (some sequences being diagnostic at various regional levels), the problem of missing or false rings can be avoided. In other words, if certain rings are known to be narrow (e.g., 1896, 1899, 1902), preceded and followed by several wide rings, then the date of a fire can be accurately identified, even if there are several missing rings between the fire-induced cambial interruption and the cambium itself. Cross dating of wood fragments (as well as entire tree cross sections) with regional master chronologies has been successfully used to reconstruct past climatic events and to date archaeological artifacts precisely (Fritts 1976).

This paper presents the results of a case study comparing two dating methods using the same set of samples.

METHODS

For the purposes of this paper "Method I" refers to the technique of adjusting fire dates by correlation of dates from adjacent trees. "Method II" refers to the application of dendrochronological techniques of cross dating using a master chronology for determining fire dates.

Method I.—Partial cross sections were cut from 123 trees (all but three of which were *Pinus ponderosa* Laws), in July 1979, on Horse Pasture Plateau, Zion National Park, Utah, USA. Each partial cross section was cut with a sprocket-nosed chain saw. Two horizontal cuts were made, followed by two vertical cuts using the nose of the chain saw bar, one parallel to the scar face, the other perpendicular (see Arno and Sneck 1977 for illustration). The resulting sample was an irregular polygon containing between 5 and 20 percent of the tree's basal area. Felling the trees and cutting of entire cross sections was not done because of the National Park status of the study area. The cutting of these small partial cross sections is generally nondestructive to ponderosa pine.

All sections were planed (a strip was cut along the interior long axis with a table saw) to provide a smoother surface for counting growth rings. Each scar was dated and the dates were placed on separate file cards for each tree. All sections were recounted at a later time to serve as a check on accuracy; if the second count did not agree with the first, a third iteration took place. These dates were in turn plotted on a large chart that displayed all fire years for all trees (illustrated in Arno and Sneck 1977), with time on the horizontal axis and individual trees on the vertical axis. The dates of each tree were then reconsidered in terms of dates on adjacent trees. The location of trees along the vertical axis of the chart was made from northwest to southeast across the study area, with the nearest neighbors of a given tree being those just above or below it on the chart.

By visually comparing the occurrence of fire in a given year for neighboring trees, judgments were made for nonsynchronous years. The following rules were elaborated by the senior author to govern the movement of dates:

1. No dates were adjusted more than 10 years. Since fire-induced stress was likely to have caused most missing rings, trees with 10–20 scars could conceivably have nearly as many missing rings.

2. Poor-quality sections were assumed unreliable and were adjusted to fit near neighbors.

3. Preference was given to adding years to a given scar date since missing rings were assumed to be much more prevalent than false rings (Soeriaatmadja 1966).

4. When a given date was moved back in time, all preceding dates were likewise moved in the same direction. Such movement generally resulted in multiple correlations between neighboring trees.

5. Priority for adjustments was given to scar dates cut close by or in the same watershed. After much examination, certain fire years appeared to be quite widespread across much of the plateau, i.e., 1881, 1879, 1875, 1872, 1866, 1864, 1860, and 1856 (for the last 30 years of frequent fire activity in the study area).

TABLE 1. Fire dates (year) for eight specimens derived from Methods I and II. Both raw (R) and adjusted (A) dates are shown for Method I.

Specimen and Method											
30-2-D			30-2-H			30-2-J			30-2-K		
IR	IA	II	IR	IA	II	IR	IA	II	IR	IA	II
1880	1879	1880	1896	1896	*	1881	1881	1879	1882	1881	1879
1860	1860	1859	1704	1704	1736				1860	1860	1863
1837	1836	1836	—	—	1668				—	—	1834?
1826	1825	1824	—	—	1627				1825	1824	1825
1783	1782	1781							1784?	1782?	—
									1753	1751	1750

Specimen and Method											
30-A			30-F			30-G			30-H		
IR	IA	II	IR	IA	II	IR	IA	II	IR	IA	II
1881	1881	1879	1886?	1881?	1879?	1879	1879	1879	—	—	1928
1867	1864	1865	1875	1868	1864?	1841	1841	1841	—	—	1921
—	—	1787?	1853	1846	1842?				1879	1879	1879?
			1841	1835	1832				1865	1864	1864
			1833	1824	1823				1843	1841	1842
			1824	1815	1815				1826	1824	1825
			1820	1811	1810				—	—	1806
			1811	1803	1802				—	—	1787
			1804	1795	1795						
			1795	1788	1786						
			1788	1782	1780						
			1783	1776	1774						
			1771	1764	1762						
			1760	1751	1751						
			1745	1736	1735						
			1732	1723	1723						
			1716	1708	—						
			1708	1699	—						
			1696	1687	1687						
			1686	1676	1675						

* Method II was not used to date between 1800 and 1979 because thirteen missing rings were discovered in that interval.

— Indicates that the date was found by only one of the two methods.

? Uncertainty for a date.

For any group of trees from the same general area (and presumed to have had the same basic fire history) the goal was to arrive at a consensus. After the entire chart had been examined, and the last adjustments made, the resulting fire years were transcribed onto the same index cards. These new dates were used in subsequent work to calculate fire incidence and frequency (Madany and West 1980).

A subsample of nine partial cross sections was verified at the Laboratory of Tree-Ring Research at the University of Arizona. The samples were the best quality specimens from the northern two sections of the study area.

Method II.—At the Laboratory of Tree-Ring Research, each of the samples was sanded to provide a better surface for dating of the ring series and analysis of the fire scars. The second author examined each of the cross sections and dated the ring series by cross dating with the regional master chronology from Bryce Canyon National Park (collection

TABLE 2. Summary of differences between Methods I and II. Both raw (R) and adjusted (A) are shown for Method II.

Specimen	Number of scars		Comparison of IR with II			Comparison of IA with II		
	Method I	Method II	Number of agree-ments	Percent of agree-ments	Average deviation	Number of agree-ments	Percent of agree-ments	Average deviation
30-2-D	5	5	1	20	1.2	1	20	0.8
30-2-H	2	4	0	0	—*	0	0	—*
30-2-J	1	1	0	0	1.0	0	0	1.0
30-2-K	5	5	1	20	2.3	0	0	1.8
30-A	2	3	0	0	2.5	0	0	1.5
30-F	20	18	0	0	9.3	5	28	1.4
30-G	2	2	2	100	0	2	100	0
30-H	4	8	1	25	.8	2	50	.5
Mean			N/A	21	2.4	N/A	25	1.0
Total			5	N/A	N/A	10	N/A	N/A
Percent of total (N = 39)			13	N/A	N/A	26	N/A	N/A

* = Sample had at least 13 missing rings during the years 1800 to 1979 so comparison value was limited; Method II not used on last 179 years.

N/A = Calculation not applicable to cell in matrix.

site located at 37°30′, 112°10′, Bryce Point), and with composite skeleton plots[1] from Zion National Park (site located at 37°14′, 112°53′) and from Mount Bangs (site located at 36°47′, 113°51′). After the ring series was dated, and all missing and false rings accounted for, dating marks were pinpricked into the wood along the dated radii and then adjacent to the scarred area. Fire scars were then examined microscopically and dated according to the apparent ring in which they occurred.

Several problems were apparent when using partial, as opposed to full, cross sections. There was considerable variability in ring sequences as a result of distortion caused by proximity to the scarred face. These distortions occasionally obscured the ring patterns and made cross dating with master chronologies difficult. This, in turn, hindered the development of a more site-specific composite of ring width patterns. Rot and insect galleries complicated the task of examining rings particularly as only an abbreviated portion of the sample tree's basal area was available.

Despite these problems, which are ordinarily circumvented in fire history studies utilizing dendrochronological techniques, eight of the nine best quality partial cross sections were successfully dated.

Results and Discussion

Table 1 compares the dates arrived at by using Methods I and II. Both unadjusted (R) and adjusted (A) dates are shown for Method I. Table 2 demonstrates that the adjusted dates in Method I are more accurate than the unadjusted dates. While the unadjusted date was wrongly adjusted in a few instances, the overall effect of adjustment was to increase the percentage of agreement with Method II and decrease the deviation. The average deviation[2] comparing adjusted and unadjusted Method I dates to dates derived using Method II is 1.0 and 2.4 years respectively. If all possible fire years shown as rows in Table 1 are

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[1] Composite skeleton plots are derived by averaging several skeleton plots of individual tree ring sequences. These are plots of relative ring width sequences (see Stokes and Smiley 1968:47–53).

[2] Average deviation (for sample) = [(Sum of individual average deviations)/(Number of samples)].

TABLE 3. Comparison of approximate time needed for dating a section by Method I and Method II (in hours).

Activity	Method I	Method II
Sanding/planing	0.25	1–2
Dating of rings and fire scars	1.5	4–12 ($\bar{x}$ = 6)
Dating check	1.5	2–4
Total	3.25	7–18 ($\bar{x}$ = 10.5)

compared for the sample population of eight trees (the ninth sample could not be dated using Method II), there are 39 pairs. There is agreement between adjusted Method I dates with Method II dates in 10 of the 39 pairs. Fire years for which no corresponding date was located with the alternate method cannot be used in this comparison. Overall, ten fire years were found with only one of the two methods, illustrating another problem of accuracy in developing a fire chronology. Judgement can vary as to whether a given cambial interruption-healing curl combination constitutes a *bona fide* fire scar.

While it appears that the majority (74 percent) of the adjusted dates were inaccurate (with the assumption that Method II is more accurate than Method I), the fact that the average deviation is only 1.0 year means that individual tree mean fire interval calculations (i.e., between two designated time intervals, such as 1750–1800) are valid. Inaccuracy would be slight and arise only from a date in error falling into the wrong time period used for calculation. In other words, whether a fire occurs in 1798 or 1799 has no bearing on computing the individual mean fire interval for the period 1750 to 1800. If, however, the question is between 1799 and 1801, an inaccurate calculation may result.

However, since composite fire intervals are much more accurate for determining fire history for a particular area (Kilgore and Taylor 1979, Dieterich 1980), the use of Method I will result in overly conservative estimates of historic fire frequency. Using Method I, certain years may be combined with other years to achieve group consensus, with the result that the presence of consecutive fire years will not be observable. For example, Method I showed only two instances of consecutive fire years for an area less than 400 ha: 1836, 1835 and 1825, 1824. Method II showed seven instances: 1880, 1879; 1865, 1864, 1863; 1842, 1841; 1825, 1824, 1823; 1787, 1786; 1781, 1780; and 1736, 1735. The inaccuracy of Method I is less of a problem in ecosystems with longer fire intervals, i.e., lodgepole pine or Douglas-fir forests. Given a large enough sample size, there is a reasonable probability that the consensus date will indeed be correct.

Conclusion

A comparison of two dating techniques demonstrated that divergent dates were generated from the same data base. Since the dendrochronological approach of Method II employs external verification and has been shown to be more accurate, the comparison was in reality a check on the accuracy of Method I. Using a consensus of fire dates from adjacent trees allows errors to persist since there is no guarantee that the specific fire date for a majority of trees is indeed the right one.

For example, Soeriaatmadja (1966) reported that, in an area of ponderosa pine forest in central Oregon known to have burned in 1938, 10 stumps showed a 1938 date, while 17 indicated 1939, and 8 carried a date of 1940. Thus, had the consensus method been applied there, the wrong date would have been ascribed to the fire. Since some ponderosa pine forests have a high periodicity of fire, the likelihood of consecutive fire years is moderately high (Dieterich 1980). Therefore, errors from employing Method I as the basis for fire history investigations are likely in parts of this forest type. Actual frequency values derived by using Method I provide useful estimations of historic fire occurrence; however, whether fires occurred at 2 to 4 or 4 to 7 year intervals in presettlement ponderosa pine forests was not significant in terms of the objectives of the Zion National Park study.[3] However,

[3] Madany, M. H. 1981. Land use-fire regime interactions with vegetation-structure of several montane forest areas of Zion National Park. M S thesis, Utah State Univ, Logan. 233 p.

this difference could be very important in answering different research questions in other contexts.

To obtain the most accurate and definitive results, future fire history investigations in ponderosa pine forests, and other ecosystems with a high incidence of fire, should employ dendrochronological techniques. Method II takes two to six times more hours per sample (Table 3), but it provides a level of accuracy unattainable by Method I. This accuracy provides a data base that will be more reliable when used in climate-fire studies, or in more refined ecological interpretations and comparisons. Full cross sections provide the best opportunity for counting rings. However, the destructiveness of this approach may preclude or limit its use in many areas. If it is not possible to cut full sections, Method II can still be used. Partial cross sections should be augmented by several increment cores taken from different places on the bole of the tree.

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