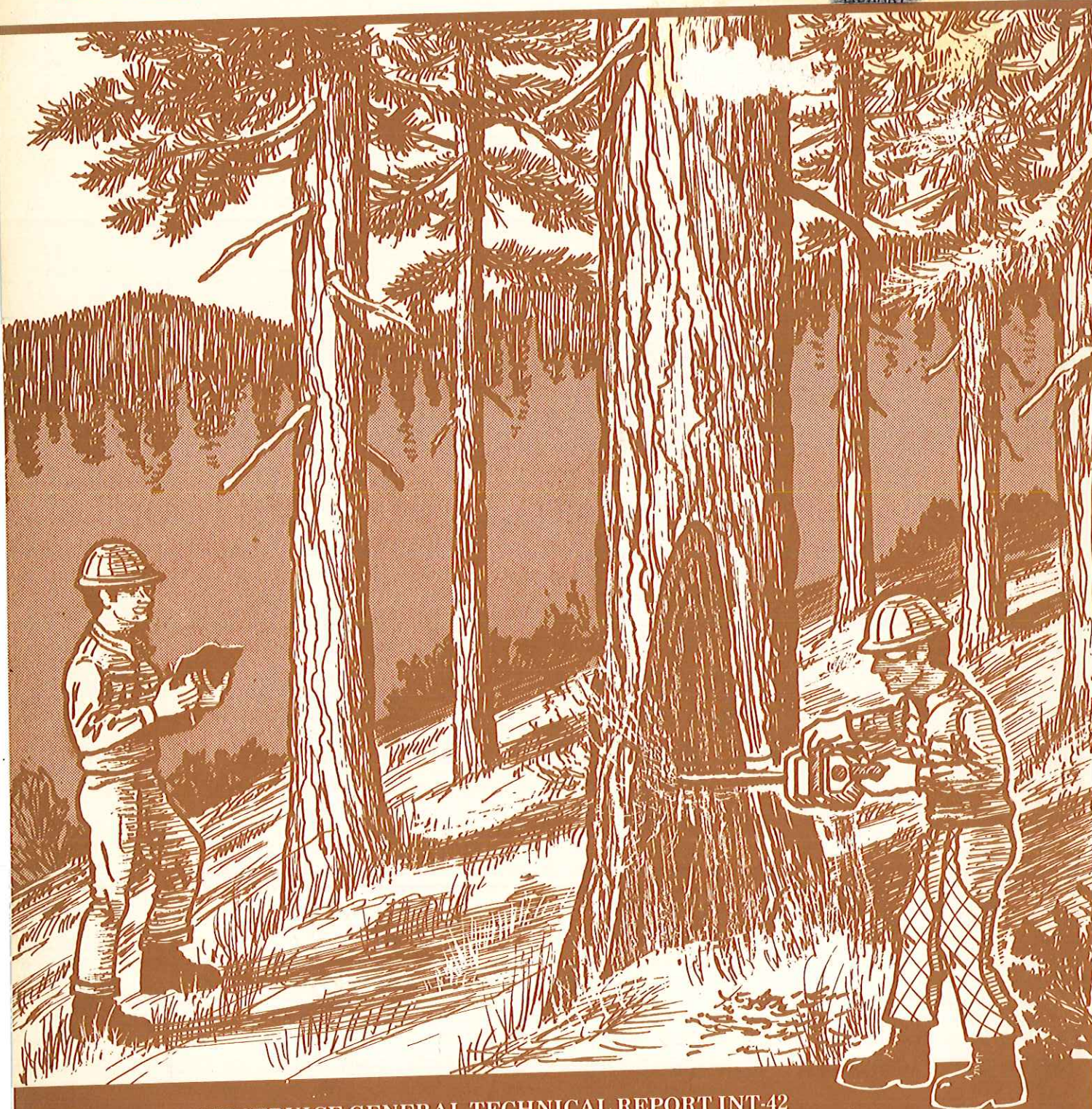


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A METHOD FOR DETERMINING FIRE HISTORY IN CONIFEROUS FORESTS OF THE MOUNTAIN WEST

STEPHEN F. ARNO and KATHY M. SNECK



USDA FOREST SERVICE GENERAL TECHNICAL REPORT INT-42
Intermountain Forest and Range Experiment Station
Forest Service, U.S. Department of Agriculture

USDA Forest Service
General Technical Report INT-42
November 1977

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Stephen F. Arno and Kathy M. Sneck

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U.S. Department of Agriculture
Ogden, Utah 84401

CONTENTS

	Page
INTRODUCTION.	1
SELECTION OF A STUDY AREA.	2
FIELD RECONNAISSANCE	3
Laying Out Transects	3
Gathering Data	4
SAMPLING FIRE-SCARRED TREES	11
Selecting Sample Trees	11
Collecting Samples	11
LABORATORY ANALYSIS	15
Preparing Cross Sections	15
Counting Rings	15
Correlating Fire Chronologies.	17
Designating Stands	20
Calculating Fire Frequency	22
Analyzing Age Classes	23
Mapping Historic Fires	25
INTERPRETATIONS	27
PUBLICATIONS CITED.	27

INTRODUCTION

Throughout much of western North America, forest managers are making a transition from a narrow policy of fire control to a broader approach called fire management (Moore 1974). This change reflects their increasing interest in using fire in fuel management, wildlife habitat management, silvicultural improvement, and natural area management. Thus, managers want to evaluate the influence of fire on forest ecosystems. But, to fully understand the role that fire has played, one should learn about the fire history. The following questions should be investigated: what were the (1) average, minimum, and maximum intervals between fires in various forest habitats? (2) sizes and intensities of fires? (3) effects of past fire on forest vegetation, particularly stand composition and age-class structure? (4) effects of modern fire suppression?

This paper outlines a method that a fire management specialist, land use planner, or research forester can use to address these questions. Most of the individual procedures were developed and used in various ways by other fire history investigators. Detailed justification of this method and comparison with various alternatives are not presented here; however, they are discussed by Arno (manuscript in preparation) and can be evaluated by reading some of the most pertinent study reports, such as:

Alberta--MacKenzie 1973, Byrne 1968, Tande 1977
Arizona--Weaver 1951
British Columbia--Howe 1915
California--Wagener 1961, Kilgore 1973, McBride and Laven 1976
Colorado--Clagg 1975
Idaho--Burkhardt and Tisdale 1976, Marshall 1928
Minnesota--Frissell 1973, Heinselman 1973
Montana--Arno 1976, Gabriel 1976, Sneck 1977
New Hampshire--Henry and Swan 1974
New Mexico--Weaver 1951
Oregon--Weaver 1959, McNeil 1975, Soeriaatmadja 1966
Washington--Weaver 1961
Wyoming--Houston 1973, Loope and Gruell 1973, Taylor 1974

The techniques employed are a relatively simple process of aging and correlating dates from fire scars on trees as well as identifying fire-initiated age classes of trees. The procedures were applied on three study areas in the Bitterroot National Forest of western Montana where they provided a detailed analysis of the role of fire since about the year 1600 (Arno 1976). Sneck (1977) recently field-tested the method in an area on the Flathead National Forest that has been more heavily logged and has had less frequent fires than the Bitterroot. As a result, improvements that she suggested have been incorporated here. This method should be applicable to coniferous forests of the western United States and adjacent portions of Canada, inland from the coastal forests.

FIELD RECONNAISSANCE

Laying Out Transects

A network of reconnaissance transects (not statistically based) should be laid out on the topographic map of the study area. As illustrated in figure 1, this network should lead through representative amounts of terrain on all aspects and elevations. Such a network will normally provide a representative sample of the forest types. Transect routes can be established to take maximum benefit of trails and roads for access. Orienting the transects along topographic contours or perpendicularly up one broad slope and down another is quite acceptable. Transects should not follow narrow ridgetops or stream bottoms for miles, because these have vegetative and fire environments that may not be typical of most of the area. Instead, transects should generally traverse broader slopes on all aspects from low to high elevations, and should be well dispersed throughout the study area. Parallel transects can be made along longitudinal or latitudinal lines; however, this approach requires more time for surveying the route and is especially slow in rugged terrain.

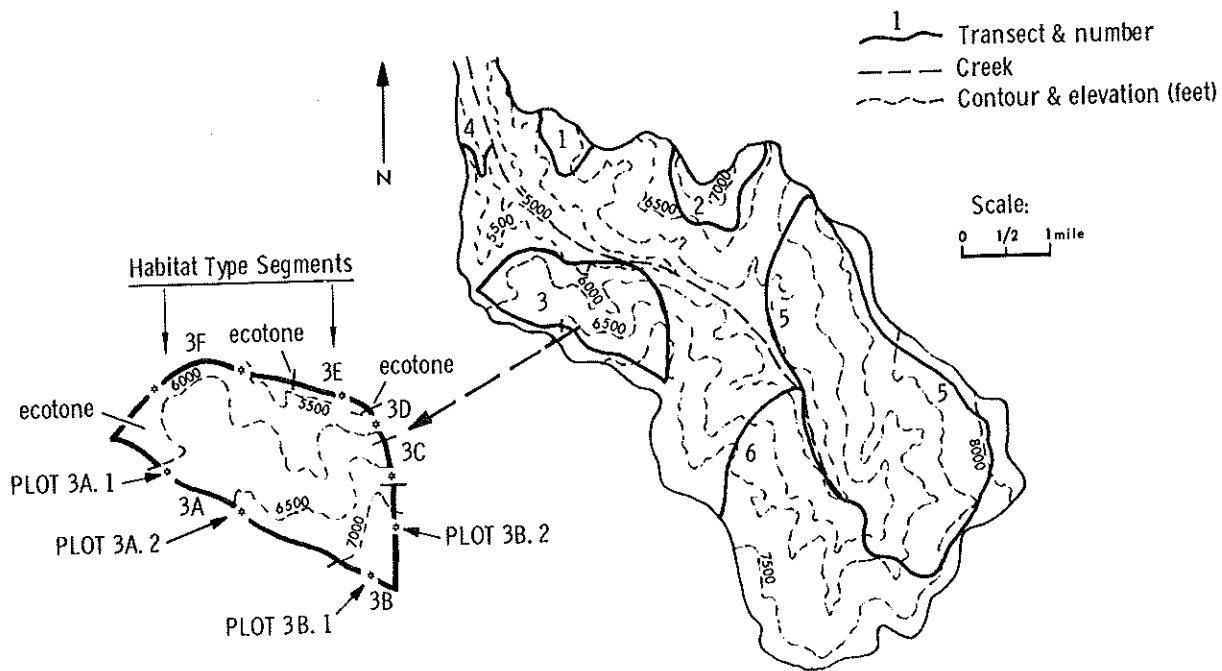
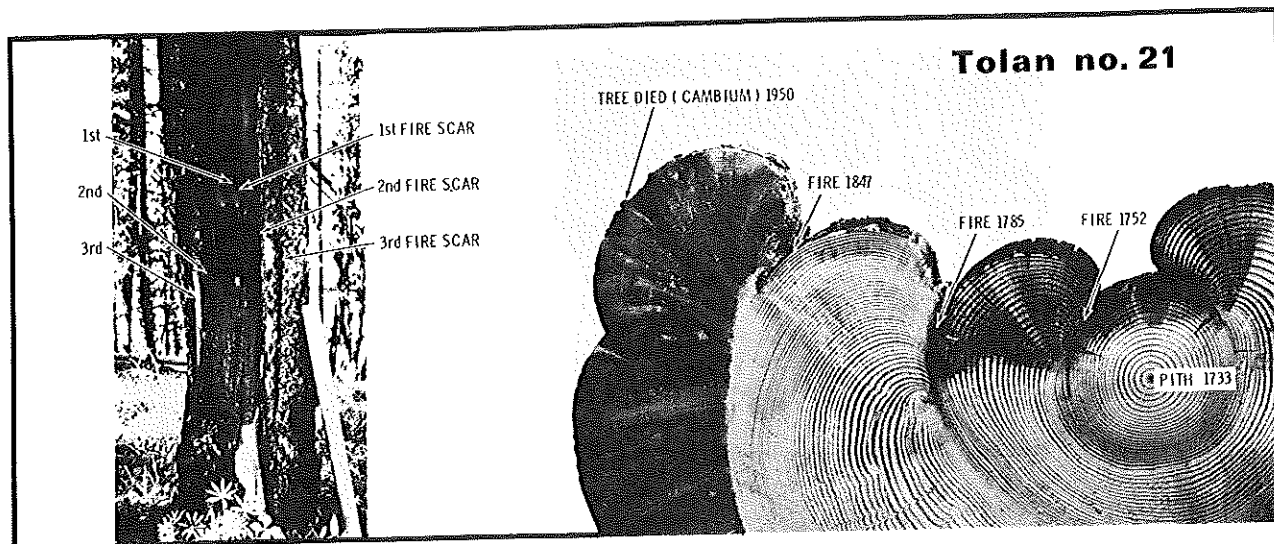


Figure 1.--Topographic map of a study area showing network of transects (which utilized trail and road access) and transect numbering scheme. Enlargement of transect 3 shows habitat type segments (3A, 3B, etc.), ecotones, sample plots (*).

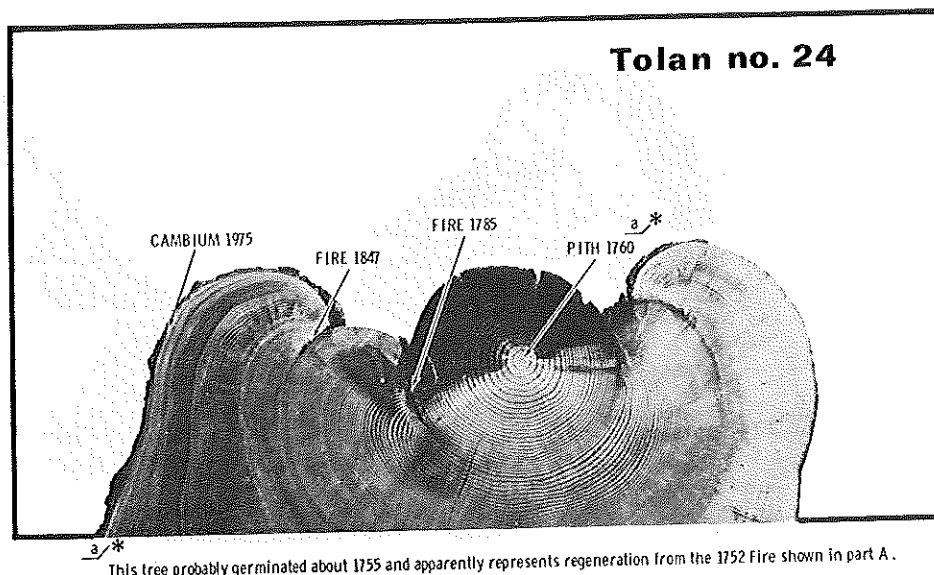
NAME <u>John Doe</u>			DATE <u>8-1-76</u>		
(CODE DESCRIPTION)			Plot No.		
TOPOGRAPHY:			Location		
HORIZONTAL CONFIGURATION:			T, R, S		
CANOPY COVERAGE CLASS:			Elevation		
1-Ridge			Aspect		
2-Upper slope			Slope		
3-Mid slope			Topography		
4-Lower slope			Configuration		
5-Bench or flat					
6-Stream bottom					
NOTE: Rate trees (>4" dbh) and regen (0-4" dbh) separately (e.g., 4/2)					
TREES Scientific Name			Canopy Coverage Class		
Abbrev <td colspan="3">Common Name </td>			Common Name		
1. Abies grandis	ABGR	grand fir	2	1	2
2. Abies lasiocarpa	ABLA	subalpine fir	1	2	1
3. Larix lyallii	LALY	alpine larch	1	1	2
4. Larix occidentalis	LAOC	western larch	1	1	1
5. Picea engelmannii	PIEN	Engelmann spruce	1	1	1
6. Picea glauca	PIGL	white spruce	1	1	1
7. Pinus albicaulis	PIAL	whitebark pine	1	1	1
8. Pinus contorta	PICO	lodgepole pine	1	1	1
9. Pinus flexilis	PIFL	limber pine	1	1	1
10. Pinus monticola	PIMO	western white pine	1	1	1
11. Pinus ponderosa	PIPO	ponderosa pine	1	1	1
12. Pseudotsuga menziesii	PSME	Douglas-fir	1	1	1
13. Thuja plicata	THPL	western redcedar	1	1	1
14. Tsuga heterophylla	TSHE	western hemlock	1	1	1
15. Tsuga mertensiana	TSME	mountain hemlock	1	1	1
SHRUBS AND SUBSHRUBS					
1. Alnus sinuata	ALSI	Sitka alder			
2. Arctostaphylos uva-ursi	ARUV	kinnikinnick			
3. Berberis repens	BERE	creeping Oregon grape			
4. Cornus canadensis	COCA	bunchberry dogwood			
5. Holodiscus discolor	HODI	ocean spray			
6. Juniperus communis (+ horizontalis)	JUCO	common (+ creeping) juniper			
7. Ledum glandulosum	LEGL	Labrador tea			
8. Linnaea borealis	LIBO	twinflower			
9. Menziesia ferruginea	MEFE	menziesia	4	3	4
10. Opiopanax horridum	OPHO	devil's club			
11. Physocarpus malvaceus	PHMA	ninebark			
12. Prunus virginiana	PRVI	chokecherry			
13. Purshia tridentata	PUTR	bitterbrush			
14. Ribes montigenum	RIMO	mountain gooseberry			
15. Shepherdia canadensis	SHCA	buffaloberry			
16. Spiraea betulifolia	SPBE	white spiraea			
17. Symphoricarpos albus	SYAL	common snowberry			
18. Symphoricarpos oreophilus	SYOR	mountain snowberry			
19. Vaccinium caespitosum	VACA	dwarf huckleberry	2	1	
20. Vaccinium globulare (+ membranaceum)	VAGL	blue huckleberry	2	3	4
21. Vaccinium scoparium (+ myrtillus)	VASC	grouse whortleberry			
PERENNIAL GRAMINOIDS					
1. Agropyron spicatum	AGSP	bluebunch wheatgrass			
2. Andropogon spp.	AND	bluestem			
3. Calamagrostis canadensis	CACA	bluejoint			
4. Calamagrostis rubescens	CARU	pinegrass	1		
5. Carex geyeri	CAGE	elk sedge			
6. Festuca idahoensis	FEID	Idaho fescue			
7. Festuca scabrella	FESC	rough fescue			
8. Luzula hitchcockii (= glabrata)	LUHI	wood-rush			1
PERENNIAL FORBS AND FERNS					
1. Actaea rubra	ACRU	baneberry			
2. Antennaria racemosa	ANRA	woods pussytoes			
3. Aralia nudicaulis	ARNU	wild sarsaparilla			
4. Arnica cordifolia	ARCO	heartleaf arnica			
5. Athyrium filix-femina	ATFI	lady fern			
6. Balsamorhiza sagittata	BASA	arrowleaf balsamroot			
7. Clematis pseudoalpina (+ tenuiloba)	CLPS	virgin's bower			
8. Clintonia uniflora	CLUN	queencup beadlily			
9. Equisetum arvense	EQAR	common horsetail			
10. Equisetum spp.	EQU	horsetails & scouring rush			
11. Galium triflorum	GATR	sweet-scented bedstraw			
12. Gymnocarpium dryopteris	GYDR	oak fern			
13. Senecio streptanthifolius	SEST	cleft-leaf groundsel			
14. Senecio triangularis	SETR	arrowleaf groundsel			
15. Smilacina stellata	SMST	starry Solomon's seal			
16. Streptopus amplexifolius	STAM	twisted stalk			
17. Thalictrum occidentale	THOC	western meadowrue			
18. Valeriana sitchensis	VASI	sitka valerian			
19. Viola orbiculata	VIOR	round-leaved violet	1	3	2
20. Xerophyllum tenax	XETE	beargrass	1	3	2
SERIES			HABITAT TYPE		
PHASE			PHASE		
			AF/MEFE		
			AF/MEFE		
			AF/MEFE		

Figure 2.--Sample habitat type-stand composition field form (Pfister and others 1977), with vegetational data from three plots located in figure 1.

Figure 4.--Examples of multiple fire scars on trees and scar patterns in cross sections.



4-A. Lodgepole pine with three fire scars



^a/* This tree probably germinated about 1755 and apparently represents regeneration from the 1752 Fire shown in part A.

4-B. Nearby lodgepole pine with two fire scars

Investigators must learn to differentiate fire scars from scars caused by fallen trees, frost cracks, root rot, and bear, rodent, or beetle damage. (These are described more fully later.) Also, they must recognize those healed-over fire scars which are indicated only by a bark seam, generally on the upslope side. Field experience will clarify the scarring characteristics of each tree species. Char on the outer bark confirms at least one fire, probably within the last 70 years. Char on the surface of any scar in a catface is evidence that a fire occurred *after* the year of that scar.

A few trees having the largest number of relatively sound fire scars in each stand should be recorded and marked for revisiting. In stands having many old-growth trees with multiple scars, it is not necessary to also tally all the younger trees with only one or two scars. The following data should be recorded for each tree in a "Log of Fire-Scarred Trees":

- (1) transect number, habitat-type-segment letter, and scarred-tree Roman numeral
- (2) species
- (3) d.b.h.
- (4) maximum height of catface
- (5) number of externally visible scars
- (6) elevation
- (7) aspect
- (8) remarks such as descriptive location and recommendation for sampling

This information (table 1, part A) will provide the basis for selecting sample trees. Each of the trees in the log should be plotted by numeral on the transect topographic map.

Fire-scarred trees can also be identified in stands that have been clearcut or heavily logged during the past few decades by systematically examining stumps. Because fire scars on low stumps are not readily apparent at a distance, careful inspection is necessary. Fire scars may have healed over and thus not be visible on the outer edge of stump, but they can be seen in the rings (on top). Fire-scarred stumps are recorded similarly to fire-scarred trees.

SAMPLING FIRE-SCARRED TREES

Selecting Sample Trees

After completing the field transects, one can examine the Log of Fire-scarred Trees and make preliminary selections for sampling. Generally, two or three sample trees should be selected for each half mile (0.8 km) of a given habitat-type segment on each transect. Some transect segments may not have fire-scarred trees because few trees survived the most recent fire. In this case, increment cores (age-class data) and transect field notes will provide fire history information within that segment.

On larger study areas having many miles of transects, distances between sample groups can be increased. (Nevertheless, the investigator should sample groups of two or three trees in close proximity in order to correlate fire-scar chronologies.) If this intensity of sampling is not feasible, establish a few small study areas with representative terrain and vegetation, correlate the findings, then extrapolate results to the larger area. An example of this approach is provided by Arno (1976).

Trees with the greatest number of externally visible, individual fire scars have the highest priority for sampling. Avoid sampling trees whose ring-count sequence may be obscured by rot.

Where candidate sample trees have similar numbers of scars and soundness, other factors can be considered. For instance, the investigator may choose to sample a ponderosa pine in preference to a Douglas-fir or western larch because the former usually has clearer scar rings. A small, old-growth tree can be chosen in preference to a larger dominant tree having a similar scar sequence.

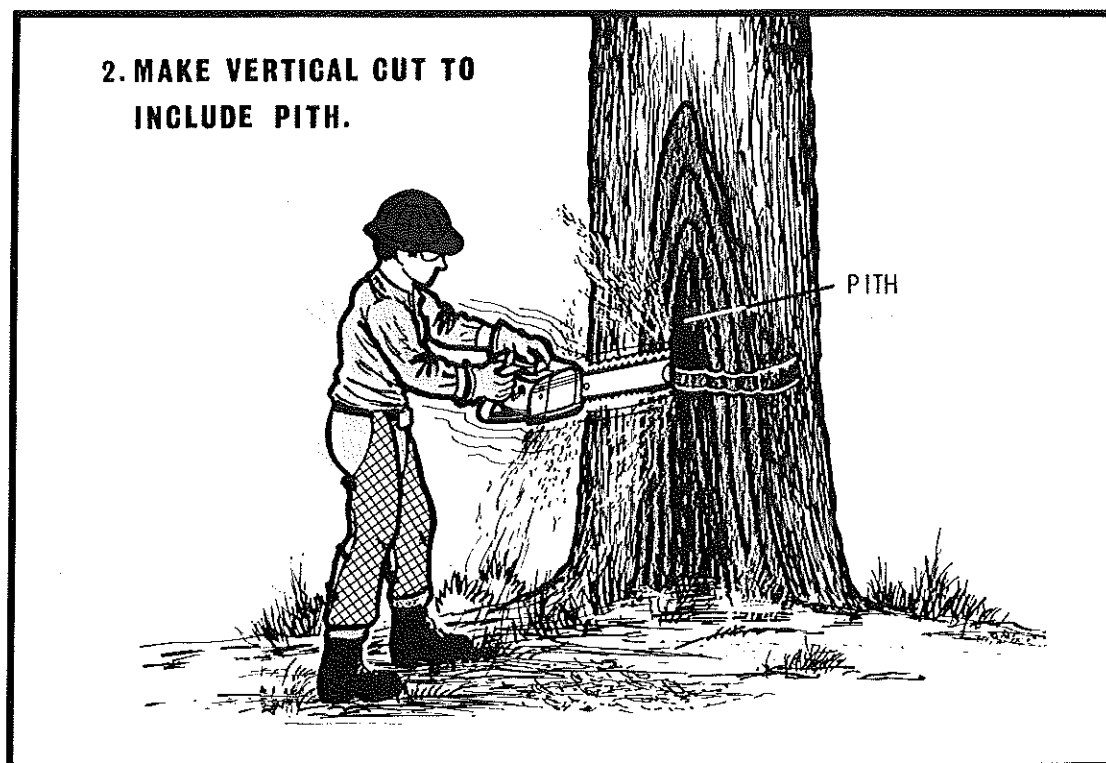
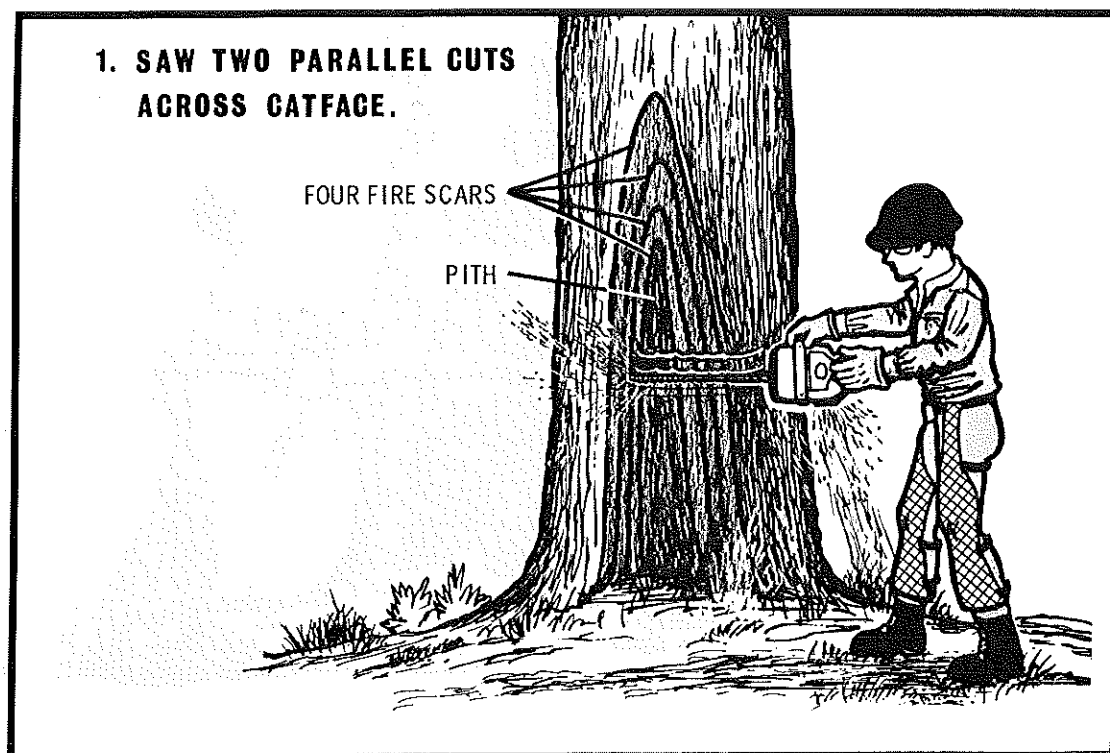
Final selections of sample trees and stumps should be recorded on a field sheet and on a map that will be used to relocate them for taking cross sections.

Collecting Samples

Return to the chosen sample trees, watching for better scar trees that may have been overlooked. Inspect each chosen tree to verify that the data supporting its selection were accurate. Check especially the maximum number of fire scars and determine the best place to cross section the trunk to obtain the full sequence of scars as well as the pith and cambium. Photograph the catface. Assign the tree a permanent number and record it in the "Log of Sampled Trees" (part B of table 1), which includes information listed in the Log of Fire-scarred Trees, plus the number of cross-sectional scars, habitat type, and photograph number. Also, plot and label the sample tree's location on the topographic map.

Sectioning techniques suggested here provide *primarily* for study needs while *secondarily* minimizing visual impact and structural damage to trees. In some areas (National Parks, wildernesses, private lands) it may be necessary to reverse the above priorities. In that case, thin wedge-shaped sections, not necessarily penetrating to the pith, can be taken (McBride and Laven 1976), with a handsaw if necessary.

Figure 5.--Collecting a partial cross section from a large tree.



These sampling procedures may require some adjustment where fires have destroyed extensive stands. In such regions, study areas should be made large enough to include some of the boundaries of the big burns. The extent of such burns is often detectable in patterns of forest development seen on aerial photographs. Fire scar *and* total age information can be obtained from (1) scattered surviving trees within the burn, (2) both young and old trees (age classes) killed by the fire, (3) pockets of surviving forest, and (4) trees at the perimeter of the burn. Regeneration can be aged to help date the large burn itself. Historical accounts are often available for dating large and destructive fires that have occurred within the last 100 years or more.

LABORATORY ANALYSIS

Preparing Cross Sections

After each day of sampling, cross sections should be laid out for drying in a heated building. Within a week or two, surfaces should be dry enough to sand, so that rings can be more accurately counted and examined. A disk sander attached to a light-weight electric drill, will suffice.

Begin sanding with coarse disks (40 to 50 grit) having the heaviest paper backing available. Then use fine and very fine (125 grit) sandpaper as necessary to bring out the rings. It is not necessary to sand the entire surface, but only a moderately wide band along and immediately behind the scars to allow for a complete ring count. Other sanding techniques, including hand sanding, are preferred by some investigators.

Counting Rings

A variable-power binocular microscope (7X to 25X) is usually essential for accurate counting. (Sometimes this can be borrowed or rented.) Select the clearest side of the cross section and count inward from the cambium. Count 1 year to the outer edge of the outermost band of (darker) summerwood, and continue to count from one band of summerwood to the next. Wetting the counting area with water and occasionally slicing obscure rings with a razor blade facilitates counting. With a very sharp red pencil, mark a dash (-) along every 10th ring and a plus (+) on each fire-scar ring as illustrated in figure 6. An alternative for wood with extremely fine rings is to puncture the ring with a fine dissecting needle. A fine red dot should also be placed near such punctures because they may disappear if the wood is wetted.

If the junction of the scar ring and undamaged tissue is obscured by pitch or rot, count past the scar ring to a clear ring beyond the scar. Then follow the clear ring around past the obstruction and count back up to the scar surface.

Record the number of years back to the most recent fire and between each previous fire as shown in table 2. Rings should be counted carefully by one person and then verified by another. On samples where some of the ring sequence is unclear, the opposite side of the cross section (or the opposite facet of the catface, in the case of a full cross section) should also be counted.

Correlating Fire Chronologies

Ring counts from each individual tree may not be entirely accurate or coincide because of pockets of obscured rings or rot, or due to occasional missing rings or false rings. More accurate estimations of the actual fire years can be developed by combining records from several trees into a "master fire chronology."

To correlate records from individual trees, arrange them on a large sheet of paper (such as 10 line/inch graph paper). The chronology from each tree is shown in a vertical column, and the trees should be arranged in a logical geographic ordering so that neighboring trees appear in adjacent columns (fig. 7). The top line of each column represents the date of the cambial ring, usually the year the samples were cut. Each inch (10 squares) downward represents 10 years.

After the 10-year intervals are labeled on the edge of the graph and adjacent trees are ordered, each individual tree chronology is plotted. The cambial-ring year is shown as a dash and the pith year as "P." If the pith was not obtained, the earliest ring on record is shown as an "E." Cross sections that were exceptionally clear (without periods of very narrow rings or partially obscured growth) are given added weight: their scar years are marked with an "X." On cross sections where some rings are slightly obscured and dates are approximate, scar years are marked with a solid dot. On cross sections especially difficult to interpret, scar years are marked with an open dot.

Next, total the number of trees scarred each year on the right, as shown in figure 7. (Totaling is done for the entire study area if it is small, or for each geographic subdivision of a larger study area.) The probable fire years can now be determined by inspecting the plotted chronologies, giving more weight to tree records shown with an "X," and using the largest totals of individual scars as an indication of the probable fire year. Fire records (including maps of burned areas) and historical accounts should be examined; often these can be used to verify the year of fires occurring within the past century.

Inspection of this chart (exemplified by fig. 7) may reveal that part of the record for a certain tree is consistently a few years out of sequence with the established probable years (for example, tree number 1 in fig. 7). Often such an individual chronology can be brought into sequence by adding a few years at one point in time, thus moving its scar dates back. This phenomenon evidently results from missing rings and usually occurs during a period when the tree grew at an exceptionally slow rate. It probably represents a temporary cessation of growth caused by defoliation or severe fire injury. Craighead (1927) found that some ponderosa pines stopped forming annual rings for as many as 5 years after defoliation and extreme fire injury, although they remained alive and ultimately resumed growth.

In other cases, it may be possible to synchronize an individual tree's fire chronology with those of its neighbors by moving its scar dates forward slightly (subtracting a few years). This may be an indication of false rings. These are rather faint and often discontinuous. In the case of cross sections that cannot easily be correlated with the emerging master fire chronology, it is important to reexamine the ring counts and the probable origin of any questionable scars.

Unless a tree has definite scars from two fires within 3 years of each other, it is best not to hypothesize separate fires occurring on the same area at such short intervals. This suggestion is made because minor ring errors present in most samples do not allow for precise detection of such close-together fire years without the conclusive evidence of a dual scar. Fires occurring 4 or more years apart will be distinguishable on the chronology graph. Ring errors and diminishing sample size decrease the accuracy of fire-scar records more than 250 years old; nevertheless, fire frequency trends and

approximate fire years can be determined by correlating fire records extending back 300 years or more on a few trees.

When the preliminary master chronology is completed, individual tree chronologies should be adjusted to definite fire years and recorded in a revised master fire chronology for use in further analysis. The revised chronology (table 3) lists fire years by stand; it is explained more fully in the next section. At this point it may be possible to integrate fire-scar sequences obtained from stumps and dead snags whose cambial-ring year is unknown. The intervals between fire scars on the dead samples can be compared with the intervals found on nearby living trees. (The year of historic logging operations or settlement can be determined by correlating fire scars found on remaining stumps, or at the butt of logs in cabins, with the fire chronology.)

Table 3.--The master fire chronology for a large study area, showing the number of sample trees scarred during each fire year in each stand and indicating fires that caused conifer regeneration (modified as an example from Arno 1976)

Fire year	STAND										Total number of scars (45)
	A.1 (4)*	B.1 (5)	B.2 (4)	B.3 (2)	D.1 (6)	D.2 (6)	D.3 (4)	E.1 (8)	E.2 (6)		
1935	--	--	--	--	1	--	--	--	--	1	
1908	3	--	--	--	1	--	--	--	--	4	
1898	1	--	--	--	--	--	--	--	--	1	
1892	4	3 ^r	-- ^r	1	2 ^r	--	-- ^r	--	--	10	
1889	--	--	--	--	2	--	--	--	2 ^{r?}	4	
1886	2	--	--	--	--	--	--	--	--	2	
1881	4	2	--	--	--	--	--	--	--	6	
1871	3	1 ^{r?}	2	2	1	3 ^r	-- ^r	1 ^r	--	13	
1863	3	3	1 ^r	--	2 ^r	--	--	--	--	9	
1855	--	--	1	--	--	--	--	--	--	1	
1847	3	3	2	2	5 ^r	5 ^r	3 ^r	-- ^{r?}	--	23	
1842	4	--	--	--	--	--	--	1	--	5	
1838	--	--	--	1	--	--	-- ^{r?}	--	--	1	
1828	3	--	2	--	--	--	--	--	--	5	
1821	--	2 ^r	-- ^r	1	3	--	-- ^r	1 ^r	--	7	
1817	3	1	--	--	--	--	--	--	--	4	
1811	--	--	--	1	--	1	--	1 ^r	2 ^r	5	
1803	4	1 ^{r?}	1	--	--	--	--	--	--	6	
1794	--	1	1 ^r	--	--	--	--	--	--	2	
1785	3	4	--	1	3 ^r	5 ^r	4 ^r	7 ^r	4 ^r	31	
1779	1	--	--	1	--	--	--	--	--	2	
1769	--	--	1	--	--	--	--	--	--	1	
1766	2	--	--	--	--	--	--	--	--	2	
1757	--	1	--	1	2 ^r	1	1	5	-- ^{r?}	11	
1752	--	3	--	1	1	1 ^r	3	2	-- ^{r?}	11	
1750	4	--	--	--	--	--	--	--	--	4	
1747	--	1	1 ^r	--	--	1	--	1	--	4	
1743	--	--	--	--	--	--	--	1	-- ^{r?}	1	
1734	--	--	1	--	--	1	--	--	--	2	
1730	--	--	--	1 [?]	--	--	--	--	--	1 [?]	
1720	1	2	--	--	--	--	2	--	--	5	
1710	1	--	1	1	--	--	--	--	--	3	
1698	--	--	--	--	1	--	--	--	--	1	
1686	1	1 ^r	--	--	--	--	--	--	--	2	
1677	--	--	--	--	1	--	--	-- ^{r?}	--	1	
1670	--	--	--	--	--	1	--	--	--	1	
1664	--	--	1	--	--	--	--	--	--	1	
1658	--	--	--	1	2	--	--	--	--	3	
1636	--	--	--	--	1	--	--	--	--	1	
1632	--	--	--	--	--	--	--	1 ^{r?}	--	1	
1611	--	--	1	--	--	--	--	--	--	1	
1595	--	--	--	--	--	--	--	1 ^{r?}	--	1	
1587	--	--	1	--	--	--	--	--	--	1	
1574	--	--	1	--	--	--	--	--	--	1	
Total scars	50	29	18	15	28	19	13	22	8	202	

* Number of sample trees.

^r Fires causing conifer regeneration based on stand age-class samples.

? Data weak.

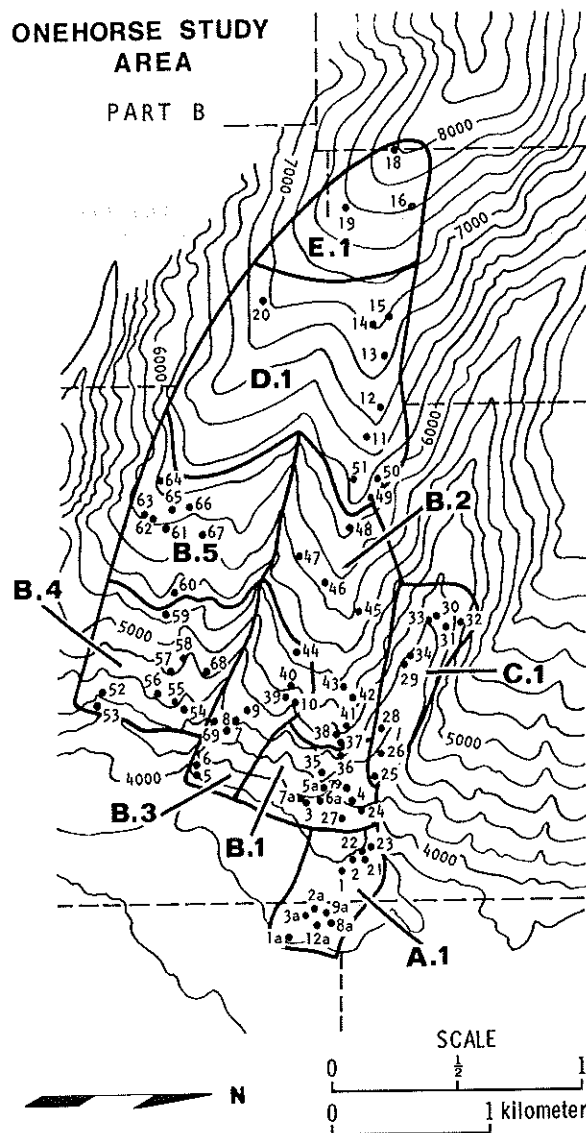
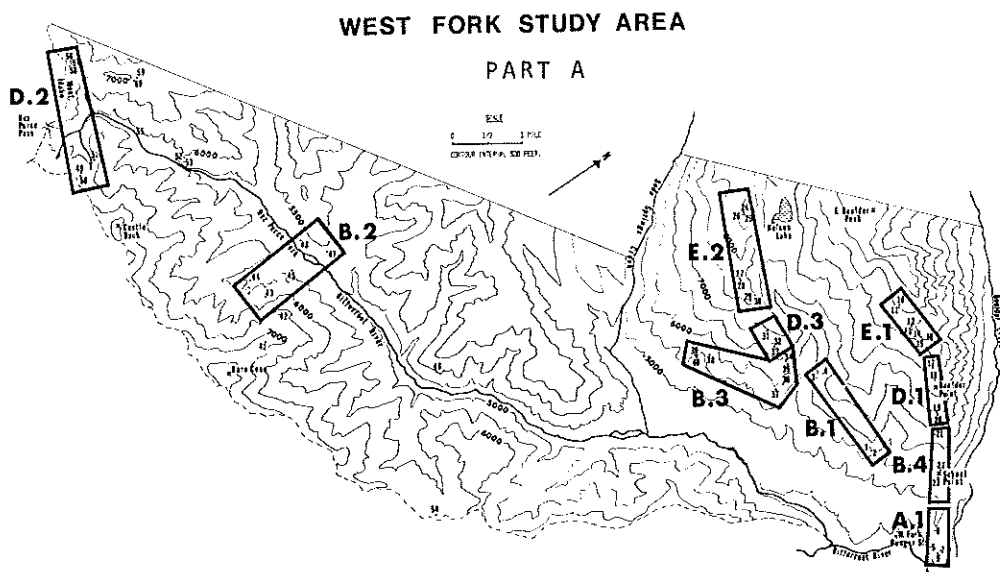


Figure 8.--Topographic maps of two study areas showing sample trees (numbers) and stands by habitat-type groups (letter-number code). Compare part A with table 4, column 10. Compare part B with table 4, column 6.

Table 5.--An example of fire frequency calculations for different stands within a single study area (Arno 1976). Stand locations are shown in figure 8B, Onehorse Study Area

Stand	No. of sample trees	No. years in period	Time period 1735 to 1900					Minimum and maximum fire-free interval
			Total no. fires	÷	Fire frequency	=		
							Years	
A.1	11	165	÷	29	=	5.7	2 & 20	
B.1	10	165	÷	24	=	6.9	3 & 21	
B.2	9	165	÷	18	=	9.2	3 & 28	
B.3	10	165	÷	15	=	11.0	3 & 31	
B.4	9	165	÷	24	=	6.9	3 & 15	
B.5	8	165	÷	12	=	13.8	3 & 31	
C.1	9	165	÷	10	=	16.5	3 & 32	
D.1	9	165	÷	10	=	16.5	3 & 33	

After the "historic fire frequency" period has been established, see how far back in time comparable frequencies were recorded. For example, in figure 9 the analysis period was 1735 to 1900, but it was reasoned that comparable frequencies extended back to about 1630 (see also table 3). Thus, rates established on the basis of a 165-year interval were apparently representative for a period of about 270 years (1630 to 1900).

It may be desirable also to calculate fire frequencies for the transition period (for example, 1900 to 1925) between the "historic" and "suppression" periods.

An example of fire frequency calculations for such periods is shown in table 5. The mean, minimum, and maximum fire-free intervals are shown for each stand. Mean intervals can be averaged for all stands in a habitat-type group. For example, the five stands in habitat type group B, table 5, have a mean fire-free interval of 10 years--this mean is shown in column 7 of table 4. This facilitates comparison of fire frequencies from one study area to another in similar habitat types, as shown in table 4. Also, comparing values from the "historic" and "suppression" periods will indicate the effect of suppression on fire frequency.

Analyzing Age Classes

The first major step in age-class analysis is to count annual rings on the increment cores gathered in field transects. Counts should be made using a variable-power binocular microscope, with the cores wetted, shaved, and sanded as necessary. Counts begin at the cambium and progress to the pith as was done in cross-section analysis. Every 10th ring (outer edge of summerwood band) should be marked with a fine red line (or a dissecting-needle puncture) and every fifth ring with a dot. Counts are made to the innermost ring or the pith and written on the core board next to the field data for that tree, as shown in figure 3.

Where an increment core missed the pith, the number of additional rings to the pith is estimated by considering the curvature and thickness of the innermost rings. As illustrated in figure 3, it is helpful to draw the circles represented by the arc of the inner rings, using a compass, and then extrapolate a similar ring width to the pith. The estimated number of additional years to the pith is then written next to the ring count with a plus sign (for example, "86 + 4").

After the counts are completed and verified, they should be tabulated by plot. Total ages of trees from each plot are listed in chronological order as shown in figure 10. To obtain the total age, add an estimate of the number of years for establishment

Once the tentative age classes have been assigned, based on the oldest tree in each class, the next step is to test for correlations between age classes and the fire-scar chronology. Consult the study area map and find the stand number (fig. 8) that applies to each age-class plot. Plots isolated from designated stands should be analyzed separately, afterwards.

The next step is to examine apparent correlations between each tentative age class and the fire years identified on that stand. For example, if an age class is 115 years (total age of the oldest trees in the class) in 1975, one would expect it to have resulted from a fire occurring only one or a few years before 1860. We can check the master fire chronology (table 3) to see if a fire was detected (via scars) in that stand a few years prior to 1860. Ten or twelve years might be considered to be a reasonable maximum interval for initial establishment after fire on most sites. Longer intervals are reasonable after very large stand-destroying fires.

If there is no fire-scar evidence during the preceding years and the age class seems rather definite, inspect fire-scar records from neighboring stands. If they show a definite fire, one can assume that it actually spread into this stand although it did not scar the sample trees. Another possibility is that very few trees in the entire area survived that fire. If this is the case, age-class data from other plots and transect notes will confirm it. Age classes not ascribable to any of the above situations apparently are not related to fire.

Considerable insight regarding the historic role of fire in age-class structure of forests can be obtained by incorporating the age-class data into the fire chronologies for each stand as shown in table 3. If these data show that age classes of seral species were apparently established without fire, this suggests that other agents such as epidemics of native insects or diseases or massive blowdowns were responsible. If these data (table 3) show that certain fires were not followed by pronounced regeneration, regeneration may have been destroyed by subsequent fire before the trees had grown large enough to withstand fire. (The fire records should be checked for this possibility.) Another possibility is that creeping ground fires did not kill enough of the stand to allow for a new age class.

Mapping Historic Fires

The size and perhaps the configuration of historic fires can be found by plotting fire evidence on a small map of the study area (fig. 11). Map each fire year (from the master chronology) separately. Indicate locations of trees scarred that year by placing an "s" next to the dot representing that tree. Indicate regeneration attributed to that fire year by drawing an "r" in the correct plot location. Using this evidence of the fire, one can now roughly outline the area covered. Aerial photos and fire suppression records may also be useful. Heinselman (1973) and Tande (1977) have made detailed maps showing areas covered by many individual fires during the course of two centuries.

INTERPRETATIONS

By inspecting the results of these various analyses, the investigator can summarize fire frequencies for both the "historic" and "suppression" periods by habitat types. He can document effects of natural fire on forest composition and stand structure by habitat type (columns 4 and 5, table 4). Using current timber type (timber inventory) and habitat-type information, he can estimate the probable effects of current fire management on forest composition, stand structure and, possibly, fuel accumulations. Considering fire frequencies and relating the maps of historic fires to the surviving tree growth as well as to age-class information in general, he can interpret relative fire intensities experienced in the various stands and habitat types. Stand-destroying fires, for instance, will be obvious from age-class data, since no surviving trees are to be found except for widely scattered veterans that generally have a scar dating to that fire. Maximum historic intervals between natural fires can be compared with intervals during the suppression period to judge ecological implications.

This information on fire history and vegetation can be correlated with fuel inventories, insect and disease information, wildlife-habitat trends, etc., to estimate the effects of various types of fire management practices. Thus, these findings should also help in selection of reasonable goals and methods for fire and fuel management.

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Describes a method for determining historic fire frequency, intensity, and size from cross sections collected from fire-scarred trees and tree age classes determined through increment borings. Tells how to interpret the influence of fire in stand composition and structure and how to identify effects of modern fire suppression.

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