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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

THE AUTHORS

STEPHEN F. ARNO is a Plant Ecologist on the Forest Ecosystems research work unit at Missoula. He earned a B.S. in forestry at Washington State University and a master's degree and a Ph.D. in forestry and plant science at the University of Montana before joining the Forest Service in 1970. This study was supported by the Fire in Multiple Use Management Research, Development, and Application Program headquartered at the Northern Forest Fire Laboratory in Missoula.

KATHY M. SNECK earned a B.S. in forestry at the University of Montana and worked 4 years as a forest fire research officer for the Forest Research Institute, CSIRO, Australia. She is now completing a master's degree in forestry at the University of Montana--her thesis presents the fire history of Coram Experimental Forest (east of Kalispell, Montana). She plans to follow a career in fire management and research.

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RESEARCH SUMMARY

This General Technical Report describes a method for investigating the history and ecological influences of wildfire in the inland coniferous forests of western North America.

The method relies on the collection and analysis of cross sections of fire-scarred trees and the identification, from increment cores, of age classes of postfire tree species. In logged areas, fire-scar and age-class data can be gathered from stumps.

The Report covers selection and layout of study areas, and the collection and analysis of samples. The authors tell how to interpret fire frequency, intensity, and size; the influence of fire on stand composition and structure; and the effects of modern fire suppression.

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.

Manpower and equipment for obtaining fire history information are not extensive. Once the study site has been selected and initial preparation made, estimated manpower allocations are as follows:

Type of Study Area	*Manpower*
1. Small (100 to 300 acres, 40 to 120 hectares), having one or a few closely related habitat types	Principal investigator: 1 to 2 weeks (field investigations and sampling, final analysis and writeup)
	Technician: 2 to 3 weeks (help with fieldwork, preparation and basic analysis of field collections)
2. Large (5,000 to 10,000 acres, 2,000 to 4,000 hectares), having diverse forest habitat types and physiography	Principal investigator: 6 to 8 weeks
	Technician: 10 weeks

About 70 percent of the time is spent in the office (planning, analysis, and writeup) and can be done during any season.

SELECTION OF A STUDY AREA

Topography and forest types should be representative of a larger vicinity to allow for reasonable extrapolation of the study results. If results will be applied to a sizable region--for example, 1,000,000 acres (400,000 ha)--it is advisable to set up three or more large study areas in different parts of the region. A watershed or other logical geographical unit should be selected as a study area and outlined on a large-scale topographic map (7-1/2 minute series or, better, 4 inches per mile). Areas with substantial remnants of unlogged or lightly selection-cut forest are most favorable for study, although it is often helpful, especially in moist forest types, to include some heavily logged areas where stumps can be analyzed for buried (healed over) fire scars. This method can also be used in logged areas where stumps are still relatively sound (stumps 30 or 40 years old are often satisfactory).

Road access should be available at least to the periphery of the study area, and in a large study area a network of trails and roads is helpful.

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.

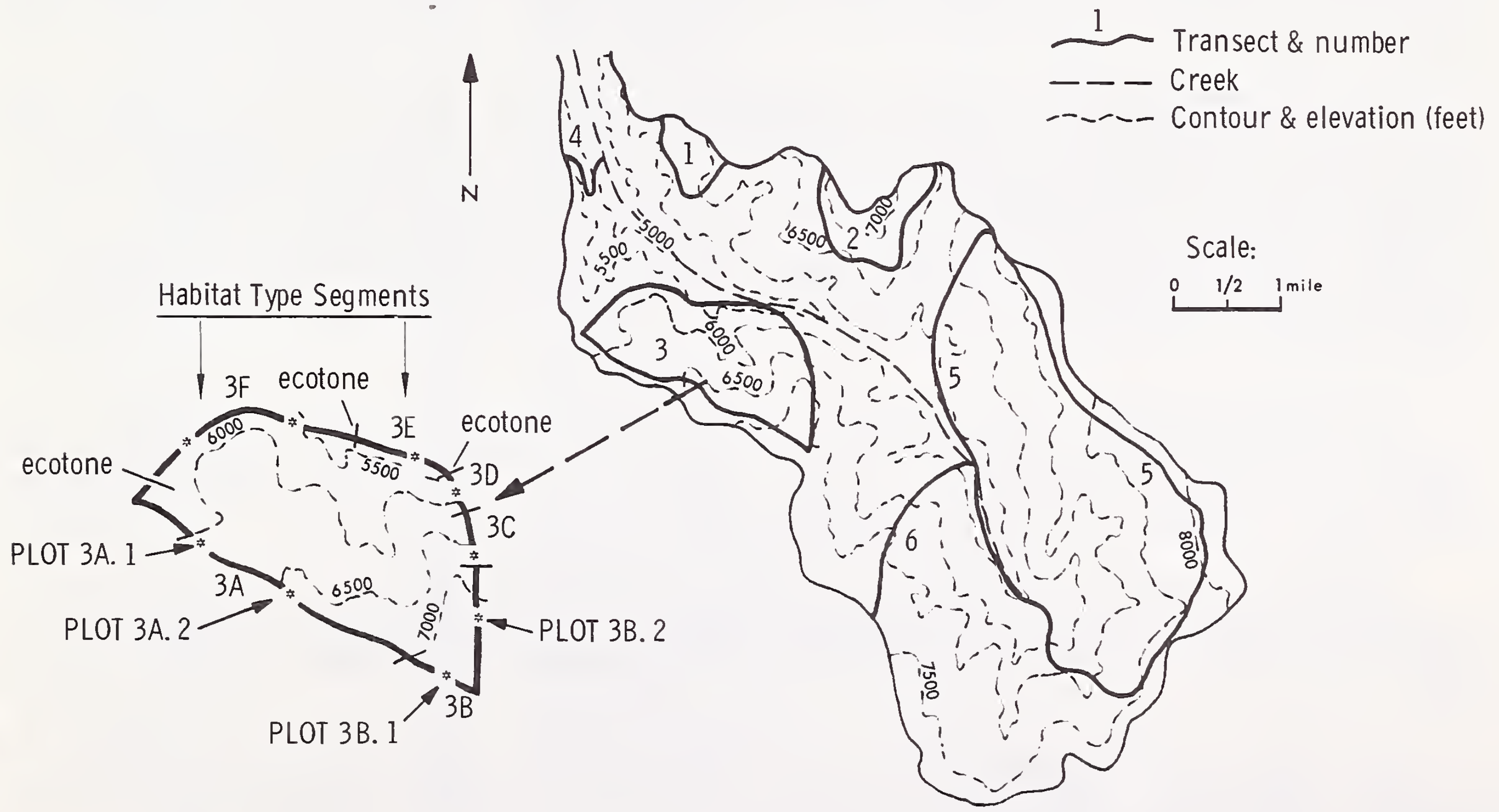


Figure 1.--Topographic map of a study area showing network of transects (which utilized trail and road access) and transect numbering scheme. Enlargement of transect 3 shows habitat type segments (3A, 3B, etc.), ecotones, sample plots (*).

Gathering Data

Recording Habitat Types

A continuous log of the forest habitat types should be kept along the transect route, by means of the most current forest habitat-type classification (or similar, ecologically based stratification of forest environments) applicable to the area. The status of these classifications in the western United States is explained in detail by Pfister (1976). In unclassified areas, it should be possible to adapt a broader system based on potential climax tree species, similar to the series level of a habitat-type classification. Vegetation should be carefully documented on habitat type-stand composition plots (described later using a field-form checklist like figure 2). Logged areas can be habitat typed by extrapolating from similar unlogged sites nearby or by using other techniques described in Pfister and others (1977).

As shown on figure 1, boundaries (ecotones) between each habitat-type segment along the transect should be determined on the ground and drawn across the transect on the topographic map. The location of each habitat-type plot should also be drawn on the map. The completed habitat-type transects can provide a basis for identifying the topographic and elevational characteristics associated with each habitat type (and, optionally, for preparing a habitat-type map of the study area). This will allow for a comparison of the role of fire by habitat type and will aid extrapolation of findings to adjacent areas having similar habitat types.

Obtaining Stand-Composition and Age-Class Data

Within each habitat-type segment of the transect, the investigator should subjectively select a site for a 1/10-acre (0.04-ha) plot having representative timber type and stand conditions. He should then record all tree species by 2-inch (5-cm) size classes in the plot. The habitat-type field-form (fig. 2) should be filled out here also.

Next, increment cores should be taken at 1 foot (0.3 m) above ground level to determine the age classes of seral tree species in the stand. Significant quantities of seral species (for example, ponderosa pine in a potential Douglas-fir climax stand or lodgepole pine in a potential subalpine fir climax) commonly regenerate after a fire. Thus age class data will be essential for interpreting the historical effects of fire on stand composition and structure. Where seral trees are unavailable, the climax species can be used with the understanding that they are less likely to have originated after a fire.

A minimum of three trees should be bored for each apparent age-size class. Rings should be carefully counted in the field with a 10-power hand lens. If the three trees representing one size class differ by more than 10 years, additional trees should be bored until each age class is represented by at least three (preferably seral) trees.

Field notes should be taken to describe stand composition (tree species) and apparent age classes along the transects. This will provide valuable information, augmented by the plot and fire-scar data, for interpreting the effects of historical fire.

All cores should be glued into core-mounting boards (fig. 3) for laboratory analysis, and labeled with the location, code number (transect number, habitat-type-segment letter, and plot number), tree species, and diameter at breast height (d.b.h.). A core board is made by cutting grooves in 1- by 8-inch (2.5- by 20-cm) lumber on a table saw. A bead of Elmers or similar "white glue" is spread in the bottom of a groove, the core is then placed in the groove, and a second core board is placed, smooth side

NAME John Doe		DATE 8-1-76			
	(CODE DESCRIPTION)	Plot No.	3A.1	3A.2	3B.1
	HORIZONTAL	Location	FIRE SCAR	STUDY AREA	
TOPOGRAPHY:	CONFIGURATION:	CANOPY COVERAGE CLASS: T, R, S	15N 19W 27	15N 19W 28	15N 19W 28
1-Ridge	1-Convex (dry)	0=Absent 3=25 to 50% Elevation	6100'	6600'	7200'
2-Upper slope	2-Straight	T=Rare to 1% 4=50 to 75% Aspect	NW	NW	NW
3-Mid slope	3-Concave (wet)	1=1 to 5% 5=75 to 95% Slope	20 %	25 %	22 %
4-Lower slope	4-Undulating	2=5 to 25% 6=95 to 100% Topography	2	3	3
5-Bench or flat		Configuration	2	2	2
6-Stream bottom		NOTE: Rate trees (>4" dbh) and regen (0-4" dbh) separately (e.g., 4/2)			

TREES Scientific Name	Abbrev	Common Name	Canopy Coverage Class		
1. Abies grandis	ABGR	grand fir	/	/	/
2. Abies lasiocarpa	ABLA	subalpine fir	2 / 1	1 / 2	1 / 2
3. Larix lyallii	LALY	alpine larch	/	/	/
4. Larix occidentalis	LAOC	western larch	/	/	/
5. Picea engelmannii	PIEN	Engelmann spruce	T / T	T /	T /
6. Picea glauca	PIGL	white spruce	/	/	/
7. Pinus albicaulis	PIAL	whitebark pine	1 / T	1 / T	2 / T
8. Pinus contorta	PICO	lodgepole pine	T /	2 / T	T /
9. Pinus flexilis	PIFL	limber pine	/	/	/
10. Pinus monticola	PIMO	western white pine	/	/	/
11. Pinus ponderosa	PIPO	ponderosa pine	/	/	/
12. Pseudotsuga menziesii	PSME	Douglas-fir	/	/	/
13. Thuja plicata	THPL	western redcedar	/	/	/
14. Tsuga heterophylla	TSHE	western hemlock	/	/	/
15. Tsuga mertensiana	TSME	mountain hemlock	2 / 1	/ T	/
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. Oplopanax 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			
20. Vaccinium globulare (+ membranaceum)	VAGL	blue huckleberry	2	1	
21. Vaccinium scoparium (+ myrtillus)	VASC	grouse whortleberry	2	3	4
PERENNIAL GRAMINOIDS					
1. Agropyron spicatum	AGSP	bluebunch wheatgrass			
2. Andropogon spp.	AND	bluestem			
3. Calamagrostis canadensis	CACA	bluejoint			
4. Calamagrostis rubescens	CARU	pinegrass			
5. Carex geyeri	CAGE	elk sedge	T		
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	sweetscented 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	T		
20. Xerophyllum tenax	XETE	beargrass	3	3	2
		SERIES	AF	AF	AF
		HABITAT TYPE	MH/MEFE	AF/MEFE	AF/LUHI
		PHASE			MEFE

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

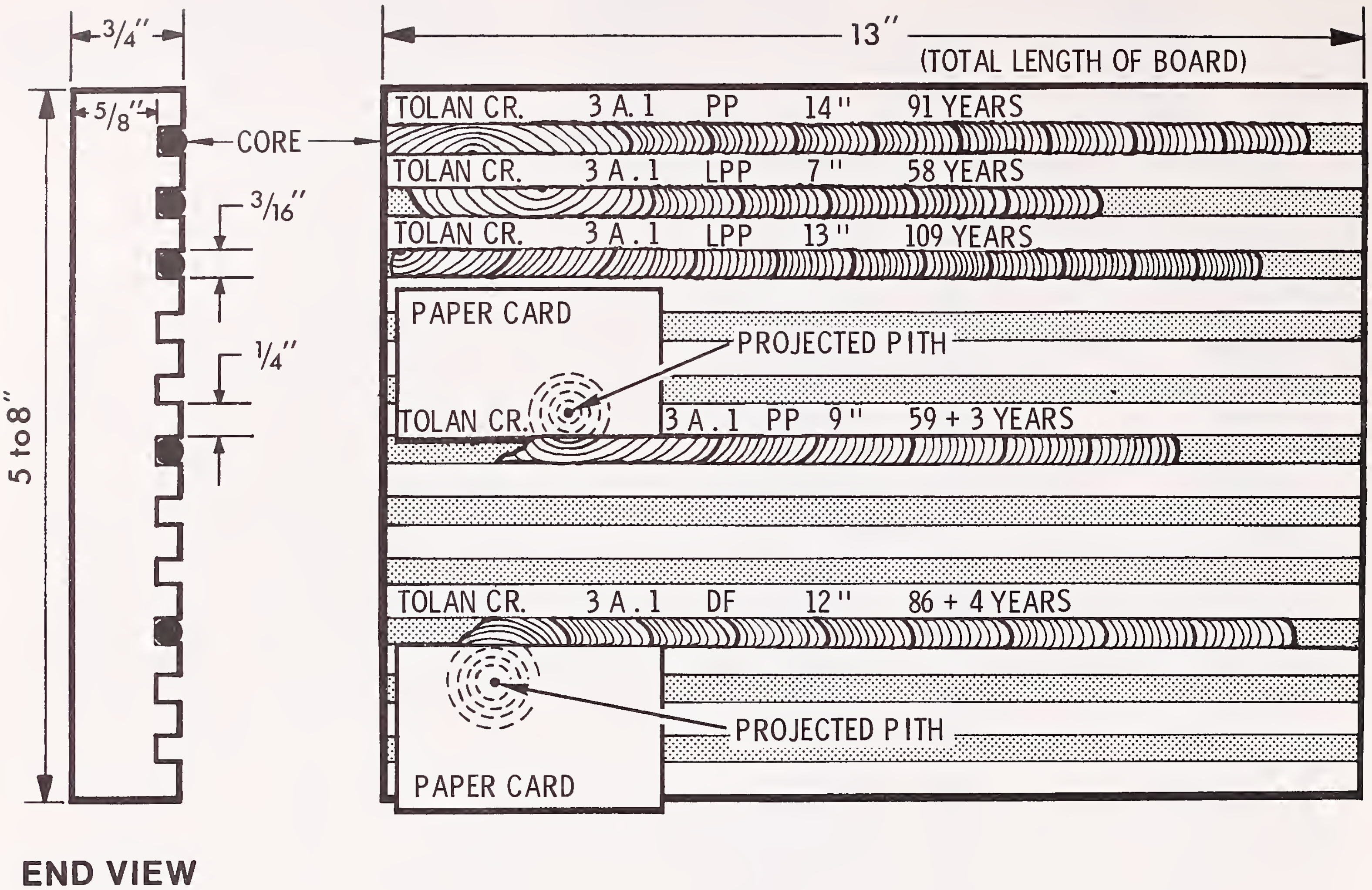


Figure 3.--Increment core mounting board, showing increment cores, ring-counting techniques, and labeling system.

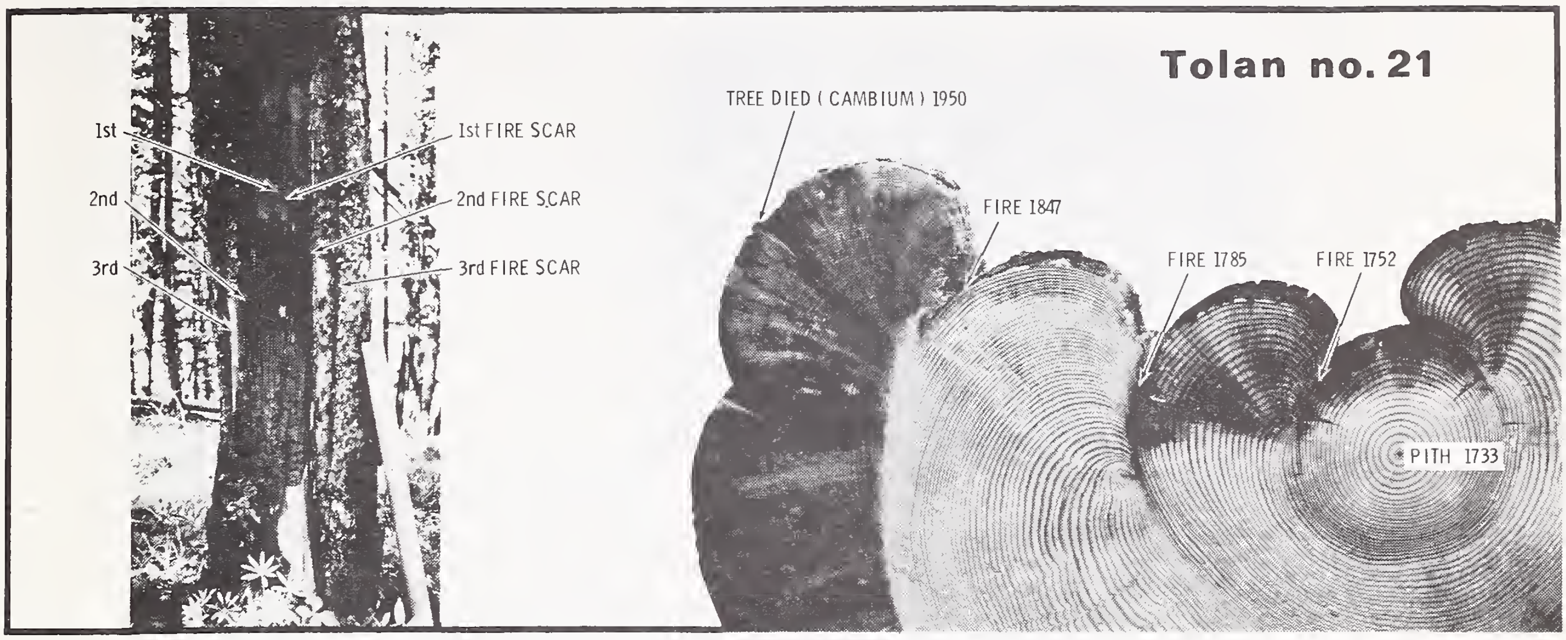
down, atop the first board. The two boards are then held together with a pair of heavy rubber bands. Also, cores can be carried in labeled plastic drinking straws while in the field, then transferred to core boards.

Stand-composition and age-class information can be collected in stands that have been clearcut or heavily logged if stumps are not too rotten or too burnt to age and if the year of logging can be determined. Species can be identified from the bark. Total age can be gathered by cross sectioning sound stumps with a chain saw; ring counts should be confirmed in the lab.

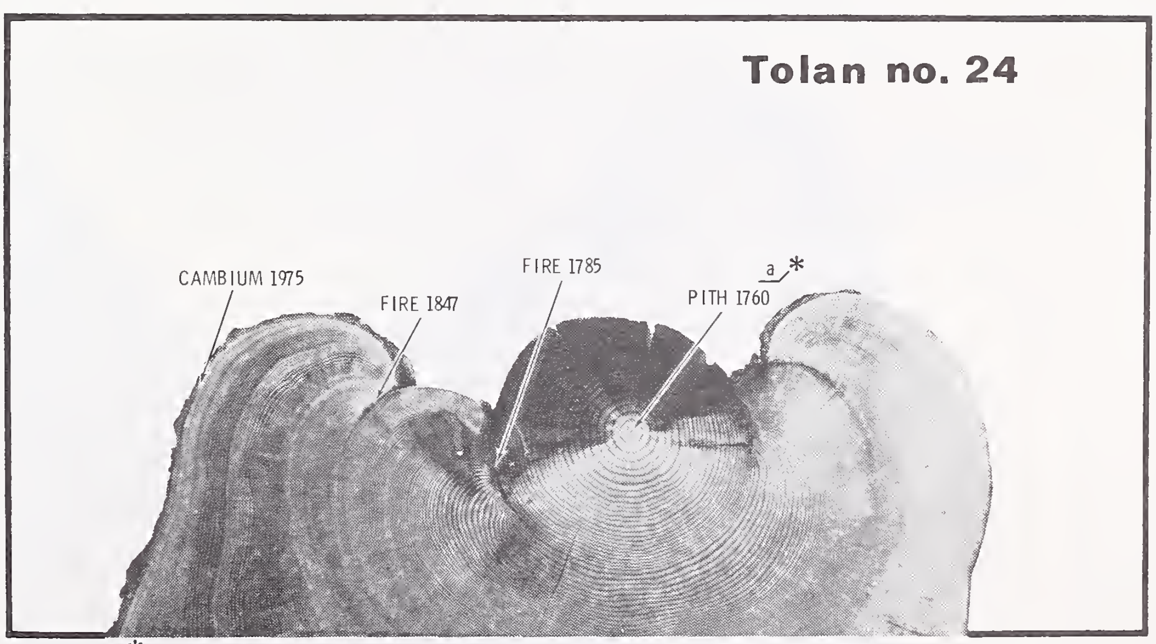
Documenting Fire-Scarred Trees

The investigator and technician should locate and record all fire-scarred trees in a swath of forest along the transect route. By walking parallel about 50 yards (45 m) apart, they can cover a swath about 100 yards (91 m) wide in relatively open forests. They should keep constant watch for the oldest "catfaced" trees available. (Catface is a term for an open scar resulting from one or more fires.) On each catface, the number of external fire scars should be counted. Each individual fire scar has a separate fold or band of healing tissue, often appearing on both sides of the catface. Sometimes these folds are partially or wholly burned off by subsequent fires, but usually a portion of each fold remains at least on one side of the catface a foot (0.3 m) or more above the ground. Figure 4 shows some examples of catfaces and corresponding cross sections of the fire scars. Catfaces are most prevalent on the upslope side, especially on old-growth trees that lean upslope.

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

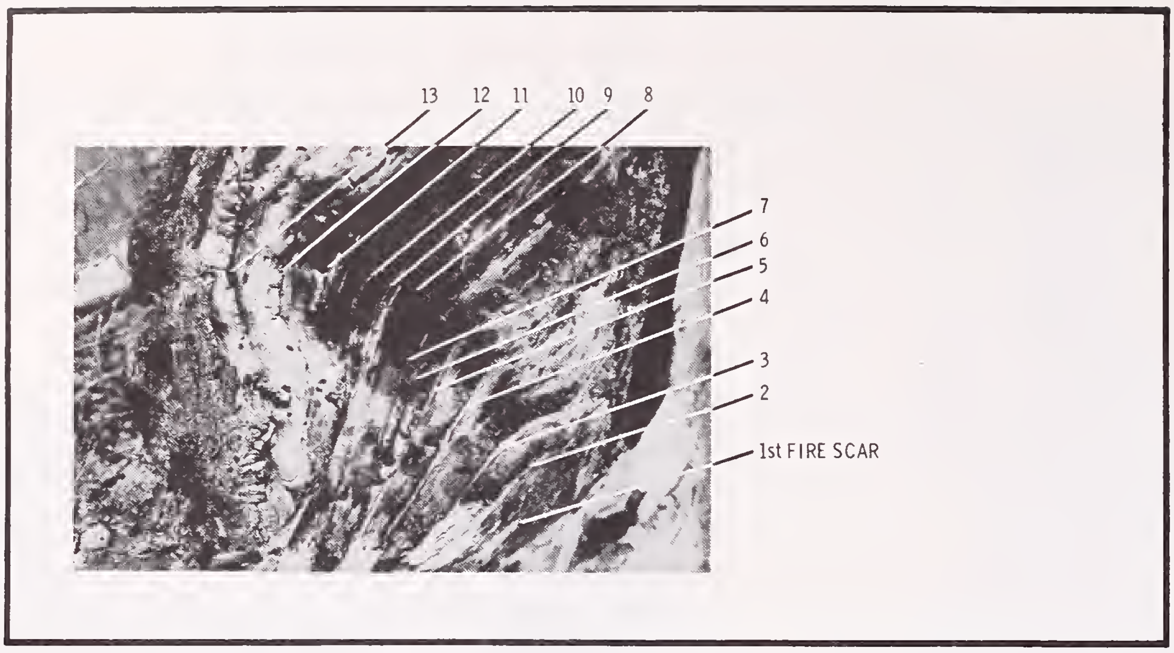


4-A. Lodgepole pine with three fire scars

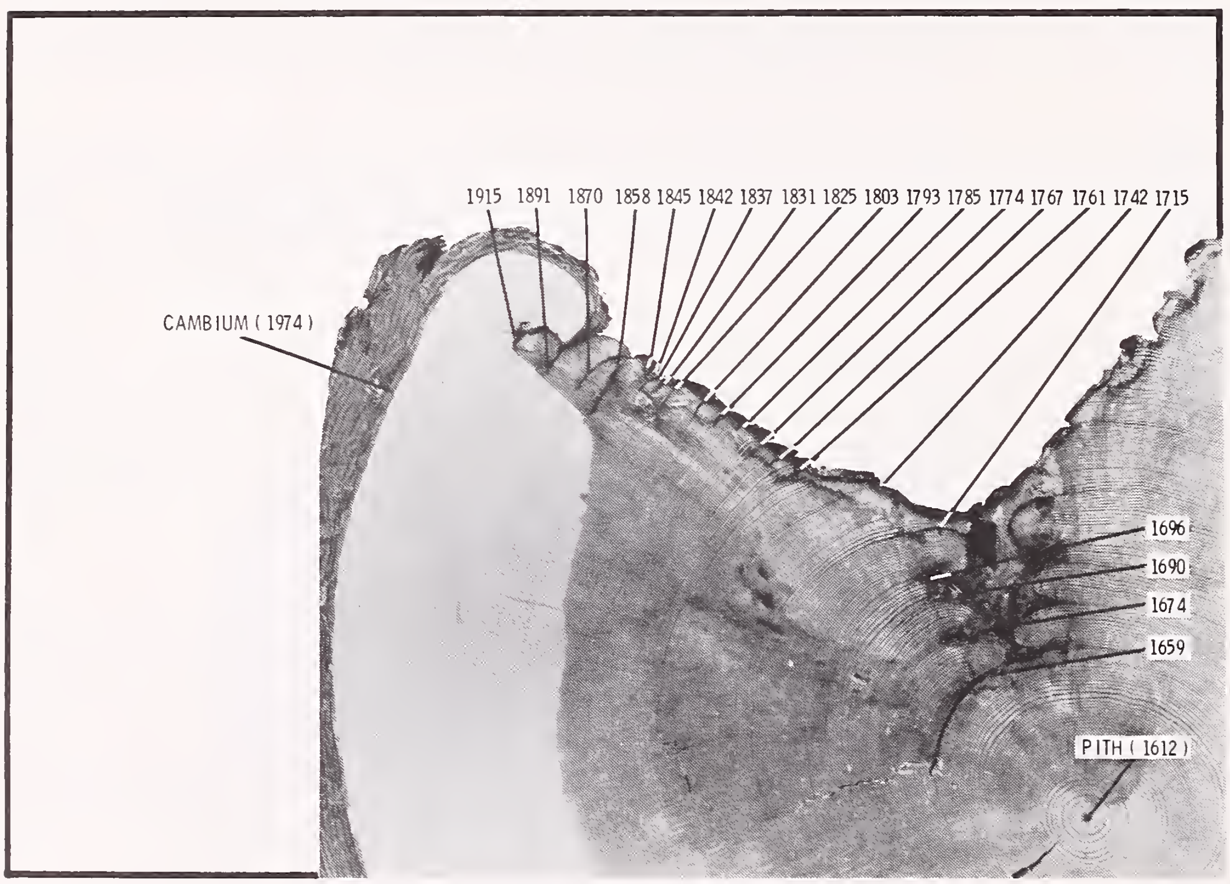


a/* This tree probably germinated about 1755 and apparently represents regeneration from the 1752 Fire shown in part A.

4-B. Nearby lodgepole pine with two fire scars



4-C. Old ponderosa pine stump with 13 externally visible scars



4-D. Ponderosa pine cross section with 21 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.

Table 1.--A "Log of Fire scarred Trees" examined in the field reconnaissance (part A), and the log of trees actually sampled (part B), in study area

PART A. LOG OF FIRE-SCARRED TREES

Transect number, h.t. segment letter, and scarred-tree numeral	Species	d.b.h.	Maximum height of cat-face	(Apparent) number of external scars	Elevation	Aspect	Remarks
		Inches	Feet		Feet	Degree	
1A-I	PP	24	6	7	4,650	110	Across bridge, 200 ft below rock outcrops, good cross section
1A-II	PP	29	7	13	5,050	90	Below large Douglas-fir snag, good c.s.
1A-III	PP	32	7	11	4,750	100	100 yds below ridgetop, good c.s.
1A-IV	LPP	20	6	4	4,800	120	Flagged close to 1A-III, slightly rotten
1B-I	PP	49	20	4	5,800	190	Possibly lightning struck, good c.s.
1B-II	PP	31	16	2	5,500	170	In dense stand of young PP, good c.s.
1B-III	PP	22	10	4	5,600	200	Double trunk, 50 yds east of trail
1B-IV	PP	20	8	1	5,500	180	In dense stand of young PP, not a good sample
1C-I	DF	24	10	2	5,400	80	Below ridge, flagged
1C-II	DF	16	3	4	5,400	65	Below ridge
1C-III	PP	23	15	6	5,650	70	On ridge spur, good c.s.

PART B. LOG OF SAMPLED TREES

Sample tree number	Reconnaissance code	Species	d.b.h.	Maximum height of cat-face	(Apparent) number of external scars	(Actual) number of internal scars	Elevation	Aspect	Habitat type and phase	Photo number	Remarks
			Inches	Feet			Feet	Degree			
1	1A-I	PP	24	6	7	9	4,650	110	DF/AGSP	1	335° from bridge, 200 ft below rock outcrops
2	1A-II	PP	29	7	13	14	5,050	90	DF/CARU PIPO	2	315° from bridge, below large DF snag
3	None 1/	PP	23	5	12	13	5,050	80	DF/AGSP	3	120 yd S of tree no. 2
4	1A-III	PP	32	7	11	13	4,750	100	DF/AGSP	4,5	100 yd below ridgetop
5	1B-I	PP	49	20	4	4	5,800	190	PP/FEID	13,14	Lightning struck
6	None 1/	PP	19	3	4	4-5	5,200	200	PP/FEID	15	100 yd N of road above pullout
7	None 1/	PP	24	3	6	7	5,650	200	PP/FEID FESC	16	Dead snag (died ca. 50± yr ago)
8	1B-III	PP	22	10	4	5	5,600	200	PP/FEID FESC	17	Double trunk, 50 yd E of trail
9	1C-II	DF	16	3	4	5	5,400	65	DF/PHMA PHMA	18	Below ridge 150 feet
10	1C-III	PP	23	15	6	6	5,650	70	DF/PHMA	19	On ridge spur

1/ Not previously discovered.

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.

Small sample trees--those less than a foot (0.3 m) thick at stump height--should generally be felled, cutting them off either well below or well above the point on the trunk where the clearest scars are apparent. After felling, cut the stump or downed tree to obtain the clearest cross section with the maximum number of fire scars.

Large, relatively sound trees are usually best sampled by taking a partial cross section from one side of the catface. As illustrated in figure 5, the pith, fire scars, and cambium can usually be obtained by severing only about 10 to 15 percent of the stem. A roller or sprocket-tipped chain saw (20- or 24-inch bar) is used to make parallel, horizontal cuts 1-1/2 to 2 inches (4 to 5 cm) apart. These extend from the pith to the cambium across the clearest portion of the scar sequence, on only one side of the catface. The cut is made just deep enough to insure that it goes behind the deepest penetration of each scar so the count can be made in unscarred tissue. (Normally this will be 3 to 4 inches deep.) Then the tip of the saw is pushed in vertically along the back of the parallel cuts, from cambium to pith. The saw wound can be painted with an asphalt-base tree paint to prevent entrance of insects or disease (McBride and Laven 1976).

Inspect the partial cross section to insure that it does extend behind each scar. Draw arrows perpendicularly across any broken parts to aid reassembly. (Glue the parts back together in the lab.) Write the sample tree number (table 1, part B) in ball-point ink on all pieces in two places on the back of the cross section, where it will not be sanded off. Also, write the sample number conspicuously on the tree or stump or use a small metal tag for this purpose.

Compare the number of fire scars on the cross section with scars on the catface. Small scars that may represent scrapes or rodent damage when the tree was a sapling should be denoted. Scrape scars resulting from falling trees and scars from mountain pine beetle attacks should be analyzed and discounted in the field also. Scrape scars are generally longer than fire scars, and the remains of the fallen tree causing the scrape can usually be found. Scars from beetle attacks often result from dieback of the cambium at more than one place along a given annual ring; these scars have an irregular shape and may be correlated to a known epidemic year.

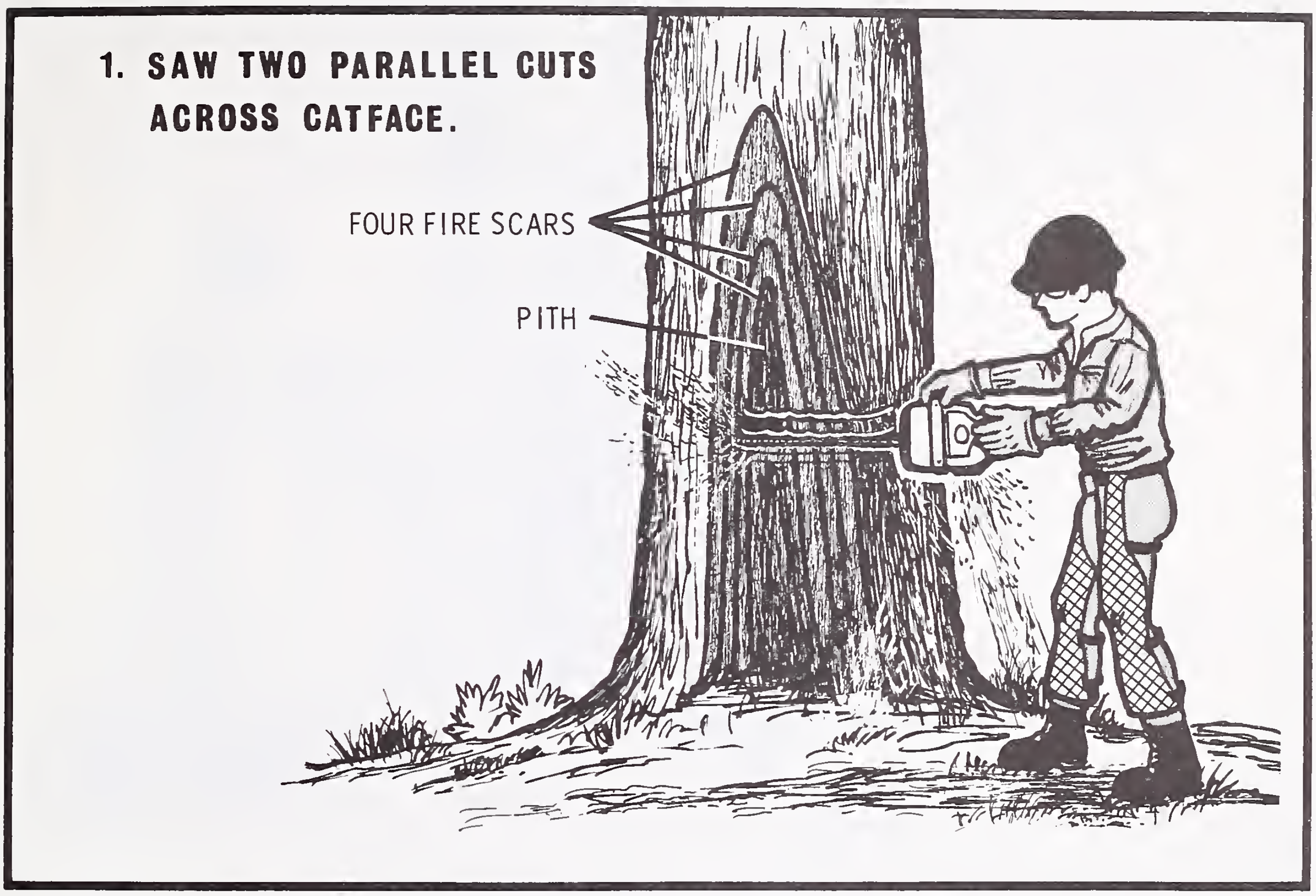
Basal scars may be caused by root rot (*Armillaria mellea*), but these usually extend up basal root buttresses rather than forming in the hollows between buttresses like fire scars. Also unlike fire scars, rot scars are not correlated with the upslope side of trees. Various cankers or animals also cause scars; these are not usually basal, bear little resemblance to fire scars, and do not char wood.

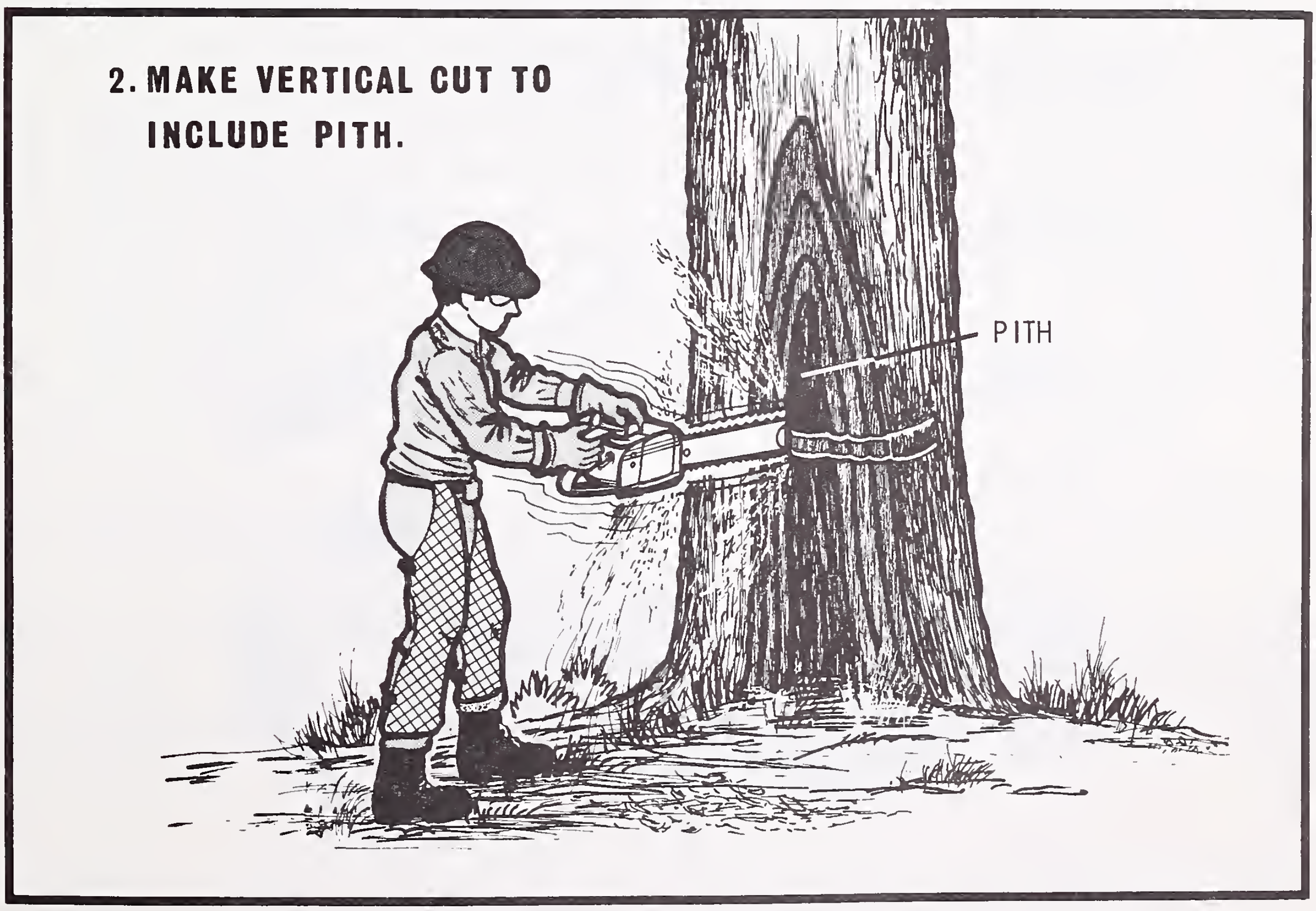
After counting the fire scars on the sample tree's cross section, enter the total in the Log of Sampled Trees (part B of table 1). Examine each tree and cross section carefully in the field because the catface and additional cross sections will not be available for checking in the laboratory.

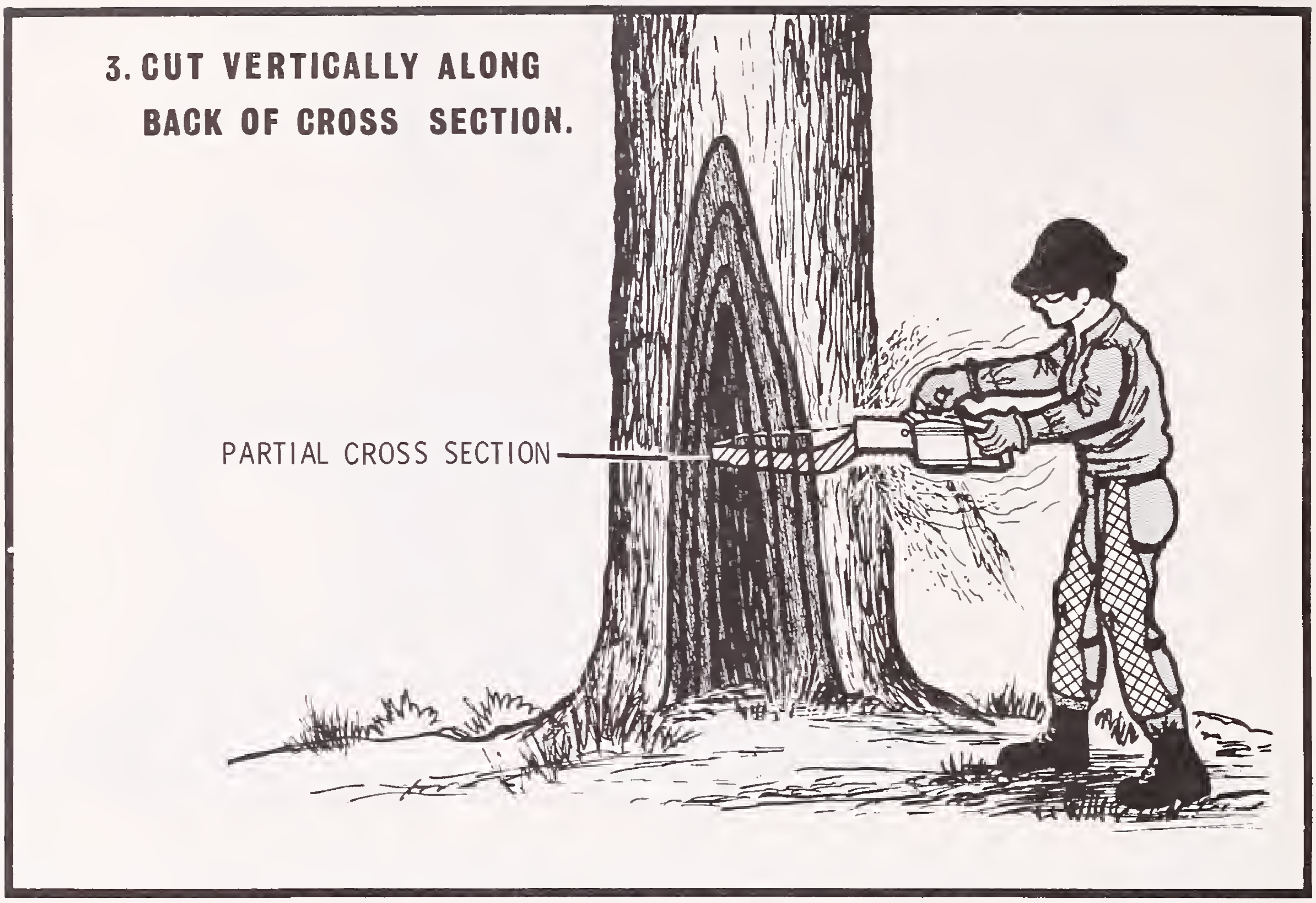
When sampling logged areas, photograph the top of each stump (vertically), using markers to pinpoint each fire scar and the pith. Preliminary ring counts can be made in the field, using a 10X hand lens if necessary. Cross sections of sound stumps can be cut and taken to the lab for documentation and for ring counting with a microscope. If the stump is not sound enough to section, obtain the best estimate of fire scar and pith dates, counting the rings several times if necessary.

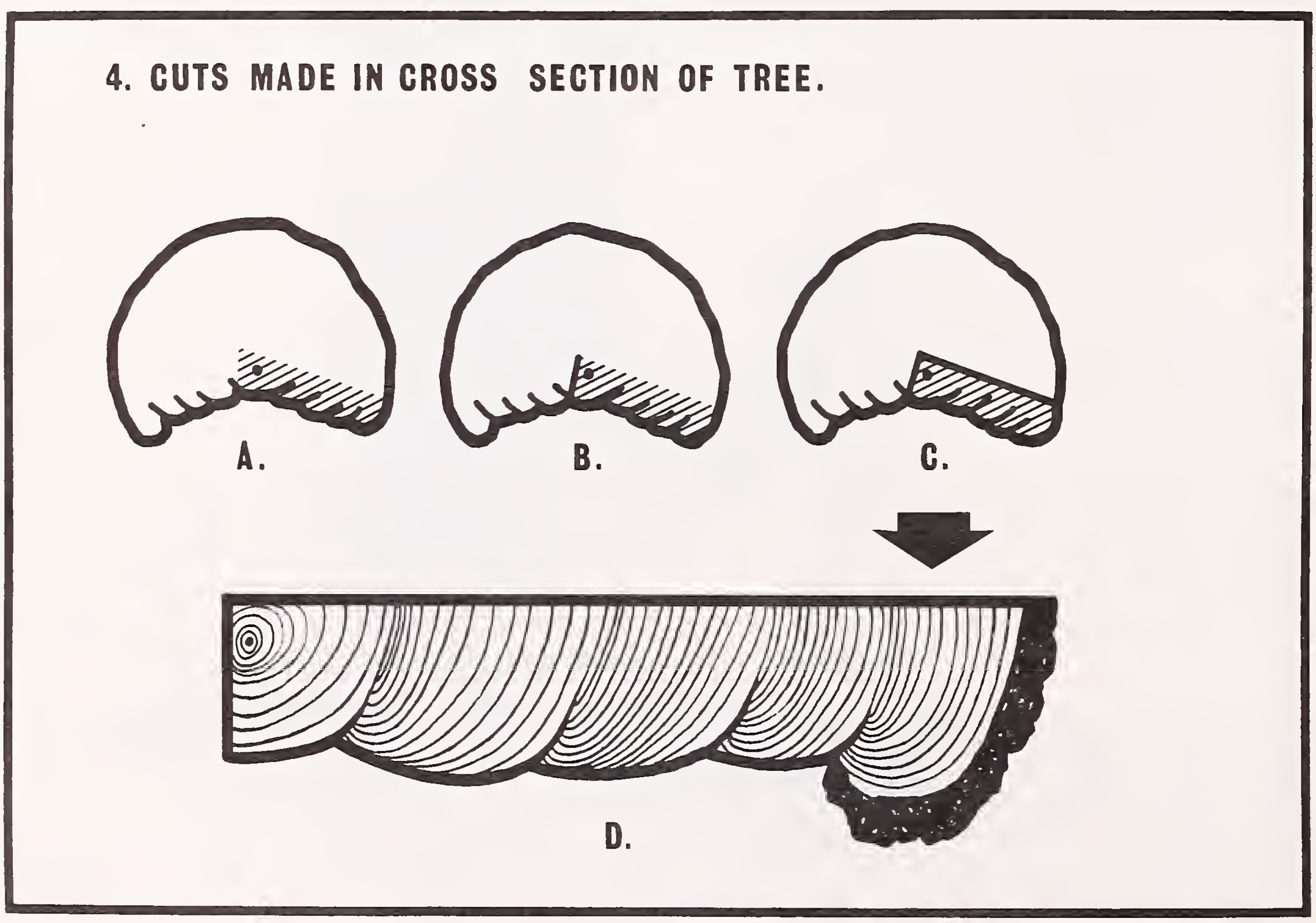
To facilitate transporting and handling, it is desirable to minimize both weight and size of the cross sections. Full cross sections often need only be about an inch thick, and if decay is not extensive, the back 40 percent of the circle, not including pith or scars, can be sawed off and left in the field. Partial cross sections should not be made thicker or deeper than necessary. The chain saw and a few cross sections, along with an extra quart of fuel, can be carried in an extra-large, aluminum-frame backpack.

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






3. CUT VERTICALLY ALONG BACK OF CROSS SECTION.
PARTIAL CROSS SECTION


4. CUTS MADE IN CROSS SECTION OF TREE.
A.
B.
C.
D.

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 lightweight 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.

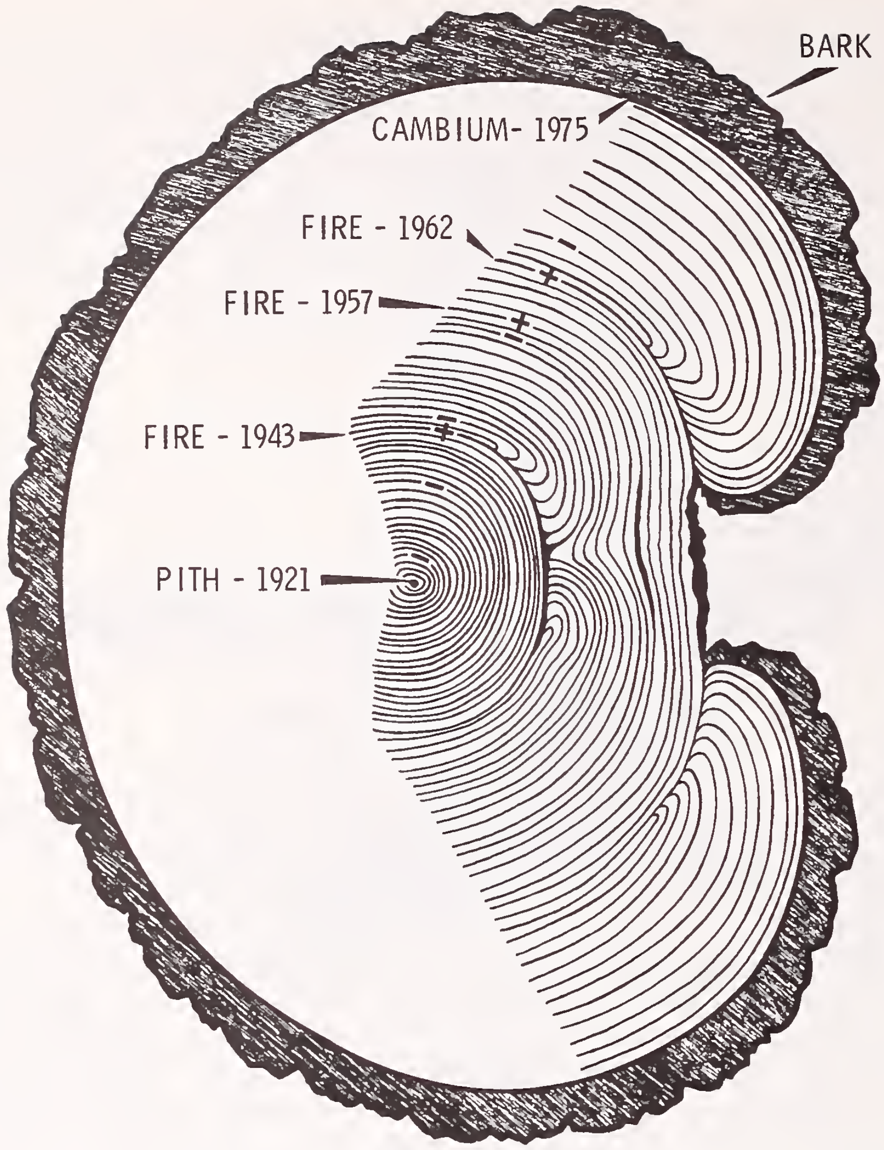


Figure 6.--How rings are counted on a fire-scar cross section. (Every 10th year in from the cambium is marked "-"; scar rings are marked "+".)

Table 2.--An example of ring-count tabulations from seven trees sampled in one stand. F = fire; P = pith

Tree Number 1		2		3		4		5		6		7	
Cambium	1975	Cambium	1975	Cambium	1975	Cambium	1975	Cambium	1975	Cambium	1975	Cambium	1975
-84 rings	1891F	-86 rings	1889F	-86 rings	1889F	-86 rings	1889F	-86 rings	1889F	-99 rings	1876F	-108 rings	1867F
-30 rings	1861F	-20 rings	1869F	-38 rings	1851F	-30 rings	1859F	-87 rings	1802F	-29 rings	1847F	- 23 rings	1844F
-15 rings	1846F	-16 rings	1853F	-49 rings	1802F	-40 rings	1819F	-38 rings	1764P	-44 rings	1803F	-103 rings	1741P
-25 rings	1821F	-24 rings	1829F	-35 rings	1767F	-17 rings	1802F			-55 rings	1748F		
-34 rings	1787F	-18 rings	1811F	-11 rings	1756F	-17 rings	1785F						
-46 rings	1741F	- 9 rings	1802F			-29 rings	1756F						
		-36 rings	1766F			-17 rings	1739F						
		-16 rings	1750F										
		-14 rings	1736P										

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

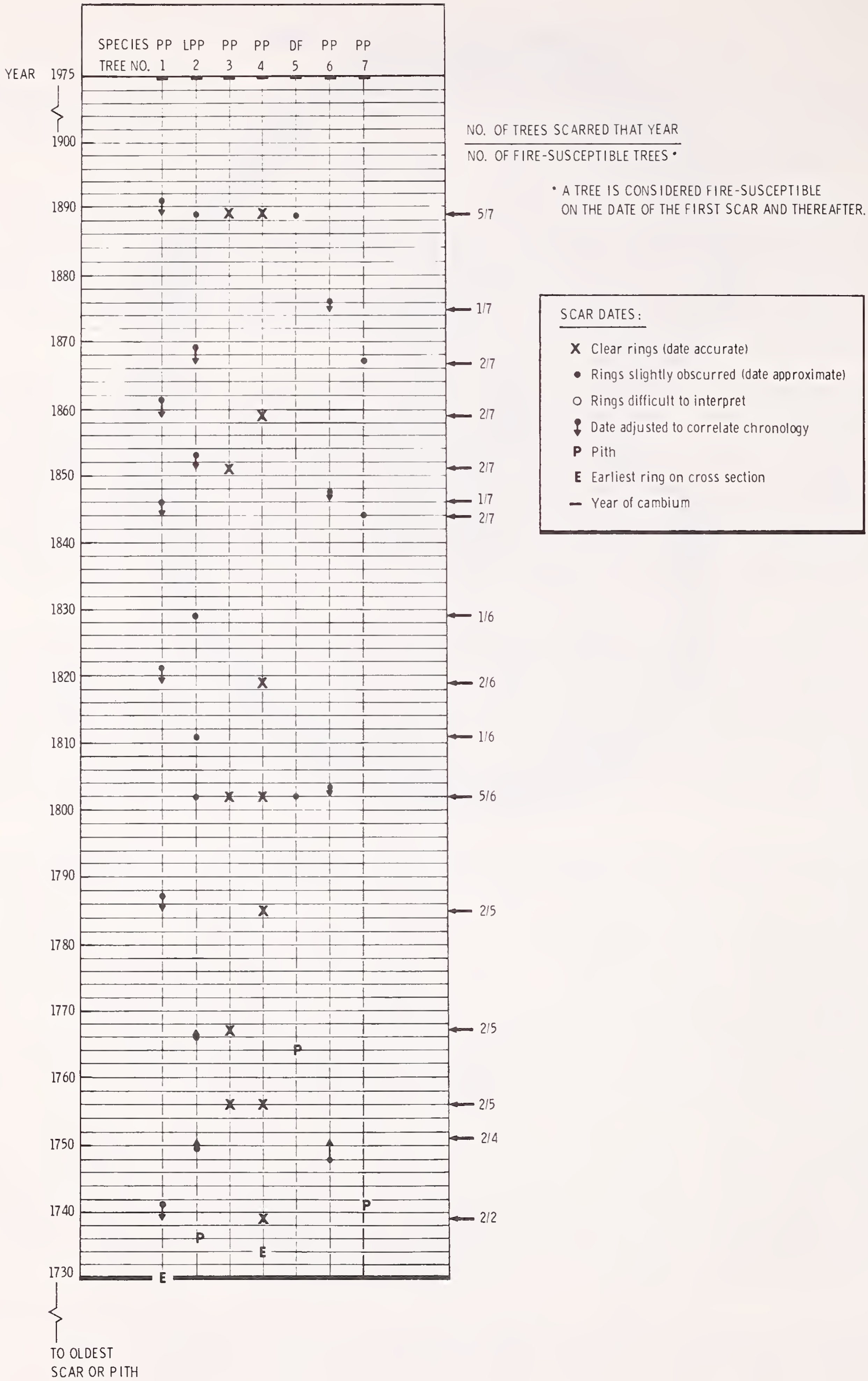


Figure 7.--Graph of the fire-scar chronologies from the seven trees in table 2, showing adjustments to obtain a master fire chronology for the stand.

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 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)	Total number of scars (45)
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	--	--	--	--	--	1
1828	3	--	2	--	--	--	--$^{r?}$	--	--	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.

Table 4.--Fire frequencies between 1735 and 1900 in three study areas stratified by habitat-type groups on the Bitterroot National Forest (modified as an example from Arno 1976)

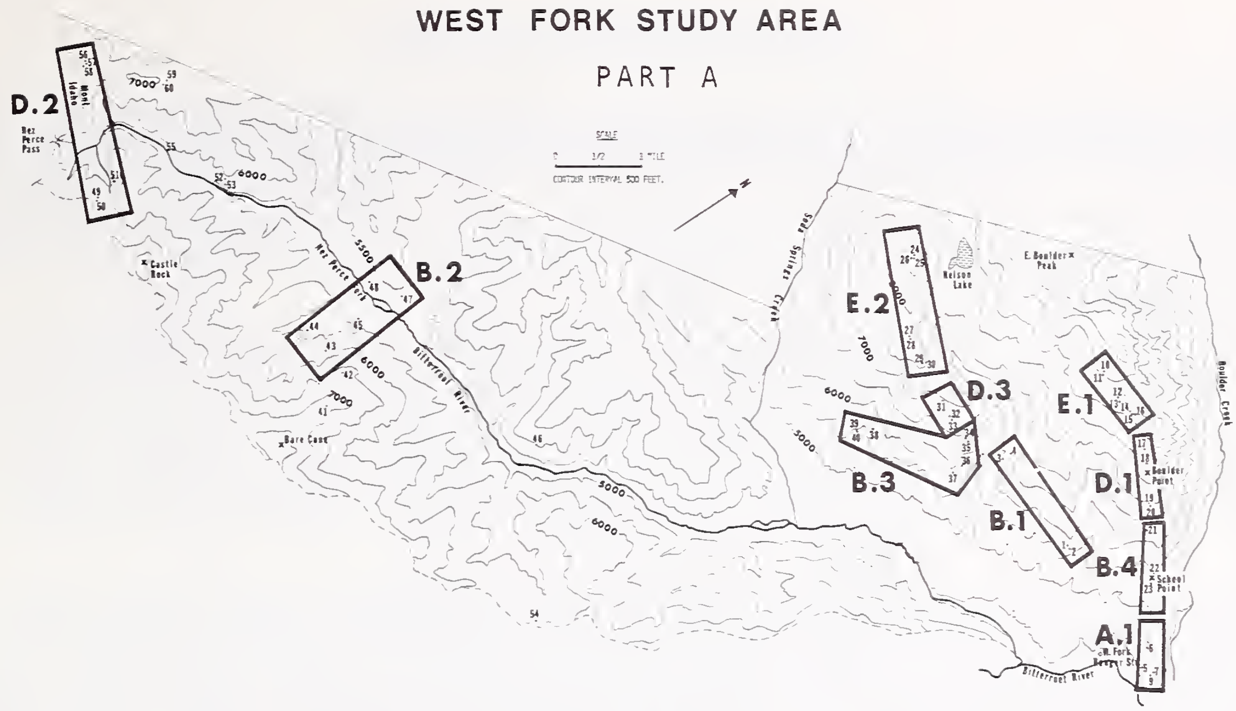
Habitat-type groups (potential climax) (Pfister and others 1977) (1)	Descriptive location (2)	General elevations (3)	Dominant trees with continued fire exclusion (most abundant tree first) (4)	Dominant overstory before 1900 (most abundant tree first) (5)	Onehorse		Tolan		West Fork	
					No. of stands (No. of trees) (6)	Mean fire-free interval (min-max interval) (7)	No. of stands (No. of trees) (8)	Mean fire-free interval (min-max interval) (9)	No. of stands (No. of trees) (10)	Mean fire-free interval (min-max interval) (11)
		Feet								
A. Pinus ponderosa/Festuca idahoensis Pseudotsuga menziesii/ Agropyron spicatum Pseudotsuga/Calamagrostis, P. ponderosa phase	Valley edge	3800-5000	Douglas-fir ponderosa pine	ponderosa pine	1 (11)	6 years (2-20)	1 (4)	11 years (2-18)	1 (4)	10 years (2-18)
B. Pseudotsuga/Physocarpus malvaceus Pseudotsuga/Calamagrostis (except Cal. phase) Pseudotsuga/Symphoricarpos albus Pseudotsuga/Vac. globulare (except Xerophyllum phase)	Montane slopes	4200-6200	Douglas-fir	ponderosa pine Douglas-fir lodgepole pine western larch	5 (46)	10 years (3-31)	3 (11)	16 years (4-29)	4 (19)	19 years (2-48)
C. Abies grandis habitat types	Moist canyon	4300-4700	grand fir	western larch lodgepole pine Douglas-fir	1 (7)	17 years (3-32)	--	--	--	--
D. Pseudotsuga/Calamagrostis, Calamagrostis phase Pseudotsuga/Vac. globulare, Xerophyllum phase Abies lasiocarpa/ Xerophyllum tenax Abies lasiocarpa/Menziesia ferruginea Abies lasiocarpa/Linnaea borealis	Lower subalpine slopes	6000-7500	subalpine fir Douglas-fir	lodgepole pine Douglas-fir	1 (9)	17 years (3-33)	3 (16)	27 years (5-62)	3 (13)	28 years (5-67)
E. Abies lasiocarpa/Luzula hitchcockii Abies lasiocarpa-Pinus albicaulis/Vac. scoparium Pinus albicaulis-Abies lasiocarpa	Upper subalpine slopes	7500-8600	subalpine fir whitebark pine	whitebark pine lodgepole pine	1 (3)	41 years (8-50)	2 (14)	30 years (4-78)	2 (14)	33 years (2-68)

Designating Stands

On large study areas, stands should be delineated to aid analysis of fire frequencies, as follows: List all the habitat types encountered at sample-tree sites and arrange them in an ecological order (for instance, by climax series and from dry-to-moist or warm-to-cold within each series). Record the numbers of the trees sampled in each habitat type. Group minor habitat types on the study area with more prevalent ones that are closely related. List the elevation, aspect, and percent slope at each sample tree and summarize these for each major habitat type. Wherever site parameters overlap substantially, major habitat types can be combined. The goal is to establish habitat-type groups that can be extrapolated to adjacent areas. Table 4 shows an example of such groups used on a fire history study in the Bitterroot National Forest.

After some of these habitat-type groups have been tentatively established, plot all sample trees on a topographic map of the study area and write in the habitat-type group found at each of these points. Inspect the map to see if it shows several (4 to 10) sample trees on the same habitat-type group within areas of a few hundred acres. If sample trees in a given habitat-type group are more dispersed than this, enlarge or redefine the habitat-type groups so that several sample trees from each habitat-type group occur within areas of a few hundred acres.

These assemblages of sample trees (on similar habitat types) should be outlined on the map, and will now be referred to as "stands." Figure 8 shows an example of such stands outlined on a topographic map. The final habitat-type groups should be assigned a letter code (A, B, etc.), and each stand a number; thus "B.3" is the code designating the third stand in habitat-type group B. Stands should be shown by their letter-number code on the map.



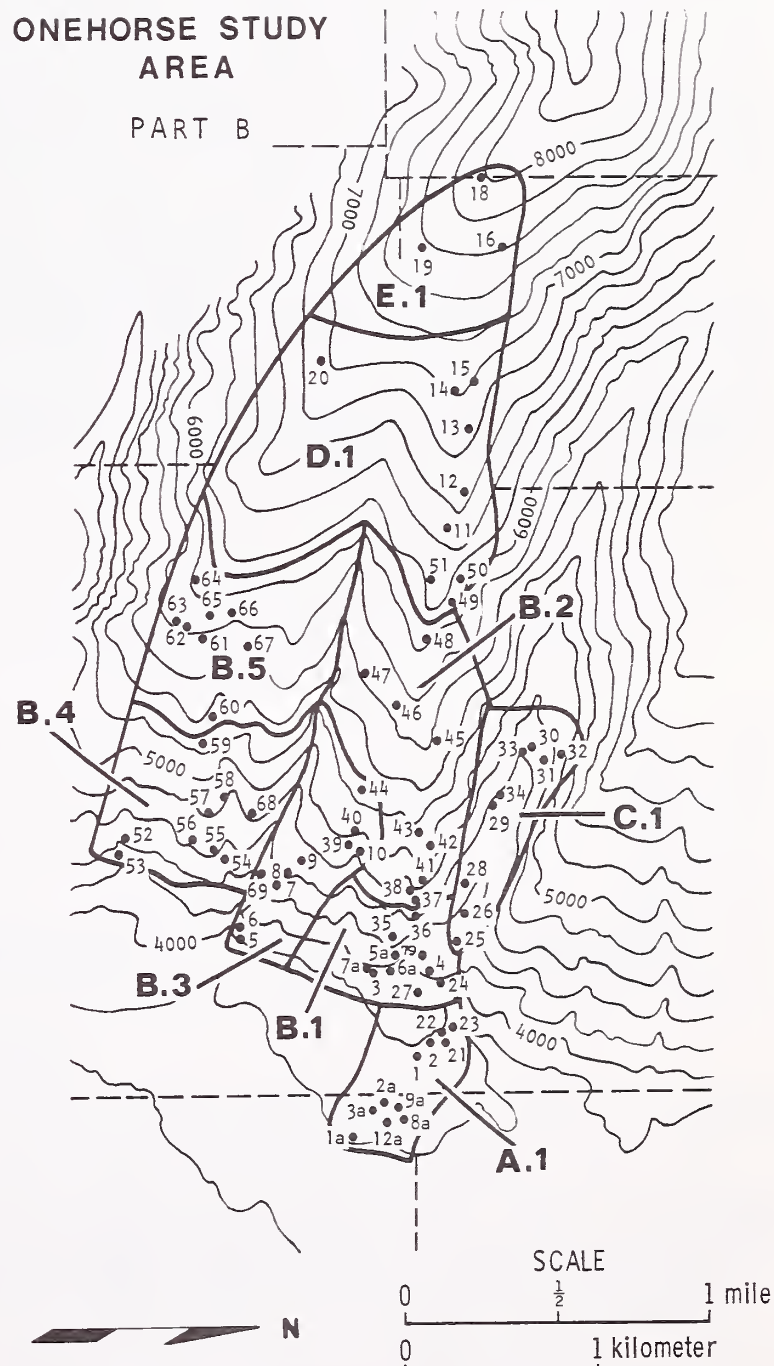


Figure 8.--Topographic maps of two study areas showing sample trees (numbers) and stands by habitat-type groups (letter-number code). Compare part A with table 4, column 10. Compare part B with table 4, column 6.

Calculating Fire Frequency

The stands and habitat-type groups can now be used for calculating fire frequencies (fire-free intervals) on an area basis. First, however, logical time periods must also be established for calculating fire frequencies. For instance, the most recent period (of perhaps 40 to 60 years, depending upon the area) can be assigned as the "fire suppression" period, reflecting the time period when organized suppression was well established and effective.

By contrast, suppression activities were generally minimal in forested areas of the Mountain West prior to 1900; thus that year might be chosen as the end of the "historic fire" period, reflecting the time when forest fires were caused primarily by lightning and native Indians. In some areas miners or settlers may have set many forest fires in the late 1800's, necessitating the delineation of still another fire period (for example, "settlement-era fire period" 1860-1910).

The beginning date chosen for analysis of the "historic fire" period will depend upon how far back the fire-scar records extend. It can be chosen arbitrarily but independently of actual fire-scar years. For instance, in one study (Arno 1976) the year 1735 was selected because it was the earliest date when at least five sample trees were alive in each stand, and thus could have recorded a fire. Later, two additional areas were studied in the same National Forest, and it was determined that each had adequate fire-scar records extending back at least to 1735. Consequently, 1735 to 1900 was then used as a standardized period enabling direct comparison of relative frequencies among all the study areas.

Before deciding upon fire frequency periods, graph the number of sample trees scarred during each fire year and the total number of "fire-susceptible trees" (trees already having been scarred at least once) in the sample, as illustrated in figure 9. Note that sample size diminishes markedly toward early years of the record, and take this into account when evaluating fire frequencies throught the record. Identify and consider any obvious changes in historic fire frequencies during the period of record when establishing frequency periods.

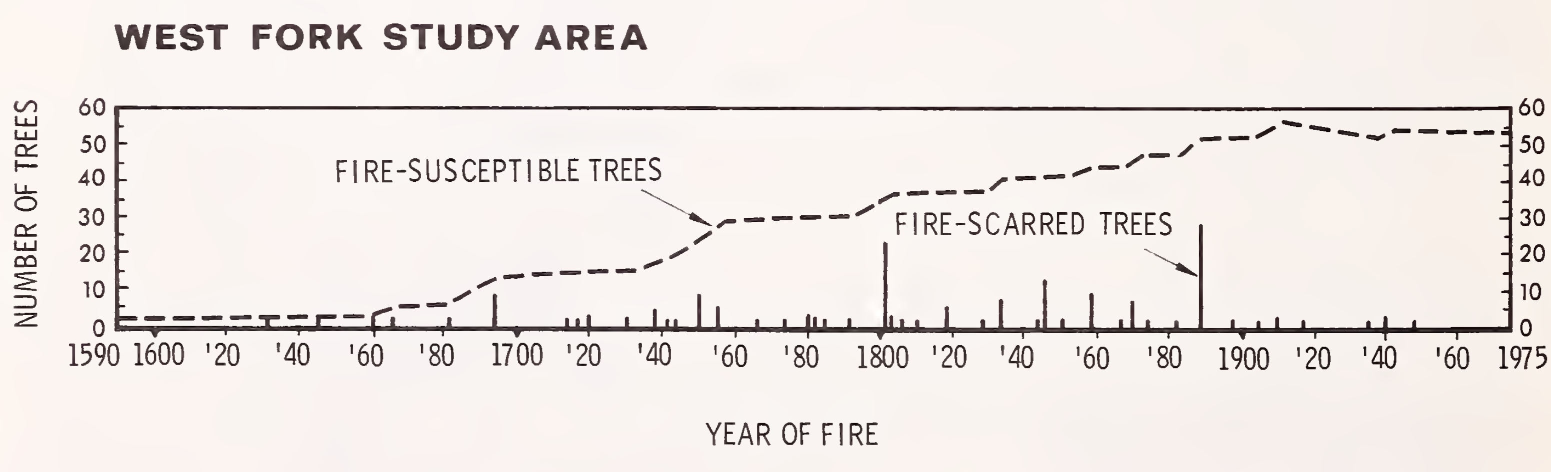


Figure 9.--Number of sample trees scarred each fire year and the total number of fire-susceptible trees in the sample (data from Arno 1976). A tree is considered fire susceptible on the date of the first scar and thereafter.

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	Time period 1735 to 1900					Minimum and maximum fire-free interval
		No. years in period	÷	Total no. fires	=	Fire frequency	
						Years	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

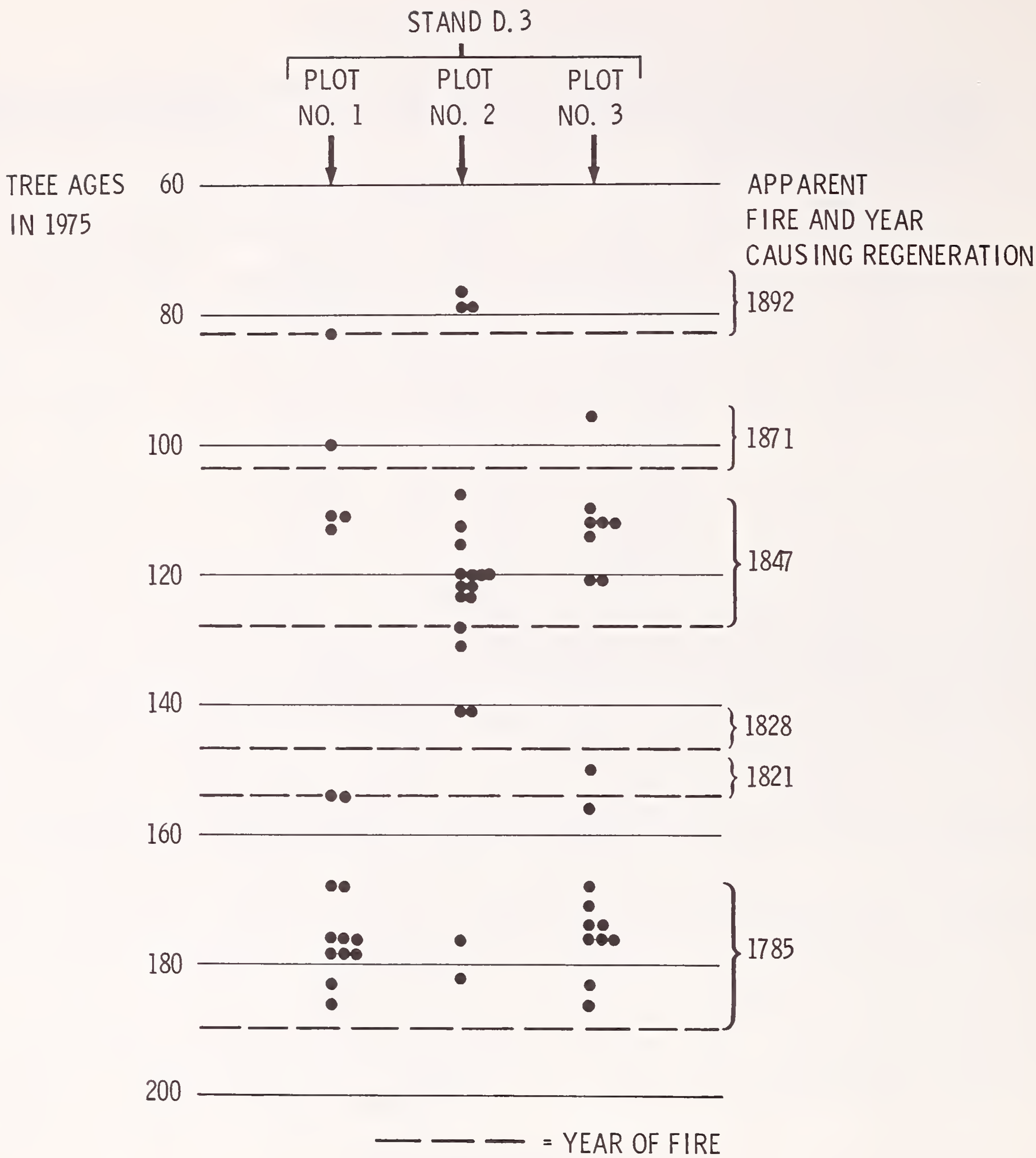


Figure 10.--Age-class designations based upon increment borings of seral trees taken in stand D.3 shown in table 3. Each dot represents total tree age, based on an increment core plus 5 years to reach boring height (1 foot).

and growth to boring height (1 foot, 30 cm). Such factors can be worked out by cutting and aging large numbers of seedlings of various species on various sites. However, considering all the variables, it may be necessary to use a general factor--for example, 5 years for trees bored at 1 foot on the Bitterroot National Forest (Arno 1976). The increment-boring data can be augmented by including the total age of cross-sectioned, fire-scarred trees with the sample from the nearest appropriate plot; only seral species should be used, however.

List the total ages of individual trees by plot, inspect them, and designate possible age classes as in figure 10. At least two similar ages are necessary for designating an age class. Because of field sampling procedures, most age classes will be identified by three or more trees.

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.

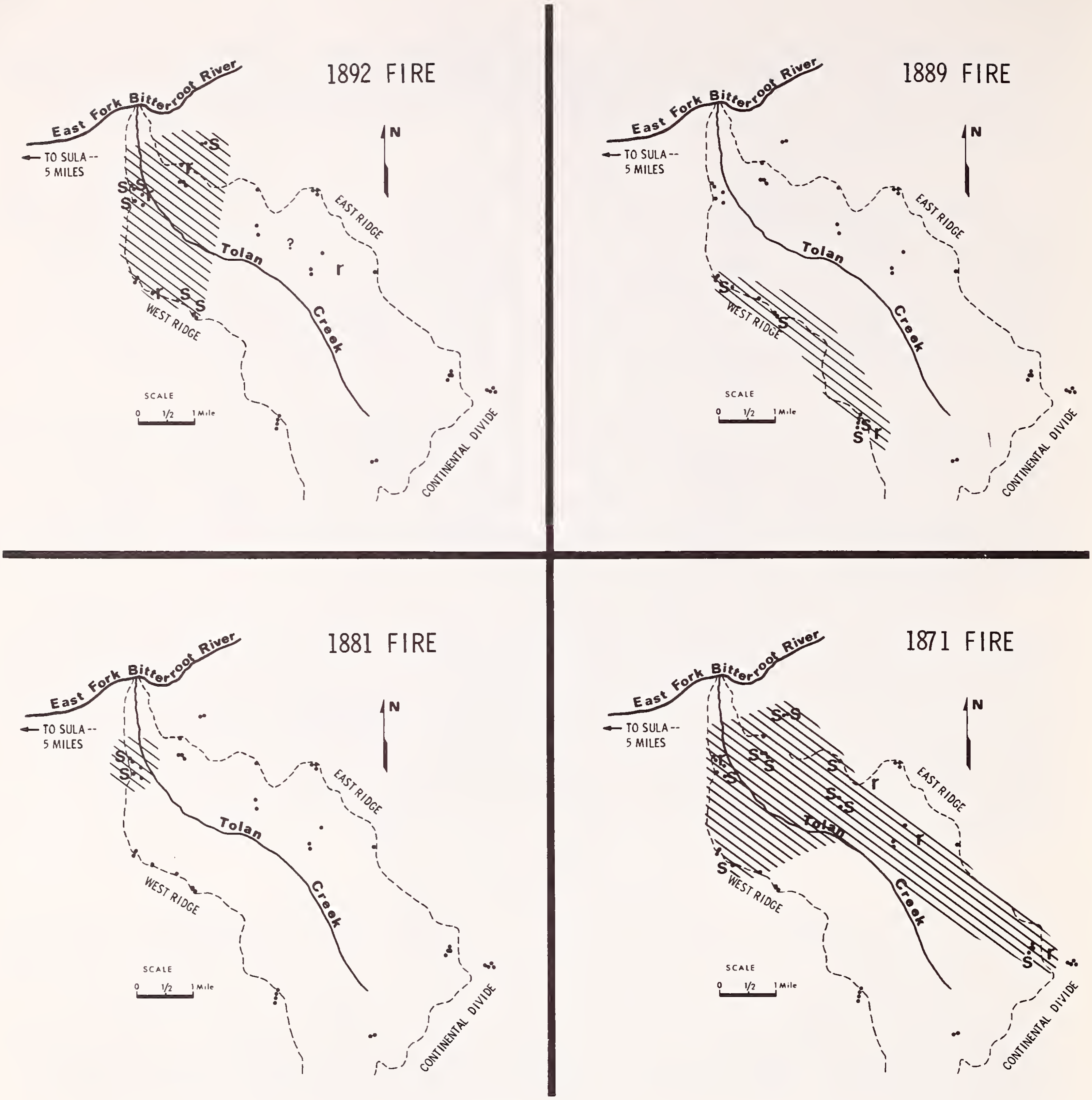


Figure 11.--Maps showing the apparent extent of fires by year on a study area. • = sample trees, s = scar on that tree that year, r = regeneration from that fire detected in that stand.

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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Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Field programs and research work units are maintained in:

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☆ U.S. GOVERNMENT PRINTING OFFICE: 1977-0-777-023/30