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Fire History of Walnut Canyon Natinal Monument

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Abstract

This report documents fire history of Walnut Canyon National Monument. Analysis of fire scar and age class of conifer regeneration provided data for the ponderosa pine forest. Primary attention was given to frequency, spread, behavior, relative intensity, and effects of fires prior to the advent of active suppression efforts in order to determine the natural occurrence and influence of fire. No data was collected for the pinyon-juniper forest and inner canyon vegetation, but observations were made and used as a basis for discussing fire characteristics.

A total of 227 fire scars were used to record 87 fire years. Twelve years were found common on both rims. A fire occurred somewhere in this forest on the average of once every 3 years.

The best record was for the period 1900 - 1750, when suppression and grazing had the least effect. The average frequency then for fires reoccurring in a stand was 14 years with a range of 6 to 21 years. The incident of fire was very low since 1900, with 6 fires recorded in 82 years. This shows the effects of settlement, i.e., grazing and suppression.

Most fires appeared to be small (less than 10 acres). However, evidence found throughout the forest showed fire was a widespread occurrence. In ponderosa, fires were low to moderate intensity burns that thinned and pruned stands and rejuvenated the plant community. In pinyon-juniper fires were very small (a few trees) or large stand replacing burns. Inner canyon burns were small, rapid burns occurring in sparse vegetation. In these two areas they were much less frequent than in ponderosa pine.

FIRE HISTORY OF WALNUT CANYON NATIONAL MONUMENT

Introduction

Walnut Canyon National Monument is going from a fire management program of total suppression to one of suppression and prescribed fire. This fire history study is part of that transition since it will provide information on past fire occurrence, frequency, spread, and relative intensity. With this information, park managers can understand the historic role of fire and implement an effective program that protects people and property from uncontrolled fire, while restoring fire as an ecological factor.

Knowing fire history of the monument provides a basis to understand the forest communities, i.e., stand structure and composition, regeneration patterns, understory features, and fuel accumulation. This can be incorporated as specific management objectives in the natural and cultural resources management plan.

General Description of Study Area

Location

Walnut Canyon National Monument, which encompasses 2,249 acres, is located in north central Arizona about 11 miles east of Flagstaff, then 3 miles south of Interstate 40 (figure 1). The general environment has been described previously (Colton 1932, Vandiver 1936, Arnberger 1947, Van Valkenburgh 1961 and Joyce 1974). A brief summary is given in this report.

Climate

The climate is typically montane with wide seasonal and daily differences possible. Winter temperature can get below 0 degrees and summer temperatures are sometimes above 100 degrees. Average annual precipitation is 20 inches. Monsoon rainstorms occur July through September, and snowfall occurs November through March. Spring and fall seasons are usually drier, especially the months of June and October.

The fire season is from late May through September when thunderstorms occur. The greatest lightning activity is during the monsoon season.

Geology

Before Lake Mary dam was built, Walnut Canyon was a typical semi-arid intermittent stream that historically flowed for a few weeks during the spring melt, and was then dry for the remainder of the year (Colton 1932). As the creek formed the canyon, it cut through and exposed volcanic basalt, kaibab limestone and coconino sandstone (Benfer 1971). Much of the lava layer has eroded so the kaibab limestone predominately forms the surface. Elevation ranges from 6860 feet on the south rim to 6340 feet on the canyon floor. Rim elevations range from 6600 feet to 6860 feet. Topography is undulating on the rim with sharp cuts made by side canyons and the main canyon. Both rim areas consist of low, outcropping limestone ridges and terraces with only a few inches of soil. Moving away from each rim, the terrain is more level and soil depths can be a few feet. Soil cover is deeper on the south rim and its north-facing slope. The canyon bottom is on coconino sandstone and is rough and uneven with some sediment deposits (Joyce 1974).

Vegetation

Walnut Canyon has three distinct broad vegetation zones. First, ponderosa pine forests dominate the western two-thirds with gambel oak interspersed. Undergrowth and litter accumulation are abundant. The forest structure shows many large, old ponderosa (200 - 500 years) with thickets of ponderosa regeneration and oak clumps. Pinyons and junipers tend to appear as individual trees; however, regeneration of one species will often be found growing under the canopy of mature individuals of the other species. Past fire is evident.

The side canyons in this section are predominately a mixture of pinyon pine and juniper on south and west facing slopes while ponderosa dominates shady slopes and drainage bottoms. Where side canyons break to undulating rim topography, an ecotone occurs being a mixture of ponderosa, pinyon and juniper where none regularly dominate. An ecotone is the overlap of two vegetation types where characteristics of both are found. Exposure and shallow topsoil favor pinyon and juniper.

Second, the eastern third is clearly a pinyon-juniper forest on the rim and in side canyons. Ponderosa occurs occasionally, mainly in side canyon drainages. Gambel oak is also an occasional species that is found growing in clumps. Undergrowth is sparse, particularly between trees. Litter occurs mainly under maturing trees and can be absent between trees. Past fire is evident here, too.

Third, the inner canyon is complex and itself has four recognized vegetation zones according to orientation, i.e., north rim, north slope, canyon bottom and south slope (Joyce 1974). Vegetation cover varies with aspect: pinyon-juniper covers north rim, mutton bluegrass-sagebrush covers north slope, box elder-Arizona walnut covers canyon bottom, and Douglas fir covers south slope. Joyce (1974) presents a detailed description of these zones. In addition, he gives the most recent plant list for Walnut Canyon National Monument. Fire evidence is rare and scattered.

Literature Review

The literature review provides information of fire in ponderosa pine forests. No literature was located discussing studies of fire in the inner canyon type of vegetation or for fire in natural stands of pinyon-juniper forest. The only information found for the latter related to fire in association with grazing and chaining.

Fire has been studies in ponderosa pine forest more than any other forest type, probably because of timber, grazing, and recreational interests. Fire frequency studies based on scar chronology show a varied reoccurrence of fire in ponderosa stands throughout western United States.

Reoccurring fire is generally a normal feature of most native vegetation types in the United States, and the portion west of the Rocky Mountains is noted for forest, shrub and grass fires. The frequency of reoccurrence, however, can vary dramatically. For example, frequency is wet western red cedar-western hemlock stands may be 400 to 600 years, while in sagebrush communities, it may be around 50 years.

Some have hypothesized that certain plant communities bring properties to the ecosystem that enhance flammability. Mutch (1970) states these properties condition the fire history, which in turn partially determines the maintenance, regression, or succession of the community. In western pine forests, forest debris (cones, needlecast, twigs and small branches) combined with grasses constitute the primary fuel for burning. Depending on the season and lightning activity, these fuels ignite readily and burn in a flashy manner. He noted that ponderosa pine produces a debris combination that helps to insure a high flammability and that certain plant characteristics enhance fire propagation. Ground fires were common, while crown fires not.

Features that enhance fire in ponderosa pine stands in the Monument include abundant litter production, slow decomposition, fairly continual ground cover of litter, grasses or shrubs, and thickets of regeneration. Pinyon-juniper stands in Walnut Canyon do not have these feature. Litter accumulates beneath mature individuals, but there is very little litter or other ground cover.

Several authors have reported on fire in ponderosa pine stands, and presented a varied frequency of 2 to 47 years throughout the range. Keen (1937, 1940) reported intervals of 16 to 18 years in eastern Oregon stands. Weaver (1959) sampled trees in the Warm Springs Indian Reservation and found a 47 year average frequency. Soeriaatmadja (1966) expanded this work and identified average intervals of 14 to 30 years with the longer on more mesic sites. Later, in the Blue Mountains of Oregon, Hall (1976) described a 10-year interval. In 1955, Weaver had already reported an 8-year frequency on the Colville Reservation in Washington.

Work had been completed in California even earlier. In 1924, Show and Kotok described fire frequency in that state's pine region, concluding that fire had been an important ecological factor for centuries and showing an interval of 8 years for all study areas. Kotok (1933) described fire in a mixed conifer stand where ponderosa was a component. He identified 221 distinct fires between 1854 and 1912 moving through the 74-acre area. A later study by McBride and Laven (1976) analyzed scars on ponderosa pine collected in the San Bernardino Mountains in southern California. They recorded a frequency of 10 years before 1905, then a 22 year frequency thereafter when organized fire suppression began.

no citation!

In the eastern end of the range, Lemon (1937) found an interval of 31 years on a single, old-growth ponderosa in the Black Hills of South Dakota. Later, in western Montana, Arno (1976) reported intervals of 6, 10 and 11 years on three locations in the Bitteroot National Forest. He found fire history and forest habitat type were closely related. In the Colorado Front Range, Rowdabaugh (1978) studied mixed conifer forests with ponderosa pine. Where found an average frequency of 84 years with a range of 28 to 165 years.

In Arizona, Weaver studied fire history in 1951 on the White River and San Carlos Apache Indian Reservations. Average fire intervals ranged from 5 to 7 years. From the Kaibab National Forest north of Grand Canyon National Park, he found a ponderosa with 19 fire scars for a 226-year period, which was an average of 12 years.

Closer to Walnut Canyon, Dieterich (1980a) studied 7 ponderosas and got an average interval of 2 years between 1745 to 1876. This study was done at Chimney Spring, a tract of virgin ponderosa pine on the Fort Valley Experimental Forest near Flagstaff, Arizona. Dieterich (1980b) also reported other fire histories for locations in northern Arizona and southern \new \mexico. The Limestone Flats area is 50 miles south of Flagstaff. The interval from 1790 to 1900 was 2 years. Thomas Creek site near Alpine, Arizona, is typical undisturbed southwest mixed conifer where frequency was reported as 77 years. In southwest New Mexico, data was collected from ponderosa pine-gambel oak stands. From 1750 to 1900 there were 38 fire years for an average interval of 4 years.

Finally, another study done in northern Arizona on the south rim of Grand Canyon National Park at Grandview provided frequency for a ponderosa pine dominant stand with gambel oak, pinyon pine and juniper. Pinyon and juniper were more abundant on the edge in the ecotone, but could be found scattered throughout the stand. Ponderosa dominated the drainage, and oak occurred as scattered groves. Duhnkrack (1982) reported a frequency of 7 years for the period 1750 to 1900. This compared to a mean frequency of 17 years for individual trees after initial scarring.

Methods

Vegetation Classification

As part of the field survey, habitat types were recorded. The system used was that developed by Hanks, Fit\hugh and Hanks (1977) for ponderosa pine communities. Pinyon and juniper communities were not done because no habitat type system existed.

Field Sampling

This fire history study was undertaken using the format of Armo and Sneck (1976). The initial field reconnaissance entailed hiking several transects throughout the Monument. The main purpose was to locate fire scarred trees that revealed long records of fire occurrence. Transects covered the rims and inner canyon, and were subjectively located to minimize the presence of basal fire scars and to represent topographic differences.

Scarred tree thought to offer good chronologies were ribboned with surveyor's tape and mapped for relocation. Each tree was assigned a number, the species recorded, and the estimate number of externally visible scars. Selecting a sample tree was determined on the basis of extent of damage to the scar (i.e., insect mining and decay), representation of elevation and topography, and the greatest number of external scars. Sample trees are recorded on figure 2.

Laboratory Analysis

Twenty-seven partial cross sections were cut according to the method shown by Armo and Sneck (1976). These were air dried and later sanded so the annual growth rings were more distinctive and to facilitate counting. The smooth surface helped in identifying and dating fire scars.

Fire scars can be confused with other types of scars left on a tree, especially to an untrained eye. Therefore, noticing growth patterns along the burned edge helps to identify fire induced scars. First, there may be a break or gap between rings. Second, charred wood and/or pitch can be present in this gap. Third, subsequent ring formation is overlapping, curvilinear growth over the break. Fourth, looking straight at the burned face, distinctive bows can be seen which are the curvilinear ring growth.

Most sections had scarred areas where insect mining made counting difficult. These insects are commonly flatheaded borer and carpenter ants that are attracted to damaged or weakened wood structure, such as that which can occur from burning and heat. Consequently, fire frequency was judged by the most reliable, clear ring counts. Interpolating dates was necessary. The largest amount of evidence or cluster around a certain date indicated the fire year. Again, weighted value was given to samples with clear ring formations.

When developing the mater fire chronology, dates were adjusted by moving scattered dates ahead in time or back towards the designated fire year according to the principles set by Armo and Sneck (1976). Two factors were considered. First, care was taken not to adjust dates too much. Distinct scar sequences on individual samples as well as previous studies by Dietrich (1980a, 1980b) showed high frequencies. Second, several ring counts of all samples were made by two individuals to get the most accurate dates. This was done to reduce error brought about by personal bias and difficulty tracing scar dates on samples with insect damage.

When doing a fire-scar history, it is rarely possible to get a full account of frequency and spread. Not all fires burning through an area will scar every tree. Burning conditions and fuel accumulation determine intensity and spread. Also, subsequent fires may burn previous scars therefore, obscure that pattern. The result is fewer fires will be recorded (Davis 1980).

Historical Records

In addition to the field sampling, an historical account of fires was sought by examining written records of fire suppression. Records were examined from Walnut Canyon National Monument and Coconino National Forest, U. S. Forest Service. The latter was done because the Forest Service had suppression responsibilities and greater capability for several years. It was only since 1977 that Monument staff actively suppressed fires.

Besides fire records, past grazing activities were studied in order to assess effects of cattle and sheep on fire ignition and spread as well as fuel conditions. This report is presented in appendix A.

Results and Discussion

When this study was initiated, the intention was to do fire history of all forest communities on the rims and in the inner canyon. Because fire scar and age-class correlation was available only in the ponderosa stands and ecotones, the study focused on that community. Scar data was rare in pinyon-juniper and inner canyon forests. However, observations are made about regarding fire history characteristics of these area.

Vegetation Classification

According to the habitat type system developed by Hanks et al (1977), there are two "types" found; one a habitat type and the other a community type. Using their definitions the distinction is described as follows. "Habitat type" is the aggregation of land units capable of producing similar climax associations. All habitat types are distinctive with respect to features such as topography, soil, hydrologic cycle, temperature relations, nutritive relations, etc. "Community type" refers to recurring plant communities in which the internal ecological distinctiveness has not been demonstrated or for which the climax state is uncertain.

Pinus ponderosa/Bouteloua gracilis (ponderosa pine/blue grama) Pipo/Bogr ht is the habitat type found in the Monument. It is the driest ponderosa pine habitat type in northern Arizona and here it is ponderosa forest and the transition to other vegetation. It is characterized by open, low density stands with lower plant coverage and more exposed soil than other pine habitat types. Typically this is a location of exposed bedrock and shallow soils. Two phases occur in the Monument.

The Pinus edulis phase (pinyon pine) Pipo/Bogr ht, Pied p is one of the driest types and is in the ecotone between ponderosa and pinyon-juniper. Pinyon is common as are blue grama and red-root eriogonum. Soils are often exposed bedrock with shallow topsoil. Fire occurrence is limited by lack of ground and canopy cover.

The Quercus quambelii phase (Sanbel oak) Pipo/Bogr ht, Quga p occurs, but is not abundant. It is found on rolling topography and gentle canyon side slopes with limestone and basalt parent material. This phase is at or near climax and is a transition from the ponderosa pine to pinyon-juniper forest. Gambel oak is common as a tree and/or shrub and blue grass occurs. Oak would diminish slowly with time and without disturbance resulting in an increase in herbaceous cover. More continuous ground and canopy cover makes this phase more burnable.

The community type found in the Monument is Pinus ponderosa Poa fendleriana (ponderosa pine/mutton bluegrass) Pipo/Pofe ct, which occurs on basalt and limestone parent material. Mutton bluegrass is the dominant grass with very few other grasses represented besides mountain muhly. Fire is more common because of increased fuels resulting mainly from pine needle litter.

Ponderosa Pine Forest

A total of 227 scars were examined on 27 cross sections from fire scarred trees. Multiple scarring was common and all cross sections were taken from ponderosa pine. No usable fire scars were found on pinyon pine, Gambel oak and juniper species. The number of scars per cross section ranged from 1 to 35. Several trees had 8 or more scars.

More fire evidence appeared on the western portion of the monument in the ponderosa pine stands. This would be expected because of the features of ponderosa stands that make them more burnable than the neighboring pinyon-juniper forests. Needle litter, as well as twig and branch debris, create a fairly uniform ground fuel that is deepest (1 to 2 feet) beneath nature ponderosas. Between trees, the litter fuel can decrease so grasses and shrubs are the primary ground cover. In the adjacent pinyon-juniper stands, litter is noticeably absent. Generally, fire debris, especially needle cast, can be found directly beneath pinyon pine and juniper trees. The older, larger trees of course have more accumulation. The marked difference between litter, i.e., ground fuel, in the two forests is very significant to fire frequency and spread. It also would influence the rate of ignition following a lightning strike because dry needle litter is the perfect starter fuel.
Many of the cross sections had insect borings which made the rings difficult to count. A few of the sections were riddled with insect galleries, so they were thrown away. Insect infestation is not always detectable on the tree exterior. However, some potential sample trees noticed in the initial field reconnaissance were not selected due to carpenter ant evidence in the catface and metallic wood borer in live wood. Both insects are attracted to trees injured by fire or other causes.

In a natural situation with frequent periodic fires, repeated burning acts as both the cause of injury and the cleansing gent. When fire scars trees, insects enter the wound. Additional fires burn the dry, punky, pitchy and/or decayed wood in the catface back to the live wood. By burning the rotten wood fire is a cleansing agent that cauterizes" the wound and leaves a layer of charcoal over the live wood. Insects eventually enter the wound again and the cycle is repeated. An interesting feature of this event is that fire creates an advantage for insects by injuring wood, and insects create an advantage for fire by making a more ignitable fuel in the catface. Pathogens such as fungi operate in a similar manner as insects.

Sample Trees and Stand Designation: The locations of the sample trees and stands are shown in Figure 2. On north rim there are five stands (IA - IE) that encompass 14 trees. On south rim five stands (IIA - IIE) include 13 sample trees. Again, all sample trees were ponderosa pine. Stands were determined by the proximity of individual trees and immediate geography with consideration of fire behavior principles. Trees were arranged into stands to combine individual fire histories in order to obtain a more accurate representation of fire over a given site.

Appendix B shows the data base used to determine stand arrangements, i.e., rim location, stand number, sample tree number and fire year. The composite history was compiled by making adjustments in the individual chronologies of stand members (Armo and Sneck 1977). Cross sections with the clearest ring formation presented the best chronology, and gave the most reliable documentation. In addition, the largest number of scars on a certain date strongly indicated the fire year. The dates were synchronized by moving the scattered scar date either ahead in time (false rings) or backwards (missing rings). Generally,1 incidents of missing or false rings would be evident for a couple sequential fire years.

Figure 2 also shows the approximate boundary for ponderosa and pinyon-juniper forests. This is approximate because the ecotone between the two stands can be wide. In addition, groups or areas of one forest can be found in the other. For example, ponderosa pine dominated in drainages of the eastern portion, and on the west side, pinyon-juniper occupies the limestone outcrop rim line on the north rim.

<u>Master Fire Chronology</u>: The master chronology presents the sequence of fire years recorded for the monument from 1938 to 1600 (Table 1). The table shows fire years by stand and the number of scars recorded per year. Regeneration relating to a fire year is also shown. Appendix B provided the data base for this table so the reader can refer to that appendix for stand information. This master chronology, too, was constructed by aligning the adjusted individual chronologies from each tree with its neighbors in the stand, and incorporating data on fire initiated regeneration. Fire years were based on data for up to 8 scars per year. A total of 227 scars were documented.

Fire years from 1938 to 1750 are most accurate, especially when regeneration was correlated. Beyond 1750, they should be considered approximate, because the sample sizes are small and accuracy diminishes with time.

The best scarred trees were selected to get a representation of the fire history of the monument. Fire scarred trees were abundant, but it was not practical or necessary to sample all scarred trees that were encountered. Obviously, this sampling would not have recorded all fires burning in the monument since 1600. It is extremely difficult, if not impossible, to record low intensity fires that do not leave long-term evidence such as scars or regeneration.

<u>Fire Occurrence</u>: A total of 87 fire years were recorded. Table 2 lists the occurrence of each fire year and whether it was

recorded for north rim, south rim or both. Twelve fire years were found in common on both rims. Information presented later in this report indicated many were widespread occurrences throughout the forest. Years in common are 1880, 1875, 1867, 1843, 1839, 1822, 1815, 1807, 1799, 1796, 1760 and 1732. Overall, there were 65 fires documented for north rim and 34 for south rim. No written records were available for fires suppressed during the past few decades.

A further breakdown of occurrence is shown in Table 3, which presents frequency for each stand. To calculate frequency, time periods were established. From 1900 to 1982 was the "suppression" period when the influence of settlement, land uses (grazing and logging) and organized suppression resulted in effective control. From 1750 to 1900 was designated as the "historical" period when fires were primarily caused by lightning and burned without interference from humans. Prior to 1750, the chronological information became too sparse to give reliable calculations.

Fire frequency denotes the number of years between fires; it is essentially the fire free interval. The greater the number of scars, the lower was the fire free interval. Hence a high frequency means a greater number of fires over time than a low frequency. By grouping trees into stands, a more accurate fire history was developed for sites. As used in this report, frequency represents the reoccurrence of fire on a particular site, usually a stand, but sometimes to an individual tree.. Table 3 shows for each stand on both rims the number of fires recorded, range of frequency considering all trees, and average frequency for the three periods (1982-1900, 1900-1750 and 1750-1600).

For all stands, occurrence was low for the suppression period 1982 to 1900. Only 6 fires were recorded in the 82 years, which reflects the influence of human settlement in the vicinity. Concerted efforts were made to suppress fires, and grazing records document heavy grazing pressure by cattle and sheep in and around the monument.

Average frequency from 1750 to 1600 is also quite low. Although the data is sparse, it is shown here as a contrast in the other periods.

The frequency information from 1900 to 1750 is a fair representation of fire history for the monument. Per stand, frequency ranged from 6 to 21 years. North rim stands had slightly lower frequencies than south rim sites. The average for stands was 13.6 years frequency on north rim and 13.4 years on south rim. This means that the average reoccurrence of fire was 13.5 years on a site (i.e., stand). Park managers can use these numbers as guidelines when programming prescribed burns. For example, an area can be designated for reburning about every 13 years. Or, if an area has not reburned by 21 years, the manager can include it in a prescribed burn.

Stands located around drainages or in swales had more fires partly because of more continuous needle or grass fuels and terrain that favored fire spread (stands IA, IE and IIA). Conversely, stands on rises or close to the rim edge had fewer fires (stands IB and IID). Stand ID was in the ecotone and a lesser frequency was found there.

Table 4 is a summary of frequency information that was presented by stand in the previous table. Overall average frequency was compared for both rims for the record periods. It was calculated by dividing the number of years in the period by the number of fires recorded during that period (see Table 2). For the best record period, 1900 - 1750, a fire occurred somewhere on north rim every 4 years and on south rim every 5 years. Combining data for both rims, this study showed a fire occurred in the ponderosa forests once every 3 years.

As background information, a sample of fire frequencies for individual trees is shown for those with 8 or more scars (Table 5). Tree 15 was exemplary with 35 scars. It is noteworthy to point out that 2,3 or 4 year intervals were common as lower frequency ranges in these multiple-scarred trees, while higher intervals of more than 30 years were recorded. Ten trees are shown here, and for the historical period (1900-1750) the frequencies ranged from 9 to 21 years. As in Table 3, if the average of the average is calculated, the composite is 14.6 years, which is the reoccurring interval of fire on the site of these individual trees. This data supports Table 3 information because of the similar frequency ranges (6-21 years versus 9-21 years) and average reoccurrence (13.5 years versus 14.6 years).

The range of frequency presented in this table is from the first fire occurrence to the last. It does not include from the last fire to the cambium. This data serves to show the wide range that can be found for individual trees, and why compiling information is necessary to get a more accurate fire history for a site.

<u>Fire Spread</u>: Using the location of scarred samples, the area spread of fire was plotted on a series of maps in Figures 3A-3I. Areal spread is shown by shading and fire dates are given. The approximate areal spreads were drawn closely around the evidence, therefore, they represent the minimum spread. Actual fire spreads were probably larger than indicated because of continuous fuels and lack of physical barriers (other than bare areas and the canyon). In addition, certain topographic features in the monument favor increased fire behavior activity, which in turn increases spread. For instance, side canyons or draws act as chimneys and grassy swales yield available, continuous fuels.

To determine areal spread, it is important to consider fuel characteristics in a ponderosa pine forest. Historically when fires were as frequent as discussed in this report, the effects would have been to maintain an open forest. This past open nature is also evident by the branching form seen now on mature trees. Post fire pockets of regeneration grew, but fire would have thinned them. Repeated fires would burn needlecast and keep it from suffocating grasses. Fire spread would be mainly through the availability of fine fuels (needlecast and grasses). Intensity was generally low so large areas of bare soil or rock could stop a burning flank. In the ecotones, ground fuel is noticeably sparse, so fire spread would be limited.

These maps illustrate significant findings of this study, which are the relative size of burns, number of fires during a year and locations of fires. Fires were generally small area, but larger burns did occur. Also, some fires were widespread throughout the ponderosa forest.

It is difficult to estimate acreage of burns. The smaller ones that were only recorded on a single tree were probably less than 5 acres, and more likely 1 or 2 acres. This estimate is based on the evidence that a fire year was recorded only on one tree in a stand, however, because fire does not scar every tree, an upper range of 5 is given. In addition, frequent fires would limit spread. Examples of these are fire years 1905, 1890, 1834, 1859, 1799 and 1791. The smallest acreage fires appear since 1890, probably showing grazing and suppression effects.

A second relative size was indicated when two or more trees in a stand had the same fire year. This is estimated as 10 to 15 acre burns, and is illustrated by fire years 1880, 1867, 1856, 1843, 1839, 1822, 1796, 1769 and 1744.

A third category of relative fire size appears. This is where a fire year occurs in more than one stand and particularly on both rims. These were recognized as widespread fires. Two considerations must be given to this interpretation. One, the area burned should be considered for the entire fire year, rather than a specific date in the year. Fires in 1880, for instance, may have been ignited throughout the summer rather than on one day when a storm passed. Second, the widespread occurrence suggests a couple of ignition points instead of one large fire burning the entire area recorded for a year. A few factors enter here. Multiple strike lightning storms with heavy rainfall are common during the monsoon season, and periodic fires would have created a fuel mosaic that would limit spread even under extreme conditions. It seems very unlikely that spot fires across the canyon would be a prime source of common fire years. Widespread fires are shown in Figure 3 for 1880, 1843, 1839, 1822, 1807, 1796, 1776 and others. It is reasonable to say that widespread fires would have burned a couple hundred acres in a year. They probably burned contiguous acreage in some of those years as shown for portions of the monument land in 1880, 1867, 1862, 1843, 1839 and 1822, for example.

The western portion of both rims and the southwest part of the south rim recorded the most activity. Fewer fires were documented from trees growing in the broad ecotone, i.e., 120, 121, 1131 and 1132. While lightning fires started within the current monument land, fires also would have spread from adjacent lands.

Fire Behavior and Effects: Fire in this forest has behavior and effects comparable to other reports for ponderosa pine. Historically, fires were very frequent in the study site with an average of 3 years overall and 4 and 5 years for north and south rims, respectively. The average reoccurrence on a site (stand or tree) was about 14 years. Intensity was low to moderate judging by the lack of evidence of stand replacing fires, such as snag fields and even-age regeneration. Big ponderosa with large branches indicate open growth stands that were kept open by repeated fires. Multiple scars were usually less than 5 feet tall, which meant low intensity, periodic fires. High intensity kills mature trees or creates tall scars.

Fire occurred throughout the ponderosa and was more frequent in the western portion than in the ecotone. Grasses, shrubs and perennial herbs are adapted and sprout or recolonize following fire. The primary effect of fire in ponderosa is rejuvenating the community by creating various age, structure and composition arrangements of plants, as well as creating a fuel mosaic and aiding decomposition. The ultimate result of frequent, periodic fires is a stand of mature, widely spaced ponderosa pine beneath which grow various aged groups of ponderosa, oak, pinyon or juniper.

Litter accumulates most beneath trees, and the understory grasses and litter compose the connecting fuel. Periodic fires create a mosaic of continuous and discontinuous fuel. This self perpetuating mosaic pattern controls the spread of ground and surface fire. Thickets of conifer regeneration will torch out, but evidence was not found of stand replacing fires in this forest type in the monument.

Fire suppression for the past decades had caused changes that make high intensity crown fires more likely. Greater accumulation of needle, cone, twig and branch litter and well developed understory of trees and shrubs allow fire to flare into the canopy from the ground. Snags and large downfall trees are abundant in ponderosa stands in the monument. Consequently, fires would tend to burn hotter and larger areas than in the past.

Pinyon-Juniper Forest

The pinyon-juniper forest grows in the transition between the ponderosa pine forest and the desert community, which is primarily sagebrush vegetation found in lowlands around the monument. The species involved are pinyon pine, Gambel oak and

Rocky Mountain, Utah, one-seed, and alligator junipers. Ponderosa pine is relegated to drainages or rarely may be found as scattered individuals or groups.

Transects were walked in the pinyon-juniper forest, but fire scar evidence was rare. Only a couple decayed scars were found on pinyon and oak, but none on junipers. Quantitative measurements were not taken to determine fire history on the eastern portion of the monument. However, observations were made during field reconnaissance regarding fire history. They are offered here in a discussion of occurrence, frequency, behavior and effects.

Sign of fire is widespread and was located throughout the entire eastern portion. Generally fires were infrequent stand replacing events, but small area burns occur. Stand replacing fires are most evident from even-aged stand and juniper snags, which will remain for decades after a fire and show its passing even after a forest has regenerated and approached maturity. Pinyon pine does not remain long as a snag because insects and diseases hasten decomposition. This type of fire can be extensive and cover several hundred acres. Small area fires are only a few acres and primarily burn a couple trees and underlying duff. These, too, seem to be infrequent.

Behavior varies. Stand replacing events are intense, wind-driven crown fires. They burn with the ferocity of a chaparral fire. Most trees are killed, but islands of unburned vegetation can be left. Small fires are less intense and carried by ladder fuels and spot fires to surrounding fuel. Wind and spotting are essential to fire spread because ground vegetation and fuel are sparse.

Fire tolerance of these tree species varies, but they are more susceptible to injury or death when small. All have low, bushy; growth forms until reaching maturity when an open branch form develops if the tree is not suppressed. Juniper foliage is not very flammable, whereas pinyon has a high pitch content that readily burns. Much of the fire tolerance is due to widely-spaced trees and sparse grass and shrub cover.

As in other forest types, small trees are often killed while larger trees survive unless fire destroys the crown. After a fire, herbs and grasses appear first followed by trees and shrubs. Grasses regenerate more quickly than shrubs and herbs, and this is partly related to moisture requirements for growth.

Inner Canyon Vegetation

Evidence of fire is uncommon in the inner canyon. On the south facing slope, scattered old juniper snags testify to past burns. There was no sign of recent fire. The exposed, rocky ledges and sparse vegetation would make fires very infrequent, fast burning and small in size. Perhaps in draws leading into side canyons, areal spread would be a few acres if fire reached heavier, continuous fuels.

A few fire scarred trees were found on the north facing slope. Sparse vegetation and exposed ledges limit spread and occurrence. One ponderosa growing on the lower slope had 9 scars, and a couple of Douglas firs had 2 or 3 scars. Fire is infrequent and not intense, although torching out may occur in regeneration and pockets of fuel accumulations. This aspect is moist, and even the upper slope may remain cool and moist even during the summer. A likely cause of fire is embers or spotfires carried over the rim from burns on south rim.

Fire sign was rare in the canyon bottom. Occasionally there would be burned stumps of ponderosa and fire regenerated oak groves where the canyon is wide. In narrow parts dense, lust shrubs grow in tall groves that deter ignition.

Management Implications

The results of this study provide information for Park staff managing a natural resources program including fire.

1. Fire is evident throughout the monument and should be restored on the ponderosa pine as an ecological influence. Prescribed burning should be used to maintain control of intensity and size, and managers should strive to replicate the low to moderate fire intensity of historical burns. Once a section is burned, it can be labelled a conditional suppression zone where natural ignitions could burn when in a predetermined prescription that defines parameters for fuel, weather, smoke, moisture, relative humidity, containment considerations, etc.

Suppression for several decades has allowed 2 to 3 feet of needle litter to accumulate beneath large ponderosa and thickets of regeneration to grow. Those plus the snags and downfall can be a serious fire hazard.

Fires are frequent in the ponderosa pine forest with one occurring somewhere in the monument on the average of every 3 years. The incident of fire reburning a site, whether a stand or tree, is about 14 years based on averaging information discussed in Tables 3 and 5. The upper range is 21 years again using data from those tables. The manager can use these two numbers to determine scheduling reburns. Once an area is burned, it could be placed in a conditional suppression zone, where unplanned fires would be allowed to burn, provided they met a predetermined prescription that included being confined to specified boundaries. If an area has not reburned by 14 years, it should be scheduled for reburning by the time it has been 21 years since the last fire.

There are about 1200 acres of ponderosa forest. A suggested goal is to burn 120 acres a year, so the first burning would be done in 10 years. This should be broken into two 60-acre blocks. By starting in the western most portion, the heaviest fuels and greatest lightning activity area would be treated first. A nosaic burn on 60 acre blocks using a spot fire ignition pattern would reduce fuels and create diversity.

2. Fire in the pinyon-juniper forest will likely be small, hence controllable by small fire fighting crews, or a large, wind driven crown fire requiring a bigger force. Managers should be prepared for either and employ existing barriers (roads, canyon, change in vegetation, rock outcrops, etc.) in fire fighting logistics. Developing a preattack plan would be an advantage.

Inner canyon fires will probably be of little consequence because of sparse fuels, rim barriers and moist environment (on north facing slope). This part of the canyon could be designated as a conditions suppression fire zone now, but care should be taken where side canyons provide lead fuels to the rim.

3. Maps and documentation should be kept for all fires occurring in the monument whether they are suppression fires or prescribed burns. Complete reports should be done for all fires and include information on location, spread, effects, behavior and burning and fuel conditions. By keeping records, the manager will understand more about fire history through observation plus make account of which portions of 60-acre blocks need reburning.

4. There are several downfall logs and snags mainly in the ponderosa forest. They are wildlife habitat, as well as a control hazard. When planning a burn, at least 3 logs per acre should be left for wildlife, and these should be tagged before burning. All snags should be lined and left unburned because they can send spot fires a long distance and spread fire out of the burn block.

   There are also logs that are the result of historical work crews felling snags or dead top trees as a part of hazard reduction to remove fuel for lightning strikes. Most of these felled trees have the butt log removed. Park managers may want to photograph these as a relic of past management activities.

Table 1. Master chronology of fire scars from sampled ponderosa pine showing the number of scars during each fire year and indicating which fires caused conifer regeneration.

North Rim

Fire Year	IA (3)+	IB (2)	IC (3)	ID (2)	IE (4)	Total number of scars (14)
1938	-	-	-	-	X	1
1935	-	-	X	-	-	1
1929	-	-	X	-	-	1
1903	-	-	X	-	-	18
1890	X	-	-	X	-	28
1886	X	-	-	-	-	18
1880	X	-	X	X	X	8R
1877	-	-	-	-	X	1
1875	-	X	-	-	-	1
1872	X	-	-	-	-	2
1870	-	-	-	-	X	1
1867	X	-	X	X	X	7R
1861	X	X	X	-	-	4R
1859	-	-	-	-	X	1
1858	-	-	X	-	-	1
1856	X	X	-	X	X	6
1848	X	X	X	-	X	8
1843	X	-	X	X	X	4
1839	X	X	X	-	X	7R
1835	X	-	-	-	-	1
1822	X	-	-	-	-	1R
1819	X	-	-	-	-	2
1815	X	-	X	-	-	2
1810	-	-	X	-	X	3
1807	X	-	X	X	-	3
1802	X	-	-	-	-	1
1799	-	-	-	-	X	1
1796	X	X	-	X	X	4
1791	X	-	-	-	-	1
1788	X	-	-	-	-	1
1787	-	-	X	-	X	4R
1785	X	-	-	-	-	1
1783	X	-	-	-	-	1
1776	X	X	-	-	X	5R
1772	-	-	-	-	X	2R
1770	-	-	X	-	-	1
1767	X	-	-	-	-	2
1760	X	-	-	-	-	1
1756	X	-	-	-	X	4R
1750	-	-	-	-	X	2
1749	X	-	-	-	-	2
1742	X	-	-	-	-	1
1740	-	-	-	-	X	2R

Fire Year	IA (3)+	IB (2)	IC (3)	ID (2)	IE (4)	Total number of scars (14)
1736	–	–	X	–	X	2
1732	–	–	–	–	X	2
1729	X	–	–	–	–	1
1725	–	–	–	–	X	3
1721	–	X	–	–	–	1
1720	X	–	X	–	X	3
1714	X	–	X	–	–	2
1709	X	–	–	–	X	2
1704	X	–	X	–	X	3
1698	X	–	X	–	–	2
1690	X	–	–	–	–	1
1677	X	–	–	–	–	1
1666	X	–	–	–	–	1
1649	X	–	–	–	–	1
1643	X	–	–	–	–	1
1640	X	–	–	–	–	1
1635	X	–	–	–	–	1
1623	X	–	–	–	–	1
1612	X	–	–	–	–	1
1600	X	–	–	–	–	1
						136

+ Number of sample trees in stand.

South Rim

Fire Year	IIA (4)	IIB (2)	IIC (3)	IID (2)	IIE (2)	Total number of scars (13)
1917	X	-	-	-	-	1R
1905	-	-	-	X	-	1
1880	-	X	X	X	X	5R
1875	-	X	-	-	X	2R
1867	-	X	X	X	X	6R
1862	X	-	-	-	-	2R
1860	-	-	X	X	-	4
1857	-	X	-	-	-	1R
1850	X	X	-	X	-	4
1843	X	-	X	X	X	5
1839	X	X	X	-	X	6
1833	X	-	-	X	-	3
1830	X	-	-	-	-	2
1828	-	-	X	-	-	1
1827	X	-	-	-	-	1
1824	-	-	-	X	X	3
1822	X	X	-	-	-	4
1815	-	-	-	-	X	1
1813	X	X	-	-	-	3
1807	X	X	-	-	-	3
1799	-	-	X	-	-	1
1796	X	-	-	-	-	3
1793	-	-	X	-	-	1
1789	X	-	X	-	-	2
1782	X	-	-	-	-	2
1775	X	-	-	-	-	2
1773	-	-	X	-	-	1
1769	X	-	-	-	-	3
1764	X	-	-	-	-	1
1760	X	-	-	-	-	2
1755	-	-	X	-	-	1
1744	X	-	-	-	-	1
1735	X	-	-	-		1
1732	-	-	X	-	-	2
						91

Table 2. Fire occurrence on north rim and south rim.

Fire year	Occurrence on North rim	Occurrence on South Rim
1938	X	-
1935	X	-
1929	X	-
1917	-	X
1905	-	X
1903	X	-
1890	X	-
1886	X	-
1880	X	X
1877	X	-
1875	X	X
1872	X	-
1870	X	-
1867	X	X
1862	-	X
1861	X	-
1860	-	X
1859	X	-
1858	X	-
1857	-	X
1856	X	-
1850	-	X
1848	X	-
1843	X	X
1839	X	X
1835	X	-
1834	X	-
1833	-	X
1830	-	X
1828	-	X
1827	-	X
1825	X	-
1824	-	X
1822	X	X
1819	X	-
1815	X	X
1813	-	X
1810	X	-
1807	X	X
1802	X	-
1799	X	X
1796	X	X
1793	-	X
1791	X	-
1789	-	X

Fire Year	Occurrence on North rim	Occurrence on South Rim
1788	X	-
1787	X	-
1785	X	-
1783	X	-
1782	-	X
1776	X	-
1775	-	X
1773	-	X
1772	X	-
1770	X	-
1769	-	X
1767	X	-
1764	-	X
1760	X	X
1756	X	-
1755	-	X
1750	X	-
1749	X	-
1744	-	X
1742	X	-
1740	X	-
1736	X	-
1735	-	X
1732	X	X
1729	X	-
1725	X	-
1721	X	-
1720	X	-
1714	X	-
1709	X	-
1704	X	-
1698	X	-
1690	X	-
1677	X	-
1666	X	-
1649	X	-
1643	X	-
1640	X	-
1635	X	-
1623	X	-
1612	X	-
1600	X	-

Table 3. Fire frequencies for each stnd according to designated fire periods.

Stand number	Number of fire scars	Range of frequency (yrs)	Average frequency (yrs) 1982-1900	1900-1750	1750-1600
			North Rim		
IA-(3)+	42	3-17	0	6	8
IB-(2)	8	5-55	0	21	150
IC-(3)	20	3-34	27	13	30
ID-(2)	7	10-36	0	21	0
IE-(4)	28	3-58	0	7	21

Average for all stands - 13.6

			South Rim		
IIA-(4)	20	3-55	82	9	75
IIB-(2)	9	5-17	0	17	0
IIC-(3)	12	3-29	0	14	150
IID-(2)	8	7-25	82	21	0
IIE-(2)	8	5-17	0	19	0

Average for all stands - 13.4

Table 4. Overall average fire frequency for north rim, south rim, and both rims according to designated fire periods.

Period	North rim	South rim	Both Rims
1982-1900	21	41	14
1900-1750	4	5	3
1750-1600	7	50	6

Table 5. Sample of fire frequencies for individual trees with eight or more fire scars.

Tree number	Number of scars	Range of frequency (yrs)+	Average frequency (yrs) 1982-1900	1900-1750	1750-1600
I 4	15	4-28	0	11	150
I 5	35	3-21	0	9	8
I 12	13	2-53	0	17	38
O 23	15	4-34	0	11	150
I 24	15	4-82	82	19	25
I 25	15	5-20	0	14	38
II 8	8	3-26	0	19	0
II 18	8	6-41	0	21	150
II 34	11	4-14	0	14	0
II 35	17	6-54	82	11	75

Average for all trees - 14.6

\+ This is the range from the first to the last scar. It does not include from the last scar to the cambium.

Appendix A. Effects of grazing at Walnut Canyon National Monument

Summary by Barbara Cheney
Park Technician, 1982

Overgrazing by domestic livestock may drastically change the vegetation of an area. The reduced vigor, lesser seed production, and eventual death of the more palatable species of the plant community allows for the increase of less desirable species such as annual invaders. Trampling results in damage plant parts, increased soil erosion, and compaction of soil, preventing water infiltration and seedling establishment. Animal movement may also result in covering vegetation with soil or dung (Heady, 1975).

The grazing history of the Walnut Canyon area is a contributing factor to the nature of the vegetational communities found within the monument today. Grazing of sheep and cattle in the Walnut Canyon area was totally unregulated until 1900, when the San Francisco \mountains Reserve required livestock owners to purchase grazing permits in an attempt to control overgrazing of sheep on the reserve (Sawyer, 1976). Records from 1904 state that the township containing Walnut Canyon, which was primarily utilized for grazing sheep, had moderate grazing value, but would not last many years longer. Vegetational changes were already being noted in some of the northern sections of the township where overgrazing caused the land to "chiefly produce course weeks" (Leiberg, Rixon, and Dodwell, 1904).

Although Walnut Canyon was established as a national monument in 1917, domestic livestock have probably grazed within its boundaries until 1979 when the boundary fence surrounding the monument was erected. Before that time, weak fences existed in various locations on the north side of the canyon associated with grazing livestock. These fences were ineffective in excluding domestic animals from the monument (Collier, 1982), which, besides disturbing vegetation, have caused damage to the Indian Cliff dwellings within the monument (Information File, WACA). Grazing permit records from the Coconino National Forest Supervisor's Office show that from 1908 to 1957, 2,000 to 4,500 sheep were grazed in allotments bordering Walnut Canyon National Monument each year. Since 1957, cattle replaced sheep on these grazing lands.

Effects of past grazing in the ponderosa pine forests located on the western and of the monument are not obvious. Ponderosa pine naturally grows in groups associated with scattered openings or parks. Grazing tends to be most intense in these park areas or where trees are scattered. Heavy stocking in ponderosa pine may cause total eradication of bunch grasses from these openings (Clary, 1975). In 1912, the northwestern rim of Walnut Canyon consisted of ponderosa pine forest that was poorly stocked with forage plants (Hill). Today, the open areas associated with this ponderosa pine forest exhibit scattered clumps of forbes and grasses, most commonly blue grama grass. The erratic nature of vegetation in these open areas is probably due to environmental stress factors such as soil nutrient concentrations or moisture regime rather than disturbance from livestock grazing activity.

Effects of past grazing are much more obvious in the pinyon-juniper woodland on the eastern side of the monument, where aerial photographs have shown a marked increase in tree density during the twentieth century. Prior to the settlement of the southwest, pinyon-juniper stands were more open and confined to rocky ridges and shallow soils. With the introduction of domestic livestock, ranges were overgrazed, weakening grass stands to the extent that they could not compete with invading tree species. The grasses became too sparse to help carry fire, which would periodically sweep across rangelands and kill trees. Tree establishment was further enhanced by the livestock disseminating seeds in their feces (Springfield, 1976).

Overgrazing might also explain the change in a vegetational community on the southeastern rim of the canyon. An area, which was described as sagebrush range in 1912 by Hill, is now a pinyon-juniper woodland. Thus, it appears that trees have encroached on sagebrush grassland and original stands of trees have become more dense due to overgrazing and the consequent ineffectiveness of fire in controlling the spread of woody plants.

Although grazing is certainly not the only factor which has shaped present day plant communities at Walnut Canyon National Monument, it is certain to have made a substantial contribution, especially within the pinyon-juniper woodland.

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Appendix B. Fire history for each stnd based on sample trees and on age classes of regenertion.

Stand 1A - North rim

Sample tree:	13	14	15	R
Year				
1890	-	-	X	-
1886	-	-	X	X
1880	-	X	X	-
1872	-	X	X	-
1867	-	X	X	X
1861	-	X	X	X
1856	-	-	X	-
1848	X	X	X	-
1843	-	-	X	-
1839	-	X	-	-
1835	-	X	-	-
1822	-	-	X	X
1815	-	-	X	-
1807	-	X	-	-
1802	-	X	-	-
1796	-	-	X	-
1791	-	X	X	-
1788	-	X	-	-
1785	-	X	X	-
1783	-	X	-	-
1776	-	X	X	-
1767	-	X	X	-
1760	-	-	X	-
1756	-	X	X	-
1749	-	X	X	-
1742	-	-	X	-
1729	-	-	X	-
1720	-	-	X	-
1714	-	-	X	-
1709	-	-	X	-
1704	-	-	X	-
1698	-	-	X	-
1690	-	-	X	-
1677	-	-	X	-
1666	-	-	X	-

Stand 1B - North rim

Sample Tree:	17	18	R
Year			
1875	X	-	-
1861	-	X	X
1856	X	-	-
1848	X	X	-
1839	X	-	X
1796	-	X	-
1776	-	X	-
1721	-	X	-

Stand 1C - North rim

Sample tree:	111	112	114	R
Year				
1935	-	-	X	-
1929	-	-	X	-
1903	-	-	X	X
1880	X	X	X	-
1867	-	X	X	-
1861	-	X	-	-
1858	-	X	-	-
1848	X	-	-	-
1843	-	X	-	-
1839	X	X	-	-
1815	-	X	-	-
1810	-	X	-	-
1807	X	-	-	-
1787	-	X	X	-
1770	X	-	-	-
1736	-	X	-	-
1720	-	X	-	-
1714	-	X	-	-
1704	-	X	-	-
1698	X	-	-	-
1649	-	-	X	-
1643	-	-	X	-
1640	-	-	X	-
1635	-	-	X	-
1623	-	-	X	-
1612	-	-	X	-
1600	-	-	X	-

Stand 1D - North Rim

Sample tree:	120	121	R
Year			
1980	-	X	X
1880	X	-	-
1867	-	X	-
1856	X	X	-
1843	-	X	-
1807	X	-	-
1796	X	-	-

Stand 1E - North rim

Sample tree:	123	124	125	126	R
Year					
1938	-	X	-	-	-
1880	X	-	X	-	X
1870	X	-	-	-	-
1867	X	-	X	-	-
1859	X	-	-	-	-
1856	-	X	X	-	-
1848	X	X	-	-	-
1843	X	-	-	-	-
1839	X	-	X	-	-
1834	X	-	-	-	-
1825	X	-	X	X	-
1819	X	X	-	-	-
1810	X	-	X	-	-
1799	-	X	-	-	-
1796	-	-	-	X	-
1787	X	-	X	-	X
1776	-	X	X	-	X
1772	-	X	X	-	X
1756	X	X	X	-	X
1750	-	X	X	-	-
1740	-	X	X	-	X
1736	-	X	-	-	-
1732	-	X	X	-	-
1725	X	X	X	-	-
1720	-	X	-	-	-
1709	-	X	-	-	-
1704	-	-	-	X	-

Stand 11A - South rim

Sample Tree:	116	118	1134	1135	R
Year					
1917	-	-	-	X	X
1862	X	-	-	X	X
1850	-	X	-	X	-
1843	-	-	X	X	-
1839	-	X	-	X	-
1833	-	X	X	-	-
1830	-	X	-	X	-
1827	-	X	-	-	-
1822	-	X	X	X	-
1813	-	-	X	X	-
1807	-	-	X	X	-
1796	-	X	-	X	-
1789	-	-	-	X	-
1782	-	-	X	X	-
1775	-	-	X	X	-
1744	-	-	-	X	-
1735	-	-	-	X	-

Stand 11B - South rim

Sample tree:	113	1113	R
Year			
1880	-	X	X
1875	-	X	X
1867	-	X	-
1857	-	X	X
1850	-	X	-
1839	-	X	-
1822	X	-	-
1813	X	-	-
1807	X	-	-

Stand 11C - South rim

Sample Tree:	1115	1118	1123	R
Year				
1880	X	-	X	X
1867	X	-	X	X
1860	-	X	-	-
1843	-	X	-	-
1839	X	X	-	-
1828	-	X	-	-
1799	-	X	-	-
1793	-	X	-	-
1789	X	-	-	-
1773	-	X	-	-
1755	X	-	-	-
1732	X	X	-	-

Stand 11D - South rim

Sample tree:	1126	1137	R
Year			
1905	-	X	-
1880	X	-	X
1867	X	-	X
1860	X	-	-
1850	X	-	-
1843	X	-	-
1833	X	-	-
1824	-	X	-

Stand 11E - South rim

Sample tree:	1131	1132
Year		
1880	X	-
1875	-	X
1867	X	X
1860	X	X
1843	X	-
1839	X	-
1824	X	X
1815	-	X

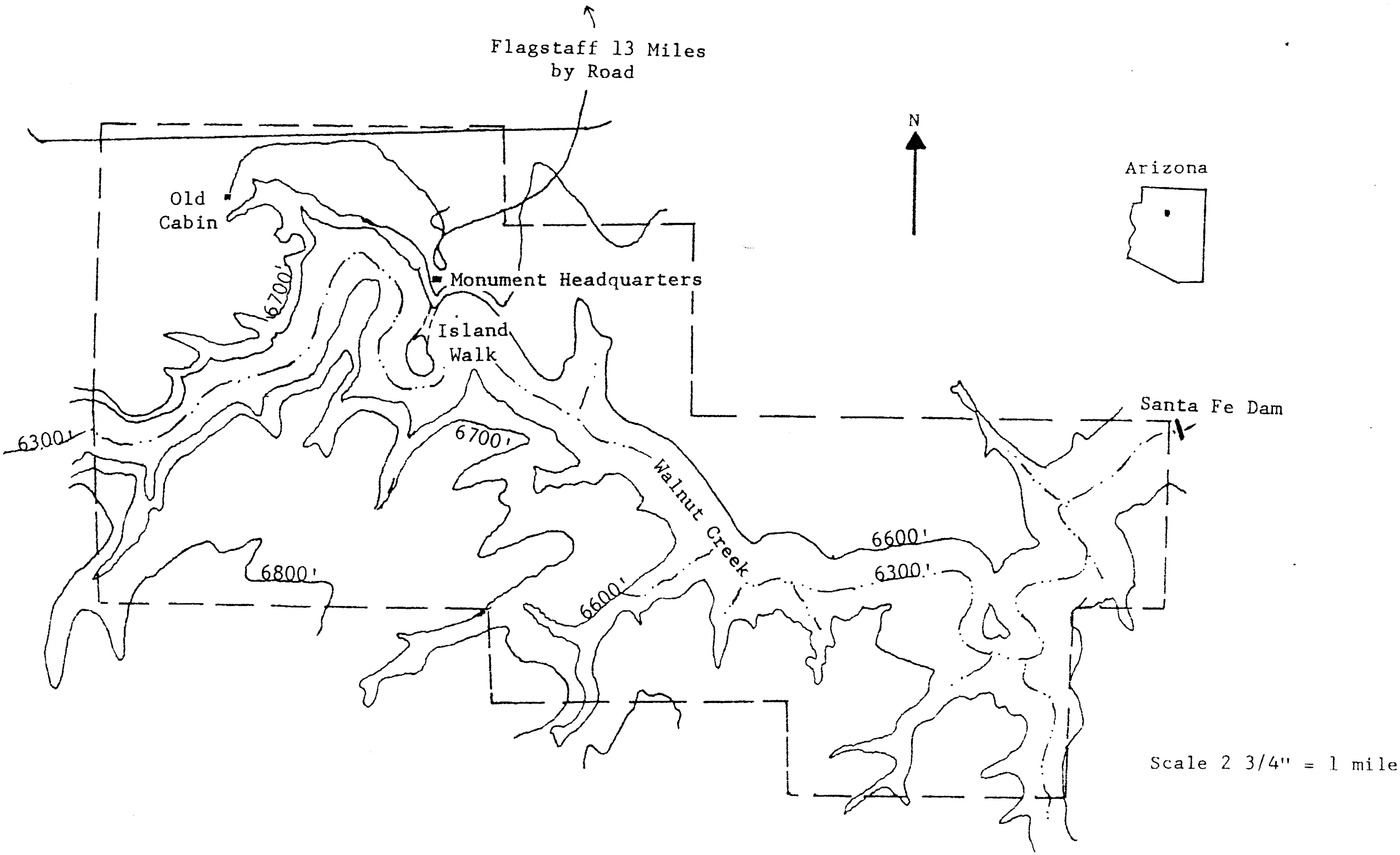

Figure 1. Location and features of Walnut Canyon National Monument

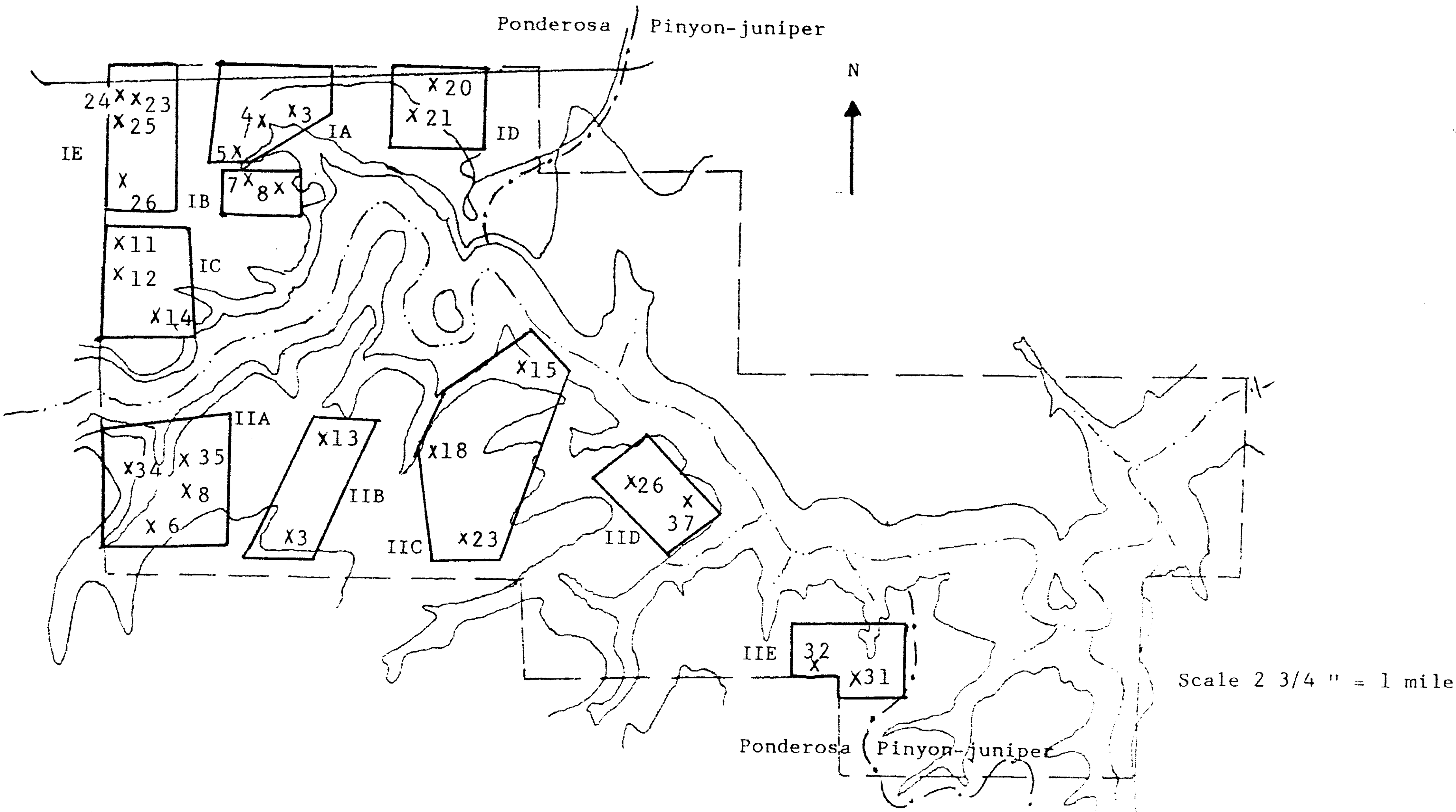

Figure 2. Location of sampled fire-scarred trees, stand designation, and general boundary of forest type.

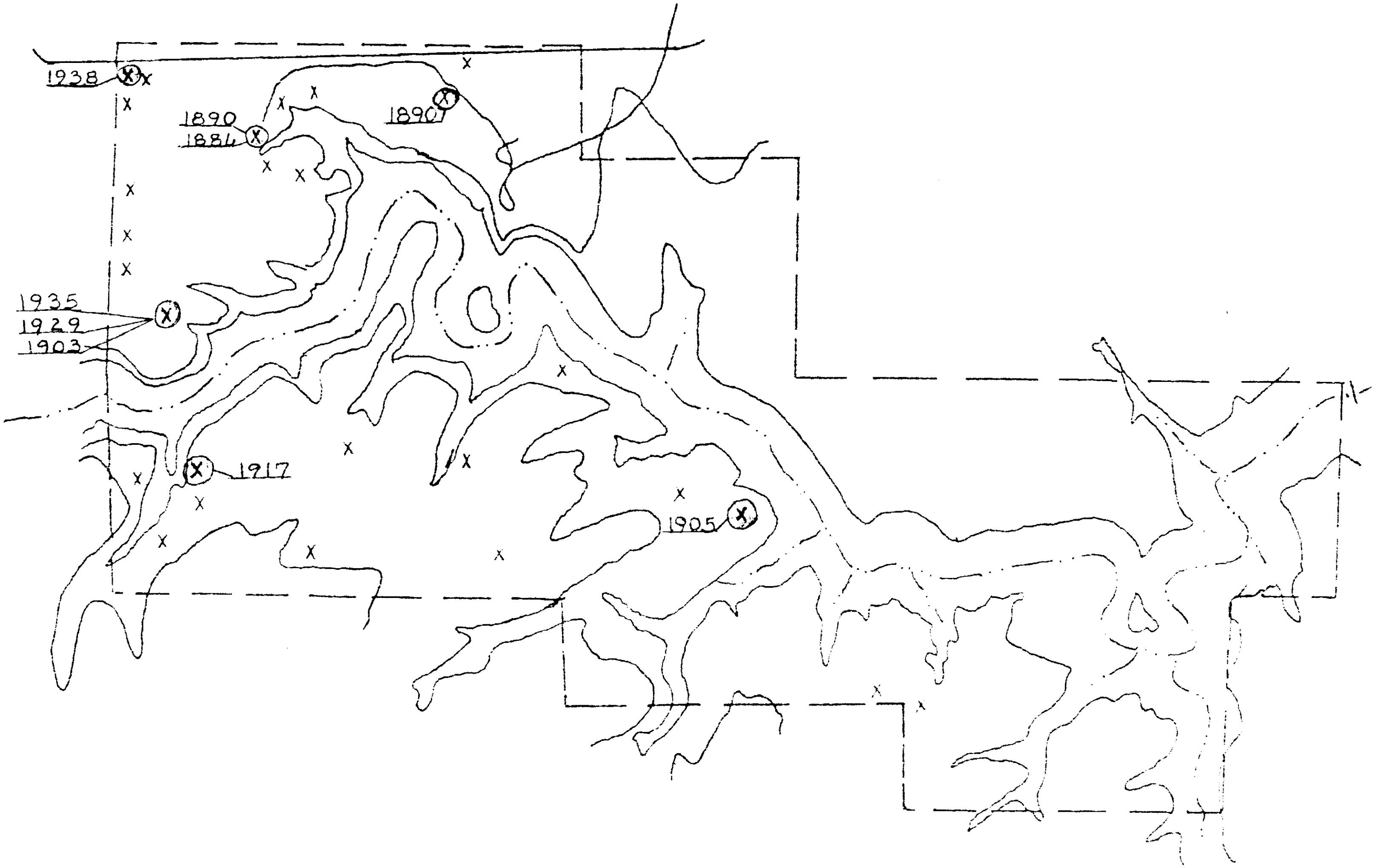

Figure 3a. Relative fire spread for fires is 1938, 1935, 1929, 1917, 1905, 1903, 1890, and 1886.

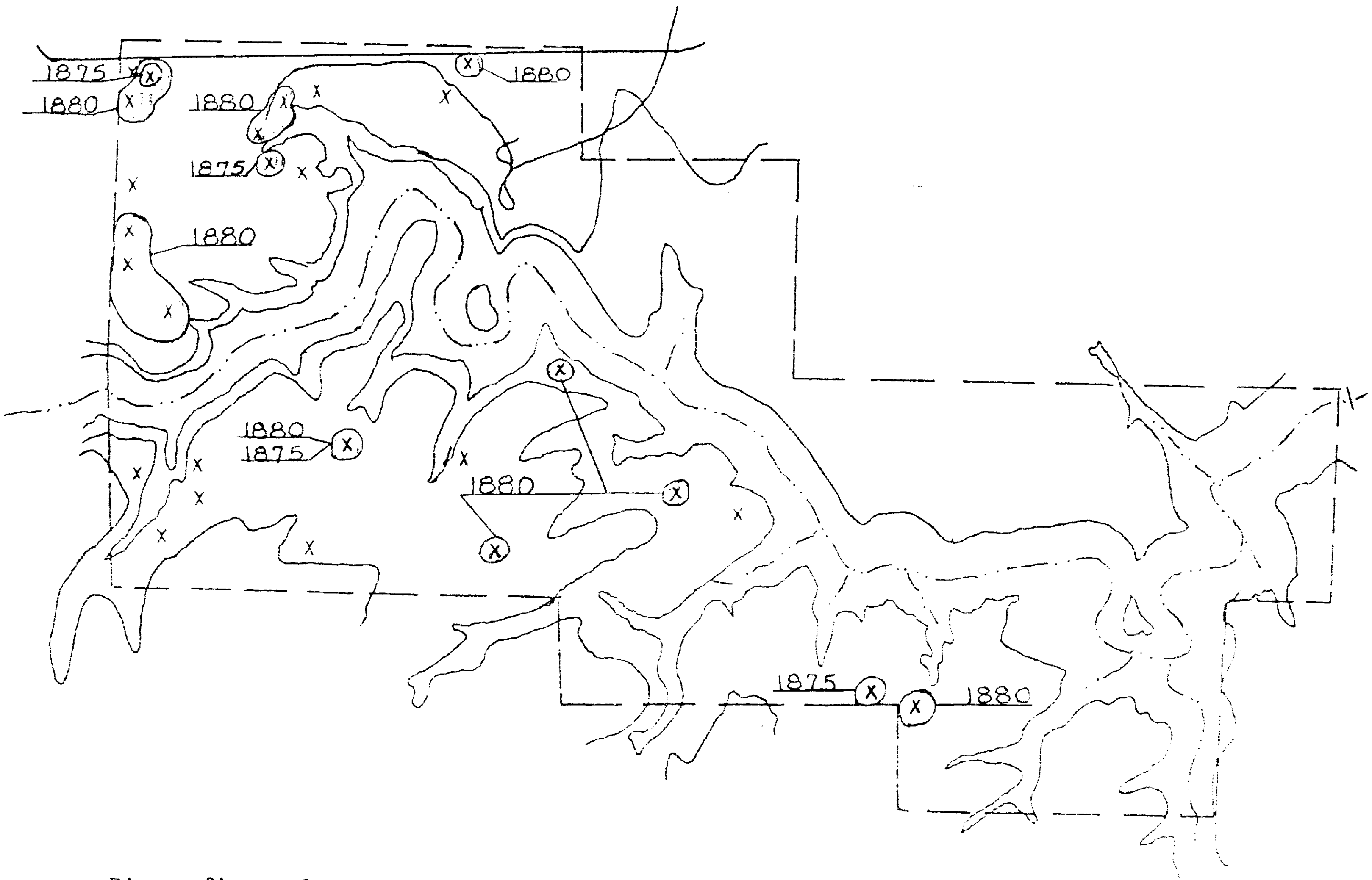

Figure 3b. Relative fire spread for fires in 1880, 1877, and 1875.

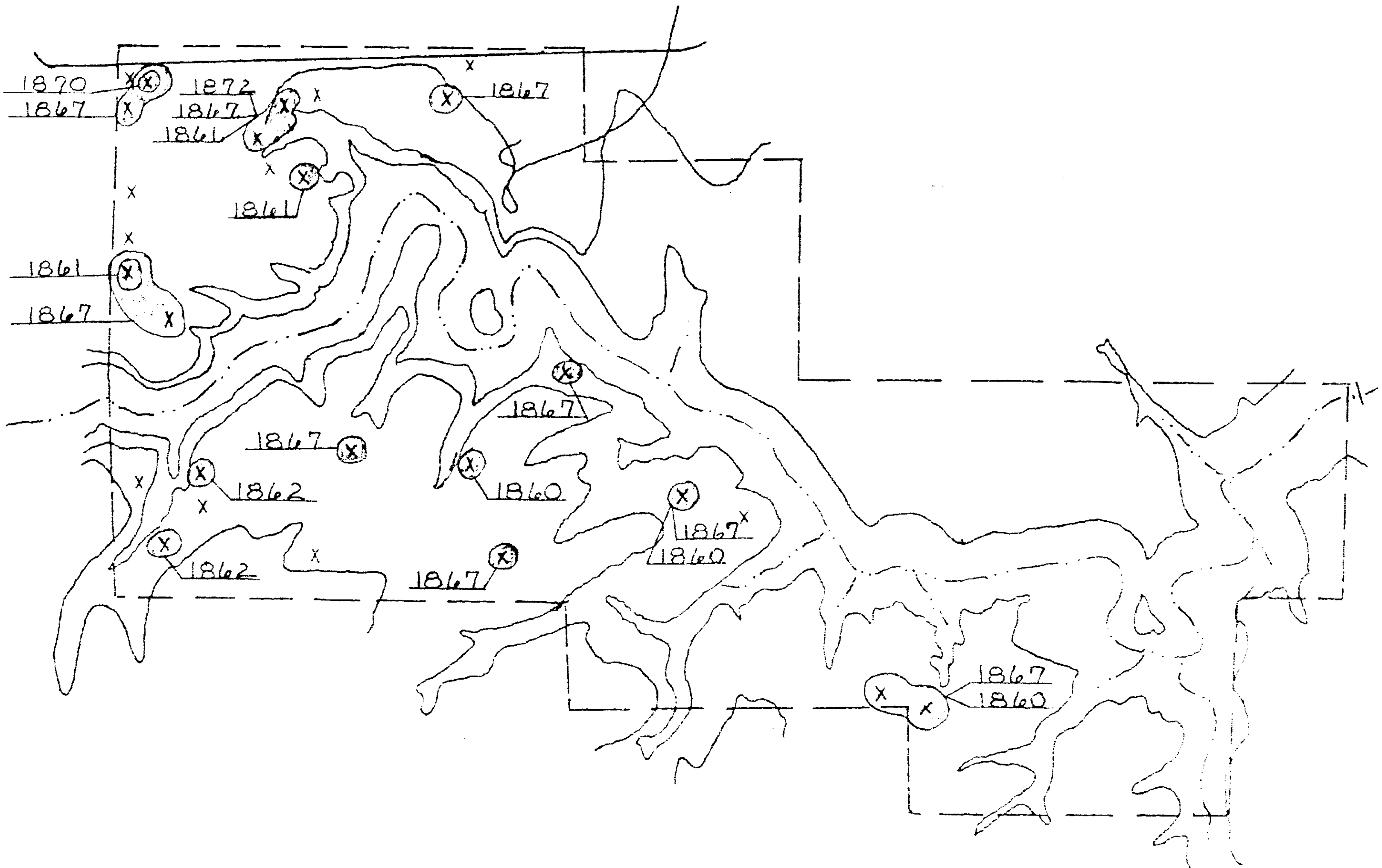

Figure 3c. Relative fire spread for fires in 1872, 1870, 1867, 1862, 1861, and 1860.

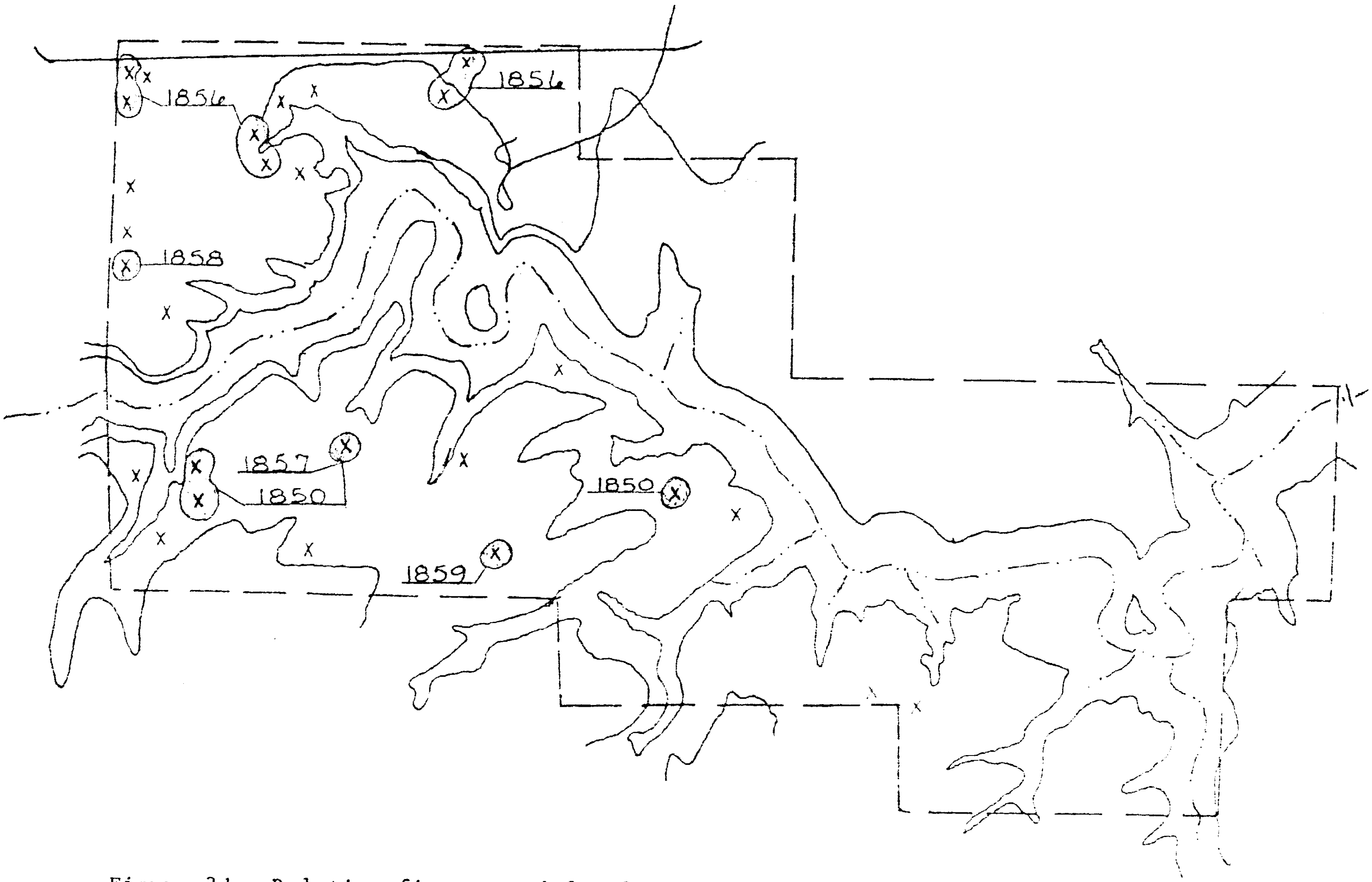

Figure 3d. Relative fire spread for fires in 1859, 1858, 1857, 1856, and 1850.

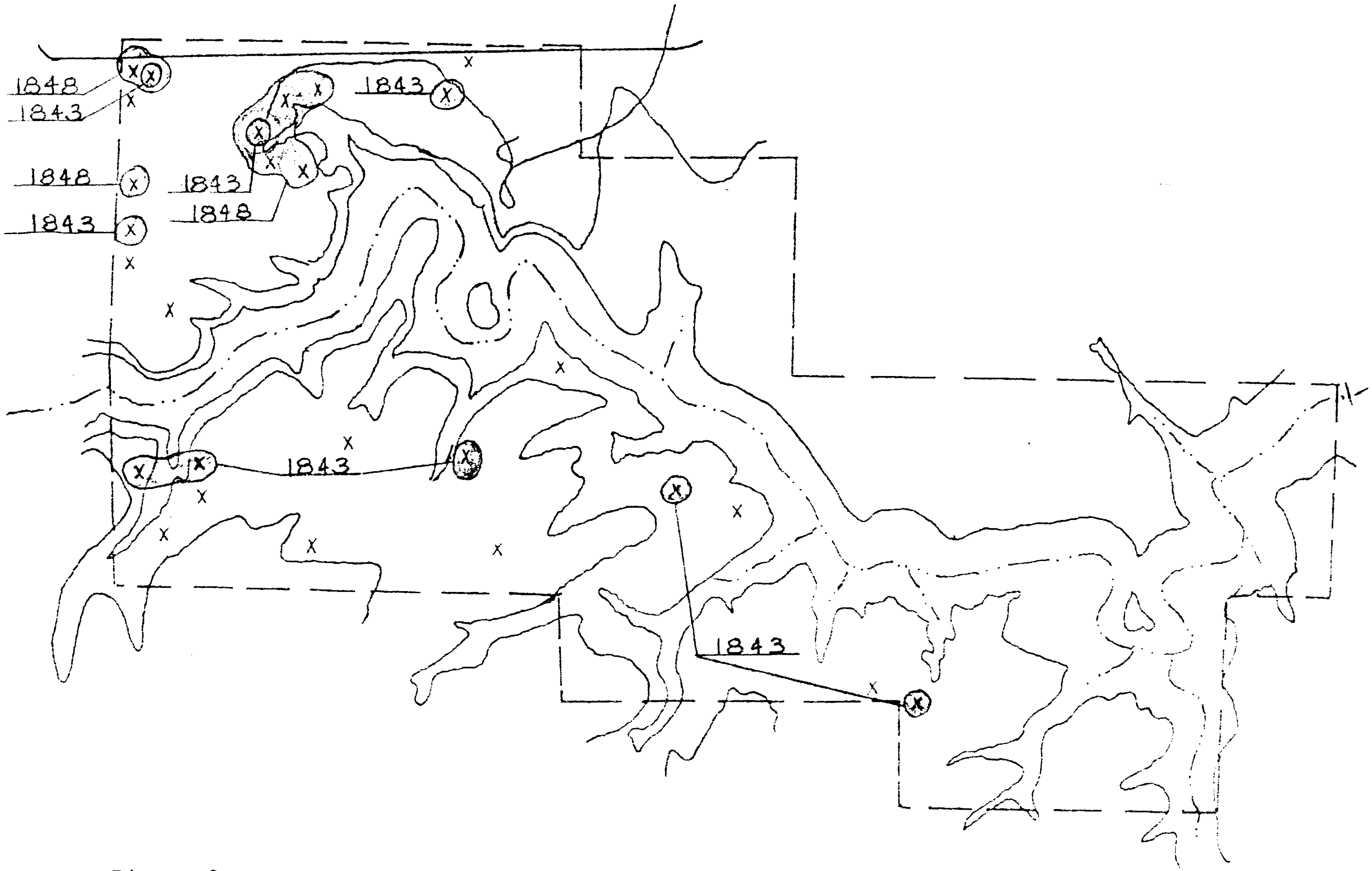

Figure 3e. Relative fire spread for fires in 1848 and 1843.

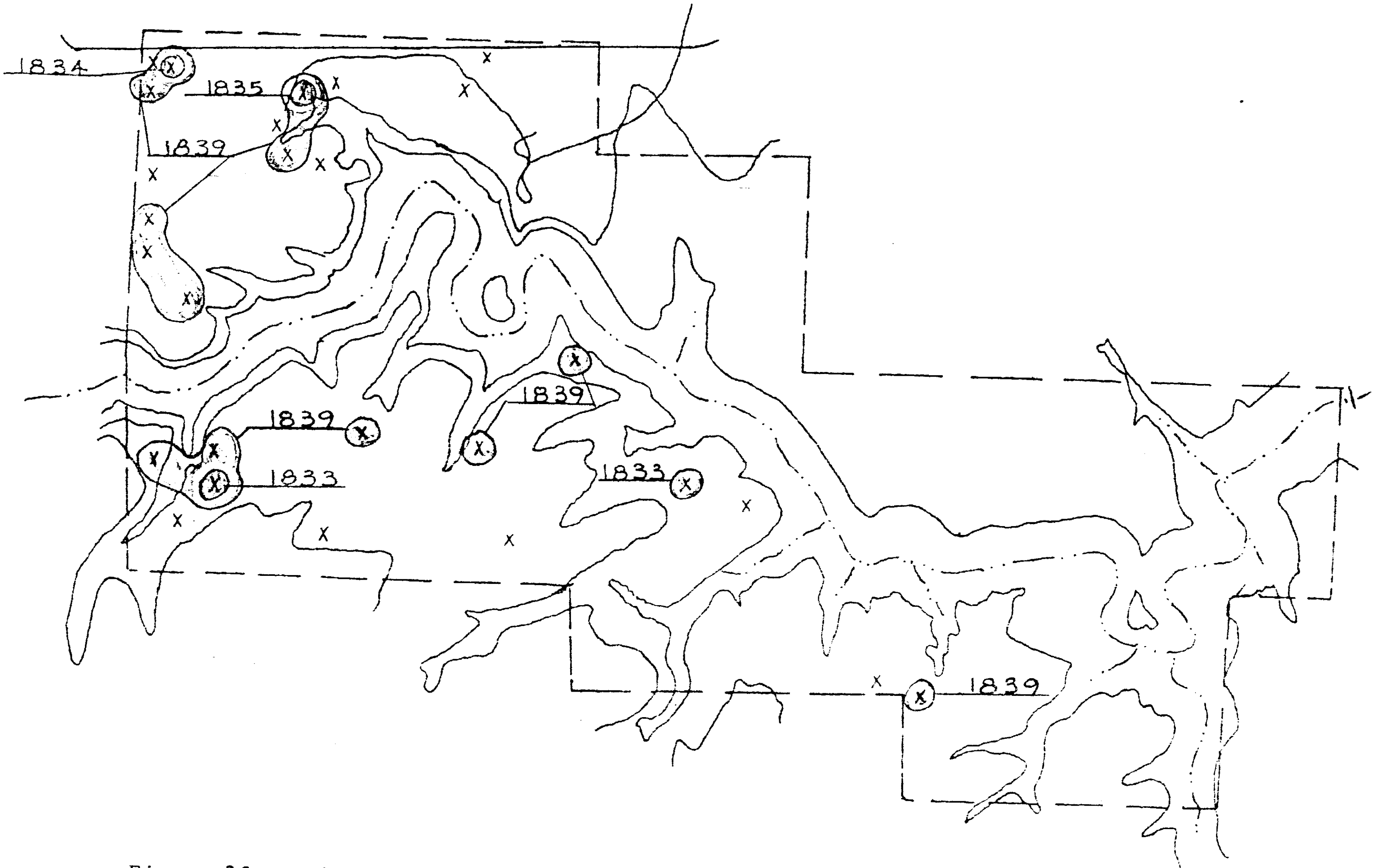

Figure 3f. Relative fire spread for fires in 1839, 1835, 1834, and 1833.

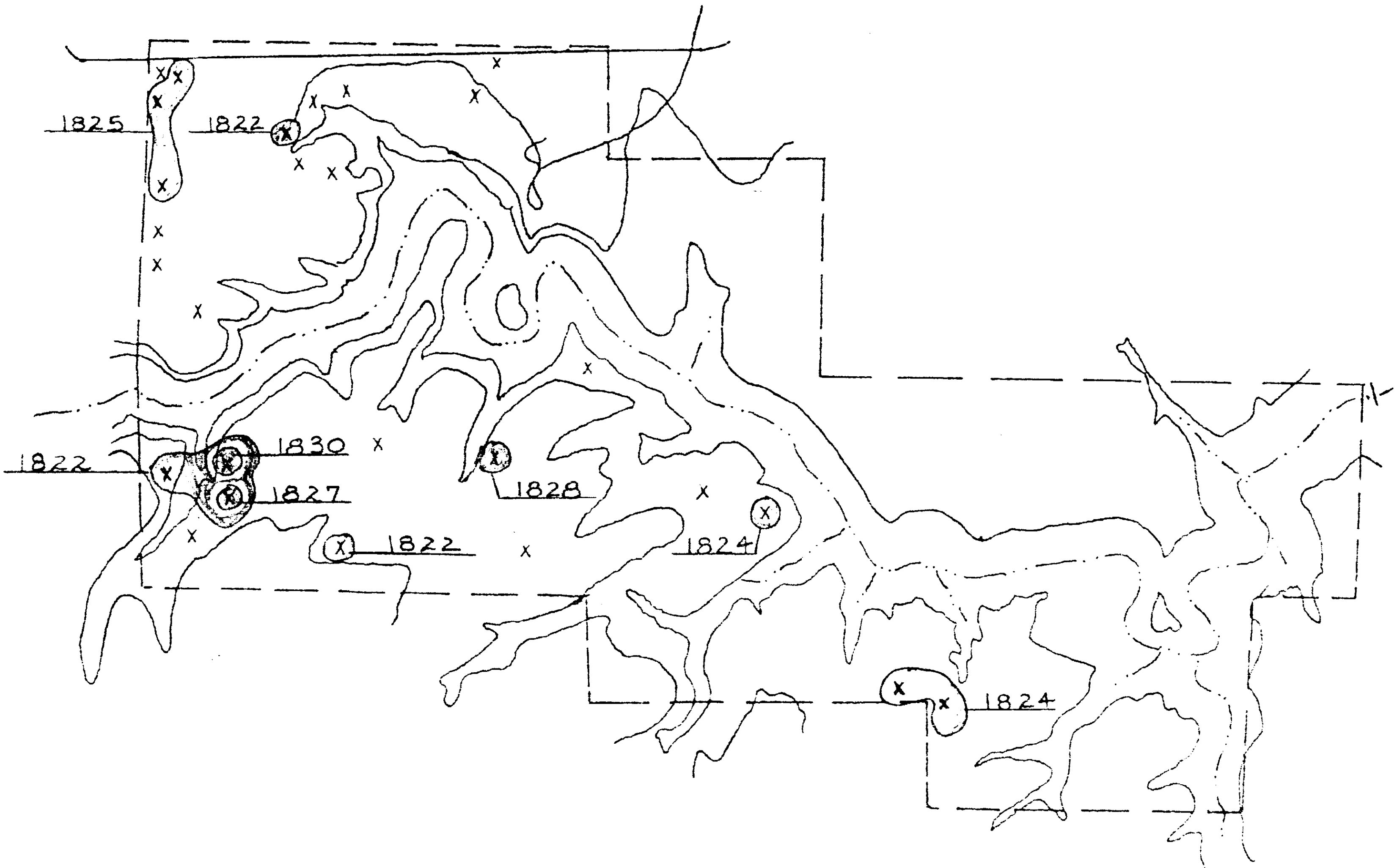

Figure 3g. Relative fire spread for fires in 1830, 1828, 1827, 1825, 1824, and 1822.

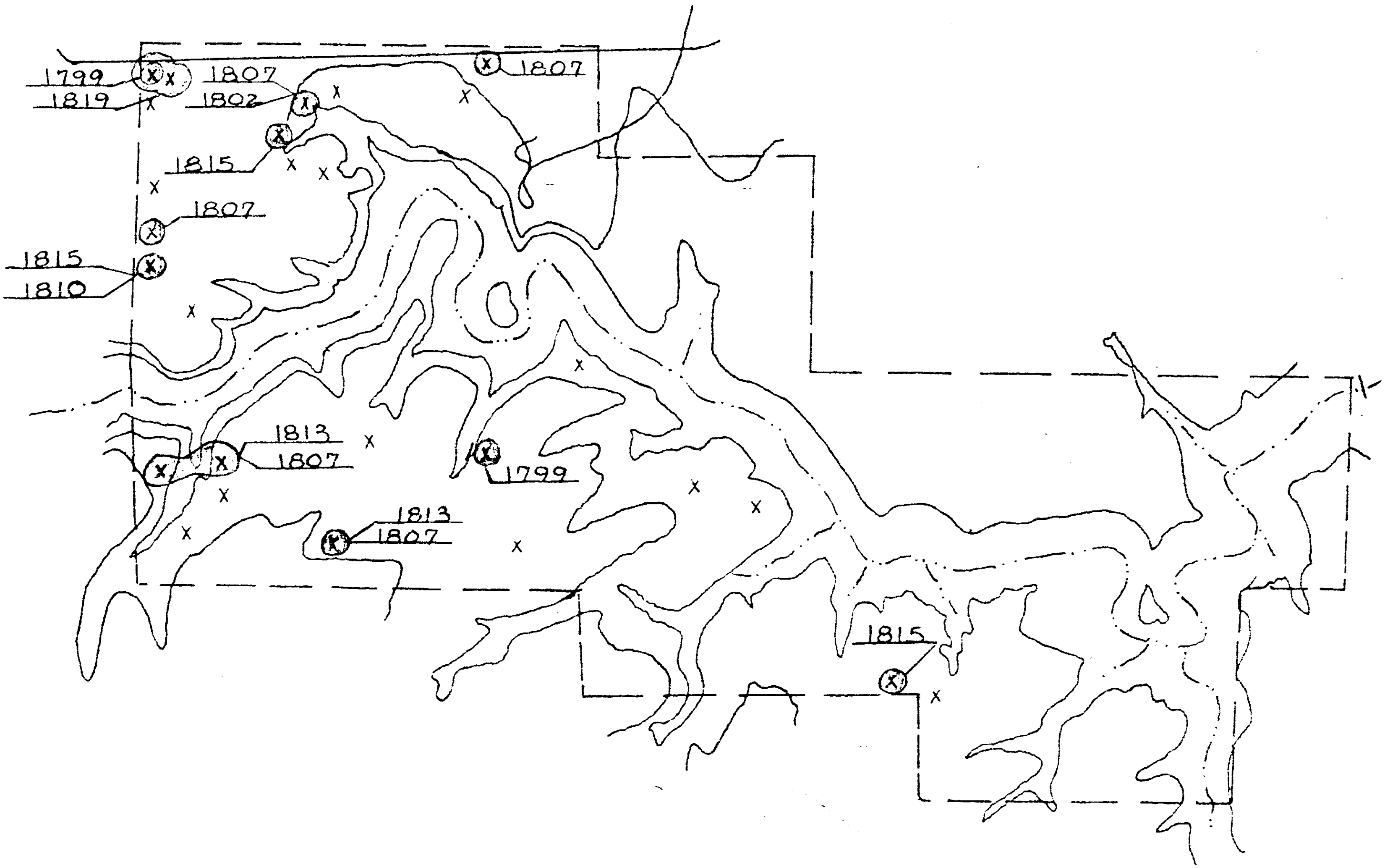

Figure 3h. Relative fire spread for fires in 1819, 1815, 1810, 1807, 1802, and 1799.

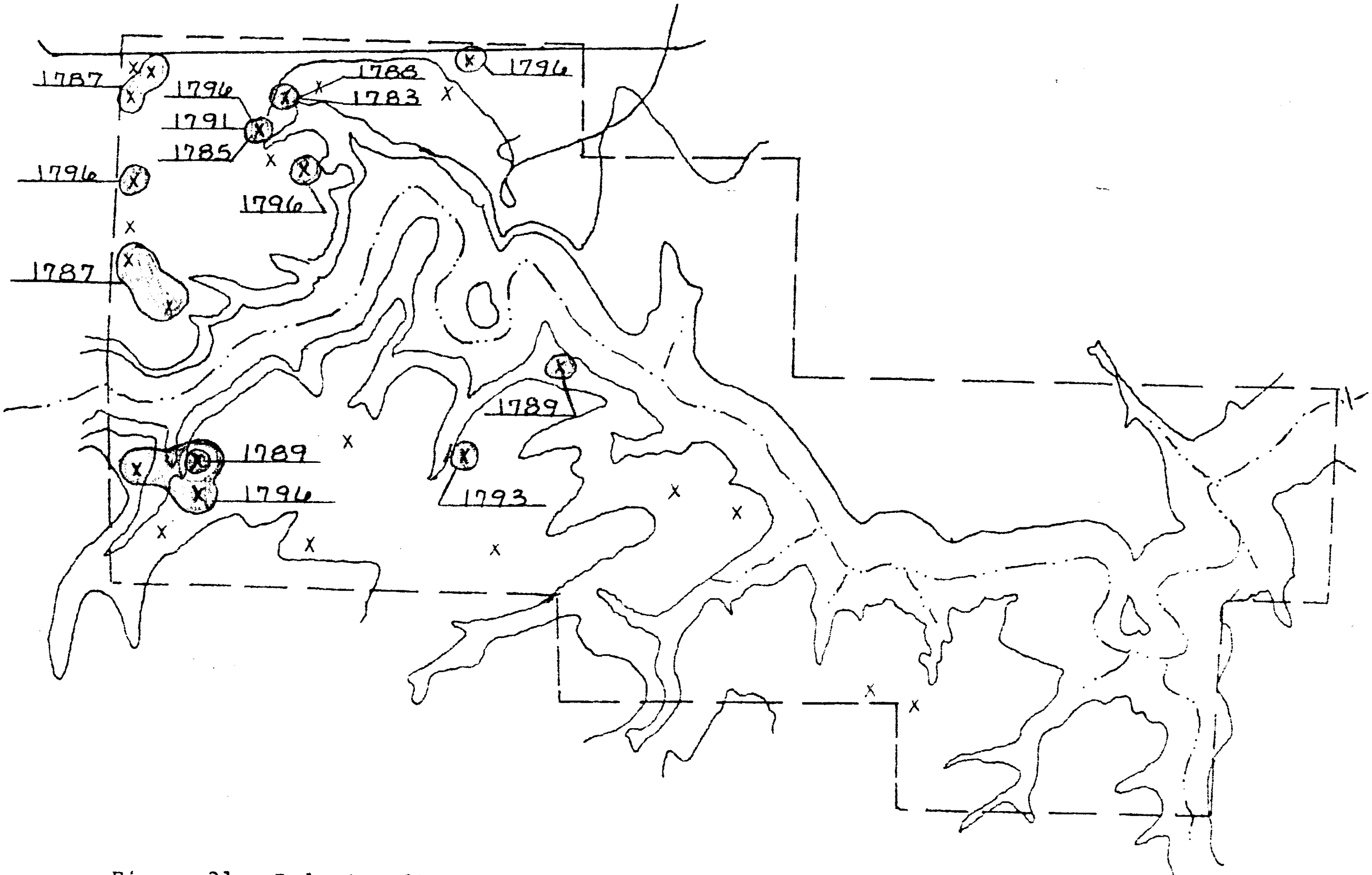

Figure 31. Relative fire spread for fires in 1796, 1793, 1791, 1789, 1788, 1787, 1785, and 1783.

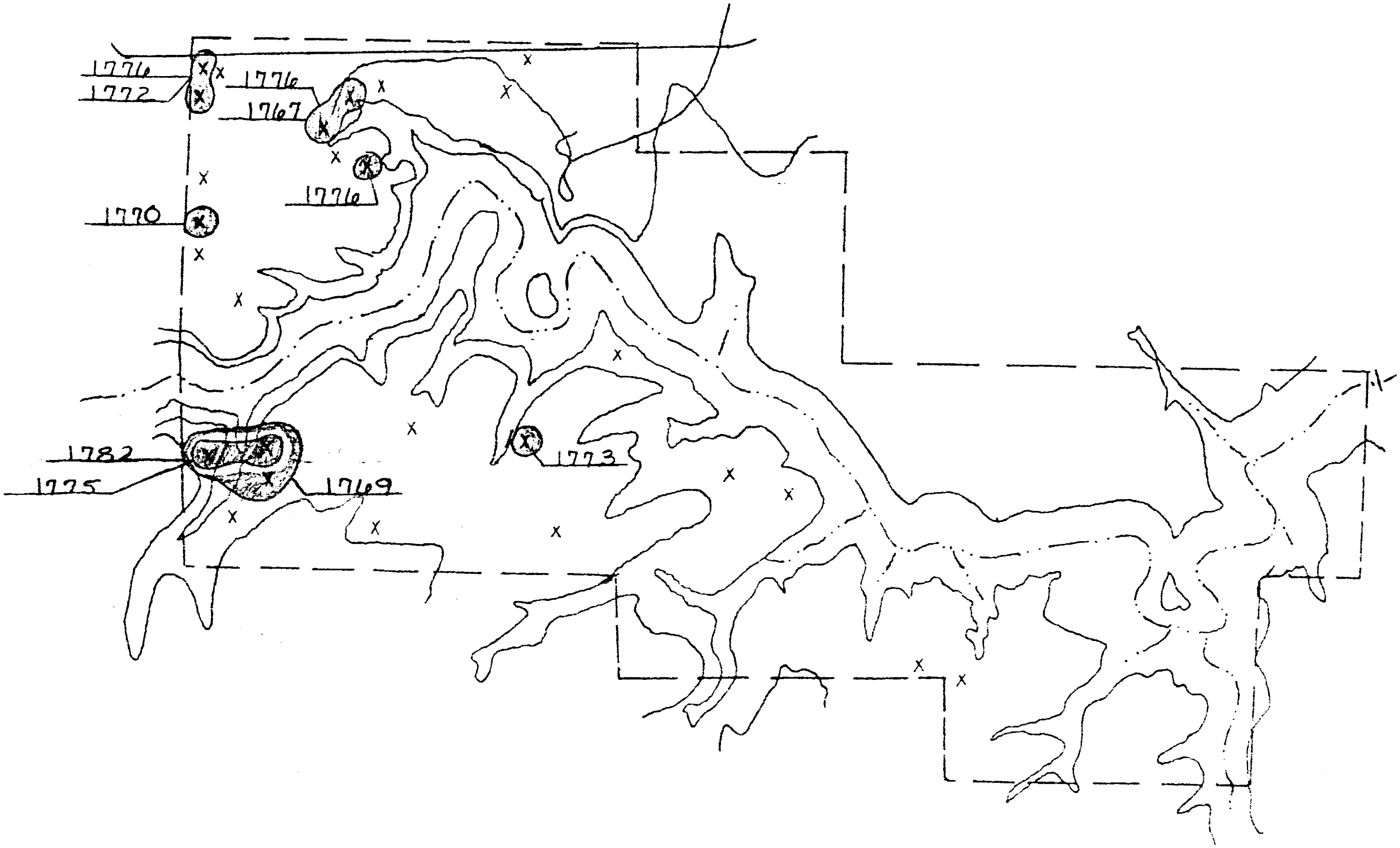

Figure 3j. Relative fire spread for fires in 1782, 1776, 1775, 1773, 1772, 1770, 1769, and 1767.

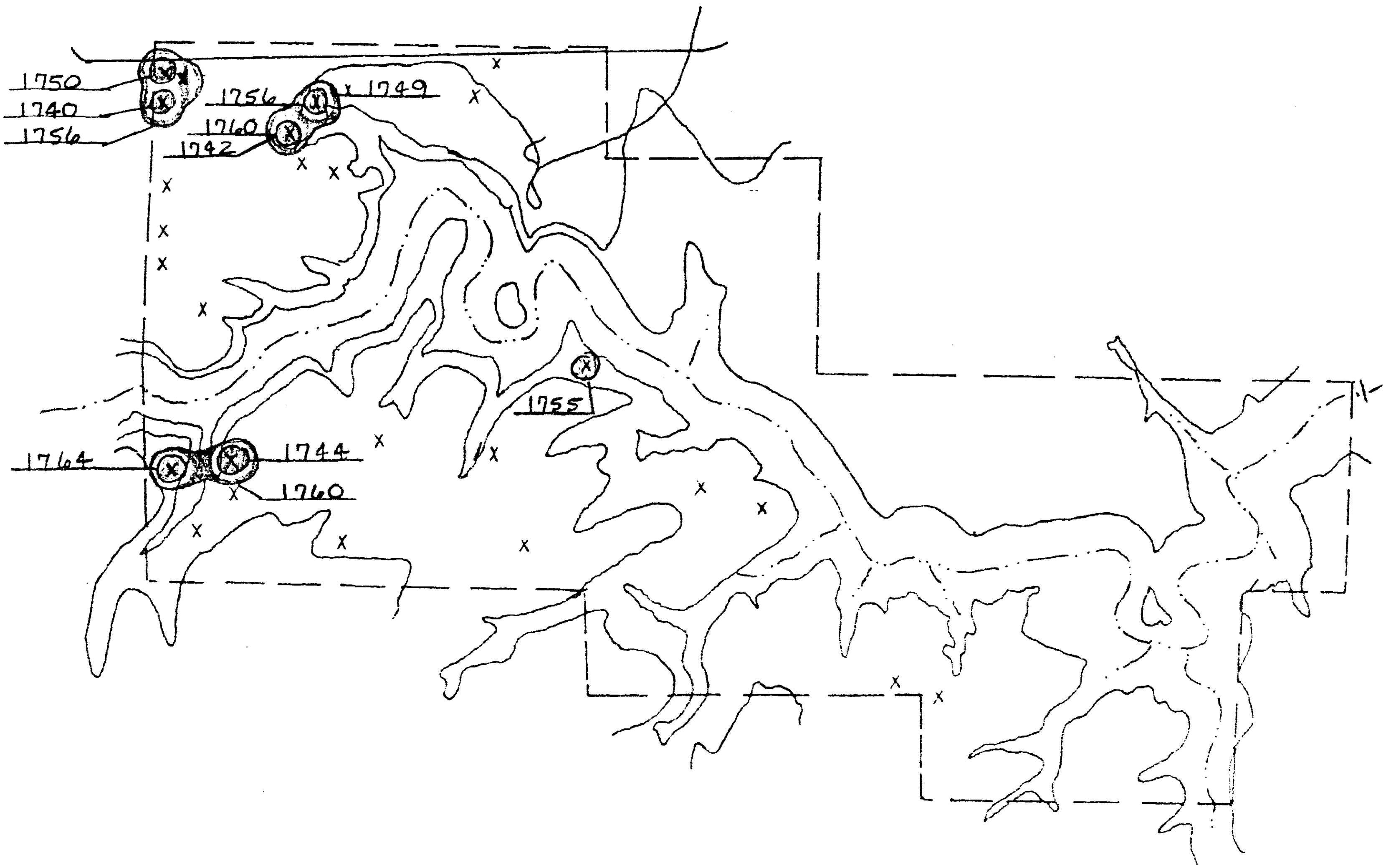

Figure 3k. Relative fire spread for fires in 1764, 1760, 1756, 1755, 1750, 1749, 1744, 1742, and 1740.

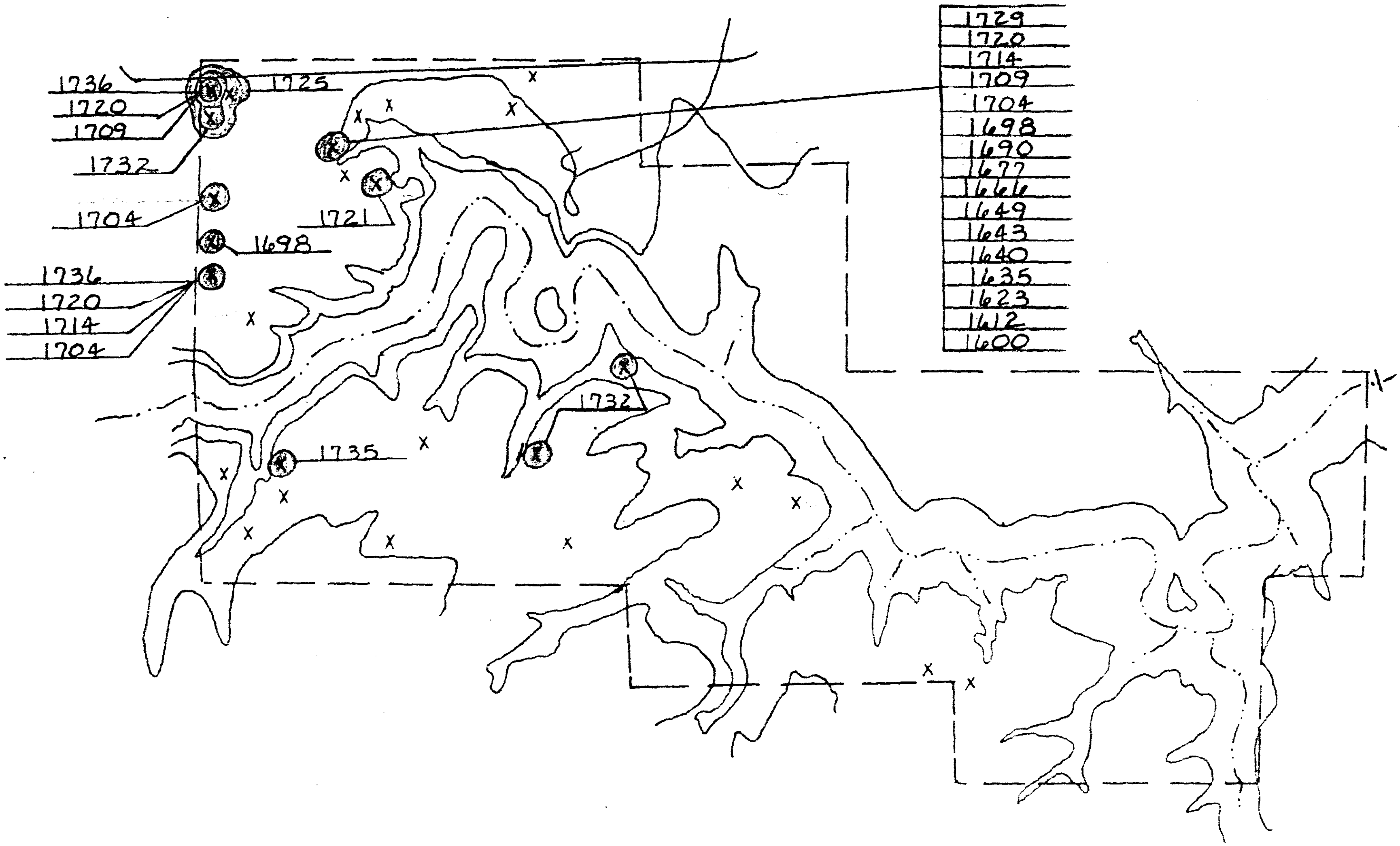

Figure 31. Relative fire spread for fires in 1736, 1735, 1732, 1729, 1725, 1721, 1720, 1714, 1709, 1704, 1698, 1690, 1677, 1666, 1649, 1643, 1640, 1635, 1623, 1612, and 1600.

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