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The History and Role of Fire in Forest Ecosystems of the Central Western Cascades of Oregon Determined by Forest Stand Analysis

by

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Abstract

THE HISTORY AND ROLE OF FIRE IN FOREST ECOSYSTEMS OF THE CENTRAL WESTERN CASCADES OF OREGON DETERMINED BY FOREST STAND ANALYSIS

by Peter H. Morrison

A reconstruction of fire history from 1150 AD to the present was made based on forest stand analysis in two study areas in the central western Cascades of Oregon. The study areas are located immediately north of the H.J. Andrews Experimental Forest within the Willamette National Forest. The Cook Creek - Quentin Creek study area is located in steep, irregular topography and has an average elevation of about 820 m. The Deer Creek study area is located in more gentle upland topography with an average elevation of 1220 m. The tree ring records available in stumps of clearcuts and road right-of-ways were used to determine origin dates of seral tree species and fire scar dates. These data were used to determine major fire episodes.

The fire regime for both study areas proved to be more complex than the initial assumptions of large, infrequent, catastrophic fires. A highly variable fire regime was found. Some sites burned every 15-20 years while other sites burned once every 400-500 years. The intensity of each fire appears to have been highly variable as well. In most cases fairly small irregular patches were burned at stand replacement intensity while other patches burned at moderate to low intensity.

Fire was more frequent in the Cook Creek - Quentin Creek study area (natural fire rotation = 96 years) than in the Deer Creek study area (natural fire rotation = 138 years). On many sites multi-aged stands were found with several age classes resulting from recurrent low to moderate intensity fires. Other sites had even-aged stands dating from the last stand replacement fire. Patches in the forest mosaic created by different levels of fire intensity in the 1800-1900 AD period were analyzed. Small patches (less than 10 hectares) dominated the patch size distribution. More area was burned by moderate to low intensity fires than by high intensity fires during that period.

The influence of physiography, environmental gradients and man's activities on the fire regime is discussed. Implications of this work for current research in these ecosystems in the areas of geomorphology, stand dynamics and wildlife habitat are also discussed.

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ACKNOWLEDGMENTS

The completion of this project would not have been possible without the assistance and encouragement of a number of people. I gratefully acknowledge their help.

Dr. Frederick Swanson (USFS Pacific Northwest Forest and Range Experiment Station, Forestry Sciences Lab, Corvallis, Oregon) was instrumental in initiating the study and offered assistance throughout its course. He provided financial assistance through the Coniferous Forest Biome project and the Long-Term Ecological Research Program of the National Science Foundation. Periodic discussions with Dr. Swanson, his critical evaluation of my methods and results, and his thorough review of the draft manuscript are greatly appreciated.

The members of my supervisory committee at the University of Washington have been most helpful during my course of studies. Dr. James Agee (National Park Service - University of Washington Cooperative Studies Unit) graciously lent his time and expertise in providing encouragement and direction in my study and assistance in analyzing the disturbance record produced by a complex fire regime. This help as well as his review of the draft manuscript are greatly appreciated. Dr. Fio Ugolini and Dr. Leo Fritschen provided intellectual stimulation and encouragement throughout my master's program. Their encouragement in this study and review of the final manuscript are gratefully acknowledged.

I would also like to acknowledge the enthusiastic discussions I have had with Peter Teensma (University of Oregon) on field techniques and fire history analysis. His assistance in gathering data at several sites and his thorough review of the draft manuscript is most appreciated. I appreciate the stimulating discussions concerning this study that I have had with Art McKee and Dr. Jerry Franklin (Forestry Sciences Lab, Corvallis, Oregon) and their continuing interest and encouragement.

I am also deeply grateful to my wife, Aileen Jeffries, for the encouragement, patience and innumerable forms of assistance she has provided during this study.

INTRODUCTION

Purpose of Study

Although the forest ecosystems of the western Oregon Cascades have been the subject of considerable research, little is known about the history of perturbations that affect these ecosystems. Since disturbances can profoundly influence the composition, structure and function of forest ecosystems this lack of information has limited our understanding of long-term forest dynamics. The purpose of this study is to provide preliminary information on natural disturbances in these forest ecosystems, particularly forest fire, which is the major large scale disturbance mechanism affecting this area. This study provides preliminary information on the history of forest fires, their frequency, intensity and effects on the vegetation mosaic in a study area in the western Cascades east of Eugene, Oregon.

History of the Study

The need for more quantitative information on forest disturbances in the western Cascades was recognized by F. J. Swanson in 1975 who initiated a project to collect information on large scale forest disturbances in the H.J. Andrews Experimental Forest and lands to the north, east and south. Approximately 190 square miles were included in this study area. The goal of this study was to produce reconnaissance level maps of large scale forest disturbances and associated forest age classes based on interpretation of tree ring records at sample sites and subsequent mapping from aerial photography. I worked on the project during 1975 and 1976 collecting field information and producing preliminary maps from this data and the aerial photography. Chris Woods, a student at the University of Oregon, collected field data for a short period of time in 1975. Fred Swanson participated periodically in field work and provided overall direction. During this period funding was obtained from the National Science Foundation through the Coniferous Forest Biome project of the U.S. International Biological Program.

After these preliminary reconnaissance level maps were prepared it was apparent that the disturbance history was considerably more complex than initially envisioned (Franklin et al. 1976, Swanson et al. 1977). Due to several factors my work on this project was interrupted for a number of years.

A parallel study of historically recorded forest fire in this area was undertaken by Constance Burke (1979). She used historical sources to document forest fire occurrence between 1850 and 1977. This study was also directed by Fred Swanson as a complement to the fire history work based on tree ring data described above.

In November 1982 I resumed analysis of the data collected in 1975 and 1976. Because of the complexity of the fire record I decided to proceed with a more detailed analysis of the disturbance record in two small study areas that are subsets of the initial study area. Additional field data were collected in June and October 1983.

James K. Agee and Fred Swanson advised me periodically as I pursued this more detailed study. Funding for this later phase was provided through funds from the National Science Foundation Long-Term Ecological Research Program to Oregon State University and the U.S. Forest Service Pacific Northwest Forest and Range Experiment Station at Corvallis, Oregon.

Peter Teensma, a graduate student at the University of Oregon, started field work on this fire history project in 1982. He has collected tree ring data at additional sites throughout the 190 square mile initial study area, concentrating on the H. J. Andrews Experimental Forest and adjacent lands. A few of these sites are located in the Cook Creek - Quentin Creek study area or the Deer Creek study area and he assisted me in data collection at several other sites. This data has been included in my subsequent analysis.

Description of the Study Areas

1. Location:

The reconnaissance study area consists of approximately 49000 hectares in the central western Cascades. This land is located within the Willamette National Forest in both Blue River, McKenzie Bridge and Sweet Home Ranger Districts. Some private timberland is included in this area. This initial study area includes portions of both the McKenzie River and South Santiam River watersheds. The two study areas selected for more intensive analysis are centrally located in this large reconnaissance study area (Figure 1). The first of these areas is located in the lower Cook Creek and Quentin Creek drainages and includes land bordering Blue River. The second area is approximately four kilometers northeast of the first and includes parts of the upper Deer Creek watershed and a small amount of land in the Sevenmile Creek, Browder Creek, Mann Creek and Wolf Creek drainages. Both study areas are rectangular and each encompasses 1943 hectares (7.5 square miles).

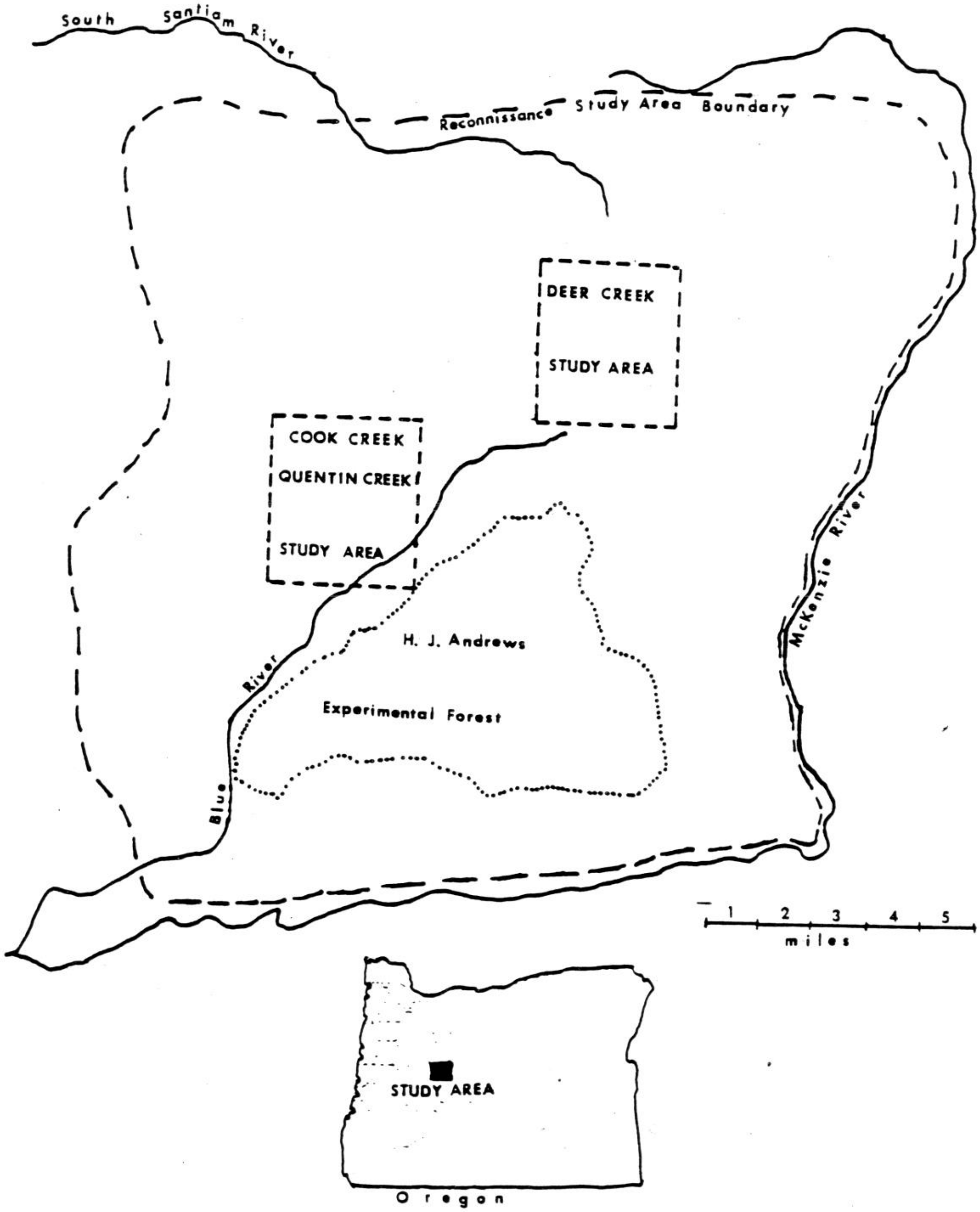


Figure 1. Location of study areas.

2. Physiography:

The study areas are situated in the mid-elevation central western Cascades. Both study areas contain major south draining watersheds. The Cook Creek - Quentin Creek study area (Figure 2) consists of steep and dissected topography with deep and narrow V-shaped valleys and sharp ridge tops. The topography of this study area developed predominately through the influence of mass wasting, surface erosion and fluvial erosion. Glacial deposits at the confluences of Cook Creek and Quentin Creek with Blue River indicate the presence of Pleistocene glacial activity in the study area (F. J. Swanson personal communication). The elevation ranges from a low point of about 524 m above sea level on Blue River to about 1295 m in the northwest corner of the study area. The average elevation is about 820 m.

The Deer Creek study area (Figure 3) consists of more gentle topography with broad valleys and ridge tops. Pleistocene glacial activity has been a dominant influence on the topography of this study area. Mass wasting, surface erosion and fluvial erosion have also influenced the topography of the study area. The elevation ranges from a low point of about 914 m on Deer Creek to an elevation of 1632 m at the summit of Wildcat Mountain along the eastern edge of the study area. The average elevation is about 1220 m.

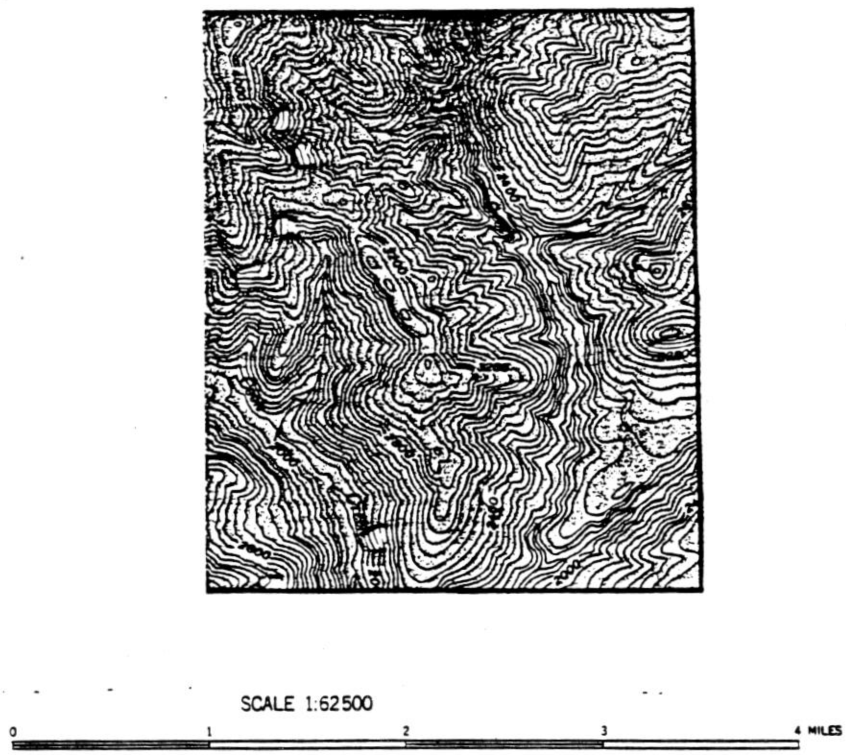


Figure 2. Topographic map - Cook Creek - Quentin Creek study area.

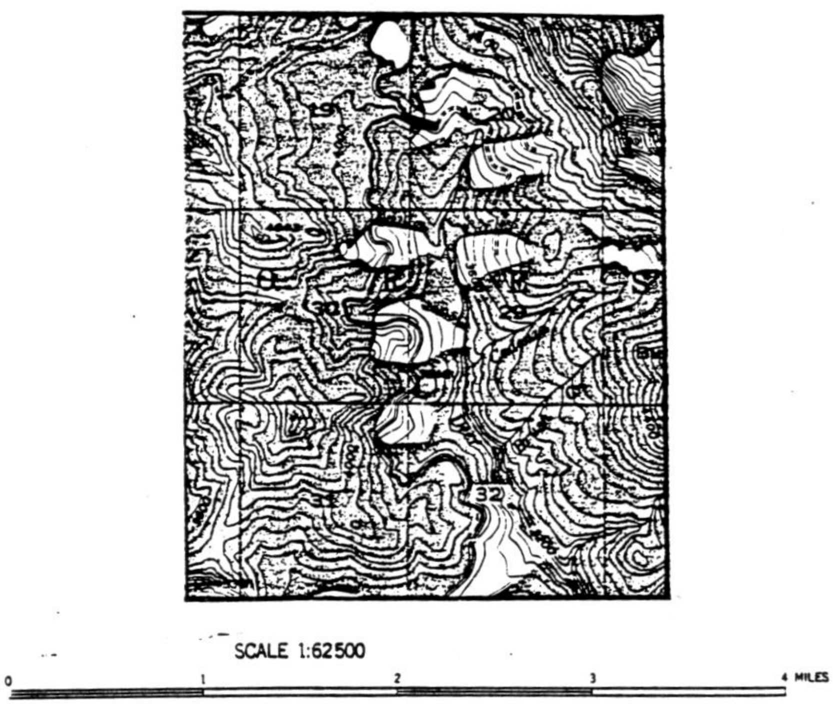


Figure 3. Topographic map - Deer Creek study area.

3. Climate:

The maritime climate of the study area is characterized by wet, relatively mild winters and dry, cool summers. Long-term meteorological data exist for two U.S. Weather Bureau stations near this area. Cascadia State Park to the north (elevation 258 m) has mean annual temperature of 10.5°C (1922-1977). McKenzie Ranger Station (elevation 419 m) to the south has a mean annual temperature of 10°C (1918-1977). The average annual precipitation at Cascadia was 1605 mm (1909-1977) and 1777 mm at McKenzie Bridge (Waring et al. 1978, Burke 1979).

Both these stations are considerably lower in elevation than the study areas. Meteorological data has been collected at the H.J. Andrews Experimental Forest since 1952. At the meteorological station in the Andrews temperatures range from -15°C during unusually cold periods in winter to summer highs exceeding 40°C (Figure 4). Annual temperature averages 9.5°C. Annual precipitation in the Andrews averages 2400 mm with more than 70 per cent falling between November and March (Figure 5). Most of this precipitation occurs during prolonged periods of rain when moist air masses rise over the Cascade crest. The months of July, August and September may be entirely rain free and periods of 60 days without rain are common (Waring et al. 1978).

Precipitation is markedly affected by elevation and totals 30 to 40 percent more at 1500 m elevation than at 600 m elevation and approaches 4000 mm annually in some places. A permanent winter snow pack occurs above 1000 to 1200 m elevation and below these elevations it is sporadic. Snowpacks of 1 to 3 m accumulate in the *Abies amabilis* zone (Dyrness et al. 1974, Waring et al. 1978).

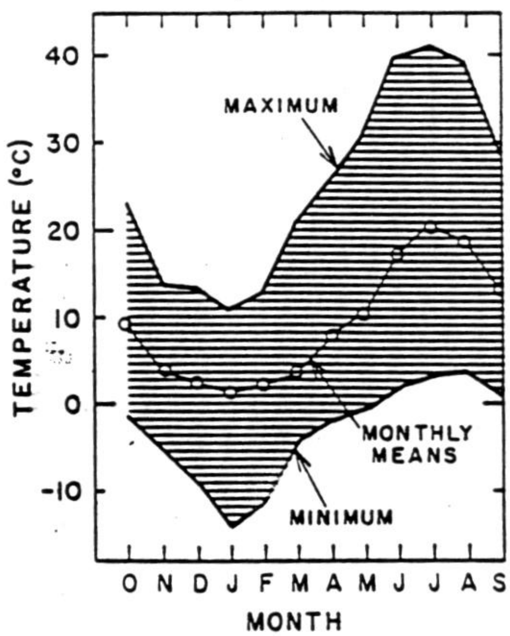


Figure 4. Typical Monthly temperatures at an elevation of 600 m in the H.J. Andrews Exp. Forest (Waring et al. 1978).

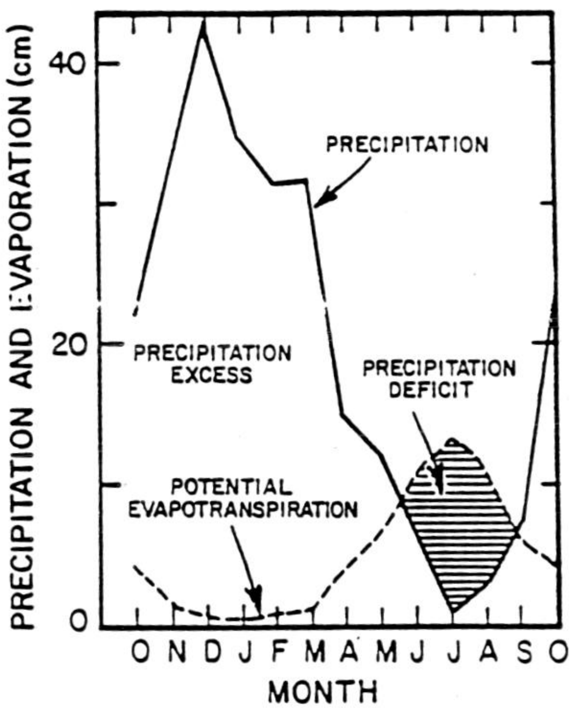


Figure 5. Characteristic pattern of precipitation and potential evapotranspiration on the H.J. Andrews Experimental Forest (Waring et al. 1978).

Due to the elevation differences the Deer Creek study area probably receives more precipitation than the Cook Creek - Quentin Creek study area but no meteorological data are available to document the differences. A winter snowpack persists into the spring in much of the Deer Creek study area. This effects fuel bed and soil moisture conditions in the early summer. Slow growth of tree seedlings at upper elevation sites is also attributed to the persistence of the winter snow pack.

A seasonal water deficit occurs due to the low summer precipitation, high temperature, and potential evapotranspiration (Figure 5). The relative humidity is generally high through the winter. The minimum relative humidity generally ranges from 40 to 50 percent in the summer and approaches 100 percent each night except when east winds bring dry air off the high desert east of the Cascades. Then relative humidity drops to 10 percent or less (Waring et al. 1978).

During the summer and early autumn the seasonal water deficit, occurrence of east winds and occasional thunderstorms all contribute to forest fire development. Fire weather conditions develop during two synoptic weather types. Seventy-five percent of the high fire danger periods occur when the Pacific High settles onshore associated with post-frontal or east winds during July. The remainder occur with the Northwest Canadian High with associated post-frontal or east winds in August or September. Topographic and convective winds during warm dry periods are locally important in the spread of fire. Summer thunderstorms are a critical element in the fire climate of the central western Cascades. Lightning storms only occur on the average of 7 days a year but caused over 60 percent of the fire ignitions recorded in recent years (Burke 1979).

4. Vegetation:

The forest vegetation in the central western Cascades is divided into two major vegetation zones: the *Tsuga heterophylla* zone and the *Abies amabilis* zone. Both zones as well as a transition zone are represented in the Cook Creek - Quentin Creek study area but only the transition zone and the *Abies amabilis* zone are present in the Deer Creek study area. The uppermost elevations of Wildcat Mountain in the Deer Creek study area are representative of the *Tsuga mertensiana* zone. The *Tsuga heterophylla* zone in the central western Cascades is located within an approximate elevation range of 300-1050 m (Dyrness et at. 1974). The major forest tree species in this zone in the Cook Creek - Quentin Creek study area are *Pseudotsuga menziesii*, *Tsuga heterophylla* and *Thuja plicata*. *Pinus monticola*, *Libocedrus decurrens* and *Pinus lambertiana* are encountered frequently in the Cook Creek - Quentin Creek study area but never compose a significant portion of the canopy. *Tsuga heterophylla* is the dominant climax tree species in this zone except for very dry sites such as *Pseudotsuga menziesii* / *Holodiscus discolor* associations where *Pseudotsuga menziesii* is the climax species. In this zone eleven climax or near-climax associations and three seral communities have been recognized in the central western Cascades. The Cook Creek - Quentin Creek study area contains a broad spectrum of these associations and seral communities. These associations range from *Pseudotsuga menziesii* / *Holodiscus discolor* on warm dry sites to *Tsuga heterophylla* /*Polystichum munitum* - *oxalis oregana* on wet sites. The *Tsuga heterophylla* /*Rhododendron macrophyllum*/*Berberis nervosa* association is the most common plant community on more modal sites where deep soils and gentle slopes are present.

Pseudotsuga menziesii is the principal seral tree species in the Tsuga heterophylla zone. Pinus monticola, Libocedrus decurrens, and Pinus lambertiana are also occasional seral species. Tsuga heterophylla is usually considered a successional species that invades a stand 50 to 100 years after disturbance, but Tsuga heterophylla may occupy the site with Pseudotsuga menziesii immediately after a disturbance producing a mixed stand (Franklin and Dyrness 1973, Dyrness et al. 1974, Zobel et al. 1976).

The Abies amabilis zone occupies the upper portion of the Cook Creek - Quentin Creek study area and all of the Deer Creek study area. In the central western Cascades it extends from approximately 1050 to 1550 m in elevation. A transition zone has been identified in the central western Cascades between the Tsuga heterophylla zone and the Abies amabilis zone in the approximate elevation range of 900 to 1150m (Zobel et al. 1976). It contains plant associations which have some characteristics of both zones. This transition zone occupies the lowest elevations in the Deer Creek study area and mid-elevations in the Cook Creek - Quentin Creek study area. The Abies amabilis zone is characterized by the climax dominance of Abies amabilis. Tsuga heterophylla is a minor climax species along with Abies amabilis especially at lower elevations. Seven climax or near climax associations and two seral communities have been identified within the Abies amabilis zone in the central western Cascades. Many of these plant associations are present in the Cook Creek - Quentin Creek study area and the Deer Creek study area. The vegetation in these two study areas typically represents the more modal plant associations in the Abies amabilis zone such as the Abies amabilis /Achlys triphylla association or the Abies amabilis /Tiarella unifoliata association.

Within the *Abies amabilis* zone in the study areas common tree species include *Pseudotsuga menziesii*, *Abies amabilis*, *Tsuga heterophylla*, *Abies procera*, *Thuja plicata*, and *Pinus monticola*. After a disturbance, *Pseudotsuga menziesii* and *Abies procera* are prominent seral species. *Pinus monticola* is an occasional seral species and *Tsuga heterophylla* may become established at the time of disturbance or develop later under a forest canopy (Franklin and Dyrness 1973, Dyrness et al. 1974, Zobel et al. 1976).

In the Deer Creek study area there are occasional non-forest communities at upper elevations. These include *Alnus sinuata* communities on fairly level sites with heavy snow accumulations and abundant seepage water or in avalanche tracks (Franklin and Dyrness 1973). Hickman (1976) has described other non-forest vegetation communities in the central western Cascades. In the Deer Creek study area, several of these are probably present. The *Senecio triangularis* wet meadow associes occupies some open areas most frequently on east or northwest facing slopes with fairly constant moisture sources and sufficiently gentle slopes to build up deep organic soils. The *Rubus parviflorus*/*Pteridium aquilinium* meadow associes occupies some moderately steep slopes and has a dynamic relationship with the surrounding forest. Fire may enlarge the meadow and invasion by trees has been observed in recently burned areas. The *Bromus carinatus*/*Rudbekia occidentalis* meadow associes occupies drier sites at higher elevations. The *Gilia aggregata*/*Polygonum douglasii*/*Eriogonum nudum* lithosolic meadow association is the driest meadow association in the central western Cascades. The *Sambucus racemosa*/*Cardamine integrifolia sinuata*/*Campanula rotundifolia* talus association occupies steep talus piles of large rectangular blocks which develop beneath high north facing andesite cliffs. The relationship between periodic fires and these non-forest communities is not clear at this time. Since these meadows are small, somewhat flammable and adjacent to forest vegetation, it is assumed that they burned to some degree when fire was present in the surrounding forest.

In both study areas there are small areas covered by rock cliffs and talus fields. A portion of Wolf Rock which is a prominent volcanic plug in the northwest corner of the Deer Creek study area occupies approximately 10 hectares of the study area. These areas are assumed to be untouched by forest fire. Along streams riparian vegetation is present. Presumably this vegetation was damaged by intense fires in the surrounding forest.

5. Current Land Use and Management of the Study Areas

Both study areas lie within the Willamette National Forest. The Cook Creek - Quentin Creek study area consists entirely of National Forest land and is managed as "General Forest" by the U.S. Forest Service. The Deer Creek study area includes about 69 hectares of private timber land in Township 14 S. Range 5 E. Section 25. A portion of the Wildcat Mountain Research Natural Area occupies the northeast corner of the Deer Creek study area in Township 14 S. Range 6 E. Sections 20 and 21. This is National Forest land but is excluded from timber production. The remainder of the study area is National Forest land managed as "General Forest".

6. Summary of Disturbance Mechanisms Affecting the Study Areas:

The study areas have been affected by several disturbance mechanisms of varying frequency and magnitude. Glaciation, climatic change and volcanic eruptions have had an influence on the study area. The Deer Creek study area shows extensive evidence of glaciation during the Pleistocene. This has been documented in the H.J. Andrews Experimental Forest immediately south of the study area. Volcanic eruptions in the high Cascades have deposited volcanic ash in the area. Mazama ash (6700 yr B.P.) has been identified in a number of sites nearby including a core of Wolf Meadow (5-10 mm thickness). A basaltic tephra layer of a few mm thickness roughly dated between 3000-3600 years B.P. is present in a Wolf Meadow core (Swanson and James 1975a, 1975b, Swanson 1979, Gottesfeld et al. 1979).

Extreme storms are the source of several types of disturbance. Shallow, soil mass movements such as slumps, small earth flows, debris avalanches and torrents are often triggered by high precipitation events in steep topography with unstable soil. Also, slow moving, deep-seated earth flows may be activated by high precipitation events. These processes have been studied extensively in the H.J. Andrews Experimental Forest and elsewhere in the central western Cascades. (Dyrness 1967, Morrison 1975, Swanson and James 1975a, Swanson and Swanston 1977). These mass movement processes are more active in the Cook Creek - Quentin Creek study area than the Deer Creek study area due to differences in topography and substrate.

Extreme storms can also result in blowdown of individual trees, groups of trees or small stands in the central western Cascades. Although blowdown is not a major disturbance mechanism in the central western Cascades as it is in the coastal regions, it does operate in certain areas. Areas such as mountain passes where wind is funneled and concentrated appear to be susceptible to blowdown events. In 1976, I observed the results of a windstorm in the Wolf Meadow area immediately south of the Deer Creek study area. The effect was a partial thinning of an old growth *Pseudotsuga menziesii* stand. The damage was not extensive and little blowdown was observed elsewhere in the surrounding country. The damage in the Wolf Meadow area seemed to be associated with its topographic position as a mountain pass between the Blue River watershed and the Deer Creek watershed. Also the presence of extensive clearcuts in the area exposed remaining trees to winds they would not have experienced in a closed stand. Little is known about the magnitude and frequency of windstorms and associated blowdown events in this area. Since they have not been a historically important disturbance mechanism, they are assumed to be of minor importance in the study areas. There is no field evidence that the effects of blowdown and fire could be confused during field work.

Insect attacks and disease outbreaks cause mortality of trees. Little is known about the importance of these mechanisms in this area. While insect outbreaks are common east of the Cascades and can cause extensive damage to timber stands, they rarely cause such damage in the central western Cascades (Childs & Shea 1967, Wickman et al. 1973, Rudinsky 1979). Insects such as the Douglas fir beetle (Dendroctonus pseudotsugae) often infest trees that have been damaged by windthrow, snow breakage or fire, and can cause mortality. In this case the insect induced mortality is an after effect of an initial disturbance and should not be considered a primary disturbance mechanism. Disease outbreaks may cause patches of mortality in some stands. Some stands in the H.J. Andrews Experimental Forest are infected by Phellinus weirii (Boone et al. 1982). Elsewhere in the central western Cascades Phellinus weirii has caused waves of forest mortality (Cook 1982).

Forest fire is considered to be the primary disturbance mechanism operating on a large spatial scale with a short return interval from a geological time perspective in the central western Cascades. There is evidence that fire has been present in these ecosystems throughout the last 10,000 years. Charcoal layers or streaks are present throughout a core of Wolf Meadow on the southern border of Deer Creek study area with some charcoal streaks below Mazama ash dated at 6700 years B.P. (Gottesfeld et al. 1979). Since 1850 AD forest fires in the Cascades and their recent effects have been observed and recorded. It is well documented that fires occurred periodically in the central western Cascades (Plummer 1903, Burke 1979). Throughout both study areas charred bark and fire-related scars can be observed on surviving conifers. Charcoal is present in the forest floor and upper A horizon at most sites. The remainder of this report documents the role that fire plays as a major disturbance process in these forest ecosystems.

METHODOLOGY

Initial Hypotheses

The reconnaissance level study in 1975 was an attempt to verify beliefs and hypotheses about the magnitude and frequency of forest fires as disturbance processes in the central western Cascades. These are described as follows:

1. It was the belief at the time that most of the forests of the central western Cascades consisted of several predominant age classes that represented regeneration after infrequent high intensity crown fires that covered large areas.

2. It was also current dogma that most of these stands were even aged or that substantial age spread (50 to 200 years) was the result of a slow rate of establishment after catastrophic fires.

3. It was recognized at the time that occasionally two age classes were present, but that this was usually limited to one additional age class created by a medium intensity fire causing partial mortality in an even-aged stand. It was believed that multi-aged stands were an exception in a forest mosaic of predominantly even-aged stands.

These hypotheses were based on general observations such as the following description by Dyrness et al. (1974) of the role of wildfire in the central western Cascades:

"Wildfires in the study area have resulted in timber stands of two general age classes, either 125 or 450 years. The

450-year-old stands are generally dominated by *Pseudotsuga menziesii* averaging 120-140 cm dbh and 45-75 m in height, with timber volumes averaging 350-750m^3/ha. The 125-year-old forests, sometimes called 'second growth,' are typically dominated by *Pseudotsuga menziesii* (*Tsuga heterophylla* zone) or *Abies procera* (*Abies amabilis* zone)."

Franklin and Waring (1980) aptly describe this assumption:

> "Foresters and ecologists have always assumed that the old growth forests dominated by Douglas-fir are even-aged. The Douglas-firs in these stands presumably were established over short time periods following major fires or other disturbances. In part, these assumptions were based upon observations of forest development and Douglas-fir regeneration following the extensive fires in the mid and late 1800's as well as in the Yacolt and Tillamook Burns of the twentieth century (Munger, 1930, 1940). For a time it was even believed that new Douglas-fir forests sprang almost instantly from seed stored in the litter layers (Hoffmann, 1917), a hypothesis later disproved by Isaac (1943). No one bothered to analyze age structures of any old-growth stands, however, to test their hypothesized even-aged nature."

Leo Isaac (1943) did much of the original work on regeneration of *Pseudotsuga menziesii* following fire. His studies indicated that in some cases reproduction filters into old burns at a slow rate. This can cause a significant age spread in the subsequent stand.

Initial Study Design and Field Sampling

The following assumptions were made at the onset of the study: 1. There would be a large scale mosaic of forest age classes on the landscape, 2. This mosaic would consist primarily of even-aged stands. 3. Fairly continuous crown fires created this mosaic of forest age classes.

Based on these assumptions further assumptions were made concerning study design and sampling methodology:

1. Since a vegetation mosaic was observed on aerial photography it was assumed that a large scale reconnaissance mapping of age classes and fire history could be accomplished through use of the aerial photography and scattered ground control sites.

2. These sample sites could be located at a fairly low density throughout the study area since it was assumed that considerable extrapolation would be possible from these points based on the aerial photography. The sites were picked in the field to be representative of age classes or age class boundaries based on aerial photography and previously collected data.

3. It was assumed that the sample size at each site could be low since the stands would be predominately even-aged and ring counts of a few tree ages would provide a sufficient estimation of the origin date of the stand.

Based on these assumptions, the field work described below was undertaken in 1975 and 1976. Upon analysis of this data it became apparent that these assumptions were valid in some areas but did not hold elsewhere. At this point I decided to select two study areas representative of some of the variability present in the larger initial study area. Both study areas were chosen in part for their higher than average initial site density. Additional sampling was undertaken in both study areas in 1983.

Field Data Collection Techniques

The basic sampling strategy was to use the most accessible information. This was available in the stumps of clearcuts, partial cuts and road right of ways. In some cases increment cores of live trees were taken to establish a stand age in areas where stumps were not available.

At each site a quick survey of the available stumps was made in order to locate stumps with scars and obtain an impression of the diameter classes present. Seral tree species were generally chosen for samples. The total tree age at the time of harvest was estimated by counting annual growth rings from the bark inward to the pith. A total ring count was recorded. Hand lenses were used extensively to facilitate counting narrow rings. The height of the stump or increment core, the diameter of the tree at stump or core height and the average width of the innermost rings were recorded. Each stump was cleaned of debris and pitch before counting and several techniques were tried to improve sections of the record that were difficult to read due to chain saw marks or logging damage. A sharp pocket knife and very sharp scraper were the most useful tools for preparing such sections.

As well as recording the total number of annual rings all scars, shakes and dramatic and abrupt periods of growth suppression or growth release were noted. Throughout this report these scars and related phenomenon are referred to by "scar code". Definite well-dated fire scars on cat-faced trees or multiple scars where charcoal is present on a buried wood surface are referred to as scar code 1; major scars covering over 25% of the circumference of an annual ring are referred to as scar code 2; other well dated scars that appear to have a fire-related origin are referred to as scar code 3; poorly dated scars, scars of uncertain origin and shakes are referred to as scar code 4. Periods of growth release and growth suppression can be caused by fires. Craighead (1927) and Keen (1937) note that severe fires that cause defoliation lead to abrupt cessation of growth followed by a period of stimulated growth. Surface fires which do not result in defoliation usually result in an increase in growth rates due to elimination of competing vegetation and a release of nutrients from organic matter. In this study abrupt and sustained growth release was recorded as scar code 5, and abrupt and sustained growth suppression was recorded as scar code 6. Both the age before cutting and a description of the disturbed annual rings were recorded.

In addition to the data on individual trees, notes were frequently taken at the site describing the condition of surrounding forests, observable fire boundaries and additional stand or site characteristics. In the field the sites were marked on aerial photographs and on topographic maps.

Collection of Site Information

In most cases the date of cut for each site was obtained from the Willamette National Forest Total Resource Inventory (TRI) data base. Occasionally the date of harvest was obtained in the field from observation of recent or ongoing logging operations. In a few cases of sites on private timber land, date of cut was approximated by bracketing, using aerial photography (available every 3 to 5 years).

The aspect and elevation of each site was obtained from 4 inch to 1 mile (1:15840) topographic base maps on which the sites were plotted. These are U.S. Forest Service management maps compiled from a 1955 USGS 15 minute (1:62500) map of the Echo

Mountain Quadrangle. The aspect categories include the eight cardinal compass directions as well as a bottom land and ridge top category for land with a unique topographic position but no easily discernible aspect. Elevations were recorded from the topographic map to the nearest 200 feet. Data were also collected on the overall aspect and elevation distribution of each study area. This information was obtained by a sampling without replacement of 200 randomly distributed points on the 4 inch to 1 mile base map for each study area.

Sample Size and Distribution

An attempt was made to obtain samples from all parts of both study areas. Due to inaccessibility and lack of clearcuts and roads (where stumps are available) some portions of each study area were sampled less intensely than other areas. Overall, there was a good distribution of sites in each study area.

Table 1 illustrates the sample size for both study areas. The columns labeled "study area +" include sites which are adjacent to the study areas but not within their boundaries. These sites were used in evaluating the fire record for both study areas since fires usually extended beyond the boundaries. The lower average number of dates per site in the Deer Creek study area is due to the fact that the fire record is less complex than in the Cook Creek - Quentin Creek study area and fewer dates were needed to evaluate each site. The sample density for the Cook Creek - Quentin Creek study area is 25.3 dates per square kilometer. In the Deer Creek study area the sample density is 20.3 dates per square kilometer.

Table 1

Sample Sizes in the Two Study Areas

	Cook Creek study area	Cook Creek - Quentin Creek study area +	Deer Creek study area	Deer Creek study area +
Sites	58	86	63	75
Counted Origin Dates	252	361	184	228
Estimated Origin Dates	36	46	64	74
Scar Dates	203	228	146	171
Total Dates	491	635	394	473
Ave. # Dates/Site	8.5	7.4	6.3	6.3

Initial Processing of Data

The data from field notebooks for sites within and in close proximity to both study areas were coded and stored in data files. Tree origin dates were calculated by subtracting the total ring count plus an estimate of tree age at stump or core height. Dates of scars, shakes and growth abnormalities were obtained by subtracting the ring count from the cut date or core date.

The estimate of age at stump height was calculated as a function of height of the stump and ring width of the innermost rings. This relationship has not been addressed by a quantitative study. Age at various heights as a function of site class has been studied (Issac 1943, Walters et al. 1961, King 1966). Frederick C. Hall, regional ecologist U.S.F.S. Region 10, (personal communication) advised using a method of calculating age to breast height whereby the age is equal to the number of rings in the inner inch.

For the purpose of this study the following formula was developed based on Hall's method with a truncation level set for small ring widths to avoid over estimation of the age at stump height:

$$AGE = 172.0 * SH/RW \text{ for } RW >= 2 \text{ mm}$$

$$AGE = 172.0 * SH/2 \text{ for } RW < 2\text{mm}$$

where:

AGE = age at stump height (years)

SH = stump height (cm)

RW = average ring width inner three rings (mm)

Sorting, Plotting and Logical Ordering of Data

Several computer programs were developed to analyze the data that were collected so that the relationships of spatial and temporal proximity became apparent. The first program, SORTAGE, organized all these data at each site in chronological order for ease in assessing the record at each site. Another program, DATEBIN, was used to plot these data in histograms. Origin dates were plotted in a histogram under the appropriate date by species code and scars were plotted by scar code. Occurrence of approximate origin dates was also plotted. This program was used to analyze each study area as a whole and specific compartments of each study area. In another program, SITEYRS, the data for each study area were sorted into five year blocks in chronological order by site code and origin date or scar date. This was useful in assessing geographical affinities within a temporal cluster of data. A fourth program, SITEBIN, was used to evaluate the number of sites that have a record of disturbance in a given interval. Origin date records and scar date records were evaluated separately. The number of sites with origin dates and the number of sites with scars (codes 1, 2, and 3 only) were plotted as histograms.

Analysis of Scar Dates

In the central western Cascades the presence of "typical" fire scars on "cat-faced" trees (as are seen in ponderosa pine stands) is rare due to the scarring characteristics of the species present, the natural fire regime of the area and the decomposition environment on the west side of the Cascades. Because of this problem, use of scar dates for determining the occurrence of a fire raises another question: How is it determined that a scar is a result of fire rather than some other disturbance?

Damage due to another tree falling and scraping the trunk can cause scarring. Insects, frost wedging and mass movements of soil or snow can also lead to scarring. These mechanisms undoubtedly have caused some of the the scars observed in this study. Usually these other mechanisms of scar formation leave scars which are unique and distinguishable from scars caused by fire.

Several characteristics distinguish fire-related scars. They commonly occur on the uphill side of a tree where fuel accumulations are greatest and where the turbulence caused by upslope convective winds during a fire causes more intense heating of the cambium. Fire-related scars are usually coincident with grooves in the bark where insulation is less. One of the most characteristic attributes of fire-related scars is their tendency to occur simultaneously at several places (at thin spots in the bark) around the circumference of a tree (Figure 6). A second attribute of fire-related scars is their tendency to occur one on top of the other. This is clearly evident in "cat-faced" trees, but is also observed frequently where the scars have healed over (Figures 6, 7 and 8).

In both study areas "cat-faced" trees are occasionally observed. In these cases multiple scars and the presence of charcoal on wood predating the scar is clear evidence of fire (Figure 9). Sometimes a "cat-face" may heal over leaving the scars and charcoal buried by more recent annual rings. In the field the presence of these positive fire scars was used to evaluate other scars occurring in the same stand. The repeated coincident age of these other scars with each other and with obvious fire scars lead me to the conclusion that most of them were fire-related. *Pseudotsuga menziesii* regeneration following a scar date further substantiates a fire event.

Figure 6. Multiple scars on Pseudotsuga menziesii. Note how scars occur in several places around the circumference of several annual rings.

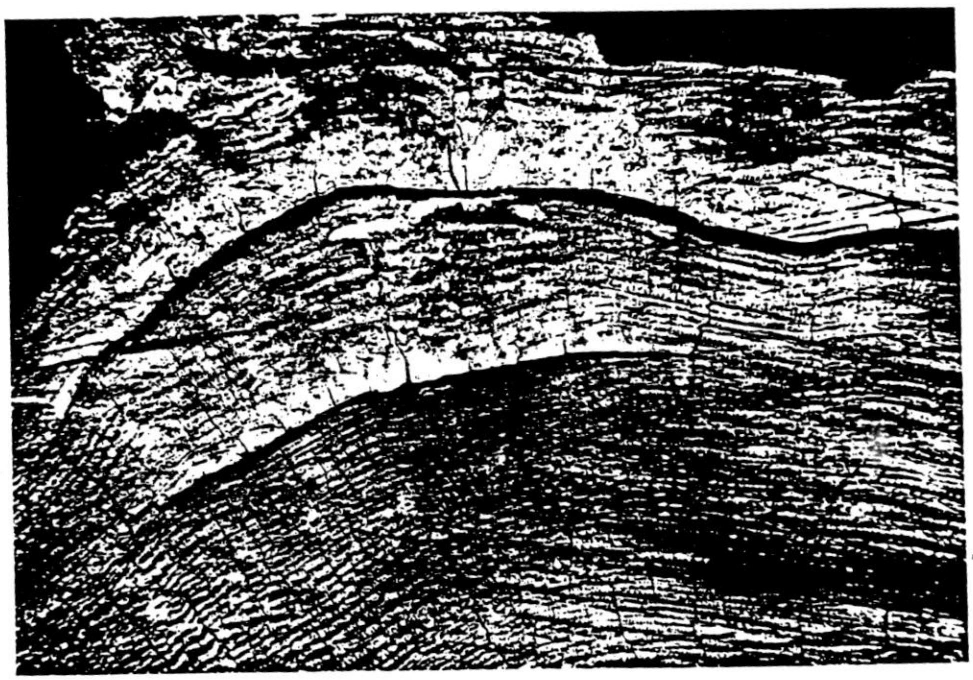


Figure 7. Detail of scars on left side of Figure 6.

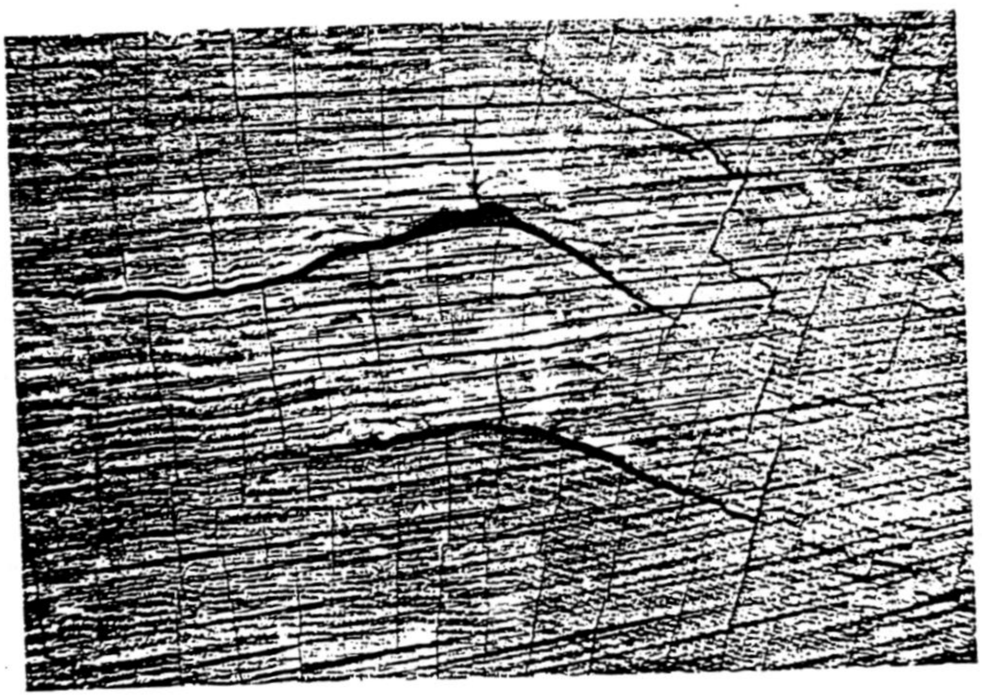


Figure 8. Detail of scars on right side of Figure 6.

Figure 9. Cat-faced <u>Pseudotsuga menziesii</u> with three scars visible as well as charred wood.

In most cases fire-related scars were observed in thick barked conifers such as Pseudotsuga menziesii, Pinus monticola, Pinus lambertiana, and Abies procera. Occasionally fire-related scars would be identified in Tsuga heterophylla, Thuja plicata or Abies amabilis which have much thinner bark (Figure 10). These scars were caused by low intensity ground fires which were able to kill small areas of cambium under the thin bark of these species. The fire-related origin of these scars was verified at several localities by the coincidence in age with other positive fire-related scars on Pseudotsuga menziesii in adjacent sites where the fire burned hotter. These scars hold a record of very low intensity fire that is not recorded by more fire resistant trees.

Sporadic scars that were not associated with at least three other scars or regeneration of seral conifer species were not used in any subsequent analysis. Some of these scars may have been caused by bark beetle attacks that caused only partial cambial mortality. Since these are uncommon in this portion of the central western Cascades, it is reasonable to assume that a minimal number of scars are insect related. Other sporadic scars may be related to physical damage due to blowdown. There is little evidence (i.e. historical records or widespread down logs oriented in a particular direction) that windstorms cause extensive blowdown in the central western Cascades. Such canopy removal by windstorm usually results in Tsuga heterophylla regeneration which is a good field characteristic of this type of event. Blowdown in the central western Cascades is usually a haphazard and spatially diffuse event and may be the cause of some of the sporadic scars observed.

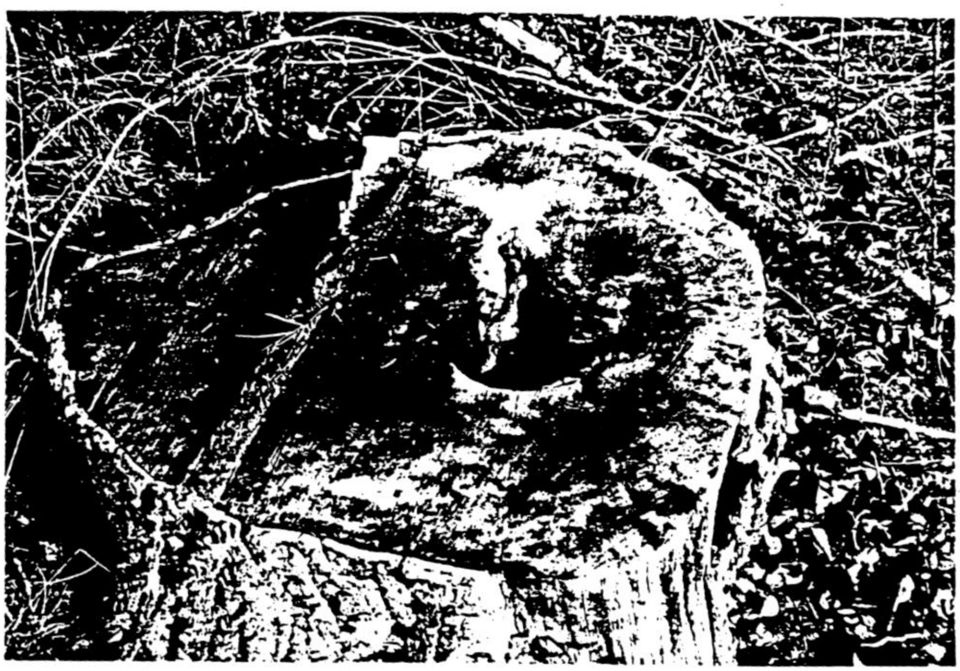


Figure 10. *Tsuga heterophylla* with large scar in several places around circumference.

Physical damage to trees from other falling trees in the central western Cascades is probably most common in the first fifty years following a crown fire. During this period, dead snags fall to the ground through regeneration which is commonly dense, therefore the likelihood of physical damage to the new age class is high. During the first fifteen years, the regeneration is so small that it will probably be killed by snag fall. After that, its chances for survival increase and therefore the chance of retaining a scar in its annual rings increases.

The age when the tree was scarred was calculated for every scar and this information was used when evaluating the significance of the scar. Many scars occurring in the initial fifty years were disregarded when determining the fire record because of the high probability of damage by falling snags. When such a scar was major (covered more than one third of the circumference) the likelihood of it having a fire related origin increases substantially. Physical damage scars are generally quite narrow due to the tangential nature of the impact. Major scars in young trees (Figure 11) which cover one third to half the circumference are most likely caused by heat from a fire.

Usually young trees that sustain significant damage to the cambium do not live long lives. Therefore disturbances which occur early in the life of a stand are poorly recorded in the tree ring record. Once a *Pseudotsuga menziesii* develops the old growth characteristics of very thick bark, only fairly major disturbances will cause scarring. Because of these factors, most scars are formed on trees which are 50 to 350 years old at the time of disturbance.

Figure 11. Pseudotsuga menziesii with large scar that extends around more than one half circumference of tree. Tree was about 45 years old when scarred.

The accuracy of scar dates depends on: 1. The accuracy of the count, 2. Missing rings or false rings, 3. The accuracy of determining the date of cut of the tree, 4. The inability of determining the season of the cut or the season in which the scar was placed.

The accuracy of the count is probably within two years when the scar occurs after 1700 AD in a tree which does not have very narrow rings. At best, scar counts occurring on trees with wide, easily countable rings are accurate to within one year. At worst, scar counts occurring on trees with very narrow or obscure rings could have a 10 year error range. When stumps had errors greater than this due to rot, pitch or logging damage the scar counts were either not recorded or recorded as approximate. These approximate counts were not used to date fires.

Missing rings are not commonly found in conifers on the west side of the Cascades and error from false or missing rings is believed to be relatively small. This error is minimized due to scar counts on complete cross sections. There has been recent concern about missing rings associated with fire scars (Zackrisson 1980). This is a problem that should receive further investigation. I estimate that an error of only two years arises due to missing or false rings in scar dates collected in the study areas.

Error from determining the cut date of the tree is usually small (1 to 2 years at most) but occasionally it could be as high as 5 years. The inability of determining the season of cut or the season of scar formation contributes two years of error.

Under average conditions I estimate a root mean square error of 6 years for scar dates. In exceptional cases the root mean square error may be as high as 12 years.

Analysis of Origin Dates

The accuracy of origin dates depends on the same factors as scar dates. It depends on the accuracy of the count, the presence of false or missing rings and the accuracy of determining the date and season of cut. Another substantial source of error arises from determination of the number of years that it took the tree to grow to stump height. This is usually the greatest source of error. I estimate that it causes an average error of 5 years. For average conditions a root mean square error of 7 years is estimated for the accuracy of origin dates. In extreme cases - such as old trees with very narrow rings a root mean square error of up to 16 years may be present. If the condition of the tree rings was such that counting error would be greater than this value, the date was recorded as approximate.

Separation of Fire Episodes

In most cases a combination of scars and tree origin dates are used to date a fire event. Fires in the study areas were broken into major and minor fires based on a set of prior criteria. The accuracy of determination of a fire date and the temporal separation of scars and origin dates to match these fire dates is subject to various errors and interpretations. Therefore the fire dates discussed in this paper are approximate and are usually based on the average scar date for a temporal cluster of scars. The question of accuracy of the data becomes important when there appear to be frequent fires such as during the 1800's. In analyzing the data for this period in the Cook - Quentin study area there was the ever present problem of whether to lump scar dates from one year with scar dates from another year. Due to the various errors inherent in the data collection techniques, some variance in scar dates from a single fire is inevitable.

During the 1800's distinct clusters of scar dates are centered around dates with a maximum number of scar dates. I used this clustering and the usual geographical affinity of sites with a specific fire date to identify individual fire events. The presence of corresponding regeneration was also a primary criterion for bracketing a fire date. Since some age spread is common in regeneration from fires, primarily scar dates were used to establish fire dates. Apparent individual fire events may be a conglomeration of several fires occurring over a period of several years. For this reason all fire-related events discussed in this study will be referred to as fire episodes. The term "fire" is occasionally used to describe such a fire episode.

The criteria established for demarcating major fires are that three or more sample sites must have scar dates or regeneration dating from the fire date. Preferably both scar dates and regeneration should be present. Regeneration from the fire must be present at one or more sites. These data must have a temporal clustering indicating a separation from other fires and a degree of geographical affinity. Scar codes 4, 5, and 6 (shakes and cracks, growth release, growth suppression) were only used to substantiate a record well established by analysis of scar codes 1, 2, and 3. If sites that are closer than 200 m to each other have a record of the same fire they are counted as one site when evaluating major and minor fires.

Minor fires are fires that occur at less than three sites. There must be a combination of regeneration and scar dates or at least three scars with coincident dates (plus or minus 3 years). These minor fires were noted in analyzing the data but were not carried through the analysis process.

An exception to this classification occurs in the oldest fires recorded in the study area. The oldest fires are recorded at only a few sites commonly without geographic continuity.

In the period prior to 1800 AD there appear to be some distinct fire events, but due to the lack of adequate information to substantiate this breakdown the older fires are lumped into wider fire episodes. These episodes are about 100 years in the 1100 to 1400 AD period, 50 years in the period from 1400 to 1500 AD and about 15 to 25 years in the interval between 1500 and 1800 AD.

Construction of Fire Maps

Major fire episodes were mapped for each study area and the occurrence or absence of fire during the particular episode was plotted at every site. Symbols were used to portray the type of record available at the site for each fire.

A wide variety of aerial photography was used in this study (Appendix I). Burns less than 100 years old were easily identified on the aerial photography but older age classes became indistinguishable. North of the Cook Creek - Quentin Creek study area an extensive fire dated 1911 AD is clearly visible. Also the extent of the 1893 fire (approximate date) is fairly clear on the aerial photography. In areas where extensive reburning of many parts of both study areas occurred during the 1800 - 1900 AD period, it is not possible to distinguish fire boundaries.

Determination of Area Disturbed by Fire Episodes

The area disturbed during each fire interval was estimated by two different procedures. In the first procedure the extent of the burned area was determined by the clustering of sites with a record of that disturbance. An approximate boundary line was drawn midway between the cluster of sites and adjacent sites with no record of the fire. The area included within this boundary was then measured with a digital planimeter.

In the second technique the approximate area burned was estimated by the following formula:

A(i) = AT * NS(i) / (NST - NRE)

where:

A(i) = Estimated area burned during the i^{th} fire episode

AT = Total area of the study area (1943 hectares)

NS(i) = Number of sites with a record of the i^{th} fire episode.

NST = Total number of sites in the study area

NRE = Number of sites where the record has been erased by later fires.

The accuracy of this technique depends on the number of sample sites and the randomness of their distribution.

With both area estimation techniques, the accuracy of the estimate decreases through time as more sites are erased from the record by later burns. Therefore the area estimates of earlier fires have more uncertainty associated with them than for later fires. This problem of decreasing accuracy as the reconstruction proceeds back through time is inherent in all fire history studies based on forest stand analysis.

The natural fire rotation (NFR) for various time intervals was calculated for each study area. This is the length of time necessary for an area equal to the study area to burn (Heinselman 1973, Romme 1980). The proportion of the study area burned by each fire episode was summed over the period of record and divided into the number of years in that time period. 1910 AD was used as an upper cut-off point due to the initiation of effective fire suppression.

Determination of Fire Intensity and Patch Characteristics

In the Cook Creek - Quentin Creek study area the 1893 fire was mapped from aerial photography based on the presence of a significantly younger age class (smaller trees). It is apparent that in some areas most of the pre-existing forest was killed by the fire, in other areas the pre-existing forest was thinned, and elsewhere there are islands and corridors of forest where little mortality occurred. In this manner, the area burned by the 1893 fire can mapped as "patches" representing three levels of fire intensity. High intensity patches represent a stand replacement fire. Medium intensity patches represent 30 to 70 percent mortality of the pre-existing stand. Low intensity patches represent little mortality to the pre-existing stand but some scarring of trees. These patches were transferred from aerial photographs to a mylar overlay on the topographic base map. A binocular mirror stereoscope was used for the initial photo interpretation work. Later, boundaries were checked with a zoom transfer scope. In many cases boundaries are gradational, so the line drawn on the map is an approximation.

In a similar fashion maps were constructed of both study areas depicting areas burned during the 1800 - 1900 AD interval. Since many separate fires covered the study areas during this period, the current distribution of areas of high, medium and low mortality resulting from these fires represents the cumulative impact of all of these fires. Since there is evidence of reburning during this period, these patches cannot be directly equated to areas representing levels of fire intensity during individual fires. However, areas of low mortality were only influenced by one or more low intensity understory burns. Patches of high mortality of the pre-1800 AD forest commonly are dominated by a single age class and can be equated with occurrence of a high intensity crown fire. However, several high intensity crown fires may have burned the same area in the 1800 - 1900 AD interval.

The areas and perimeters of all the patches of the 1893 AD fire in the Cook Creek - Quentin Creek study area and the 1800 - 1900 AD cumulative mortality patches were obtained using an electronic digital planimeter.

RESULTS: COOK CREEK - QUENTIN CREEK STUDY AREA

Fire History of Study Area

Data from the Cook Creek - Quentin Creek study area were pooled and plotted according to five year bins using the computer program DATEBIN (Figure 12). After 1900 AD there is little record of scarring or regeneration. Both scars and regeneration are present for almost every five year interval from 1800 AD to 1900 AD. Peaks of regeneration tend to lag behind peaks in the scar data. During the period from 1800 AD to 1650 AD, both scars and regeneration are present in most five year bins. The diminished number of entries in each bin is probably due more to much of the record being erased by fires in the 1800 - 1900 AD period than to less disturbance by fire during this period.

There is a conspicuous lack of regeneration and very few scar dates during the period from 1650 AD to 1580 AD. This is interpreted as an absence of significant fire during this period. During the 1575 - 1485 AD period, scars and origin dates are present in most five year bins. The number is lower than in later periods probably due to erasure of the record by previous fires. Prior to 1485 AD much of the record has been erased by previous fires so the disturbance history is obscure. Fourteen percent of the sites exhibit origin dates between 1480 and 1385. At five percent of the sites there are origin dates between 1200 AD and 1155 AD. The origin dates during this last period correspond to similar origin dates found in surrounding areas.

Many of the disturbances described above were widespread and not limited to a few sites. Since Figure 12 is a plot of all origin dates and scar dates in the study area, commonly more than one entry from each site is present in each bin. In order to assess the record of disturbance on a site by site basis, the

KEY TO ORIGIN DATE CODES AND SCAR CODES

D = Douglas-fir
H = Western hemlock
S = Pacific silver fir
R = Western red cedar
W = Western white pine
N = Noble fir
A = Approximate date (Douglas-fir)

1 = Definite fire scar
2 = Major scar
3 = Normal scar
4 = Shake
5 = Abrupt growth release
6 = Abrupt growth suppression

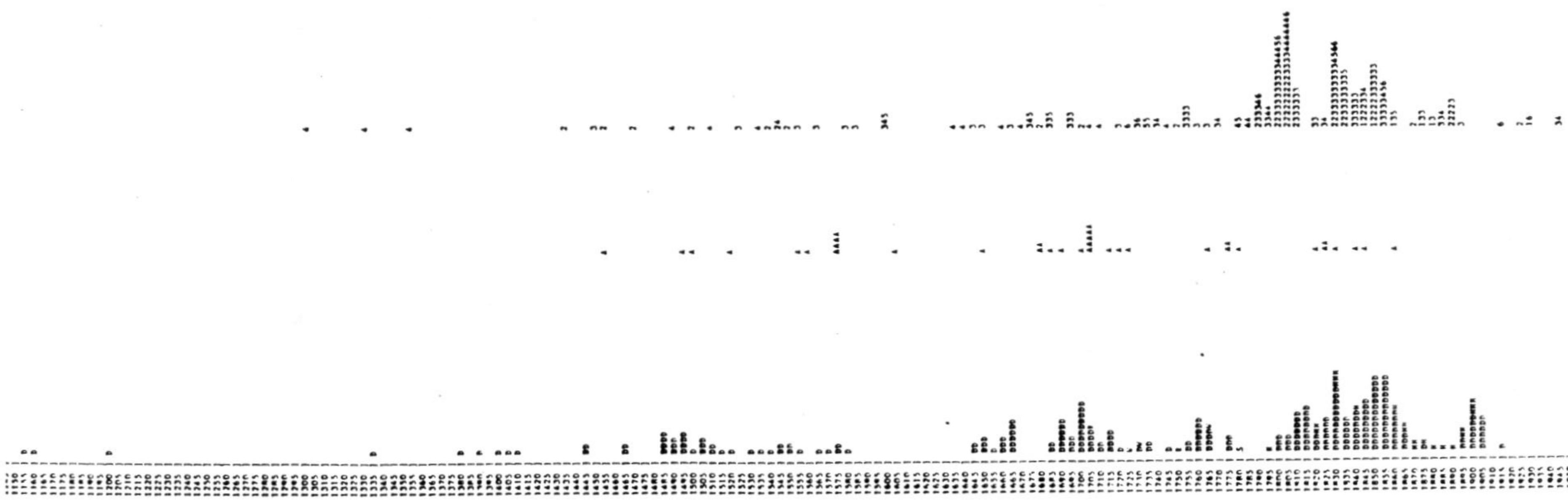


Figure 12. Histogram of all origin dates and scar dates – Cook Creek – Quentin Creek study area.

computer program SITEBIN was used. Figure 13 represents the occurrence of regeneration or scarring (Codes 1, 2 and 3 only) on a site basis. The number of asterisks represent the number of sites where origin or scar dates were found during the time interval. Figure 13 is plotted based on 20 year intervals. The same temporal distribution pattern is seen as in Figure 12, except on a more compressed scale. The computer program SITEYRS was used to assess the geographical affinity of the sites.

The results from these three programs along with a detailed analysis of the data at each individual site were used in determining major fire episodes for the study area. Table 2 lists these major fire episodes. Each fire episode during the 1800 - 1900 AD period may represent one fire and the scatter of data may result from sampling errors. A mean date is associated with each fire episode. On the other hand, scar dates and origin dates from two or more fires may have been lumped into one fire episode.

The separation of fires during the 1800 - 1900 AD period presented some difficulty due the short time intervals between fires. Histograms of the 1800 - 1900 AD period broken down by one year intervals reveal eight major fire episodes and a few minor localized disturbances (Figures 14 and 15).

The mean fire return interval (MFRI) for the study area as a whole for several time periods was calculated and is presented in Table 3. This value is area dependent but it is useful in gaining an understanding of the frequency and periodicity of fire occurrence in watersheds or management units of similar size.

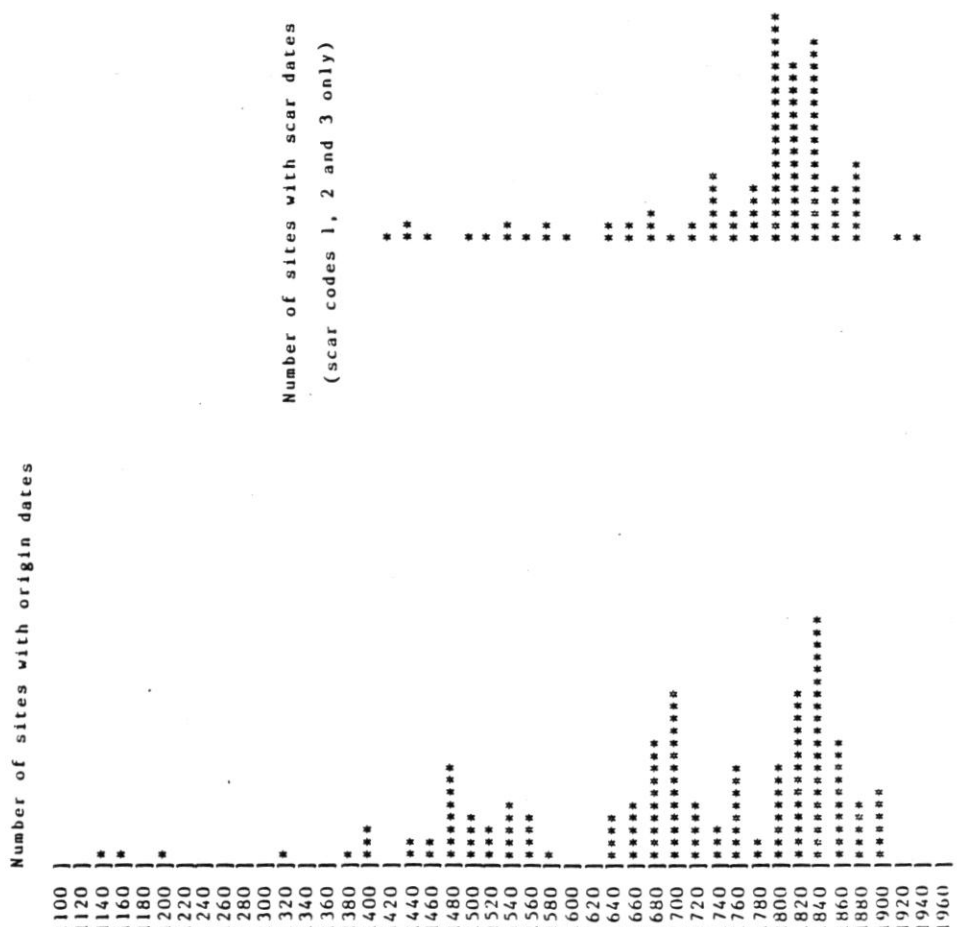


Figure 13. Histogram of number of sites with origin dates and scar dates - Cook Creek - Quentin Creek study area.

Table 2
Master Fire Chronology
Cook Creek - Quentin Creek study area

Mean Date	Fire Episode	Fire Interval (time since last fire)
1893	1896-1891	38
1855	1857-1852	6
1849	1851-1847	8
1841	1845-1839	7
1834	1837-1831	21
1813	1816-1812	6
1807	1810-1805	7
1800	1804-1798	28
1772	1774-1770	14
1758	1764-1752	55
1703	1709-1699	14
1689	1695-1683	31
1658	1671-1648	92
1566	1586-1549	34
1532	1545-1511	57
1475	1500-1445	75
1400	1410-1380	250
1150	1200-1100	

KEY TO SCAR CODES

1 = Definite fire scar
2 = Major scar
3 = Normal scar
4 = Shake
5 = Abrupt growth release
6 = Abrupt growth suppression

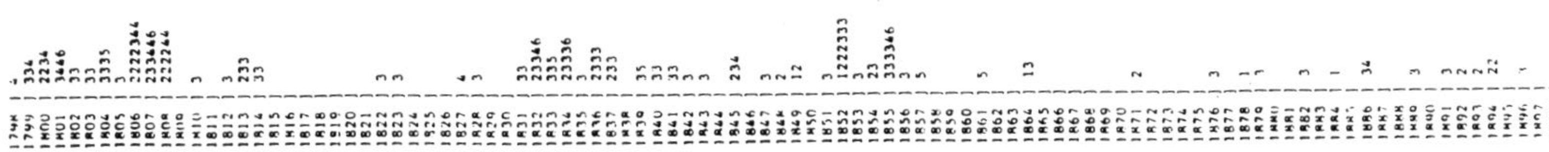


Figure 14. Histogram of all scar dates in the 1800-1900 AD period - Cook Creek - Quentin Creek study area.

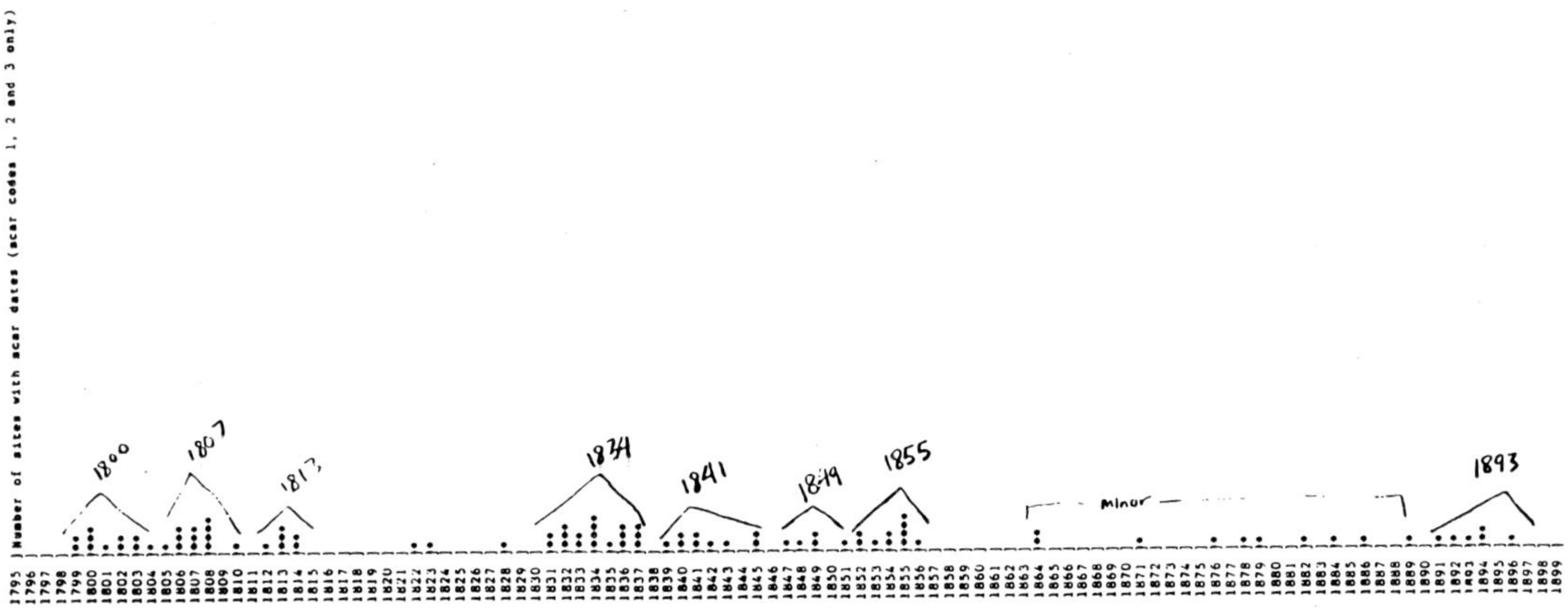


Figure 15. Histogram of sites with scars in the 1800-1900 AD period - Cook Creek - Quentin Creek study area.

TABLE 3

Mean Fire Return Interval

Cook Creek - Quentin Creek Study Area

Time period	MFRI (years)
1893 AD - 1800 AD	13.3
1893 AD - 1703 AD	19.0
1893 AD - 1658 AD	19.6
1893 AD - 1532 AD	25.8
1893 AD - 1400 AD	30.8
1893 AD - 1150 AD	43.7

All of the fire episodes after 1500 AD disturbed less than fifty percent of the study area (Table 4). However, all of these fires burned areas outside of the study area as well. These fire episodes were all primarily low to moderate intensity. Only the 1689 and 1658 fires burned at high intensity through more than fifty percent of the sites which recorded that fire. Prior to 1500 AD the data base is insufficient to assess the extent of fires. The extent of each major fire was mapped (Appendix II). These maps indicate approximate locations for these disturbances.

A comparison of the estimated area burned during each fire interval calculated by the ratio method and measured by planimeter is presented in Table 5. It is apparent that there is some discrepancy between planimeter measured fire areas and areas that are estimated by the ratio method. Both methods are only approximations and should not be taken to be exact values. A much larger data base would be necessary to obtain a better estimate of the areas of these fires.

TABLE 4

LIST OF MAJOR FIRES

COOK CREEK - QUENTIN CREEK STUDY AREA

NOTE: THE RECORD FOR EACH FIRE IS LISTED IN TERMS OF HOW MANY SITES FALL INTO EACH OF THE FOLLOWING CATEGORIES:
A = NUMBER OF SITES WHERE THIS IS OLDEST ORIGIN DATE
B = NUMBER OF SITES WITH ORIGIN DATE ONLY (NOT OLDEST)
C = NUMBER OF SITES WITH ORIGIN DATE AND SCAR DATE
D = NUMBER OF SITES WITH SCAR DATE ONLY
E = NUMBER OF SITES WITH NO RECORD OF THIS FIRE
F = NUMBER OF SITES WHERE RECORD HAS BEEN ERASED BY PREVIOUS FIRES

FIRE YEAR	AREA (HA)	----- Fire Intensity ----- (Percent of Fire)			RECORD					
		HIGH	MED	LOW	A	B	C	D	E	F
1893	307	11	56	33	1	2	3	3	48	0
1855	347	20	60	20	2	1	5	2	46	1
1849	360	30	50	20	3	3	2	2	44	3
1841	343	11	44	44	1	2	2	4	42	6
1834	855	18	45	36	4	6	4	8	28	7
1813	422	0	60	40	0	4	2	4	36	11
1807	591	0	14	86	0	2	0	12	32	11
1800	549	15	15	69	2	0	2	9	33	11
1772	221	20	20	60	1	1	0	3	39	13
1758	407	11	56	33	1	2	3	3	34	14
1703	786	41	53	6	7	8	1	1	25	15
1689	666	58	17	25	7	2	0	3	23	22
1658	694	60	10	30	6	1	0	3	18	29
1566	706	38	38	25	3	2	1	2	14	35
1532	818	38	50	13	3	3	1	1	11	38
1475	1457	67	17	17	8	1	1	2	4	41
1400	1214	100	0	0	5	0	0	0	3	49
1150	1942	100	0	0	3	0	0	0	0	54

TABLE 5

Estimated Area Burned During Each Fire Episode By Two Methods

Fire Year	Planimeter measured (hectares)	Ratio calculated (hectares)
1893	351	307
1855	540	347
1849	402	360
1841	386	343
1834	945	855
1813	565	422
1807	452	591
1800	322	549
1772	238	221
1758	217	407
1703	549	786
1689	515	666
1658	700	694
1566	1116	706
1532	1544	818

There is insufficient data to estimate areas burned prior to 1500.

The natural fire rotation for several time intervals was calculated based on these area estimates (Table 6). The larger natural fire rotation values associated with longer time intervals are probably due to erasure of the record of early fires rather than by less burning during these periods. Because no major fire has burned the study area since 1910, the natural fire rotation for 1910 to the present is infinite. This suggests that fire suppression has been effective.

Table 6

Natural Fire Rotation

Cook Creek - Quentin Creek Study Area

Period of Record	NFR (years) (Area by Planimeter)	NFR (years) (Area by Ratio)
1910-1800	54	57
1910-1700	82	79
1910-1600	97	92
1910-1500	90	99

Disturbance History at Individual Sites

In the process of preparing the maps and analyzing the distribution of each fire, the disturbance record at each site was assessed. Not all scar and origin dates could be tied to a specific fire episode but many corresponded to one of the major fires. The others were either due to small scale disturbances such as blowdown of a few trees or fires that burned through only one or two sites. Scatter in the data due to inaccuracy is probably responsible for some extraneous dates.

The major fire record on a site-by-site basis is presented in Appendix III. The date of each major fire episode recorded at the site is listed along with the type of record present at the site for that fire. At some sites the record consisted of conifer regeneration with one or more counted origin dates corresponding to the major fire episode. The record at other sites included both scar dates (one or more) and origin dates (one or more) corresponding to the major fire episode. At other sites may best be illustrated by Figures 30 and 31. The record of origin dates and scar dates for both areas shows a general decrease with earlier dates. The origin date record in the Deer Creek study area is distinctly bi-modal, whereas the record in the Cook Creek - Quentin Creek study area is tri-modal. These distributions do not correspond well to either the negative exponential age class distribution model (Van Wagner 1978) or to the Weibull curve age class distribution model (Rowe et al. 1975).

A comparison was made of the areas of the mortality patches resulting from the 1800 - 1900 AD fires in both study areas (Figure 32). This mortality distribution is decidedly skewed toward the low mortality side for the Deer Creek study area, whereas medium mortality patches cover more area in the Cook Creek - Quentin Creek study area. In the Cook Creek - Quentin Creek study area, the area covered by high and low mortality patches is about equal. It appears that the fire intensity distribution may differ considerably from one fire to another. Since there is some evidence of more extensive and higher intensity fires in both study areas preceding 1800 AD, it should not be assumed that the fire intensity distribution remains constant through time.

The patch size distributions of high mortality patches created during the 1800 - 1900 AD period indicate that small patches (under three hectares) of stand replacement level mortality are predominate in both study areas. This analysis only applies to this time period and this trend may or may not hold for earlier periods.

The fire record in the Cook Creek - Quentin Creek study area appears to be one of fairly frequent medium to low intensity fires that occasionally crown out and create small patches of

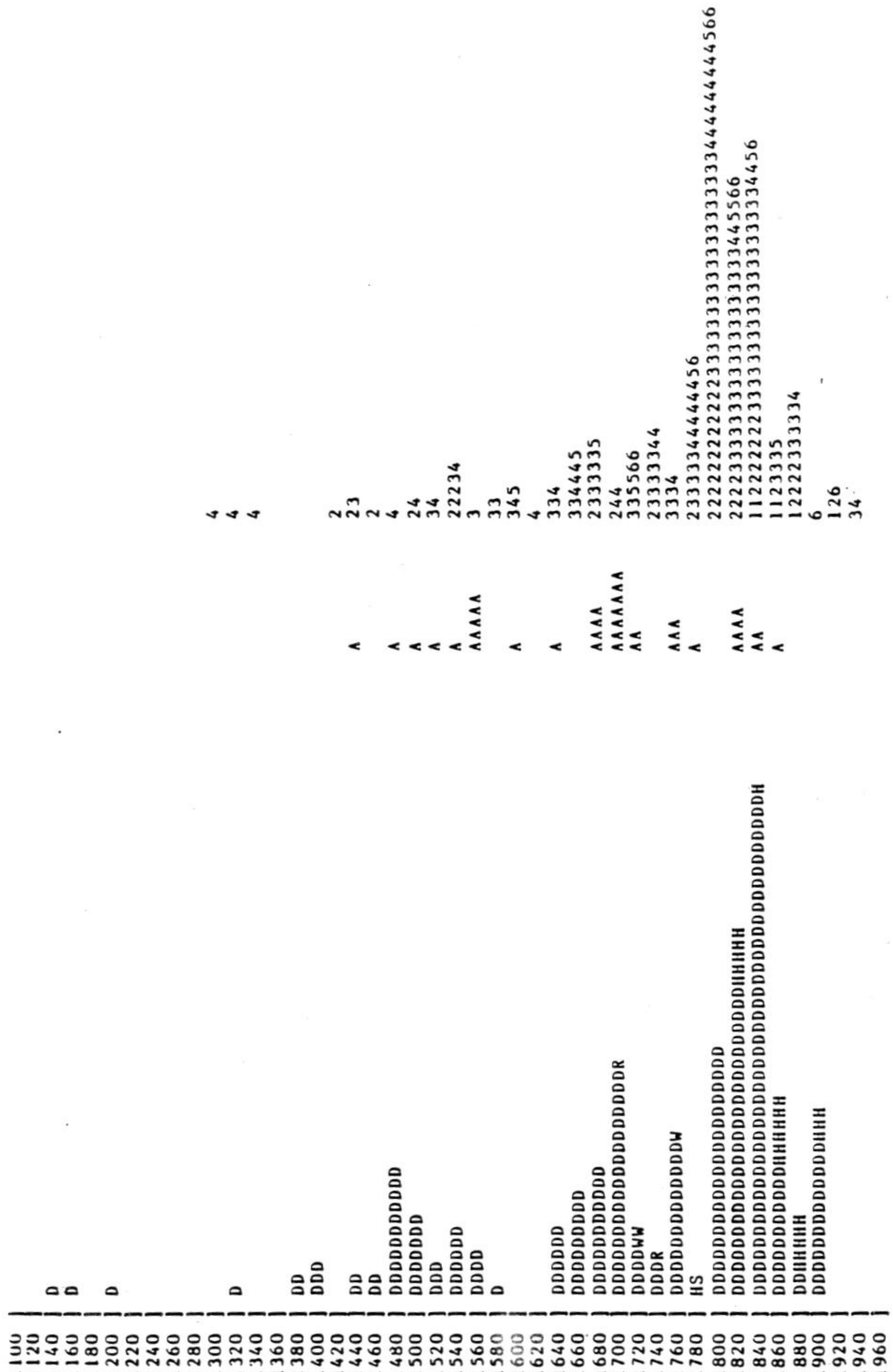


Figure 30. Histogram of all origin and scar dates (20 year intervals) - Cook Creek - Quentin Creek study area.

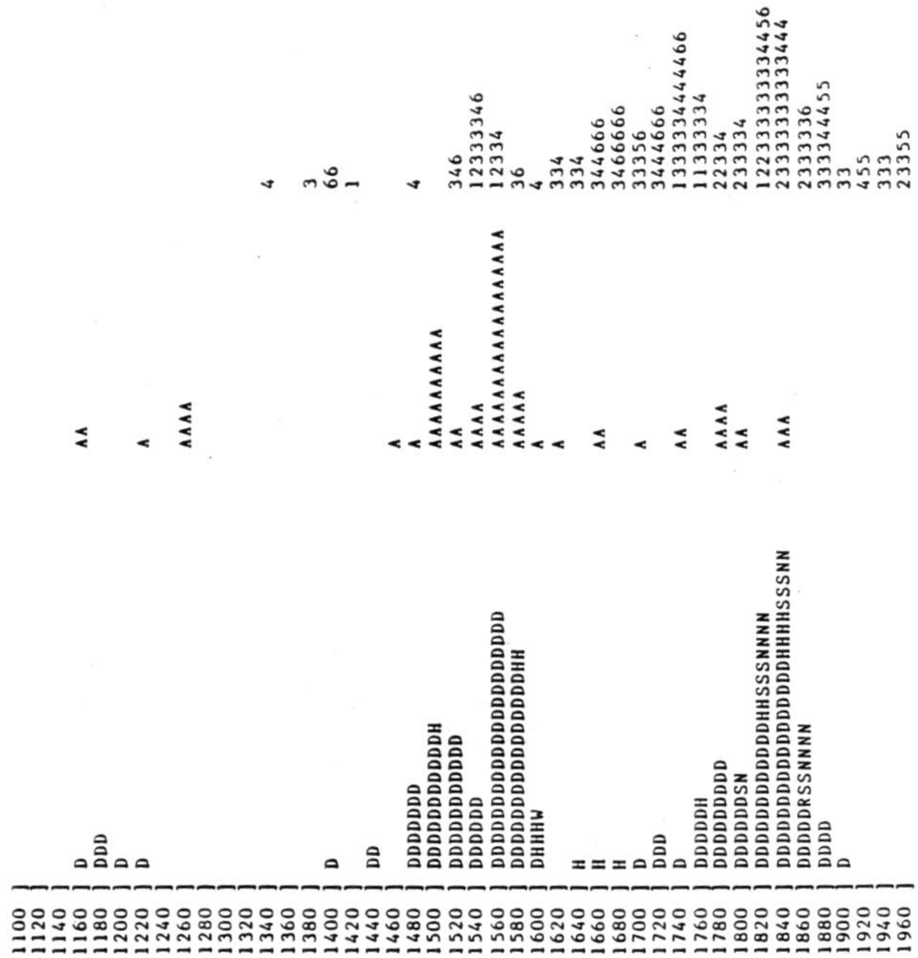


Figure 31. Histogram of all origin and scar dates (20 year intervals) - Deer Creek study area.

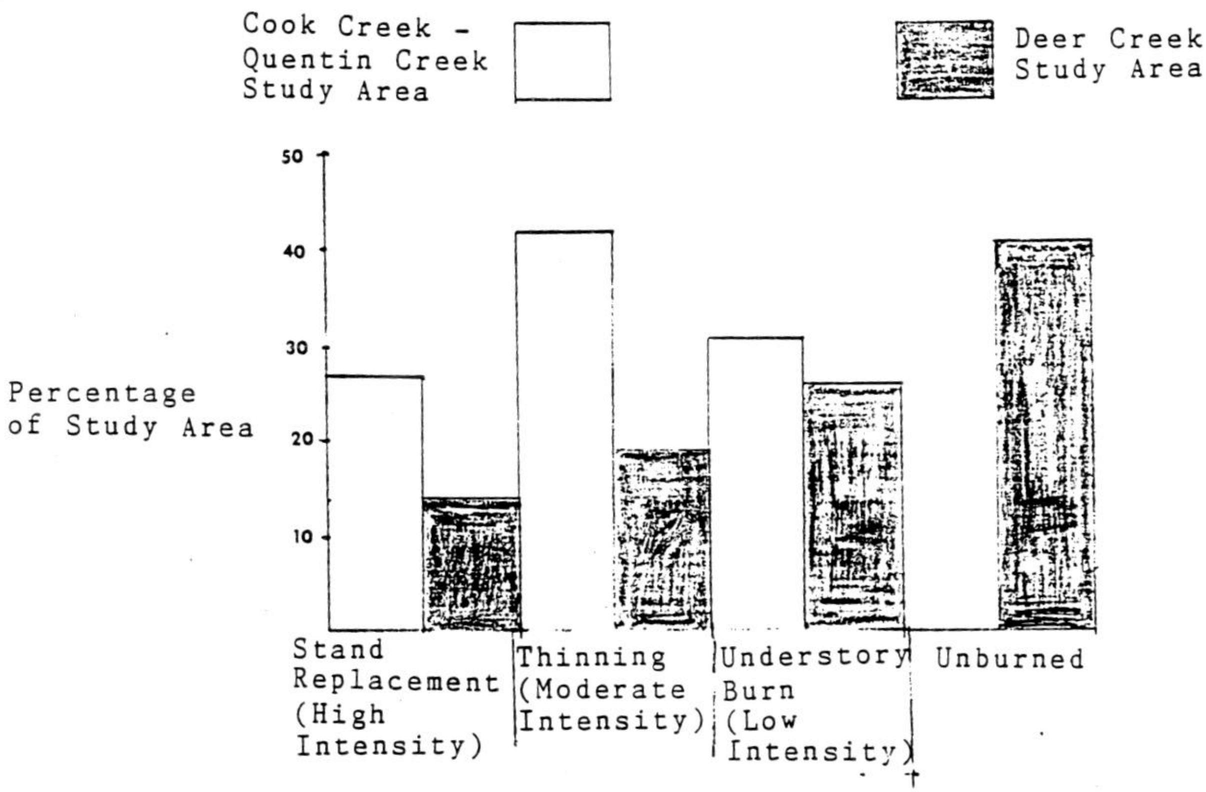


Figure 32. Comparison of fire intensity distribution for patches created during 1800-1900 AD interval in both study areas.

even-age stands. More commonly these fires thin the pre-existing stand to some extent. The stands generated by these fires are generally multi-aged with an average of over two age classes present at each site. Regeneration from more than four fires occurs at 15.8% of the sites. Within the limitations of the record it appears that fires occur with a degree of temporal regularity. Between 1703 and 1893 major fires occurred every 18.5 years on the average with a range of 6 to 55 years.

In the Deer Creek study area fire is less frequent on the whole. Small fires of medium to low intensity occur periodically in upper elevation areas. There is also evidence that larger stand replacement fires occur infrequently. Most of the Deer Creek study area was burned at least once during the 1480 - 1580 AD interval and extensive fairly even-age stands resulting from the last fire of this period fill most of the central part of the study area. It is interesting that very little record of disturbance occurring after 1580 AD was found in this extensive stand even though fire was fairly common on the periphery. The exact nature of the 1480 - 1580 AD fires in the Deer Creek study area is difficult to determine due to a lack of fire scar data for this interval. It may be that only two or three catastrophic fires occurred with later ones reburning sections burned in the past or it may be that a conglomeration of five or more fires (similar to the 1800 - 1900 AD interval in the Cook Creek - Quentin Creek study area) created the existing old-growth stands.

Although the two study areas are in close geographical proximity there are some significant environmental, climatic and physiographic differences between them. These differences may explain some of the differences observed in the fire record for the two study areas. A colder, wetter climate created by the higher average elevation of the Deer Creek study area would most likely lead to less frequent fire. This relationship is challenged though by the substantially higher fire frequencies observed in the upper elevation range of the Deer Creek study area compared to lower elevations in the same study area. These upper elevations would presumably be colder and wetter than the lower elevations. It is apparent that other factors besides major climate and environmental gradients caused by elevation are important in determining fire history in the central western Cascades.

In the Deer Creek study area the topography is relatively smooth and gentle compared to many areas in the central western Cascades. The spread of fairly large stand replacement fires would be possible in such terrain. The fairly wet and cold climate at this elevation may create a situation where fuels are rarely in condition to carry a fire. The combination of these two factors would result in the occurrence of infrequent but fairly extensive stand replacement fires as seen in the lower elevations of the Deer Creek study area. In the upper elevation country lightning occurrence may be higher. This country may also be more exposed to desiccating east winds which could dry out a fuel bed in a short period of time. In most cases these fires do not spread far due to numerous wet areas in the upper elevation Deer Creek study area. These factors could lead to the regime of more frequent but less intense fires seen in the upper elevation Deer Creek study area.

Because of the complex topography of the Cook - Quentin Creek study area there are many potential fire boundaries such as streams and wet areas, ridge tops, and changes in aspect and habitat type. It is finely dissected, convoluted topography. There are few long, unbroken slopes; few expanses of similar aspect, and little flat or rolling topography which would contribute to fire spread. Anywhere in the area the movement of a fire one way or the other will carry it across a ridge or stream, change of aspect , or through a dry or wet pocket. All of these will alter the behavior of the fire.

In this irregular landscape fire encounters a large variety of fuel conditions relating to ease of ignition, rate of combustion and rate of spread. Wind patterns are highly irregular in complex topography. One would expect that fires would be patchy, change intensity frequently and generally have a low areal extent in this type of topography. If one assumes ignition possibilities are random during periods of favorable climate such as the 1800 - 1900 period there is a chance of a fire almost any year at some point in the study area. But it may not spread far. Some years there will be much greater probability for spread of fires and these will be the major fire years. This can be due to greater than normal ignition frequency or a drier climate than normal combined with an adequate ignition frequency.

The Cook Creek - Quentin Creek study area is characterized by a wide variety of environments. The environment is much more diverse than the rather uniformly dry, east-side ponderosa pine forests. It is also much more diverse than the more uniformly wet coastal forests of the Pacific Northwest. In the ponderosa pine forests, fires are of more uniform intensity and spread more extensively due to more uniform dryness. In the moist coastal forests there is a tendency for fewer more intense fires of a stand replacement type (Agee 1981, Martin 1982). So the hybrid situation in the Cook Creek - Quentin Creek study area is a combination of a varied topography and a moderate climate between the dry and wet extremes.

It was expected that some major differences in fire history would be associated with aspect. In both study areas the low sample size in several aspect categories made it impossible to test for significant differences in fire history with respect to aspect. However, no major systematic differences were apparent. The aspect distributions of both study areas are fairly heavily biased toward south facing orientations and a relatively small number of sample sites were located on north facing aspects. A better test of this relationship would be possible in a larger study area with an equal number of sample sites from north and south facing aspects. Another major factor in the failure to see major differences in the fire return intervals between north and south aspects is that fire behavior is influenced by many large scale landscape factors. Actual site characteristics may be less important in determining fire behavior than they are for determination of plant habitat. The influence from the surrounding area can swamp out the influence of aspect at an individual site.

A relationship may exist between elevation and fire history in the central western Cascades. The longest site fire return intervals for all fires occurred in the 3500 - 3999 feet elevation category in both study areas. Fires appear to be more frequent both above and below this elevation range. An analysis of the fire record for a larger area would be necessary to verify this tendency.

Visual analysis of the fire intensity patch map for the 1893 Cook Creek - Quentin Creek study area fire and the patch maps for the 1800 -1900 AD period for both study areas reveals that very little mortality was caused by the fires of this period in bottom land locations adjacent to major streams. Extensive corridors of old-growth trees are found along major stream systems. These factors indicate that the site fire return interval for bottom land sites may be long and that low to moderate intensity fires may be most common in these sites.

In both study areas there is tremendous variability in the fire record from site to site. Some sites appear to burn every 15 to 30 years while others appear to be fire free for 400 to 500 years. This variability has not been explained by a simple analysis of aspect and elevation. A more complex analysis of site characteristics combining factors such as slope position, slope, aspect, and elevation may reveal relationships between fire history and site characteristics that are not apparent here. Some of the variability noted in this study may also be due to the randomness of fire occurrence.

Man's Influence on the Fire Record

The impact of aboriginal burning on the two study areas is uncertain. After a through review of existing literature, Burke (1979) concluded that aboriginal use of fire in the central western Cascades was limited to campfires. Forest fires may have been caused by aboriginal campfires that were left burning and ignited surrounding fuels. It is impossible to determine if this was the cause of any of the fires recorded in the study areas.

It has been postulated that forest fire incidence increased during the Euro-American settlement period due to fires started by trappers, miners, sheepherders, and explorers (Burke 1979). This period extends from 1850 AD to 1910 AD when fire suppression was initiated. In the two study areas the opposite was the case. During the 1850 - 1910 AD interval the natural fire rotation for the Cook Creek - Quentin Creek study area was 151 years compared to 31.4 years for the 1800 - 1850 pre-settlement period. Likewise the NFR for the Deer Creek study area was 265 years for the 1850 - 1910 AD period but only 95.7 years for the 1800 - 1850 pre-settlement period. Kilgore and Taylor (1979) reported that a similar decrease in fire incidence occurred in sequoia-mixed conifer forests in the last half of the 1800's. Regular, intentional, aboriginal burning of these forests is historically documented. Their results suggest that aboriginal people were a significant ignition source and that the dramatic decrease of aboriginal populations in the last half of the 1800's may be responsible for a decline in fire frequency. A similar decline in aboriginal populations occurred in Oregon (Burke 1979) and this may be responsible for the dramatic decrease in fire frequency found in the two study areas after 1850 AD. There is no record of a major fire in either study area after 1910 AD. Several very small man caused and lightning caused fires occurred in both study areas since 1910 AD (Burke 1979) but did not spread presumably due to suppression activities. It appears that these efforts have successfully reduced small and medium scale fires such as occurred during the 1800 - 1900 AD period. But the length of record is too short to tell if all major wildfires have been successfully eliminated.

Comparison of Fire History in this Study with Other Areas in the Pacific Northwest.

The fire history of Mount Rainier National Park has been documented by Hemstrom and Franklin (1982). They describe a fire regime of infrequent stand replacement fires as characteristic of that area. The fires they describe also burned extensive areas at one time. A natural fire rotation of 465 years is estimated for the 1850 - 1200 AD time span. While their study has been criticized for details of dendrochronologic techniques (Swetnam et al. 1983, Dunwiddie 1983) it has been assumed that other montane forests in the Pacific Northwest follow a similar fire regime.

The fire regime in the central western Cascades is transitional between northwestern California and western Washington. Thornburgh (1982) describes the mixed evergreen forests of northwestern California as a complex mosaic of early and late successional communities resulting from a long history of fire. Many of these relatively undisturbed forests have a history of frequent light ground fires. The result is two or three storied stands with each story being even aged.

A study of the developmental history of dry coniferous forests in the central western Cascades shows some similarity to the results presented in this paper (Means 1981). Means estimated a mean fire interval of 103 years for all dry site plots and a mean fire interval of 144 years for all Tsuga heterophylla climax plots. His histogram of fire dates (which is a composite from many sites scattered over a large area) shows considerable similarity to the histogram presented in this paper for the Cook Creek - Quentin Creek study area. It is particularly interesting to note the abundance of fires (dated by fire scars) in the 1900 - 1800 AD interval in his histogram.

Implications for Geomorphological Research

The results of this study which indicate a highly variable fire regime lead to different hypotheses about the effect of fire on hydrology, erosion and sediment transport than one would hypothesize based on the previous assumptions of large scale, infrequent, stand replacement fires. An understanding of the effect of the natural fire regime of an area on geomorphological processes is helpful in understanding the interaction of these processes with other ecosystem components in unmanaged forests. This understanding is also useful in assessing the impact of management activities on accelerated erosion and sediment production in that it helps establish a baseline. In discussing the implications of this research for hypotheses about the effect of fire on hydrology, erosion and sediment transport I consider the effects of fire in terms of watersheds of about 20 square km. In the central western Cascades this usually implies a drainage basin containing a third or fourth order stream (based on nomenclature of Strahler (1952)).

The hydrologic results of large scale stand replacement fires are generally a dramatic increase in stream flows and stream temperatures for several years (Helvey 1972, Helvey et al. 1976, Wright 1981). When a watershed in the central western Cascades is burned in this manner at 200 - 400 year return intervals dramatic peaks in runoff above the baseflow would be anticipated. Also peaks in stream temperatures would be observed due to lack of shade along stream corridors. But results of this paper suggest that such dramatic increases in stream flow and temperature in third or fourth order watersheds in the central western Cascades would be rare. More frequent but smaller peaks would be observed due to small patches being burned at more frequent intervals. Since the mean fire occurrence interval is about 15 years for the two study areas (during the 1800 - 1900 AD period) often the effect of one fire on increased stream flows in a watershed would still be in effect when another fire occurred. Therefore, long intervals could elapse before stream flow returned to undisturbed conditions. In this process the peaks might be averaged out to some extent in these watersheds. Long term stream temperatures may not be elevated significantly by forest fires because the frequent occurrence of unburned or lightly burned forest buffer zones maintains shade around major streams.

The effect of fire on erosion processes can be complex in the central western Cascades (Swanson 1981). Fires can affect surface erosion processes; shallow, rapid soil mass movements; and slow, deep-seated soil mass movements. The effect of fire on erosion processes is directly related to fire intensity. High intensity fires have usually been assumed, but the presence of low to intermediate intensity fires in the central western Cascades may necessitate modifications to initial hypotheses about the effect of fire on erosion.

Very low intensity understory burns may not cause a large increase in surface erosion since the organic soil layers may not be completely consumed. Also since little loss of root strength occurs and the water balance of the site may not be significantly altered, the potential for shallow soil mass movements will not be markedly increased by underburns.

In more intense fires the loss of organic matter can lead to accelerated surface erosion due to dry ravel, surface creep, rill and sheetwash erosion, and needle-ice formation and melt (Swanson 1981). An increase in shallow, rapid soil mass movements will occur only after stand replacement or partial stand replacement fires. These higher intensity fires can alter soil water balances in favor of hillslope instability and cause a decline in rooting strength resulting in additional instability. Since the effects of fire on erosion processes is dependent on the intensity and spatial extent of the fire it is difficult to predict the erosional consequences of an individual fire in a ecosystem with a highly variable fire regime.

Sediment production and transport on a watershed level will also be substantially different under the fire regime documented in this study compared to the fire regime of large scale, infrequent and catastrophic fire which has been assumed for the central western Cascades. Based on this assumed fire regime Swanson (1981) hypothesized peaks of accelerated sediment yield of five times the baseflow rate induced by catastrophic fires occurring on a 200 year return interval in western Cascade watersheds. The results presented in this paper indicate that although some fires may be widespread, they are patchy and of variable intensity. Consequently an individual fire will only burn at stand replacement intensity through small portions of a watershed. Due to this factor, as well as the relatively frequent occurrence of fire on a watershed basis, peaks of accelerated sediment production will be dampened and smoothed in a similar fashion as increased stream flows. The transport of sediment may be influenced by the patchy character of many fires. Often areas burned at high intensity are interspersed among unburned or lightly burned areas. Unburned areas are also often adjacent to streams. Interception and storage of sediment produced in more severely disturbed areas by these less disturbed areas may have a significant impact on the sediment production from the watershed as a whole.

The effect of the fire regime documented in this study on aquatic ecosystems is largely defined by the effects discussed above on stream flow, stream temperature and sediment production. It appears that in a third or fourth order drainage basin, fire may be viewed as more of a chronic disturbance mechanism than a catastrophic one. This factor would have a strong influence on the stability of these aquatic ecosystems.

Implications for Forest Succession and Stand Dynamics Research

The development of hypotheses about the processes of succession and stand development in the northwest has largely been limited to consideration of ecosystem changes occurring after catastrophic disturbance where the existing stand is eliminated and the site reduced to a bare ground state (Dyrness 1965, 1973, Franklin and Dyrness 1973, Franklin and Hemstrom 1981, Hemstrom and Dale 1982, Zamora 1982, Henderson 1982). The common tendency has been to develop models and explore the processes involved with successional changes from a bare ground state through seral stages to maturity and eventually senescence of a forest stand. In these studies the possible influence of partial stand replacement fires and underburns on stand dynamics is not considered.

The importance of both infrequent stand replacement fire and relatively frequent medium to low intensity fire in the forest ecosystems of the central western Cascades has been well documented in this study. It is important to understand the development of stands originating after stand replacement fires. But an understanding of the processes of stand dynamics in the central western Cascades will be incomplete without considering the effects of chronic low and intermediate intensity burns.

Some sites are present in both study areas in which stand replacement fires have been absent for at least 800 years and a forest canopy has persisted despite low and moderate intensity fires. Interesting information about ecosystem structure, stability, diversity and successional trends will be obtained from models which consider the dynamics of such multi-age stands developing under a frequent disturbance regime. Such models should consider disturbances leaving a significant forest canopy.

Recently the need for consideration of disturbances of all magnitudes and frequencies has been mentioned but little emphasis has been placed on this research (Franklin 1982, Martin 1982, Oliver 1982, Thornburgh 1982). Stephen Veirs (1982) has presented an interesting study of the influence of frequent moderate and low intensity fires on stand dynamics and succession in the coast redwood forests of northern California. Stephen Arno (1982) has included the effects of frequent surface fires in an analysis of forest succession in Pseudotsuga menziesii / Physocarpus malvaceus habitat types of Montana. In the central western Cascades Joseph Means (1982) has noted evidence of low and moderate intensity fire in dry habitats and mentions that these fires effect stand development and structure. These repeated fires result in negative exponential diameter distributions and all age stands.

There are a number of areas where our understanding of the dynamics of the forests in the central western Cascades could be expanded by further studies of stand development that examine the effects of the disturbance regime documented in this paper. These include the following:

1. What is the influence of low intensity fire on the stand dynamics of understories which include many fire-sensitive species, and how does episodic understory mortality effect overstory stand dynamics?

2. Climax forests are rarely found in these ecosystems due to

the persistence of long lived *Pseudotsuga menziesii* in the canopy. Several generations of *Tsuga heterophylla* and *Abies amabilis* come and go in the understory during the lifetime of long lived *Pseudotsuga menziesii*. Is the relatively short persistence of *Tsuga heterophylla* and *Abies amabilis* due in part to underburns? What role do these underburns play in the delayed development of a hypothetical climax forest?

3. In this study the origin dates of understory species such as *Tsuga heterophylla* and *Abies amabilis* in old-growth stands were closely associated with the date of the last low intensity fire. This has been documented by other investigators as well (Franklin and Waring 1980, Franklin and Hemstrom 1981, Means 1982). Does this imply that *Tsuga heterophylla* or *Abies amabilis* regeneration is significantly enhanced by substrate conditions and opening of growing space after a low intensity fire?

4. There is the question of the cause of the wide age range in old growth stands in the central western Cascades as documented by a number of investigators (Franklin and Waring 1980, Franklin and Hemstrom 1981, Means 1982). A number of theories have been proposed to explain this phenomenon. The most prominent theory is that one or more catastrophic fire(s) burned much of this area about 450 to 500 years ago and *Pseudotsuga menziesii* took a long period (100 to 200 years) to fully occupy these sites due to a lack of seed source and other factors. The results presented in this paper indicate that this broad age range in old-growth forests is probably due to multi-age stands which developed in the presence of a moderate frequency, variable intensity fire regime. Little evidence exists that supports the theory that one or more widespread catastrophic fires created the existing old-growth forests in my study areas. They appear to have originated after many separate small fires. Further research into the age

distributions of stands in this area and regeneration after wildfire is needed in order to understand the age distributions of old-growth stands.

5. An understanding of the type, speed and completeness of regeneration following fire in the central western Cascades is still incomplete. This lack of knowledge is related to the above discussion but applies to all ages of forest stands. Recently there has been considerable emphasis on long time lags before complete stocking of a site occurs after a fire (Franklin and Hemstrom 1981, Hemstrom and Franklin 1982, Means 1982). In my data there is abundant evidence that rapid recolonization of many sites was common after most fires in both study areas. This is documented by the narrow age ranges present in the regeneration after many fires. Rapid recolonization by seral tree species following fire is consistent with the fact that the fires tend to be patchy and often moderate intensity, leaving an abundant seed source. After some fires (and on certain sites) slow recolonization was certainly the case but data from this study indicate that it is the exception rather than the rule. More investigation of regeneration after a variety of intensities of wildfire will be needed to understand this situation.

6. Stand development in a relatively homogeneous situation such as an even-age stand would be quite different from stand development patterns in non-homogeneous forests dominated by a complex patch mosaic of variable aged stands. In such a situation the dynamics of one individual patch will be influenced by edge effects produced by adjacent patches. In order to understand the dynamics of the forests in the central western Cascades it is important to determine the influence of this complex age class patch mosaic.

Implications for Wildlife Habitat Research

The complexity of stand age class structure and the intricate patch mosaic of age classes that has been documented in this paper has important implications in terms of wildlife habitat. There has been considerable interest in wildlife habitat requirements in northwestern coniferous forests and the importance of old-growth forests in meeting the habitat requirements of certain non-game species (Maser and Thomas 1978, Meslow 1978, Wiens 1978, Edgerton and Thomas 1978, Meslow et al. 1981). Wildlife biologists have based their understanding of the type, nature and availability of wildlife habitat in northwestern coniferous forests on the stand models developed by forest ecologists. These views have not given sufficient consideration to the complex processes of stand dynamics and succession in the central western Cascades where a highly variable fire regime is present. Consequently much of the investigation of habitat requirements and availability has been limited to consideration of simplified successional stages (i.e. grass/forb - shrub/seedling - sapling/pole - young growth - mature - old growth) (Meslow 1978, Edgerton and Thomas 1978, Bull 1978, Canutt and Poppino 1978).

The use of these simplified successional stages is helpful in gaining an understanding of the various habitats present in coniferous forests. It is particularly useful in assessing the impact of even-age silvicultural practices on wildlife habitat. But a model based on these stages may be inadequate in describing the wildlife habitat of unmanaged forests operating under a natural fire regime. It is useful to understand the habitat opportunities which occur under natural conditions in order to assess the impact of silvicultural modifications of the forest.

The results of this study indicate that the forests in the central western Cascades are dominated by multi-age stands which in themselves provide a much more diverse and complex habitat than is present in any seral stage of an even-age stand. These multi-age stands may be dominated by a given age class but contain individuals or small patches of other age classes. There are certainly many examples of even-age stands representing a particular seral stage, but it is important for wildlife biologists to note that the majority of a forest may be more complex and therefore represent a more complex habitat situation.

Old growth stands are important as wildlife habitat because of the complexity and variability present as well as their structural massiveness. Wildlife biologists recognize that this structural complexity, great vertical development with considerable intra-stand variability and horizontal patchiness allow a relatively high number of unique wildlife species and individuals to live in old-growth forests (Meslow et al. 1981). This complexity and patchiness of old-growth stands has been considered the result of small scale disturbances which have influenced the stand (e.g. lightning, windthrow, insect infestation) during their development. The role of low intensity fire in creating this complexity has not been given sufficient attention. Most old growth stands in my two study areas have experienced one or more understory or partial stand replacement fires since establishment of the oldest age class. These fires may well be responsible for much of the structural complexity and variability present in these stands.

The complex age class patch mosaic described in the Cook Creek - Quentin Creek study area and to a somewhat lesser extent in the Deer Creek study area has interesting implications for wildlife habitat. The amount of edge existing between successional stages, the configuration of the edges and the contrast between plant communities on both sides of the edge are important factors in the abundance and diversity of wildlife species in an area (Black and Thomas 1978, Thomas et al. 1978, Welty 1982:485). The degree of interspersion of plant communities and successional stages in a particular area significantly influences wildlife habitat diversity. Wildlife biologists have developed measures of habitat diversity as a function of edge called "diversity indexes." The diversity index is the ratio of the perimeter of a patch to the perimeter of a circle with the same area as that of the patch (Patton 1975:172, Thomas et al. 1978). This is identical to the patch irregularity index that I have used to describe patches in my two study areas. The patch irregularity indexes (or diversity indexes) for age class patches in both study areas is high which suggests a highly diverse wildlife habitat.

It is interesting to note that in the two study areas the low mortality patches left after the 1800 - 1900 AD fires also represent the distribution of old-growth stands. Although most of the trees in these patches are greater than 250 years old, some may be 180 to 250 years in age and are regarded in the following discussion as old-growth. Forests in this age range typically begin exhibiting old-growth characteristics (Franklin et al. 1981).

As a result of fire suppression activities in the last 70 years and a possible decline in aboriginal burning in the central western Cascades the amount of contrast between successional stages along edges has diminished considerably. The degree of contrast between plant communities on both sides of an edge has important implications for wildlife habitat (Thomas et al. 1978). Almost all of the edges present in the existing forest occur between mature and old-growth forests and the contrast is only moderate compared to the contrast that would have existed in 1900

AD. It is quite possible that fire suppression activities have already altered wildlife habitat substantially compared to what existed in an unmanaged state.

Although much of the Cook Creek - Quentin Creek study area appears to be dominated by old-growth forests, the old-growth stands usually occur in small, irregular patches. In the Cook Creek - Quentin Creek study area 74% of these old-growth patches are less than 10 hectares and 51% of them are less than 3 hectares. The patches of old-growth in the Cook Creek - Quentin Creek study area that are over 20 hectares all have patch irregularity indexes greater than 2.0 indicating that their perimeters are at least 100% greater than the perimeter of a circle the same size. These old-growth stands occupy about 31% of the study area. Much of the remainder of the study area (42%) is occupied by medium mortality stands which contain a mixture of old growth and mature forests. In these "partial old-growth stands" old-growth trees may occur as an even intermixture with mature trees or as patches less than 0.2 hectares. In wildlife habitat terms most of the Cook Creek - Quentin Creek study area would probably have satisfied (prior to logging) the requirements of old-growth obligate species even though only about 31% is strictly old-growth forest. This is because of the close proximity of these stands to one another, their interconnection and their complex interspersion in a forest mosaic which contains "partial old-growth stands." Because of the high degree of interspersion and edge effect, the quality of habitat in this study area may be greater than if it was all uniform even-age old-growth forest.

The Deer Creek study area presents a different wildlife habitat picture. Here 67% of the study area consisted (prior to logging) of relatively undisturbed old-growth forest. Most of this area (41%) was contained in one large old-growth patch (797 only one or more scar dates were present. A few sites only had approximate origin dates recorded. The fire frequency at the site (mean fire interval), listed in Appendix III, is calculated for both the total period of record at the site (a function of the oldest tree at the site) and for the interval from 1800 AD to 1910 AD. The mean fire interval at most sites is considerably less during the 1800 - 1900 AD period. This may be due to more frequent fire during this period but may also be an artifact of less available record of fire in preceding periods.

Appendix IV represents a summary of the fire history at each site. For the Cook Creek - Quentin Creek study area the average site fire frequency (mean fire interval) for all fires was 96 years and 150 years for stand replacement and partial stand replacement fires. There were an average of 3.3 fires recorded per site and there was an average of 2.2 forest age classes per site. On the average 1.1 understory fires were recorded per site.

<u>Results from Intensive Study Sites</u>

The record of fire in the Cook Creek - Quentin Creek study area as described above is probably biased because low intensity burns may be too cool to leave a scar record on many trees. At many sites only a few stumps were sampled and a more complex fire record might have been found if more stumps had been included. Intensive sampling was done to determine if a more complex fire record would be evident.

A large number of trees were sampled (sites QU40, QU50, QU51 and QU52) from a stand that had been cut on a south slope at about 853 m elevation in the northeast sector of the Cook Creek - Quentin Creek study area. This was near an area where numerous scars and age classes had been observed. The intent of this sampling was to investigate the disturbance history in a stand where the likelihood of fire was high. A histogram based on 10 year bins illustrates the scar and origin data in this stand (Figure 16). In the interval between 1400 AD and 1940 AD eighteen decades had at least one scar date (codes 1, 2 and 3) and 5 additional decades exhibited shakes, abrupt growth release, or abrupt growth suppression (Codes 4, 5 and 6). There are 13 decades where Pseudotsuga menziesii origin dates are present and four additional decades where Tsuga heterophylla origin dates are present. During the 1800-1940 AD period, there are four positive fire scars and 10 bins with scar codes 1, 2 or 3. This indicates a possible mean fire interval of about 14 years during the 1800-1940 AD period, and about 16 years for the 1800-1910 AD period. Not all the scars may have been caused by fire. An expanded histogram for this stand covering the 1800-1910 AD period based on 2 year increments illustrates the data for this period in more detail (Figure 17). The results of this intensive sampling indicate that a more complex fire record can be found by sampling a large number of stumps at a site.

KEY TO ORIGIN DATE CODES AND SCAR CODES

D = Douglas-fir	1 = Definite fire scar
H = Western hemlock	2 = Major scar
S = Pacific silver fir	3 = Normal scar
R = Western red cedar	4 = Shake
W = Western white pine	5 = Abrupt growth release
N = Noble fir	6 = Abrupt growth suppression
A = Approximate date (Douglas-fir)	

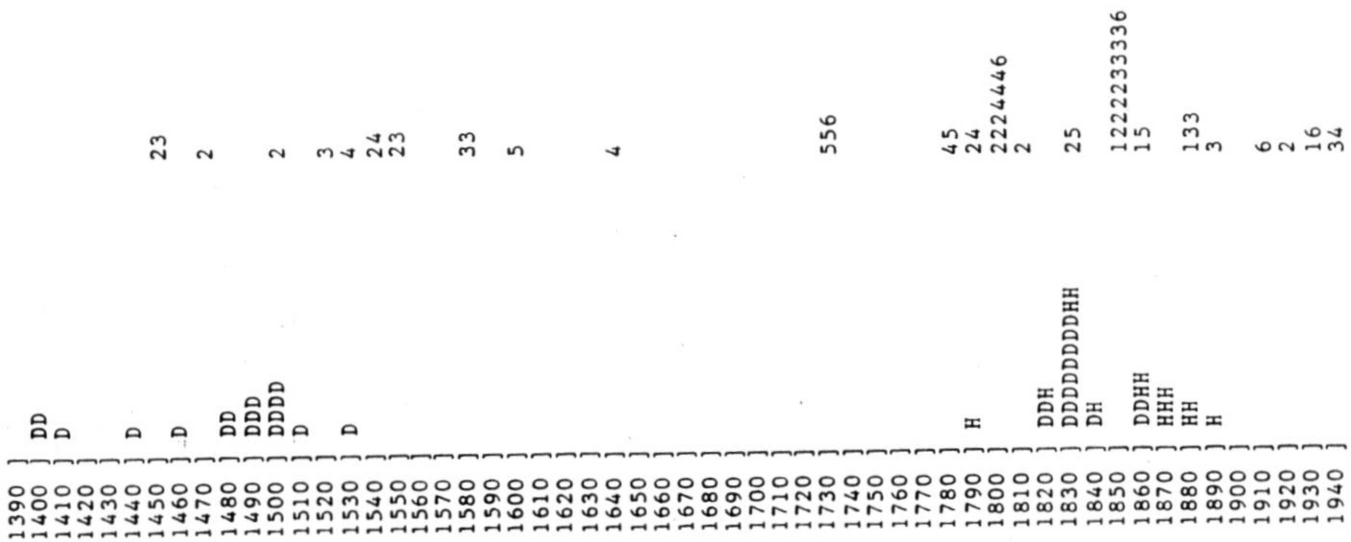


Figure 16. Histogram of of all origin dates and scar dates at intensive sites: Cook Creek - Quentin Creek study area.

KEY TO ORIGIN DATE CODES AND SCAR CODES

D = Douglas-fir
H = Western hemlock
S = Pacific silver fir
R = Western red cedar
W = Western white pine
N = Noble fir
A = Approximate date (Douglas-fir)

1 = Definite fire scar
2 = Major scar
3 = Normal scar
4 = Shake
5 = Abrupt growth release
6 = Abrupt growth suppression

Year	Scar codes	Origin codes
1800	24446	
1802		
1804		
1806		
1808	22	
1810	2	
1812		
1814		
1816		
1818		
1820		
1822		
1824		H
1826		DD
1828		
1830		DDD
1832	52	DHH
1834		DD
1836		DD
1838		
1840		
1842		
1844		H
1846		
1848		D
1850		
1852	1222333	
1854	236	
1856		
1858		
1860	5	D
1862		
1864	1	DH
1866		H
1868		
1870		
1872		HH
1874		
1876		
1878		H
1880		H
1882	31	
1884		H
1886		
1888	3	
1890		H
1892		
1894		
1896	3	
1898		
1900		
1902		
1904		
1906		
1908		

Figure 17. Histogram of origin dates and scar dates 1800-1900 AD interval at intensive sites - Cook Creek - Quentin Creek study area.

Patch Characteristics and Fire Intensity Analysis

A map was constructed depicting patches of three levels of fire intensity during the 1893 fire in Cook Creek - Quentin Creek study area (Figure 18). A complex mosaic of patches was created by the fire. Extensive corridors of lightly burned, low mortality stands extend through a background of medium intensity burn where stand thinning occurred. Complex patches of high intensity stand replacement fire occurred within this medium intensity background.

The irregularity of the patches and the amount of edge present in the patch mosaic has important implications for wildlife habitat and stand dynamics. An analysis of these patches is summarized in Table 7. The patch irregularity index is an indicator of the roundness of each patch. It is the ratio of the perimeter of the patch divided by the perimeter of a circle with the same area as the patch. The average irregularity index for the high intensity patches was 1.33. Low intensity patches had an average irregularity index of 1.52. This indicates that the patches are quite irregular as compared to a circle (which has an irregularity index of 1.0). Seventeen percent of the patches have irregularity indexes exceeding 2.0, which indicates they have twice the amount of edge that a circle would have. The total perimeter, which is a measure of the edge effect of all the patches was about equal for high intensity patches (18060 m) and low intensity patches (19881 m).

Small patches dominate the size distribution of high intensity patches created by the 1893 fire (Figure 19). Forty percent of the high intensity patches are less than one hectare and 84 percent are less than four hectares. The largest high intensity patch created in the Cook Creek - Quentin Creek study area by the 1893 fire was 20 hectares. Medium size patches are predominant

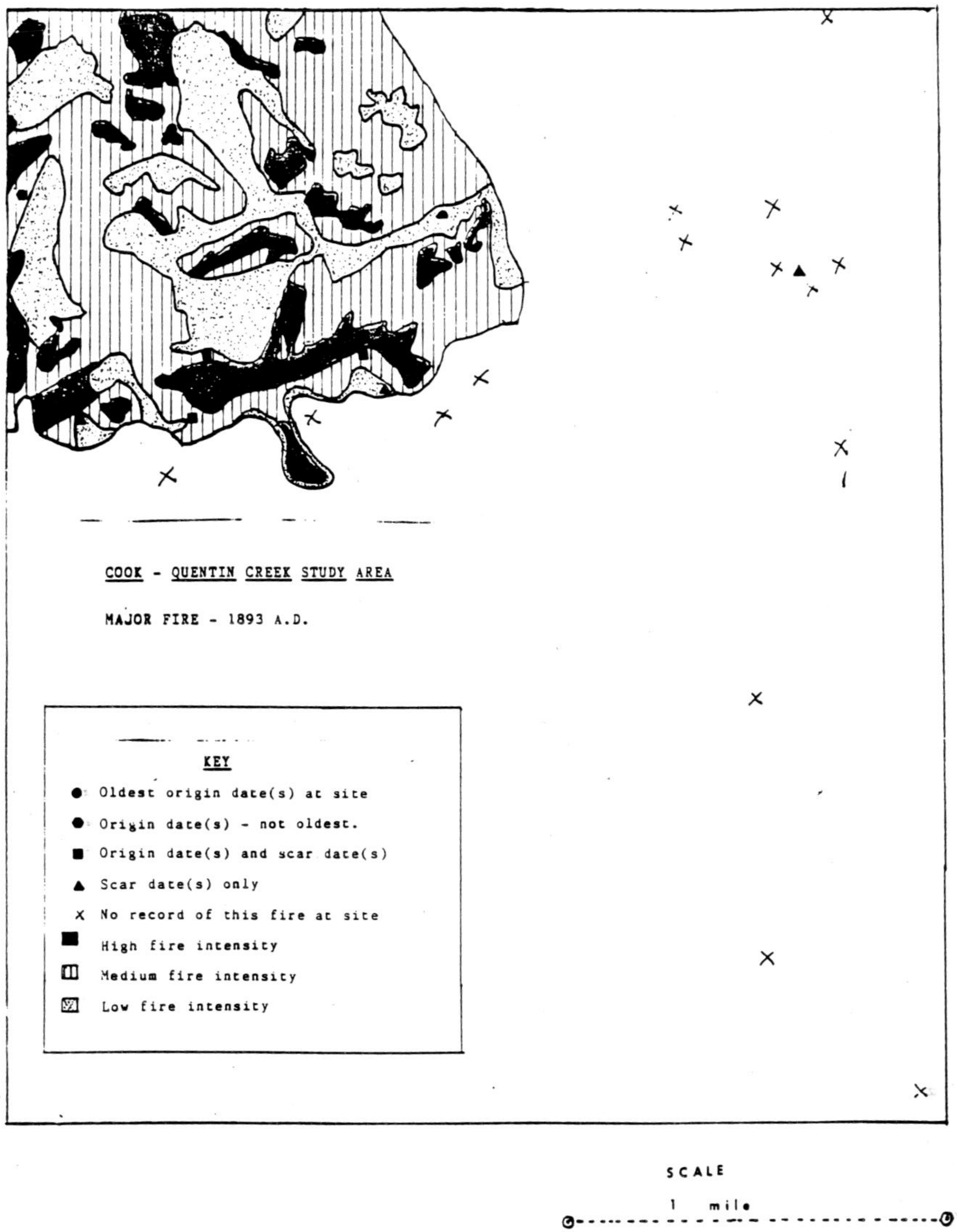


Figure 18. Fire intensity patch map for 1893 fire episode - Cook Creek - Quentin Creek study area.

Table 7

Patch Analysis Summary for 1893 AD Fire Episode

Cook Creek - Quentin Creek Study Area

Patch Type	Area (hectares)	Percent of Fire Area	Mean Patch Irregularity Index	Total Edge (meters)
Low Intensity	101	29	1.515	19881
Medium Intensity	188	53	---	---
High Intensity	62	18	1.333	18060
Total	351			

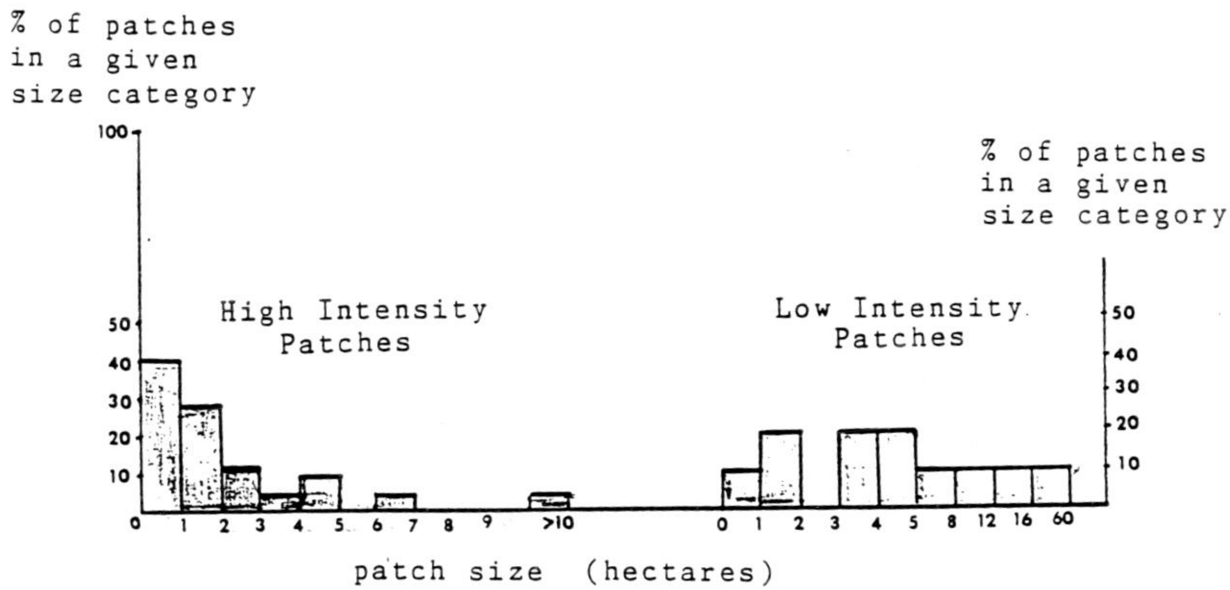


Figure 19. Patch size distribution for 1893 fire episode - Cook Creek - Quentin Creek study area.

in the low intensity distribution. Although 90 percent of the patches are less than 20 hectares, only 10 percent are less than one hectare. Sixty percent of the patches are between 3 and 16 hectares in size. Because the patches were truncated at the edge of the study area a bias is introduced in favor of smaller patch sizes. The effect of this bias was not studied.

The 1893 fire was predominantly a medium intensity thinning fire in the Cook Creek - Quentin Creek study area. Of the total area burned by the fire, 53 percent was a medium intensity burn, 18 percent was a high intensity burn and 29 percent was a low intensity burn.

The patch distribution for the 1800 - 1900 AD period in the Cook Creek - Quentin Creek study area is mapped in Figure 20. The high, medium and low mortality areas represent the cumulative impact of all the fires during that period. A complex patch mosaic exists with extensive patches and corridors of low mortality areas. Several large, high mortality patches exist as well as many small high mortality patches amidst a background of medium level mortality areas.

The average irregularity index for the high intensity patches is 1.45 and 1.49 for low intensity patches (Table 8). The total perimeter is about equal for low and high intensity patches. Figure 21 illustrates the patch size distribution for high intensity patches. Small patches dominate the distribution as in the 1893 fire. Eighty-eight percent of the patches are less than ten hectares, 67 percent are less than four hectares and 38 percent are less than one hectare.

Figure 20. Cumulative mortality patches created by fires in the 1800-1900 AD interval - Cook Creek - Quentin Creek study area.

Table 8

Patch Analysis Summary for 1800-1900 AD fires

Cook Creek - Quentin Creek Study Area

Patch Type	Area (hectares)	Percent of Fire Area	Mean Patch Irregularity Index	Total Edge (meters)
Low Mortality	601	31	1.493	104890
Medium Mortality	824	42	---	---
High Mortality	530	27	1.449	94757
Total	1955			

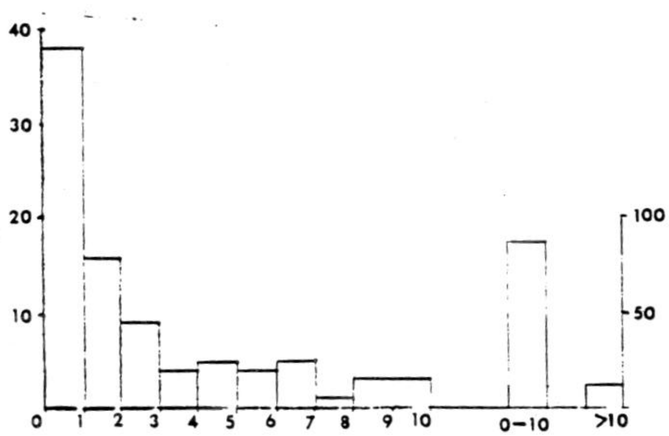


Figure 21. Patch size distribution for stand replacement patches created during the 1800-1900 interval - Cook Creek - Quentin Creek study area.

The 1800-1900 AD fires in the Cook Creek - Quentin Creek study area created patches of medium level mortality over 42.1 percent of the study area and patches of high level mortality over 27.1 percent of the study area. Patches of low level mortality cover 30.7 percent of the study area.

Analysis of Fire History in Relation to Aspect and Elevation

The overall aspect and elevation distribution of the Cook Creek - Quentin Creek study area was estimated by a random sample of 200 points. This distribution and the distribution of sample sites with respect to aspect and elevation is summarized in Appendix V. A chi-square goodness of fit analysis (Zar 1974) was used to test if the aspect and elevation distributions of the sample sites conform to the expected aspect and elevation distribution of the study area. The observed and expected aspect distributions can be assumed to be from the same population at a 95% confidence level in the $0.50<P<0.75$ probability range. The observed and expected elevation distributions can be assumed to be from the same population at a 95% confidence level in the $0.10<P<0.25$ probability range. These conclusions imply that the sample sites represent a relatively good sample of the study area with respect to aspect and elevation.

The fire record of the Cook Creek - Quentin Creek study area was analyzed to see if there was any relationship between fire history and aspect or elevation (Table 9). In the Cook Creek - Quentin Creek study area no easily discernible relationship exists between any of these measures of site fire history and aspect or elevation. The mean fire intervals are substantially higher for the 3500-3999 feet elevation category and the number of age classes is substantially lower but it is difficult to determine if this is significant due to the low sample size in

TABLE 9

ANALYSIS OF FIRE HISTORY ACCORDING TO ASPECT AND ELEVATION

COOK CREEK - QUENTIN CREEK STUDY AREA

ASPECT	N	MEAN AGECL	MEAN UNDER	MEAN SFF1	MEAN SFF2
N	1	2.00	2.00	109	218
NE	2	3.50	1.50	50	88
E	5	1.00	1.00	73	149
SE	13	1.69	1.31	109	183
S	7	3.14	1.71	107	181
SW	8	2.25	1.13	78	106
W	5	2.60	1.20	133	250
NW	3	3.00	1.33	75	107
R	12	2.00	0.33	93	105
B	1	2.00	0.00	111	111

ELEVATION	N	MEAN AGECL	MEAN UNDER	MEAN SFF1	MEAN SFF2
< 2500	12	2.67	0.58	94	119
2500-2999	21	2.29	1.71	92	171
3000-3499	21	1.90	0.76	91	126
3500-3999	3	1.33	1.00	171	302
4000-4499	0	0.00	0.00	0	0
> 4500	0	0.00	0.00	0	0

N = Number of sites in aspect or elevation category

MEAN AGECL = Mean number of age classes at sites

MEAN UNDER = Mean number of underburns at sites

MEAN SFF1 = Mean fire frequency of all fires at sites

MEAN SFF2 = Mean fire frequency of stand replacement or partial stand replacement fires at sites.

this category. Ideally, to determine if significant differences occur between elevation or aspect categories, a single factor analysis of variance and Newman-Keuls multiple range test would be applied to this data. Unfortunately, due to the wide variation in sample size for each category, the probability of a Type I error becomes large enough to render these tests unsatisfactory (Zar 1974).

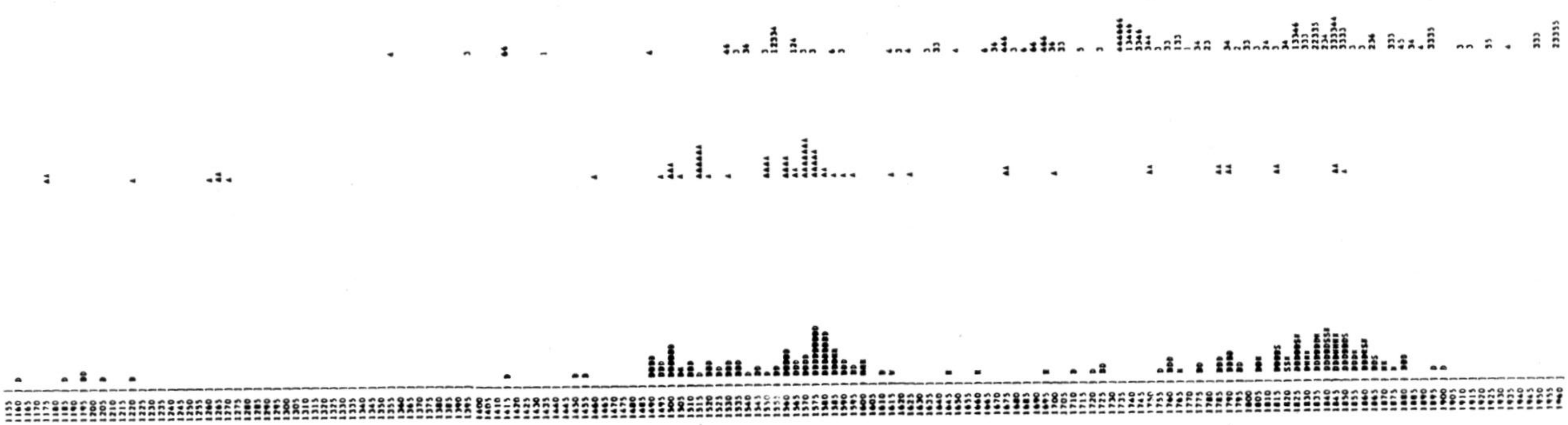
RESULTS: DEER CREEK STUDY AREA

The analysis of the Deer Creek study area data proceeded along the same lines as that for the Cook Creek - Quentin Creek study area data. To avoid repetition, this description will not be repeated unless different procedures were used.

Fire History of Study Area

Figure 22 illustrates the data for the Deer Creek study area pooled from all the sites and plotted according to five year bins. Between 1900 and the present only scattered scar dates were found in the Deer Creek study area. These represent small spot fires or other disturbance mechanisms. Scars and origin dates are present in most bins from 1800 - 1900 AD with many bins represented by numerous scars and origin dates. During the 1700 - 1800 AD interval, most bins have at least one or two scar dates and/or origin dates. Unlike the Cook Creek - Quentin Creek study area, fires in the 1800 - 1900 AD period did not erase much of the earlier tree ring record in the Deer Creek study area. Therefore the lack of data in this period most likely represents fewer fires in the Deer Creek study area during this interval. Between 1600 - 1700 AD, only scattered scars and a few origin dates are found. Extensive fire activity is evident in the Deer Creek study area during the 1490 - 1600 AD interval. Because few existing trees survived fires during this interval, the scar record is limited.

Prior to 1490 little record exists due to the widespread stand replacement fires of the 1490-1600 interval. One fire scar was recorded in 1436 and there are a few old trees that date from this period. There is no record of fire for the two hundred year interval from 1220 to 1415. During the 1160 - 1220 interval, a



KEY TO ORIGIN DATE CODES AND SCAR CODES

D = Douglas-fir		1 = Definite fire scar	
H = Western hemlock		2 = Major scar	
S = Pacific silver fir		3 = Normal scar	
R = Western red cedar		4 = Shake	
W = Western white pine		5 = Abrupt growth release	
N = Noble fir		6 = Abrupt growth suppression	
A = Approximate date (Douglas-fir)			

Figure 22. Histogram of all origin dates and scar dates – Deer Creek study area.

few origin dates from old surviving _Pseudotsuga menziesii_ indicate regeneration following fires in this time period.

Fires during the 1480 - 1580 period were more widespread than fires in more recent times. Seventy-three percent of the sites had conifers dating from the 1480-1580 AD interval compared to 54 percent of the sites with conifer regeneration during the 1780-1880 AD interval (Figure 23).

A master fire chronology (Table 10) was formed for the Deer Creek study area based on the analysis of data from each individual site, the results presented in Figures 22 and 23 and an assessment of the geographical affinity of sites with similar dates. Fourteen major fires were identified.

The separation of fires during the 1800-1900 AD period was difficult due to the short intervals between fires. Histograms of this period with one year bins were used to analyze the temporal separation of scar dates and to assess the site based occurrence of scars (Figures 24 and 25).

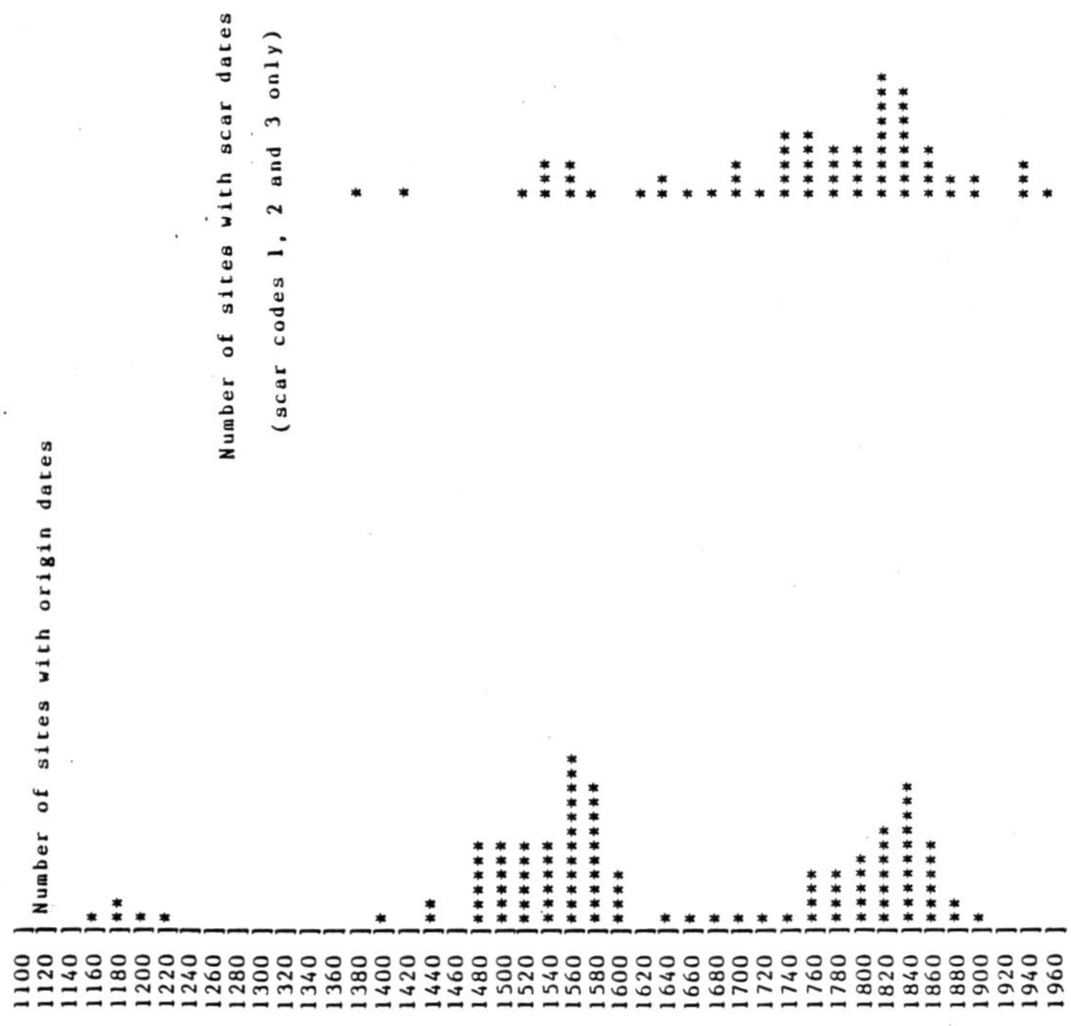


Figure 23. Histogram of number of sites with origin dates and scar dates - Deer Creek study area.

Table 10
Master Fire Chronology
Deer Creek Study Area

Mean Date	Fire Episode	Fire Interval (time since last fire)
1893	1897-1888	15
1878	1880-1875	14
1864	1869-1857	14
1850	1854-1847	10
1840	1845-1836	11
1829	1833-1826	33
1796	1807-1788	30
1769	1780-1757	29
1740	1744-1735	165
1575	1591-1568	23
1552	1557-1537	37
1515	1530-1490	79
1436	1455-1415	236
1200	1222-1164	?

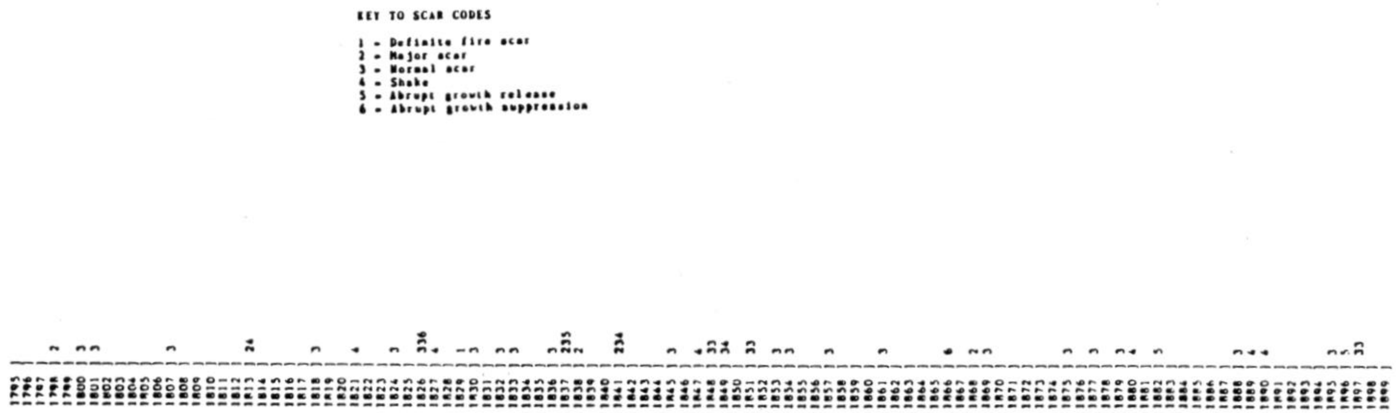


Figure 24. Histogram of all scar dates in the 1800-1900 AD period - Deer Creek study area.

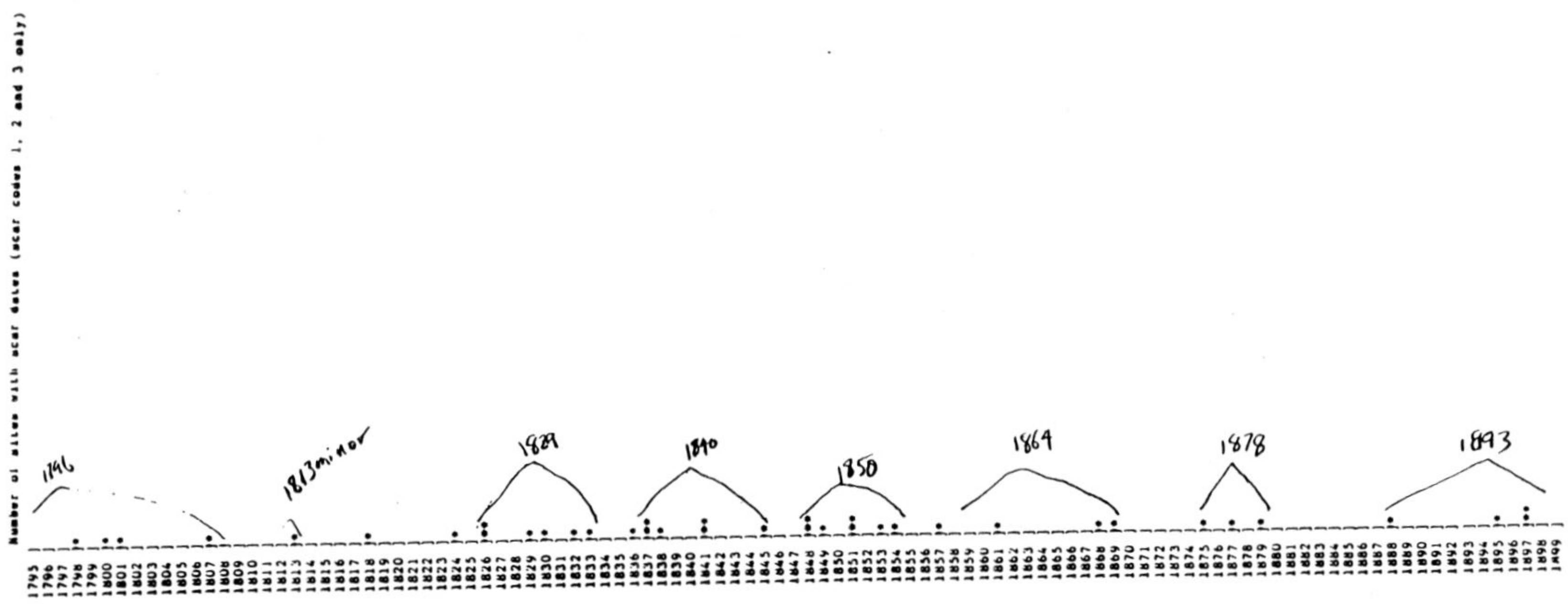


Figure 25. Histogram of sites with scars in the 1800-1900 AD period - Deer Creek study area.

The mean fire return interval for the study area as a whole for several time periods is listed in Table 11.

Table 11

Mean Fire Return Interval for the Deer Creek study area

Time period	MFRI (years)
1893 AD - 1796 AD	16.2
1893 AD - 1740 AD	19.5
1893 AD - 1515 AD	34.6
1893 AD - 1436 AD	38.3
1893 AD - 1200 AD	53.5

Table 12 lists the area burned during each fire episode (estimated by the ratio method), the percentage of sites with high, medium or low mortality and the type of record available for each fire. A comparison of the estimated area burned during each fire episode as calculated by two methods is listed in Table 13. It appears that the ratio method is the more conservative area estimation technique for the Deer Creek study area. It is important to emphasize that the areas calculated by these two methods are only rough approximations.

TABLE 12

LIST OF MAJOR FIRES

DEER CREEK STUDY AREA

NOTE: THE RECORD FOR EACH FIRE IS LISTED IN TERMS OF HOW MANY SITES FALL INTO EACH OF THE FOLLOWING CATEGORIES:
A = NUMBER OF SITES WHERE THIS IS OLDEST ORIGIN DATE
B = NUMBER OF SITES WITH ORIGIN DATE ONLY (NOT OLDEST)
C = NUMBER OF SITES WITH ORIGIN DATE AND SCAR DATE
D = NUMBER OF SITES WITH SCAR DATE ONLY
E = NUMBER OF SITES WITH NO RECORD OF THIS FIRE
F = NUMBER OF SITES WHERE RECORD HAS BEEN ERASED BY PREVIOUS FIRES

FIRE YEAR	AREA (HA)	----- Fire Intensity ----- (Percent of Fire)			RECORD					
		HIGH	MED	LOW	A	B	C	D	E	F
1893	154	0	20	80	0	1	0	4	58	0
1878	92	0	67	33	0	1	1	1	60	0
1864	154	0	40	60	0	1	1	3	58	0
1850	277	11	56	33	1	2	3	3	54	0
1840	282	11	67	22	1	3	3	2	53	1
1829	255	13	25	63	1	1	1	5	53	2
1796	324	20	50	30	2	4	1	3	50	3
1769	268	25	13	63	2	0	1	5	50	5
1740	69	0	50	50	0	1	0	1	54	7
1575	971	79	18	4	22	3	2	1	28	7
1552	800	57	14	29	8	2	0	4	20	29
1515	1644	82	18	0	18	4	0	0	4	37
1436	1457	50	17	33	3	1	0	2	2	55
1200	1942	100	0	0	5	0	0	0	0	58

Table 13

Estimated Area Burned During Each Fire Episode By Two Methods

Fire Year	Planimeter measured (hectares)	Ratio calculated (hectares)
1893	101	154
1878	140	92
1864	236	154
1850	321	277
1840	580	282
1829	315	255
1796	405	324
1740	193	69
1575	1025	971
1552	928	800
1515	1856	1644

There is insufficient data to estimate areas burned prior to 1500.

Maps of each major fire were constructed based on the analysis of the site date for each fire (Appendix VI). They indicate approximate locations for the area burned during each fire episode.

The natural fire rotation was calculated for several time intervals (Table 14). Because of the low incidence of fire after 1600 AD and the widespread fires from 1500 - 1600 AD the natural fire rotation for the 1910 - 1500 AD period is markedly lower than the two preceding time periods.

Table 14

Natural Fire Rotation - Deer Creek Study Area

Period of Record	NFR (years) (Area by Planimeter)	NFR (years) (Area by Ratio)
1910-1800	126	176
1910-1700	163	217
1910-1600	241	321
1910-1500	126	150

Disturbance History at Individual Sites

The fire record at individual sites is summarized in Appendices VII and VIII. In the Deer Creek study area the average site fire frequency (mean fire interval) for all fires is 233 years and 272 years for medium and high intensity fires. There were an average of 2.1 fires recorded per site, an average of 1.6 age classes per site and an average of 0.5 understory fires per site.

Results from Intensive Sites

In the Deer Creek study area a large sample of trees were taken in an old growth stand (that had been cut) on a gentle northeast slope at 1097 m elevation. These intensive sites are DR01, DR02, DR52 and DR53. Previous sampling in the area indicated that the stand was even-age with little age spread. The intent of the sampling was to verify this and to determine the amount of age spread present. It was also the intention to test whether more intensive sampling would reveal a more complex fire record. A histogram based on 10 year bins illustrates the scar and origin data in this stand (Figure 26). All *Pseudotsuga menziesii* origin dates occur in an interval between 1540 AD and 1590 AD and all but one are found between 1560 AD and 1590 AD. This is a remarkably narrow age spread for old-growth forests. Several *Tsuga heterophylla* and one *Pinus monticola* were found in the period between 1600 AD and 1700 AD.

The scar record is ambiguous. No fire scars or major scars were found. Most of the scars (code 3) were found on one tree (*Pinus monticola*) and were somewhat obscure and of questionable origin. The other codes plotted in the histogram represent shakes (4) and periods of growth suppression (6) or growth release (5). My conclusion is that one very low intensity fire burned through the stand since 1590 AD. An expanded histogram for the period between 1500 and 1600 AD based on 2 year bins illustrates the spread of *Pseudotsuga menziesii* regeneration in this stand (Figure 27).

Year	Origin dates	Scar dates
1530		
1540	D	
1550		
1560	DDD	
1570	DDDDDD	
1580	DDDDDH	
1590	D	
1600		
1610	W	4
1620		
1630		
1640	H	
1650		4
1660	H	
1670		66
1680		6
1690	H	46666
1700		36
1710		5
1720		
1730		446
1740		46
1750		3
1760		33
1770		
1780		
1790		4
1800		
1810		3
1820		36
1830		
1840		
1850		3
1860		6
1870		
1880		5
1890		
1900		
1910		
1920		
1930		
1940		
1950		
1960		23355

KEY TO ORIGIN DATE CODES AND SCAR CODES

D = Douglas-fir
H = Western hemlock
S = Pacific silver fir
R = Western red cedar
W = Western white pine
N = Noble fir
A = Approximate date (Douglas-fir)

1 = Definite fire scar
2 = Major scar
3 = Normal scar
4 = Shake
5 = Abrupt growth release
6 = Abrupt growth suppression

Figure 26. Histogram of of all origin dates and scar dates at intensive sites - Deer Creek study area.

1530	
1532	
1534	
1536	
1538	
1540	D
1542	
1544	
1546	
1548	
1550	
1552	
1554	
1556	
1558	
1560	D
1562	
1564	
1566	
1568	DD
1570	D
1572	
1574	D
1576	
1578	DDDD
1580	DD
1582	DD
1584	DH
1586	
1588	
1590	
1592	
1594	
1596	D
1598	

KEY TO ORIGIN DATE CODES AND SCAR CODES

D = Douglas-fir
H = Western hemlock
S = Pacific silver fir
R = Western red cedar
W = Western white pine
N = Noble fir
A = Approximate date (Douglas-fir)

1 = Definite fire scar
2 = Major scar
3 = Normal scar
4 = Shake
5 = Abrupt growth release
6 = Abrupt growth suppression

Figure 27. Histogram of origin dates and scar dates 1530-1600 AD interval at intensive sites - Deer Creek study area.

Patch Characteristics and Fire Intensity Analysis

The patches created by the cumulative impact of the 1800-1900 AD fires in the Deer Creek study area are mapped in Figure 28. The 1800-1900 AD fires only burned 59% of the study area. Much of this area was burned at low intensity with patches of unburned land interspersed. A larger scale and less complex patch mosaic was found here compared to the Cook Creek - Quentin Creek study area. Medium sized patches dominate the size distribution of stand replacement patches (Table 15 and Figure 29).

The cumulative effect of the 1800-1900 AD fires in the Deer Creek study area created patches of medium level mortality in 19% of the study area and patches of high level mortality in 14% of the study area. Understory burns covered 26% of the study area during this interval and 41% of the study area was unburned.

Figure 28. Cumulative mortality patches created by fires in the 1800-1900 AD interval - Deer Creek study area.

Table 15

Patch Analysis Summary for 1800-1900 AD fires

Deer Creek Study Area

Patch Type	Area (hectares)	Percent of Fire Area	Mean Patch Irregularity Index	Total Edge (meters)
Low Mortality	502	43	1.515	51021
Medium Mortality	364	32	---	---
High Mortality	228	25	1.316	39089
Total	1154			

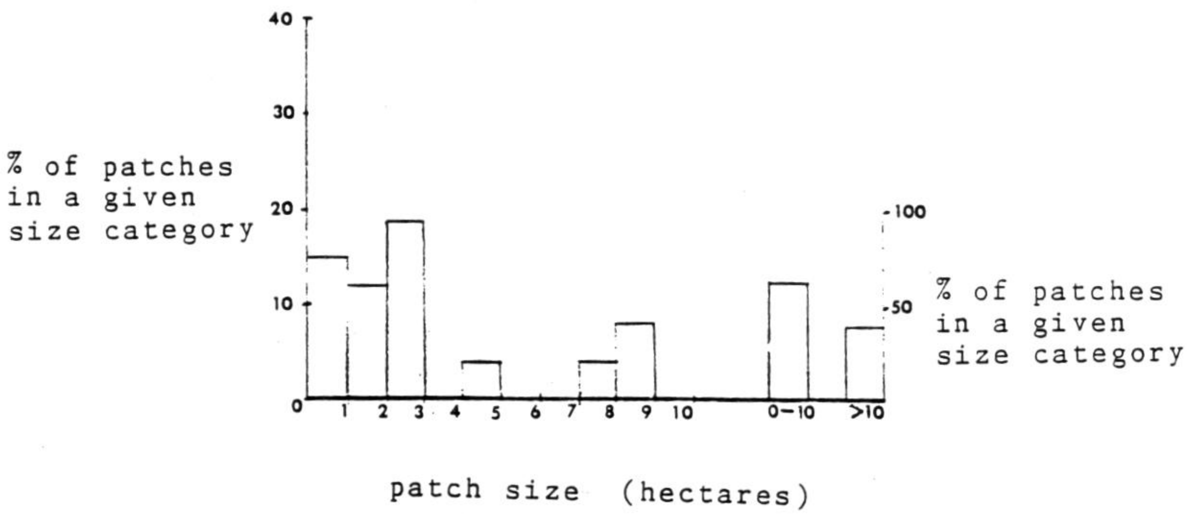


Figure 29. Patch size distribution for stand replacement patches created during the 1800-1900 interval - Deer Creek study area.

Analysis of Fire History in Relation to Aspect and Elevation

The overall aspect and elevation distribution of the Deer Creek study area was estimated by a random sample of 200 points. This distribution and the distribution of sample sites with respect to aspect and elevation is summarized in Appendix IX. A chi-square goodness of fit analysis was used to test if the aspect and elevation distributions of the sample sites conform to the expected aspect and elevation distribution of the study area. The observed and expected aspect distributions can be assumed to be from the same population at a 95% confidence level in the $0.75<P<0.90$ probability range. The observed and expected elevation distributions can be assumed to be from the same population at a 95% confidence level in the $0.25<P<0.50$ probability range. These conclusions imply that the sample sites are a representative sample of the study area with respect to aspect and elevation.

In the Deer Creek study area no easily discernible relationship exists between any of these measures of site fire history and aspect (Table16). Fire was more frequent in the upper elevation country (4000 - 4499 feet) than at lower elevations. The map of patches created during the 1800 - 1900 AD period also shows that these fires were limited to upper elevations. The mid to lower elevations in the Deer Creek study area appear to be infrequently visited by fire.

TABLE 16

ANALYSIS OF FIRE HISTORY ACCORDING TO ASPECT AND ELEVATION

DEER CREEK STUDY AREA

ASPECT	N	MEAN AGECL	MEAN UNDER	MEAN SFF1	MEAN SFF2
N	3	1.33	0.33	286	342
NE	6	1.17	0.00	319	319
E	10	1.60	0.50	272	299
SE	3	2.67	0.67	158	168
S	13	1.62	0.92	172	221
SW	10	1.70	0.10	253	261
W	8	1.38	0.50	233	298
NW	1	2.00	0.00	179	179
R	4	1.50	0.00	274	274
B	5	1.60	1.80	164	316

ANALYSIS OF FIRE HISTORY ACCORDING TO ELEVATION

ELEVATION	N	MEAN AGECL	MEAN UNDER	MEAN SFF1	MEAN SFF2
< 2500	0	0.00	0.00	0	0
2500-2999	0	0.00	0.00	0	0
3000-3499	8	1.63	1.13	216	311
3500-3999	24	1.29	0.29	270	301
4000-4499	31	1.81	0.58	209	240
> 4500	0	0.00	0.00	0	0

N = Number of sites in aspect or elevation category

MEAN AGECL = Mean number of age classes at sites

MEAN UNDER = Mean number of underburns at sites

MEAN SFF1 = Mean fire frequency of all fires at sites

MEAN SFF2 = Mean fire frequency of stand replacement or partial stand replacement fires at sites.

DISCUSSION

There has been recent concern that rigorous dendrochronological techniques should be applied when determining the fire history of an area. These would include proper preparation of wedges, cores or stem cross-sections; examination and counting of rings under a binocular microscope and cross dating of samples with each other establishing the synchronaeity of rings (Stokes 1980, Dieterich 1980b, Swetnam et al. 1983). Ideal reconstruction of past fires would also be based on fire scars fitting classic descriptions from ponderosa pine forests.

Reconstruction of the fire history of these study areas did not follow these guidelines. They are easier to apply to more xeric forest communities such as found in the eastern side of the Cascades and Rocky Mountains where fires are more frequent, less intense and leave an ample fire scar record which is not readily erased by decomposition. These techniques are very time consuming and can yield excellent results in areas with frequent fire. In such areas a few trees can yield a rich record if proper dendrochronological techniques are used (Arno 1976, Arno and Sneck 1977, Arno 1980, Dieterich 1980a). In the forests of the western Cascades the absence of many typical fire-scarred trees and the longer fire return interval makes a much larger sample size covering a larger area necessary. Since the objectives of this study were to enhance our understanding of stand development and ecological issues, a large representative sample is more important than the high precision that dendroclimatology necessitates. Otherwise the results would not have a wide applicability. For practical purposes this necessitates some deviation from the ideal techniques described above.

This study makes no claims for determining precise dates of individual fires. It does establish that fire was an important disturbance factor in the central western Cascades and the magnitude and frequency of the disturbance varied considerably on both temporal and spatial scales. The study used three levels of criteria to establish a major fire episode: tree-level criteria, stand-level criteria and inter-stand-level criteria. Tree-level criteria included the interpretation of scar and origin dates for both accuracy and likelihood of creation as a result of fire. Stand-level criteria were based on the repeatability of the tree-level data throughout a stand. The deciphering of major fire episodes relied on the repeatability of stand-level data among several stands with some geographic continuity. The interpretations made at each level are substantiated by the other levels. The results of this study are based on a substantial tree ring record which represents the highest sampling density for this scale of fire history study yet reported in the Pacific Northwest.

Comparison of the Fire History of the Two Study Areas

Fire occurred in both study areas with some regularity as demonstrated by the average fire incidence in the Cook Creek - Quentin Creek study area of 43.7 years over the 1893 - 1150 AD time period and 52.5 years in the Deer Creek study area over the 1893 - 1200 AD time period. These estimates are conservative since the record of many older fires was probably destroyed and some fires may be too cool to scar trees. During the last 300 years fires in both study areas were of a limited size. During this period there were no fires that burned more than half of either study area and only one fire (1834 Cook Creek - Quentin Creek study area fire) that burned more than one-third of either study area. But almost all of these fires extended beyond the boundaries of the two study areas so the total area influenced by each fire is unknown. It appears that the area burned during many fire episodes may be extensive, but also patchy with extensive unburned areas intermixed. This could result from multiple ignition from one lightning storm, spotting or variable fire behavior. It could also result from several fires burning in different areas one or two years apart. The degree of resolution possible with the current data base is not sufficient to separate such closely spaced events.

A comparison of the mean dates and ranges of the major fire periods for both study areas is an indication that fire during these periods was widespread. Both study areas experienced a fire episode with a mean date of 1893 AD. The 1878 AD and 1864 AD fires in the Deer Creek study area correspond to two minor fires recorded in the Cook Creek - Quentin Creek study area that were not included in the list of major fires. The 1849 AD and 1841 AD Cook Creek - Quentin Creek study area fires differ by only one year from the 1850 AD and 1840 AD Deer Creek study area fires. The 1800 AD Cook Creek - Quentin Creek study area and 1796 AD Deer Creek study area fire episodes cover essentially the same range with slightly different mean dates. During the 1580 - 1490 AD period, fire was prevalent in both study areas but it is difficult to assess the coincidence in dates due to the lack of resolution in the data. There is a conspicuous lack of fire between 1580 and 1650 AD in both study areas. A preliminary analysis of data from much of the large initial study area shows this to hold for a larger area. Since this period is bracketed on both sides by periods of fairly high fire activity it may be reasonable to assume that some large scale climatic factor is responsible for the low fire activity during this period.

During the 1490 - 1580 AD interval fire activity is high in both study areas. It appears that several fairly widespread fires burned during this period. The exact number of fires during this period is difficult to determine due to lack of sufficient scar data and error associated with the scar data that is available. The available scar and origin date record does indicate that at least three major fire episodes occurred in each study area during this interval. These fires are the origin of many of the extensive old growth forest stands found throughout the central western Cascades. It should not be assumed that these old growth stands originated from catastrophic stand replacement fires. They could have easily originated from the cumulative impact of many smaller fires such as occurred during the 1800 - 1900 AD interval in the Cook Creek - Quentin Creek study area. More study is needed to draw conclusions about the nature of the fires during this interval.

A few very old *Pseudotsuga menziesii* were found scattered through both study areas. These origin dates span the interval from 1150 to 1220 AD. Scattered trees as well as some large even-age stands of similar age are found throughout the large reconnaissance study area. It is apparent that considerable fire activity occurred throughout a large area. Since these surviving *Pseudotsuga menziesii* are seral species and were usually found in cold, wet sites it may be postulated that some truly catastrophic fire may have spread through the central western Cascades during this period.

Although there are many similarities between the fire history of the two study areas, there are also substantial differences which demonstrate that significant heterogeneity in the fire history record exists in the central western Cascades. The natural fire rotation is substantially different between the two study areas. Over the 1910 - 1800 AD interval the NFR (average of that calculated from both area estimation methods) is 55.5 years for the Cook Creek - Quentin Creek study area and 151 years for the Deer Creek study area. This difference is even greater over the 1910 - 1600 AD time interval. The NFR for the 1910 - 1500 AD interval in the Deer Creek study area is less than the NFR for the 1910-1600 AD interval because of wide spread fires that burned parts of this study area from 1500 - 1600 AD. Over this entire period the NFR for the Cook Creek - Quentin Creek study area is 94.5 years compared to 138 years for the Deer Creek study area. This is an indication that fire burned over about 32% more area in the Cook Creek - Quentin Creek study area than the Deer Creek study area during the 1910 - 1500 AD interval.

In the Cook Creek - Quentin Creek study area the average site fire return interval for all fires is 96 years and for stand replacement and partial stand replacement fires it is 150 years. In the Deer Creek study area the comparative values are 233 years and 272 years. On this basis it appears that the occurrence of fire on a site by site basis is 2.4 times more frequent in the Cook Creek - Quentin Creek study area than the Deer Creek study area.

Both these methods of estimating of fire history leave much to be desired. They are both influenced heavily by the time interval chosen for the analysis. They are also both influenced adversely by the erasure of record by preceding fires. The fire return interval method is best applied to xeric forest ecosystems with a fire regime of low intensity fires that recur frequently. The NFR method is best applied to areas where stand replacement fires burn distinct patches over a longer time frame. Since the fire regime in this area is intermediate between these two extremes neither method applies itself well to the data.

The differences in the fire record of the two study areas

AD. It is quite possible that fire suppression activities have already altered wildlife habitat substantially compared to what existed in an unmanaged state.

Although much of the Cook Creek - Quentin Creek study area appears to be dominated by old-growth forests, the old-growth stands usually occur in small, irregular patches. In the Cook Creek - Quentin Creek study area 74% of these old-growth patches are less than 10 hectares and 51% of them are less than 3 hectares. The patches of old-growth in the Cook Creek - Quentin Creek study area that are over 20 hectares all have patch irregularity indexes greater than 2.0 indicating that their perimeters are at least 100% greater than the perimeter of a circle the same size. These old-growth stands occupy about 31% of the study area. Much of the remainder of the study area (42%) is occupied by medium mortality stands which contain a mixture of old growth and mature forests. In these "partial old-growth stands" old-growth trees may occur as an even intermixture with mature trees or as patches less than 0.2 hectares. In wildlife habitat terms most of the Cook Creek - Quentin Creek study area would probably have satisfied (prior to logging) the requirements of old-growth obligate species even though only about 31% is strictly old-growth forest. This is because of the close proximity of these stands to one another, their interconnection and their complex interspersion in a forest mosaic which contains "partial old-growth stands." Because of the high degree of interspersion and edge effect, the quality of habitat in this study area may be greater than if it was all uniform even-age old-growth forest.

The Deer Creek study area presents a different wildlife habitat picture. Here 67% of the study area consisted (prior to logging) of relatively undisturbed old-growth forest. Most of this area (41%) was contained in one large old-growth patch (797 between plant communities on both sides of the edge are important factors in the abundance and diversity of wildlife species in an area (Black and Thomas 1978, Thomas et al. 1978, Welty 1982:485). The degree of interspersion of plant communities and successional stages in a particular area significantly influences wildlife habitat diversity. Wildlife biologists have developed measures of habitat diversity as a function of edge called "diversity indexes." The diversity index is the ratio of the perimeter of a patch to the perimeter of a circle with the same area as that of the patch (Patton 1975:172, Thomas et al. 1978). This is identical to the patch irregularity index that I have used to describe patches in my two study areas. The patch irregularity indexes (or diversity indexes) for age class patches in both study areas is high which suggests a highly diverse wildlife habitat.

It is interesting to note that in the two study areas the low mortality patches left after the 1800 - 1900 AD fires also represent the distribution of old-growth stands. Although most of the trees in these patches are greater than 250 years old, some may be 180 to 250 years in age and are regarded in the following discussion as old-growth. Forests in this age range typically begin exhibiting old-growth characteristics (Franklin et al. 1981).

As a result of fire suppression activities in the last 70 years and a possible decline in aboriginal burning in the central western Cascades the amount of contrast between successional stages along edges has diminished considerably. The degree of contrast between plant communities on both sides of an edge has important implications for wildlife habitat (Thomas et al. 1978). Almost all of the edges present in the existing forest occur between mature and old-growth forests and the contrast is only moderate compared to the contrast that would have existed in 1900 central western Cascades are dominated by multi-age stands which in themselves provide a much more diverse and complex habitat than is present in any seral stage of an even-age stand. These multi-age stands may be dominated by a given age class but contain individuals or small patches of other age classes. There are certainly many examples of even-age stands representing a particular seral stage, but it is important for wildlife biologists to note that the majority of a forest may be more complex and therefore represent a more complex habitat situation.

Old growth stands are important as wildlife habitat because of the complexity and variability present as well as their structural massiveness. Wildlife biologists recognize that this structural complexity, great vertical development with considerable intra-stand variability and horizontal patchiness allow a relatively high number of unique wildlife species and individuals to live in old-growth forests (Meslow et al. 1981). This complexity and patchiness of old-growth stands has been considered the result of small scale disturbances which have influenced the stand (e.g. lightning, windthrow, insect infestation) during their development. The role of low intensity fire in creating this complexity has not been given sufficient attention. Most old growth stands in my two study areas have experienced one or more understory or partial stand replacement fires since establishment of the oldest age class. These fires may well be responsible for much of the structural complexity and variability present in these stands.

The complex age class patch mosaic described in the Cook Creek - Quentin Creek study area and to a somewhat lesser extent in the Deer Creek study area has interesting implications for wildlife habitat. The amount of edge existing between successional stages, the configuration of the edges and the contrast

Implications for Wildlife Habitat Research

The complexity of stand age class structure and the intricate patch mosaic of age classes that has been documented in this paper has important implications in terms of wildlife habitat. There has been considerable interest in wildlife habitat requirements in northwestern coniferous forests and the importance of old-growth forests in meeting the habitat requirements of certain non-game species (Maser and Thomas 1978, Meslow 1978, Wiens 1978, Edgerton and Thomas 1978, Meslow et al. 1981). Wildlife biologists have based their understanding of the type, nature and availability of wildlife habitat in northwestern coniferous forests on the stand models developed by forest ecologists. These views have not given sufficient consideration to the complex processes of stand dynamics and succession in the central western Cascades where a highly variable fire regime is present. Consequently much of the investigation of habitat requirements and availability has been limited to consideration of simplified successional stages (i.e. grass/forb - shrub/seedling - sapling/pole - young growth - mature - old growth) (Meslow 1978, Edgerton and Thomas 1978, Bull 1978, Canutt and Poppino 1978).

The use of these simplified successional stages is helpful in gaining an understanding of the various habitats present in coniferous forests. It is particularly useful in assessing the impact of even-age silvicultural practices on wildlife habitat. But a model based on these stages may be inadequate in describing the wildlife habitat of unmanaged forests operating under a natural fire regime. It is useful to understand the habitat opportunities which occur under natural conditions in order to assess the impact of silvicultural modifications of the forest.

The results of this study indicate that the forests in the distributions of stands in this area and regeneration after wildfire is needed in order to understand the age distributions of old-growth stands.

5. An understanding of the type, speed and completeness of regeneration following fire in the central western Cascades is still incomplete. This lack of knowledge is related to the above discussion but applies to all ages of forest stands. Recently there has been considerable emphasis on long time lags before complete stocking of a site occurs after a fire (Franklin and Hemstrom 1981, Hemstrom and Franklin 1982, Means 1982). In my data there is abundant evidence that rapid recolonization of many sites was common after most fires in both study areas. This is documented by the narrow age ranges present in the regeneration after many fires. Rapid recolonization by seral tree species following fire is consistent with the fact that the fires tend to be patchy and often moderate intensity, leaving an abundant seed source. After some fires (and on certain sites) slow recolonization was certainly the case but data from this study indicate that it is the exception rather than the rule. More investigation of regeneration after a variety of intensities of wildfire will be needed to understand this situation.

6. Stand development in a relatively homogeneous situation such as an even-age stand would be quite different from stand development patterns in non-homogeneous forests dominated by a complex patch mosaic of variable aged stands. In such a situation the dynamics of one individual patch will be influenced by edge effects produced by adjacent patches. In order to understand the dynamics of the forests in the central western Cascades it is important to determine the influence of this complex age class patch mosaic.

the persistence of long lived *Pseudotsuga menziesii* in the canopy. Several generations of *Tsuga heterophylla* and *Abies amabilis* come and go in the understory during the lifetime of long lived *Pseudotsuga menziesii*. Is the relatively short persistence of *Tsuga heterophylla* and *Abies amabilis* due in part to underburns? What role do these underburns play in the delayed development of a hypothetical climax forest?

3. In this study the origin dates of understory species such as *Tsuga heterophylla* and *Abies amabilis* in old-growth stands were closely associated with the date of the last low intensity fire. This has been documented by other investigators as well (Franklin and Waring 1980, Franklin and Hemstrom 1981, Means 1982). Does this imply that *Tsuga heterophylla* or *Abies amabilis* regeneration is significantly enhanced by substrate conditions and opening of growing space after a low intensity fire?

4. There is the question of the cause of the wide age range in old growth stands in the central western Cascades as documented by a number of investigators (Franklin and Waring 1980, Franklin and Hemstrom 1981, Means 1982). A number of theories have been proposed to explain this phenomenon. The most prominent theory is that one or more catastrophic fire(s) burned much of this area about 450 to 500 years ago and *Pseudotsuga menziesii* took a long period (100 to 200 years) to fully occupy these sites due to a lack of seed source and other factors. The results presented in this paper indicate that this broad age range in old-growth forests is probably due to multi-age stands which developed in the presence of a moderate frequency, variable intensity fire regime. Little evidence exists that supports the theory that one or more widespread catastrophic fires created the existing old-growth forests in my study areas. They appear to have originated after many separate small fires. Further research into the age

forest canopy has persisted despite low and moderate intensity fires. Interesting information about ecosystem structure, stability, diversity and successional trends will be obtained from models which consider the dynamics of such multi-age stands developing under a frequent disturbance regime. Such models should consider disturbances leaving a significant forest canopy.

Recently the need for consideration of disturbances of all magnitudes and frequencies has been mentioned but little emphasis has been placed on this research (Franklin 1982, Martin 1982, Oliver 1982, Thornburgh 1982). Stephen Veirs (1982) has presented an interesting study of the influence of frequent moderate and low intensity fires on stand dynamics and succession in the coast redwood forests of northern California. Stephen Arno (1982) has included the effects of frequent surface fires in an analysis of forest succession in Pseudotsuga menziesii / Physocarpus malvaceus habitat types of Montana. In the central western Cascades Joseph Means (1982) has noted evidence of low and moderate intensity fire in dry habitats and mentions that these fires effect stand development and structure. These repeated fires result in negative exponential diameter distributions and all age stands.

There are a number of areas where our understanding of the dynamics of the forests in the central western Cascades could be expanded by further studies of stand development that examine the effects of the disturbance regime documented in this paper. These include the following:

1. What is the influence of low intensity fire on the stand dynamics of understories which include many fire-sensitive species, and how does episodic understory mortality effect overstory stand dynamics?

2. Climax forests are rarely found in these ecosystems due to

aquatic ecosystems is largely defined by the effects discussed above on stream flow, stream temperature and sediment production. It appears that in a third or fourth order drainage basin, fire may be viewed as more of a chronic disturbance mechanism than a catastrophic one. This factor would have a strong influence on the stability of these aquatic ecosystems.

Implications for Forest Succession and Stand Dynamics Research

The development of hypotheses about the processes of succession and stand development in the northwest has largely been limited to consideration of ecosystem changes occurring after catastrophic disturbance where the existing stand is eliminated and the site reduced to a bare ground state (Dyrness 1965, 1973, Franklin and Dyrness 1973, Franklin and Hemstrom 1981, Hemstrom and Dale 1982, Zamora 1982, Henderson 1982). The common tendency has been to develop models and explore the processes involved with successional changes from a bare ground state through seral stages to maturity and eventually senescence of a forest stand. In these studies the possible influence of partial stand replacement fires and underburns on stand dynamics is not considered.

The importance of both infrequent stand replacement fire and relatively frequent medium to low intensity fire in the forest ecosystems of the central western Cascades has been well documented in this study. It is important to understand the development of stands originating after stand replacement fires. But an understanding of the processes of stand dynamics in the central western Cascades will be incomplete without considering the effects of chronic low and intermediate intensity burns.

Some sites are present in both study areas in which stand replacement fires have been absent for at least 800 years and a fires. These higher intensity fires can alter soil water balances in favor of hillslope instability and cause a decline in rooting strength resulting in additional instability. Since the effects of fire on erosion processes is dependent on the intensity and spatial extent of the fire it is difficult to predict the erosional consequences of an individual fire in a ecosystem with a highly variable fire regime.

Sediment production and transport on a watershed level will also be substantially different under the fire regime documented in this study compared to the fire regime of large scale, infrequent and catastrophic fire which has been assumed for the central western Cascades. Based on this assumed fire regime Swanson (1981) hypothesized peaks of accelerated sediment yield of five times the baseflow rate induced by catastrophic fires occurring on a 200 year return interval in western Cascade watersheds. The results presented in this paper indicate that although some fires may be widespread, they are patchy and of variable intensity. Consequently an individual fire will only burn at stand replacement intensity through small portions of a watershed. Due to this factor, as well as the relatively frequent occurrence of fire on a watershed basis, peaks of accelerated sediment production will be dampened and smoothed in a similar fashion as increased stream flows. The transport of sediment may be influenced by the patchy character of many fires. Often areas burned at high intensity are interspersed among unburned or lightly burned areas. Unburned areas are also often adjacent to streams. Interception and storage of sediment produced in more severely disturbed areas by these less disturbed areas may have a significant impact on the sediment production from the watershed as a whole.

The effect of the fire regime documented in this study on frequent intervals. Since the mean fire occurrence interval is about 15 years for the two study areas (during the 1800 - 1900 AD period) often the effect of one fire on increased stream flows in a watershed would still be in effect when another fire occurred. Therefore, long intervals could elapse before stream flow returned to undisturbed conditions. In this process the peaks might be averaged out to some extent in these watersheds. Long term stream temperatures may not be elevated significantly by forest fires because the frequent occurrence of unburned or lightly burned forest buffer zones maintains shade around major streams.

The effect of fire on erosion processes can be complex in the central western Cascades (Swanson 1981). Fires can affect surface erosion processes; shallow, rapid soil mass movements; and slow, deep-seated soil mass movements. The effect of fire on erosion processes is directly related to fire intensity. High intensity fires have usually been assumed, but the presence of low to intermediate intensity fires in the central western Cascades may necessitate modifications to initial hypotheses about the effect of fire on erosion.

Very low intensity understory burns may not cause a large increase in surface erosion since the organic soil layers may not be completely consumed. Also since little loss of root strength occurs and the water balance of the site may not be significantly altered, the potential for shallow soil mass movements will not be markedly increased by underburns.

In more intense fires the loss of organic matter can lead to accelerated surface erosion due to dry ravel, surface creep, rill and sheetwash erosion, and needle-ice formation and melt (Swanson 1981). An increase in shallow, rapid soil mass movements will occur only after stand replacement or partial stand replacement

Implications for Geomorphological Research

The results of this study which indicate a highly variable fire regime lead to different hypotheses about the effect of fire on hydrology, erosion and sediment transport than one would hypothesize based on the previous assumptions of large scale, infrequent, stand replacement fires. An understanding of the effect of the natural fire regime of an area on geomorphological processes is helpful in understanding the interaction of these processes with other ecosystem components in unmanaged forests. This understanding is also useful in assessing the impact of management activities on accelerated erosion and sediment production in that it helps establish a baseline. In discussing the implications of this research for hypotheses about the effect of fire on hydrology, erosion and sediment transport I consider the effects of fire in terms of watersheds of about 20 square km. In the central western Cascades this usually implies a drainage basin containing a third or fourth order stream (based on nomenclature of Strahler (1952)).

The hydrologic results of large scale stand replacement fires are generally a dramatic increase in stream flows and stream temperatures for several years (Helvey 1972, Helvey et al. 1976, Wright 1981). When a watershed in the central western Cascades is burned in this manner at 200 - 400 year return intervals dramatic peaks in runoff above the baseflow would be anticipated. Also peaks in stream temperatures would be observed due to lack of shade along stream corridors. But results of this paper suggest that such dramatic increases in stream flow and temperature in third or fourth order watersheds in the central western Cascades would be rare. More frequent but smaller peaks would be observed due to small patches being burned at more regime.

The fire regime in the central western Cascades is transitional between northwestern California and western Washington. Thornburgh (1982) describes the mixed evergreen forests of northwestern California as a complex mosaic of early and late successional communities resulting from a long history of fire. Many of these relatively undisturbed forests have a history of frequent light ground fires. The result is two or three storied stands with each story being even aged.

A study of the developmental history of dry coniferous forests in the central western Cascades shows some similarity to the results presented in this paper (Means 1981). Means estimated a mean fire interval of 103 years for all dry site plots and a mean fire interval of 144 years for all *Tsuga heterophylla* climax plots. His histogram of fire dates (which is a composite from many sites scattered over a large area) shows considerable similarity to the histogram presented in this paper for the Cook Creek - Quentin Creek study area. It is particularly interesting to note the abundance of fires (dated by fire scars) in the 1900 - 1800 AD interval in his histogram.

similar decrease in fire incidence occurred in sequoia-mixed conifer forests in the last half of the 1800's. Regular, intentional, aboriginal burning of these forests is historically documented. Their results suggest that aboriginal people were a significant ignition source and that the dramatic decrease of aboriginal populations in the last half of the 1800's may be responsible for a decline in fire frequency. A similar decline in aboriginal populations occurred in Oregon (Burke 1979) and this may be responsible for the dramatic decrease in fire frequency found in the two study areas after 1850 AD. There is no record of a major fire in either study area after 1910 AD. Several very small man caused and lightning caused fires occurred in both study areas since 1910 AD (Burke 1979) but did not spread presumably due to suppression activities. It appears that these efforts have successfully reduced small and medium scale fires such as occurred during the 1800 - 1900 AD period. But the length of record is too short to tell if all major wildfires have been successfully eliminated.

Comparison of Fire History in this Study with Other Areas in the Pacific Northwest.

The fire history of Mount Rainier National Park has been documented by Hemstrom and Franklin (1982). They describe a fire regime of infrequent stand replacement fires as characteristic of that area. The fires they describe also burned extensive areas at one time. A natural fire rotation of 465 years is estimated for the 1850 - 1200 AD time span. While their study has been criticized for details of dendrochronologic techniques (Swetnam et al. 1983, Dunwiddie 1983) it has been assumed that other montane forests in the Pacific Northwest follow a similar fire

In both study areas there is tremendous variability in the fire record from site to site. Some sites appear to burn every 15 to 30 years while others appear to be fire free for 400 to 500 years. This variability has not been explained by a simple analysis of aspect and elevation. A more complex analysis of site characteristics combining factors such as slope position, slope, aspect, and elevation may reveal relationships between fire history and site characteristics that are not apparent here. Some of the variability noted in this study may also be due to the randomness of fire occurrence.

Man's Influence on the Fire Record

The impact of aboriginal burning on the two study areas is uncertain. After a through review of existing literature, Burke (1979) concluded that aboriginal use of fire in the central western Cascades was limited to campfires. Forest fires may have been caused by aboriginal campfires that were left burning and ignited surrounding fuels. It is impossible to determine if this was the cause of any of the fires recorded in the study areas.

It has been postulated that forest fire incidence increased during the Euro-American settlement period due to fires started by trappers, miners, sheepherders, and explorers (Burke 1979). This period extends from 1850 AD to 1910 AD when fire suppression was initiated. In the two study areas the opposite was the case. During the 1850 - 1910 AD interval the natural fire rotation for the Cook Creek - Quentin Creek study area was 151 years compared to 31.4 years for the 1800 - 1850 pre-settlement period. Likewise the NFR for the Deer Creek study area was 265 years for the 1850 - 1910 AD period but only 95.7 years for the 1800 - 1850 pre-settlement period. Kilgore and Taylor (1979) reported that a sample size in several aspect categories made it impossible to test for significant differences in fire history with respect to aspect. However, no major systematic differences were apparent. The aspect distributions of both study areas are fairly heavily biased toward south facing orientations and a relatively small number of sample sites were located on north facing aspects. A better test of this relationship would be possible in a larger study area with an equal number of sample sites from north and south facing aspects. Another major factor in the failure to see major differences in the fire return intervals between north and south aspects is that fire behavior is influenced by many large scale landscape factors. Actual site characteristics may be less important in determining fire behavior than they are for determination of plant habitat. The influence from the surrounding area can swamp out the influence of aspect at an individual site.

A relationship may exist between elevation and fire history in the central western Cascades. The longest site fire return intervals for all fires occurred in the 3500 - 3999 feet elevation category in both study areas. Fires appear to be more frequent both above and below this elevation range. An analysis of the fire record for a larger area would be necessary to verify this tendency.

Visual analysis of the fire intensity patch map for the 1893 Cook Creek - Quentin Creek study area fire and the patch maps for the 1800 -1900 AD period for both study areas reveals that very little mortality was caused by the fires of this period in bottom land locations adjacent to major streams. Extensive corridors of old-growth trees are found along major stream systems. These factors indicate that the site fire return interval for bottom land sites may be long and that low to moderate intensity fires may be most common in these sites.

bute to fire spread. Anywhere in the area the movement of a fire one way or the other will carry it across a ridge or stream, change of aspect , or through a dry or wet pocket. All of these will alter the behavior of the fire.

In this irregular landscape fire encounters a large variety of fuel conditions relating to ease of ignition, rate of combustion and rate of spread. Wind patterns are highly irregular in complex topography. One would expect that fires would be patchy, change intensity frequently and generally have a low areal extent in this type of topography. If one assumes ignition possibilities are random during periods of favorable climate such as the 1800 - 1900 period there is a chance of a fire almost any year at some point in the study area. But it may not spread far. Some years there will be much greater probability for spread of fires and these will be the major fire years. This can be due to greater than normal ignition frequency or a drier climate than normal combined with an adequate ignition frequency.

The Cook Creek - Quentin Creek study area is characterized by a wide variety of environments. The environment is much more diverse than the rather uniformly dry, east-side ponderosa pine forests. It is also much more diverse than the more uniformly wet coastal forests of the Pacific Northwest. In the ponderosa pine forests, fires are of more uniform intensity and spread more extensively due to more uniform dryness. In the moist coastal forests there is a tendency for fewer more intense fires of a stand replacement type (Agee 1981, Martin 1982). So the hybrid situation in the Cook Creek - Quentin Creek study area is a combination of a varied topography and a moderate climate between the dry and wet extremes.

It was expected that some major differences in fire history would be associated with aspect. In both study areas the low likely lead to less frequent fire. This relationship is challenged though by the substantially higher fire frequencies observed in the upper elevation range of the Deer Creek study area compared to lower elevations in the same study area. These upper elevations would presumably be colder and wetter than the lower elevations. It is apparent that other factors besides major climate and environmental gradients caused by elevation are important in determining fire history in the central western Cascades.

In the Deer Creek study area the topography is relatively smooth and gentle compared to many areas in the central western Cascades. The spread of fairly large stand replacement fires would be possible in such terrain. The fairly wet and cold climate at this elevation may create a situation where fuels are rarely in condition to carry a fire. The combination of these two factors would result in the occurrence of infrequent but fairly extensive stand replacement fires as seen in the lower elevations of the Deer Creek study area. In the upper elevation country lightning occurrence may be higher. This country may also be more exposed to desiccating east winds which could dry out a fuel bed in a short period of time. In most cases these fires do not spread far due to numerous wet areas in the upper elevation Deer Creek study area. These factors could lead to the regime of more frequent but less intense fires seen in the upper elevation Deer Creek study area.

Because of the complex topography of the Cook - Quentin Creek study area there are many potential fire boundaries such as streams and wet areas, ridge tops, and changes in aspect and habitat type. It is finely dissected, convoluted topography. There are few long, unbroken slopes; few expanses of similar aspect, and little flat or rolling topography which would contrieven-age stands. More commonly these fires thin the pre-existing stand to some extent. The stands generated by these fires are generally multi-aged with an average of over two age classes present at each site. Regeneration from more than four fires occurs at 15.8% of the sites. Within the limitations of the record it appears that fires occur with a degree of temporal regularity. Between 1703 and 1893 major fires occurred every 18.5 years on the average with a range of 6 to 55 years.

In the Deer Creek study area fire is less frequent on the whole. Small fires of medium to low intensity occur periodically in upper elevation areas. There is also evidence that larger stand replacement fires occur infrequently. Most of the Deer Creek study area was burned at least once during the 1480 - 1580 AD interval and extensive fairly even-age stands resulting from the last fire of this period fill most of the central part of the study area. It is interesting that very little record of disturbance occurring after 1580 AD was found in this extensive stand even though fire was fairly common on the periphery. The exact nature of the 1480 - 1580 AD fires in the Deer Creek study area is difficult to determine due to a lack of fire scar data for this interval. It may be that only two or three catastrophic fires occurred with later ones reburning sections burned in the past or it may be that a conglomeration of five or more fires (similar to the 1800 - 1900 AD interval in the Cook Creek - Quentin Creek study area) created the existing old-growth stands.

Although the two study areas are in close geographical proximity there are some significant environmental, climatic and physiographic differences between them. These differences may explain some of the differences observed in the fire record for the two study areas. A colder, wetter climate created by the higher average elevation of the Deer Creek study area would most

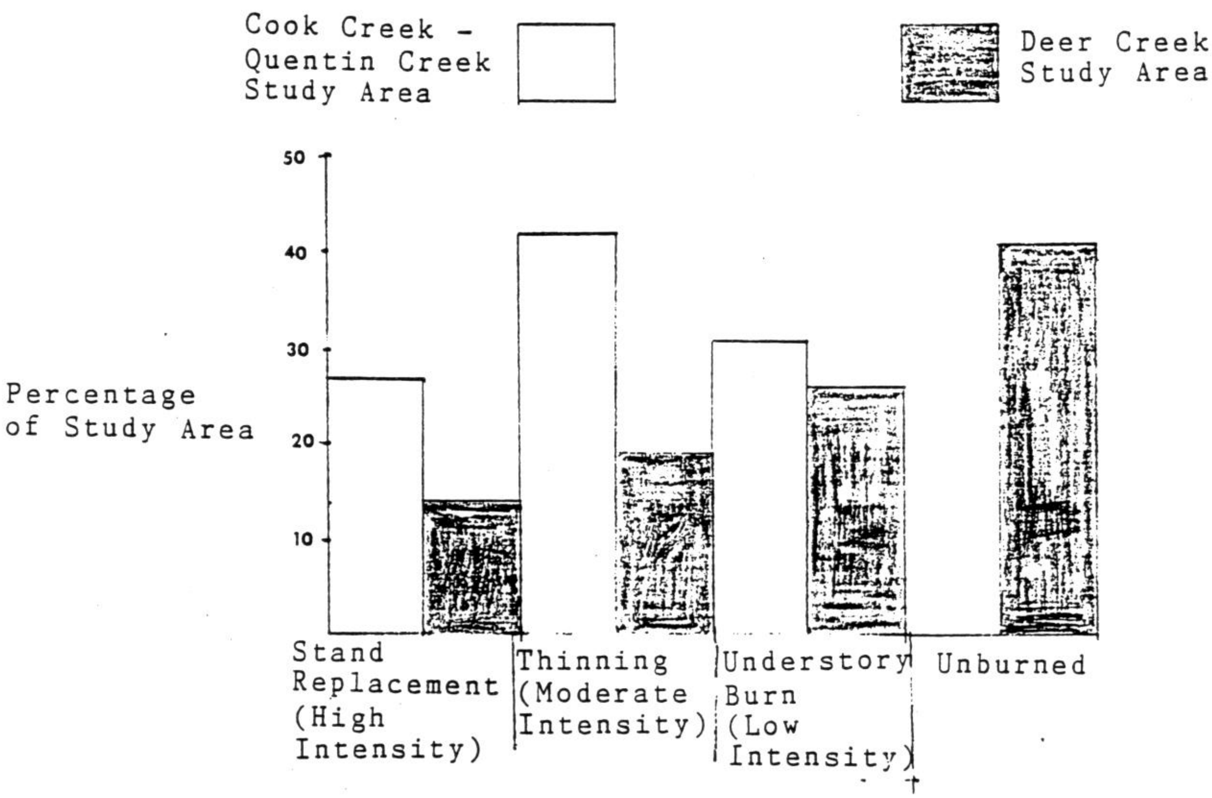


Figure 32. Comparison of fire intensity distribution for patches created during 1800-1900 AD interval in both study areas.

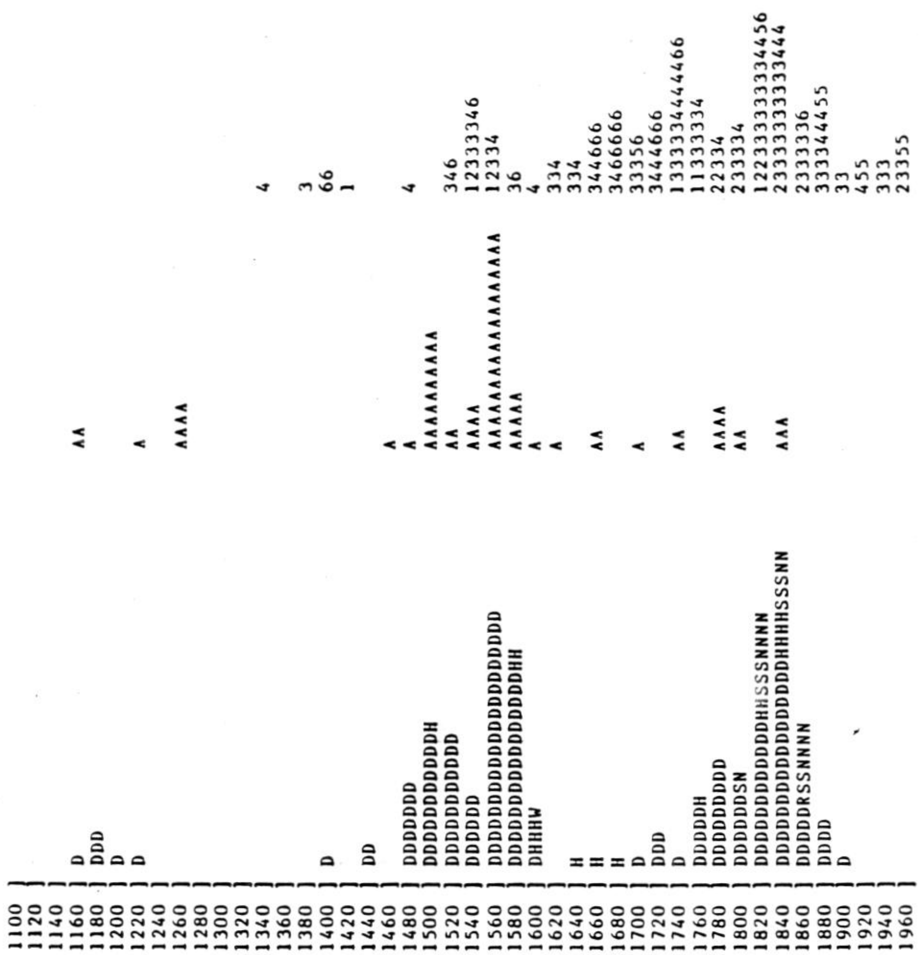


Figure 31. Histogram of all origin and scar dates (20 year intervals) - Deer Creek study area.

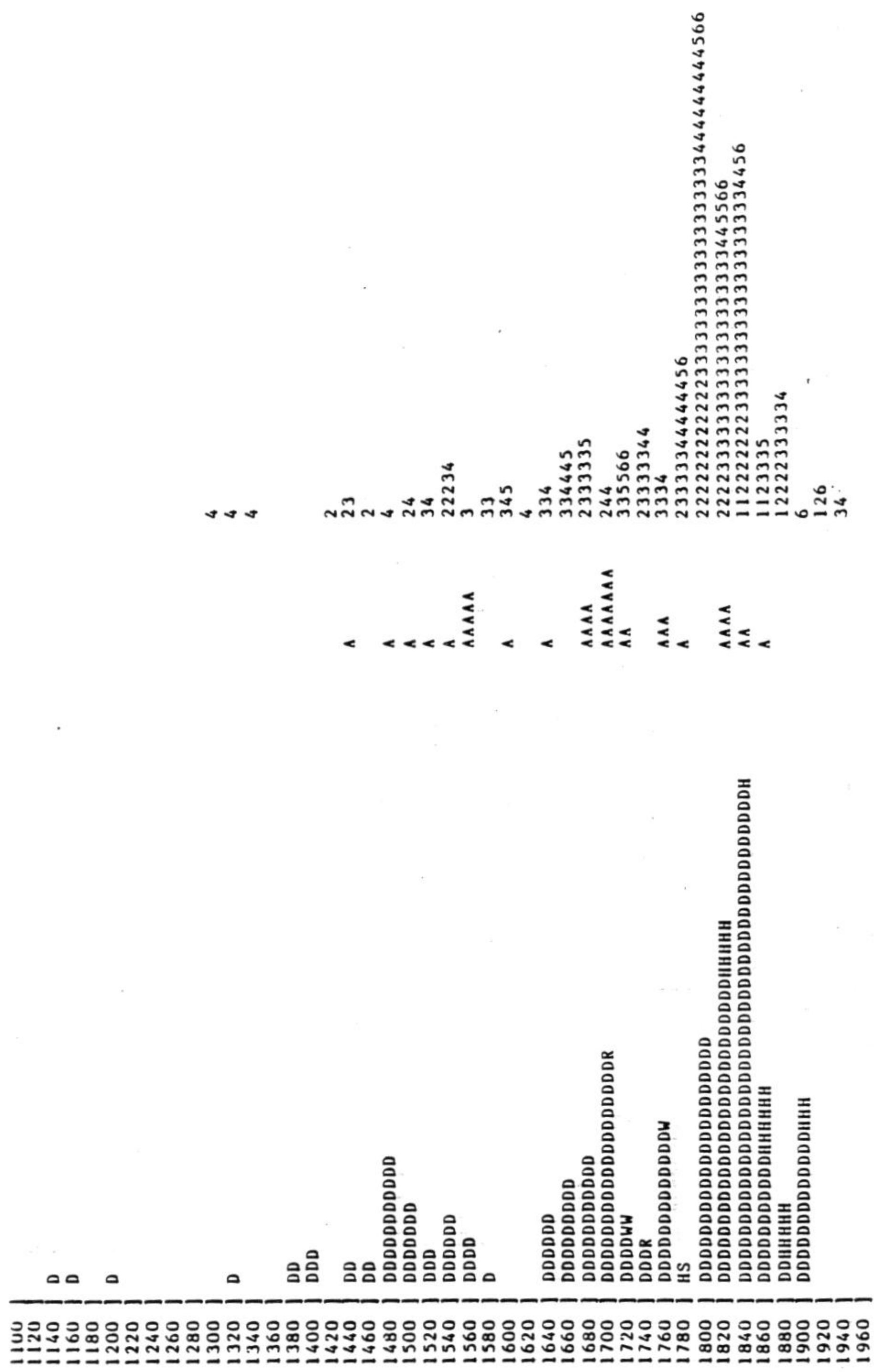


Figure 30. Histogram of all origin and scar dates (20 year intervals) - Cook Creek - Quentin Creek study area.

may best be illustrated by Figures 30 and 31. The record of origin dates and scar dates for both areas shows a general decrease with earlier dates. The origin date record in the Deer Creek study area is distinctly bi-modal, whereas the record in the Cook Creek - Quentin Creek study area is tri-modal. These distributions do not correspond well to either the negative exponential age class distribution model (Van Wagner 1978) or to the Weibull curve age class distribution model (Rowe et al. 1975).

A comparison was made of the areas of the mortality patches resulting from the 1800 - 1900 AD fires in both study areas (Figure 32). This mortality distribution is decidedly skewed toward the low mortality side for the Deer Creek study area, whereas medium mortality patches cover more area in the Cook Creek - Quentin Creek study area. In the Cook Creek - Quentin Creek study area, the area covered by high and low mortality patches is about equal. It appears that the fire intensity distribution may differ considerably from one fire to another. Since there is some evidence of more extensive and higher intensity fires in both study areas preceding 1800 AD, it should not be assumed that the fire intensity distribution remains constant through time.

The patch size distributions of high mortality patches created during the 1800 - 1900 AD period indicate that small patches (under three hectares) of stand replacement level mortality are predominate in both study areas. This analysis only applies to this time period and this trend may or may not hold for earlier periods.

The fire record in the Cook Creek - Quentin Creek study area appears to be one of fairly frequent medium to low intensity fires that occasionally crown out and create small patches of hectares) that has not been burned since 1740 AD. But even this extensive area is not uniform. Some sections are multi-age stands with trees ranging from 850 to 250 years in age while other sections are even-age old-growth stands of varying ages. The amount of edge and interspersion of habitats in the Deer Creek study area is considerably less than in the Cook Creek - Quentin Creek study area.

These two study areas represent examples of the type and variety of wildlife habitat existing in the central western Cascades. A better understanding of patch size requirements of certain wildlife species and the effect of interspersion and edges could be obtained from a more comprehensive investigation of these factors coupled with wildlife species censuses.

CONCLUSIONS

This study provided a test of widespread beliefs about the role of fire in the central western Cascades. My initial hypothesis that fire was an infrequent but catastrophic disturbance mechanism in these ecosystems appears to be too simplistic in light of the results of this study. These results indicate that the fire regime is highly variable. Large scale stand replacement fires occur in some situations but fairly frequent low and medium intensity fires are more common.

There are differences and similarities in the fire regimes of the two study areas. Fire is less frequent in the Deer Creek study area than in the Cook Creek - Quentin Creek study area. There is an indication that some fires in the Deer Creek study area are more catastrophic. The average incidence of fire in both study areas is similar, averaging 15 years between fires during the 1893 - 1796 AD interval and 30 years between fires during the 1893 - 1515 AD interval. There are many coincident mean fire dates between the two study areas. This is an indication that while fires were patchy they were widespread. Another indication is that almost all of the fires burned beyond the boundaries of both study areas. The differences between the fire regimes of two study areas is probably a function of climatic and physiographic factors.

The natural fire rotation for the Cook Creek - Quentin Creek study area is 94.5 years over the 1910 - 1500 AD interval. This is 32 percent less than the NFR for the Deer Creek study area (138 years). The average site fire return interval is also less for the Cook Creek - Quentin Creek study area (96 years) than for the Deer Creek study area (223 years). If these two study areas are representative of the central western Cascades, one might postulate that the natural fire rotation for the area as a whole is about 115 years. Likewise, the average site fire frequency would be about 160 years. However, a cursory analysis of the data from the initial reconnaissance level study indicates that the Cook Creek - Quentin Creek study area is more representative of the region as a whole than the Deer Creek study area. These estimates are very conservative for two other reasons. Early fires are poorly recorded due to mortality of trees caused by later fires. Low intensity burns are also poorly recorded. All these factors have biased these estimates in favor of a longer natural fire rotation and average site fire return interval.

Another factor that characterizes this area is that the incidence of fire is highly variable from site to site. Some sites burned every 15 - 20 years on the average while other sites burned once every 400 - 500 years.

There has been considerable speculation about the origin of old-growth forests found in the central western Cascades. The results of this study indicate that they originated from a sequence of many widespread but variable intensity fires. Although there may have been a somewhat higher fire incidence during the 1450 - 1580 AD period there is no evidence in these study areas that one or more catastrophic fires burned the entire region. It appears that the fire regime has been fairly uniform, except for some minor fluctuations, through the last 600 years.

The fire intensity distributions for both study areas reveal that most of the area that burned during the 1800 - 1900 AD period was burned at a low to moderate level of intensity. High intensity patches tended to be small and irregular. Low intensity patches were also irregular and correspond to the distribution of old-growth stands. These are frequently found along stream corridors.

Man's influence on the fire history of the study areas is difficult to determine. It does appear that fire suppression has been reasonably effective. No major fires have occurred in either study area since 1893 AD, but several fires have burned in the surrounding area during the 1900's. There is an indication that aboriginal people were responsible for some fire ignition, but no solid evidence was found.

The results of this study have interesting implications for other areas of ecological research in the central western Cascades. Streamflow rates and sediment production rates from medium size watersheds would be affected differently by the fire regime discussed in this study compared to the fire regime that has been usually assumed. The results of this study challenge some of the current concepts of succession and stand dynamics that have been developed for the central western Cascades. These results indicate that a complex mosaic of wildlife habitat types has been created by the patchy and variable intensity fires which burned in this area prior to fire suppression. Considerable habitat diversity was created by the edge effects of interspersed irregular patches of various age classes.

The results from these two study areas give an indication of the variability and complexity found in the fire record of this region. A more comprehensive study is needed covering a larger area to verify whether these results are truly representative of the region as a whole.

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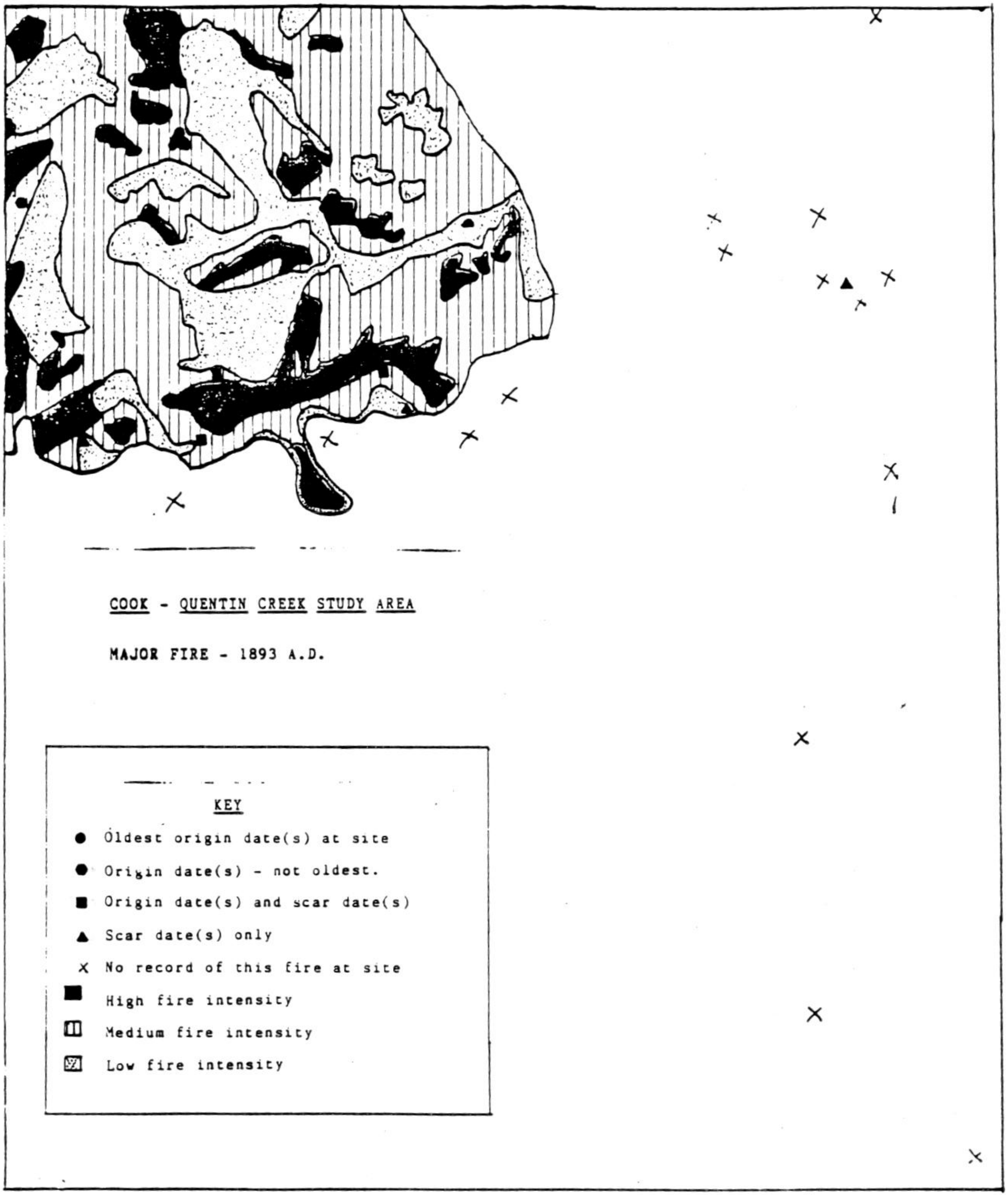
APPENDIX I

Specifications of Aerial Photography

Year	Flight Name	Scale	Film Type
1979	12-616180	1:15,840	color
1974	F70-41047	1:70,000	black & white
1967	ESF	1:15,840	black & white
1959	EGI	1:12,800	black & white
1946	DEK	1:20,000	black & white

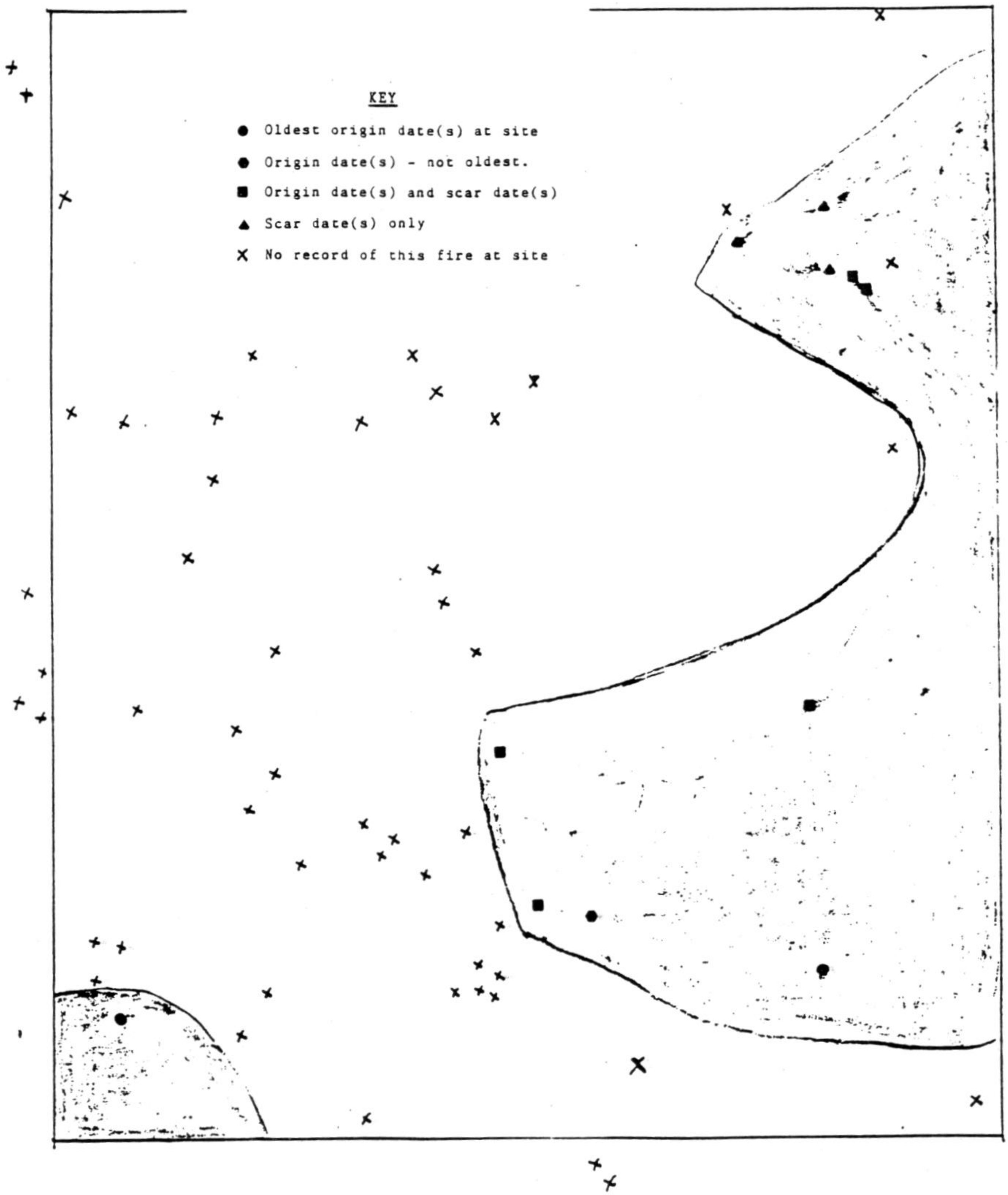
APPENDIX II


COOK - QUENTIN CREEK STUDY AREA
MAJOR FIRE - 1893 A.D.
KEY
Oldest origin date(s) at site
Origin date(s) - not oldest.
Origin date(s) and scar date(s)
Scar date(s) only
No record of this fire at site
High fire intensity
Medium fire intensity
Low fire intensity

APPENDIX II (CONTINUED)

COOK CREEK - QUENTIN CREEK STUDY AREA

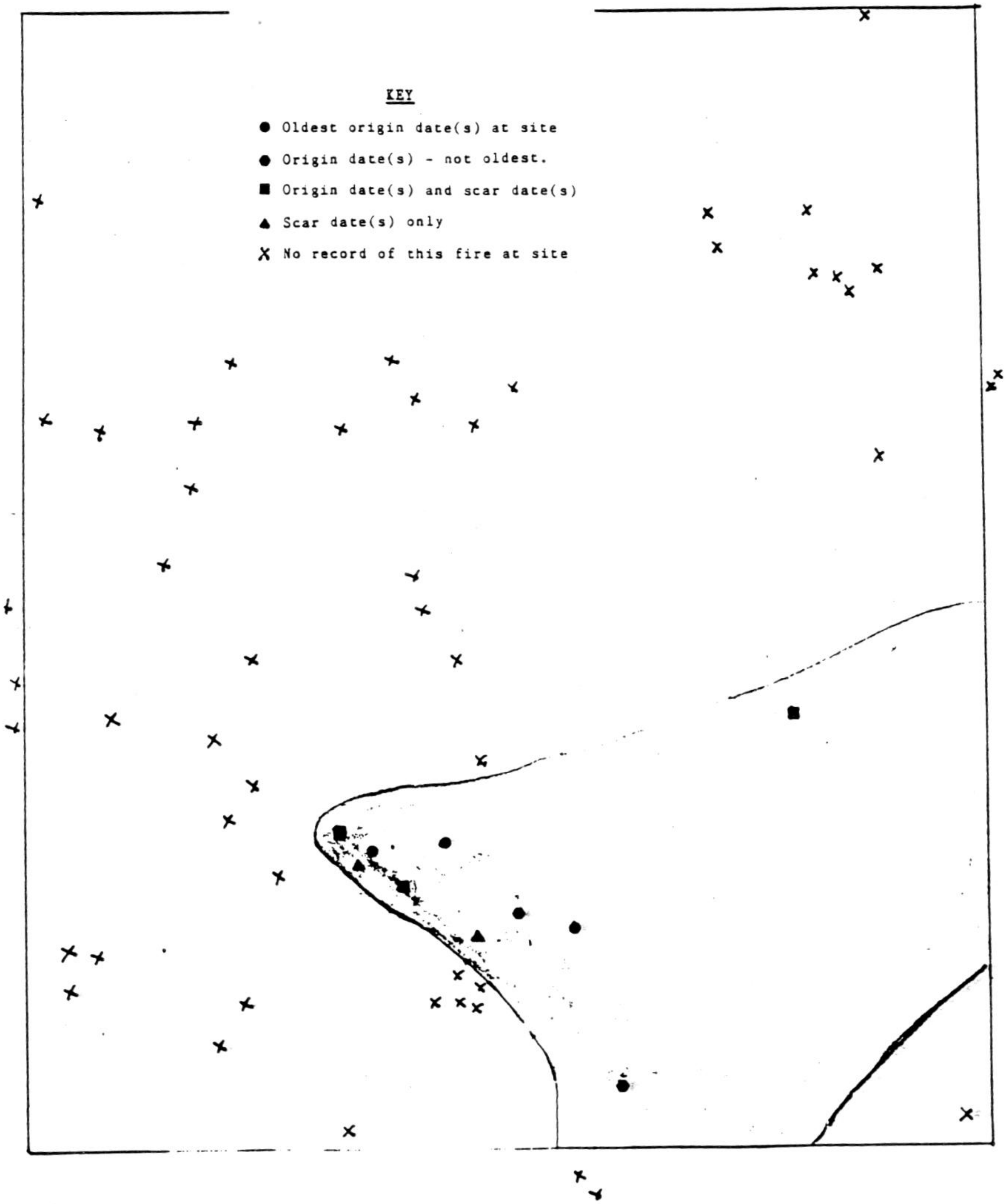
MAJOR FIRE EPISODE - 1855 A.D. (1857-1852)



APPENDIX II (CONTINUED)

COOK CREEK - QUENTIN CREEK STUDY AREA

MAJOR FIRE EPISODE - 1849 A.D. (1851-1847)



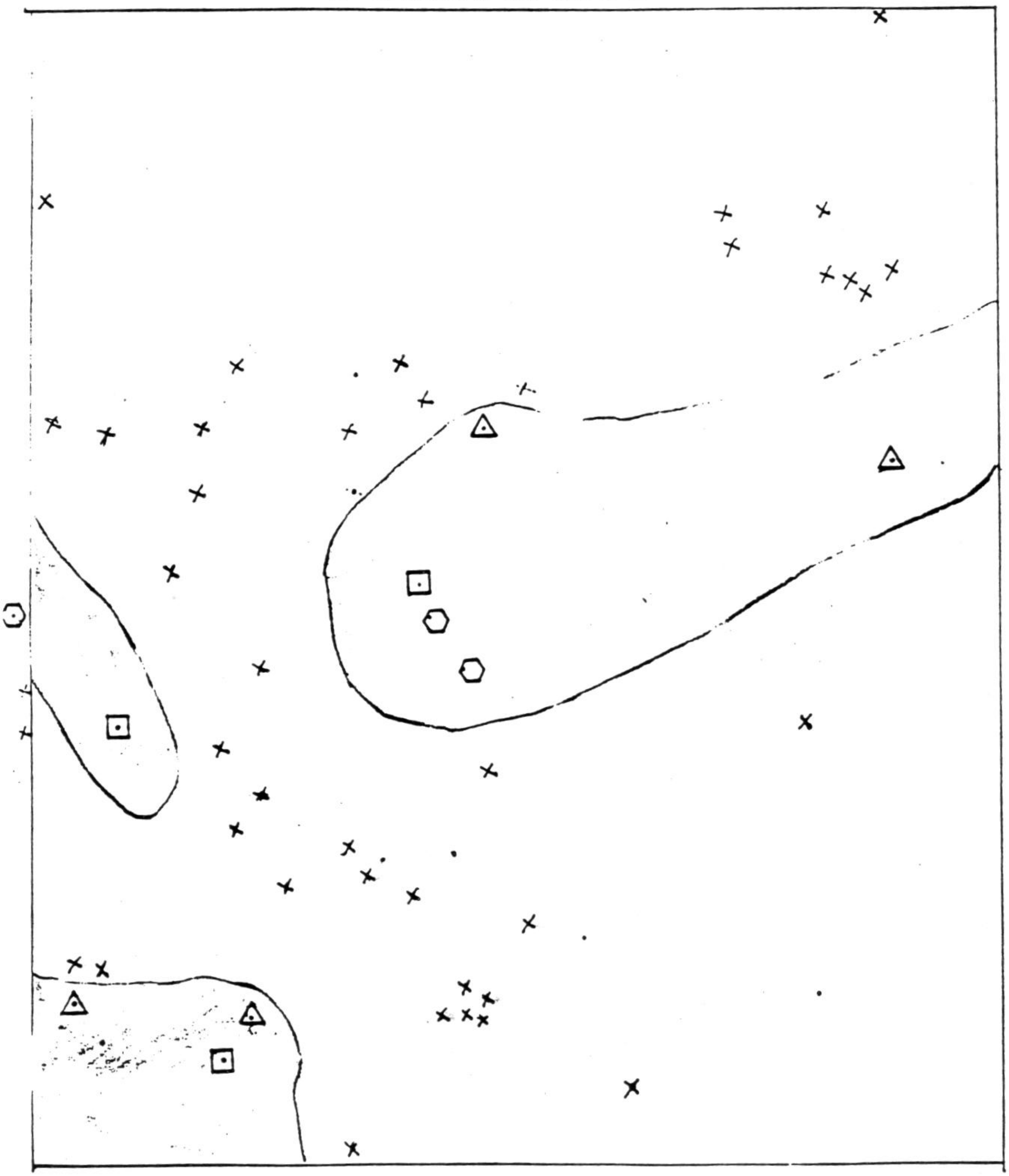
APPENDIX II (CONTINUED)

COOK CREEK - QUENTIN CREEK STUDY AREA

MAJOR FIRE EPISODE - 1841 A.D. (1845-1839)

KEY

○— Oldest origin date(s) at site
⬡— Origin date(s) - not oldest.
□— Origin date(s) and scar date(s)
△— Scar date(s) only
×— No record of this fire at site



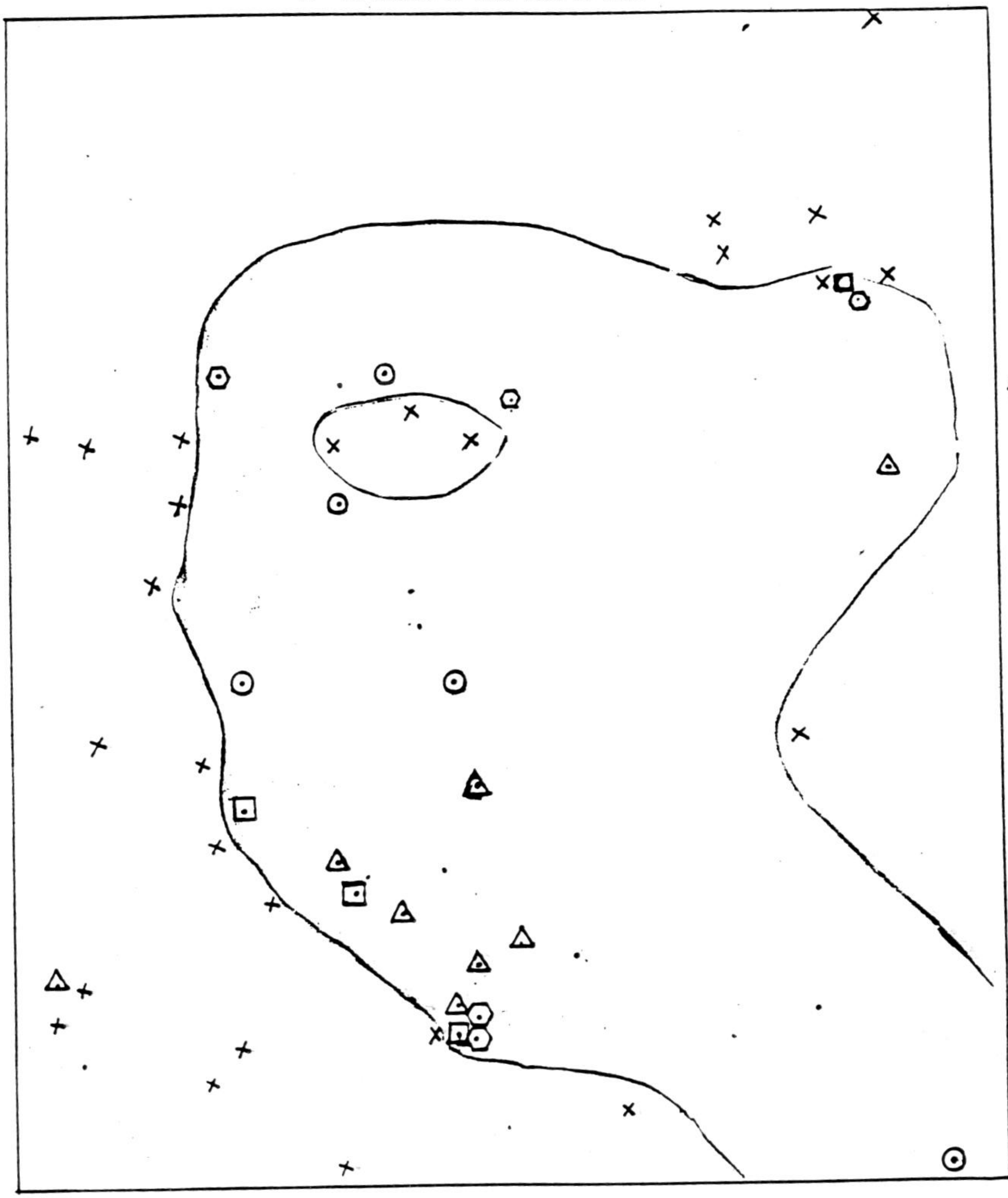
APPENDIX II (CONTINUED)

COOK CREEK - QUENTIN CREEK STUDY AREA

MAJOR FIRE EPISODE - 1834 A.D. (1837-1831)

KEY

○— Oldest origin date(s) at site
⬡— Origin date(s) - not oldest.
□— Origin date(s) and scar date(s)
△— Scar date(s) only
×— No record of this fire at site



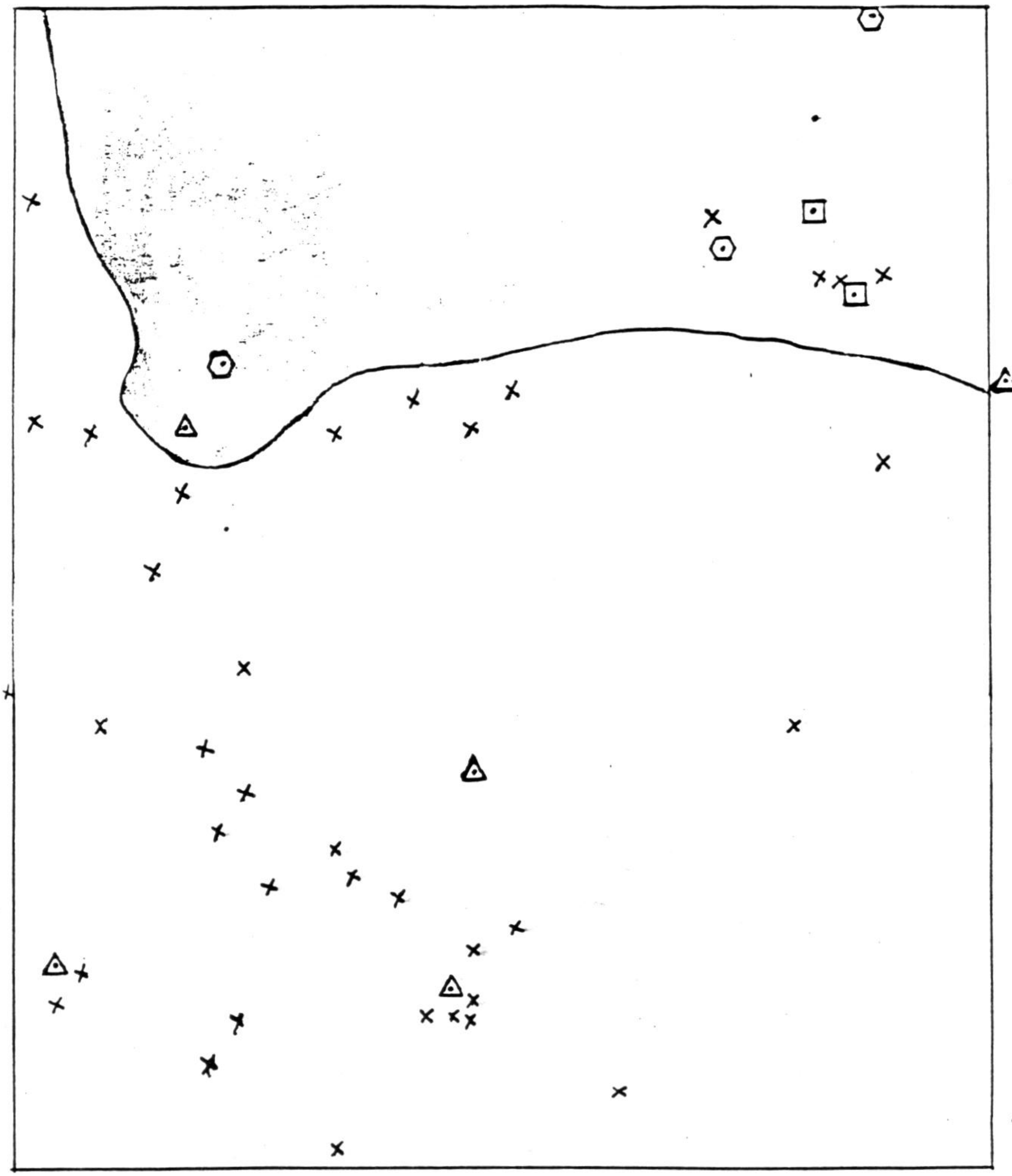
APPENDIX II (CONTINUED)

COOK CREEK - QUENTIN CREEK STUDY AREA

MAJOR FIRE EPISODE - 1813 A.D. (1816-1812)

KEY

○— Oldest origin date(s) at site
⬡— Origin date(s) - not oldest.
□— Origin date(s) and scar date(s)
△— Scar date(s) only
X— No record of this fire at site



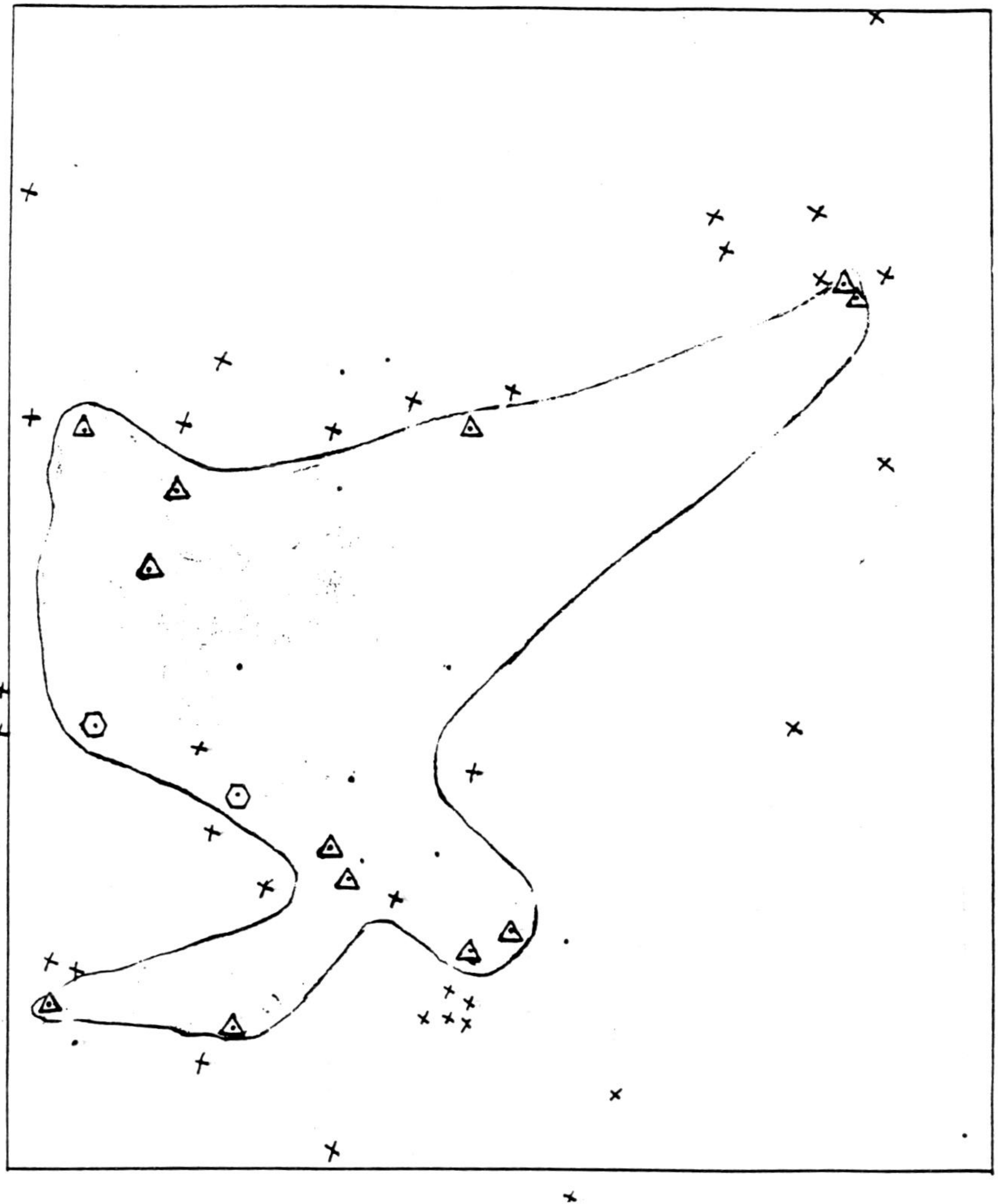
APPENDIX II (CONTINUED)

COOK CREEK - QUENTIN CREEK STUDY AREA

MAJOR FIRE EPISODE - 1807 A.D. (1810-1805)

KEY

○— Oldest origin date(s) at site
⬡— Origin date(s) - not oldest.
□— Origin date(s) and scar date(s)
△— Scar date(s) only
×— No record of this fire at site



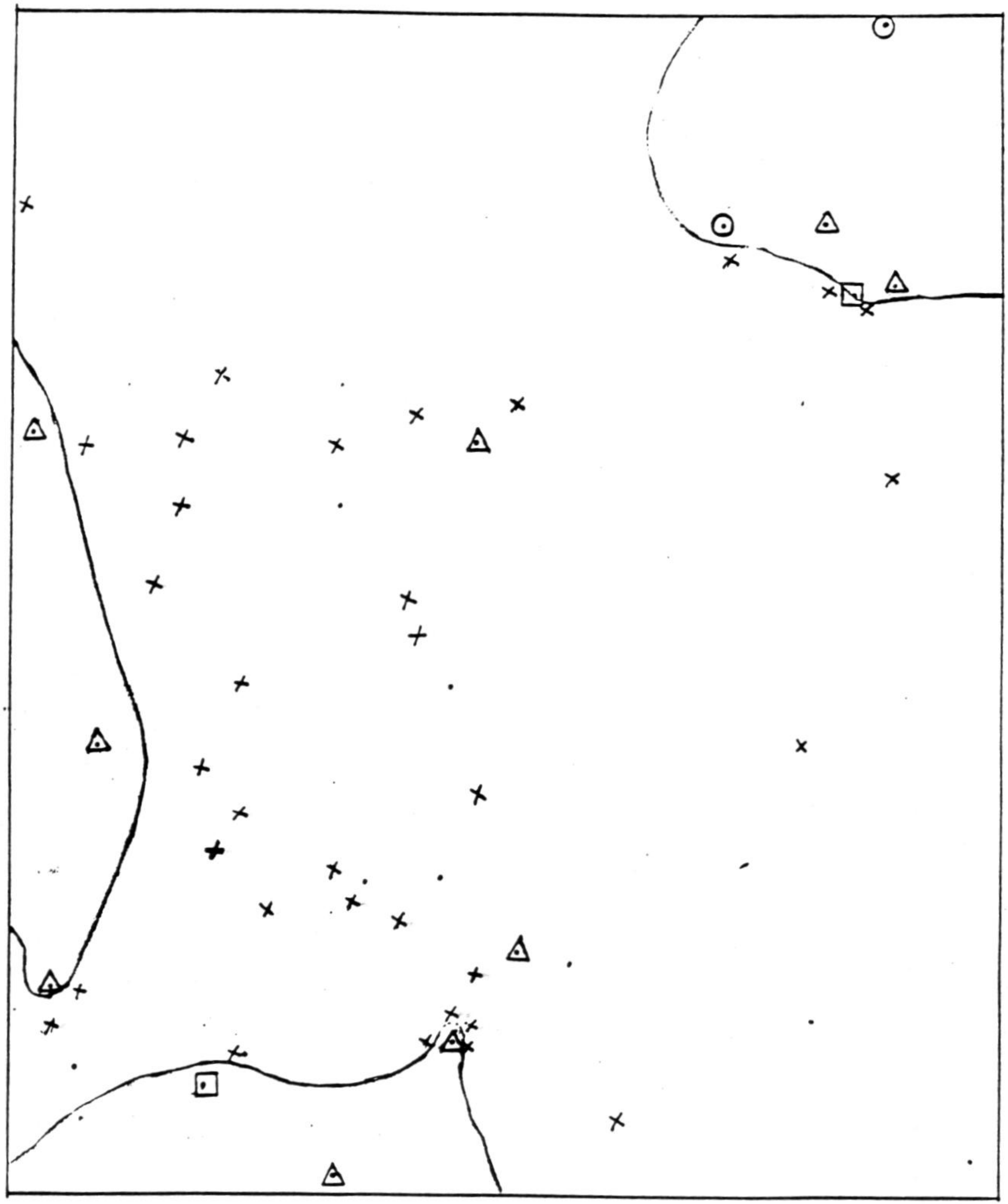
APPENDIX II (CONTINUED)

COOK CREEK - QUENTIN CREEK STUDY AREA

MAJOR FIRE EPISODE - 1800 A.D. (1804-1798)

KEY

○— Oldest origin date(s) at site
○— Origin date(s) - not oldest.
□— Origin date(s) and scar date(s)
△— Scar date(s) only
×— No record of this fire at site



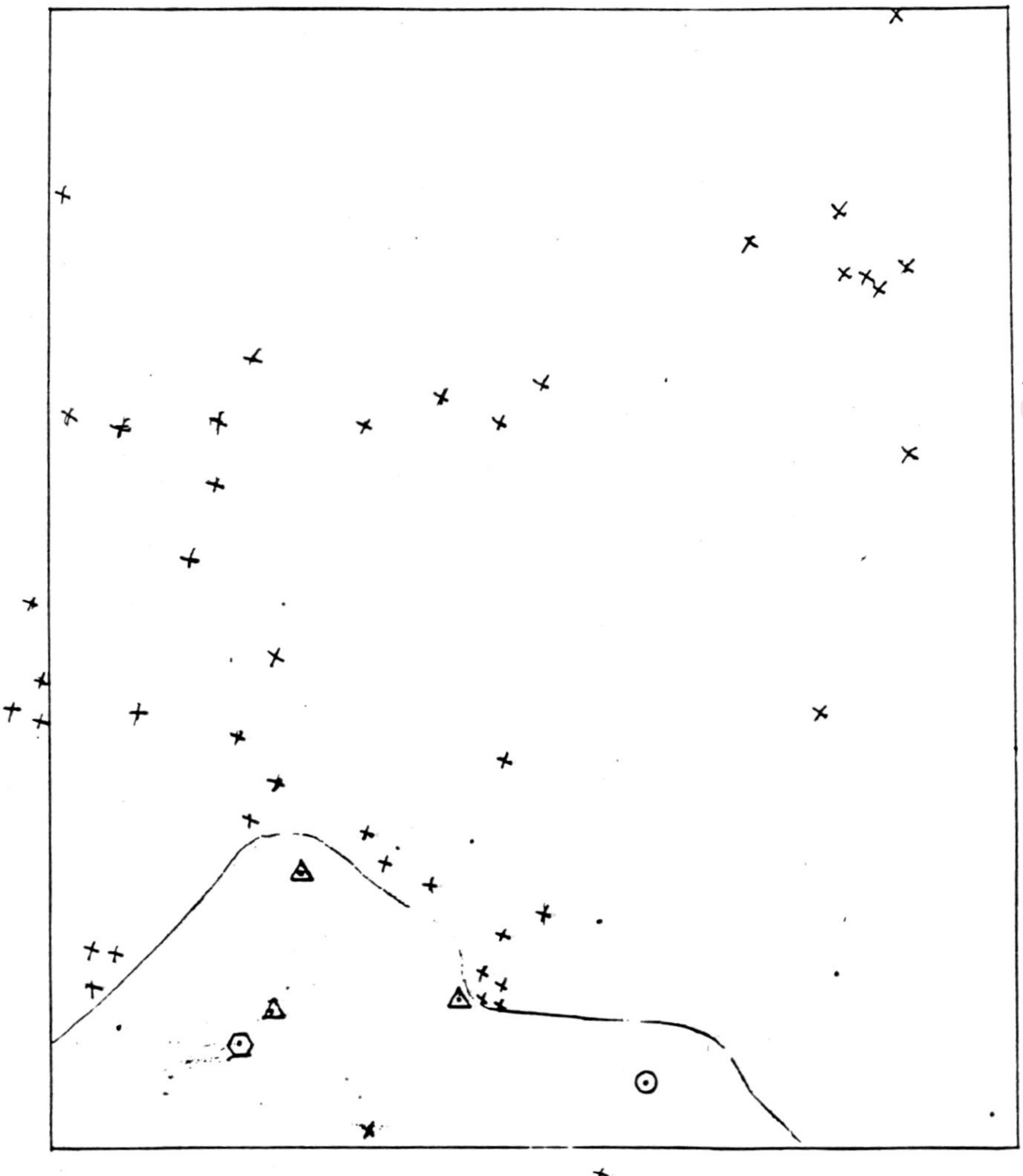
APPENDIX II (CONTINUED)

COOK CREEK - QUENTIN CREEK STUDY AREA

MAJOR FIRE EPISODE - 1772 A.D. (1774-1770)

KEY

○— Oldest origin date(s) at site
○— Origin date(s) - not oldest.
□— Origin date(s) and scar date(s)
△— Scar date(s) only
×— No record of this fire at site



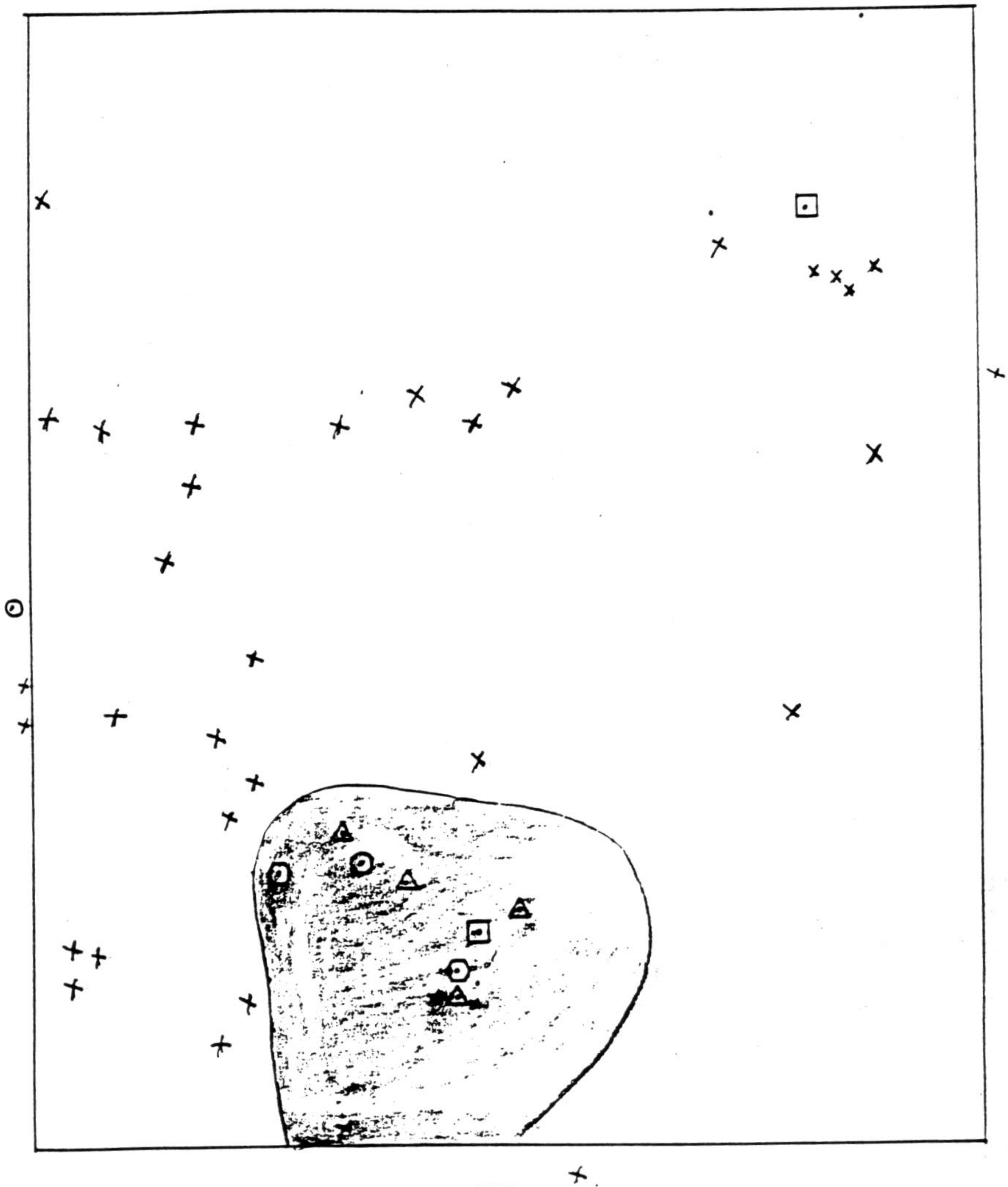
APPENDIX II (CONTINUED)

COOK CREEK - QUENTIN CREEK STUDY AREA

MAJOR FIRE EPISODE - 1758 A.D. (1764-1752)

KEY

○— Oldest origin date(s) at site
○— Origin date(s) - not oldest.
□— Origin date(s) and scar date(s)
△— Scar date(s) only
×— No record of this fire at site



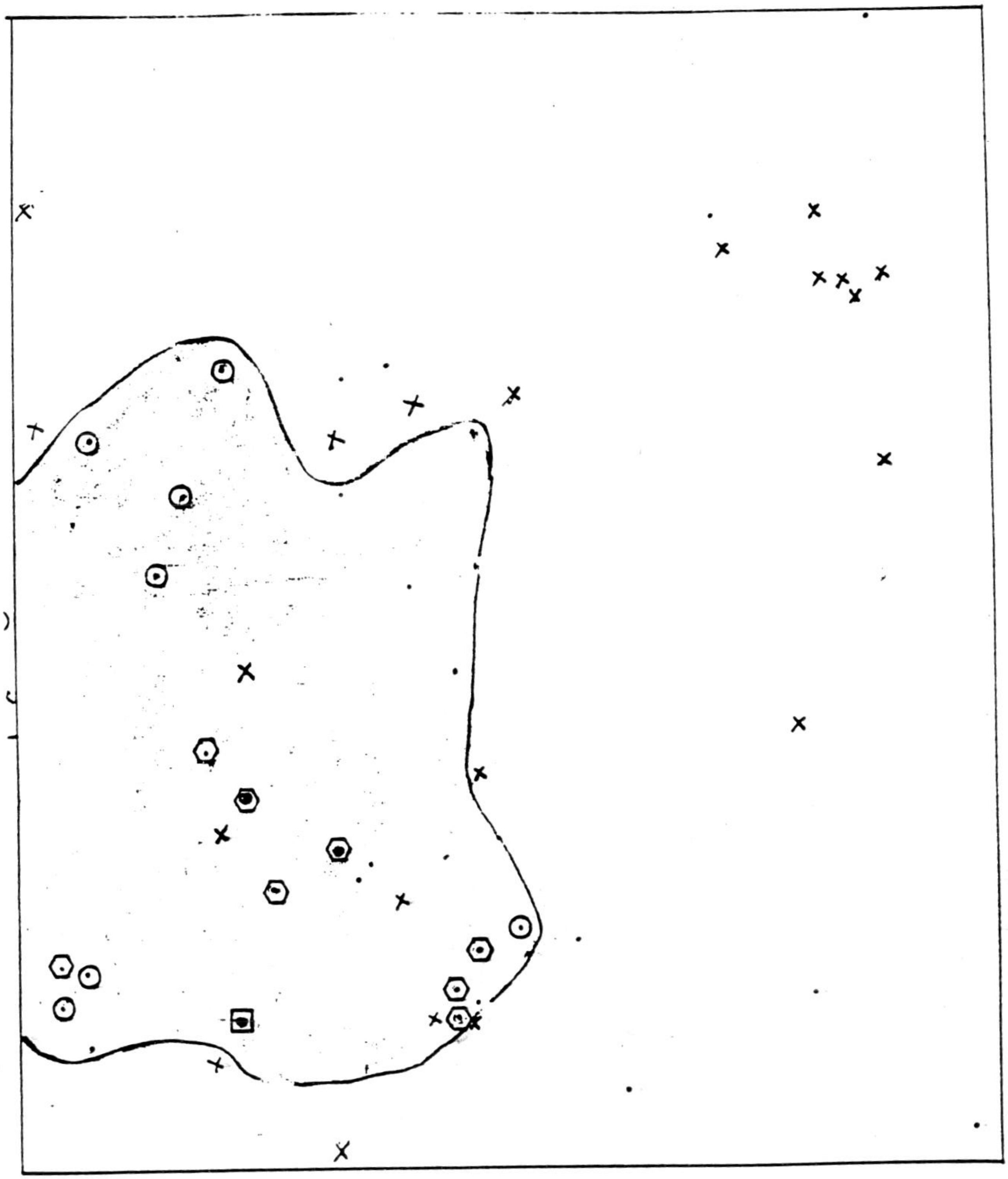
APPENDIX II (CONTINUED)

COOK CREEK - QUENTIN CREEK STUDY AREA

MAJOR FIRE EPISODE - 1703 A.D. (1709-1699)

KEY

○— Oldest origin date(s) at site
⬡— Origin date(s) - not oldest.
□— Origin date(s) and scar date(s)
△— Scar date(s) only
×— No record of this fire at site



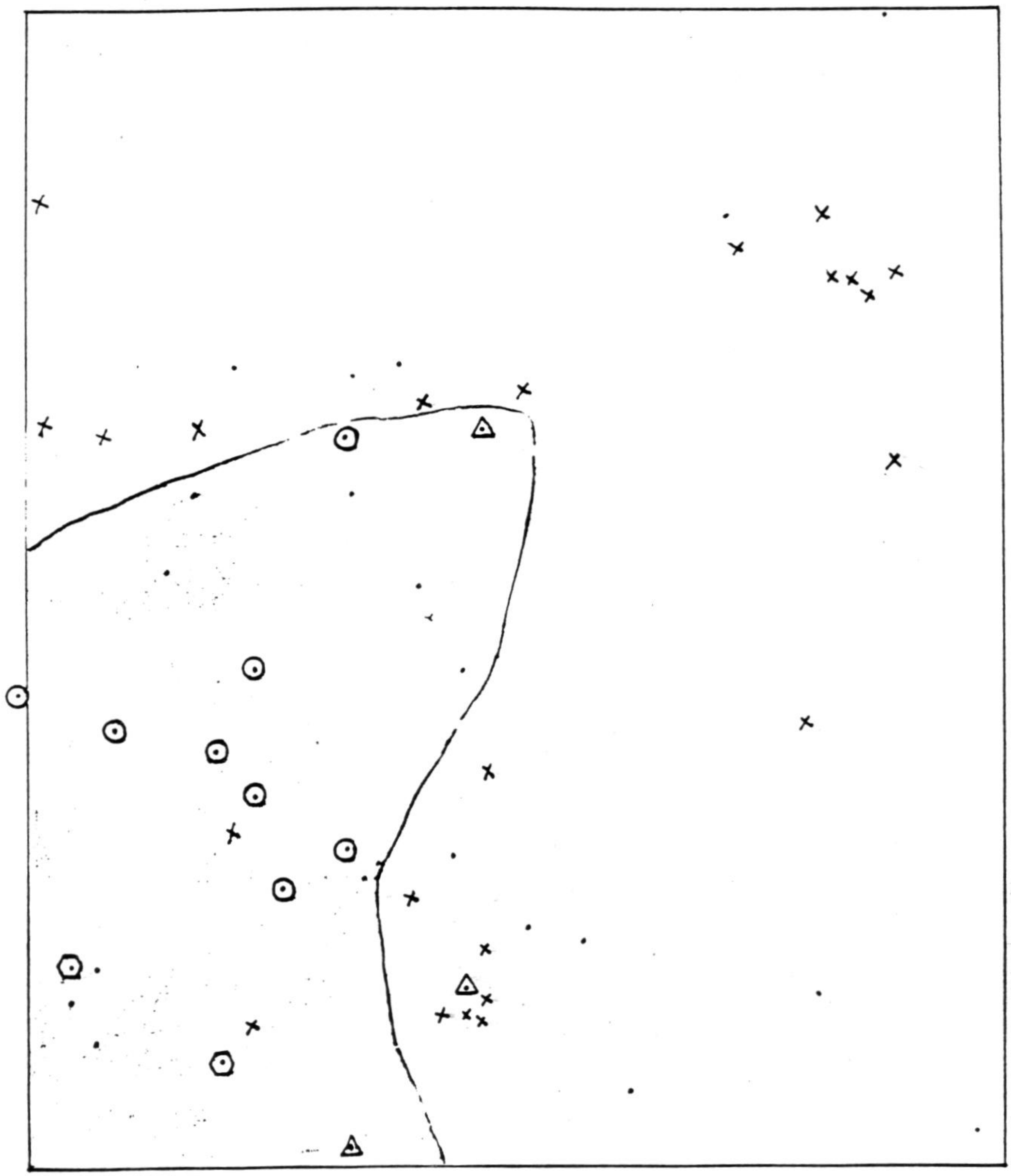
APPENDIX II (CONTINUED)

COOK CREEK - QUENTIN CREEK STUDY AREA

MAJOR FIRE EPISODE - 1689 A.D. (1695-1683)

KEY

○— Oldest origin date(s) at site
⬡— Origin date(s) - not oldest.
□— Origin date(s) and scar date(s)
△— Scar date(s) only
×— No record of this fire at site



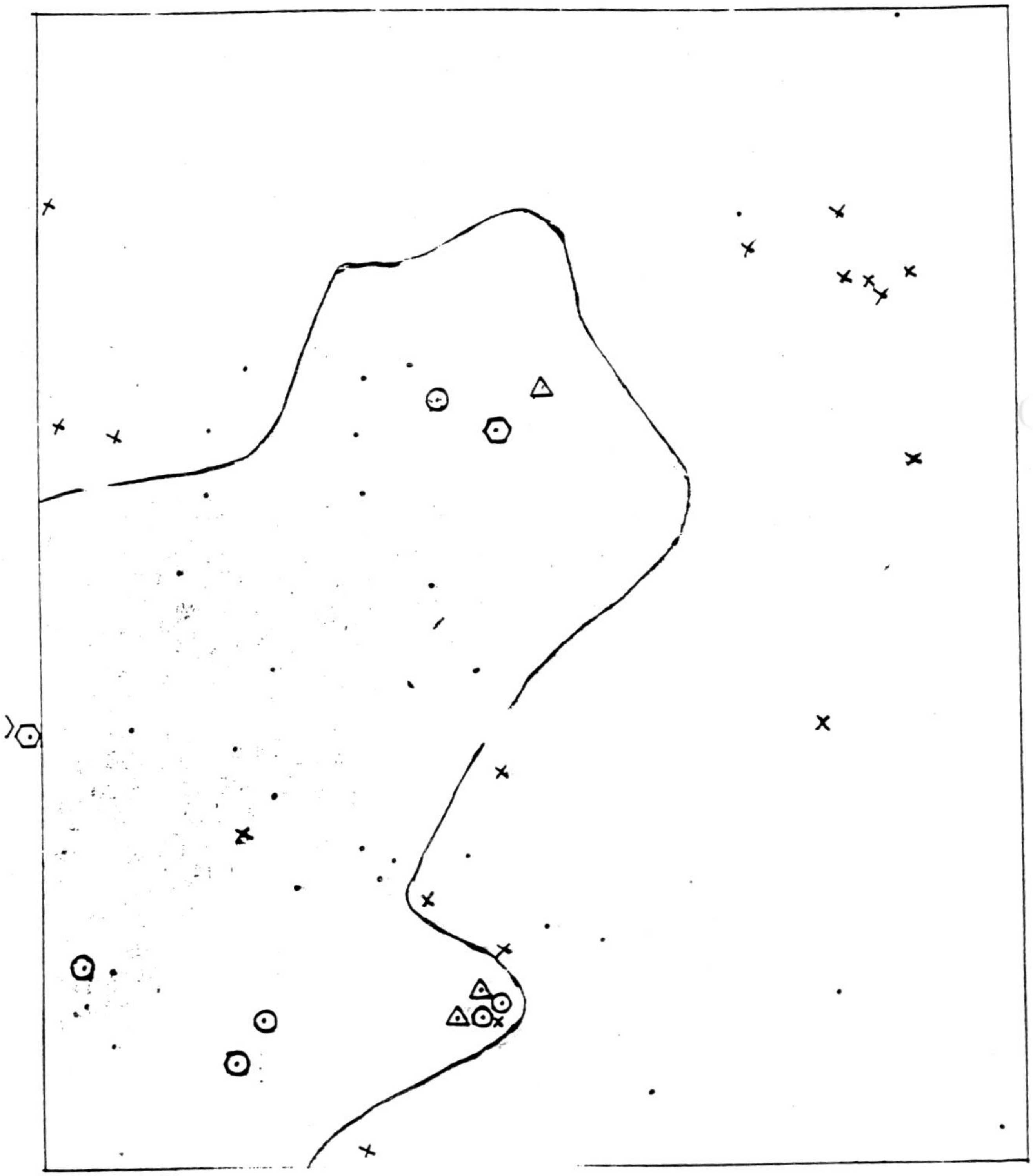
APPENDIX II (CONTINUED)

COOK CREEK - QUENTIN CREEK STUDY AREA

MAJOR FIRE EPISODE - 1658 A.D. (1671-1648)

KEY

○— Oldest origin date(s) at site
⬡— Origin date(s) - not oldest.
□— Origin date(s) and scar date(s)
△— Scar date(s) only
X— No record of this fire at site



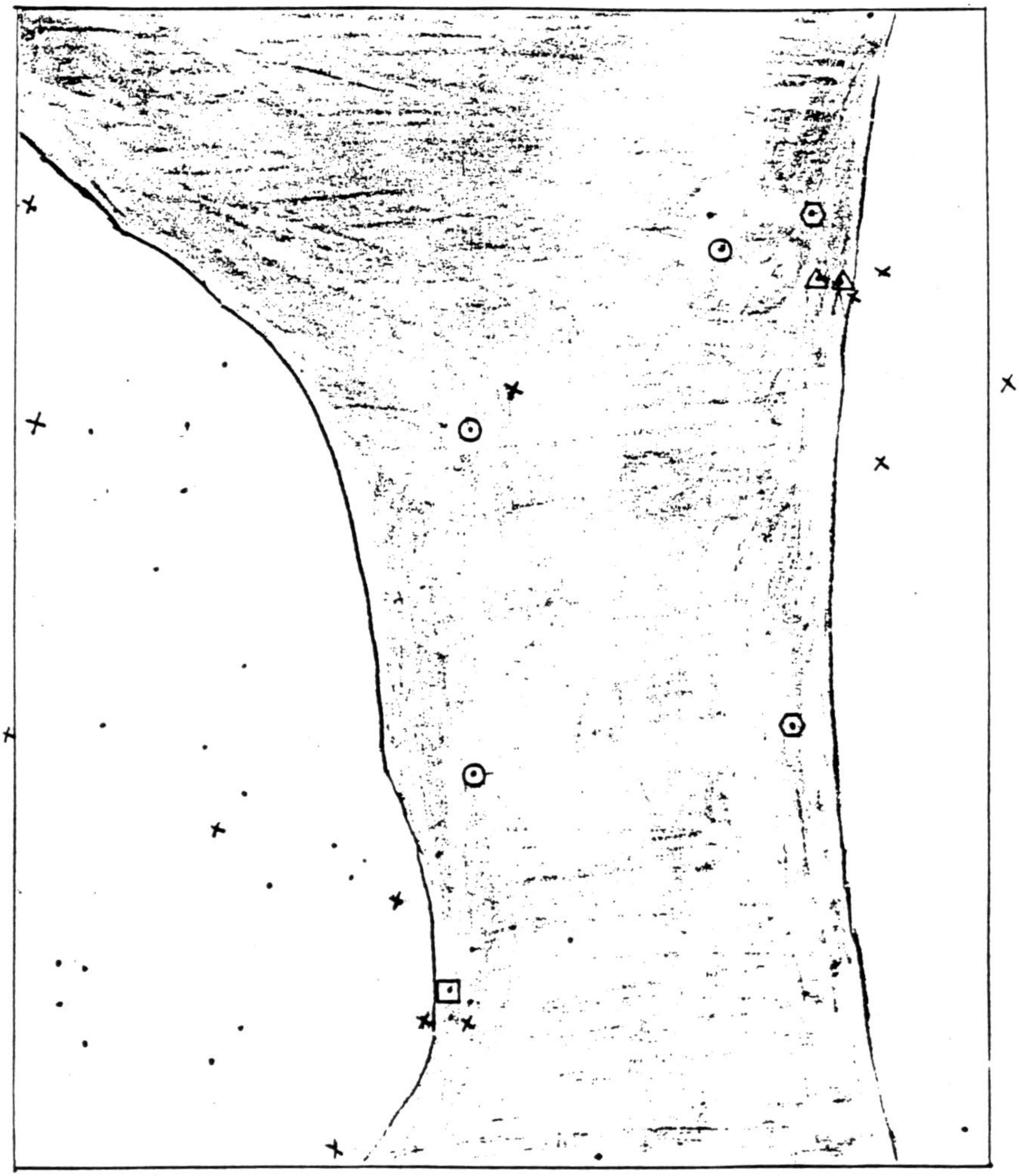
APPENDIX II (CONTINUED)

COOK CREEK - QUENTIN CREEK STUDY AREA

MAJOR FIRE EPISODE - 1566 A.D. (1586-1549)

KEY

○— Oldest origin date(s) at site
⬡— Origin date(s) - not oldest.
□— Origin date(s) and scar date(s)
△— Scar date(s) only
×— No record of this fire at site



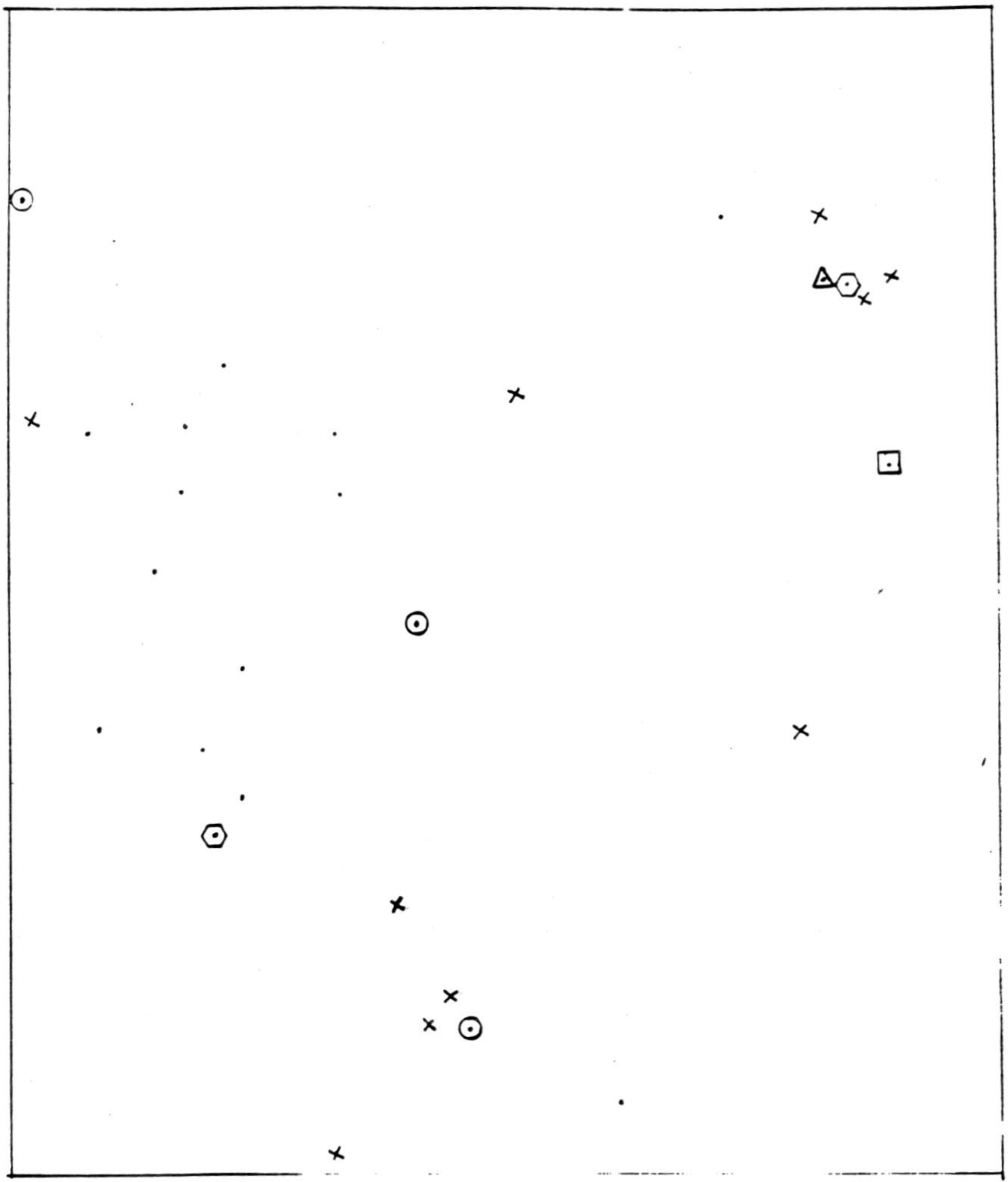
APPENDIX II (CONTINUED)

COOK CREEK - QUENTIN CREEK STUDY AREA

MAJOR FIRE EPISODE - 1532 A.D. (1545-1511)

KEY

○— Oldest origin date(s) at site
⬡— Origin date(s) - not oldest.
□— Origin date(s) and scar date(s)
△— Scar date(s) only
×— No record of this fire at site



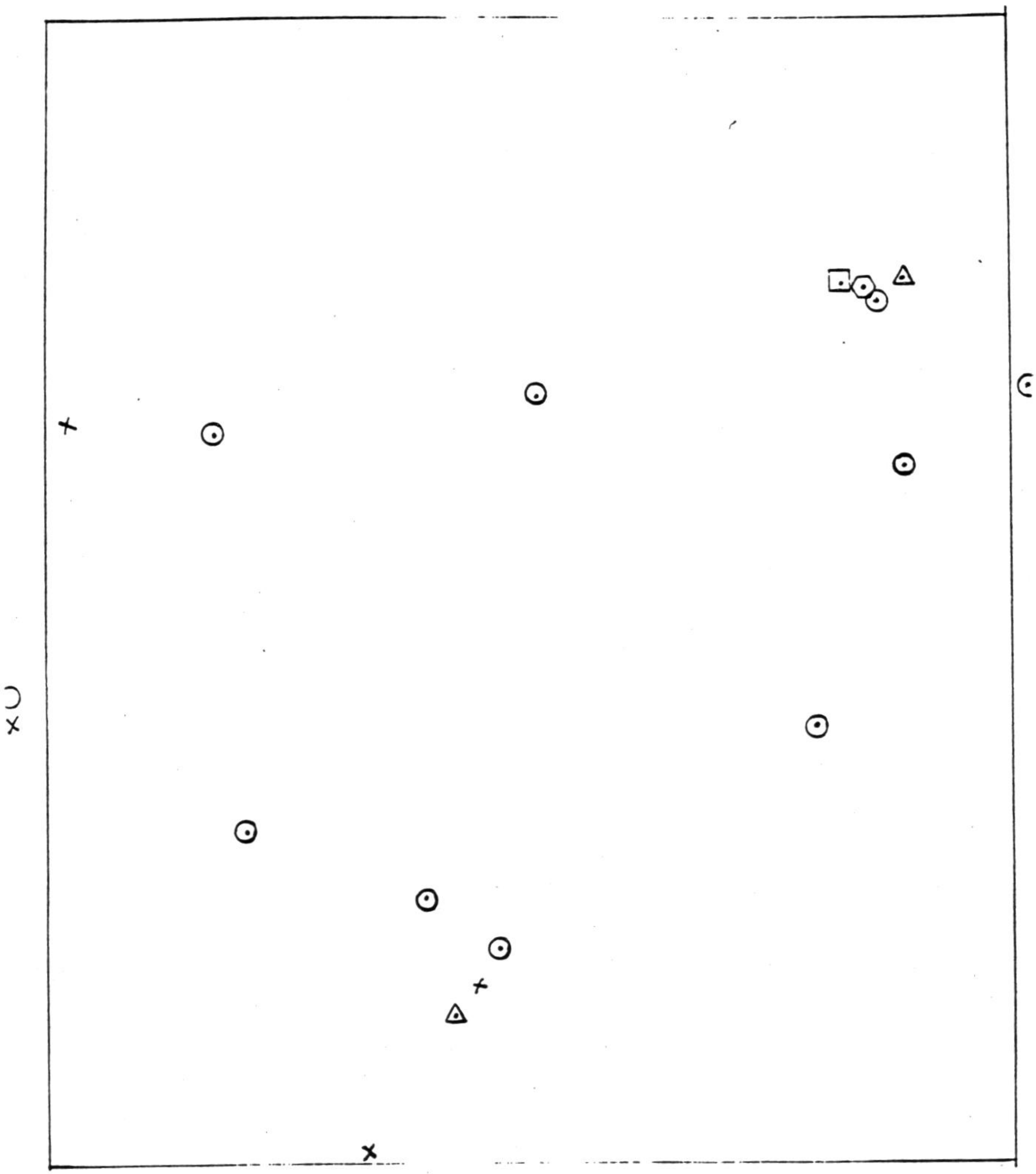
APPENDIX II (CONTINUED)

COOK CREEK - QUENTIN CREEK STUDY AREA

MAJOR FIRE EPISODE - 1475 A.D. (1500-1445)

KEY

○— Oldest origin date(s) at site
○— Origin date(s) - not oldest.
□— Origin date(s) and scar date(s)
△— Scar date(s) only
×— No record of this fire at site



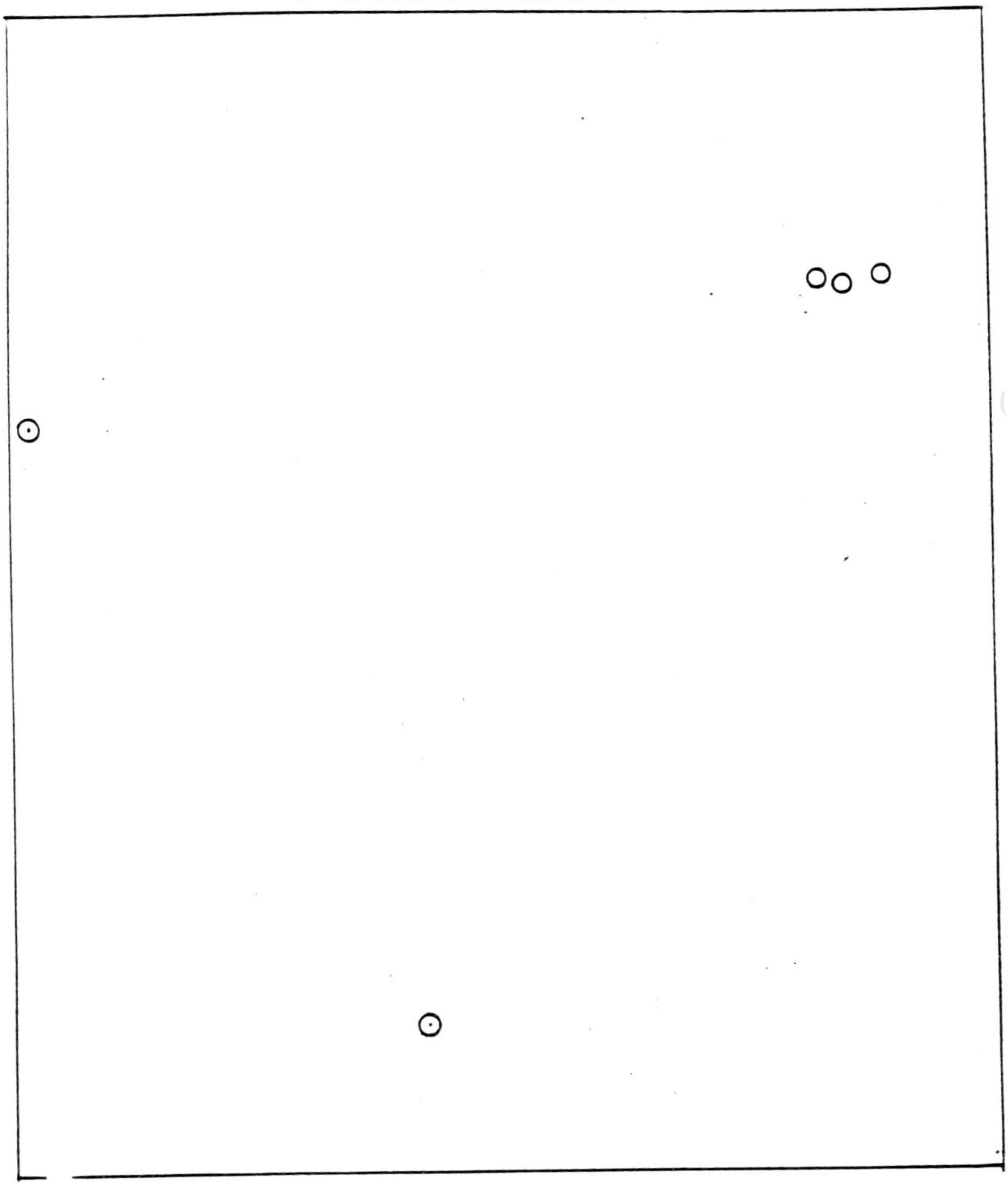
APPENDIX II (CONTINUED)

COOK CREEK - QUENTIN CREEK STUDY AREA

MAJOR FIRE EPISODE - 1400 A.D. (1410-1380)

KEY

○— Oldest origin date(s) at site
⊙— Origin date(s) - not oldest.
□— Origin date(s) and scar date(s)
△— Scar date(s) only
×— No record of this fire at site



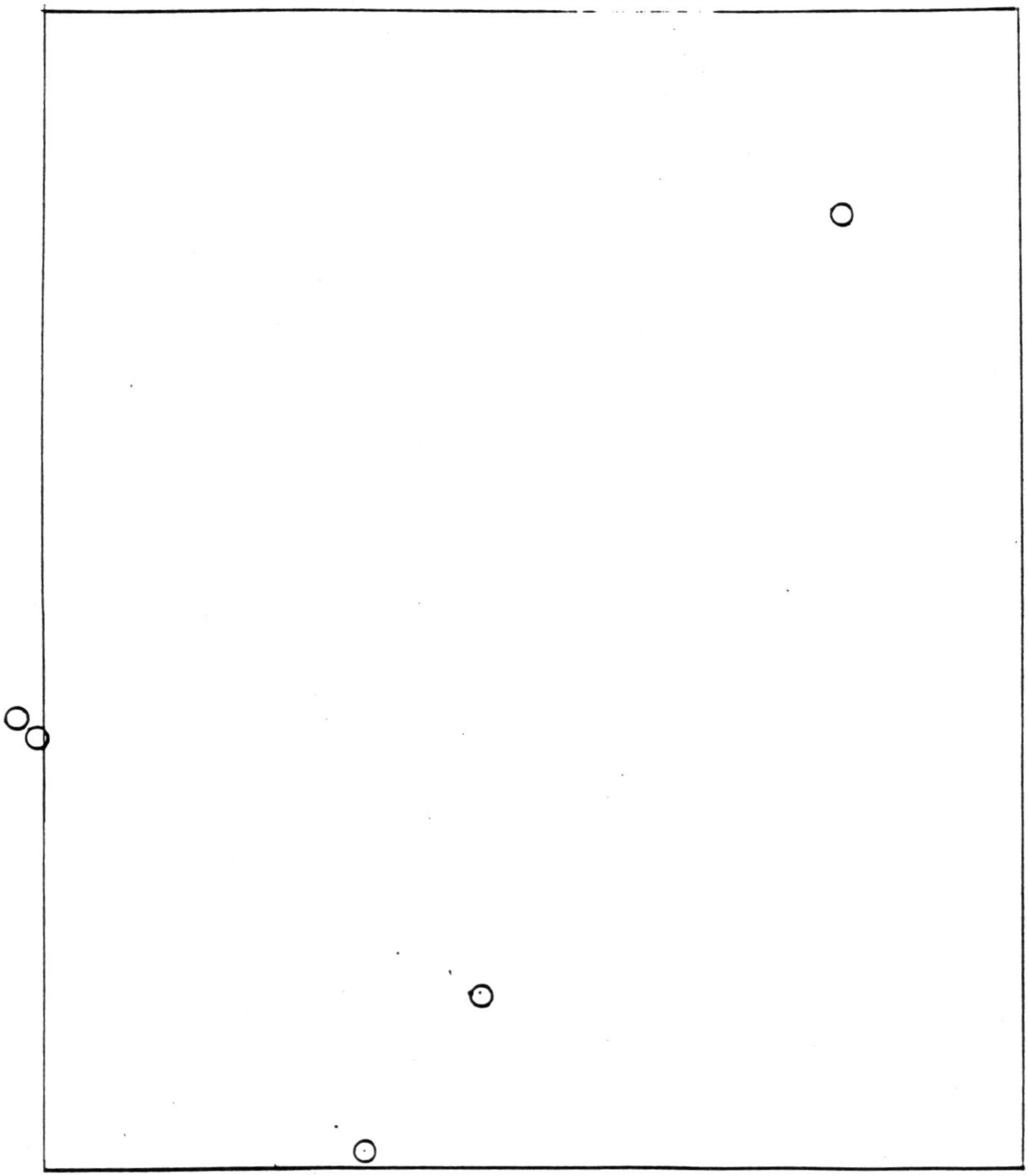
APPENDIX II (CONTINUED)

COOK CREEK - QUENTIN CREEK STUDY AREA

MAJOR FIRE EPISODE - 1150 A.D. (1200-1100)

KEY

○— Oldest origin date(s) at site
○— Origin date(s) - not oldest.
□— Origin date(s) and scar date(s)
△— Scar date(s) only
×— No record of this fire at site



APPENDIX II (CONTINUED)

APPENDIX III
FIRE RECORD BY SITE

FIRE HISTORY SUMMARY BY SITE

COOK - QUENTIN CREEK STUDY AREA

NOTE - RECORD AT SITE CODES ARE AS FOLLOWS:
1 = TREE ORIGIN DATE(S) ONLY,
2 = TREE ORIGIN DATE(S) AND SCAR DATE(S),
3 = SCAR DATE(S) ONLY,
4 = BASED ON APPROXIMATE ORIGIN DATE.

SITE - BR06 ELEVATION - 2200 ASPECT - R 1 FIRE RECORDED
FIRE DATE RECORD AT SITE
1855 (1)
SITE FIRE FREQUENCY - 55 BETWEEN 1910 AD. AND 1855 AD.
SITE FIRE FREQUENCY - 110 BETWEEN 1910 AD. AND 1800 AD.

SITE - BR23 ELEVATION - 2600 ASPECT - NW 1 FIRE RECORDED
FIRE DATE RECORD AT SITE
1834 (1)
SITE FIRE FREQUENCY - 76 BETWEEN 1910 AD. AND 1834 AD.
SITE FIRE FREQUENCY - 110 BETWEEN 1910 AD. AND 1800 AD.

SITE - CO01 ELEVATION - 2200 ASPECT - SW 2 FIRES RECORDED
FIRE DATE RECORD AT SITE
1475 (1) 1532 (1)
SITE FIRE FREQUENCY - 218 BETWEEN 1910 AD. AND 1475 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - CO02 ELEVATION - 2200 ASPECT - SW 4 FIRES RECORDED
FIRE DATE RECORD AT SITE
1689 (1) 1703 (1) 1758 (1) 1772 (3)
SITE FIRE FREQUENCY - 55 BETWEEN 1910 AD. AND 1689 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - CO04 ELEVATION - 2200 ASPECT - SE 2 FIRES RECORDED
FIRE DATE RECORD AT SITE
1689 (1) 1703 (1)
SITE FIRE FREQUENCY - 111 BETWEEN 1910 AD. AND 1689 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - CO06 ELEVATION - 2800 ASPECT - SE 1 FIRE RECORDED
FIRE DATE RECORD AT SITE
1703 (1)
SITE FIRE FREQUENCY - 207 BETWEEN 1910 AD. AND 1703 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

APPENDIX III (CONTINUED)

SITE - C007 ELEVATION - 2600 ASPECT - E 1 FIRE RECORDED
FIRE DATE RECORD AT SITE
1855 (1)
SITE FIRE FREQUENCY - 55 BETWEEN 1910 AD. AND 1855 AD.
SITE FIRE FREQUENCY - 110 BETWEEN 1910 AD. AND 1800 AD.

SITE - C008 ELEVATION - 2200 ASPECT - NE 5 FIRES RECORDED
FIRE DATE RECORD AT SITE
1658 (1) 1689 (1) 1772 (1) 1800 (2) 1841 (2)
SITE FIRE FREQUENCY - 50 BETWEEN 1910 AD. AND 1658 AD.
SITE FIRE FREQUENCY - 55 BETWEEN 1910 AD. AND 1800 AD.

SITE - C009 ELEVATION - 2800 ASPECT - E 3 FIRES RECORDED
FIRE DATE RECORD AT SITE
1703 (1) 1807 (3) 1841 (3)
SITE FIRE FREQUENCY - 69 BETWEEN 1910 AD. AND 1703 AD.
SITE FIRE FREQUENCY - 55 BETWEEN 1910 AD. AND 1800 AD.

SITE - C011 ELEVATION - 2000 ASPECT - W 4 FIRES RECORDED
FIRE DATE RECORD AT SITE
1150 (1) 1532 (1) 1689 (3) 1800 (3)
SITE FIRE FREQUENCY - 190 BETWEEN 1910 AD. AND 1150 AD.
SITE FIRE FREQUENCY - 110 BETWEEN 1910 AD. AND 1800 AD.

SITE - C020 ELEVATION - 2200 ASPECT - NW 4 FIRES RECORDED
FIRE DATE RECORD AT SITE
1689 (1) 1703 (1) 1807 (1) 1834 (2)
SITE FIRE FREQUENCY - 55 BETWEEN 1910 AD. AND 1689 AD.
SITE FIRE FREQUENCY - 55 BETWEEN 1910 AD. AND 1800 AD.

SITE - C021 ELEVATION - 2400 ASPECT - B 2 FIRES RECORDED
FIRE DATE RECORD AT SITE
1689 (4) 1834 (4)
SITE FIRE FREQUENCY - 111 BETWEEN 1910 AD. AND 1689 AD.
SITE FIRE FREQUENCY - 110 BETWEEN 1910 AD. AND 1800 AD.

SITE - C022 ELEVATION - 2200 ASPECT - SW 4 FIRES RECORDED
FIRE DATE RECORD AT SITE
1689 (1) 1800 (3) 1807 (1) 1841 (2)
SITE FIRE FREQUENCY - 55 BETWEEN 1910 AD. AND 1689 AD.
SITE FIRE FREQUENCY - 37 BETWEEN 1910 AD. AND 1800 AD.

SITE - C023 ELEVATION - 2800 ASPECT - W 5 FIRES RECORDED
FIRE DATE RECORD AT SITE
1658 (1) 1703 (1) 1758 (2) 1800 (3) 1834 (2)
SITE FIRE FREQUENCY - 50 BETWEEN 1910 AD. AND 1658 AD.
SITE FIRE FREQUENCY - 55 BETWEEN 1910 AD. AND 1800 AD.

APPENDIX III (CONTINUED)

SITE - C024 ELEVATION - 2800 ASPECT - R 2 FIRES RECORDED
FIRE DATE RECORD AT SITE
1532 (1) 1834 (1)
SITE FIRE FREQUENCY - 189 BETWEEN 1910 AD. AND 1532 AD.
SITE FIRE FREQUENCY - 110 BETWEEN 1910 AD. AND 1800 AD.

SITE - C025 ELEVATION - 3000 ASPECT - R 2 FIRES RECORDED
FIRE DATE RECORD AT SITE
1658 (4) 1834 (4)
SITE FIRE FREQUENCY - 126 BETWEEN 1910 AD. AND 1658 AD.
SITE FIRE FREQUENCY - 110 BETWEEN 1910 AD. AND 1800 AD.

SITE - C026 ELEVATION - 2800 ASPECT - NW 8 FIRES RECORDED
FIRE DATE RECORD AT SITE
1150 (1) 1566 (2) 1658 (3) 1689 (3) 1703 (1) 1758 (1)
1813 (3) 1834 (3)
SITE FIRE FREQUENCY - 95 BETWEEN 1910 AD. AND 1150 AD.
SITE FIRE FREQUENCY - 55 BETWEEN 1910 AD. AND 1800 AD.

SITE - C027 ELEVATION - 2600 ASPECT - W 4 FIRES RECORDED
FIRE DATE RECORD AT SITE
1400 (1) 1475 (3) 1658 (3) 1772 (3)
SITE FIRE FREQUENCY - 128 BETWEEN 1910 AD. AND 1400 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - C028 ELEVATION - 2800 ASPECT - SW 6 FIRES RECORDED
FIRE DATE RECORD AT SITE
1689 (1) 1703 (1) 1758 (3) 1807 (3) 1834 (3) 1849 (2)
SITE FIRE FREQUENCY - 37 BETWEEN 1910 AD. AND 1689 AD.
SITE FIRE FREQUENCY - 37 BETWEEN 1910 AD. AND 1800 AD.

SITE - C029 ELEVATION - 2800 ASPECT - SW 4 FIRES RECORDED
FIRE DATE RECORD AT SITE
1758 (1) 1807 (3) 1834 (2) 1849 (3)
SITE FIRE FREQUENCY - 38 BETWEEN 1910 AD. AND 1758 AD.
SITE FIRE FREQUENCY - 37 BETWEEN 1910 AD. AND 1800 AD.

SITE - C030 ELEVATION - 2600 ASPECT - SW 1 FIRE RECORDED
FIRE DATE RECORD AT SITE
1849 (1)
SITE FIRE FREQUENCY - 61 BETWEEN 1910 AD. AND 1849 AD.
SITE FIRE FREQUENCY - 110 BETWEEN 1910 AD. AND 1800 AD.

SITE - C031 ELEVATION - 2800 ASPECT - SW 4 FIRES RECORDED
FIRE DATE RECORD AT SITE
1475 (1) 1758 (3) 1834 (3) 1849 (2)
SITE FIRE FREQUENCY - 109 BETWEEN 1910 AD. AND 1475 AD.
SITE FIRE FREQUENCY - 55 BETWEEN 1910 AD. AND 1800 AD.

SITE - CO32 ELEVATION - 3200 ASPECT - R 1 FIRE RECORDED
FIRE DATE RECORD AT SITE
1849 (1)
SITE FIRE FREQUENCY - 61 BETWEEN 1910 AD. AND 1849 AD.
SITE FIRE FREQUENCY - 110 BETWEEN 1910 AD. AND 1800 AD.

SITE - CO33 ELEVATION - 3000 ASPECT - SE 2 FIRES RECORDED
FIRE DATE RECORD AT SITE
1703 (1) 1807 (3)
SITE FIRE FREQUENCY - 104 BETWEEN 1910 AD. AND 1703 AD.
SITE FIRE FREQUENCY - 110 BETWEEN 1910 AD. AND 1800 AD.

SITE - CO34 ELEVATION - 3000 ASPECT - E 2 FIRES RECORDED
FIRE DATE RECORD AT SITE
1703 (1) 1807 (3)
SITE FIRE FREQUENCY - 104 BETWEEN 1910 AD. AND 1703 AD.
SITE FIRE FREQUENCY - 110 BETWEEN 1910 AD. AND 1800 AD.

SITE - CO35 ELEVATION - 3200 ASPECT - S 3 FIRES RECORDED
FIRE DATE RECORD AT SITE
1475 (1) 1813 (3) 1893 (2)
SITE FIRE FREQUENCY - 145 BETWEEN 1910 AD. AND 1475 AD.
SITE FIRE FREQUENCY - 55 BETWEEN 1910 AD. AND 1800 AD.

SITE - CO36 ELEVATION - 3600 ASPECT - E 3 FIRES RECORDED
FIRE DATE RECORD AT SITE
1703 (1) 1807 (3) 1893 (3)
SITE FIRE FREQUENCY - 69 BETWEEN 1910 AD. AND 1703 AD.
SITE FIRE FREQUENCY - 55 BETWEEN 1910 AD. AND 1800 AD.

SITE - CO37 ELEVATION - 3800 ASPECT - SE 2 FIRES RECORDED
FIRE DATE RECORD AT SITE
1400 (1) 1800 (3)
SITE FIRE FREQUENCY - 255 BETWEEN 1910 AD. AND 1400 AD.
SITE FIRE FREQUENCY - 110 BETWEEN 1910 AD. AND 1800 AD.

SITE - QUO1 ELEVATION - 2000 ASPECT - SE 2 FIRES RECORDED
FIRE DATE RECORD AT SITE
1772 (1) 1849 (1)
SITE FIRE FREQUENCY - 69 BETWEEN 1910 AD. AND 1772 AD.
SITE FIRE FREQUENCY - 110 BETWEEN 1910 AD. AND 1800 AD.

SITE - QUO2 ELEVATION - 3000 ASPECT - R 6 FIRES RECORDED
FIRE DATE RECORD AT SITE
1475 (1) 1703 (1) 1758 (2) 1807 (3) 1834 (3) 1849 (3)
SITE FIRE FREQUENCY - 73 BETWEEN 1910 AD. AND 1475 AD.
SITE FIRE FREQUENCY - 37 BETWEEN 1910 AD. AND 1800 AD.

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SITE - QU0[illegible]     ELEVATION - 3200     ASPECT - S      4 FIRES RECORDED
FIRE DATE   RECORD AT SITE
1566 (1)   1813 (3)   1834 (3)   1855 (2)
SITE FIRE FREQUENCY -  86    BETWEEN 1910 AD. AND 1566 AD.
SITE FIRE FREQUENCY -  37    BETWEEN 1910 AD. AND 1800 AD.

SITE - QU04     ELEVATION - 3200     ASPECT - E      1 FIRE RECORDED
FIRE DATE   RECORD AT SITE
1841 (1)
SITE FIRE FREQUENCY -  69    BETWEEN 1910 AD. AND 1841 AD.
SITE FIRE FREQUENCY - 110    BETWEEN 1910 AD. AND 1800 AD.

SITE - QU05     ELEVATION - 3400     ASPECT - R      4 FIRES RECORDED
FIRE DATE   RECORD AT SITE
1703 (1)   1813 (1)   1834 (1)   1893 (2)
SITE FIRE FREQUENCY -  52    BETWEEN 1910 AD. AND 1703 AD.
SITE FIRE FREQUENCY -  37    BETWEEN 1910 AD. AND 1800 AD.

SITE - QU06     ELEVATION - 3800     ASPECT - W      2 FIRES RECORDED
FIRE DATE   RECORD AT SITE
1532 (1)   1893 (1)
SITE FIRE FREQUENCY - 189    BETWEEN 1910 AD. AND 1532 AD.
SITE FIRE FREQUENCY - 110    BETWEEN 1910 AD. AND 1800 AD.

SITE - QU11     ELEVATION - 2400     ASPECT - W      4 FIRES RECORDED
FIRE DATE   RECORD AT SITE
1475 (1)   1566 (1)   1849 (1)   1855 (2)
SITE FIRE FREQUENCY - 109    BETWEEN 1910 AD. AND 1475 AD.
SITE FIRE FREQUENCY -  55    BETWEEN 1910 AD. AND 1800 AD.

SITE - QU13     ELEVATION - 3000     ASPECT - S      6 FIRES RECORDED
FIRE DATE   RECORD AT SITE
1150 (1)   1566 (1)   1758 (2)   1800 (3)   1813 (2)   1855 (3)
SITE FIRE FREQUENCY - 127    BETWEEN 1910 AD. AND 1150 AD.
SITE FIRE FREQUENCY -  37    BETWEEN 1910 AD. AND 1800 AD.

SITE - Q14A     ELEVATION - 3200     ASPECT - R      1 FIRE RECORDED
FIRE DATE   RECORD AT SITE
1800 (1)
SITE FIRE FREQUENCY - 110    BETWEEN 1910 AD. AND 1800 AD.
SITE FIRE FREQUENCY - 110    BETWEEN 1910 AD. AND 1800 AD.

SITE - Q14B     ELEVATION - 3200     ASPECT - SE     3 FIRES RECORDED
FIRE DATE   RECORD AT SITE
1566 (4)   1813 (1)   1855 (3)
SITE FIRE FREQUENCY - 115    BETWEEN 1910 AD. AND 1566 AD.
SITE FIRE FREQUENCY -  55    BETWEEN 1910 AD. AND 1800 AD.
```

APPENDIX III (CONTINUED)

SITE - QU35 ELEVATION - 2600 ASPECT - N 4 FIRES RECORDED
FIRE DATE RECORD AT SITE
1475 (1) 1532 (2) 1834 (3) 1841 (3)
SITE FIRE FREQUENCY - 109 BETWEEN 1910 AD. AND 1475 AD.
SITE FIRE FREQUENCY - 55 BETWEEN 1910 AD. AND 1800 AD.

SITE - QU37 ELEVATION - 3400 ASPECT - SW 2 FIRES RECORDED
FIRE DATE RECORD AT SITE
1800 (1) 1813 (1)
SITE FIRE FREQUENCY - 55 BETWEEN 1910 AD. AND 1800 AD.
SITE FIRE FREQUENCY - 55 BETWEEN 1910 AD. AND 1800 AD.

SITE - QU38 ELEVATION - 2800 ASPECT - SE 7 FIRES RECORDED
FIRE DATE RECORD AT SITE
1566 (1) 1658 (1) 1689 (3) 1703 (3) 1800 (3) 1807 (3) 1841 (3
SITE FIRE FREQUENCY - 49 BETWEEN 1910 AD. AND 1566 AD.
SITE FIRE FREQUENCY - 37 BETWEEN 1910 AD. AND 1800 AD.

SITE - QU39 ELEVATION - 3200 ASPECT - SE 1 FIRE RECORDED
FIRE DATE RECORD AT SITE
1689 (1)
SITE FIRE FREQUENCY - 221 BETWEEN 1910 AD. AND 1689 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - QU40 ELEVATION - 2800 ASPECT - S 4 FIRES RECORDED
FIRE DATE RECORD AT SITE
1400 (1) 1475 (2) 1532 (3) 1566 (3)
SITE FIRE FREQUENCY - 128 BETWEEN 1910 AD. AND 1400 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - QU41 ELEVATION - 2600 ASPECT - SE 2 FIRES RECORDED
FIRE DATE RECORD AT SITE
1849 (1) 1855 (1)
SITE FIRE FREQUENCY - 31 BETWEEN 1910 AD. AND 1849 AD.
SITE FIRE FREQUENCY - 55 BETWEEN 1910 AD. AND 1800 AD.

SITE - QU42 ELEVATION - 3000 ASPECT - SE 7 FIRES RECORDED
FIRE DATE RECORD AT SITE
1703 (1) 1758 (3) 1800 (3) 1807 (3) 1834 (3) 1849 (1) 1855 (2
SITE FIRE FREQUENCY - 30 BETWEEN 1910 AD. AND 1703 AD.
SITE FIRE FREQUENCY - 22 BETWEEN 1910 AD. AND 1800 AD.

SITE - QU43 ELEVATION - 3400 ASPECT - R 2 FIRES RECORDED
FIRE DATE RECORD AT SITE
1834 (1) 1841 (1)
SITE FIRE FREQUENCY - 38 BETWEEN 1910 AD. AND 1834 AD.
SITE FIRE FREQUENCY - 55 BETWEEN 1910 AD. AND 1800 AD.

APPENDIX III (CONTINUED)

SITE - QU44   ELEVATION - 3400   ASPECT - R   2 FIRES RECORDED
FIRE DATE RECORD AT SITE
1532 (4) 1841 (4)
SITE FIRE FREQUENCY - 189   BETWEEN 1910 AD. AND 1532 AD.
SITE FIRE FREQUENCY - 110   BETWEEN 1910 AD. AND 1800 AD.

SITE - QU45   ELEVATION - 3400   ASPECT - R   2 FIRES RECORDED
FIRE DATE RECORD AT SITE
1834 (4) 1893 (1)
SITE FIRE FREQUENCY - 38   BETWEEN 1910 AD. AND 1834 AD.
SITE FIRE FREQUENCY - 55   BETWEEN 1910 AD. AND 1800 AD.

SITE - QU46   ELEVATION - 3200   ASPECT - SE   1 FIRE RECORDED
FIRE DATE RECORD AT SITE
1893 (1)
SITE FIRE FREQUENCY - 17   BETWEEN 1910 AD. AND 1893 AD.
SITE FIRE FREQUENCY - 110   BETWEEN 1910 AD. AND 1800 AD.

SITE - QU47   ELEVATION - 3200   ASPECT - R   2 FIRES RECORDED
FIRE DATE RECORD AT SITE
1834 (1) 1893 (2)
SITE FIRE FREQUENCY - 38   BETWEEN 1910 AD. AND 1834 AD.
SITE FIRE FREQUENCY - 55   BETWEEN 1910 AD. AND 1800 AD.

SITE - QU48   ELEVATION - 3000   ASPECT - S   2 FIRES RECORDED
FIRE DATE RECORD AT SITE
1658 (1) 1893 (3)
SITE FIRE FREQUENCY - 126   BETWEEN 1910 AD. AND 1658 AD.
SITE FIRE FREQUENCY - 110   BETWEEN 1910 AD. AND 1800 AD.

SITE - QU49   ELEVATION - 2800   ASPECT - R   3 FIRES RECORDED
FIRE DATE RECORD AT SITE
1475 (1) 1658 (3) 1834 (1)
SITE FIRE FREQUENCY - 145   BETWEEN 1910 AD. AND 1475 AD.
SITE FIRE FREQUENCY - 110   BETWEEN 1910 AD. AND 1800 AD.

SITE - QU50   ELEVATION - 2800   ASPECT - S   10 FIRES RECORDED
FIRE DATE RECORD AT SITE
1400 (1) 1475 (1) 1532 (1) 1566 (3) 1800 (2) 1807 (3)
1813 (1) 1834 (2) 1855 (2) 1893 (3)
SITE FIRE FREQUENCY - 51   BETWEEN 1910 AD. AND 1400 AD.
SITE FIRE FREQUENCY - 18   BETWEEN 1910 AD. AND 1800 AD.

SITE - QU51   ELEVATION - 2600   ASPECT - S   5 FIRES RECORDED
FIRE DATE RECORD AT SITE
1475 (1) 1807 (3) 1813 (2) 1834 (1) 1855 (2)
SITE FIRE FREQUENCY - 87   BETWEEN 1910 AD. AND 1475 AD.
SITE FIRE FREQUENCY - 28   BETWEEN 1910 AD. AND 1800 AD.

APPENDIX III (CONTINUED)

SITE - QU52 ELEVATION - 2800 ASPECT - SE 3 FIRES RECORDED
FIRE DATE RECORD AT SITE
1400 (1) 1475 (3) 1800 (3)
SITE FIRE FREQUENCY - 170 BETWEEN 1910 AD. AND 1400 AD.
SITE FIRE FREQUENCY - 110 BETWEEN 1910 AD. AND 1800 AD.

SITE - 0019 ELEVATION - 2800 ASPECT - SE 6 FIRES RECORDED
FIRE DATE RECORD AT SITE
1658 (1) 1689 (1) 1703 (1) 1800 (3) 1813 (3) 1834 (3)
SITE FIRE FREQUENCY - 42 BETWEEN 1910 AD. AND 1658 AD.
SITE FIRE FREQUENCY - 37 BETWEEN 1910 AD. AND 1800 AD.

SITE - 0020 ELEVATION - 2000 ASPECT - NE 5 FIRES RECORDED
FIRE DATE RECORD AT SITE
1658 (1) 1703 (2) 1772 (3) 1807 (3) 1841 (3)
SITE FIRE FREQUENCY - 50 BETWEEN 1910 AD. AND 1658 AD.
SITE FIRE FREQUENCY - 55 BETWEEN 1910 AD. AND 1800 AD.

AVERAGE SITE FIRE FREQUENCY - 96.25141

APPENDIX IV

SUMMARY OF FIRE HISTORY AT EACH SITE

COOK CREEK - QUENTIN CREEK STUDY AREA

SITE	ELEVATION	ASPECT	#FIRES	#AGECL	#UNDER	SFF1	SFF2	RECYRS
BR06	2200	R	1	1	0	55	55	55
BR23	2600	NW	1	1	0	76	76	76
CO01	2200	SW	2	2	0	218	218	435
CO02	2200	SW	4	3	1	55	74	221
CO04	2200	SE	2	2	0	111	111	221
CO06	2800	SE	1	1	0	207	207	207
CO07	2600	E	1	1	0	55	55	55
CO08	2200	NE	5	5	0	50	50	252
CO09	2800	E	3	1	2	69	207	207
CO11	2000	W	4	2	2	190	380	760
CO20	2200	NW	4	4	0	55	55	221
CO21	2400	B	2	2	0	111	111	221
CO22	2200	SW	4	3	1	55	74	221
CO23	2800	W	5	4	1	50	63	252
CO24	2800	R	2	2	0	189	189	378
CO25	3000	R	2	2	0	126	126	252
CO26	2800	NW	8	4	4	95	190	760
CO27	2600	W	4	1	3	128	510	510
CO28	2800	SW	6	3	3	37	74	221
CO29	2800	SW	4	2	2	38	76	152
CO30	2600	SW	1	1	0	61	61	61
CO31	2800	SW	4	2	2	109	218	435
CO32	3200	R	1	1	0	61	61	61
CO33	3000	SE	2	1	1	104	207	207
CO34	3000	E	2	1	1	104	207	207
CO35	3200	S	3	2	1	145	218	435
CO36	3600	E	3	1	2	69	207	207
CO37	3800	SE	2	1	1	255	510	510
QU01	2000	SE	2	2	0	69	69	138
QU02	3000	R	6	3	3	73	145	435
QU03	3200	S	4	2	2	86	172	344
QU04	3200	E	1	1	0	69	69	69
QU05	3400	R	4	4	0	52	52	207
QU06	3800	W	2	2	0	189	189	378
QU11	2400	W	4	4	0	109	109	435
QU13	3000	S	6	4	2	127	190	760
Q14A	3200	R	1	1	0	110	110	110
Q14B	3200	SE	3	2	1	115	172	344
QU35	2600	N	4	2	2	109	218	435
QU37	3400	SW	2	2	0	55	55	110
QU38	2800	SE	7	2	5	49	172	344
QU39	3200	SE	1	1	0	221	221	221
QU40	2800	S	4	2	2	128	255	510
QU41	2600	SE	2	2	0	31	31	61
QU42	3000	SE	7	3	4	30	69	207
QU43	3400	R	2	2	0	38	38	76
QU44	3400	R	2	2	0	189	189	378
QU45	3400	R	2	2	0	38	38	76
QU46	3200	SE	1	1	0	17	17	17
QU47	3200	R	2	2	0	38	38	76
QU48	3000	S	2	1	1	126	252	252
QU49	2800	R	3	2	1	145	218	435
QU50	2800	S	10	7	3	51	73	510
QU51	2600	S	5	4	1	87	109	435
QU52	2800	SE	3	1	2	170	510	510
0019	2800	SE	6	3	3	42	84	252
0020	2000	NE	5	2	3	50	126	252

AVE. NO. OF FIRES PER SITE - 3.3
AVE. NO. OF AGE CLASSES PER SITE - 2.2
AVE. NO. OF UNDER BURNS PER SITE - 1.1
AVERAGE SITE FIRE FREQUENCY (ALL FIRES) - 96
AVERAGE SITE FIRE FREQUENCY OF STAND REPLACEMENT
OR PARTIAL STAND REPLACEMENT FIRES - 150

#FIRES = Number of total fires at site
#AGECL = Number of age classes at site
#UNDER = Number of underburns at site
SFF1 = Site fire frequency (years) of all fires
SFF2 = Site fire frequency (years) of stand replacement and partial stand replacement fires
RECYRS = Length of record at site (years back from 1910 AD)

APPENDIX V

Overall Aspect and Elevation Distribution
Cook Creek - Quentin Creek Study Area

Aspect	N	NE	E	SE	S	SW	W	NW	Ridge	Bottom
% of study area	3.5	8	12	16	10.5	14.5	7	6.5	15	7

Elevation	% of study area
< 2500 feet	36
2500 - 2999 feet	27
3000 - 3499 feet	30
3500 - 3999 feet	5.5
4000 - 4499 feet	1.5
> 4500 feet	0

Aspect and Elevation Distribution of Sample Sites
Cook Creek - Quentin Creek Study Area

Aspect	N	NE	E	SE	S	SW	W	NW	Ridge	Bottom
No. of sites	1	2	5	13	7	8	5	3	12	1
% of sites	1.7	3.5	8.8	22.8	12.3	14.0	8.8	5.	21.1	1.7

Elevation	No. of Sites	% of Sites
< 2500 feet	12	21.1
2500 - 2999 feet	21	36.8
3000 - 3499 feet	21	36.8
3500 - 3999 feet	3	5.3
4000 - 4499 feet	0	0
> 4500 feet	0	0

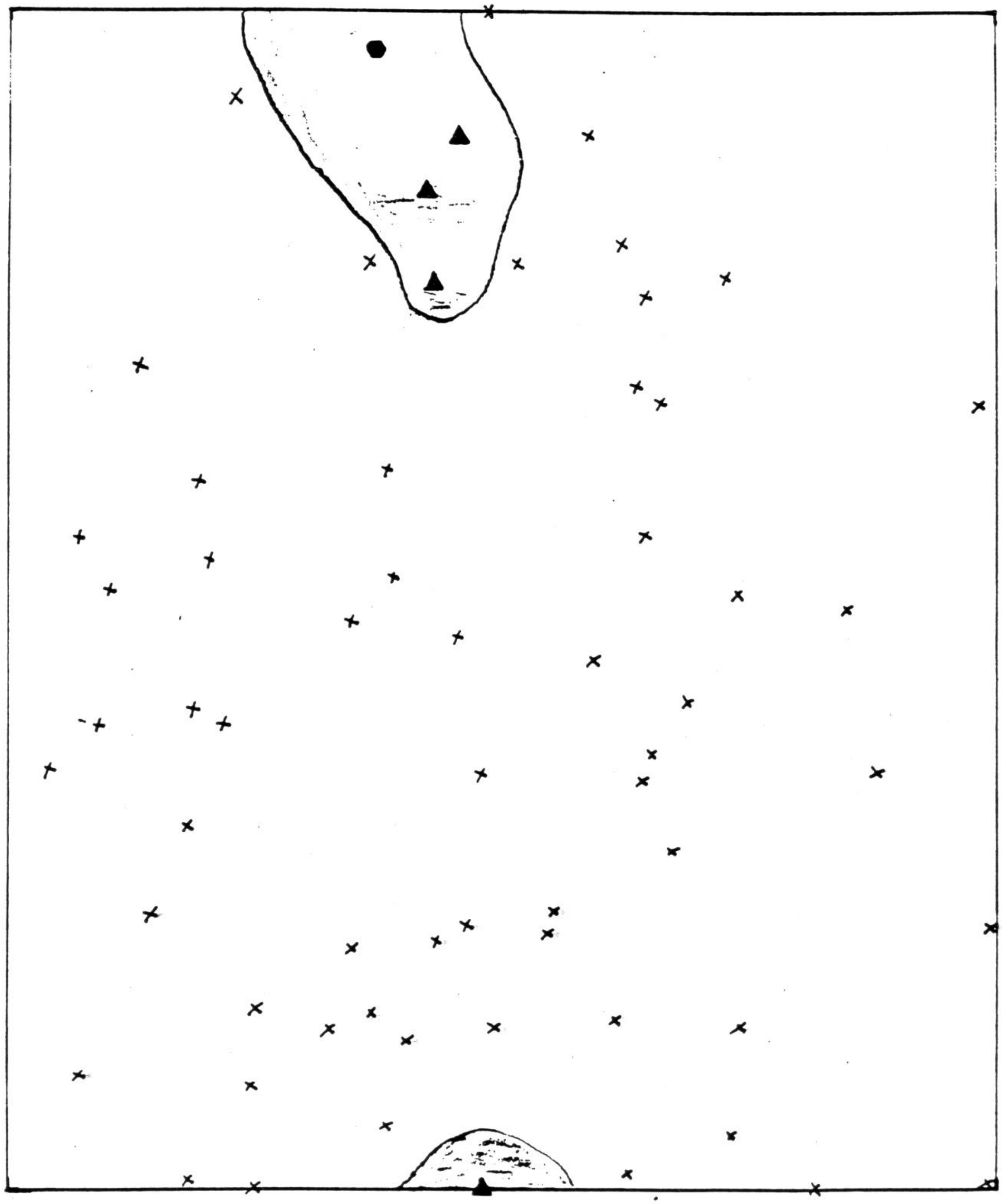
APPENDIX VI

DEER CREEK STUDY AREA

MAJOR FIRE EPISODE - 1893 A.D. (1897-1888)

KEY

○— Oldest origin date(s) at site
○— Origin date(s) - not oldest.
□— Origin date(s) and scar date(s)
△— Scar date(s) only
×— No record of this fire at site



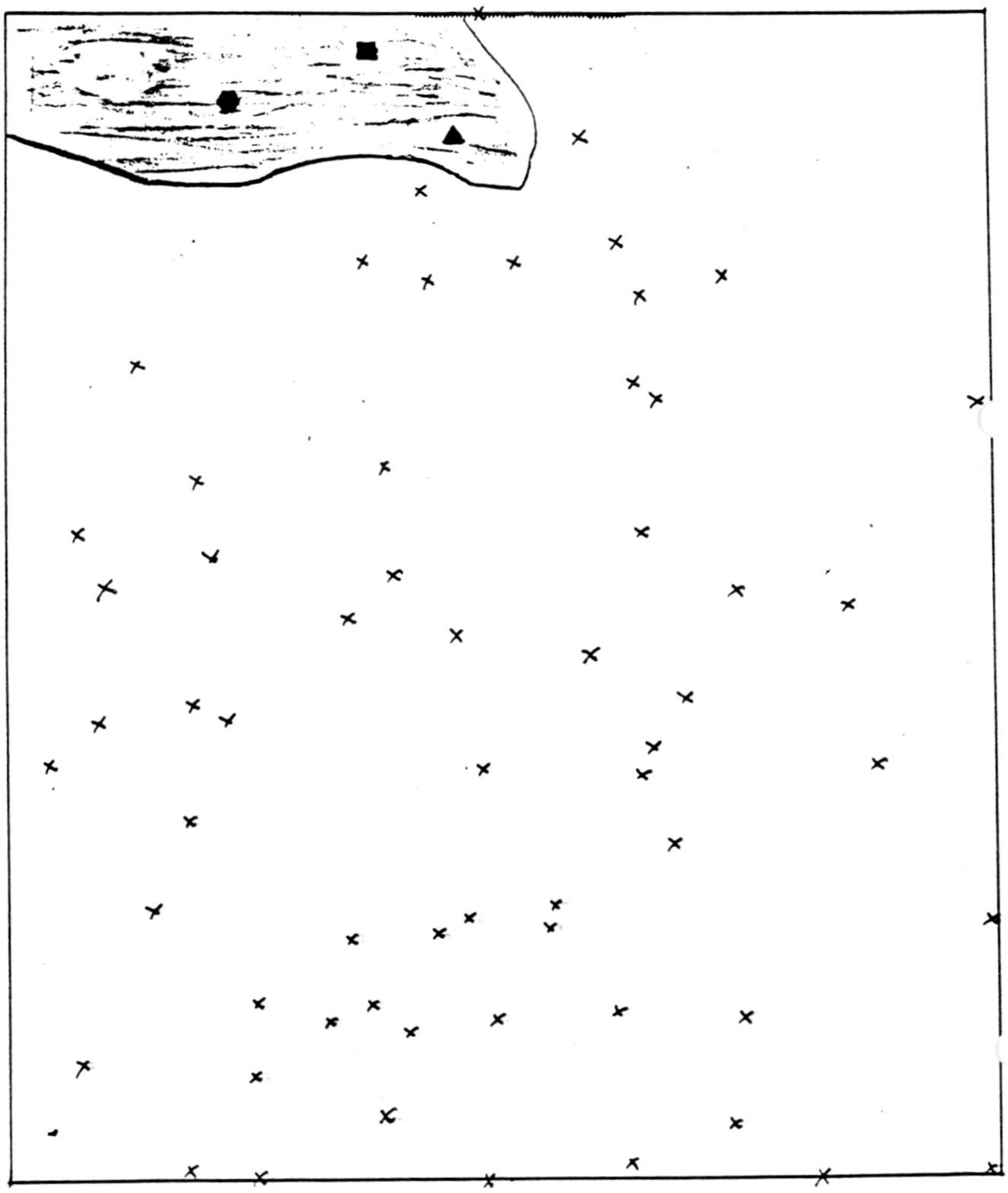
APPENDIX VI (CONTINUED)

DEER CREEK STUDY AREA

MAJOR FIRE EPISODE - 1878 A.D. (1880-1875)

KEY

○— Oldest origin date(s) at site
○— Origin date(s) - not oldest.
□— Origin date(s) and scar date(s)
△— Scar date(s) only
×— No record of this fire at site



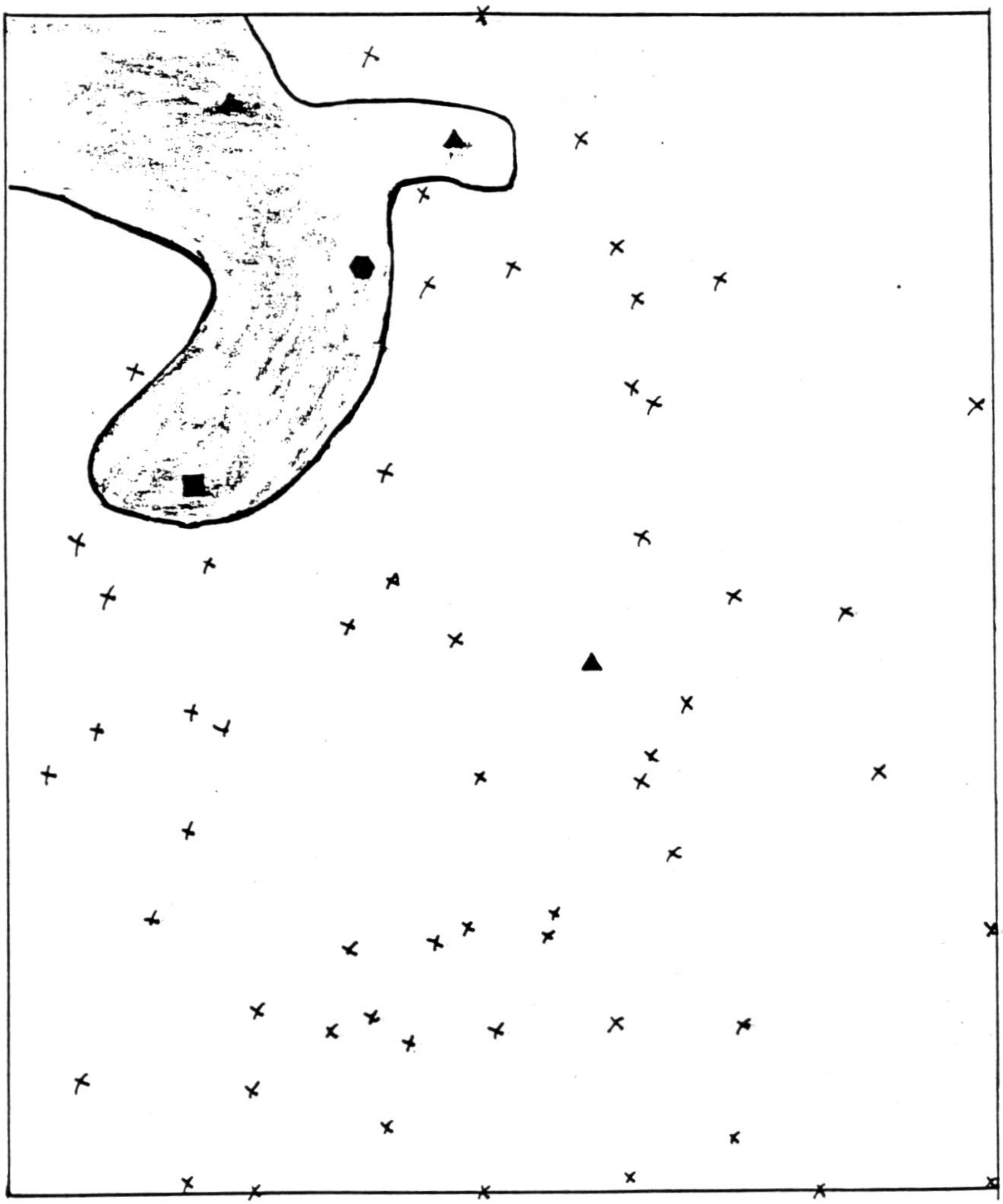
APPENDIX VI (CONTINUED)

DEER CREEK STUDY AREA

MAJOR FIRE EPISODE - 1864 A.D. (1869-1857)

KEY

○— Oldest origin date(s) at site
⬡— Origin date(s) - not oldest.
□— Origin date(s) and scar date(s)
△— Scar date(s) only
×— No record of this fire at site



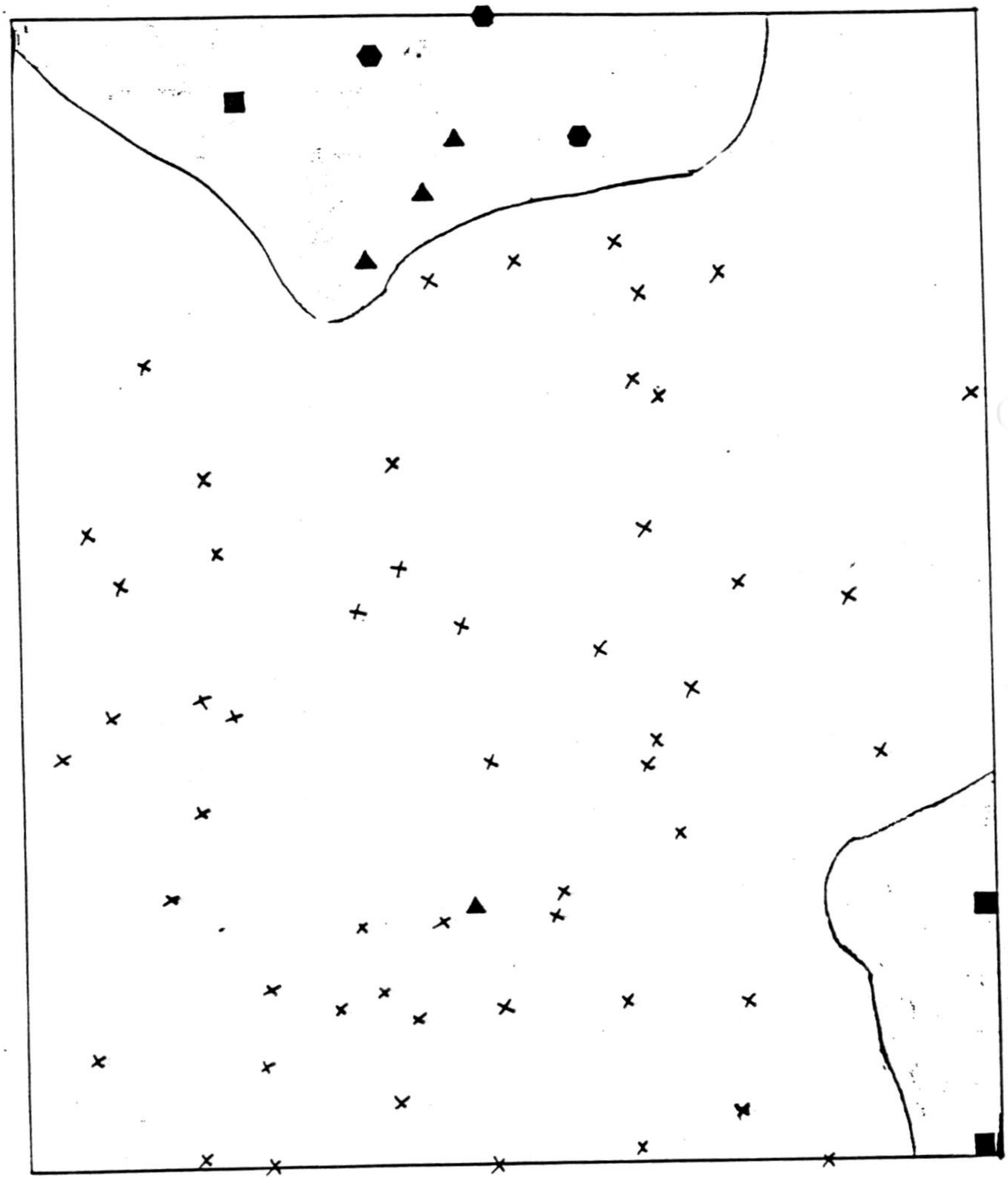
APPENDIX VI (CONTINUED)

DEER CREEK STUDY AREA

MAJOR FIRE EPISODE - 1850 A.D. (1854-1847)

KEY

○— Oldest origin date(s) at site
⬡— Origin date(s) - not oldest.
□— Origin date(s) and scar date(s)
△— Scar date(s) only
×— No record of this fire at site



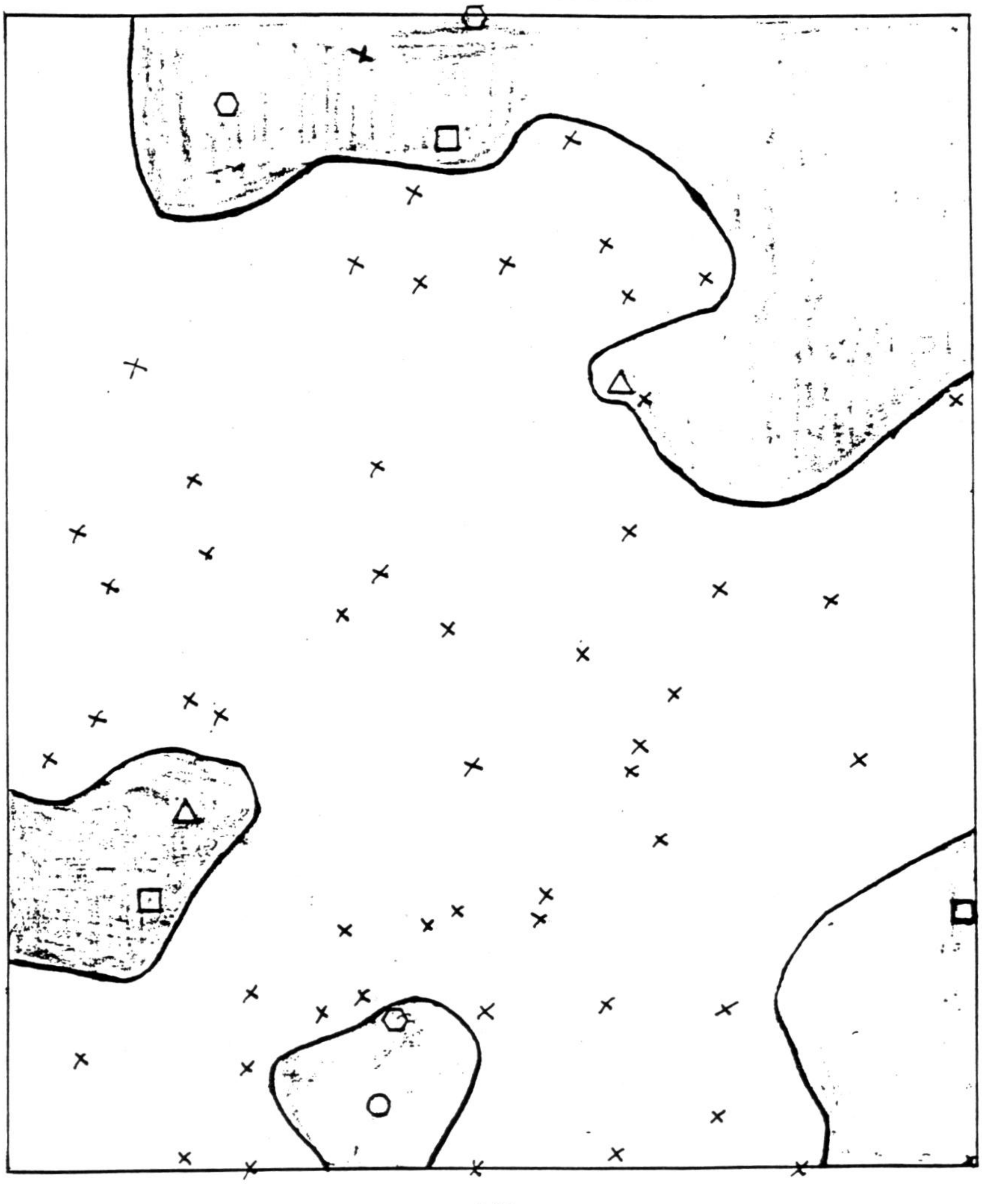
APPENDIX VI (CONTINUED)

DEER CREEK STUDY AREA

MAJOR FIRE EPISODE - 1840 A.D. (1845-1836)

KEY

○— Oldest origin date(s) at site
⬡— Origin date(s) - not oldest.
□— Origin date(s) and scar date(s)
△— Scar date(s) only
×— No record of this fire at site



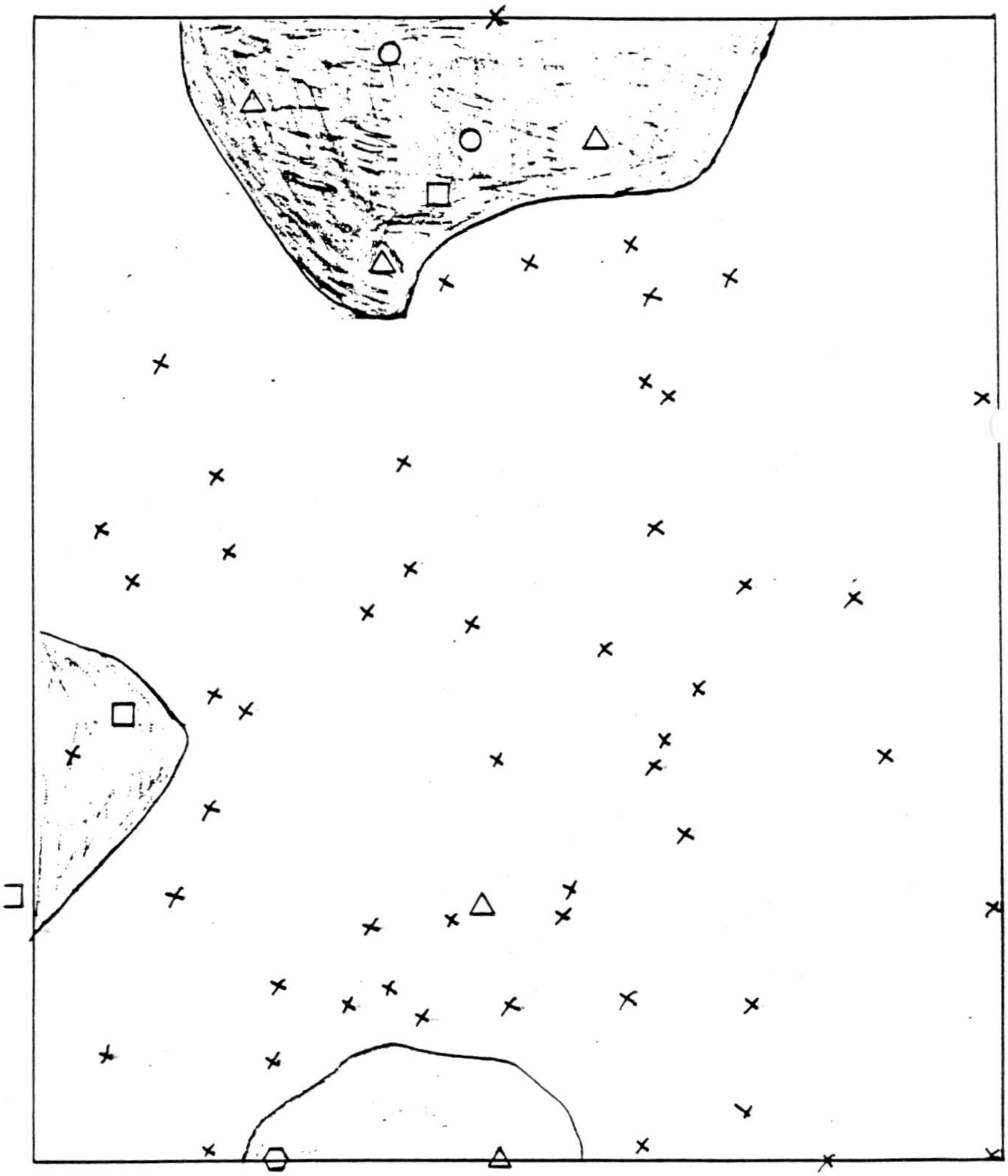
APPENDIX VI (CONTINUED)

DEER CREEK STUDY AREA

MAJOR FIRE EPISODE - 1829 A.D. (1833-1826)

KEY

○— Oldest origin date(s) at site
○— Origin date(s) - not oldest.
□— Origin date(s) and scar date(s)
△— Scar date(s) only
×— No record of this fire at site



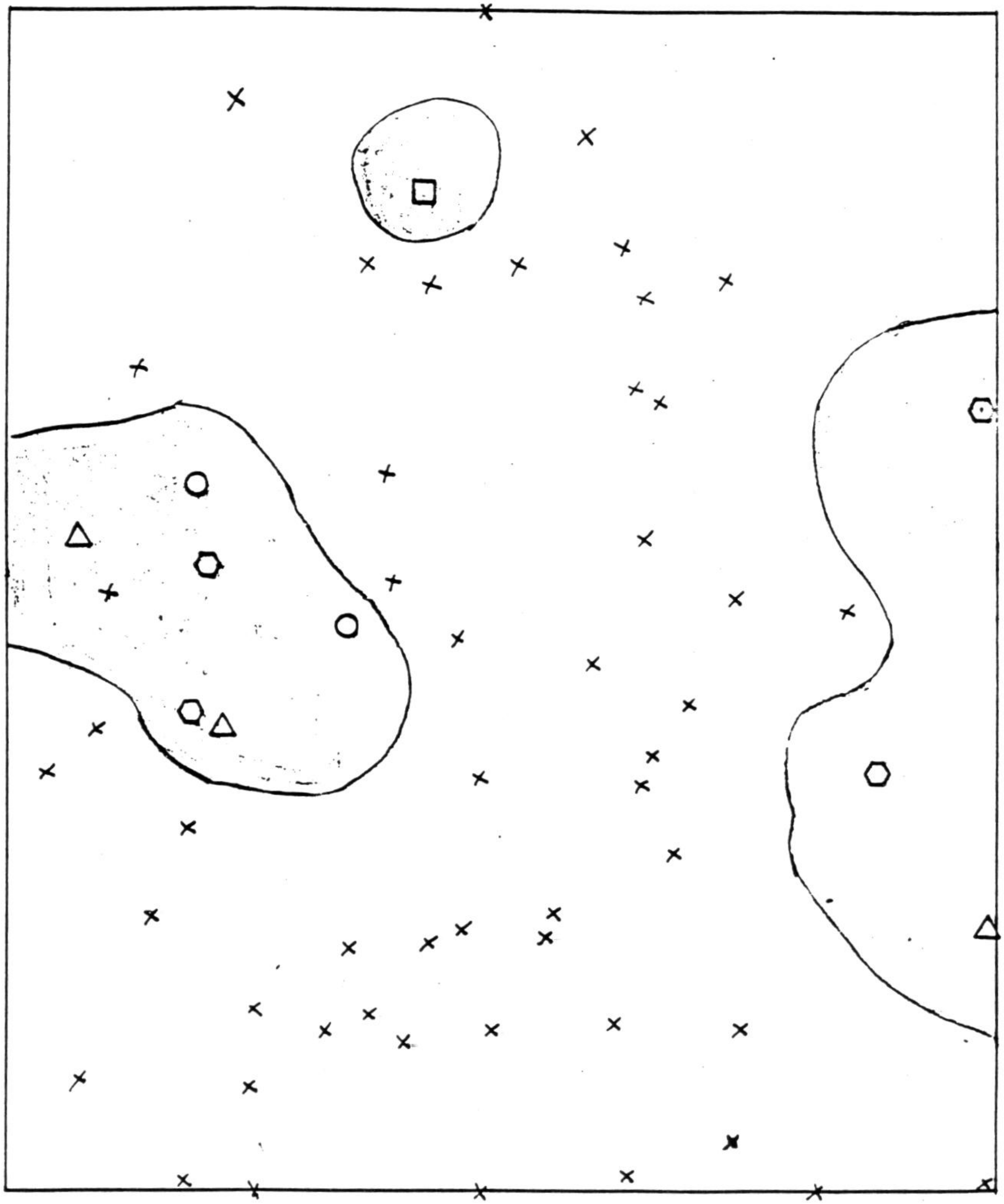
APPENDIX VI (CONTINUED)

DEER CREEK STUDY AREA

MAJOR FIRE EPISODE - 1796 A.D. (1807-1788)

KEY

○— Oldest origin date(s) at site
⬡— Origin date(s) - not oldest.
□— Origin date(s) and scar date(s)
△— Scar date(s) only
×— No record of this fire at site



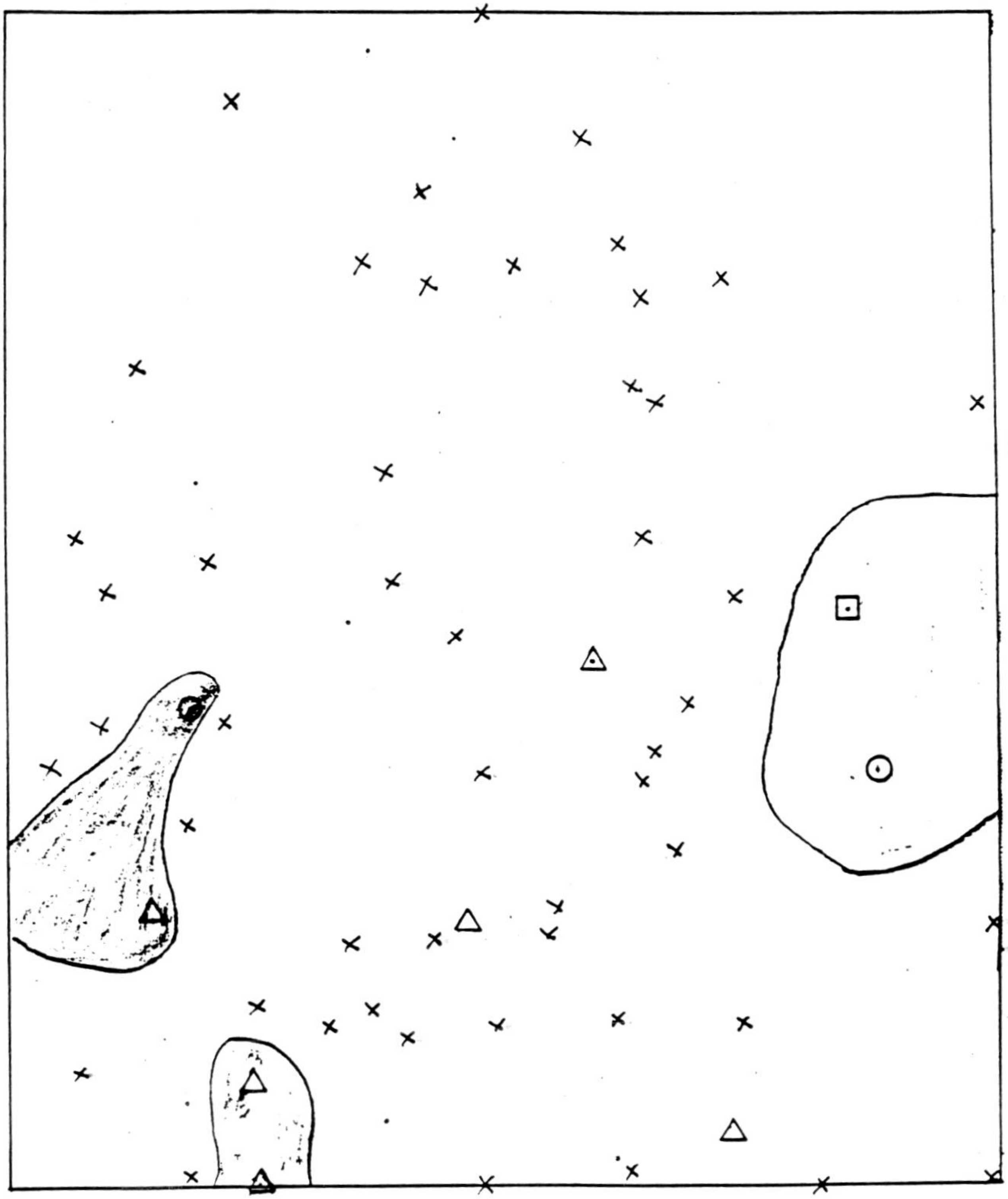
APPENDIX VI (CONTINUED)

DEER CREEK STUDY AREA

MAJOR FIRE EPISODE - 1769 A.D. (1780-1757)

KEY

○— Oldest origin date(s) at site
○— Origin date(s) - not oldest.
□— Origin date(s) and scar date(s)
△— Scar date(s) only
X— No record of this fire at site

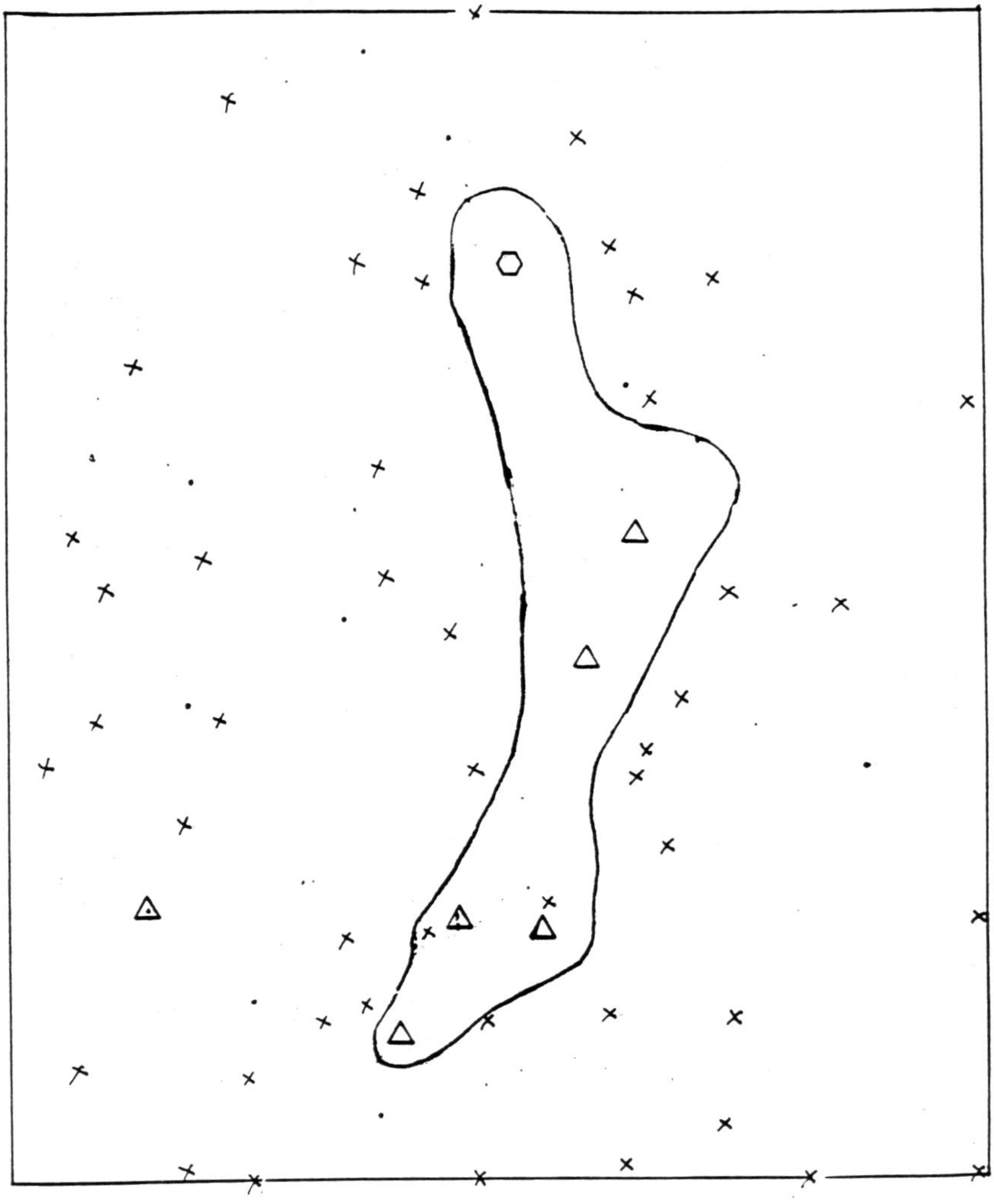


DEER CREEK STUDY AREA

MAJOR FIRE EPISODE - 1740 A.D. (1744-1735)

KEY

○— Oldest origin date(s) at site
⬡— Origin date(s) - not oldest.
□— Origin date(s) and scar date(s)
△— Scar date(s) only
×— No record of this fire at site



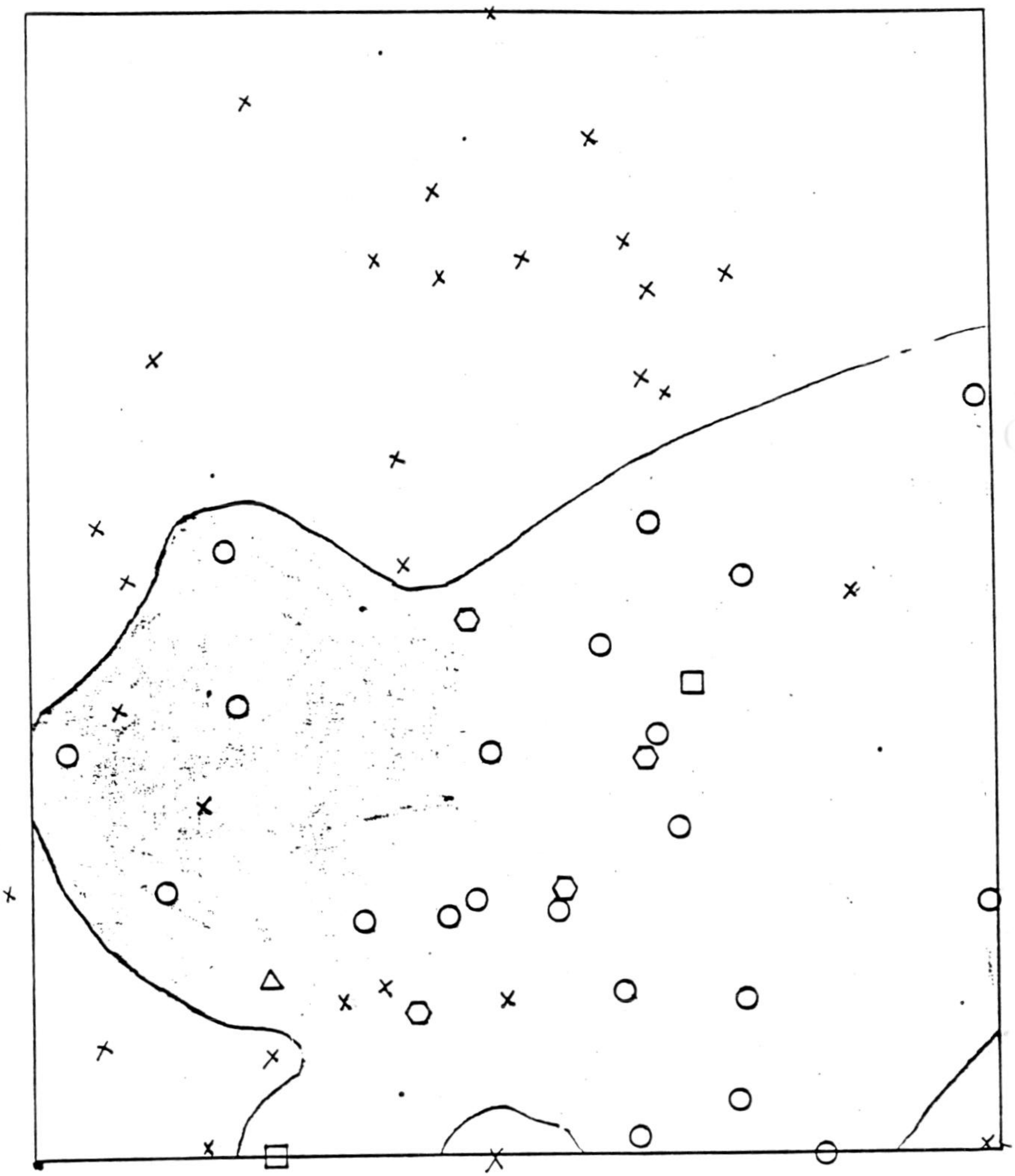
APPENDIX VI (CONTINUED)

DEER CREEK STUDY AREA

MAJOR FIRE EPISODE - 1575 A.D. (1591-1568)

KEY

○— Oldest origin date(s) at site
⬡— Origin date(s) - not oldest.
□— Origin date(s) and scar date(s)
△— Scar date(s) only
×— No record of this fire at site



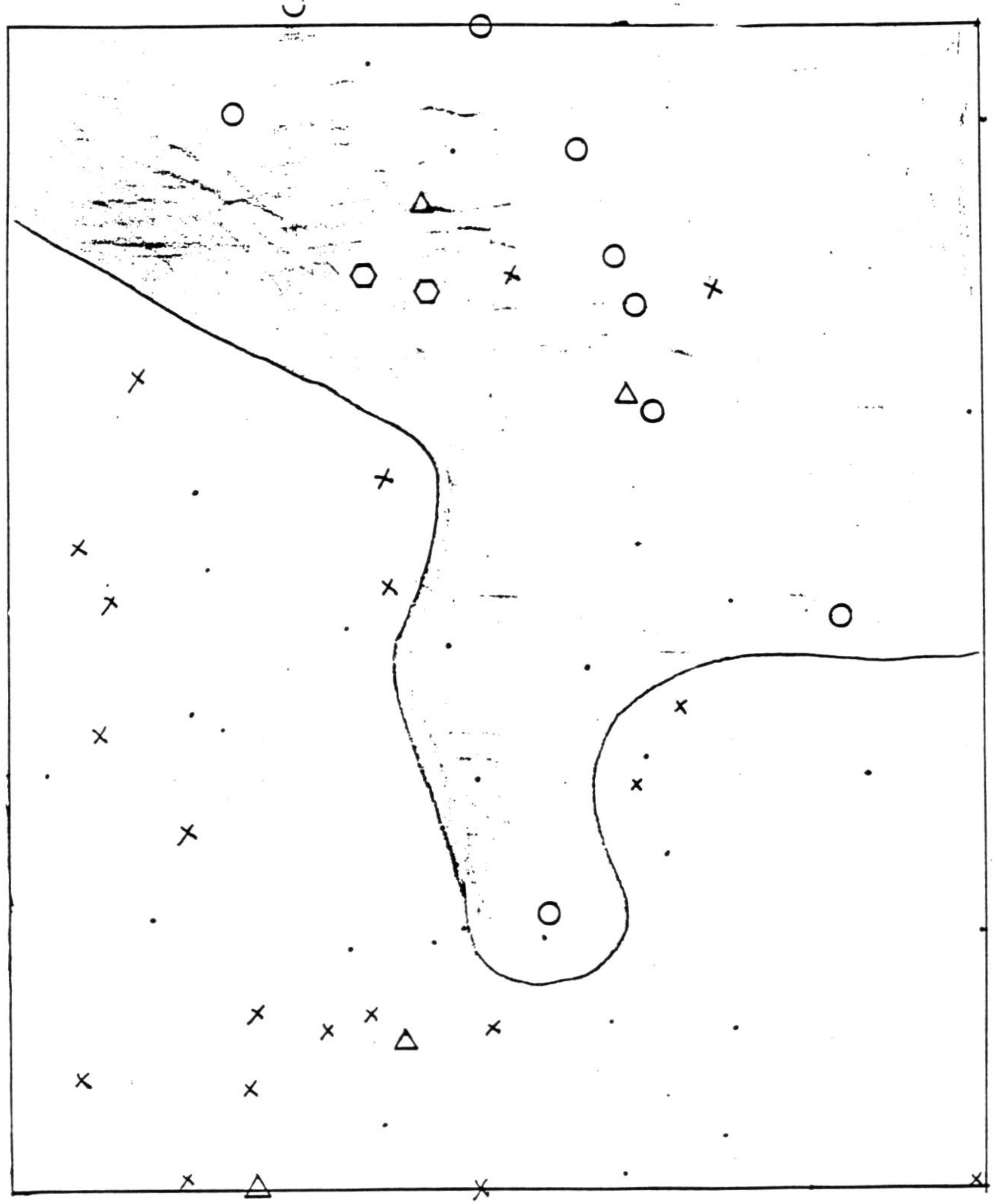
APPENDIX VI (CONTINUED)

DEER CREEK STUDY AREA

MAJOR FIRE EPISODE - 1552 A.D. (1557-1537)

KEY

○— Oldest origin date(s) at site
⬡— Origin date(s) - not oldest.
□— Origin date(s) and scar date(s)
△— Scar date(s) only
×— No record of this fire at site



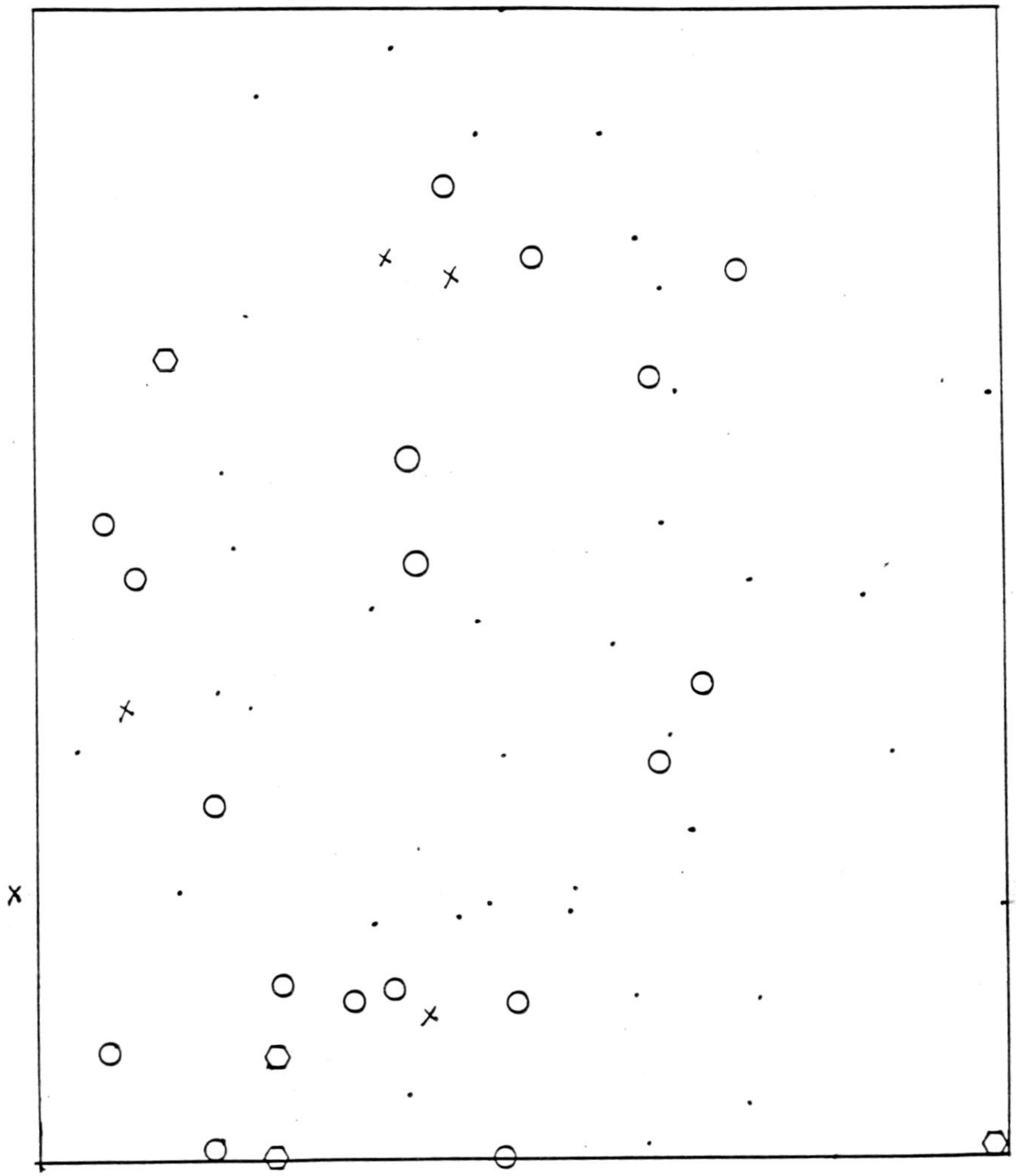
APPENDIX VI (CONTINUED)

DEER CREEK STUDY AREA

MAJOR FIRE EPISODE - 1515 A.D. (1530-1490)

KEY

○— Oldest origin date(s) at site
⬡— Origin date(s) - not oldest.
□— Origin date(s) and scar date(s)
△— Scar date(s) only
×— No record of this fire at site



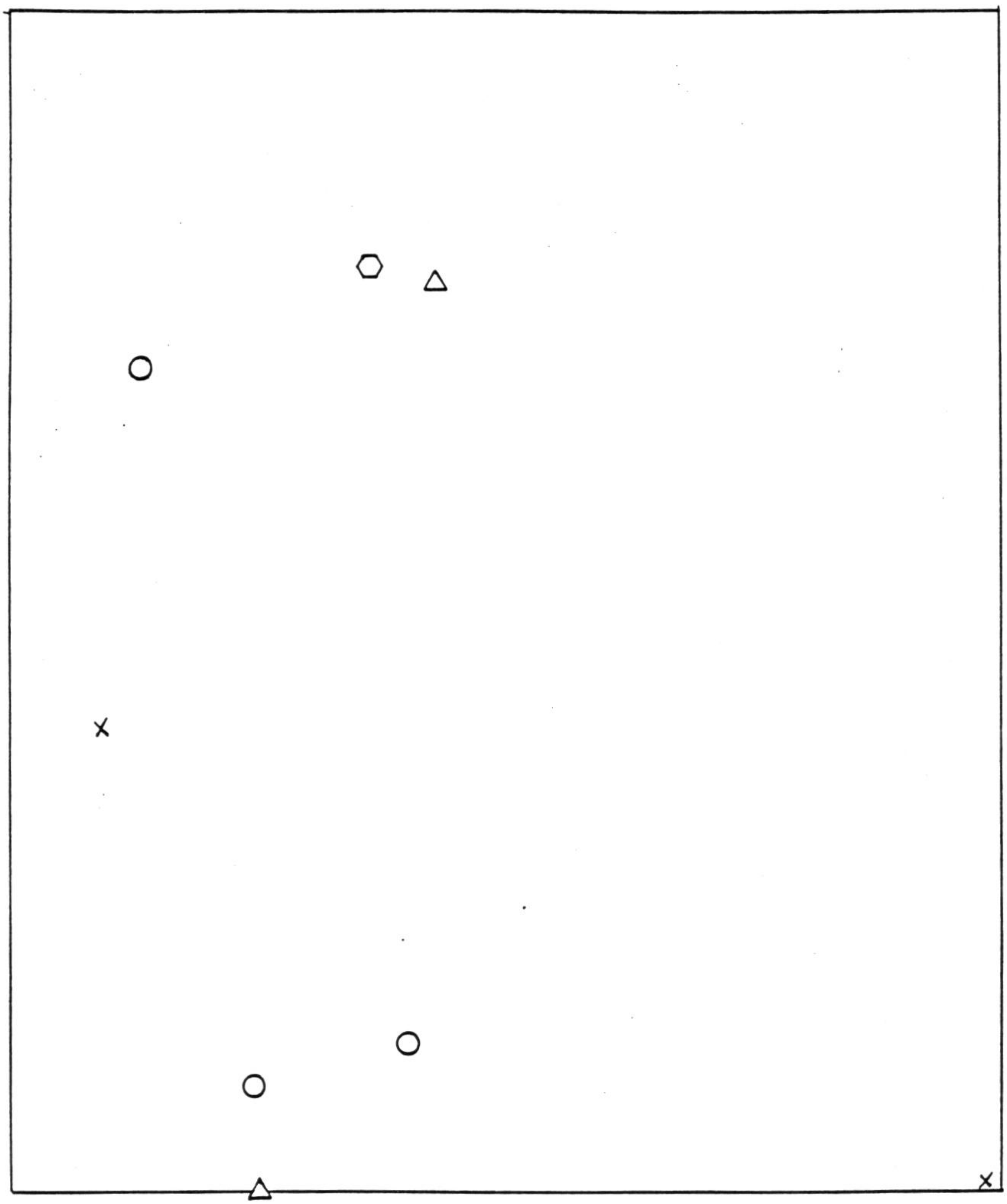
APPENDIX VI (CONTINUED)

DEER CREEK STUDY AREA

MAJOR FIRE EPISODE - 1436 A.D. (1455-1415)

KEY

○— Oldest origin date(s) at site
⬡— Origin date(s) - not oldest.
□— Origin date(s) and scar date(s)
△— Scar date(s) only
×— No record of this fire at site



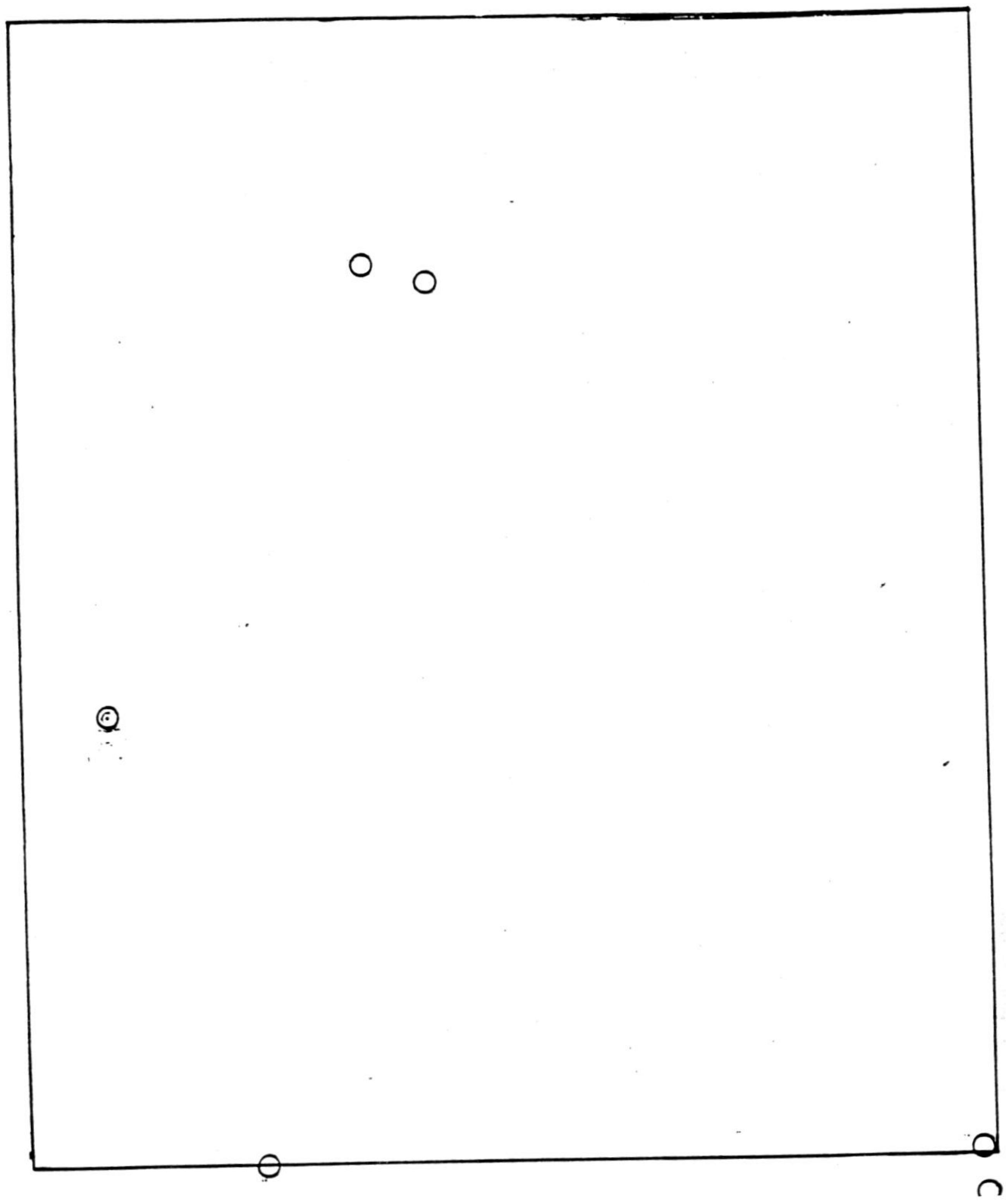
APPENDIX VI (CONTINUED)

DEER CREEK STUDY AREA

MAJOR FIRE PERIOD - 1200 A.D. (1220-1164)

KEY

○— Oldest origin date(s) at site
○— Origin date(s) - not oldest.
□— Origin date(s) and scar date(s)
△— Scar date(s) only
×— No record of this fire at site



APPENDIX VI (CONTINUED)

APPENDIX VII

FIRE RECORD BY SITE

FIRE HISTORY SUMMARY BY SITE

DEER CREEK STUDY AREA

NOTE - RECORD AT SITE CODES ARE AS FOLLOWS:
1 = TREE ORIGIN DATE(S) ONLY,
2 = TREE ORIGIN DATE(S) AND SCAR DATE(S),
3 = SCAR DATE(S) ONLY,
4 = BASED ON APPROXIMATE ORIGIN DATE.

SITE - BR11 ELEVATION - 3600 ASPECT - E 1 FIRE RECORDED
FIRE DATE RECORD AT SITE
1515 (1)
SITE FIRE FREQUENCY - 395 BETWEEN 1910 AD. AND 1515 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - DR01 ELEVATION - 3600 ASPECT - NE 2 FIRES RECORDED
FIRE DATE RECORD AT SITE
1552 (1) 1575 (1)
SITE FIRE FREQUENCY - 179 BETWEEN 1910 AD. AND 1552 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - DR02 ELEVATION - 3600 ASPECT - NE 1 FIRE RECORDED
FIRE DATE RECORD AT SITE
1575 (1)
SITE FIRE FREQUENCY - 335 BETWEEN 1910 AD. AND 1575 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - DR11 ELEVATION - 4200 ASPECT - S 3 FIRES RECORDED
FIRE DATE RECORD AT SITE
1552 (4) 1829 (3) 1850 (1)
SITE FIRE FREQUENCY - 119 BETWEEN 1910 AD. AND 1552 AD.
SITE FIRE FREQUENCY - 55 BETWEEN 1910 AD. AND 1800 AD.

SITE - DR12 ELEVATION - 4000 ASPECT - W 1 FIRE RECORDED
FIRE DATE RECORD AT SITE
1552 (4)
SITE FIRE FREQUENCY - 358 BETWEEN 1910 AD. AND 1552 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - DR13 ELEVATION - 4000 ASPECT - SW 1 FIRE RECORDED
FIRE DATE RECORD AT SITE
1552 (1)
SITE FIRE FREQUENCY - 358 BETWEEN 1910 AD. AND 1552 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - DR15 ELEVATION - 4200 ASPECT - S 4 FIRES RECORDED
FIRE DATE RECORD AT SITE
1575 (1) 1796 (3) 1840 (2) 1850 (2)
SITE FIRE FREQUENCY - 84 BETWEEN 1910 AD. AND 1575 AD.
SITE FIRE FREQUENCY - 55 BETWEEN 1910 AD. AND 1800 AD.

SITE - DR16 ELEVATION - 4000 ASPECT - SW 2 FIRES RECORDED
FIRE DATE RECORD AT SITE
1769 (1) 1796 (1)
SITE FIRE FREQUENCY - 71 BETWEEN 1910 AD. AND 1769 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - DR17 ELEVATION - 4000 ASPECT - NW 2 FIRES RECORDED
FIRE DATE RECORD AT SITE
1552 (1) 1769 (2)
SITE FIRE FREQUENCY - 179 BETWEEN 1910 AD. AND 1552 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - DR18 ELEVATION - 3600 ASPECT - S 1 FIRE RECORDED
FIRE DATE RECORD AT SITE
1575 (1)
SITE FIRE FREQUENCY - 335 BETWEEN 1910 AD. AND 1575 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - DR19 ELEVATION - 3600 ASPECT - W 2 FIRES RECORDED
FIRE DATE RECORD AT SITE
1515 (4) 1575 (4)
SITE FIRE FREQUENCY - 198 BETWEEN 1910 AD. AND 1515 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - DR20 ELEVATION - 3600 ASPECT - W 2 FIRES RECORDED
FIRE DATE RECORD AT SITE
1515 (1) 1575 (2)
SITE FIRE FREQUENCY - 198 BETWEEN 1910 AD. AND 1515 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - DR21 ELEVATION - 3800 ASPECT - S 1 FIRE RECORDED
FIRE DATE RECORD AT SITE
1575 (4)
SITE FIRE FREQUENCY - 335 BETWEEN 1910 AD. AND 1575 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - DR22 ELEVATION - 4000 ASPECT - S 2 FIRES RECORDED
FIRE DATE RECORD AT SITE
1515 (4) 1740 (4)
SITE FIRE FREQUENCY - 198 BETWEEN 1910 AD. AND 1515 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - DR23 ELEVATION - 4200 ASPECT - SE 6 FIRES RECORDED
FIRE DATE RECORD AT SITE
1552 (4) 1829 (3) 1840 (1) 1850 (2) 1864 (3) 1878 (1)
SITE FIRE FREQUENCY - 60 BETWEEN 1910 AD. AND 1552 AD.
SITE FIRE FREQUENCY - 22 BETWEEN 1910 AD. AND 1800 AD.

SITE - DR24 ELEVATION - 4200 ASPECT - SW 3 FIRES RECORDED
FIRE DATE RECORD AT SITE
1552 (4) 1840 (1) 1850 (1)
SITE FIRE FREQUENCY - 119 BETWEEN 1910 AD. AND 1552 AD.
SITE FIRE FREQUENCY - 55 BETWEEN 1910 AD. AND 1800 AD.

SITE - DR25 ELEVATION - 4000 ASPECT - E 6 FIRES RECORDED
FIRE DATE RECORD AT SITE
1200 (4) 1436 (4) 1552 (4) 1829 (3) 1850 (3) 1864 (1)
SITE FIRE FREQUENCY - 118 BETWEEN 1910 AD. AND 1200 AD.
SITE FIRE FREQUENCY - 37 BETWEEN 1910 AD. AND 1800 AD.

SITE - DR26 ELEVATION - 4000 ASPECT - E 1 FIRE RECORDED
FIRE DATE RECORD AT SITE
1515 (1)
SITE FIRE FREQUENCY - 395 BETWEEN 1910 AD. AND 1515 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - DR27 ELEVATION - 4000 ASPECT - S 2 FIRES RECORDED
FIRE DATE RECORD AT SITE
1575 (4) 1796 (1)
SITE FIRE FREQUENCY - 168 BETWEEN 1910 AD. AND 1575 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - DR28 ELEVATION - 3800 ASPECT - SE 1 FIRE RECORDED
FIRE DATE RECORD AT SITE
1515 (4)
SITE FIRE FREQUENCY - 395 BETWEEN 1910 AD. AND 1515 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - DR29 ELEVATION - 3800 ASPECT - E 1 FIRE RECORDED
FIRE DATE RECORD AT SITE
1796 (1)
SITE FIRE FREQUENCY - 114 BETWEEN 1910 AD. AND 1796 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - DR30 ELEVATION - 3600 ASPECT - N 1 FIRE RECORDED
FIRE DATE RECORD AT SITE
1575 (1)
SITE FIRE FREQUENCY - 335 BETWEEN 1910 AD. AND 1575 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - DR31 ELEVATION - 3600 ASPECT - E 1 FIRE RECORDED
FIRE DATE RECORD AT SITE
1575 (4)
SITE FIRE FREQUENCY - 335 BETWEEN 1910 AD. AND 1575 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - DR32 ELEVATION - 3600 ASPECT - E 1 FIRE RECORDED
FIRE DATE RECORD AT SITE
1575 (1)
SITE FIRE FREQUENCY - 335 BETWEEN 1910 AD. AND 1575 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - DR33 ELEVATION - 3200 ASPECT - NE 1 FIRE RECORDED
FIRE DATE RECORD AT SITE
1575 (1)
SITE FIRE FREQUENCY - 335 BETWEEN 1910 AD. AND 1575 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

APPENDIX VII (CONTINUED)

SITE - DR34 ELEVATION - 3200 ASPECT - B 2 FIRES RECORDED
FIRE DATE RECORD AT SITE
1575 (1) 1769 (3)
SITE FIRE FREQUENCY - 168 BETWEEN 1910 AD. AND 1575 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - DR35 ELEVATION - 3200 ASPECT - B 1 FIRE RECORDED
FIRE DATE RECORD AT SITE
1575 (4)
SITE FIRE FREQUENCY - 335 BETWEEN 1910 AD. AND 1575 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - DR50 ELEVATION - 3400 ASPECT - SW 3 FIRES RECORDED
FIRE DATE RECORD AT SITE
1200 (4) 1515 (4) 1850 (2)
SITE FIRE FREQUENCY - 237 BETWEEN 1910 AD. AND 1200 AD.
SITE FIRE FREQUENCY - 110 BETWEEN 1910 AD. AND 1800 AD.

SITE - DR51 ELEVATION - 3400 ASPECT - SW 1 FIRE RECORDED
FIRE DATE RECORD AT SITE
1575 (1)
SITE FIRE FREQUENCY - 335 BETWEEN 1910 AD. AND 1575 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - DR52 ELEVATION - 3600 ASPECT - NE 1 FIRE RECORDED
FIRE DATE RECORD AT SITE
1575 (1)
SITE FIRE FREQUENCY - 335 BETWEEN 1910 AD. AND 1575 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - DR53 ELEVATION - 3600 ASPECT - NE 1 FIRE RECORDED
FIRE DATE RECORD AT SITE
1575 (1)
SITE FIRE FREQUENCY - 335 BETWEEN 1910 AD. AND 1575 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - DR54 ELEVATION - 4200 ASPECT - N 2 FIRES RECORDED
FIRE DATE RECORD AT SITE
1575 (1) 1796 (3)
SITE FIRE FREQUENCY - 168 BETWEEN 1910 AD. AND 1575 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - DR55 ELEVATION - 4200 ASPECT - R 2 FIRES RECORDED
FIRE DATE RECORD AT SITE
1769 (1) 1796 (1)
SITE FIRE FREQUENCY - 71 BETWEEN 1910 AD. AND 1769 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - DR56 ELEVATION - 4000 ASPECT - E 1 FIRE RECORDED
FIRE DATE RECORD AT SITE
1575 (1)
SITE FIRE FREQUENCY - 335 BETWEEN 1910 AD. AND 1575 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

APPENDIX VII (CONTINUED)

SITE - DR57 ELEVATION - 3800 ASPECT - E 4 FIRES RECORDED
FIRE DATE RECORD AT SITE
1200 (1) 1436 (3) 1552 (1) 1893 (3)
SITE FIRE FREQUENCY - 178 BETWEEN 1910 AD. AND 1200 AD.
SITE FIRE FREQUENCY - 110 BETWEEN 1910 AD. AND 1800 AD.

SITE - DR58 ELEVATION - 3800 ASPECT - S 2 FIRES RECORDED
FIRE DATE RECORD AT SITE
1515 (1) 1575 (3)
SITE FIRE FREQUENCY - 198 BETWEEN 1910 AD. AND 1515 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - DR59 ELEVATION - 3800 ASPECT - E 1 FIRE RECORDED
FIRE DATE RECORD AT SITE
1515 (1)
SITE FIRE FREQUENCY - 395 BETWEEN 1910 AD. AND 1515 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - DR60 ELEVATION - 3800 ASPECT - E 4 FIRES RECORDED
FIRE DATE RECORD AT SITE
1436 (1) 1552 (3) 1575 (1) 1840 (1)
SITE FIRE FREQUENCY - 119 BETWEEN 1910 AD. AND 1436 AD.
SITE FIRE FREQUENCY - 110 BETWEEN 1910 AD. AND 1800 AD.

SITE - DR61 ELEVATION - 4200 ASPECT - W 3 FIRES RECORDED
FIRE DATE RECORD AT SITE
1575 (1) 1769 (3) 1840 (2)
SITE FIRE FREQUENCY - 112 BETWEEN 1910 AD. AND 1575 AD.
SITE FIRE FREQUENCY - 110 BETWEEN 1910 AD. AND 1800 AD.

SITE - DR62 ELEVATION - 4400 ASPECT - W 2 FIRES RECORDED
FIRE DATE RECORD AT SITE
1515 (1) 1840 (3)
SITE FIRE FREQUENCY - 198 BETWEEN 1910 AD. AND 1515 AD.
SITE FIRE FREQUENCY - 110 BETWEEN 1910 AD. AND 1800 AD.

SITE - DR64 ELEVATION - 3400 ASPECT - B 4 FIRES RECORDED
FIRE DATE RECORD AT SITE
1575 (1) 1740 (3) 1769 (3) 1864 (3)
SITE FIRE FREQUENCY - 84 BETWEEN 1910 AD. AND 1575 AD.
SITE FIRE FREQUENCY - 110 BETWEEN 1910 AD. AND 1800 AD.

SITE - DR65 ELEVATION - 3600 ASPECT - W 1 FIRE RECORDED
FIRE DATE RECORD AT SITE
1575 (1)
SITE FIRE FREQUENCY - 335 BETWEEN 1910 AD. AND 1575 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - DR66 ELEVATION - 3800 ASPECT - SW 1 FIRE RECORDED
FIRE DATE RECORD AT SITE
1575 (1)
SITE FIRE FREQUENCY - 335 BETWEEN 1910 AD. AND 1575 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - DR67 ELEVATION - 3800 ASPECT - W 3 FIRES RECORDED
FIRE DATE RECORD AT SITE
1515 (1) 1552 (3) 1840 (3)
SITE FIRE FREQUENCY - 132 BETWEEN 1910 AD. AND 1515 AD.
SITE FIRE FREQUENCY - 110 BETWEEN 1910 AD. AND 1800 AD.

SITE - DR68 ELEVATION - 4000 ASPECT - SW 1 FIRE RECORDED
FIRE DATE RECORD AT SITE
1552 (1)
SITE FIRE FREQUENCY - 358 BETWEEN 1910 AD. AND 1552 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - MA08 ELEVATION - 4000 ASPECT - S 2 FIRES RECORDED
FIRE DATE RECORD AT SITE
1515 (4) 1796 (3)
SITE FIRE FREQUENCY - 198 BETWEEN 1910 AD. AND 1515 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - MA09 ELEVATION - 4000 ASPECT - S 1 FIRE RECORDED
FIRE DATE RECORD AT SITE
1515 (4)
SITE FIRE FREQUENCY - 395 BETWEEN 1910 AD. AND 1515 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - MA12 ELEVATION - 4000 ASPECT - N 2 FIRES RECORDED
FIRE DATE RECORD AT SITE
1200 (1) 1829 (2)
SITE FIRE FREQUENCY - 355 BETWEEN 1910 AD. AND 1200 AD.
SITE FIRE FREQUENCY - 110 BETWEEN 1910 AD. AND 1800 AD.

SITE - MA13 ELEVATION - 4000 ASPECT - W 1 FIRE RECORDED
FIRE DATE RECORD AT SITE
1575 (4)
SITE FIRE FREQUENCY - 335 BETWEEN 1910 AD. AND 1575 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - SM03 ELEVATION - 4400 ASPECT - S 2 FIRES RECORDED
FIRE DATE RECORD AT SITE
1796 (1) 1864 (2)
SITE FIRE FREQUENCY - 57 BETWEEN 1910 AD. AND 1796 AD.
SITE FIRE FREQUENCY - 110 BETWEEN 1910 AD. AND 1800 AD.

SITE - SM04 ELEVATION - 4400 ASPECT - R 2 FIRES RECORDED
FIRE DATE RECORD AT SITE
1436 (1) 1515 (1)
SITE FIRE FREQUENCY - 237 BETWEEN 1910 AD. AND 1436 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - WI02 ELEVATION - 4400 ASPECT - SW 2 FIRES RECORDED
FIRE DATE RECORD AT SITE
1575 (4) 1796 (1)
SITE FIRE FREQUENCY - 168 BETWEEN 1910 AD. AND 1575 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

APPENDIX VII (CONTINUED)

SITE - WI03 ELEVATION - 4200 ASPECT - SW 1 FIRE RECORDED
FIRE DATE RECORD AT SITE
1515 (1)
SITE FIRE FREQUENCY - 395 BETWEEN 1910 AD. AND 1515 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - WM01 ELEVATION - 3400 ASPECT - B 7 FIRES RECORDED
FIRE DATE RECORD AT SITE
1200 (1) 1436 (3) 1515 (1) 1552 (3) 1575 (2) 1769 (3) 1829 (1
SITE FIRE FREQUENCY - 101 BETWEEN 1910 AD. AND 1200 AD.
SITE FIRE FREQUENCY - 110 BETWEEN 1910 AD. AND 1800 AD.

SITE - WM02 ELEVATION - 3400 ASPECT - B 3 FIRES RECORDED
FIRE DATE RECORD AT SITE
1515 (1) 1829 (3) 1893 (3)
SITE FIRE FREQUENCY - 132 BETWEEN 1910 AD. AND 1515 AD.
SITE FIRE FREQUENCY - 55 BETWEEN 1910 AD. AND 1800 AD.

SITE - WM03 ELEVATION - 3600 ASPECT - S 1 FIRE RECORDED
FIRE DATE RECORD AT SITE
1840 (1)
SITE FIRE FREQUENCY - 70 BETWEEN 1910 AD. AND 1840 AD.
SITE FIRE FREQUENCY - 110 BETWEEN 1910 AD. AND 1800 AD.

SITE - WR02 ELEVATION - 3600 ASPECT - SW 3 FIRES RECORDED
FIRE DATE RECORD AT SITE
1436 (1) 1515 (1) 1769 (3)
SITE FIRE FREQUENCY - 158 BETWEEN 1910 AD. AND 1436 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - WR03 ELEVATION - 3800 ASPECT - R 1 FIRE RECORDED
FIRE DATE RECORD AT SITE
1515 (1)
SITE FIRE FREQUENCY - 395 BETWEEN 1910 AD. AND 1515 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - WR04 ELEVATION - 4000 ASPECT - R 1 FIRE RECORDED
FIRE DATE RECORD AT SITE
1515 (4)
SITE FIRE FREQUENCY - 395 BETWEEN 1910 AD. AND 1515 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - WR05 ELEVATION - 4000 ASPECT - NE 1 FIRE RECORDED
FIRE DATE RECORD AT SITE
1515 (4)
SITE FIRE FREQUENCY - 395 BETWEEN 1910 AD. AND 1515 AD.
NO FIRES BETWEEN 1910 AD. AND 1800 AD.

SITE - 0305 ELEVATION - 4200 ASPECT - SE 3 FIRES RECORDED
FIRE DATE RECORD AT SITE
1850 (1) 1878 (2) 1893 (1)
SITE FIRE FREQUENCY - 20 BETWEEN 1910 AD. AND 1850 AD.
SITE FIRE FREQUENCY - 37 BETWEEN 1910 AD. AND 1800 AD.

APPENDIX VII (CONTINUED)

SITE - 0306 ELEVATION - 4200 ASPECT - S 6 FIRES RECORDED
FIRE DATE RECORD AT SITE
1829 (1) 1840 (2) 1850 (3) 1864 (3) 1878 (3) 1893 (3)
SITE FIRE FREQUENCY - 14 BETWEEN 1910 AD. AND 1829 AD.
SITE FIRE FREQUENCY - 18 BETWEEN 1910 AD. AND 1800 AD.

SITE - 0307 ELEVATION - 4000 ASPECT - S 6 FIRES RECORDED
FIRE DATE RECORD AT SITE
1515 (1) 1552 (3) 1796 (2) 1829 (3) 1850 (3) 1893 (3)
SITE FIRE FREQUENCY - 66 BETWEEN 1910 AD. AND 1515 AD.
SITE FIRE FREQUENCY - 37 BETWEEN 1910 AD. AND 1800 AD.

AVERAGE SITE FIRE FREQUENCY - 233.2

APPENDIX VIII
SUMMARY OF FIRE HISTORY AT EACH SITE
DEER CREEK STUDY AREA

SITE	ELEVATION	ASPECT	#FIRES	#AGECL	#UNDER	SFF1	SFF2	RECYRS
BR11	3600	E	1	1	0	395	395	395
DR01	3600	NE	2	2	0	179	179	358
DR02	3600	NE	1	1	0	335	335	335
DR11	4200	S	3	2	1	119	179	358
DR12	4000	W	1	1	0	358	358	358
DR13	4000	SW	1	1	0	358	358	358
DR15	4200	S	4	3	1	84	112	335
DR16	4000	SW	2	2	0	71	71	141
DR17	4000	NW	2	2	0	179	179	358
DR18	3600	S	1	1	0	335	335	335
DR19	3600	W	2	2	0	198	198	395
DR20	3600	W	2	2	0	198	198	395
DR21	3800	S	1	1	0	335	335	335
DR22	4000	S	2	2	0	198	198	395
DR23	4200	SE	6	4	2	60	90	358
DR24	4200	SW	3	3	0	119	119	358
DR25	4000	E	6	4	2	118	178	710
DR26	4000	E	1	1	0	395	395	395
DR27	4000	S	2	2	0	168	168	335
DR28	3800	SE	1	1	0	395	395	395
DR29	3800	E	1	1	0	114	114	114
DR30	3600	N	1	1	0	335	335	335
DR31	3600	E	1	1	0	335	335	335
DR32	3600	E	1	1	0	335	335	335
DR33	3200	NE	1	1	0	335	335	335
DR34	3200	B	2	1	1	168	335	335
DR35	3200	B	1	1	0	335	335	335
DR50	3400	SW	3	3	0	237	237	710
DR51	3400	SW	1	1	0	335	335	335
DR52	3600	NE	1	1	0	335	335	335
DR53	3600	NE	1	1	0	335	335	335
DR54	4200	N	2	1	1	168	335	335
DR55	4200	R	2	2	0	71	71	141
DR56	4000	E	1	1	0	335	335	335
DR57	3800	E	4	2	2	178	355	710
DR58	3800	S	2	1	1	198	395	395
DR59	3800	E	1	1	0	395	395	395
DR60	3800	E	4	3	1	119	158	474
DR61	4200	W	3	2	1	112	168	335
DR62	4400	W	2	1	1	198	395	395
DR64	3400	B	4	1	3	84	335	335
DR65	3600	W	1	1	0	335	335	335
DR66	3800	SW	1	1	0	335	335	335
DR67	3800	W	3	1	2	132	395	395
DR68	4000	SW	1	1	0	358	358	358
MA08	4000	S	2	1	1	198	395	395
MA09	4000	S	1	1	0	395	395	395
MA12	4000	N	2	2	0	355	355	710
MA13	4000	W	1	1	0	335	335	335
SM03	4400	S	2	2	0	57	57	114
SM04	4400	R	2	2	0	237	237	474
WI02	4400	SW	2	2	0	168	168	335
WI03	4200	SW	1	1	0	395	395	395
WM01	3400	B	7	4	3	101	178	710
WM02	3400	B	3	1	2	132	395	395
WM03	3600	S	1	1	0	70	70	70
WR02	3600	SW	3	2	1	158	237	474
WR03	3800	R	1	1	0	395	395	395
WR04	4000	R	1	1	0	395	395	395
WR05	4000	NE	1	1	0	395	395	395
0305	4200	SE	3	3	0	20	20	60
0306	4200	S	6	2	4	14	41	81
0307	4000	S	6	2	4	66	198	395

AVE. NO. OF FIRES PER SITE - 2.1
AVE. NO. OF AGE CLASSES PER SITE - 1.6
AVE. NO. OF UNDER BURNS PER SITE - 0.5
AVERAGE SITE FIRE FREQUENCY (ALL FIRES) - 233
AVERAGE SITE FIRE FREQUENCY OF STAND REPLACEMENT OR PARTIAL STAND REPLACEMENT FIRES - 272

#FIRES = Number of total fires at site
#AGECL = Number of age classes at site
#UNDER = Number of underburns at site
SFF1 = Site fire frequency (years) of all fires
SFF2 = Site fire frequency (years) of stand replacement and partial stand replacement fires
RECYRS = Length of record at site (years back from 1910 AD)

APPENDIX IX

Overall Aspect and Elevation Distribution
Deer Creek Study Area

Aspect	N	NE	E	SE	S	SW	W	NW	Ridge	Bottom
% of study area	4.5	8	15.5	9	19	16	14	4.5	4.5	5

Elevation	% of study area
< 2500 feet	0
2500 - 2999 feet	0
3000 - 3499 feet	10
3500 - 3999 feet	31
4000 - 4499 feet	56
> 4500 feet	6

Aspect and Elevation Distribution of Sample Sites
Deer Creek Study Area

Aspect	N	NE	E	SE	S	SW	W	NW	Ridge	Bottom
No. of sites	3	6	10	3	13	10	8	1	4	5
% of sites	4.8	9.5	15.9	4.8	20.6	15.9	12.7	1.6	6.3	7.9

Elevation	No. of Sites	% of Sites
< 2500 feet	0	0
2500 - 2999 feet	0	0
3000 - 3499 feet	8	12.7
3500 - 3999 feet	24	38.1
4000 - 4499 feet	31	49.2
> 4500 feet	0	0