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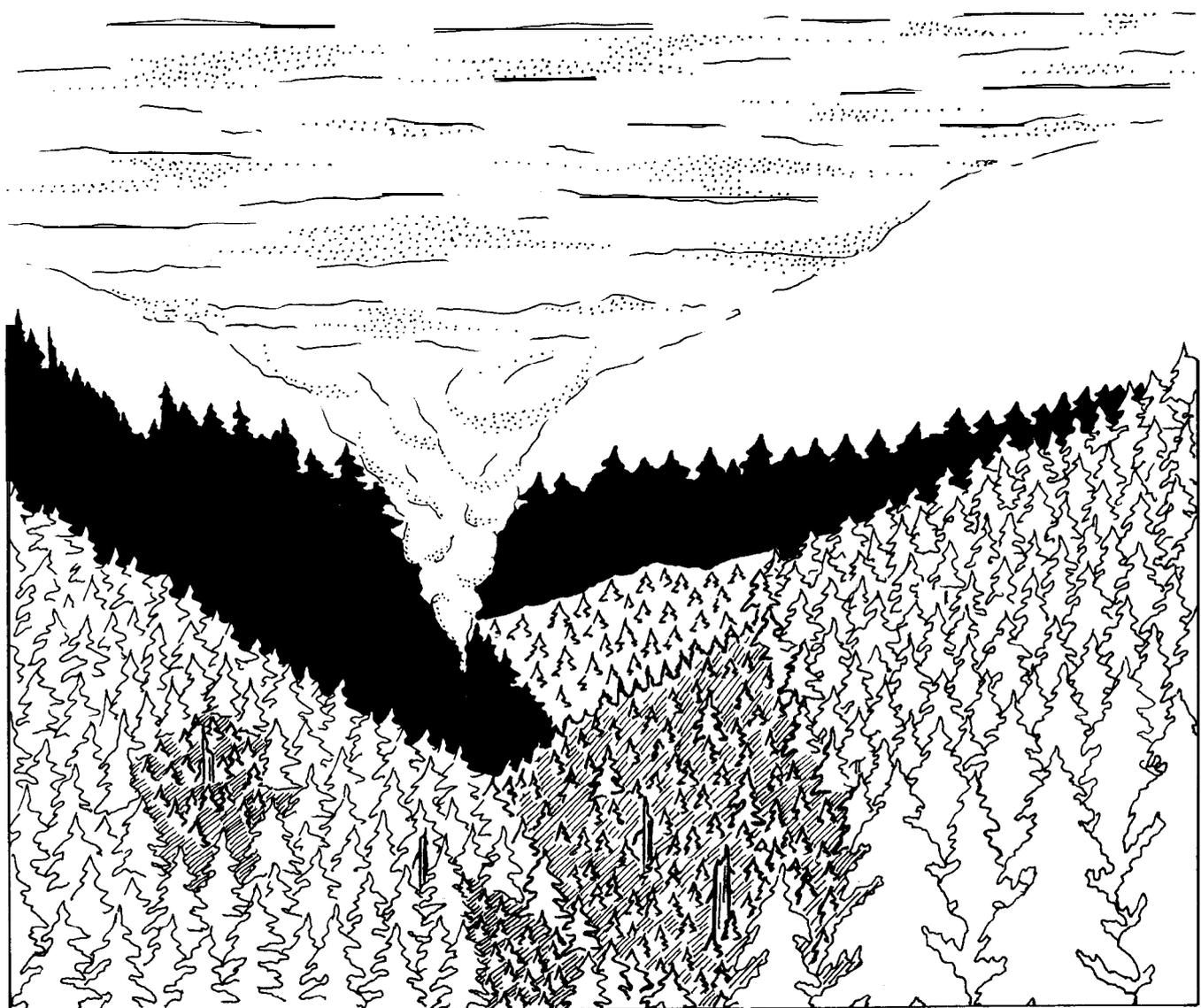
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Fire History and Pattern in a Cascade Range Landscape

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Abstract

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Fire history from years 1150 to 1985 was reconstructed by analyzing forest stands in two 1940-hectare areas in the central-western Cascade Range of Oregon. Serving as records for major fire episodes, these stands revealed a highly variable fire regime. The steeper, more dissected, lower elevation Cook-Quentin study area experienced more frequent fires (natural fire rotation = 95 years) that were commonly low to moderate in severity. The Deer study area, with its cooler, moister conditions and gentler topography, had a regime of less frequent (natural fire rotation = 149 years), predominantly stand-replacement fires. Fires created a complex mosaic of stands with variable date and severity of last burn. Fire-created forest patches originating in 1800-1900 are mostly less than 10 hectares. Since 1900, very little of the study areas burned, possibly because of fire suppression. Old-growth forest conditions have persisted on some sites through numerous fires and over many centuries.

Keywords: History (fire), patch dynamics, old-growth forest, wildfire fire ecology.

Summary

Fire history from years 1150 to 1985 was reconstructed by analyzing forest stands in two 1940-hectare areas in the central-western Cascade Range of Oregon. The purpose of this study was to understand the natural regime of wildfire, the dominant, natural disturbance process in this area. This understanding can serve as a reference point for interpreting the effects of forest management practices on the patterns of forest vegetation across the landscape. Altered landscape patterns of forest cover, whether by wildfire, management activities, or other processes, can profoundly affect wildlife, drainage basin hydrology, and characteristics of large-scale ecosystems.

Based on tree-ring records observed on stumps in clearcuts and road rights-of-way, the records of major fire episodes revealed a highly variable fire regime. Some sites burned at a 20-year frequency, and others had not burned for over 400 years. The Cook-Quentin study area, which is the steeper, more dissected, lower elevation site of the two areas, experienced more frequent fires (natural fire rotation = 95 years) that were commonly low to moderate in severity. The Deer study area, which has cooler, moister conditions and gentler topography, has a regime of less frequent (natural fire rotation = 149 years), predominantly stand-replacement fires. Fires have created a complex mosaic of stands with variable date and severity of last burn. Patches originating from fires from 1800 to 1900 are mostly less than 10 hectares, although burning in a single fire episode could be widespread, as is indicated by common fire episode dates at sites separated by 10 kilometers.

Fires have not been uniformly distributed through time. Fires were uncommon between about 1580 and 1650 in both areas and from 1580 to 1800 in Deer study area for unknown reasons. Since 1900, very little of the study areas burned, possibly because of fire suppression. The frequency of documented lightning-set fires indicates that lightning was a sufficient source to account for the observed fire record. Indians living in the area may also have been a source of ignition in the presettlement period.

At least two fire regimes were observed in these two study areas. The higher elevation, low relief Deer study area experienced more infrequent, high-severity fire. A more widespread pattern found in both the Cook-Quentin study area and a broader area of reconnaissance study revealed a fire regime with more frequent, more low to moderate severity, and patchier fire than previously recognized. As a consequence of this fire regime, some forest areas at both stand (1 hectare) and landscape (hundreds of hectares) scales have sustained old-growth characteristics through numerous fires and over many centuries.

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Introduction

Wildfires have been a major, natural disturbance in the forest landscape of the central-western Cascade Range of Oregon. Viewing the landscape from a high point, one can see that fires of variable intensity and areal extent have created a complex mosaic of forest patches. In the past, fire was an integral part of the ecosystem, affecting wildlife habitat, forest stand dynamics, soil properties, and watershed hydrology. Fire suppression since the turn of the century and logging since about 1950 have changed the extent and role of fire in this landscape.

The tree-ring record of forests in this area embody the history of fires over the last 800 years. The time is now optimum for reading this record-over the past several decades about 30 to 40 percent of the central-western Cascade Range has been clearcut, so the tree-ring record can be observed readily on the surfaces of stumps. Only in the oldest of these clearcuts have the stumps decomposed so that the record is becoming lost. The geographic pattern of forest age-classes before cutting can be interpreted from aerial photographs predating significant logging.

We undertook this study to capitalize on the opportunity to interpret the record of forest history before it is lost and to establish an understanding of the natural disturbance regime of these forests. Knowledge of natural forest dynamics serves as a useful reference for evaluating the effects of forest management practices on all aspects of ecosystem structure and function.

In this study, we examined the natural characteristics of fires, including their frequency, severity, and geographic patterns over the last 800 years. This work began with a reconnaissance study of forest history in a 490-square-kilometer (km^2) area of forest land east of Eugene, Oregon (fig. 1). This preliminary study revealed a forest of very complex structure resulting from a complex fire regime. The great complexity of the forest fire history led to the detailed study of two 1940-hectare (ha) areas reported here. These two areas lie within the large reconnaissance study area and represent the range of fire regimes in terms of frequency, areal extent, and severity of burning.

Examination of this fire history leads to questions about human impacts on fire and about implications of the historical fire regime for forest management. The roles of native people and white explorers, trappers, and ultimately settlers in the area must be addressed in interpreting periods of high and low fire frequency. In this study, the processes we found to be responsible for the origin and maintenance of old-growth forest conditions, which are widespread in this landscape, are counter to what our understanding was at the beginning of the study. These new insights can guide future forest management.

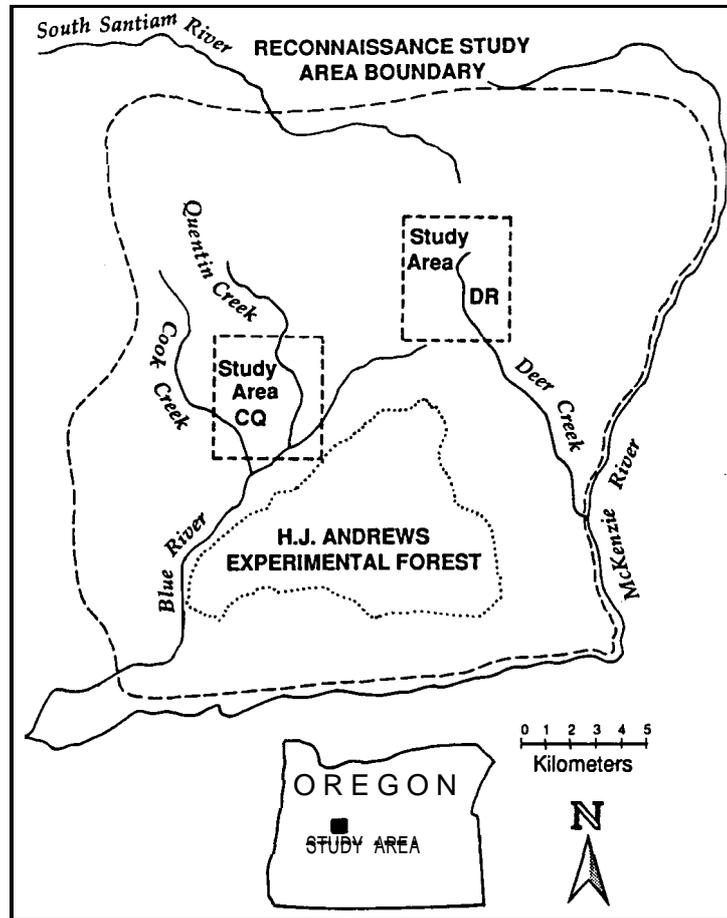


Figure 1-Location of study areas.

Fire and Fire History
Research in the
Cascade Range

Forest fire has been one of the primary disturbance mechanisms affecting natural forests in the central-western Cascade Range of Oregon for at least 10,000 years. Charcoal layers are present throughout a core of Wolf Meadow (in the eastern part of the study area) with some charcoal streaks below Mazama ash (6,700 years before present). Forest fires in the Cascade Range have been observed and recorded since at least 1850 (Burke 1979, Martin and others 1976, Plummer 1903). Throughout the area, charred bark and fire scars are found on surviving conifers. Charcoal is on the forest floor and in upper soil horizons at most sites. Burke (1979) summarizes written records of the extensive history of fires in the central-western Cascade Range. A series of previous studies records an apparent decrease in natural fire size and severity and an increase in frequency along a transect extending from Mount Rainier to northern California.

The fire history of Mount Rainier National Park was documented by Hemstrom and Franklin (1982). They describe a fire regime of infrequent, widespread, stand-replacement fires as characteristic of the park. The study was based primarily on stand age data from increment core samples. A natural fire rotation of 465 years is estimated for 1200-1850.

The fire regime recorded in old-growth Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) (scientific names of plants are from Hitchcock and Cronquist (1973)) forests northeast of Mount St. Helens includes large stand-replacement fires and relatively frequent, low-severity fires (Yamaguchi 1986). The fire frequency of these low-severity fires was one fire per 40 to 50 years during the first 150 years of stand development and one fire per 125 to 150 years thereafter.

In a study of the developmental history of dry, coniferous forests in the central-western Cascade Range, Means (1981) observes a mean fire interval of 103 years for all dry-site plots and a mean fire interval of 144 years for all plots in the western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) zone. Many of Mean's study sites are within 10 km of areas considered in this study.

Stewart (1984, 1986) describes the forest structure of the western hemlock-Pacific silver fir (*Abies amabilis* Dougl. ex Forbes) transition zone at 10 sites, 7 km north-west of the Cook-Quentin study area. He notes 15 fires over an interval of 750 years and concluded that periodic fires of variable severity and extent create an age-class patch mosaic. He found both multiaged and even-aged stands. Many of his fire dates correspond closely with those found in this study.

In the Klamath Mountains, further south, Atzet and others (1988) report fire frequency ranging from 15 to 50 years in series of sites extending from the Ashland watershed, westward through the Kalmiopsis Wilderness. Individual fires in this area ranged from severe to light, as evidenced by the spatial complexity-of burn severity in the 1987 Silver Complex Fire.

These studies and unpublished observations suggest a general pattern of increased frequency and decreased severity of natural fires from north to south down the Cascade Range to the Klamath Mountains in southwest Oregon. The areas examined in this study lie midway in this gradient and include sites with quite varied fire regimes.

In addition to these natural fire patterns, the fire regime of the Pacific Northwest in this century has included 10 000+ ha human-caused, stand-replacement fires. Some of the extensive areas burned by the initial Yaoclt (1902) and Tillamook (1933) fires (Moms 1934) were subsequently reburned. Reestablishment of trees was consequently suppressed by severely limited seed source, brush establishment, altered soil-nutrient status and microbiology, and possibly other effects. Portions of these burned areas are requiring many decades for successful reforestation, despite intensive management efforts.

In the initial reconnaissance study area, several medium-size, stand-replacement fires caused by human activity have been documented in the early part of this century (Burke 1979). In 1911, the Seven-Mile Fire (8 km north of the Cook-Quentin study area) burned about 1500 ha in one stand-replacement patch (Burke 1979). This area had previously been burned in 1885 and 1897 and partially burned in 1936 (Burke 1979, Plummer 1903). Immediately north of the Cook-Quentin study area is a 250-ha patch burned by a stand-replacement fire in 1911. Directly south of the Deer study area, the predominantly stand-replacement Carpenter Mountain Fire (1912) burned about 400 ha.

Description of the Study Areas

Location and physiography-The reconnaissance study area is in the Willamette National Forest. The area includes some private timberland and portions of the McKenzie River and South Santiam River watersheds. The two areas that were selected for more intensive analysis are centrally located in the reconnaissance area (fig. 1), and each covers 1940 ha.

Both study areas are at mid-elevation in the central-western Cascade Range and within major south-draining watersheds. The Cook-Quentin study area (fig. 2) consists of steep, dissected topography with deep, V-shaped valleys and sharp ridges. This topography developed predominantly through the influence of mass wasting, surface erosion, and fluvial erosion. Glacial activity played a minor role. The elevation of Cook-Quentin study area ranges from 524 meters (m) above sea level along Blue River to 1295 m in the northwest corner of the study area with an average elevation of about 820 m.

The Deer study area (fig. 3) consists of more gentle topography with broad valleys and ridge tops. Pleistocene glaciers sculpted these landforms and mass wasting; surface erosion and fluvial erosion have also been important. The elevation ranges from 914 m on Deer Creek to 1832 m at the summit of Wildcat Mountain, and the average elevation is about 1220 m.

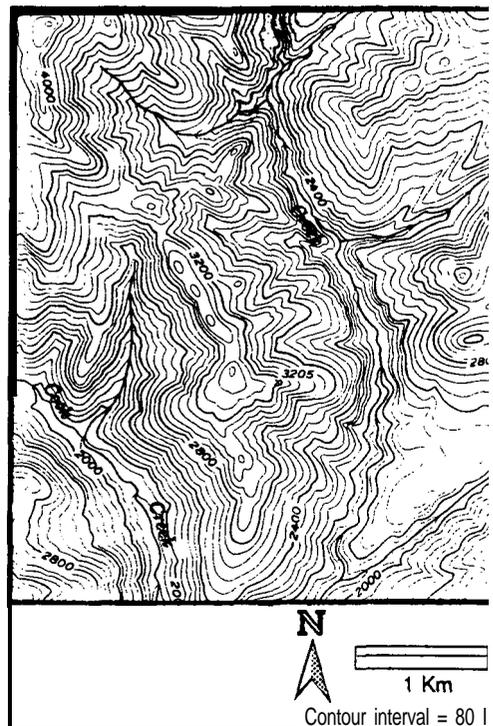


Figure 2-Topographic map for the Cook-Quentin study area.

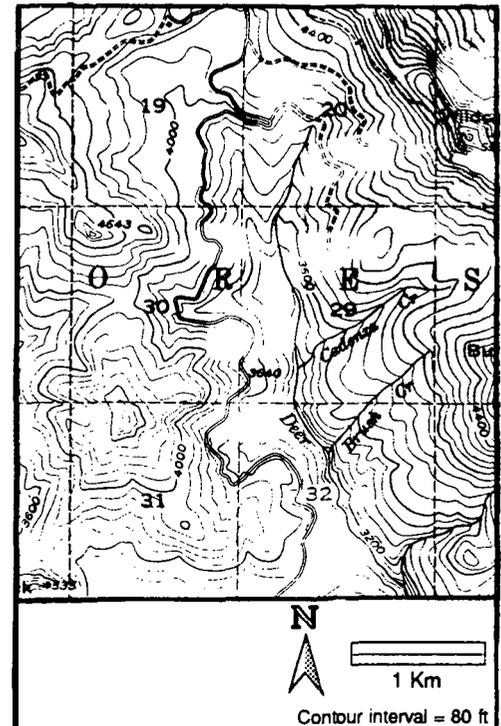


Figure 3-Topographic map for the Deer study area.

Climate-The maritime climate of this area is characterized by wet, relatively mild winters and dry, cool summers. At a meteorological station in the adjacent H.J. Andrews Experimental Forest, annual temperatures average 9.5 °C at 430 m elevation. Annual precipitation averages 2400 millimeters (mm) with more than 70 percent falling between November and March in prolonged periods of rain and snow. July, August, and September may be entirely rain free, and periods of 60 days without rain are common. Precipitation in this area is markedly affected by elevation; 1500 m elevations receive 30 to 40 percent more precipitation than 600 m elevations. A permanent winter snowpack occurs above 1000 to 1200 m elevation; below these elevations, snowpack is sporadic (Waring and others 1978).

The Deer study area probably receives more precipitation than the Cook-Quentin study area because of elevation differences. A winter snowpack persists into the spring in much of the Deer study area, affecting fuel and soil moisture in the early summer.

Forest fire initiation and spread are promoted by several climatic factors. Summer thunderstorms occur on the average of only 7 days a year but caused over 60 percent of the fire ignitions recorded in recent years (Burke 1979). A seasonal water deficit occurs during the summer because of low precipitation, high temperature, and high potential evapotranspiration. Periodic, summer, east winds bring dry air from the high desert east of the Cascade Range, and relative humidity can drop to 10 percent or less (Waring and others 1978). Topographic and convective winds during warm, dry periods are locally important in the spread of fire.

Vegetation-The forest vegetation in the central-western Cascade Range is divided into two major vegetation zones: the western hemlock zone (300-1050 m elevation range) and the Pacific silver fir zone (1050-1550 m) (Franklin and Dyrness 1973). Both zones, as well as a transition zone, are represented in the Cook-Quentin study area, but only the transition zone and the Pacific silver fir zone are present in the Deer study area. The uppermost elevations of Wildcat Mountain in the latter study area are representative of the mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.) zone (Dyrness and others 1974).

Within the western hemlock zone, the principal seral tree species is Douglas-fir. Western white pine (*Pinus monticola* Dougl. ex D. Don), incense-cedar (*Calocedrus decurrens* (Torr.) Florin.), and sugar pine (*Pinus lambertiana* Dougl.) are occasional seral species. Plant associations of the western hemlock zone found in the Cook-Quentin study area range between Douglas-fir/oceanspray (*Holodiscus discolor* (Pursh) Maxim.) and western hemlock/rhododendron (*Rhododendron macrophyllum* D. Don ex G. Don)-Oregon oxalis (*Oxalis oregana* Nutt.). Western hemlock and western redcedar (*Thuja plicata* Donn ex D. Don) are tolerant, climax species that may occupy a site with Douglas-fir immediately after a disturbance or invade 50-100 years later (Dyrness and others 1974, Franklin and Dyrness 1973, Zobel and others 1976).

The Pacific silver fir zone is characterized by climax dominance of Pacific silver fir. Western hemlock and western redcedar are minor climax species. Plant associations of the Pacific silver fir zone commonly found in both study areas include the Pacific silver fir/vanillaleaf (*Achlys triphylla* (Smith) DC.) and Pacific silver fir/coolwort foam flower (*Tiarella trifoliata* L.) associations. After a disturbance, Douglas-fir and noble fir (*Abies procera* Rehd.) are prominent seral species. Western white pine is an occasional seral species and western hemlock may become established at the time of disturbance or develop later under a forest canopy (Dyrness and others 1974, Franklin and Dyrness 1973, Zobel and others 1976).

Forest vegetation is essentially continuous across both study areas. Small areas of talus, rock outcrops, and wet areas form very localized barriers that may impede the spread of some fires. Sitka alder (*Alnus sinuata* (Regel) Rydb.) communities exist in the Deer study area on several level sites with heavy snow accumulation and abundant seepage water and on steep, snow avalanche tracks; these communities may impede the spread of fire. Several wet and dry meadow communities are present in the Deer study area on flats and south-facing slopes. Fire may be impeded by wet meadow and bog areas but spread readily through the dry meadow communities, enlarging these meadows. Subsequent reinvasion of dry meadows by trees has been observed (Hickman 1976).

Nonfire disturbances-Nonfire disturbances can be considered in terms of their distinctiveness from fire on spatial and temporal levels and their relative importance as forest disturbances. High wind can cause blowdown of individual trees, groups of trees, or small stands. Although substantial damage to stands from blowdown has occurred in the Oregon Coast Range near the Columbia River and in the western foothills of the Oregon Cascade Range, little extensive damage has been observed in the interior portions of the western-central Cascade Range (Lynott and Cramer 1966, Orr 1963).

During the 1962 Columbus Day storm that caused extensive blowdown in parts of the Pacific Northwest, only a few small scattered patches of light blowdown (less than 1.5 to 6 ha per km²) were observed in the central-western Cascade Range of Oregon (Orr 1963). Scattered blowdown of individual trees did occur in the study areas during this storm. Blowdown of old-growth forests along clearcut margins has been observed in the nearby H.J. Andrews Experimental Forest (Gratkowski 1956); this phenomenon was also observed during fieldwork near Wolf Meadow in 1976, but no evidence of extensive patches of blowdown was found.

In natural forests of the study areas, blowdown appears to be a spatially diffuse disturbance of primary importance at the levels of individual trees and small groups of trees. Fire boundaries may be enlarged somewhat by blowdown, but the presence of numerous snags probably ameliorates the effect of opening the canopy. Regeneration resulting from wind storms is differentiated from fire regeneration by the low abundance of early seral tree species in areas disturbed by wind storms.

Although insect outbreaks are common east of the Cascade Range and cause extensive damage to timber stands, they rarely cause such damage in the western Cascade Range (Childs and Shea 1967, Rudinsky 1979, Wickman and others 1973). In the western Cascade Range, Douglas-fir beetle (*Dendroctonus pseudotsugae* Hopkins) damage may occasionally be important to individual trees but is not considered significant to stands. Douglas-fir beetles can infest individual trees that have been damaged by windthrow, snow breakage, or fire and can lead to mortality. This mortality is a secondary effect of the initial disturbance.

Disease outbreaks may cause small patches of mortality. Some stands in the H.J. Andrews Experimental Forest and elsewhere in the central-western Cascade Range are infected by (*Phellinus weirii* (Murr.) Gilbertson) (Boone and others 1982, Cook 1982). Disturbance patches resulting from *Phellinus* infection are easily identified by their unique morphology and by the persistence of the infection.

Methods

Hypotheses and Study Design

We conducted the study to quantify the magnitude and frequency of forest fires in the central-western Cascade Range. We assumed that forest stands in this region were predominantly even-aged, representing regeneration after infrequent, high-severity fires covering large areas. The study was designed to sample an area larger than the area of one or two fires, so that a few fires would not dominate the record.

Field samples of tree and scar ages were used in conjunction with interpretation of aerial photography to map forest age-classes similar to the work of Heinselman (1973). Analysis based on this design indicated that a more complex, fine-scale mosaic of stands existed than had been originally assumed. Also, many fires of variable severity had produced multiaged stands. Additional sampling was undertaken in the two small study areas reported here to better quantify the frequency and intensity of fire.

Field Data Collection Techniques

Stumps in clearcuts, partial cuts, and road rights-of-way were sampled. Increment cores of live trees were taken to establish tree age in areas where stumps were not available. At each sample site, a quick survey of the available stumps was made to locate stumps with scars and obtain an impression of the diameter classes present. Early seral tree species were generally chosen for sampling. The total tree age at the time of harvest was estimated by counting annual growth rings. A hand lens was used to count narrow rings. The height of the stump or the increment core, diameter of the tree at stump or core height, average width of the innermost rings, and species were recorded.

All scars, shakes (ring delaminations), and dramatic and abrupt periods of growth suppression or growth release were noted. Throughout this report, these scars and related phenomena are referred to by scar type. Both the age of scar occurrence and a description of disturbed annual rings were recorded.

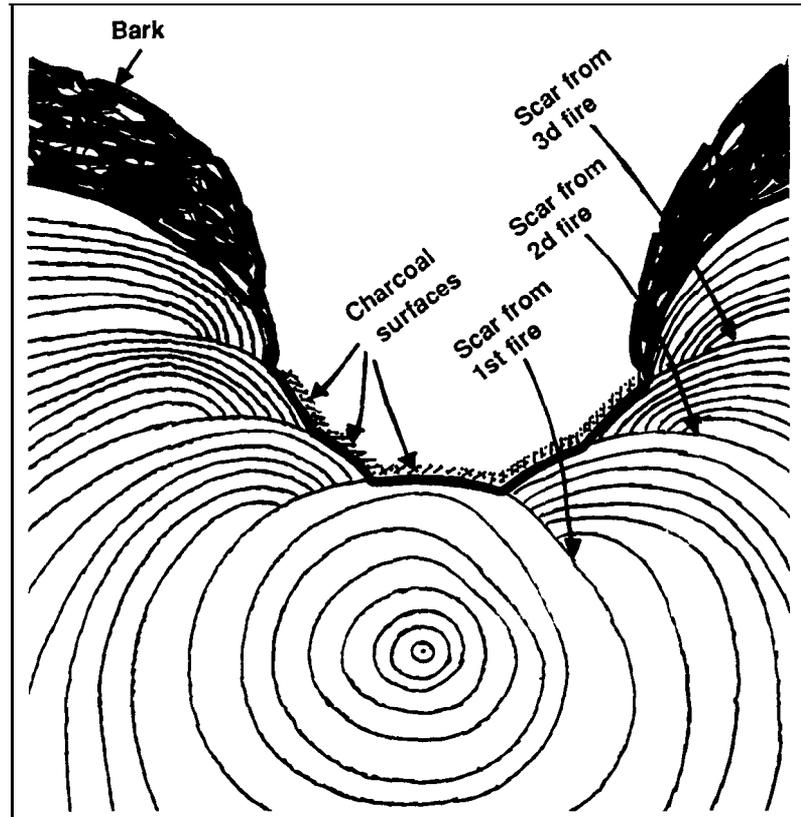


Figure 4-Characteristics of classic fire scars

Assessment of Scar Record

Fire history studies in dry coniferous forests have relied on classic fire scars found on cat-faced trees (Arno 1976, Arno and Sneck 1977, Dieterich 1980, Tande 1979). These classic fire scars are occasionally found in the wetter forests of western Oregon (fig. 4). Classic fire scars are formed by a series of two or more fires. The first fire kills a large area of cambium under the thin bark of a young tree, and the bark sloughs off of this area. Scar tissue starts to grow over the wound, but the cambium under the thin-barked scar tissue is killed by a subsequent fire before the wound heals over. The second fire leaves some charcoal on the exposed wood of the initial scar. This process can repeat many times. Trees with classic fire scars become sensitive recording devices of fire because the relatively unprotected cambium is continually present. Multiple scars, charcoal surfaces, and an open cat-face are the hallmarks of a classic fire scar. These scars are denoted as scar type 1 in this study.

Several factors in the central-western Cascade Range cause fire scars to be “buried” rather than exposed. Because tree growth rates are much higher than in dry coniferous forests, scars heal more rapidly. Fires are less frequent, allowing more time for an initial scar to heal over before another fire passes through the stand. A third factor in the balance is that heart rot and other tree diseases are much more active in the relatively wet and warm climate of the central-western Cascade Range. Fungi usually cause the early death of most trees that receive massive scars early in their growth. These young, scarred trees and the few older trees that do develop classic fire scars have much higher mortality rates than their counterparts in dry coniferous forests and, therefore, are not in place long as sensitive recorders of fire.

In our study, 88 percent of the tree scars used for reconstruction of fire history occurred after the first 50 years of growth. The thick bark of mature Douglas-fir in this region usually protects a tree from massive scarring during a fire, and scars that form from fire are usually small, occurring at the deep furrows in the bark that form as the bole expands. These scars (fig. 5) usually heal over in 5 to 15 years. Classic fire scars are rare because their development requires a fire-return interval rate shorter than the closure rate of the scars and a decomposition rate slow enough that the tree stays alive--conditions rarely met in the western Cascade Range.

Two types of fire scars in addition to classic fire scars were used in this study. Type 2 scars are large, well-dated scars of probable fire origin covering over 25 percent of the bole circumference. Type 3 scars are smaller, well-dated scars of probable fire origin (figs. 5 and 6). The numbering of scar types does not reflect their accuracy or their utility in reconstructing fire history.

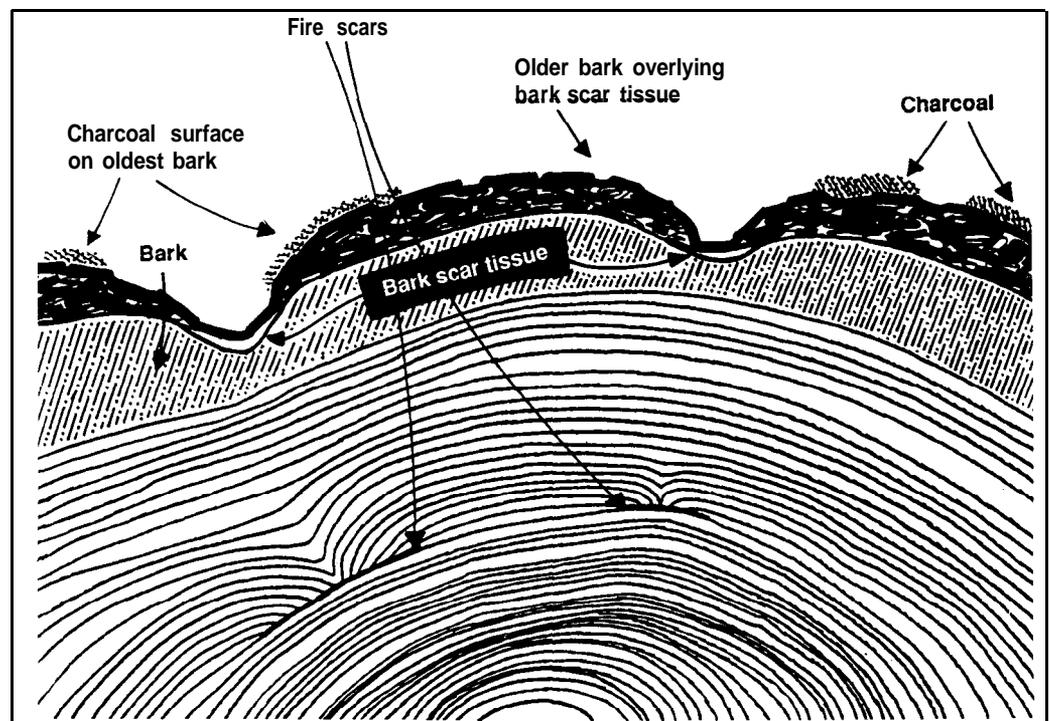


Figure 5--Small buried fire scars at deep furrows in bark.

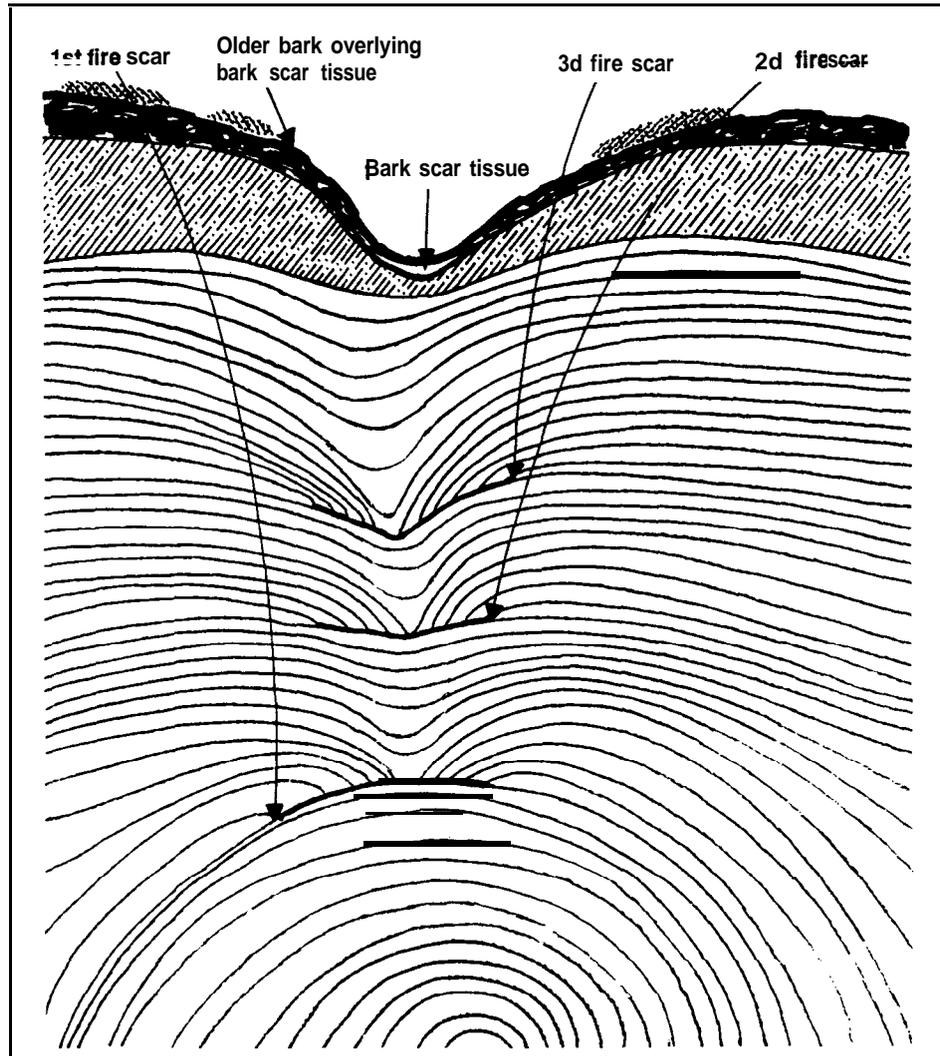


Figure 6—Small fire scars on a common radius.

Several characteristics distinguish scar types 2 and 3 from scars of other origin. The fire scars 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. They usually coincide with grooves in the bark where insulation is least. One of the most characteristic attributes of scars in type 3 is their tendency to occur simultaneously at several places around the circumference of a tree (fig. 5). Often, scarring will occur under the thin bark of the healed-over scar, and multiple scars will develop along the same radius (fig. 6). These type 2 and 3 fire scars lack charcoal surfaces because no exposed dead wood was present at the time of the second fire. They will also lack an open cat-face.

Several other indicators were used to validate the fire origin of type 2 and 3 scars. The presence of charcoal on bark predating the scar was used as an indirect indicator of fire origin. Uncut stands adjacent to sample sites were examined to confirm the presence of charred bark and related fire scars. Another reliable field indicator of fire origin was charred, older bark partially overlying the bark scar tissue (fig. 5). This feature negates bear damage and physical impact as possible scarring mechanisms, because this older bark would be removed during such disturbances.

Only 12 percent of the scars used in this study were found on trees less than 50 years old at the time of scarring. Only 3 percent were found on trees less than 20 years old. Where these scars were used in reconstructing fire history, additional scars from the same fire were always present at the site on trees older than 50 years at the time of scarring, or early seral tree origin dates were present.

Mechanisms other than fire can cause scarring: bears; mass movements of soil, rock, or snow; and falling trees or snags. Bears can scar young trees, but significant scarring of trees older than 50 years is unlikely. Bears leave claw marks in wood layers beneath the cambium. These marks, which are several ring widths deep, can be seen in scars in the field.

Mass-movement scars usually are associated with considerable physical damage to underlying wood (Morrison 1975). Their association with distinctive landforms and geomorphic surfaces makes interpretation obvious.

Tree-fall scars often show some damage to the underlying wood. Most commonly, young trees are damaged by tree fall because of their thin bark and the high density of snags in young post-wildfire stands. Tree-fall scars are generally narrow. With trees less than 50 years old, we used only scars covering more than 25 percent of the circumference (type 2), which is sufficient to rule out tree fall as a cause. On older trees with narrow scars, several criteria were used to rule out tree-fall: (1) the presence of bark predating the scar overlying the scar callous tissue, (2) synchronous radii scars, and (3) scars occurring in concave portions of the tree bole.

Fire scars were usually observed in thick-barked conifers such as Douglas-fir, western white pine, sugar pine, and noble fir. Some fire scars were identified in western hemlock, western redcedar, and Pacific silver fir, which have relatively thin bark. The fire origin of these scars was inferred at several localities because they coincided in age with classic fire scars on Douglas-fir in adjacent sites. Scars on western hemlock and Pacific silver fir were also observed at the edge of recent slash burns; such scars may record low-severity fire that is not recorded by more fire-resistant trees, such as Douglas-fir.

Periods of abrupt and sustained 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 that do not cause defoliation usually result *in* growth increase by eliminating competing vegetation and releasing nutrients from organic matter. These ring-width abnormalities, poorly dated scars, scars of uncertain origin, and shakes were noted in the field but not used in the fire history reconstruction.

The accuracy of scar dates depends on (1) accuracy of the count, (2) missing or false rings, (3) accuracy of determining the date of cut of the tree, and (4) ability to determine the season of the cut or damage event. The accuracy of the count was estimated to be ± 2 years. Missing rings are not common in conifers on the west side of the Cascade Range[†] and are a negligible source of error, but missing rings have been associated with fire scars in northern European species (Zackrisson 1980). Because missing rings associated with fire scars have not been reported in studies in the Western United States (Arno 1976, Arno 1982, Arno and Sneek 1977, Dieterich 1980), we assumed that they contribute only + 2 years of error. Uncertainty of the harvest date is usually small (1-2 years at most), but it can be ± 3 years. The inability to determine the season of cut or scar formation contributes ± 1 years of error. A root mean square error (the square root of the sum of the square of the individual error estimates) of ± 4 years for scar dates was estimated.

Accuracy of Tree-Origin Dates

The accuracy of origin dates depends on both the factors affecting scar dates and the error that arises in determining tree age at stump height. An error of ± 4 years was attributed to the uncertainty of determining age at stump height. A root mean square error of ± 6 years was estimated for the accuracy of origin dates. Because the lag in tree establishment after a fire is highly variable, origin dates represent only an upper limit for the date of a fire.

Collection of Site Information

The date of cut for each sample site was obtained from the Willamette National Forest Total Resource Inventory database. Rarely, the date of harvest was based on observation of logging operations or by bracketing with aerial photography (available every 3 to 12 years from 1946). The aspect and elevation of each site were obtained from topographic maps.

Sample Size and Distribution

Because of inaccessibility, some portions of each study area were sampled less intensely than other areas. Sample sites, however, were well distributed throughout each study area (table 1). Sites within a 1-km fringe around each study area were also considered because fires usually extended beyond the study area boundaries. The sample density for the Cook-Quentin study area was 22.3 origin and scar dates per square kilometer. In the Deer study area, the sample density was 17.2 origin and scar dates per square kilometer.

Data Analysis

Tree origin dates were calculated by subtracting total ring count and an estimate of tree age at stump or core height from the cut date. Dates of scars were obtained by subtracting the ring count from the cut date.

[†] Personal communications, Linda Brubaker, 1988. College of Forest Resources, University of Washington, Seattle, WA 98195.

Table I-Sample sizes in the Deer and Cook-Quentin study areas

Area	Sites	Counted origin dates	Estimated origin dates	Probable fire scar dates	Total dates	Dates per site
Cook-Quentin area	57	252	36	145	433	7.6
Cook-Quentin area +/-1-km fringe	86	361	46	170	577	6.7
Deer area	63	184	64	86	334	5.3
Deer area +/-1-km fringe	75	228	74	102	404	5.4

The estimate of age at stump height was based on the height of the stump and the width of the innermost rings, with the following equation, based on suggestions from F.C. Hall:²

$$\text{AGE} = 0.1852 * \text{SH}/\text{RW} \text{ (for RW}>2\text{mm) and}$$

$$\text{AGE} = 0.1852 * \text{SH}/2 \text{ (for RW}\leq 2\text{mm);}$$

where

AGE = age at stump height (years),

SH = stump height (centimeters), and

RW = average ring width inner three rings (mm).

In this paper, the terms "fire" and "fire episode" are used synonymously to refer to one or more events interpreted as fires that occurred in a short interval. Criteria for establishing a fire episode were evaluated at three levels: tree, stand, and landscape. Tree-level criteria were the interpretation of scar and origin dates for both accuracy and likelihood of creation by fire. A stand-level criterion was based on the redundancy of the tree-level data throughout a stand sample. A landscape-level criterion was based on the redundancy of stand-level data among several stands with some geographic continuity. The interpretations made at each level were checked against observations at the other levels.

The temporal clustering of scar dates and the geographical affinity of sites with these dates were used to date fire episodes. The presence of corresponding regeneration dates was also a primary criterion for bracketing a fire date. Because a large spread of tree ages has been observed in regeneration after some fires (Hemstrom and Franklin 1982), scar dates were used to estimate dates of fire episodes, based on the average date of a cluster of scar dates.

² Personal communication, Frederick Hall, 1988, Pacific Northwest Region, 319 S.W. Pine St., P.O. Box 3623, Portland, OR 97208.

The minimum criteria for interpreting the occurrence of a major fire in either study area follow:

1. Five or more sites had to have scars or regeneration dating from the fire.
2. Both scar and early seral tree regeneration data had to exist for all but the oldest fires (for which scar data were nonexistent).
3. Only well-dated scars with high probability of fire origin (types 1, 2, and 3) were used to date major fires. Only type 1 and 2 scars were used on trees that were less than 50 years old at the time of scarring.
4. A cluster of nearby contemporaneous fire-scar dates must have existed, with criteria becoming more relaxed in earlier time periods,

During 1800-1900, fire scars had to be present in at least three sites within a 4-year period. During 1710-1800, three sites had to have scars within a 6-year period, and during 1600-1710, a minimum of two sites had to have scars within a 6-year period. Prior to 1600, fire scars were usually present at two or more sites within a 10-year period, but dating was based more heavily on tree regeneration data.

5. The maximum timespan for including sites with fire scars in a major fire episode was: 7 years for 1800-1900 and 12 years for 1600-1800.

6. Geographic affinity for most sites that recorded a fire episode had to be established. Sites within 200 m of one another that recorded the same fire were counted as one site in the evaluation of major fires.

Supporting evidence for all fires was found at sites beyond the study area boundaries. The presence of these data was not a criterion for interpreting the occurrence of a fire, but adds support to our conclusions. Although evidence existed in both study areas for numerous smaller fires that burned one or more sites, this evidence did not meet the above criteria. These apparently minor fires were not considered in subsequent analysis.

Construction of fire maps and estimation of burn area-Major fire episodes in each study area were mapped based on the field sampling and interpretation of five sets of aerial photographs taken between 1946 and 1979 at scales of 1:12,800 to 1:70,000. Burns less than 100 years old were easily identified on the aerial photographs, but older age classes were more difficult to distinguish. In areas with multiple fires during the 1800-1900 period, stand boundaries could not be distinguished.

The area burned during each fire episode was estimated by two procedures. In the first, extent of the burned area was determined by clustering sites with a record of that event. An approximate boundary line was drawn midway between the cluster of sites and adjacent sites with no record of the fire. Sometimes where fire boundaries were between stands of distinctly different age, boundary line interpretations were made from aerial photographs; the area included within this boundary was measured with a digital planimeter.

In the second procedure, the approximate area burned was estimated by

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

where

- A(i) = estimated area burned during the i^{th} fire episode,
- AT = total study area (1940 ha),
- NS(i) = number of sites with a record of the i^{th} fire episode,
- NST = total number of sites in the study area, and
- 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 area-burned estimates decreases as the record at more sites is erased by later burns. This problem is inherent in all fire history studies based on forest-stand analysis.

The natural fire rotation for various intervals was calculated for each study area as the length of time necessary for an area equal in size to the study area to be burned by a series of fires (Heinselman 1973, Romme 1980), based on a mapped reconstruction of the area burned by each fire. For each site, fire frequency was calculated as the average fire-free interval between 1910 and the earliest fire recorded at a site. The analysis period ends in 1910 because this date marks the beginning of effective fire suppression in the study areas (Burke 1979). This estimate of fire frequency is most meaningful where multiple fires were recorded at one site. The estimate may overestimate or underestimate the actual fire frequency at sites where the one recorded fire has erased the record of all previous fires.

Determination of fire severity and patch characteristics-In the Cook-Quentin study area, one recent fire was mapped from aerial photographs with verification from field samples. Three levels of fire-induced mortality of the previous stand were mapped: (1) high severity, 70 to 100 percent; (2) moderate severity, 30 to 70 percent, and (3) low severity, <30 percent and some scarring of trees. Boundaries are often gradational, so interpretation is subjective. Maps were also constructed of both study areas, depicting areas burned during 1800-1900 with high, medium, and low mortality from the cumulative effect of several fires. The areas and perimeters of all the mapped patches were measured with an electronic digital planimeter.

Results

Fire History

Cook-Quentin study area-Tree origin and scar data were evaluated for each site, and an interpretation of fire occurrence for the site was made. Comparisons of fire records between adjacent sites and among all sites in the Cook-Quentin study area were used to refine these interpretations. and fire occurrence at each site was tabulated (table 2).

Eighteen major fire episodes occurred in the Cook-Quentin study area (table 3). All these fires were recorded at five sites or more except for the 1150 fire, which was recorded at only three sites. The 1400 and 1150 fires were documented only by origin dates. interpretation of all other fires was based on numerous tree origin and fire scar dates.

Table 2—Fire history by site for the Cook-Quentin study area

FIRE RECORD AT EACH SITE IS AS FOLLOWS:
 O = TREE ORIGIN DATE(S)
 S = SCAR DATE(S)
 A = BASED ON APPROXIMATE ORIGIN DATE

SITE	FIRE EPISODE																	
	1893	1855	1849	1841	1834	1813	1807	1800	1772	1758	1703	1689	1658	1566	1532	1475	1400	1150
BR06																		
BR23		0			0													
C001															0	0		
C002									S	0	0	0						
C004											0	0						
C006											0							
C007		0																
C008				S&O				S&O	0			0	0					
C009				S			S				0							
C011								S				S			0			0
C020					S&O		0				0							
C021					A													
C022				S&O			0	S										
C023					S&O			S		S&O	0		0		0			
C024					0													
C025					A													
C026					S	S				0	0	S	A	S&O				0
C027									S				S					
C028			S&O		S		S		S	0	0					S	0	
C029			S		S&O		S		0									
C030			0															
C031			S&O		S					S								0
C032			0															
C033							S				0							
C034							S				0							
C035	S&O						S											0
C036	S						S				0							
C037								S										0
QU01			0						0									
QU02			S		S		S			S&O	0							0
QU03		S&O			S	S								0				
QU04				0														
QU05	S&O				0	0					0							
QU06	0														0			
QU11		S&O	0											0				0
QU13		S					S&O		S	S&O				0				
Q14A								0										
Q14B		S				0								A				
QU35				S	S										S&O	0		
QU37						0		0										
QU38				S			S	S			S	S	0	0				
QU39												0						
QU40														S	S	S&O	0	
QU41		0	0															
QU42		S&O	0		S		S	S		S	0							
QU43				0	0													
QU44				A											A			
QU45	0				A													
QU46	0																	
QU47	S&O				0													
QU48	S												0					
QU49					0								S				0	
QU50	S	S&O			S&O	0	S	S&O						S	0	0	0	0
QU51		S&O			0	S&O	S									0	0	0
QU52								S								S		0
0019					S	S	S	S			0	0	0					
0020				S			S		S	S&O		0	0					

Table 3—Fire chronology for the Cook-Quentin study area

Mean fire year	Fire episode	Length of episode	Time since previous fire	Sites with record of fire
----- Years -----				Number
1893	1891-1896	5	38	9
1855	1852-1857	5	6	10
1849	1847-1851	4	8	10
1841	1839-1845	6	7	9
1834	1831-1837	6	21	22
1813	1812-1816	4	6	10
1807	1805-1810	5	7	14
1800	1798-1804	6	28	13
1772	1770-1774	4	14	5
1758	1752-1764	12	55	9
1703	1699-1709	10	14	17
1689	1683-1695	12	31	12
1658	1648-1671	23	92	10
1566	1549-1586	37	34	8
1532	1511-1545	34	57	8
1475	1475-1500	25	75	12
1400	1380-1410	30	250	5
1150	1150-1200	50		3

Table 4—Fire chronology for the Deer study area

Mean fire year	Fire episode	Length of episode	Time since previous fire	Sites with record of fire
----- Years -----				Number
1897	1895-1897	2	47	5
1850	1847-1854	7	12	9
1838	1836-1841	5	9	9
1829	1826-1833	7	29	8
1800	1798-1801	3	36	9
1764	1757-1768	11	189	7
1575	1568-1591	23	23	28
1552	1537-1557	20	37	13
1515	1490-1530	40	79	22
1436	1415-1455	40	236	6
1200	1164-1222	58		5

Deer study area—Thirteen major fire episodes occurred in the Deer study area (table 4), based on evidence at five or more sites per episode. The 1515 and 1200 fires were documented only by origin dates; other fires, however, were represented by both origin and scar dates (table 5).

Table 5—Fire history by site for the Deer study area

FIRE RECORD AT EACH SITE IS AS FOLLOWS:
 O = TREE ORIGIN DATE(S)
 S = SCAR DATE(S)
 A = BASED ON APPROXIMATE ORIGIN DATE

SITE	FIRE EPISODE												
	1893	1878	1864	1850	1840	1829	1796	1769	1575	1552	1515	1436	1200
BR11													
DR01									O	O			
DR02									O				
DR11				O		S				A			
DR12										A			
DR13										O			
DR15				S&O	S&O		S		O				
DR16							O	O					
DR17								S&O		O			
DR18									O				
DR19									A		A		
DR20									S&O		O		
DR21									A				
DR22												A	
DR23		O	S	S&O	O	S				A			
DR24				O	O					A			
DR25				S&O		S				A		A	A
DR26											O		
DR27							O		A				
DR28											A		
DR29							O						
DR30									O				
DR31									A				
DR32									O				
DR33									O				
DR34								S	O				
DR35									A				
DR50				S&O							A		A
DR51									O				
DR52									O				
DR53									O				
DR54							S		O				
DR55							O	O					
DR56									O				
DR57	S									O		S	O
DR58									S		O		
DR59											O		
DR60						O			O			O	
DR61						S&O		S	O				
DR62						S					O		
DR64								S	O				
DR65									O				
DR66									O				
DR67						S				S	O		
DR68										O			
MA08							S					A	
MA09												A	
MA12						S&O							O
MA13									A				
SM03				S&O									
SM04											O	O	
WI02								O		A			
WI03											O		
WM01						O		S	S&O	S	O	S	O
WM02	S					S					O		
WM03						O					O		
WR02								S			O	O	
WR03											O		
WR04											A		
WR05											A		
O305	O	S&O		O		O							
O306	S	S	S	S	S&O	O				S	O		
O307	S			S		S	S&O						

Table 6—Area burned during fire episodes in the Cook-Quentin study area

Fire year	Burned area		Record ^a						Area by fire-severity class		
	Ratio method	Planimeter method	A	B	C	D	E	F	High	Medium	Low
	----- Hectares -----		----- Number of sites -----						----- Percent -----		
1893	307	351	1	2	3	3	48	0	11	56	33
1855	347	540	2	1	5	2	46	1	20	60	20
1849	360	402	3	3	2	2	44	3	30	50	20
1841	343	386	1	2	2	4	42	6	11	44	44
1834	855	945	4	6	4	8	28	7	18	45	36
1813	422	565	0	4	2	4	36	11	0	60	40
1807	591	452	0	2	0	12	32	11	0	14	86
1800	549	322	2	0	2	9	33	11	15	15	69
1772	221	238	1	1	0	3	39	13	20	20	60
1758	407	217	1	2	3	3	34	14	11	56	33
1703	786	549	7	8	1	1	25	15	41	53	6
1689	666	515	7	2	0	3	23	22	58	17	25
1658	694	700	6	1	0	3	18	29	60	1	30
1566	706	1116	3	2	1	2	14	35	38	38	25
1532	818	1544	3	3	1	1	11	38	38	50	13
1475	1457	—	8	1	1	2	4	41	67	17	17
1400	1214	—	5	0	0	0	3	49	100	0	0
1150	1942	—	3	0	0	0	0	54	100	0	0

— = Burn area was not defined by of planimetric method because of small sample size and, in some cases, scattered distribution of sites recording the fire year.

^a The record for each fire is listed for: A = sites where fire date is oldest origin date; B = sites with origin date only (not oldest); C = sites with origin date and scar date; D = sites with scar date only; E = sites with no record of this fire; F = sites where record has been erased by subsequent fires.

Spatial Distribution of Fires

Cook-Quentin study area—None of the fire episodes after 1500 disturbed more than 61 percent of the study area (table 6). All of these fires, however, burned areas outside of the study area as well. Interpretation of fire severity was made according to the following criteria: sites with only scar dates were classified as burned at low severity, sites with origin dates resulting from the fire and from the preexisting forest were classified as burned at moderate severity, sites with origin dates resulting from the fire, but no older origin dates were classified as burned at high severity. Based on these criteria, fires in the Cook-Quentin study area were primarily of low to moderate severity. Only the 1689 and 1658 fires burned at high severity through more than 50 percent of the sites that recorded those fires. Before 1500, the database was insufficient to assess the extent of fires.

The extent of each major fire was mapped (fig. 7), and a comparison of the estimated area burned during each fire interval was calculated by the ratio method and measured by planimeter (table 6). Less than a 10-percent discrepancy between the estimates of the two methods resulted. The two methods became more dissimilar before 1600 because of record erasure.

(Text continues on page 38.)

Cook-Quentin Study Area
MAJOR FIRE EPISODE-1893
(1891-1896)

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
- ≡ Burned area

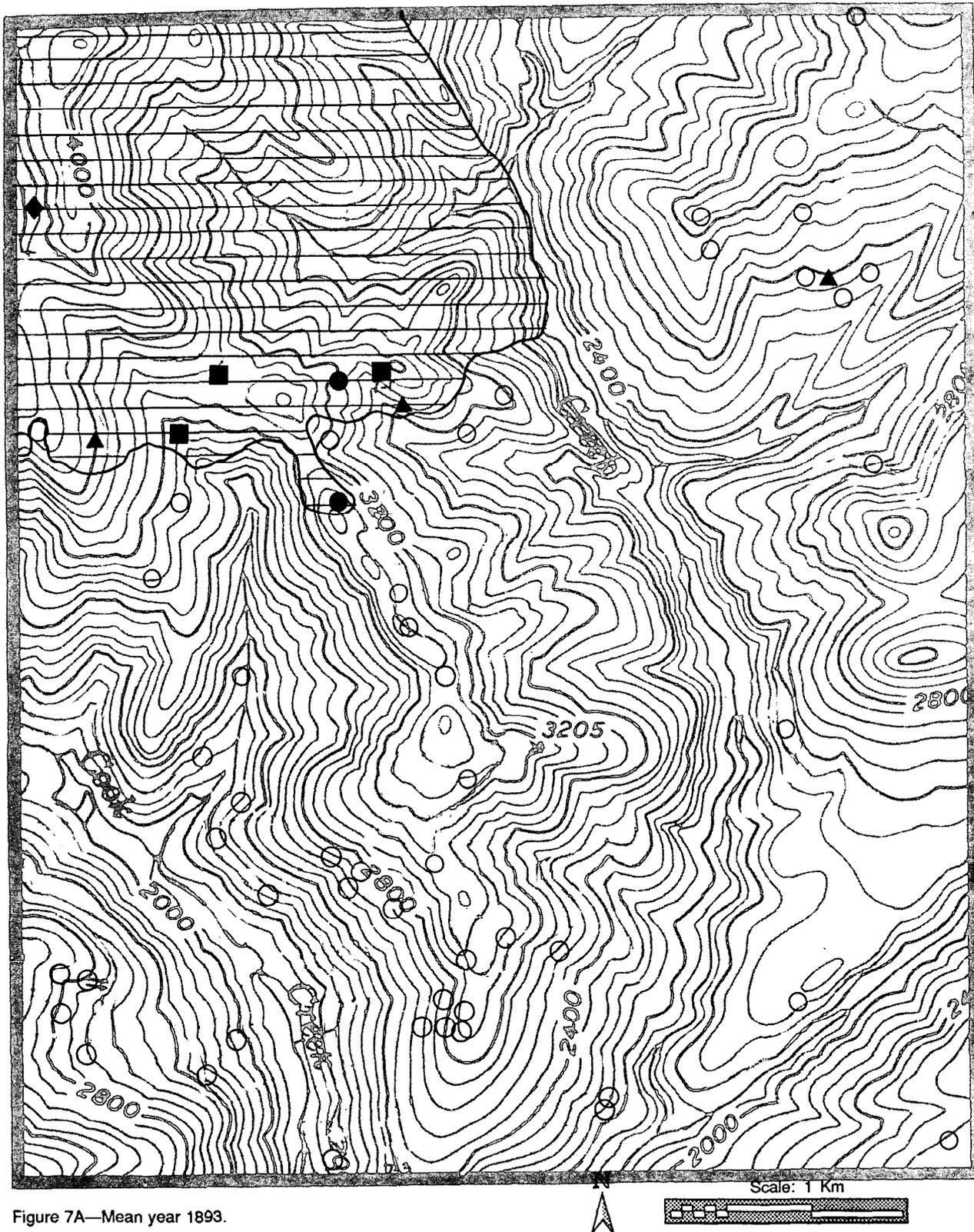


Figure 7A—Mean year 1893.

Cook-Quentin Study Area
MAJOR FIRE EPISODE-1855
(1852-1857)

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
- ≡ Burned area

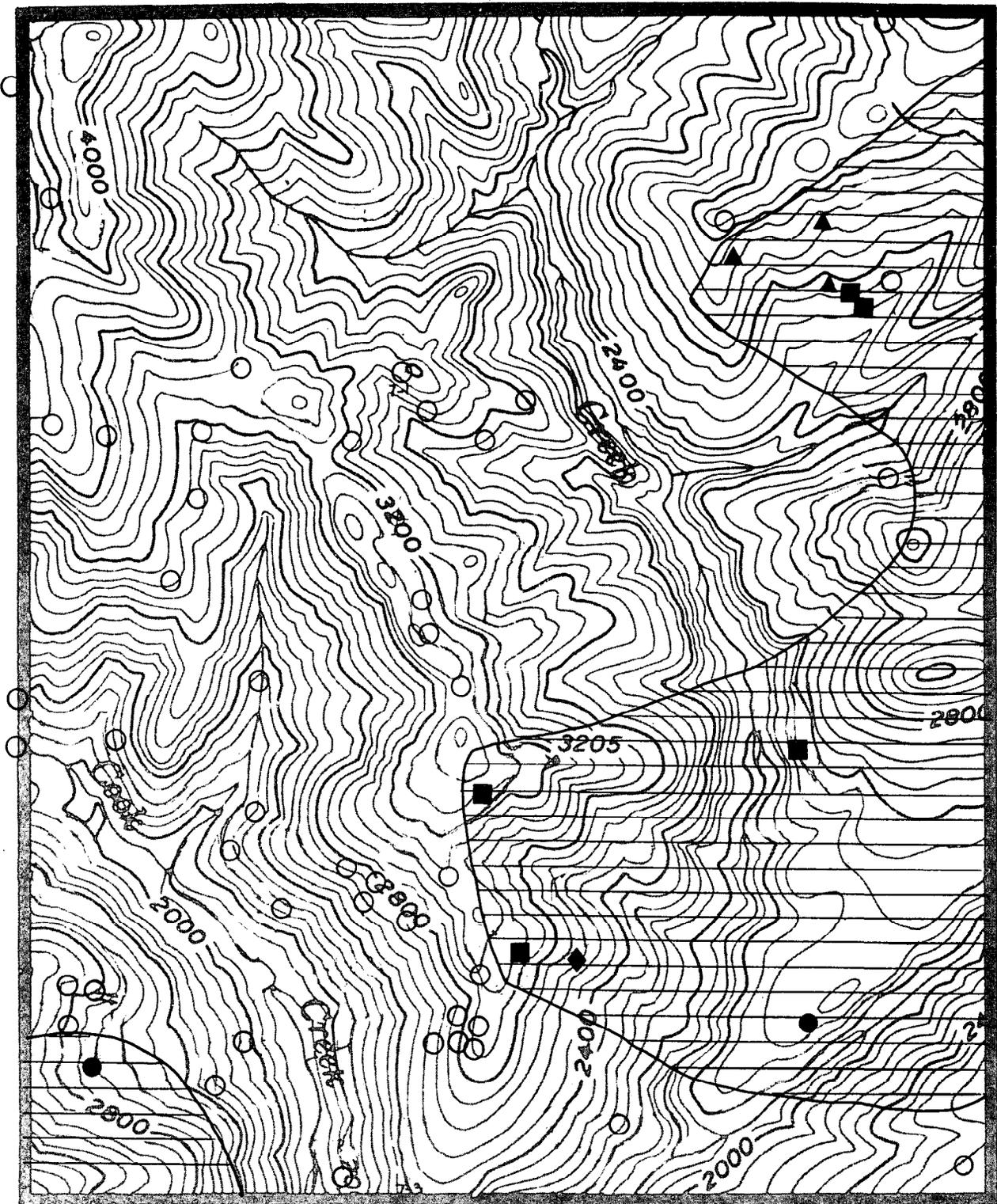
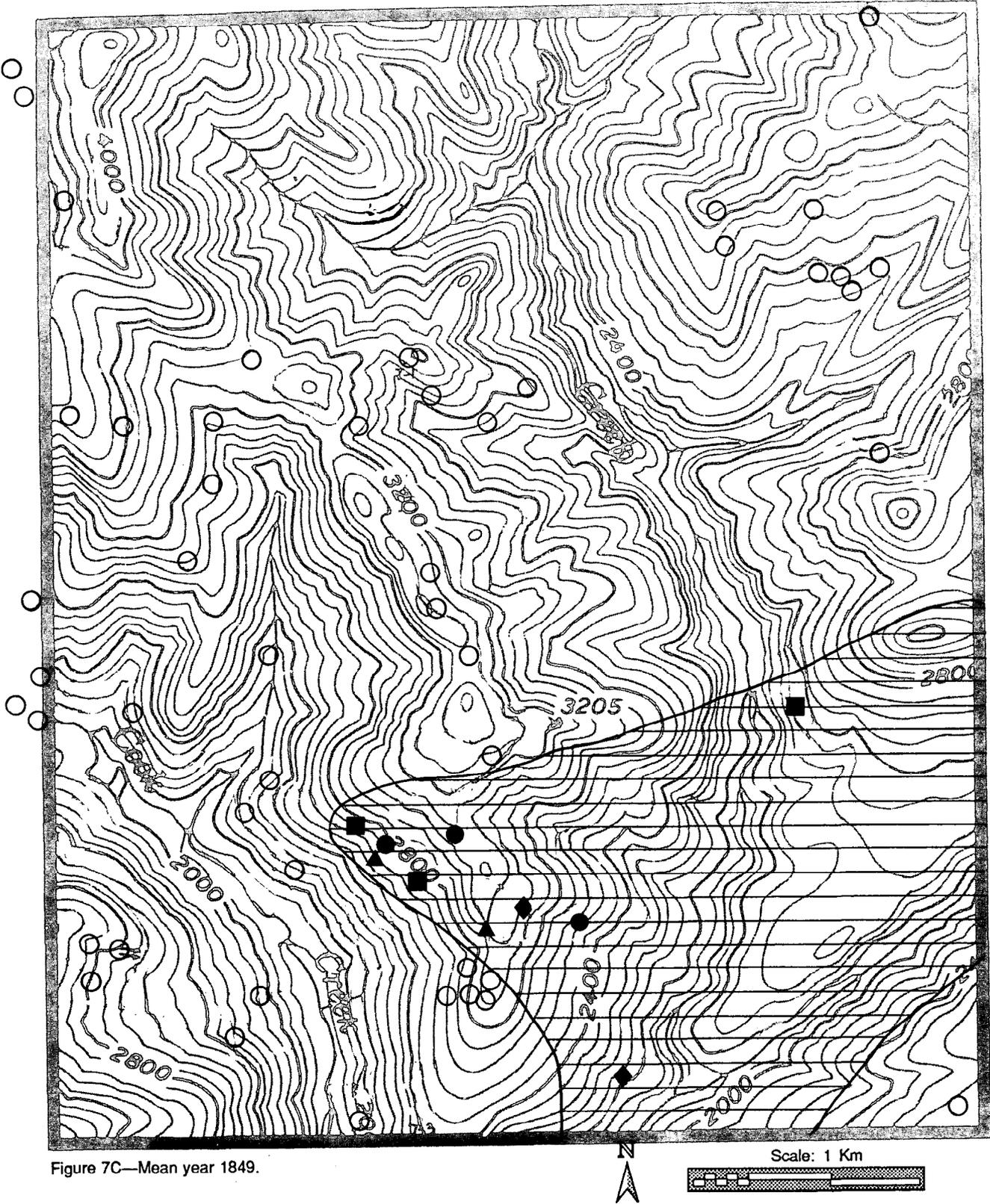


Figure 7B—Mean year 1855.

Cook-Quentin Study Area
MAJOR FIRE EPISODE-1849
(1847-1851)

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
- ≡ Burned area



Cook-Quentin Study Area
MAJOR FIRE EPISODE-1841
(1839-1845)

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
- ≡ Burned area

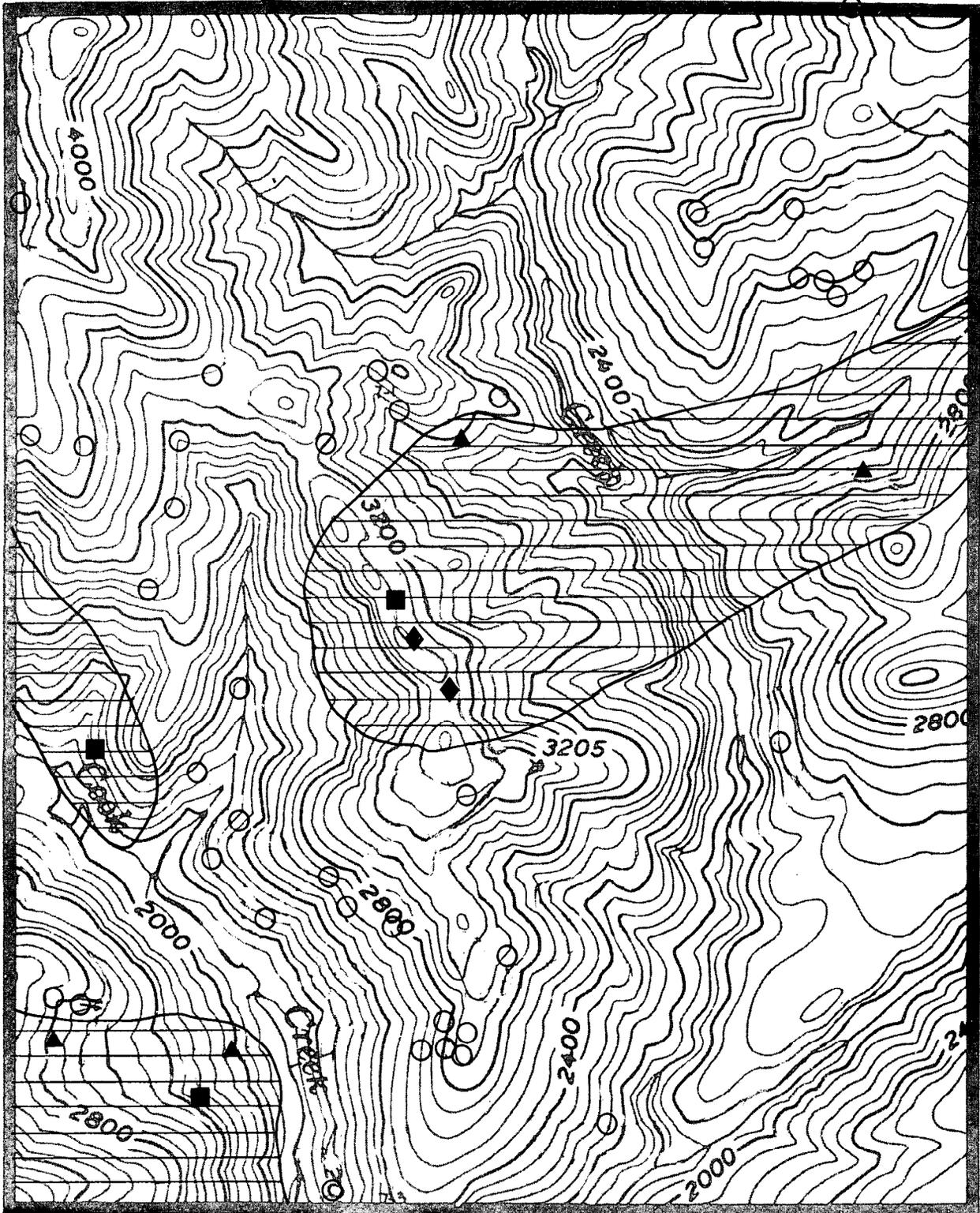
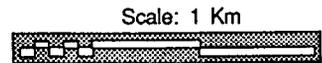


Figure 7D—Mean year 1841.



Cook-Quentin Study Area
MAJOR FIRE EPISODE-1834
(1831-1837)

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
- ≡ Burned area

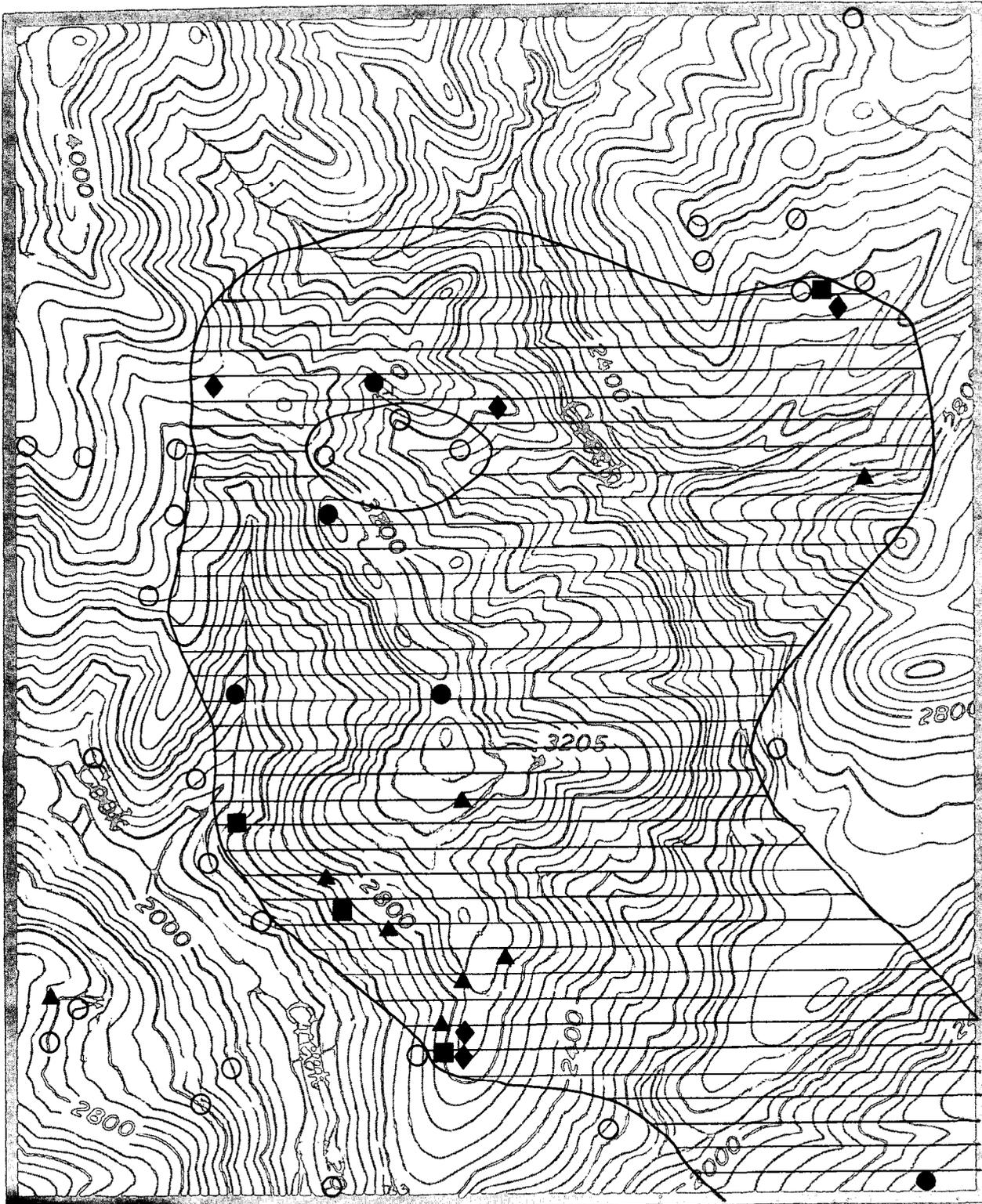


Figure 7E—Mean year 1834.

