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Fire History and Pattern in a Cascade Range Landscape

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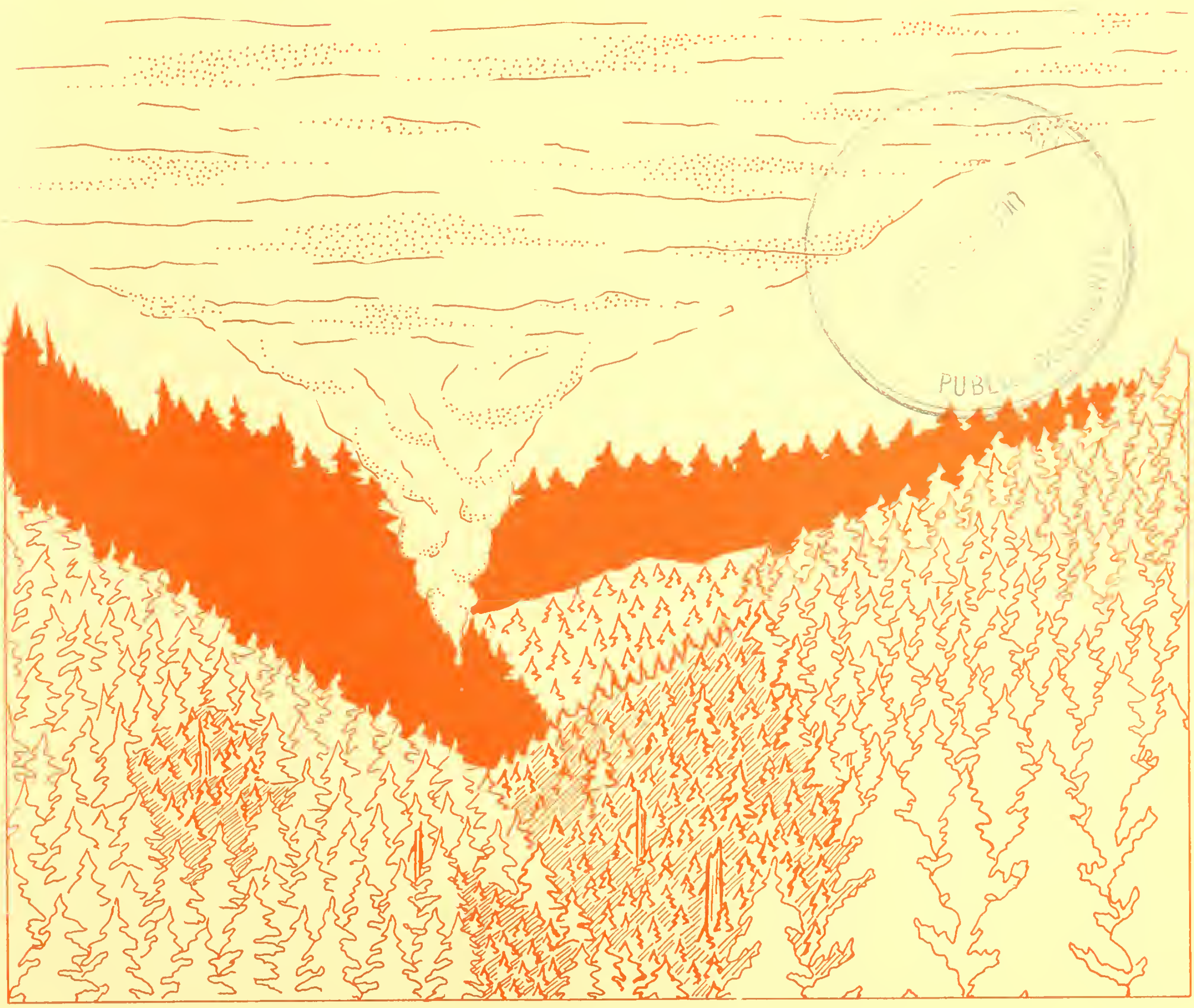

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Abstract

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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.

Contents

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.

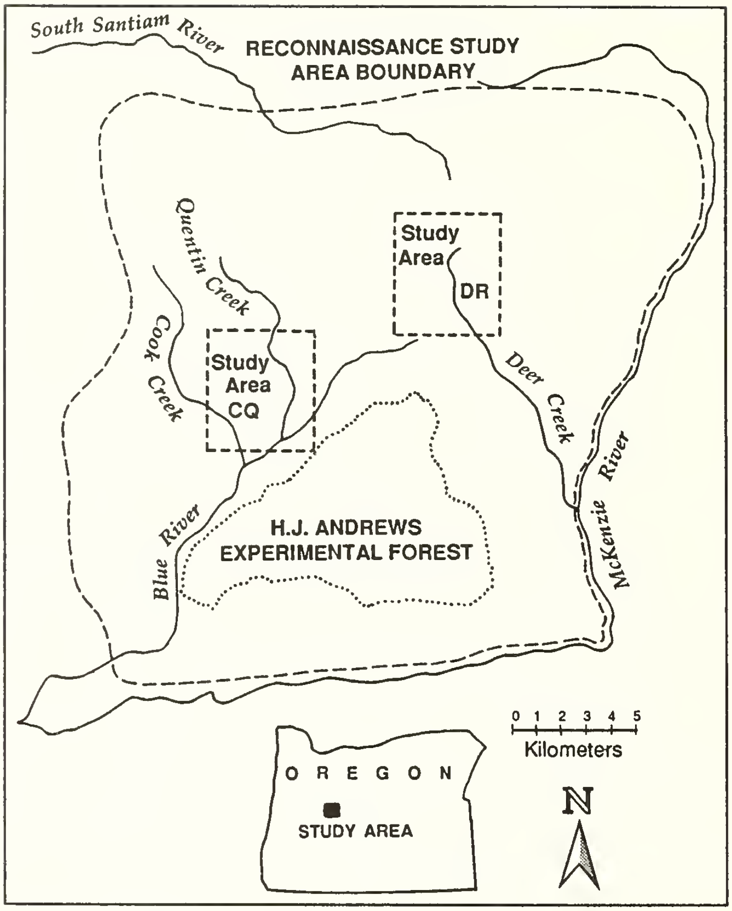

Figure 1—Location of study areas.

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 l979, 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 northwest 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 Yacolt (1902) and Tillamook (1933) fires (Morris 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 reconnaisance 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 1632 m at the summit of Wildcat Mountain, and the average elevation is about 1220 m.

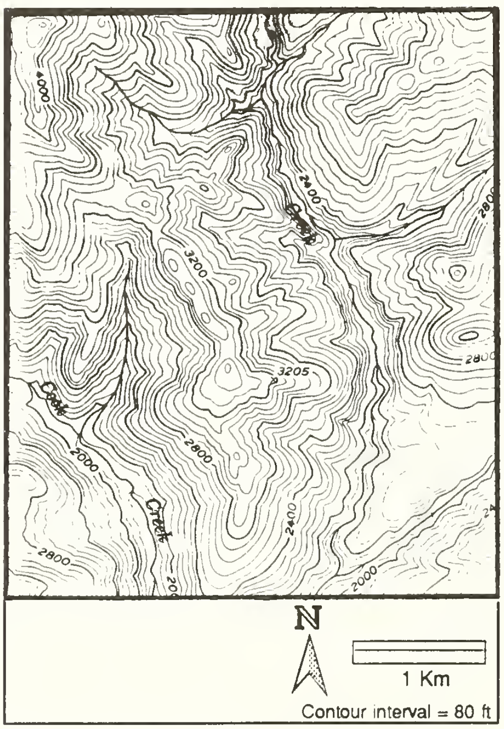

Figure 2—Topographic map for the Cook-Quentin study area.

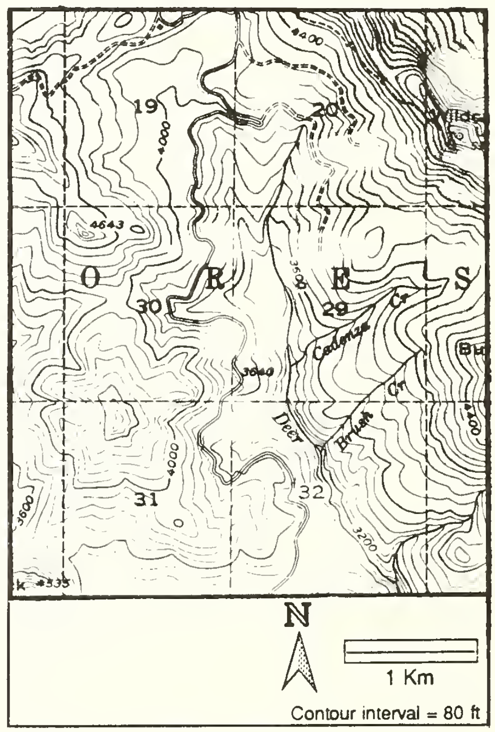

Figure 3—Topographic map for the Deer study area.

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 l976).

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 km^2) 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.

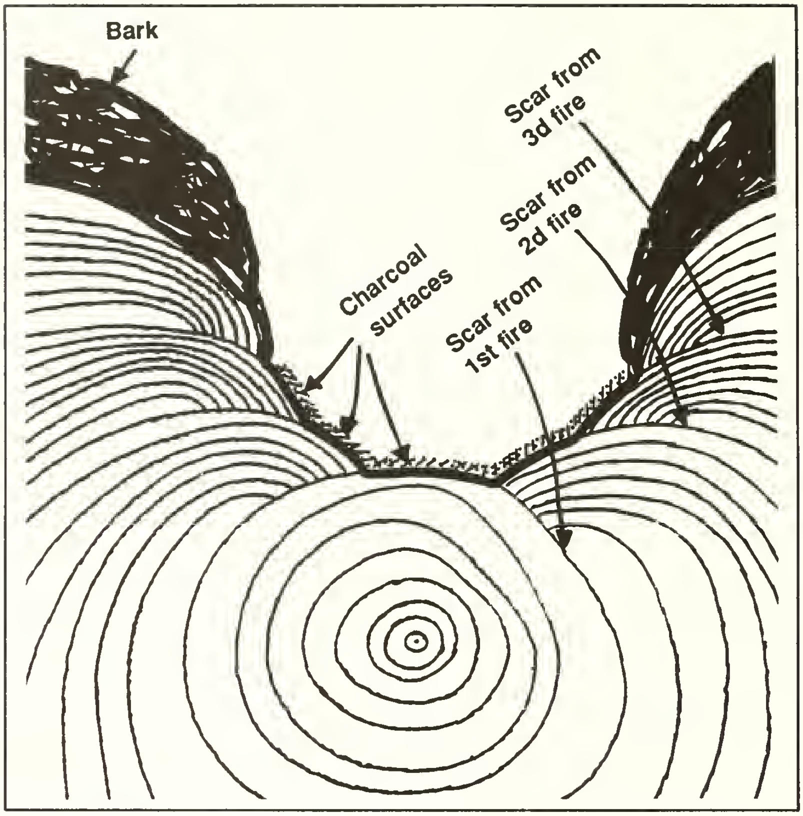

Figure 4—Characteristics of classic fire scars.

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.

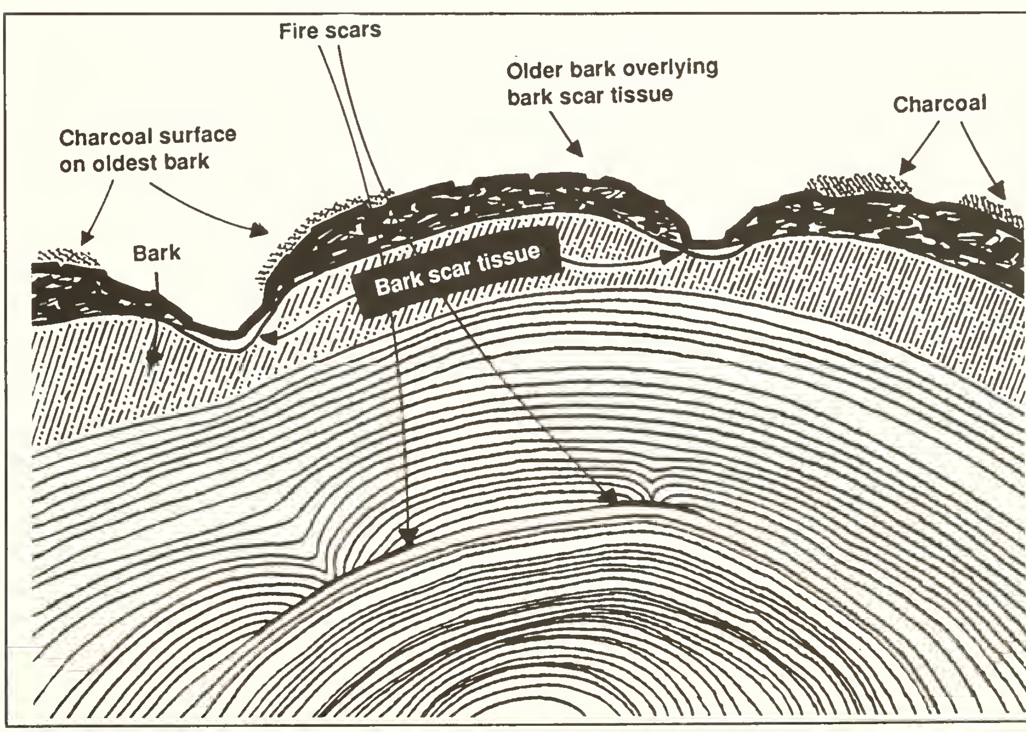

Figure 5—Small buried fire scars at deep furrows in bark.

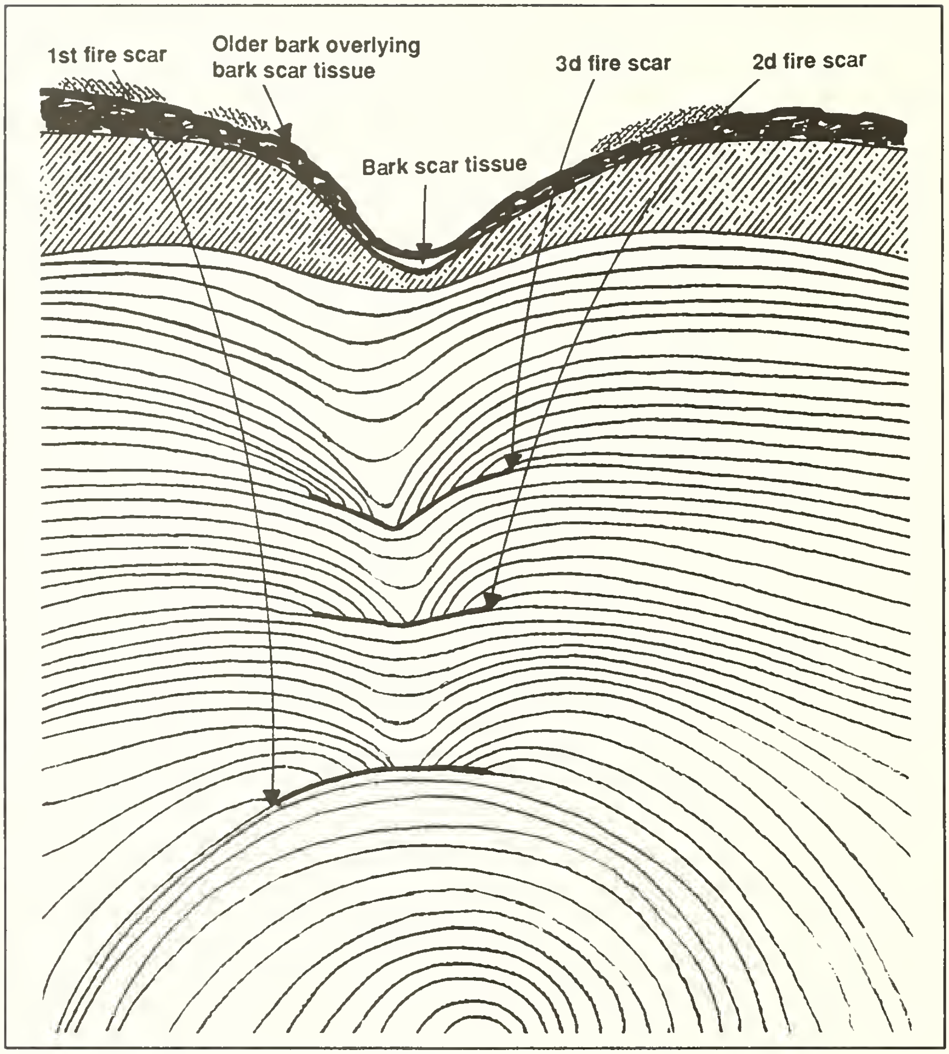

Figure 6—Small fire scars on a common radius.

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[1] 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 Sneck 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.

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

Table 1—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]

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

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		O																
BR23					O													
CO01															O	O		
CO02									S	O	O	O						
CO04											O	O						
CO06											O							
CO07		O																
CO08				S&O				S&O	O			O	O					
CO09				S			S				O							
CO11								S				S			O			O
CO20					S&O		O				O	O						
CO21					A							A						
CO22				S&O			O	S				O						
CO23					S&O			S		S&O	O		O					
CO24					O										O			
CO25					A								A					
CO26					S	S				O	O	S	S	S&O				O
CO27									S				S			S	O	
CO28			S&O		S		S			S	O	O						
CO29			S		S&O		S			O								
CO30			O															
CO31			S&O		S					S						O		
CO32			O															
CO33							S				O							
CO34							S				O							
CO35	S&O					S										O		
CO36	S						S				O							
CO37								S									O	
QU01			O						O									
QU02			S		S		S			S&O	O					O		
QU03		S&O			S	S								O				
QU04				O														
QU05	S&O				O	O					O							
QU06	O														O			
QU11		S&O	O											O		O		
QU13		S				S&O		S		S&O				O				O
Q14A								O										
Q14B		S				O								A				
QU35				S	S										S&O	O		
QU37						O		O										
QU38				S			S	S			S	S	O	O				
QU39												O						
QU40														S	S	S&O	O	
QU41		O	O															
QU42		S&O	O		S		S	S		S	O							
QU43				O	O													
QU44				A											A			
QU45	O				A													
QU46	O																	
QU47	S&O				O													
QU48	S												O					
QU49					O								S			O		
QU50	S	S&O			S&O	O	S	S&O						S	O	O	O	
QU51		S&O			O	S&O	S									O		
QU52								S								S	O	
0019					S	S		S			O	O	O					
0020				S			S		S		S&O		O					

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											O		
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				O						
SM04											O	O	
WI02							O		A				
WI03											O		
WM01						O		S	S&O	S	O	S	O
WM02	S					S					O		
WM03					O								
WR02								S			O	O	
WR03											O		
WR04											A		
WR05											A		
0305	O	S&O		O		O							
0306	S	S	S	S	S&O	O							
0307	S			S		S	S&O			S	O		

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

	Burned area		Record[a]						Area by fire-severity class		
Fire year	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.*)

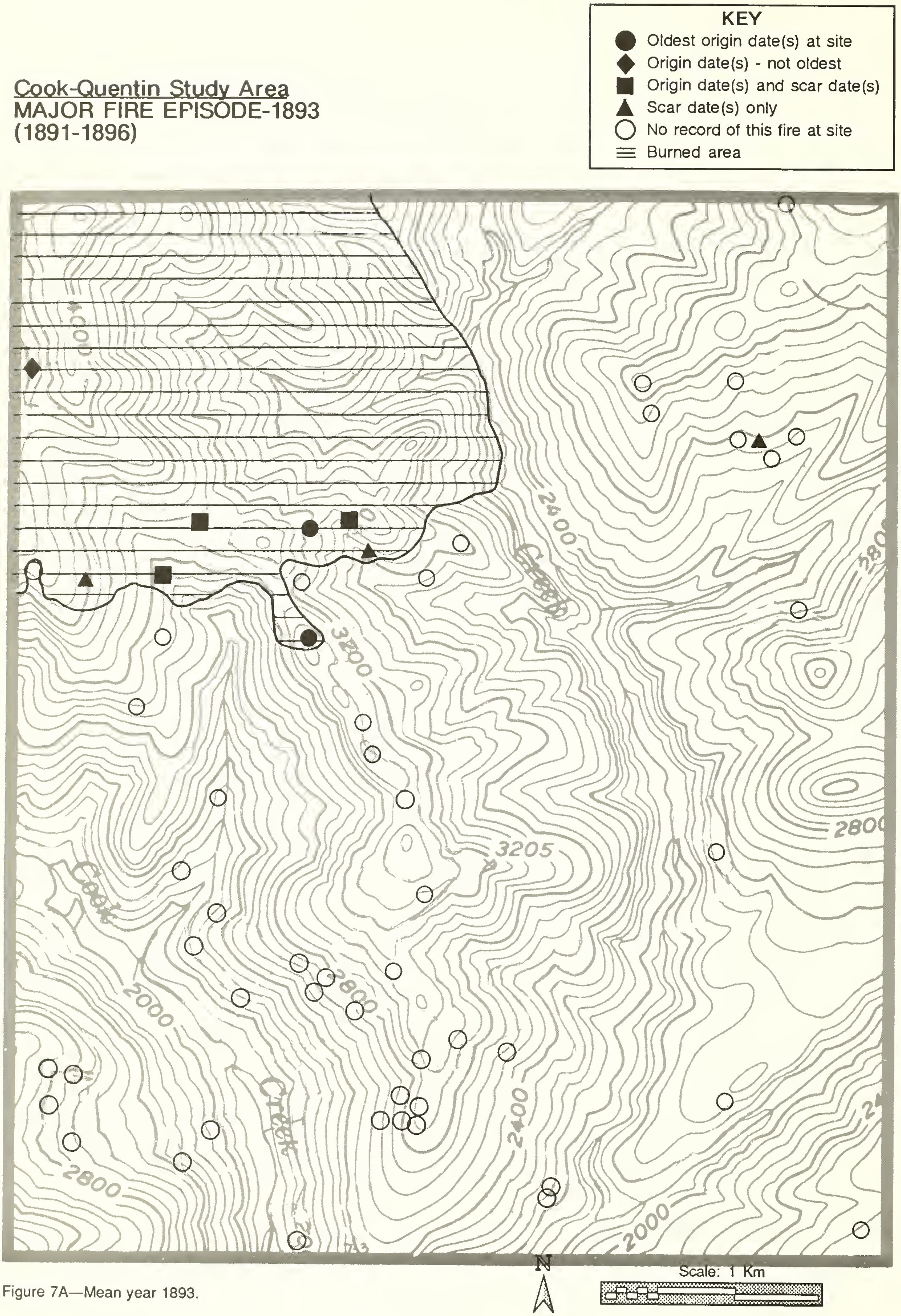


Figure 7A—Mean year 1893.

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

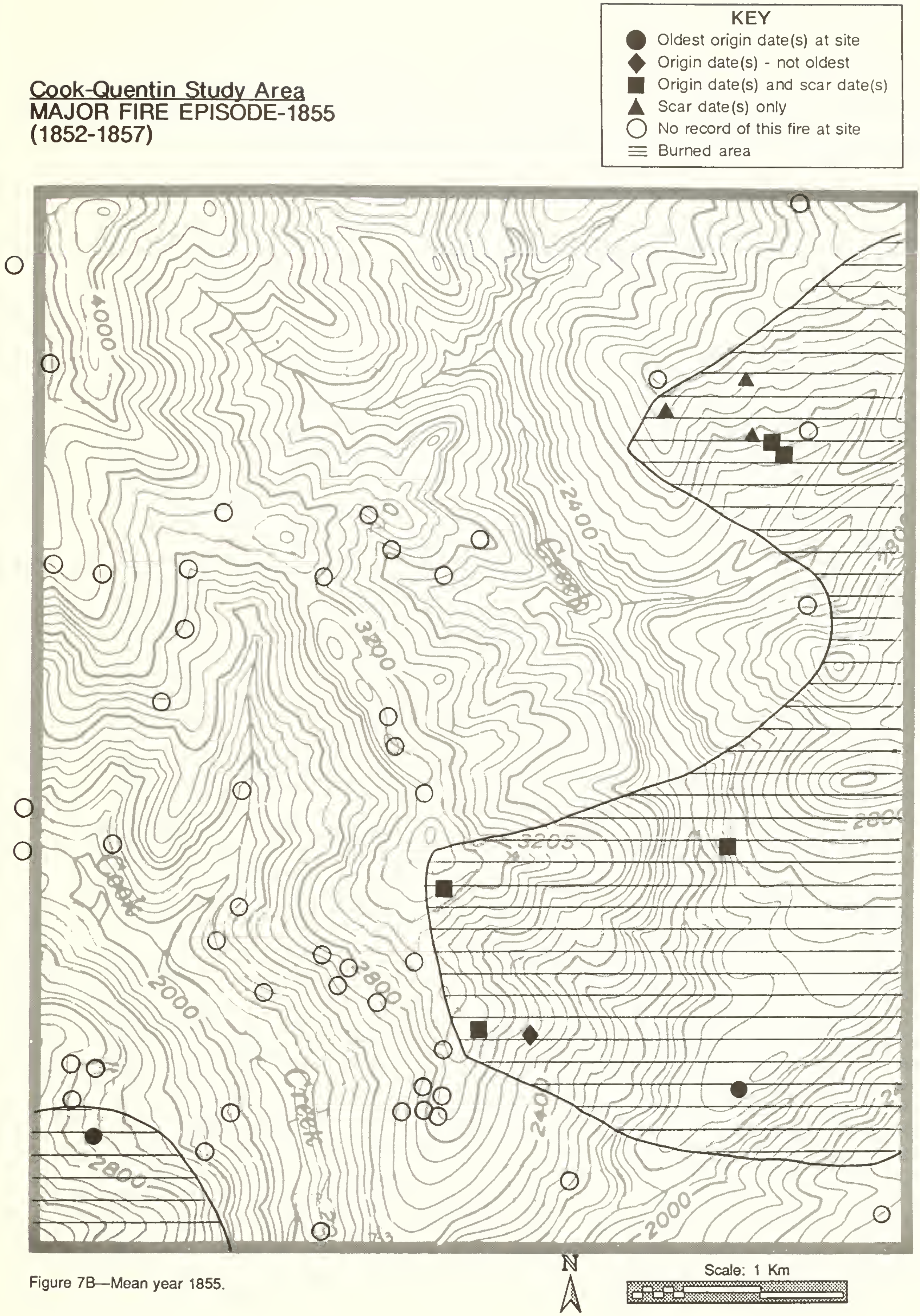


Figure 7B—Mean year 1855.

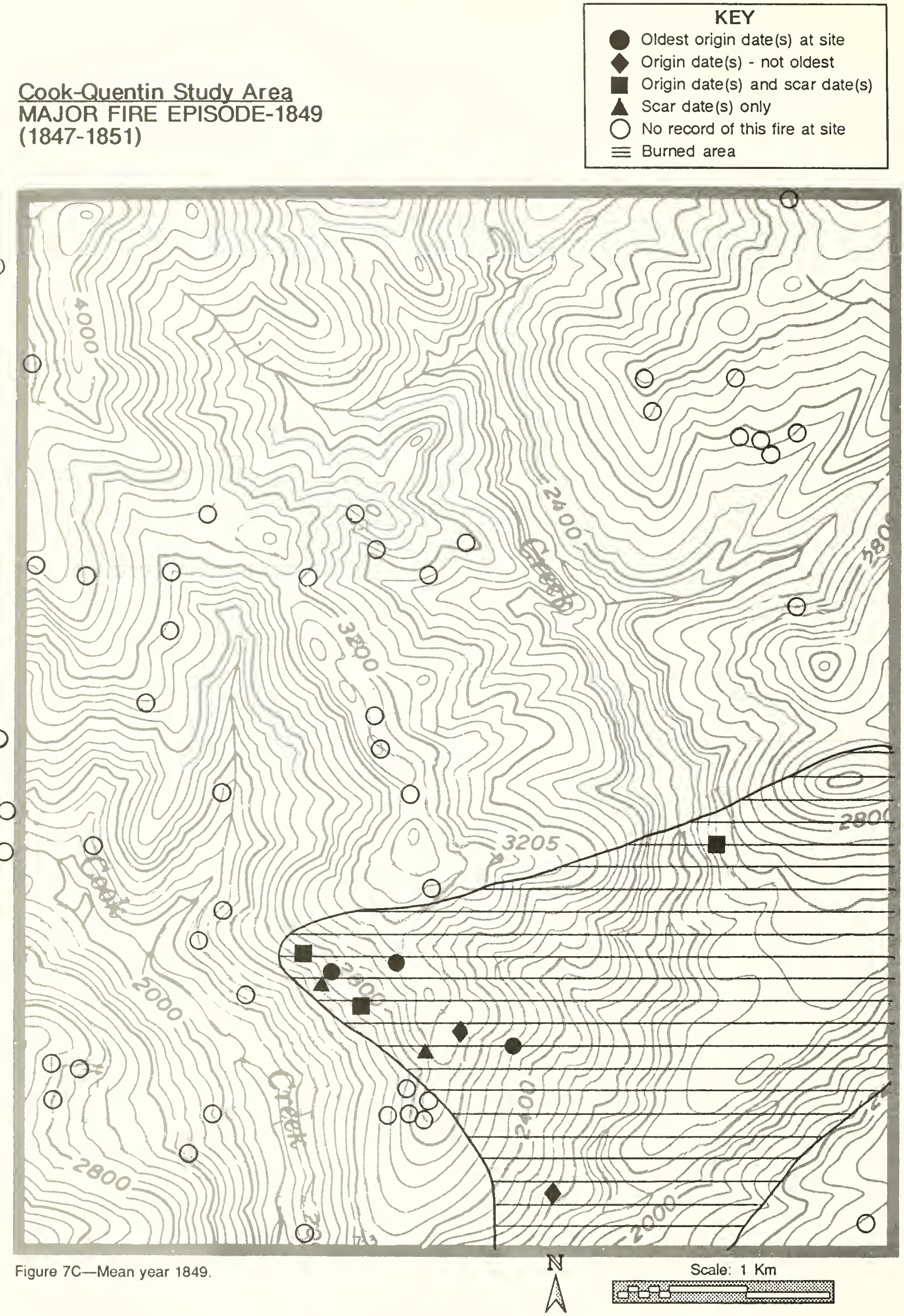


Figure 7C—Mean year 1849.

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

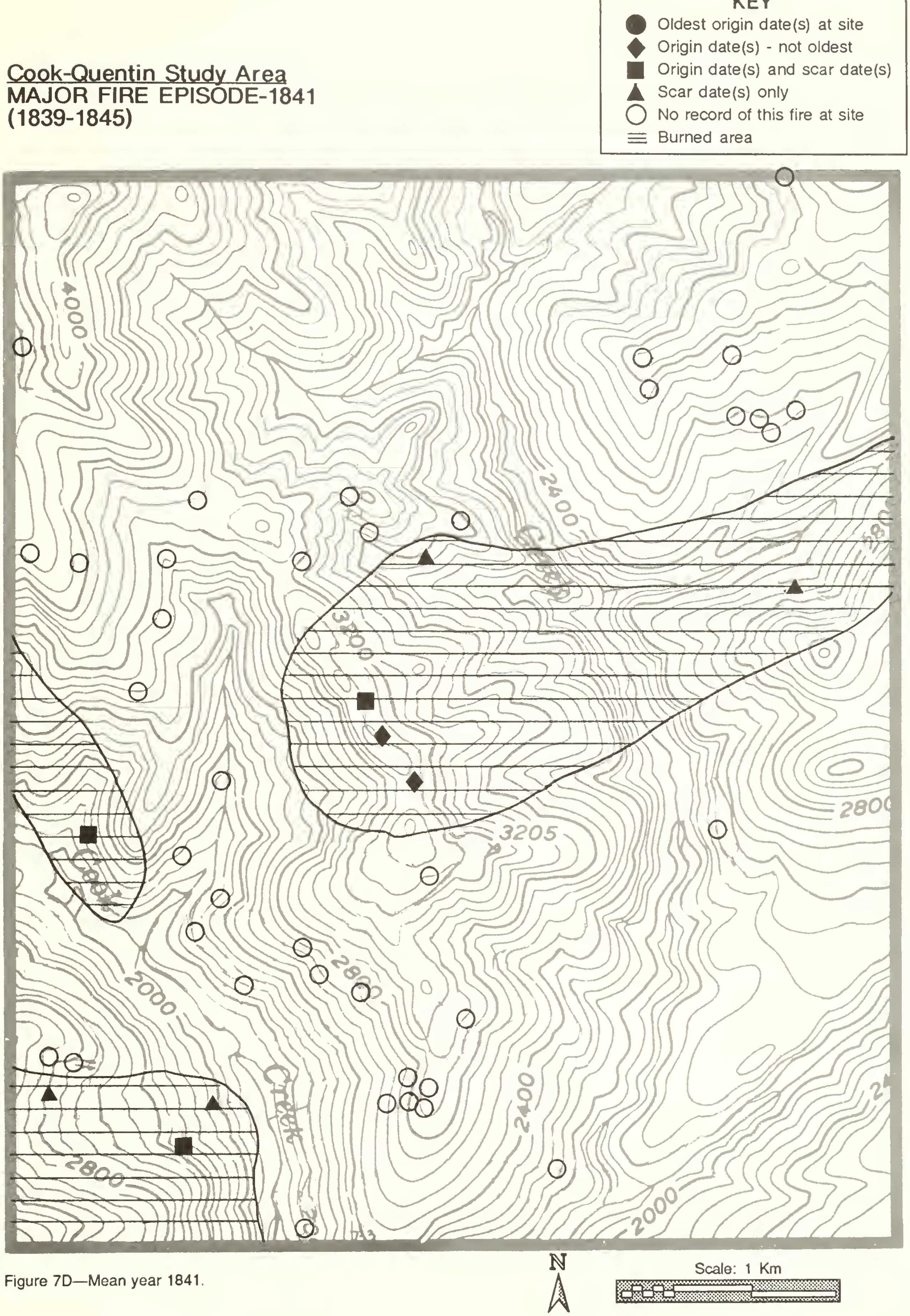


Figure 7D—Mean year 1841.

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

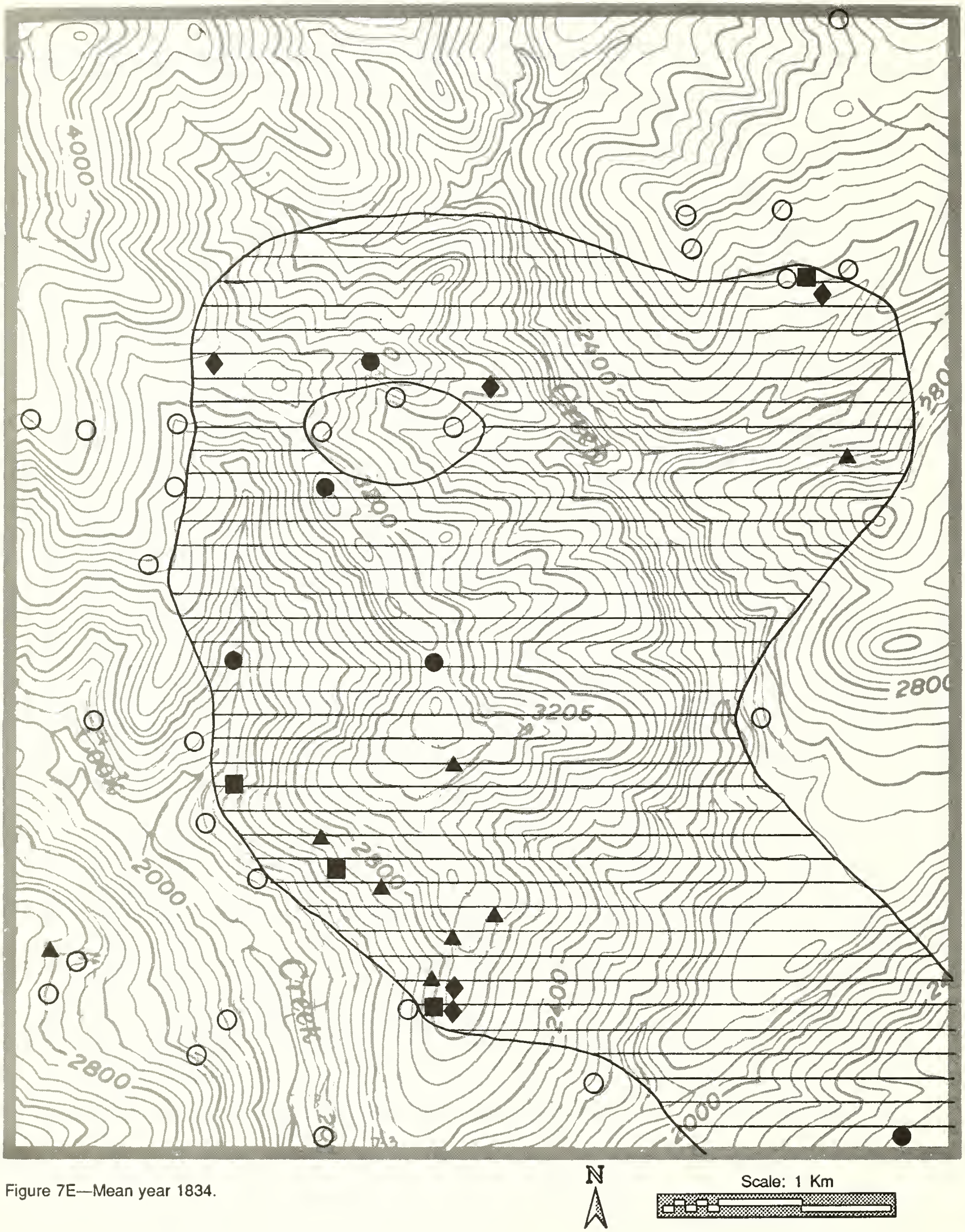


Figure 7E—Mean year 1834.

Cook-Quentin Study Area
MAJOR FIRE EPISODE-1813
(1812-1816)

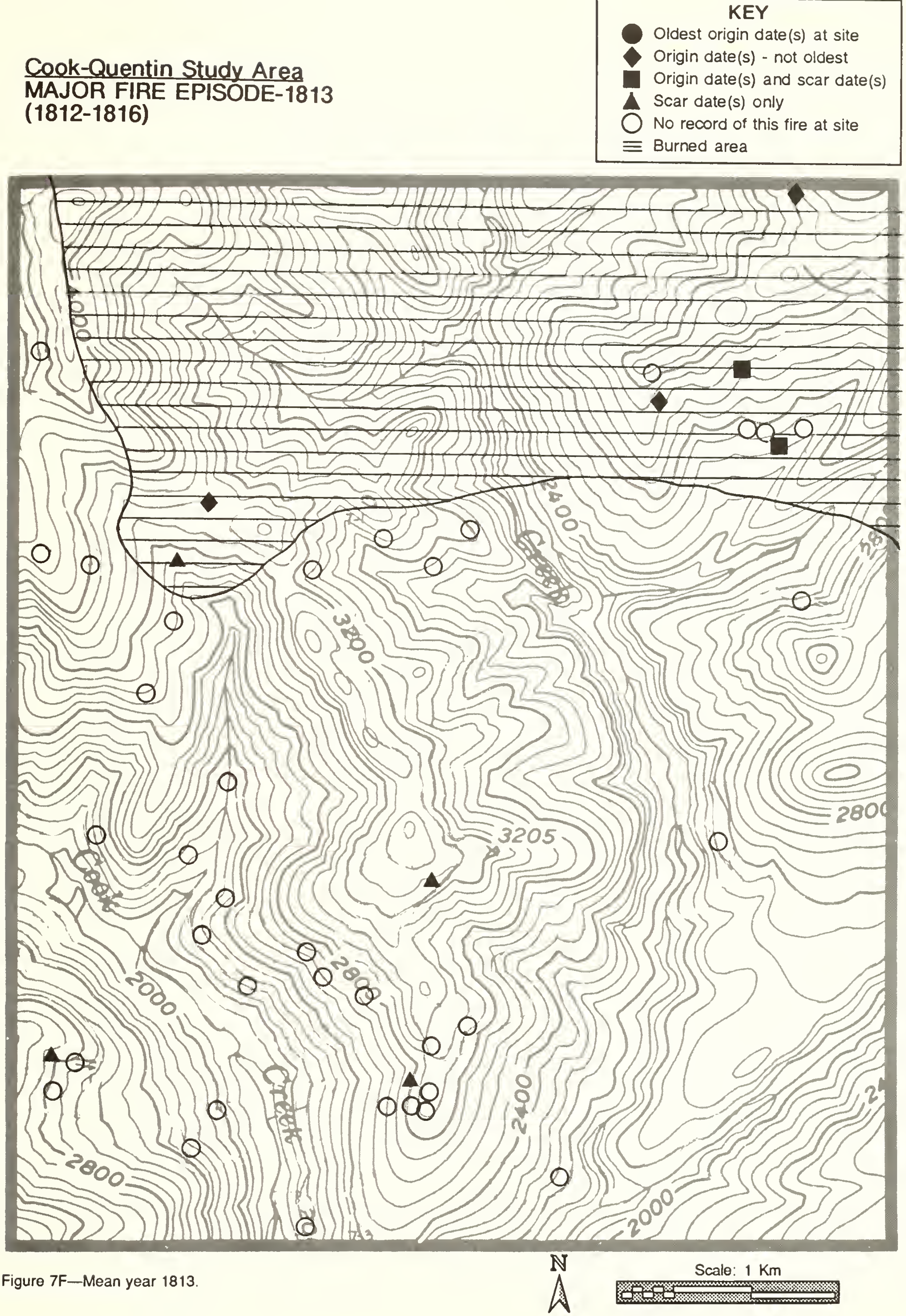


Figure 7F—Mean year 1813.

Cook-Quentin Study Area
MAJOR FIRE EPISODE-1807
(1805-1807)

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

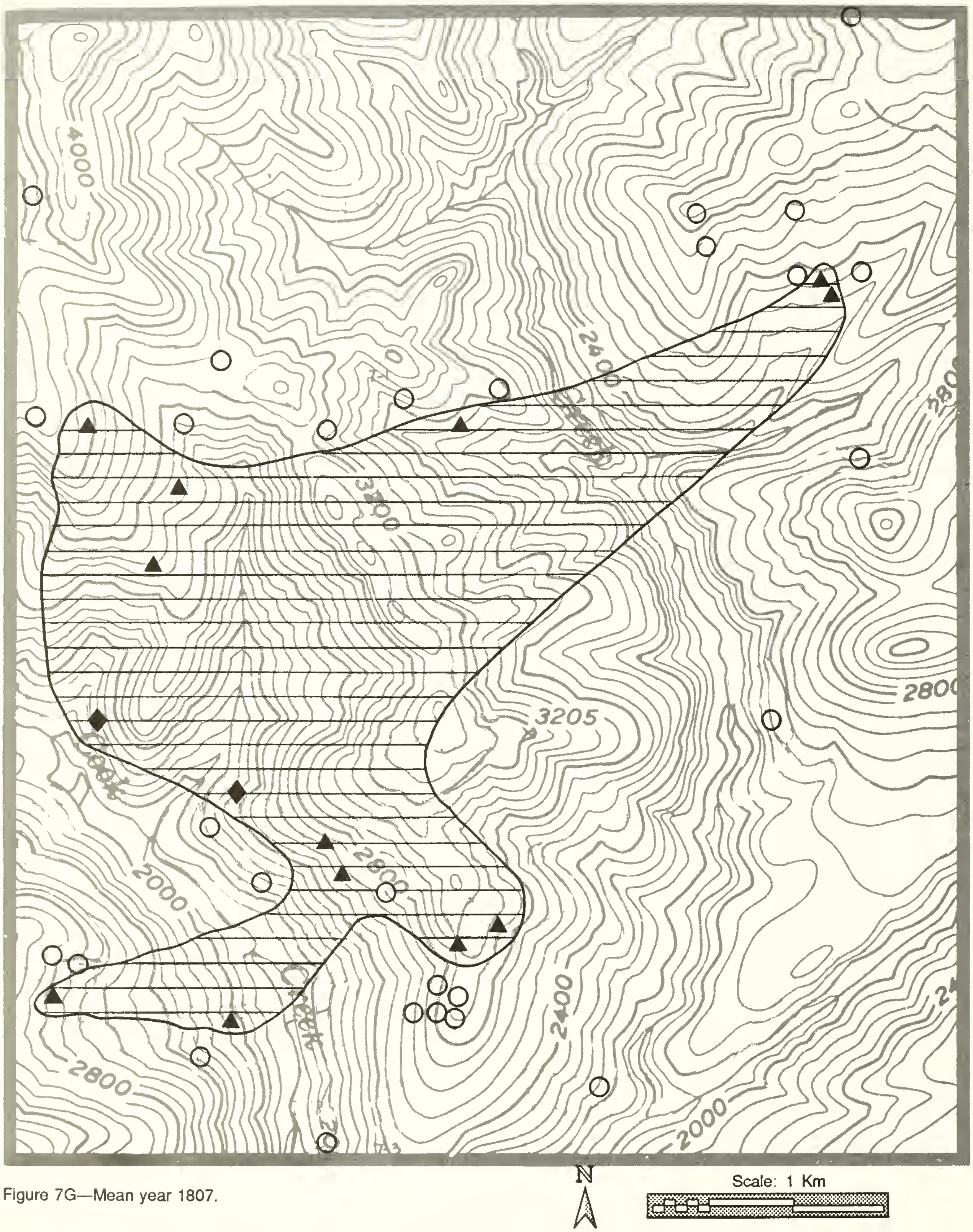


Figure 7G—Mean year 1807.

Cook-Quentin Study Area
MAJOR FIRE EPISODE-1800
(1798-1804)

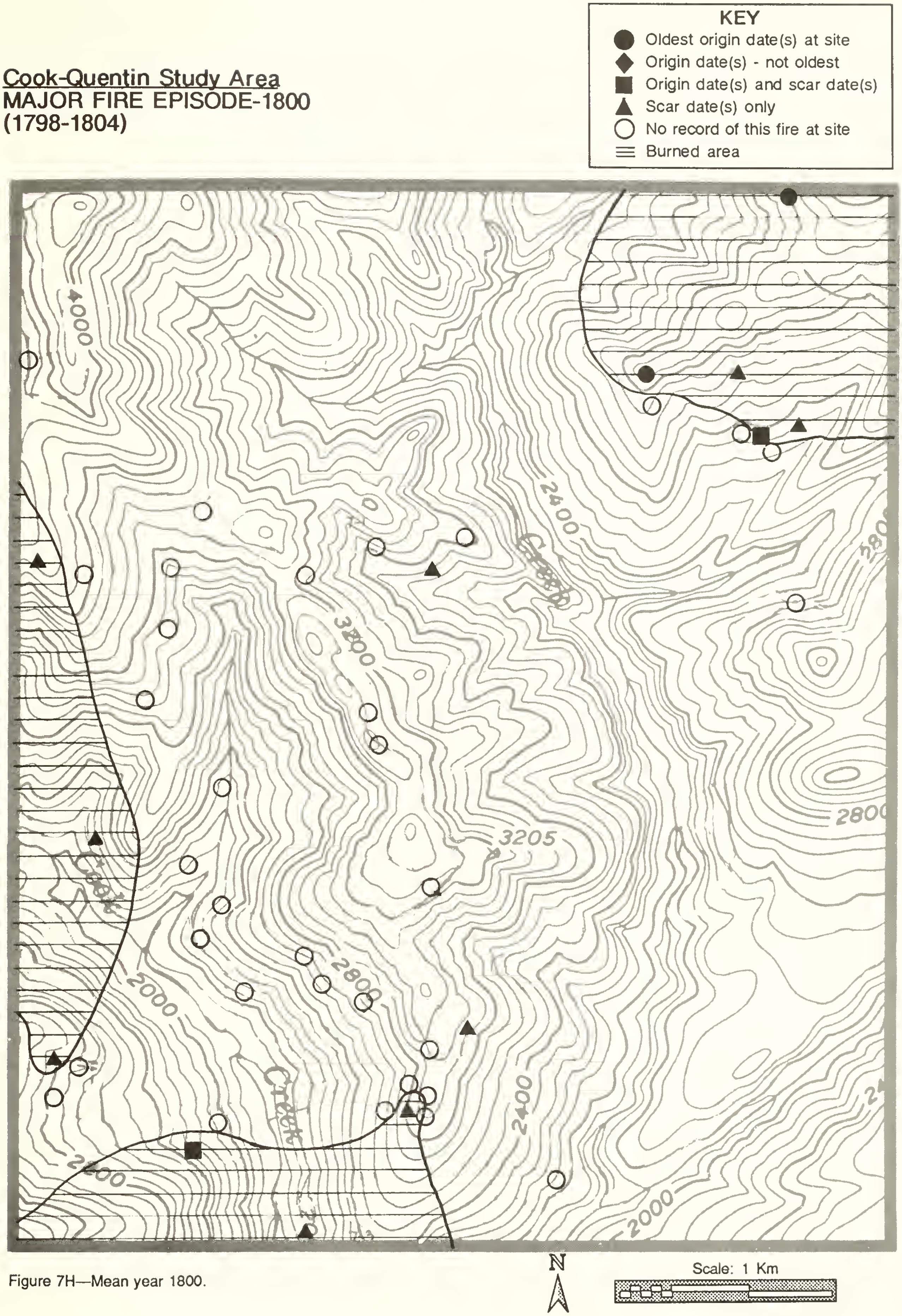
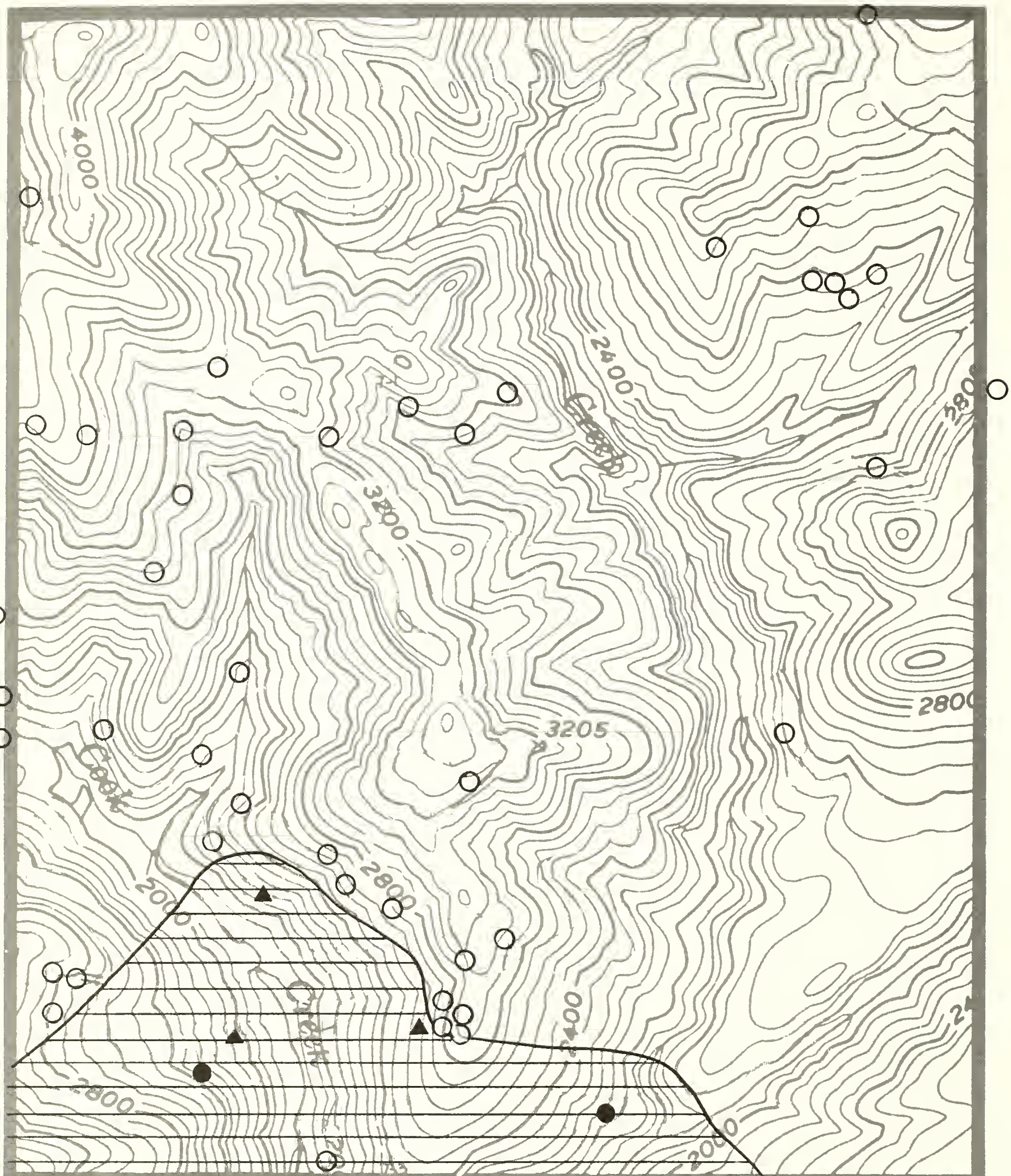


Figure 7H—Mean year 1800.

Cook-Quentin Study Area
MAJOR FIRE EPISODE-1772 (1770-1774)

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



N

Scale: 1 Km

Figure 7I—Mean year 1772.

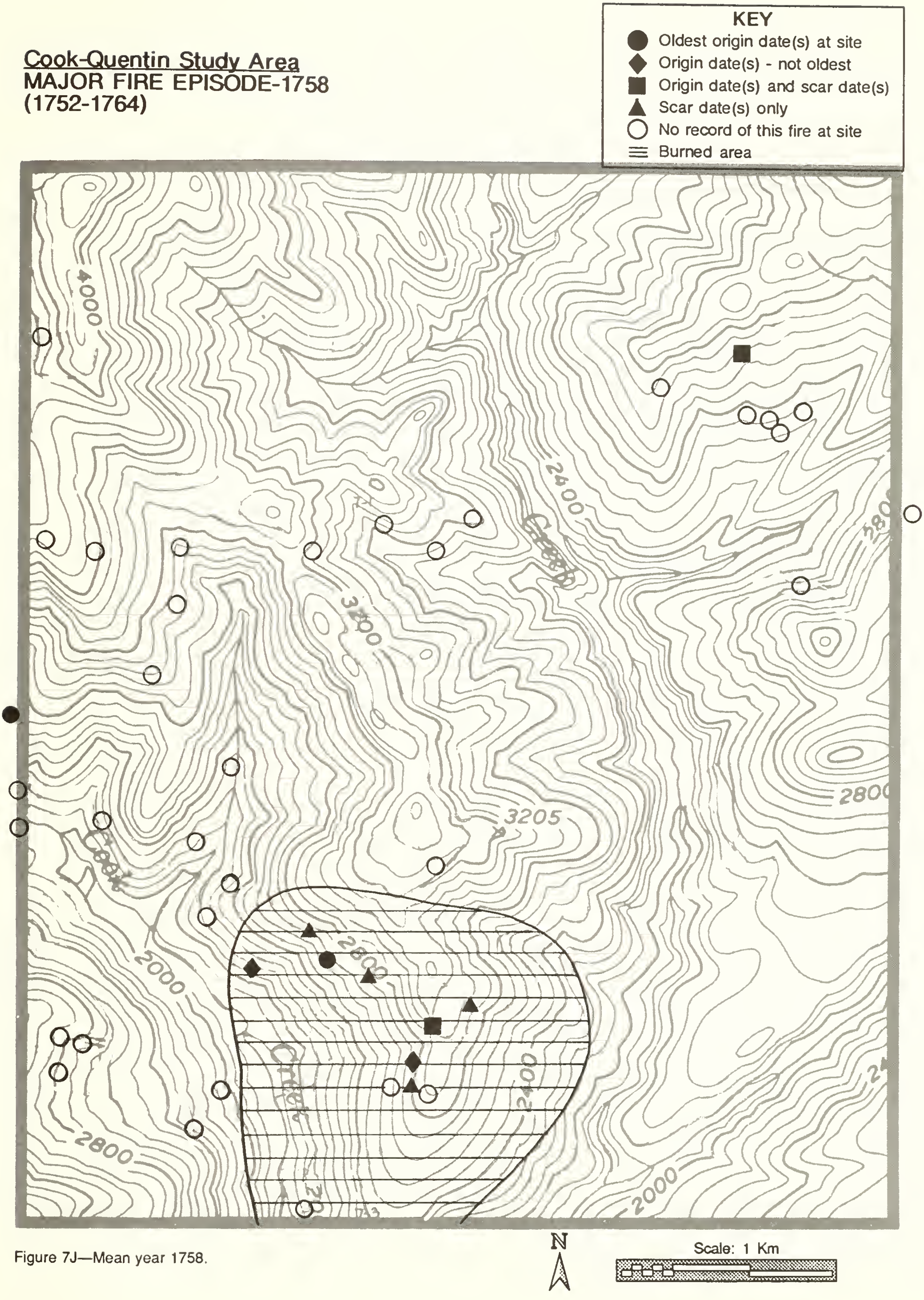


Figure 7J—Mean year 1758.

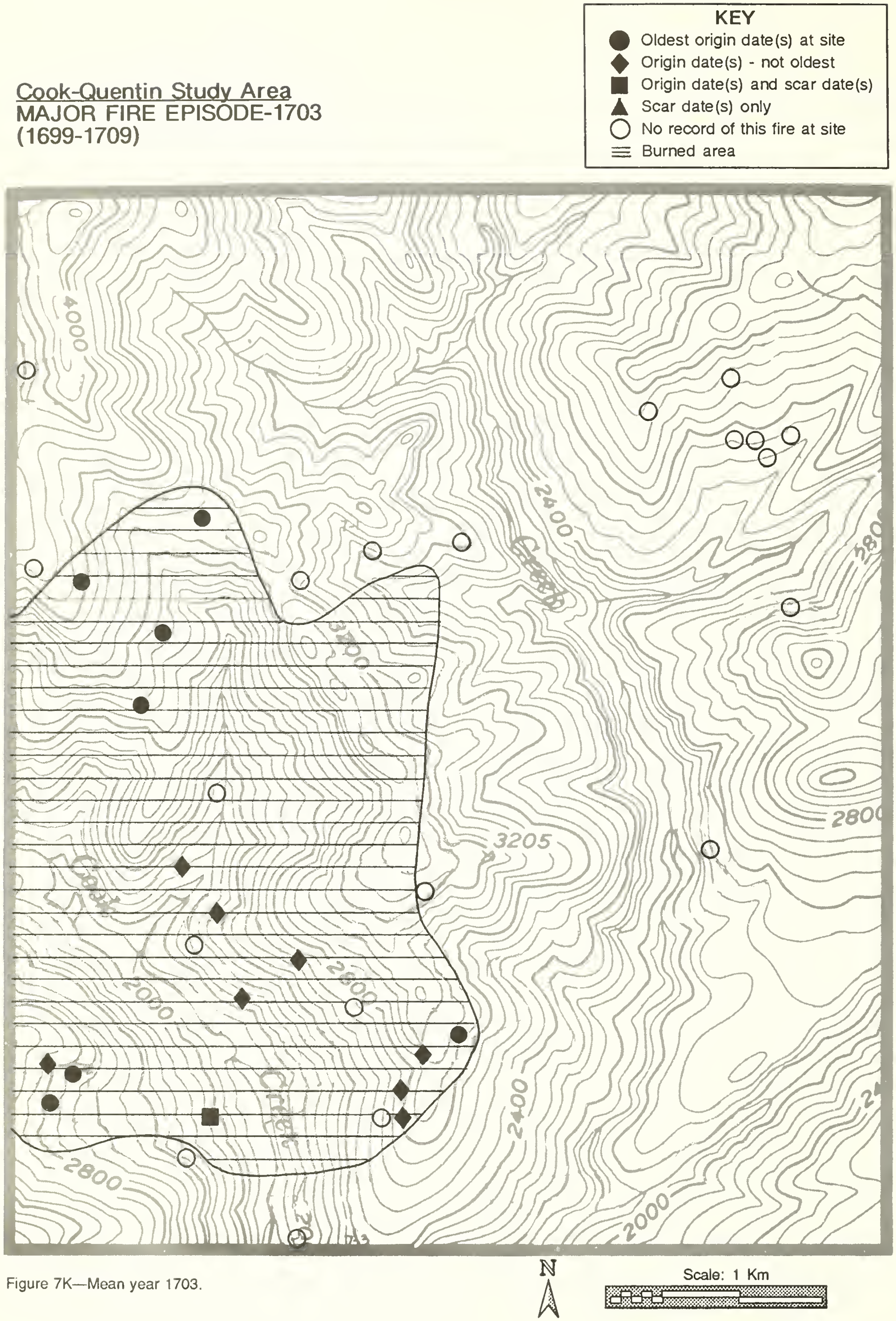
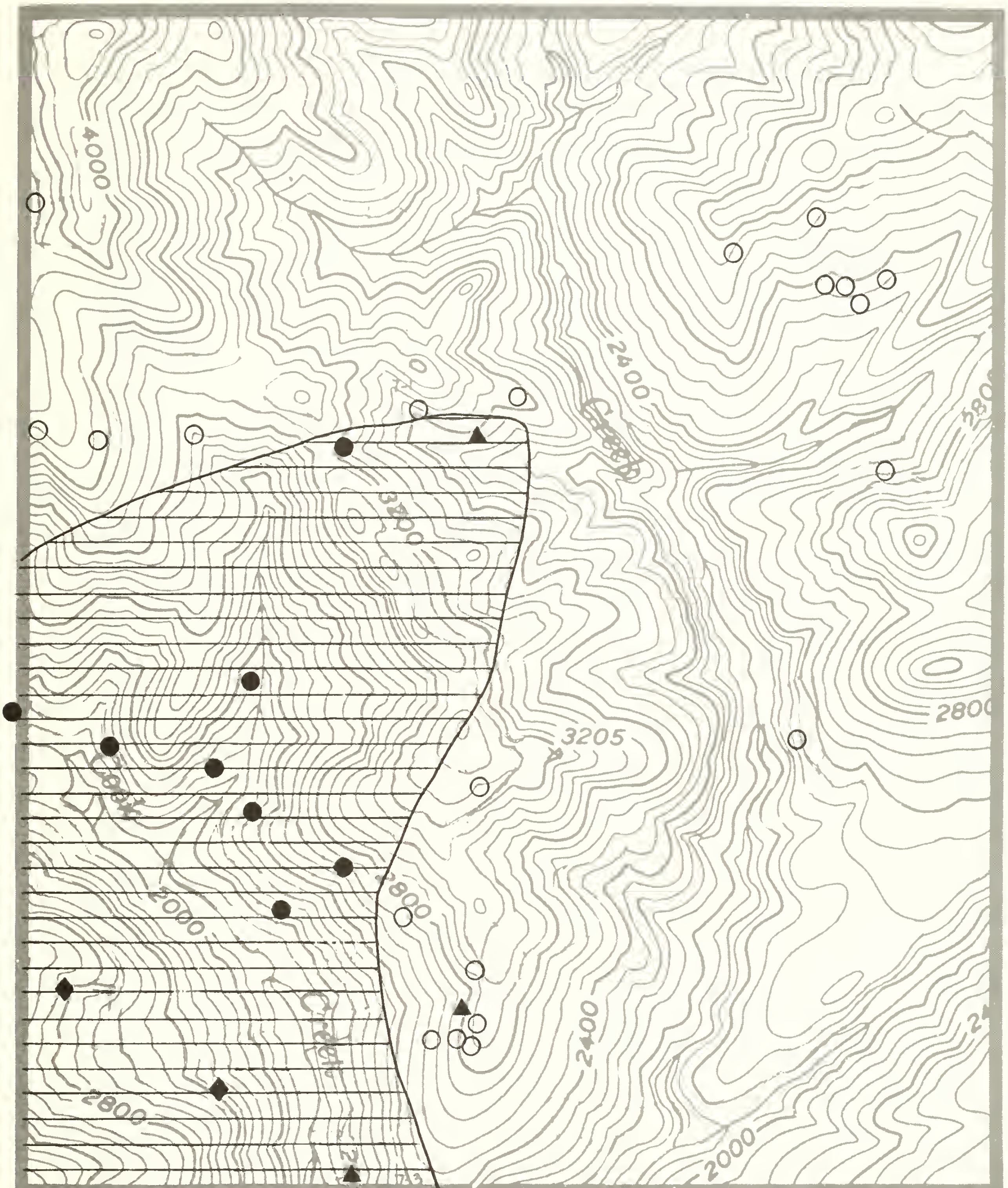


Figure 7K—Mean year 1703.

Cook-Quentin Study Area
MAJOR FIRE EPISODE-1689
(1683-1695)

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



N

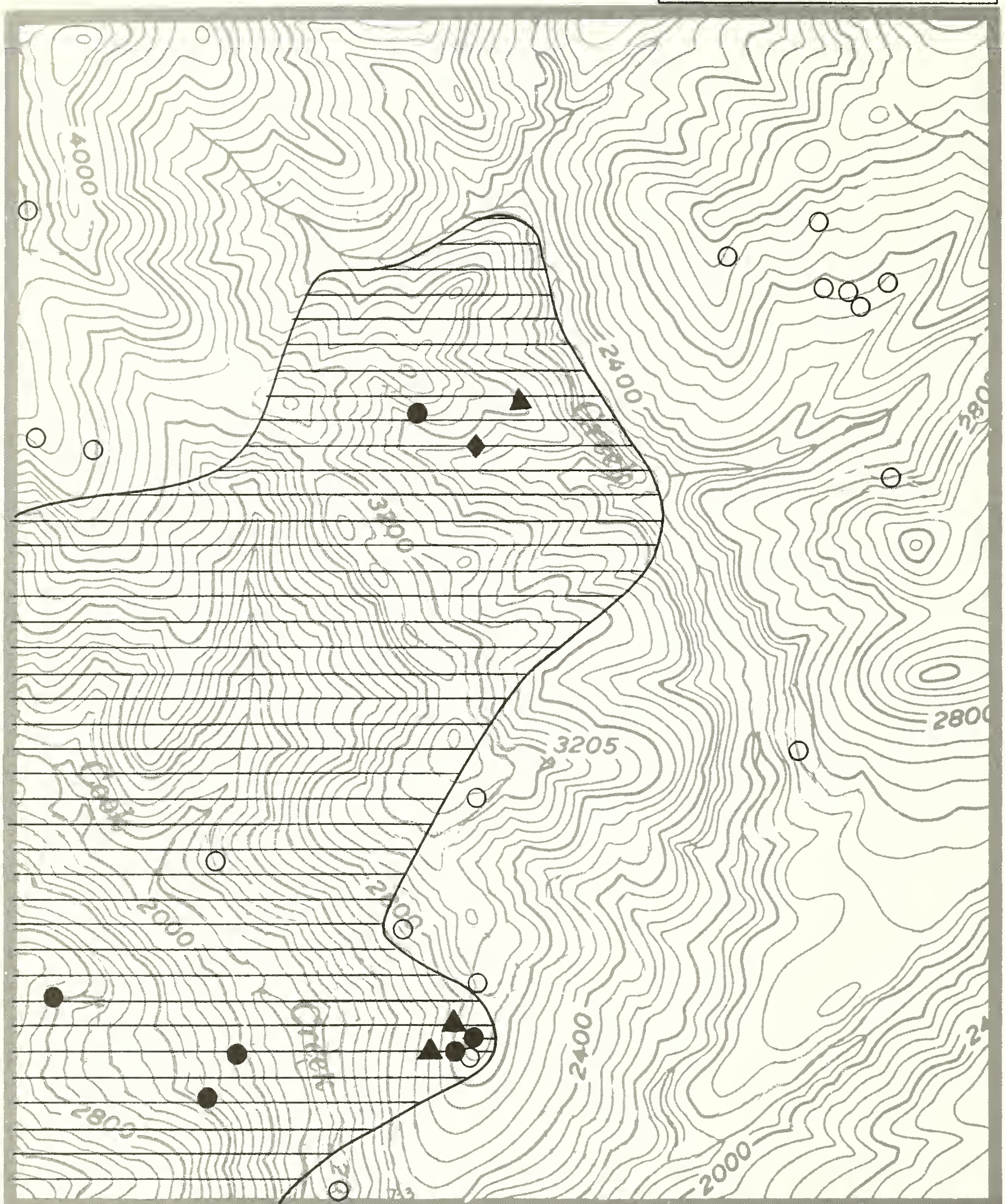
Scale: 1 Km

Figure 7L—Mean year 1689.

Cook-Quentin Study Area
MAJOR FIRE EPISODE-1658
(1648-1671)

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



N

Scale: 1 Km

Figure 7M—Mean year 1658.

Cook-Quentin Study Area
MAJOR FIRE EPISODE-1566
(1549-1586)

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

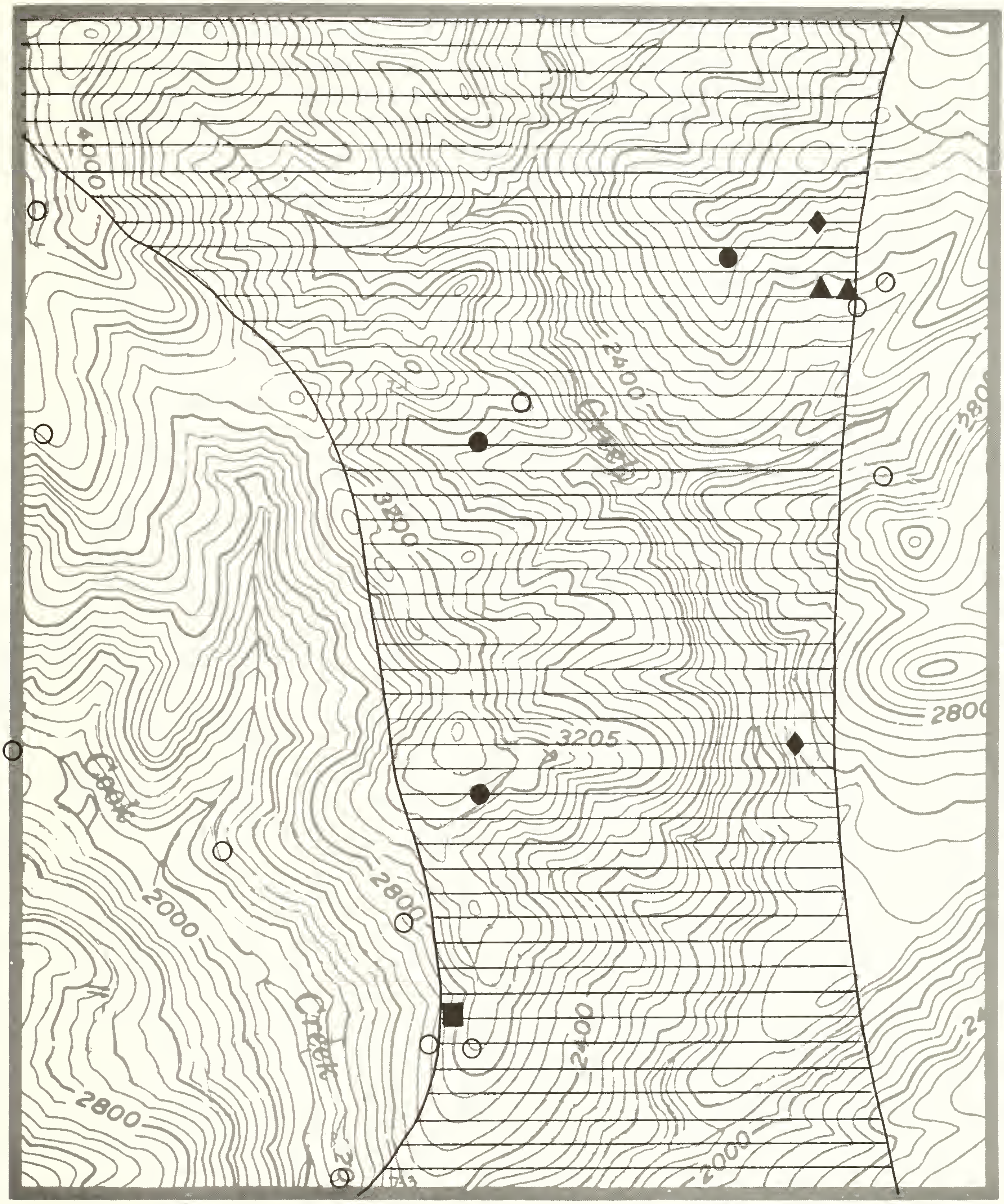


Figure 7N—Mean year 1566.

N

Scale: 1 Km

Cook-Quentin Study Area
MAJOR FIRE EPISODE-1532
(1511-1545)

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

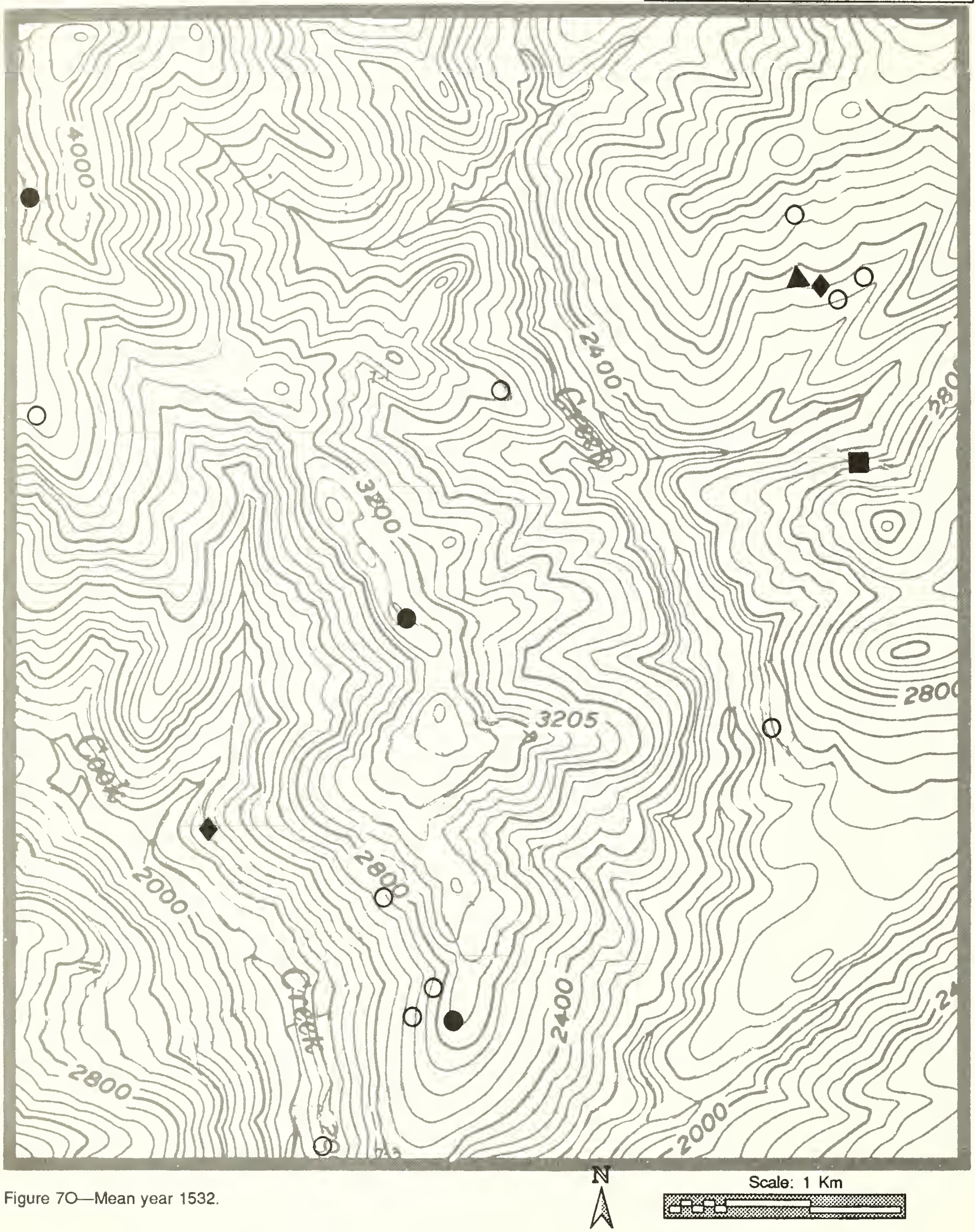


Figure 70—Mean year 1532.

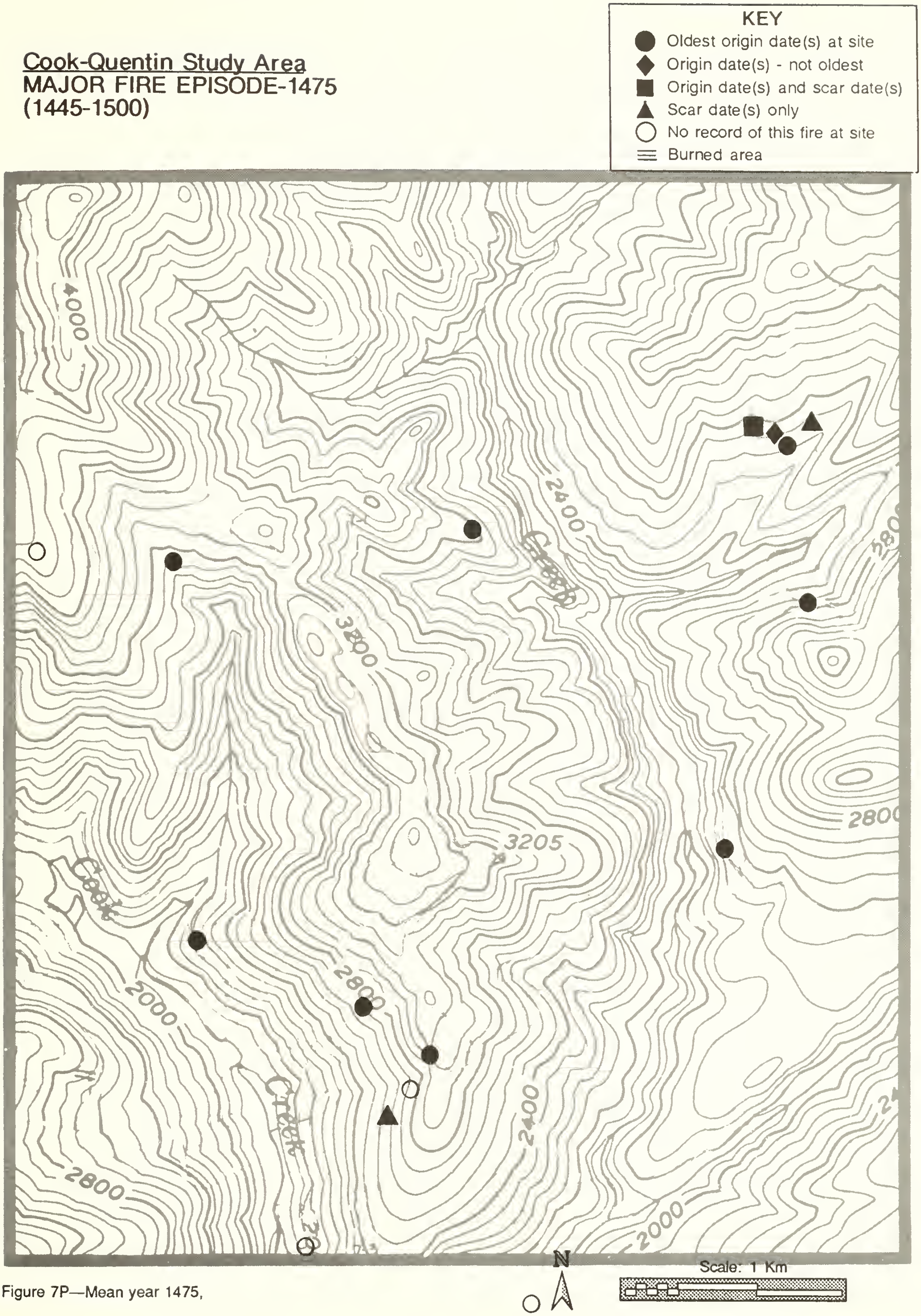


Figure 7P—Mean year 1475,

Cook-Quentin Study Area
MAJOR FIRE EPISODE-1400
(1380-1410)

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

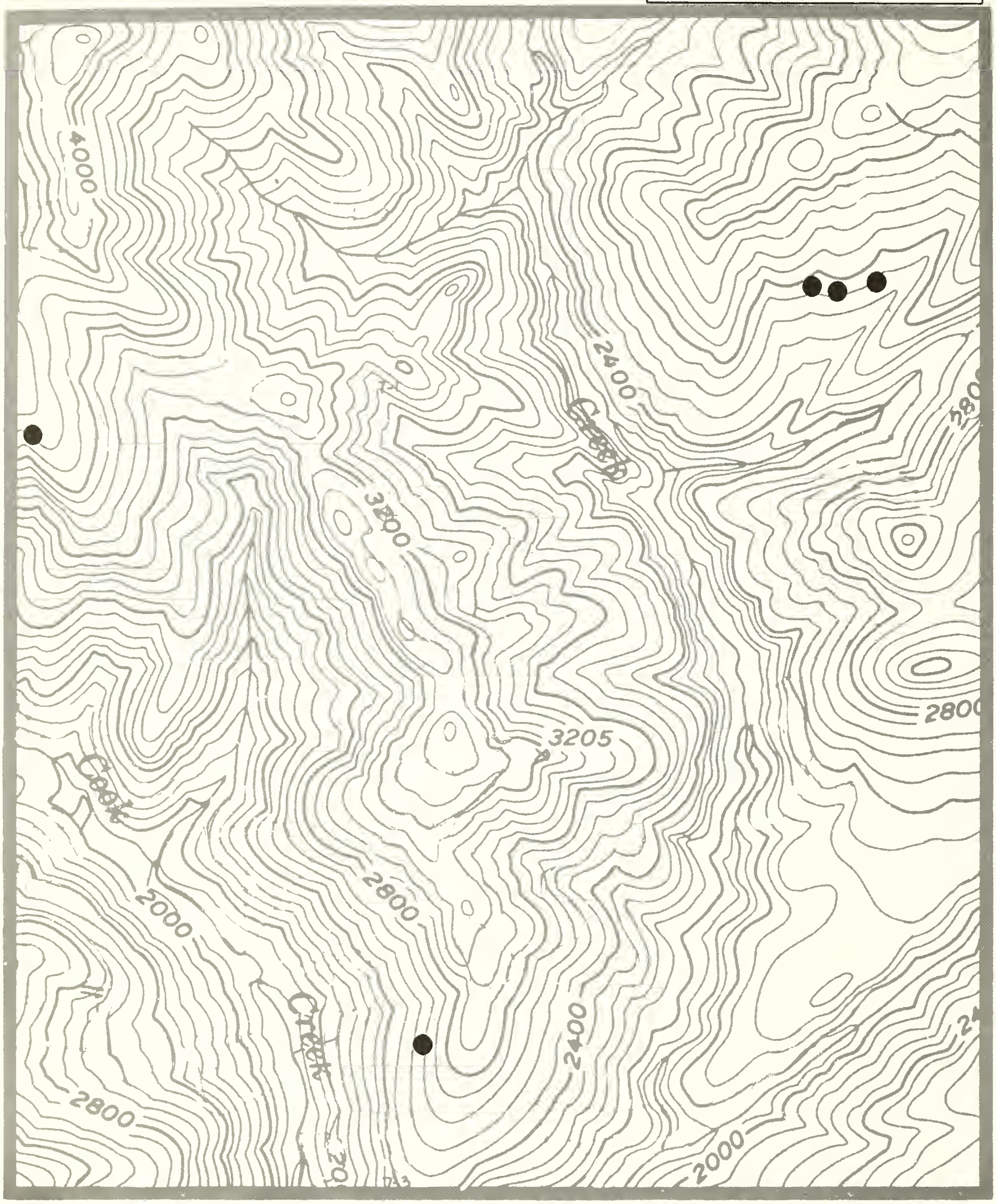


Figure 7Q—Mean year 1400.

N

Scale: 1 Km

Cook-Quentin Study Area
MAJOR FIRE EPISODE-1150
(1150-1200)

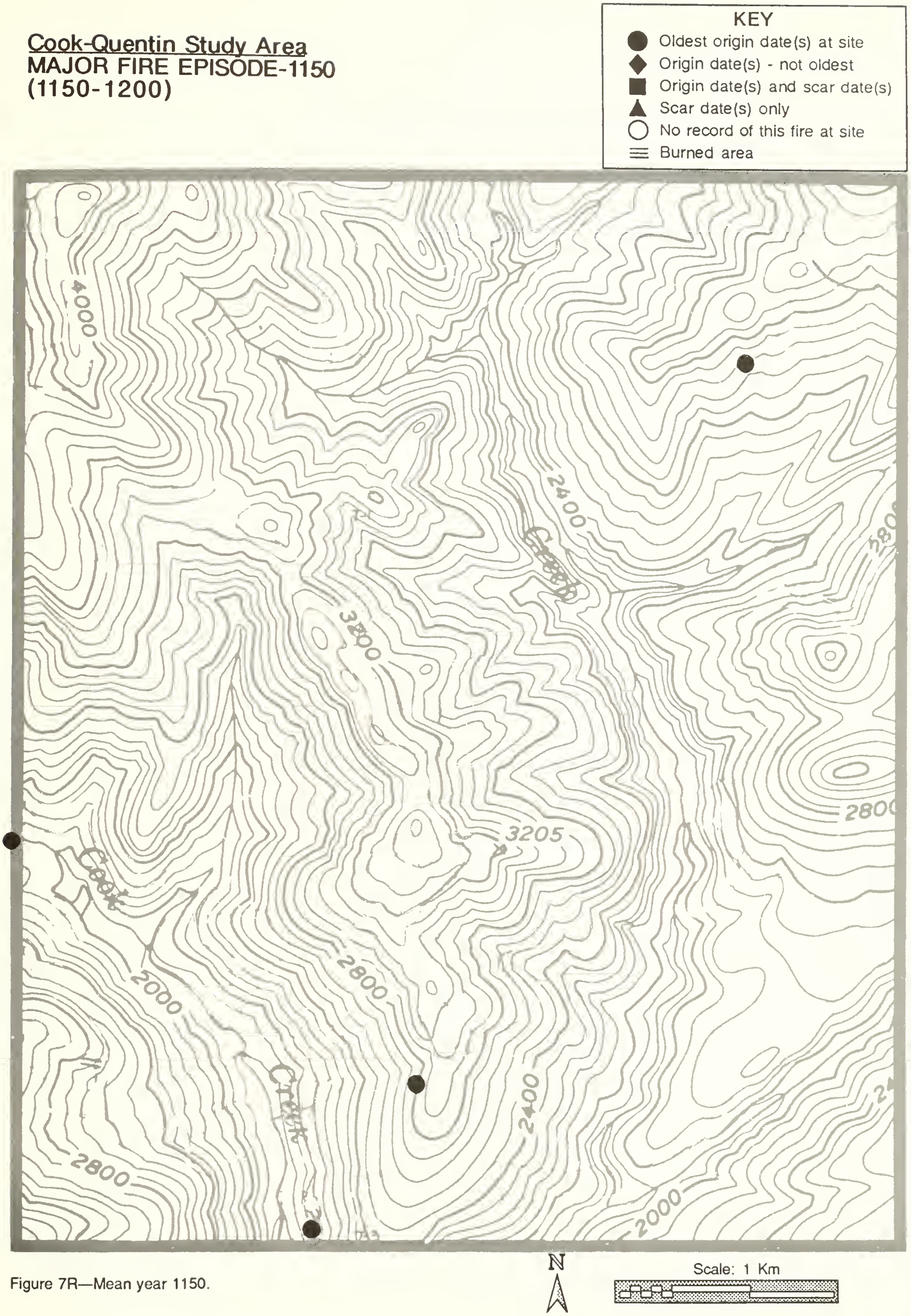


Figure 7R—Mean year 1150.

Deer study area—All fires recorded in the Deer study area burned beyond study area boundaries. In the 1500's, several larger fires with high severity covered most of the study area (table 7, fig. 8). Fires during the 1700-1900 period were of mainly low to moderate severity and burned small areas. Fires during the 1800's burned small areas in the upper elevations.

Human Influences

Cook-Quentin study area—Both Euro-American and aboriginal people have influenced fire regimes. After a review of historical documents, Burke (1979) postulated an increase in forest fire incidence in the central-western Cascade Range during a "Euro-American settlement period" extending from 1850 to 1910 when explorers, trappers, miners, sheepherders, and others used the accessible areas of the Cascade Range.

In the Cook-Quentin study area, fires burned 13 ha per year during this 60-year settlement period. Fire occurrence was higher (25 ha per year) in a comparable 60-year period a century earlier before Euro-American influences (1750-1810). From 1810 to 1850 (when aboriginal populations were waning because of smallpox epidemics, and Euro-American influence was minimal) fires burned 54 ha per year in the Cook-Quentin study area.

No clear effect of human influence on the fire regime was seen in this study area. The highest fire incidence occurred during the period of least human influence. We concluded that in this study area lightning ignition of fire was predominant, and human influence was relatively insignificant until fire suppression became effective. The variation among the three periods discussed above may well be an artifact of randomness of fire occurrence, study area size, and the length of the periods evaluated.

Table 7—Area burned during fire episodes in the Deer study area

Fire year	Burned area: Ratio method	Burned area: Planimeter method	Record[a]: A	B	C	D	E	F	Area by fire-severity class: High	Medium	Low
	Hectares		*Number of sites*						*Percent*		
1897	154	101	0	1	0	4	58	0	0	20	80
1850	277	321	0	3	4	2	54	0	0	78	22
1838	277	580	1	3	3	2	54	0	11	67	22
1829	251	315	1	1	1	5	54	1	13	25	63
1800	287	368	3	4	1	1	52	2	33	56	11
1764	234	369	2	0	1	4	51	5	29	14	57
1575	971	1025	22	3	2	1	28	7	79	18	4
1552	743	928	8	2	0	3	21	29	62	15	23
1515	1644	1856	18	4	0	0	4	37	82	18	0
1436	1457	—	3	1	0	2	2	55	50	17	33
1200	1942	—	5	0	0	0	0	58	100	0	0

— = Burn area was not defined by 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 the: A = sites where this is oldest origin year, B = sites with origin year only (not oldest), C = sites with origin year and scar year, D = sites with scar year only, E = sites with no record of this fire, F = sites where record has been erased by subsequent fires.

(*Text continues on page 50.*)

Deer Study Area
MAJOR FIRE EPISODE-1897 (1895-1897)

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

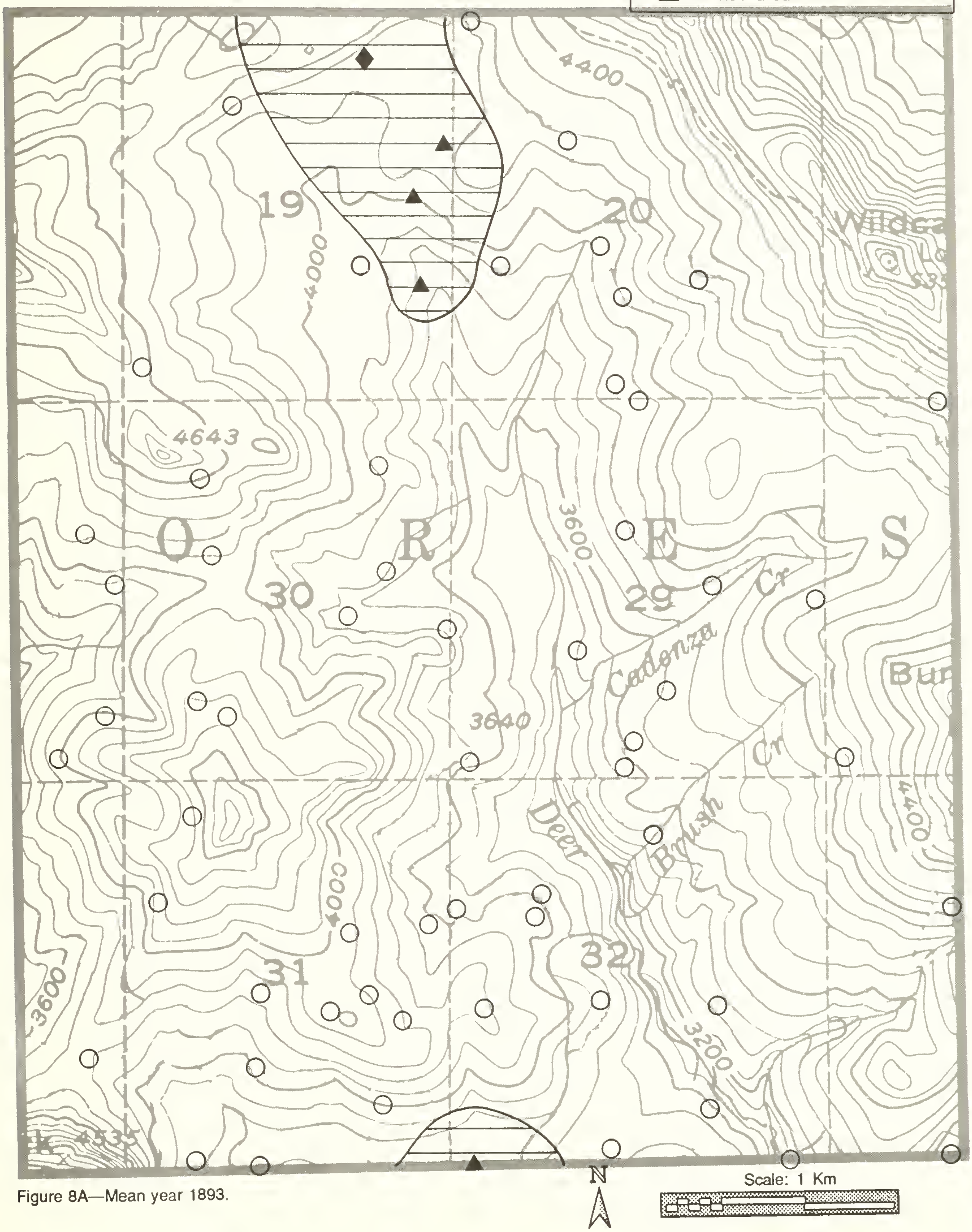


Figure 8A—Mean year 1893.

Deer Study Area
MAJOR FIRE EPISODE-1850
(1847-1854)

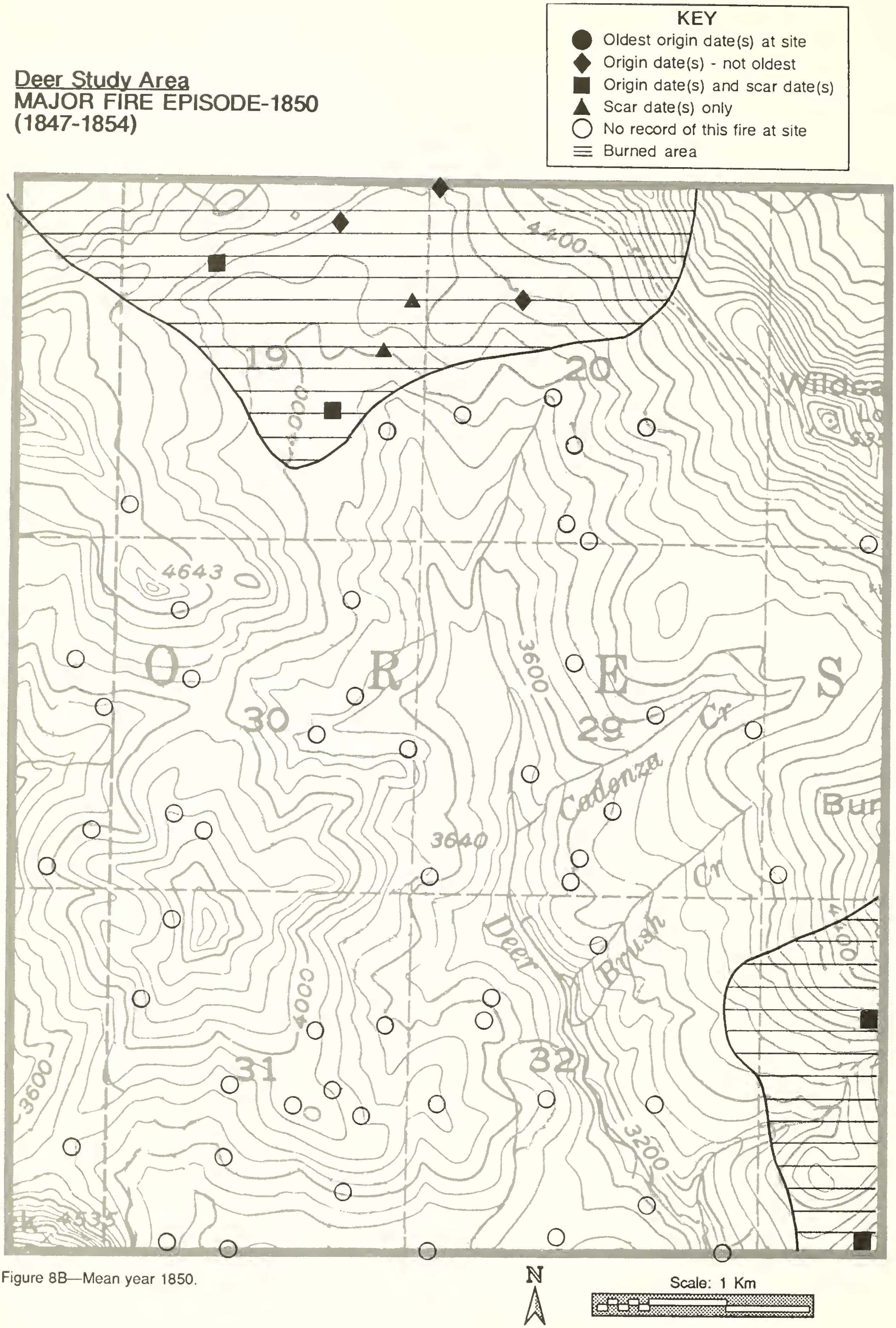


Figure 8B—Mean year 1850.

Deer Study Area
MAJOR FIRE EPISODE-1838
(1826-1833)

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

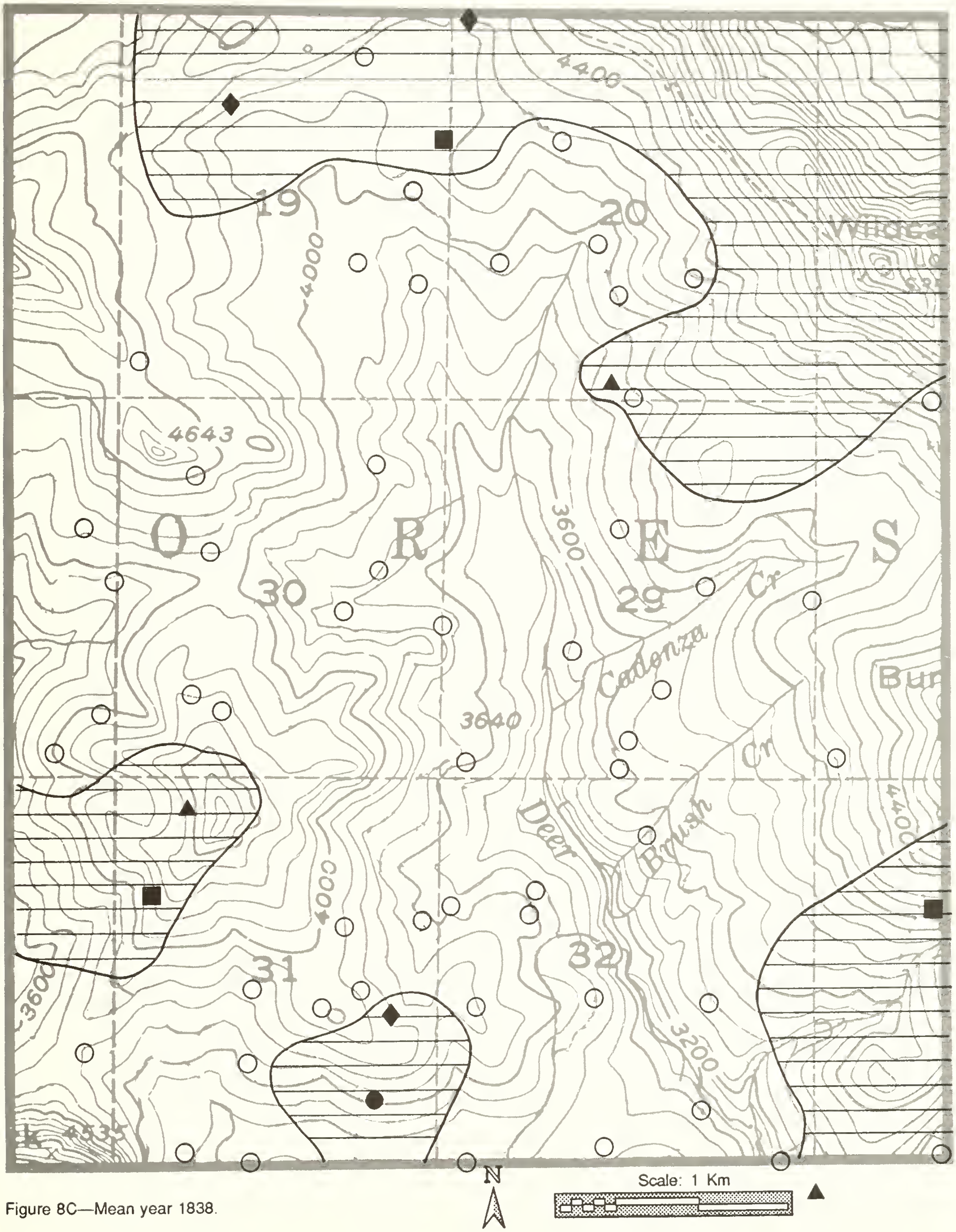


Figure 8C—Mean year 1838.

Deer Study Area
MAJOR FIRE EPISODE-1829
(1826-1833)

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

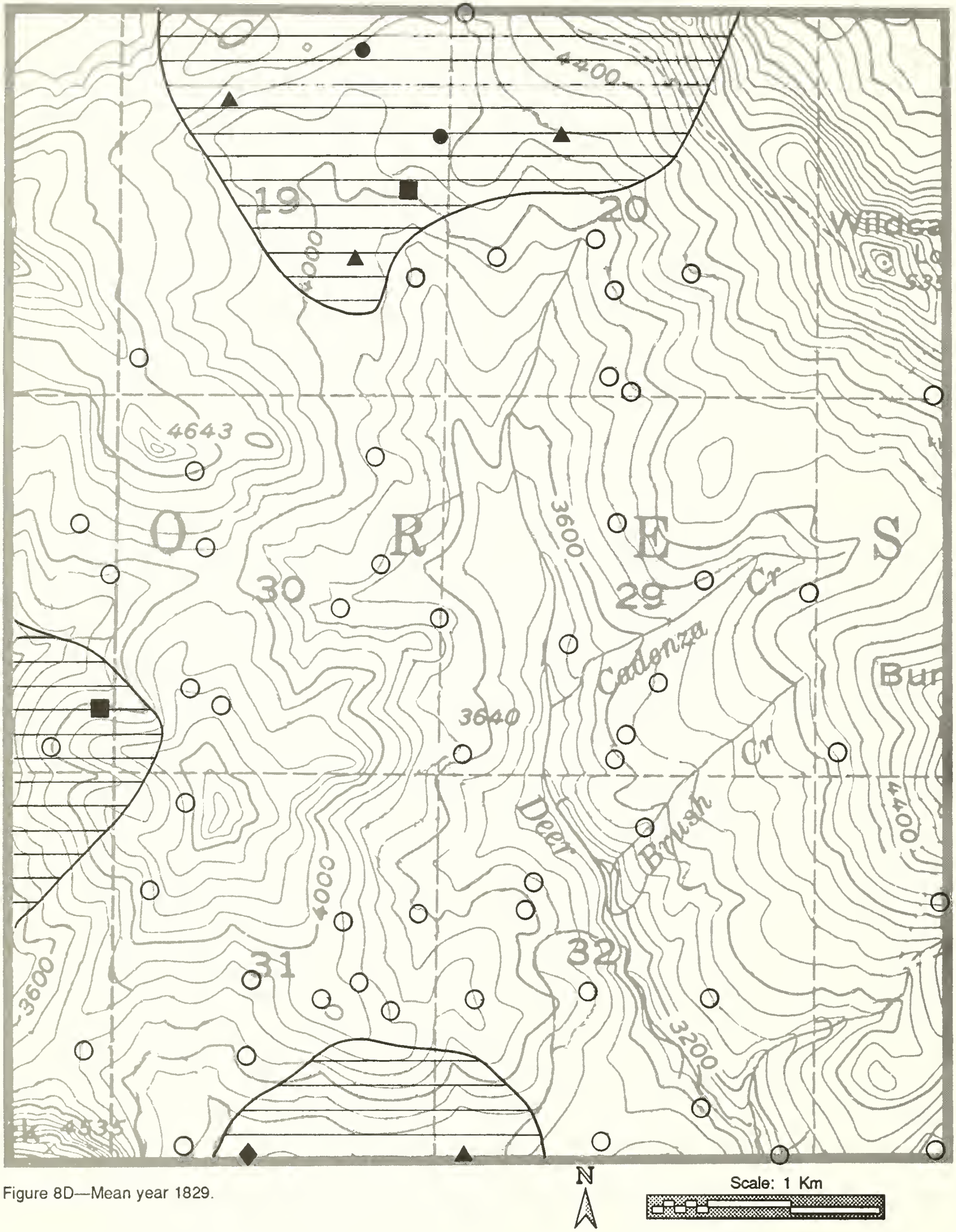


Figure 8D—Mean year 1829.

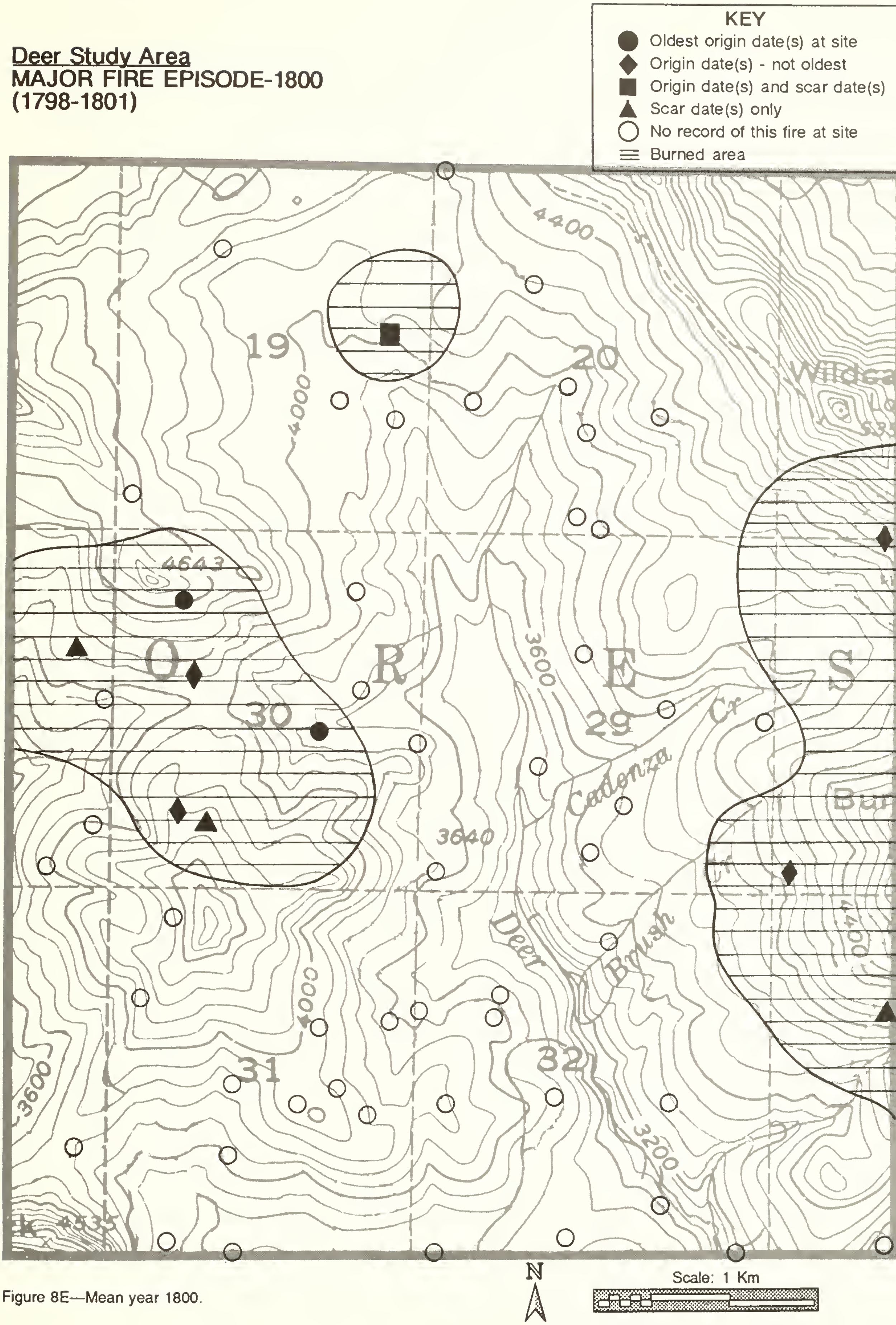


Figure 8E—Mean year 1800.

Deer Study Area
MAJOR FIRE EPISODE-1764
(1757-1768)

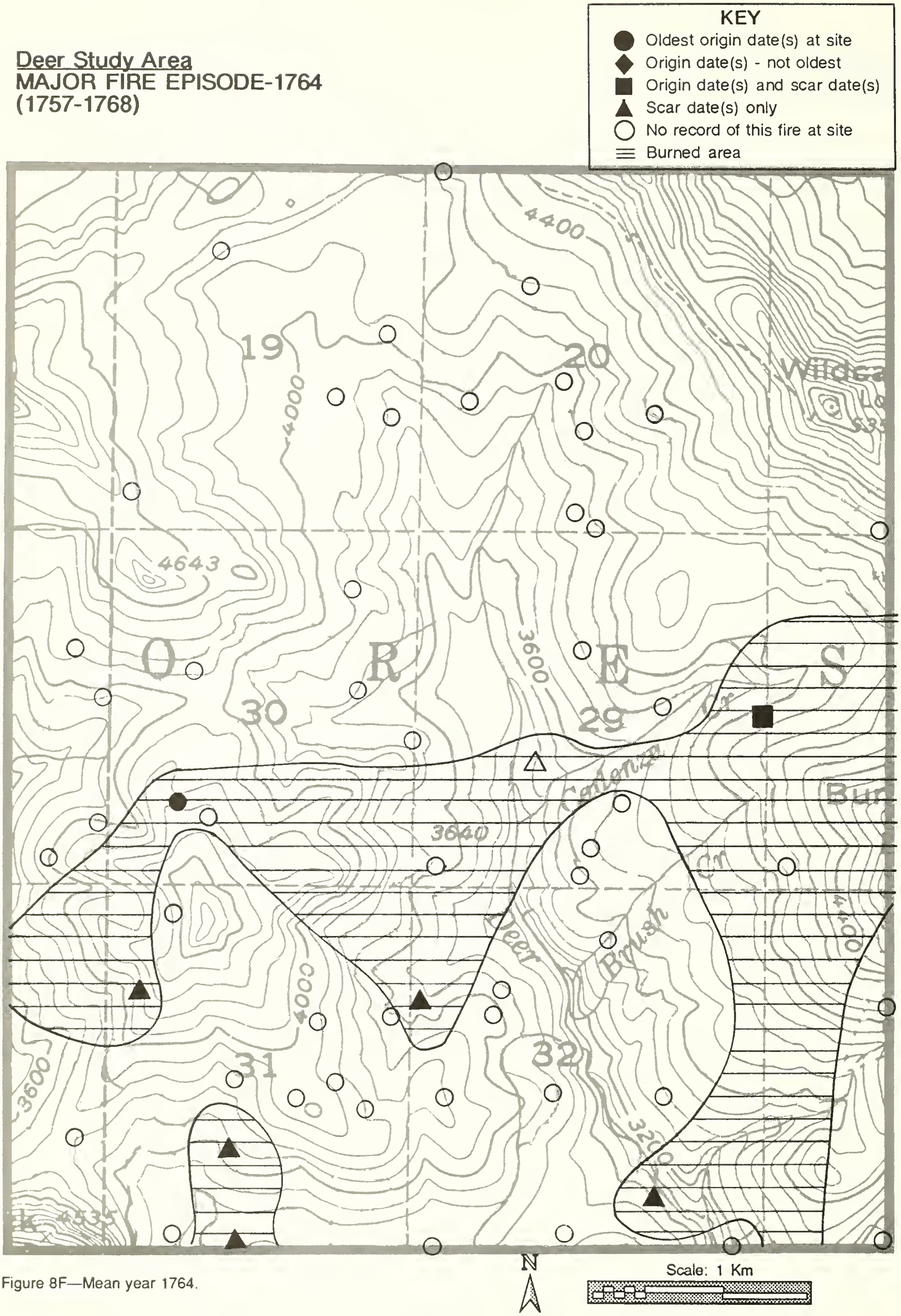


Figure 8F—Mean year 1764.

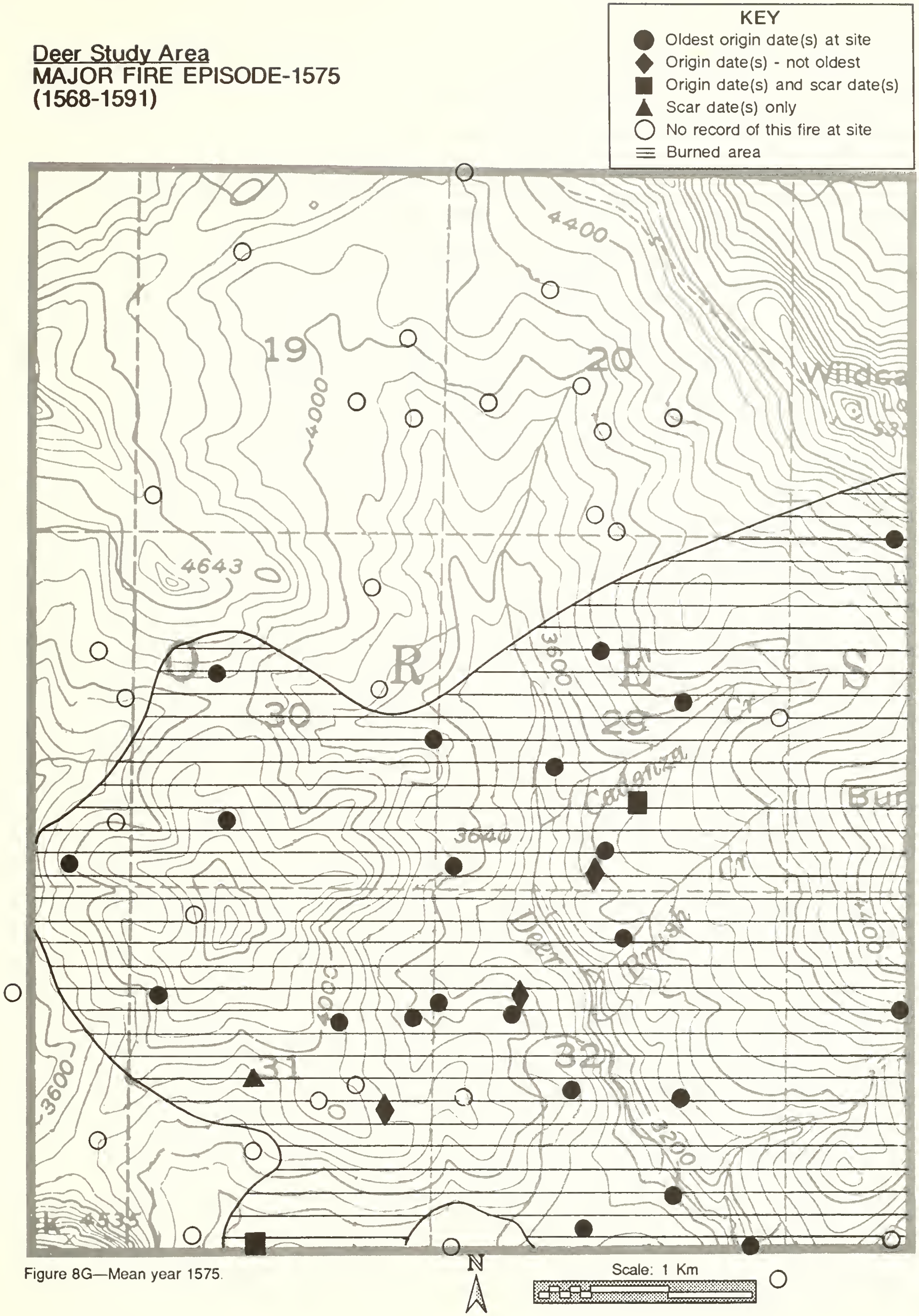


Figure 8G—Mean year 1575.

Deer Study Area
MAJOR FIRE EPISODE-1552
(1537-1557)

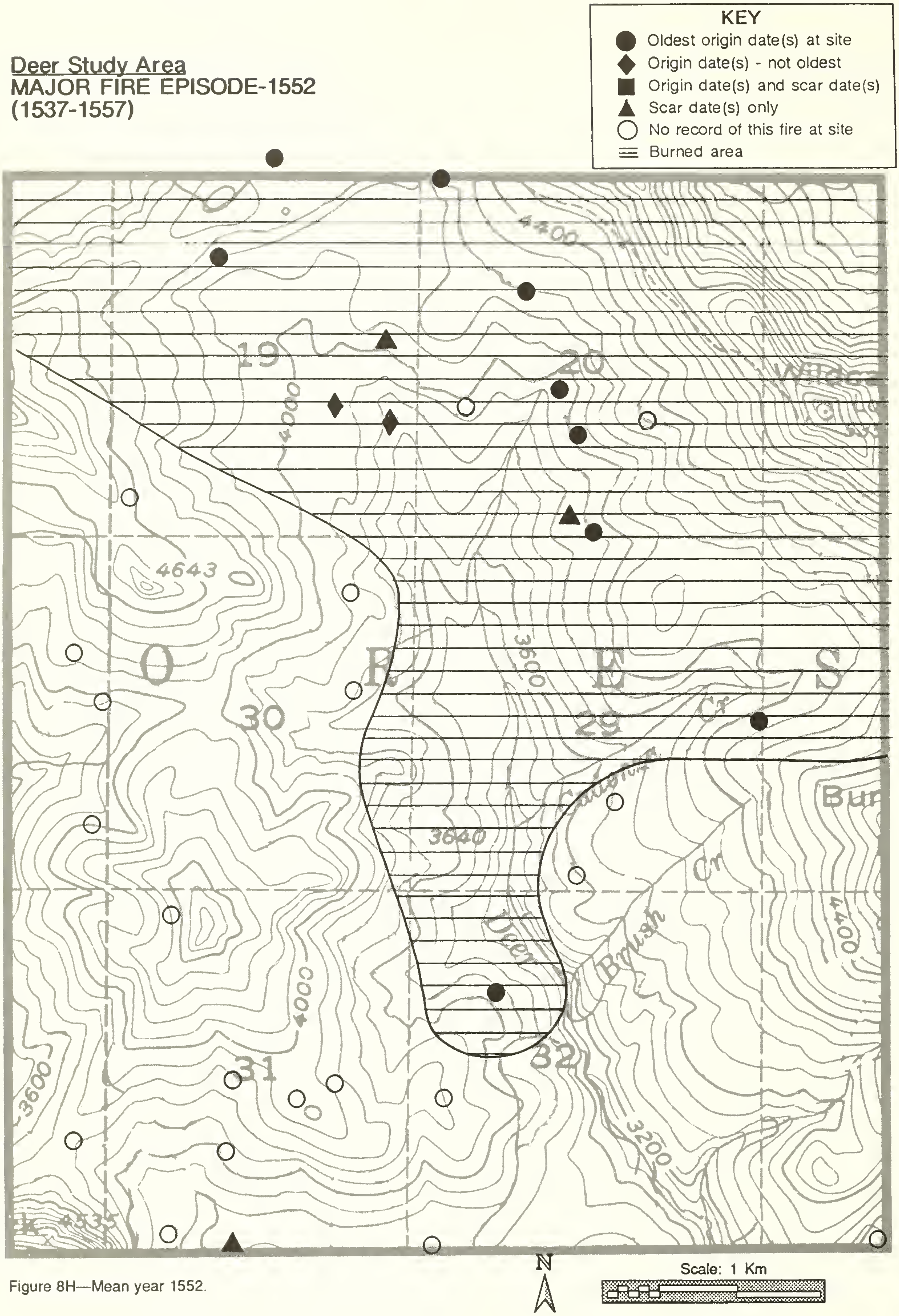


Figure 8H—Mean year 1552.

Deer Study Area
MAJOR FIRE EPISODE-1515
(1490-1530)

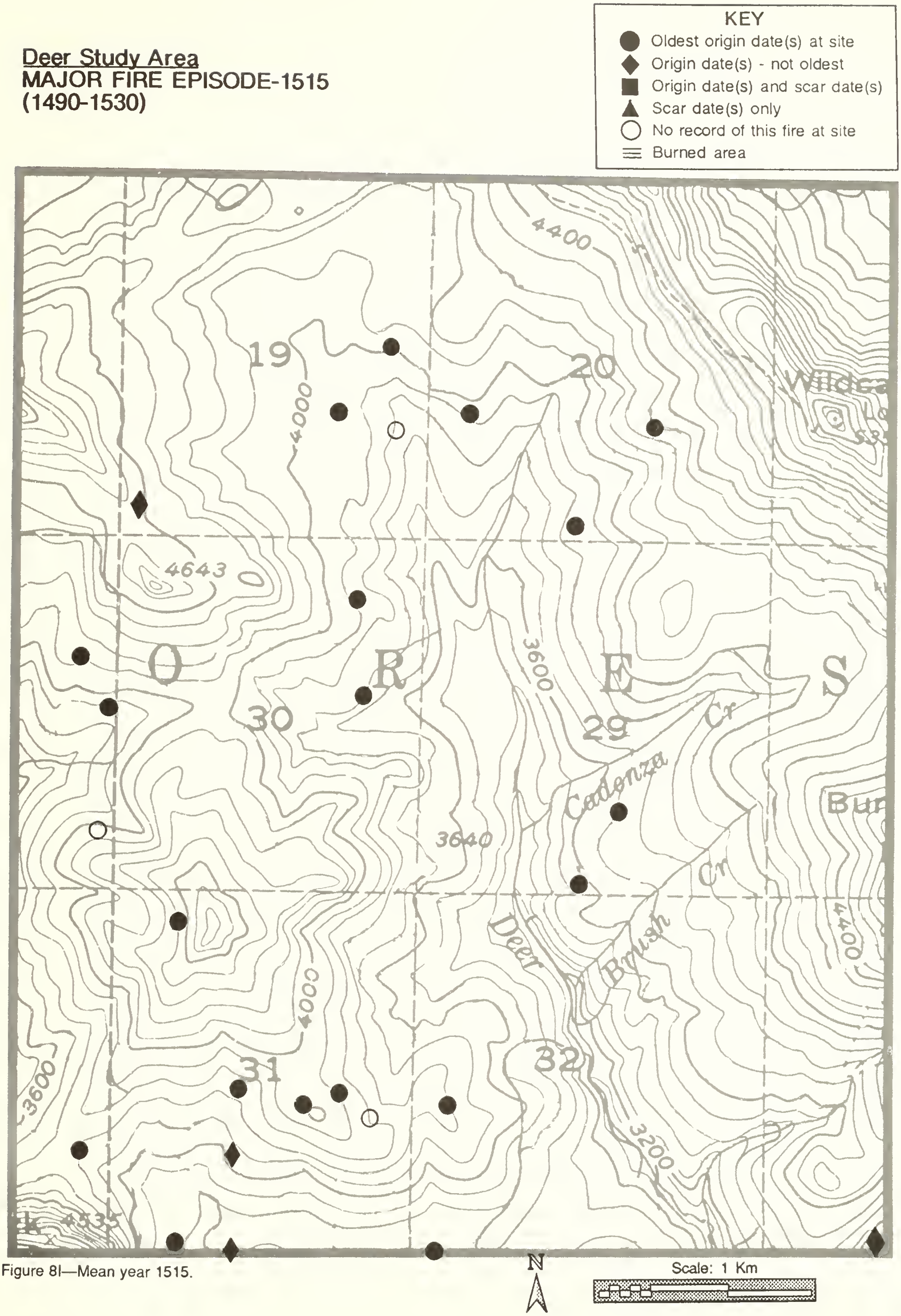


Figure 8l—Mean year 1515.

Deer Study Area
MAJOR FIRE EPISODE-1436
(1415-1455)

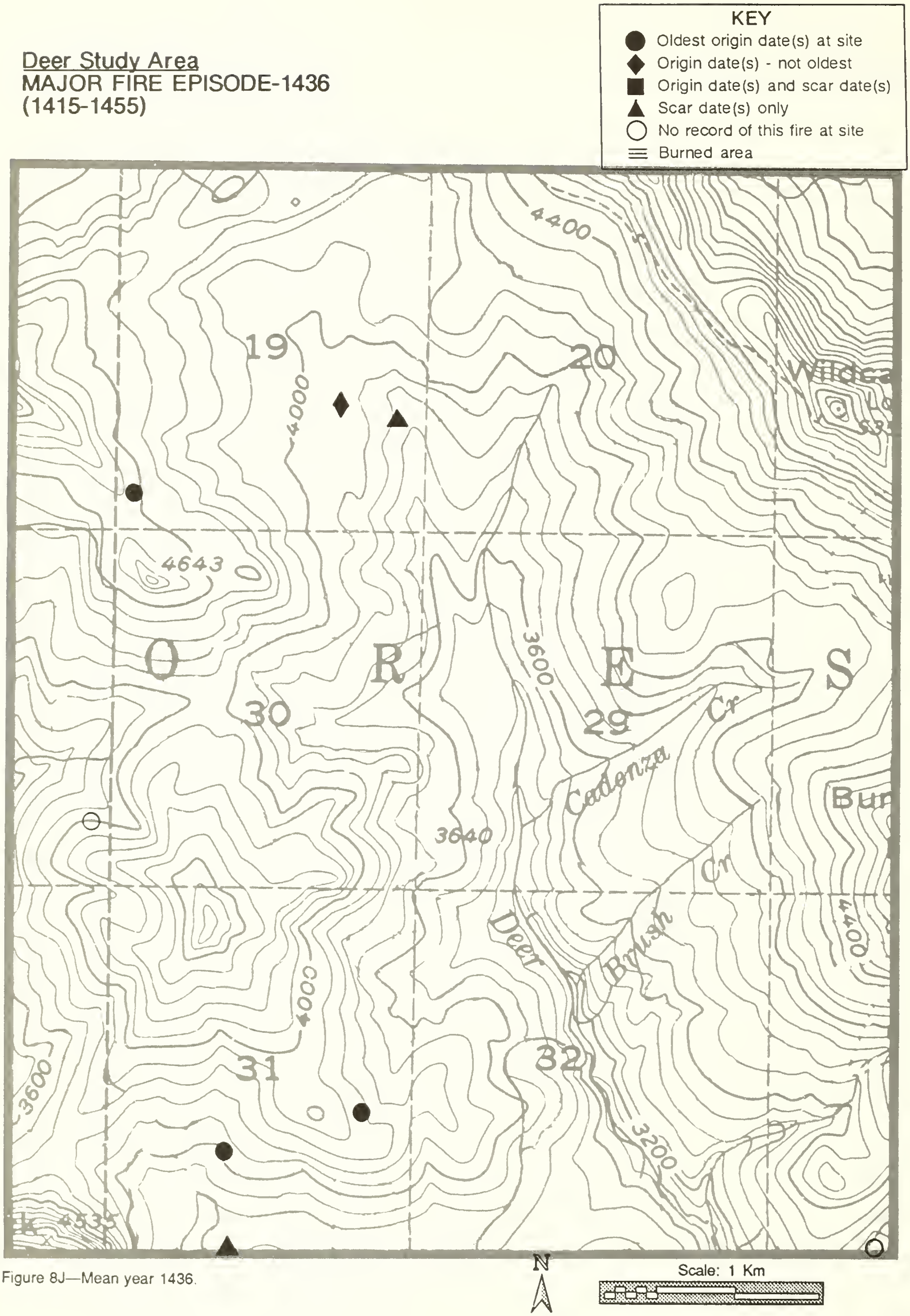


Figure 8J—Mean year 1436.

Deer Study Area
MAJOR FIRE EPISODE-1200
(1164-1222)

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

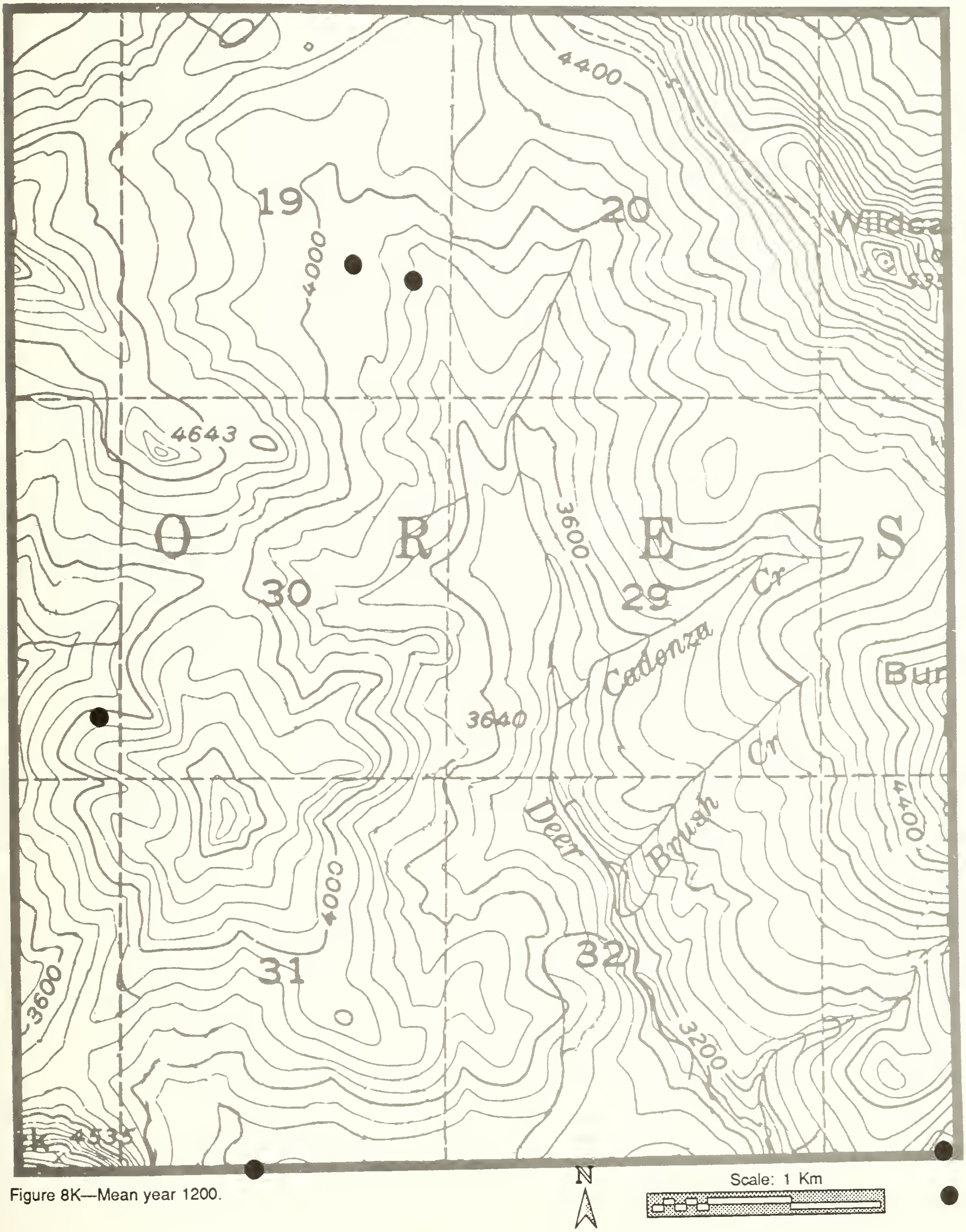


Figure 8K—Mean year 1200.

Deer study area—In the Deer study area, fires burned 7 ha per year during the 1850-1910 Euro-American settlement period. In the 1750-1810 presettlement period, fires burned 11 ha per year. The highest fire incidence (18 ha per year) in this study area was during the period with possibly the least human influence (1810-50). We concluded that lightning was an adequate source of ignition for the fires recorded in these stands and that human ignition was a minor influence.

Temporal Distribution of Fires

Cook-Quentin study area—The temporal distribution of sites with tree origin dates and fire scar dates is depicted in fig. 9. The trend of a diminishing number of sites with recorded fires in earlier periods is caused by erasure of record. After we accounted for this trend, establishment of early seral trees and occurrence of fire scars on a site-by-site basis were relatively constant through time with a few short fluctuations.

The natural fire rotation was calculated based on the estimated area burned by each fire. This natural fire rotation for the 1500-1910 period was 95 years. Because no major fire has burned the study area since 1910, the natural fire rotation for 1910 to the present is infinite. This may be the effect of fire suppression activities, climate, chance, or a combination of these factors.

For the Cook-Quentin study area, the average fire frequency for all fires at all levels of severity was 96 years. Excluding low-severity fires, the average fire frequency was 150 years. An average of 3.3 fires was recorded per site, and 2.2 forest age-classes were found per site. On average, 1.1 low-severity fires were recorded per site.

Deer study area—Fewer sites in the Deer study area than in the Cook-Quentin study area had fire scars and early seral trees dating from 1700-1910 (fig. 10). The large number of sites with tree origin dates between 1480 and 1600 reflects more extensive fires during this period and less erasure of record by later fires.

The natural fire rotation for the Deer study area during 1500-1910 was 149 years. In this study area, the average fire frequency for all fires of all levels of severity is 241 years. Excluding low-severity fires, the average fire frequency was 276 years. Per site, averages of 1.9 fires of all severity levels, 1.5 age classes, and 0.4 low-severity fires were found.

```
Number of sites
with origin dates

1100   ]
1120   ]
1140   ]*
1160   ]*
1180   ]
1200   ]*
1220   ]
1240   ]
1260   ]
1280   ]
1300   ]
1320   ]*
1340   ]                      Number of sites with scar dates
1360   ]                      (scar types 1, 2, and 3 only)
1380   ]*
1400   ]***
1420   ]                      *
1440   ]**                    **
1460   ]**                    *
1480   ]********
1500   ]****                  *
1520   ]***                   *
1540   ]*****                 **
1560   ]****                  *
1580   ]*                     **
1600   ]                      *
1620   ]
1640   ]****                  **
1660   ]*****                 **
1680   }**********            ***
1700   ]**************        *
1720   ]*****                 **
1740   ]***                   ******
1760   ]********              ***
1780   ]**                    *****
1800   ]********              *******************
1820   ]**************        ****************
1840   ]********************  *****************
1860   ]**********            *****
1880   ]*****                 *******
1900   ]******
1920   ]                      *
1940   ]                      *
1960   ]
```

Figure 9—Histogram of number of sites in the Cook-Quentin study area with tree origin and scar dates.

```
Number of sites
with origin dates

1100     ]
1120     ]
1140     ]
1160     ]*
1180     ]**
1200     ]*
1220     ]*
1240     ]
1260     ]
1280     ]
1300     ]                     Number of sites with scar dates
1320     ]                     (scar types 1, 2, and 3 only)
1340     ]
1360     ]
1380     ]                     *
1400     ]*
1420     ]                     *
1440     ]**
1460     ]
1480     ]******
1500     ]******
1520     ]******               *
1540     ]******               ***
1560     ]************         ***
1580     ]**********           *
1600     ]****
1620     ]                     *
1640     ]*                    **
1660     ]*                    *
1680     ]*                    *
1700     ]*                    ***
1720     ]*                    *
1740     ]*                    *****
1760     ]****                 *****
1780     ]****                 ****
1800     ]*****                ****
1820     ]*******              *********
1840     ]**********           ********
1860     ]******               ****
1880     ]**                   **
1900     ]*                    **
1920     ]
1940     ]                     ***
1960     ]                     *
```

Figure 10—Histogram of number of sites in the Deer study are with tree origin and scar dates.

Results From Intensive Study Sites

Cook-Quentin study area—This record of fire in the Cook-Quentin study area probably underestimated the frequency of low-severity burns, which did not scar many trees. At most sites, only a few stumps were sampled, and a more complex fire record might have been found in a larger sample. We used intensive sampling for determining if a more complex fire record would become evident with increasing sample size.

Decade		Origin dates	Scar dates
1390	]		
1400	]	DD	
1410	]	D	
1420	]		
1430	]		
1440	]	D	
1450	]		23
1460	]	D	
1470	]		2
1480	]	DD	
1490	]	DDD	
1500	]	DDDD	2
1510	]	D	
1520	]		3
1530	]	D	
1540	]		2
1550	]		23
1560	]		
1570	]		
1580	]		33
1590	]		
1600	]		
1610	]		
1620	]		
1630	]		
1640	]		
1650	]		
1660	]		
1670	]		
1680	]		
1690	]		
1700	]		
1710	]		
1720	]		
1730	]		
1740	]		
1750	]		
1760	]		
1770	]		
1780	]		
1790	]	H	2
1800	]		222
1810	]		2
1820	]	DDH	
1830	]	DDDDDDDDHH	2
1840	]	DH	
1850	]		122223333
1860	]	DDHH	1
1870	]	HHH	
1880	]	HH	133
1890	]	H	3
1900	]		
1910	]		
1920	]		2
1930	]		1
1940	]		3

Key to origin date codes and scar types

D = Douglas-fir
H = Western hemlock

1 = Well-dated classic fire scars.
2 = Well-dated scars covering over 25% ring circumference.

3 = Well-dated smaller scars of probable fire origin.

Figure 11—Histogram of all origin dates and scar dates at intensive sites in the Cook-Quentin study area.

Forty-six stumps were sampled within a 4-ha area at four adjacent sites in a stand on a south slope at about 850 m elevation in the northeast sector of the Cook-Quentin study area. We expected this area to have experienced frequent fire. In the interval between 1400 and 1940, eighteen decades (33 percent) had at least one well-dated probable fire scar (fig. 11). Douglas-fir origin dates were present in 13 decades (24 percent). Between 1800 and 1940, there were four positive fire scars and 10 decades with well-dated fire-related scars, ir dicating a possible mean fire interval of about 14 years during the 1800-1940 period.

Intensive-sampling results indicated that the complexity of the fire record observed at this site increased as a function of the number of tree-ring histories obtained at a site. The original sample of four stumps in this area recorded four major fires. Another five major fires were discovered after sampling 42 additional stumps.

Deer study area—An intensive sample was used to evaluate the effect of sample intensity on number of fires detected. In the Deer study area, a sample of 20 trees from four adjacent sites in a 6-ha area was taken in an old-growth stand that had been clearcut on a gentle northeast slope at 1100 m elevation. Previous sampling in the area indicated that the stand had a narrow distribution of ages and had experienced one fire.

All but one Douglas-fir origin date in this intensive sample occurred between 1560 and 1590. This narrow age range is likely the result of one major fire, as indicated by the original sample of four stumps in this stand. Additional sampling revealed that western hemlock was established 50 to 100 years after the last Douglas-fir origin date. A few scars of uncertain origin were recorded, but we found no conclusive evidence of low-severity fire in this stand. Increasing the number of samples taken at this site did not show an increase in the complexity of the fire record we observed.

Patch Characteristics and Fire-Severity Analysis

Cook-Quentin study area—A map was constructed to depict the complex mosaic of patches that resulted from three levels of stand disturbance by a 1893 fire in the Cook-Quentin study area (fig. 12). Extensive corridors of low-mortality stands extended through a matrix of stands thinned by a medium-severity fire. Patches from high-mortality fire also occurred within this matrix. Of the total area burned by the fire, 53 percent was medium mortality, 18 percent was high mortality, and 29 percent was low mortality.

Patches created in this area by the 1893 fire were numerous and irregular (table 8). The patch-irregularity index (ratio of the perimeter of the patch divided by the perimeter of a circle with the same area) was 1.52 for low-mortality patches and 1.33 for high-mortality patches. Both low- and high-mortality patches had high densities of edge.

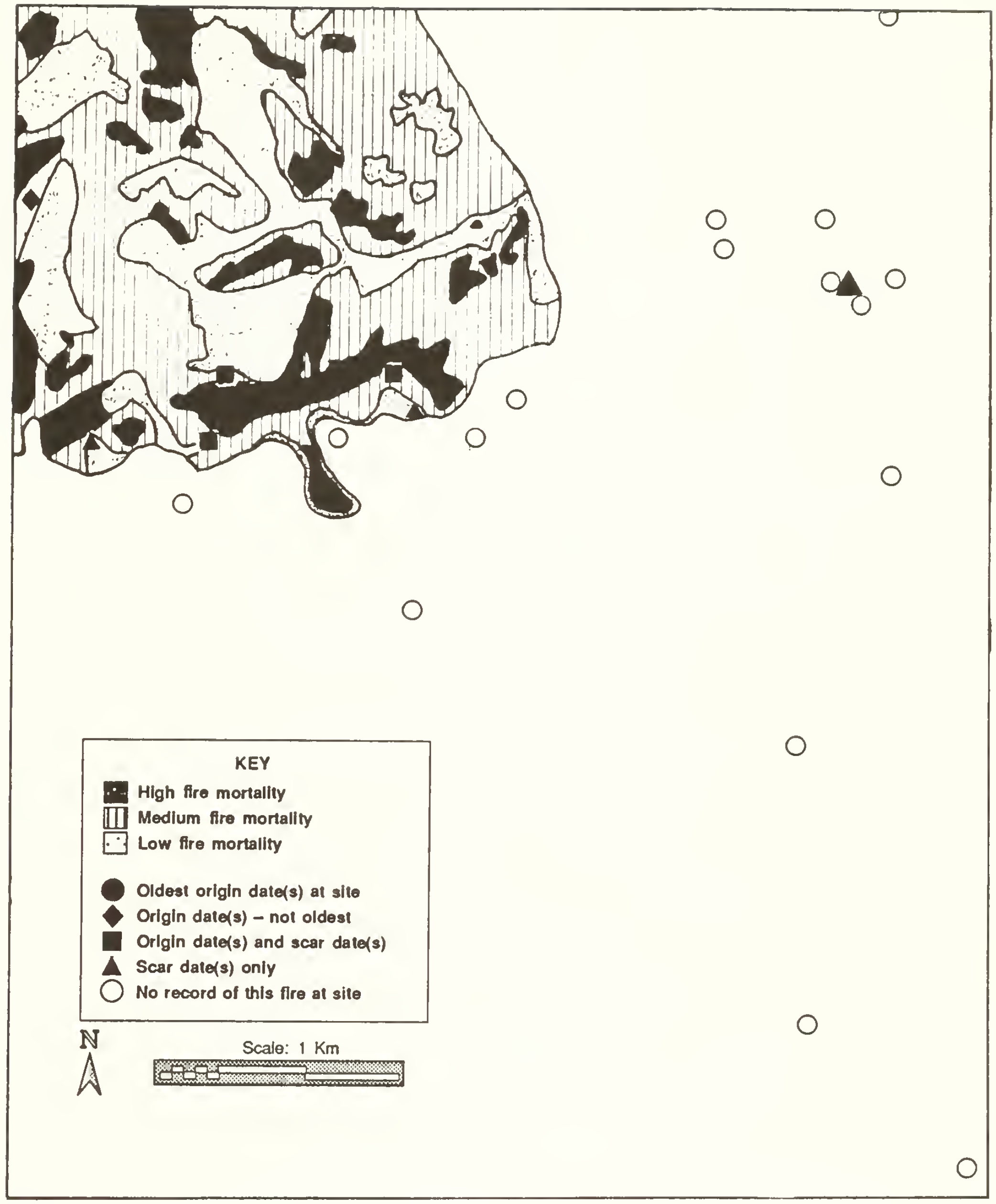


Figure 12—Fire-mortality patches for 1893 fire episode in the Cook-Quentin study area.

Table 8—Patch analysis for 1893 fire episode in the Cook-Quentin study area

Patch type	Area	Fire area	Mean patch irregularity index	Total edge	Edge density	
					Type 1[a]	Type 2[b]
	km²	*percent*		*km*	*km per km²*	
Low mortality	1.01	29	1.[illegible]2	19.9	5.7	19.7
Medium mortality	1.88	53	—	—	—	—
High mortality	0.62	18	1.33	18.1	5.2	29.2
Total	3.51					

— = Not determined for medium mortality patches.
[a] Total edge per total fire area.
[b] Total edge per total patch type area.

Small patches dominated the size distribution of high-mortality patches created by the 1893 fire (fig. 13). Ninety-six percent of the high-mortality patches were less than 10 ha and covered 68 percent of the high-mortality area. Although 72 percent of the medium-mortality patches were less than 10 ha, they accounted for only 5 percent of the area of medium mortality. Likewise, 70 percent of low-mortality patches were less than 10 ha but accounted for only 19 percent of the area. Nineteen percent of all patches were truncated by the boundary of the study area. Aerial photograph analysis of boundaries of patches extending beyond study-area boundaries indicated that truncation does not markedly affect the patch-size distribution.

The patch distribution for the 1800-1900 period in the Cook-Quentin study area represented the cumulative high, medium, and low mortality from all the fires during that period (fig. 14). Extensive patches and corridors of low-mortality areas formed a complex patch mosaic. Many high-mortality patches of variable size existed amid a medium-mortality matrix that covered 42 percent of the study area (table 9).

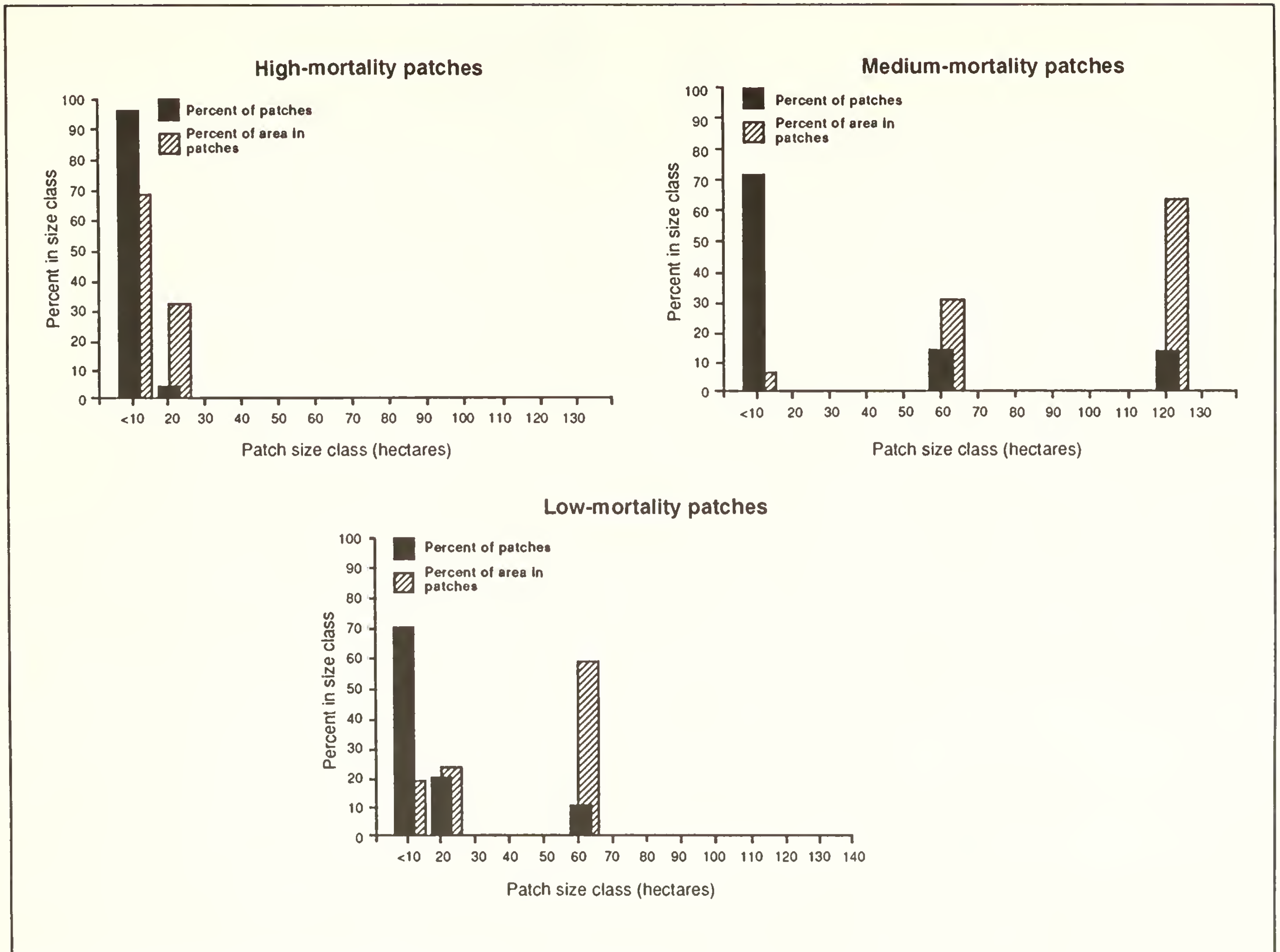


Figure 13—Patch-size distribution for 1893 fire episode in the Cook-Quentin study area.

Figure 14—Fire-mortality patches for 1800-1900 in the Cook-Quentin study area.

Table 9—Patch-analysis summary for 1800-1900 fires in the Cook-Quentin study area

Patch type	Area	Fire area	Mean patch irregularity index	Total edge	Edge density	
					Type 1[a]	Type 2[b]
	km^2	*percent*		*km*	*km per km^2*	
Low mortality	6.01	31	1.49	10.5	0.54	1.75
Medium mortality	8.24	42	—	—	—	—
High mortality	5.30	27	1.45	94.8	4.85	17.89
Total	19.55					

— = Not determined for medium mortality patches.
[a] Total edge per total fire area.
[b] Total edge per total patch type area.

The average irregularity index for the high-mortality patches was 1.45 and 1.49 for low-mortality patches. The total perimeter and edge density were about equal for low- and high-mortality patches. Small patches dominated the size distribution of patches as in the 1893 fire; 88 percent of high-mortality patches were less than 10 ha and accounted for 31 percent of the high-mortality area (fig. 15). Ninety-six percent of the high-mortality patches were less than 30 ha and accounted for 53 percent of the area. Two large patches (about 105 ha each) accounted for 39 percent of the area. Similar patch-size distributions existed for medium- and low-mortality patches.

Deer study area—Fires in 1800-1900 burned only 59 percent of the Deer study area, forming larger and less complex patches than in the Cook-Quentin study area (fig. 16). Much of the Deer study area burned at low severity in this period (table 10). Patch-size distribution was similar in many respects to the Cook-Quentin study area, but we found fewer patches less than 10 ha (fig. 17). Although 62 percent of high-mortality patches were less than 10 ha, they accounted for 17 percent of the high-mortality area. Eighty-nine percent of the high-mortality patches were less than 30 ha and accounted for 61 percent of the area. Similar patterns were observed for medium-mortality patches. Low-mortality patches less than 10 ha were frequent but occupied only 6 percent of the area. The shape of high-mortality patches was somewhat less irregular than in the Cook-Quentin study area. Low-mortality patches formed the matrix in the Deer study area; therefore, they had a higher irregularity index than in the Cook-Quentin study area.

(*Text continues on page 64.*)

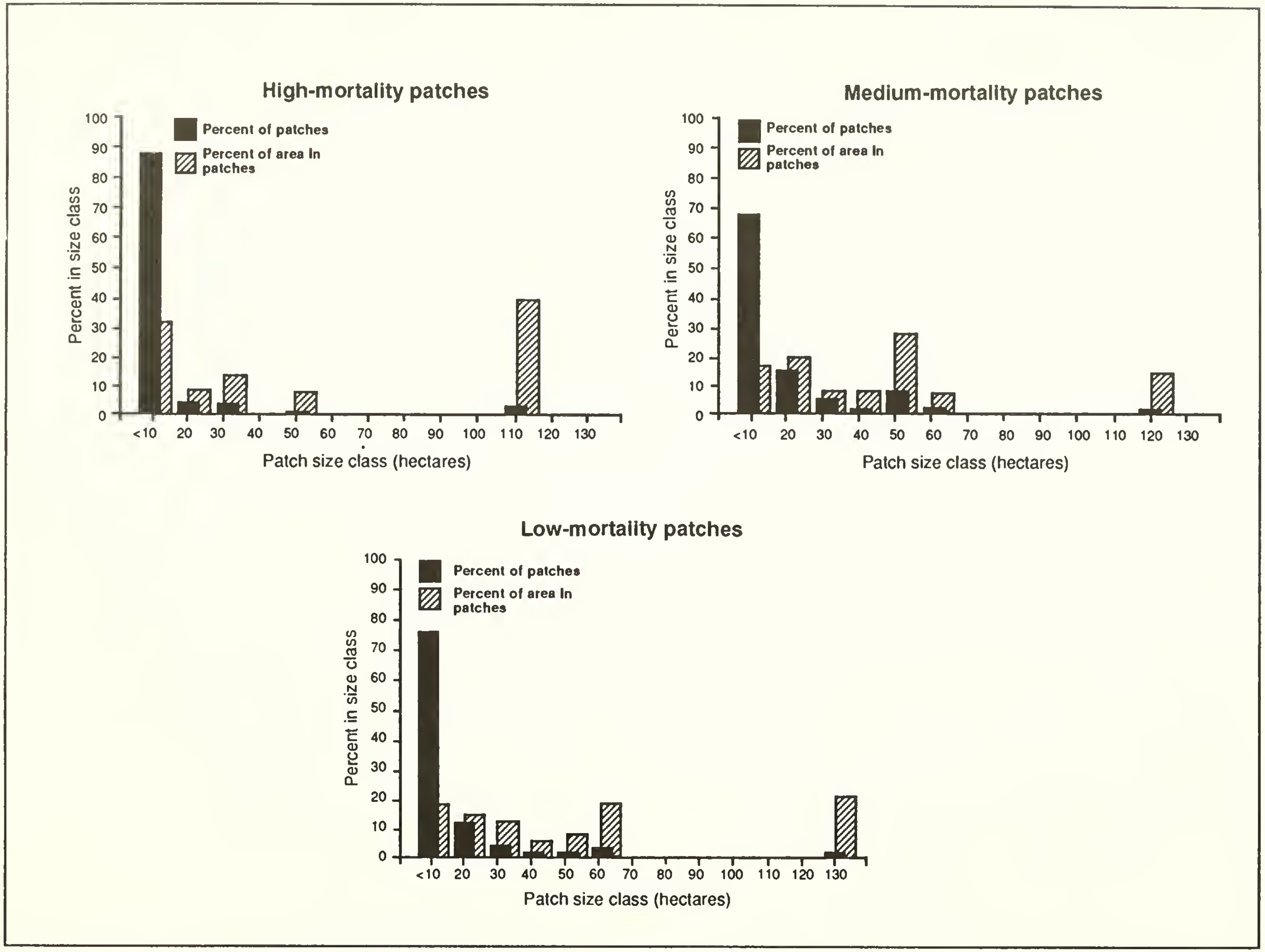


Figure 15—Patch-size distribution for 1800-1900 in the Cook-Quentin study area.

Figure 16—Fire mortality patches for 1800-1900 in the Deer study area.

Table 10—Patch-analysis summary for 1800-1900 fires in the Deer study area

Patch type	Area	Fire area	Mean patch irregularity index	Total edge	Edge density	
					Type 1[a]	Type 2[b]
	km^2	*percent*		*km*	*km per km^2*	
Low mortality	5.02	43	1.52	51.0	4.4	19.2
Medium mortality	3.64	32	—	—	—	—
High mortality	2.28	25	1.32	39.1	3.4	17.1
Total	11.54					

— = Not determined for medium mortality patches.
[a] Total edge per total fire area.
[b] Total edge per total patch type area.

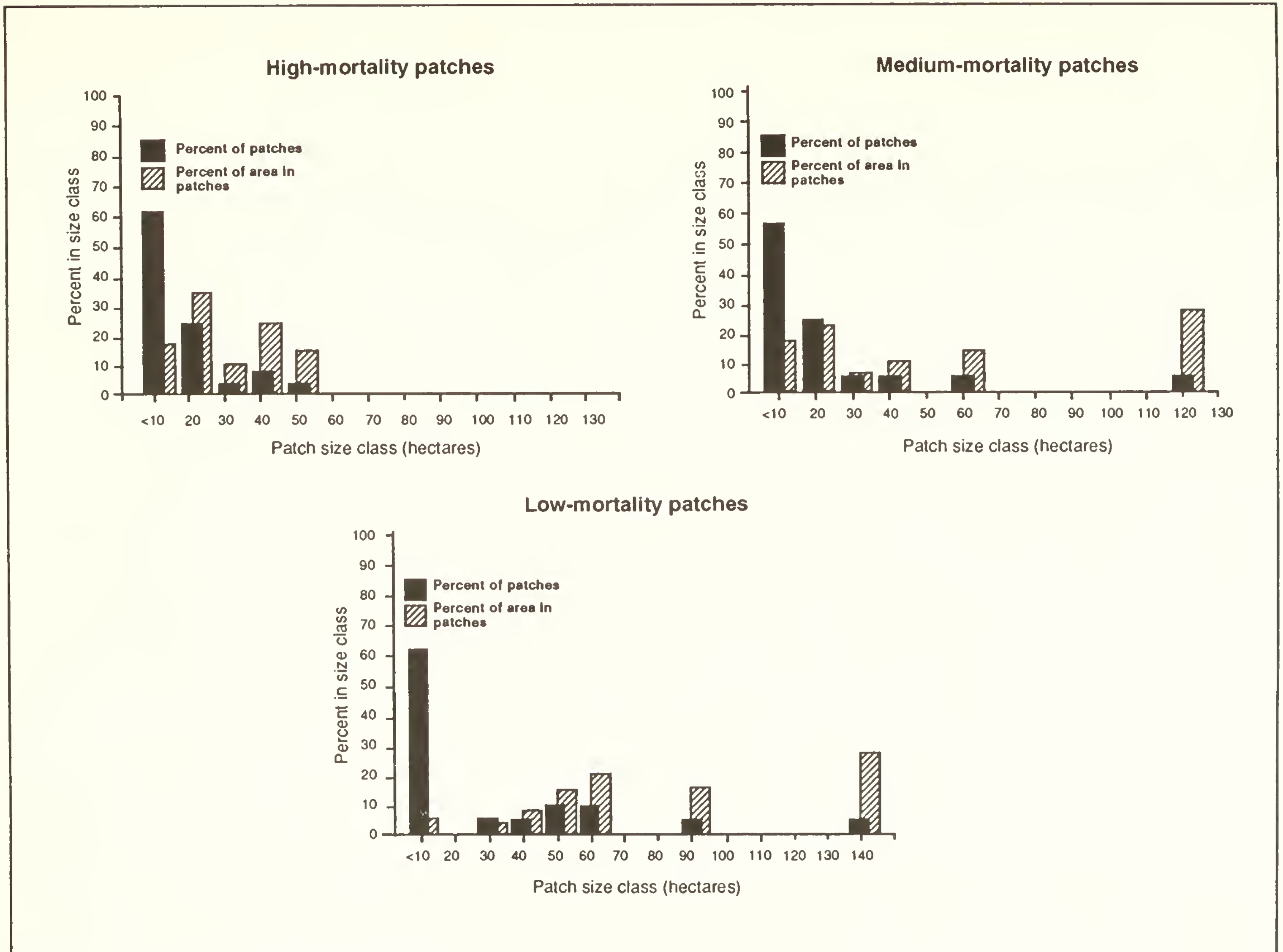


Figure 17—Patch-size distribution for 1800-1900 in the Deer study area.

Analysis of Fire History in Relation to Aspect and Elevation

To assess possible effects of elevation and aspect on fire occurrence, we pooled the data from both study areas. We compared the aspect and elevation distribution of sample sites with overall distribution for the study areas estimated by a random sample of 400 points (tables 11 and 12). A chi-square goodness-of-fit analysis (Zar 1974) was used to test if the aspect and elevation distributions of the sample sites conformed to the expected aspect and elevation distributions of the study area; no significant difference was found between the observed and expected elevation or aspect distributions ($p = 0.05$). This implies that the sample sites represent a good sample of the study area with respect to aspect and elevation.

Table 11—Distributions of aspect in study areas based on random sample (n=400) and field sample sites

Aspect	Random sample	Field sample sites	
	Percent	*Number*	*Percent*
North	4.0	4	3.3
Northeast	8.0	8	6.7
East	13.8	15	12.5
Southeast	12.5	16	13.3
South	14.8	20	16.7
Southwest	15.3	18	15.0
West	10.5	13	10.8
Northwest	5.5	4	3.3
Ridge	9.8	16	13.3
Valley floor	6.0	6	5.0

Table 12—Distributions of elevation in study areas based on random sample (n=400) and field sample sites

Elevation	Random sample	Field sample sites	
Meters	*Percent*	*Number*	*Percent*
<915	31.5	33	27.5
915-1066	20.0	29	24.2
1067-1219	18.3	27	22.5
>1220	30.3	31	25.8

Although apparent differences existed in various measures of site fire history that are dependent on aspect, low sample size in many aspect categories made these relations impossible to assess statistically (table 11). Site fire history is somewhat dependent on elevation (table 13). A single-factor analysis of variance and Newman-Keuls multiple range test (Zar 1974) revealed that the mean number of age classes and low-severity fires were significantly different ($p = 0.05$) between sites above and below 915 m elevation. The average fire frequencies for all fires and for only moderate and severe fires were significantly different between sites above and below 1067 m. In general, more age classes and more fires occurred at low elevations than at high elevations in the study areas.

Table 13—Analysis of fire history for both study areas in relation to aspect and elevation

Position	Age class	Low-severity fires	Mean fire frequency: All fires	Mean fire frequency: Moderate and high severity fires
	- - - - Mean number - - -		*- - - - - - - - Years - - - - - - - - -*	
Aspect:				
North	1.50	.75	242	311
Northeast	1.88	.50	230	257
East	1.40	.53	210	250
Southeast	1.88	1.13	120	179
South	2.05	1.05	174	221
Southwest	1.94	.56	176	192
West	1.92	.85	183	270
Northwest	2.75	1.25	99	125
Ridge	1.81	.25	143	152
Valley floor	1.67	1.00	172	281
Elevation (meters):				
<915	2.49	1.42	90	151
915-1066	1.83	.76	130	178
1067-1219	1.30	.37	254	300
>1220	1.71	.35	226	247

Discussion

Because the objective of this study was to provide an extensive sample of fire frequency and severity in the two study areas, a high sample density was more important than high precision with rigorous dendrochronological techniques applied to a small number of trees. The sampling for the original reconnaissance study (with a sample density of about seven trees per km^2) revealed a complex forest history, but the sample was inadequate for describing important aspects of fire history in the area. The resolution of the fire record was significantly increased by additional sampling in the two study areas. Sample density was increased to 14.7 trees per km^2, one of the highest sampling densities for fire history studies reported in the literature (table 14). Nevertheless, because of the complexity of the fire regime, important aspects of the fire history still could not be addressed. Results from intensive sites indicate that even higher sampling densities than used in the study can yield a more complete fire record on some sites. On sites with one or two fires recorded in even-aged stands, little is gained by more intensive sampling.

In the central-western Cascade Range of Oregon, both frequent low- to moderate-severity fires and stand-replacement fires recurring at intervals of 6 to 800 years have been important. The relative importance of fires for each type is unknown. Results of this study and the work of Means (1981) and Stewart (1986) indicate that frequent, noncatastrophic fire was widespread in the central-western Cascade Range.

Comparison of the Fire History of the Two Study Areas

Many similarities exist in the fire history of the two study areas. During the last 300 years, only the 1834 fire in the Cook-Quentin study area burned more than one-third of either study area. Because all fires in the study areas extended beyond the area boundaries, the total area influenced by each fire was not determined. Fire was widespread during many fire episodes. The 1800 fire burned in both study areas. The 1849 and 1841 fires in the Cook-Quentin study area may be equivalent to the 1850 and 1838 fires in the Deer study area. Many of these fire episodes were also noted by Stewart (1984) in a study area 7 km to the northwest of the Cook-Quentin study area. In both study areas, fire was conspicuously absent between 1580 and 1650—a period bracketed by fairly high fire activity.

Table 14—Sampling densities of selected fire history studies

Study	Trees sampled	Origin and probable fire scar dates	Study area
	no. per km^2	*no. per km^2*	*km^2*
Morrison and Swanson (this study)	13.8	19.8	39
Hemstrom and Franklin (1982)	1.3	1.3	770
Tande (1979)	8.1	9.6	432
Kilgore and Taylor (1979)	12.1	36.6	18
Arno (1976)	2.3	14.5	73
Heinselman (1973)	0.8	0.9	3480

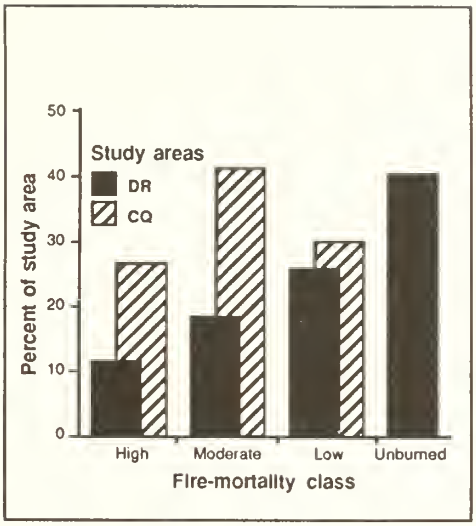


Figure 18—Comparison of fire-severity distribution for patches created from fire during 1800-1900 in both study areas. DR = Deer and CQ = Cook-Quentin study areas.

Several fairly widespread fires burned through both study areas during 1490-1580. The number of fires and coincidence in dates between study areas during this period are difficult to determine because of the paucity of scar data, but at least three major fire episodes occurred in each study area during this interval. These fires mark the origin of much of the old-growth forest in the study areas. A few Douglas-fir stumps with origin dates between 1150 and 1220 are scattered through both study areas. Individual trees and scattered stands of similar age were found in other parts of the initial reconnaissance study area, indicating that fire activity was widespread during this period.

Although many similarities exist between the fire history of the two study areas, substantial differences demonstrate significant heterogeneity in the fire history of the central-western Cascade Range. For instance, between 1500 and 1910 the natural fire rotation for the Cook-Quentin study area is 95 years compared to 149 years for the Deer study area. Based on calculated average fire frequencies of 96 years for the Cook-Quentin study area and 241 years for the Deer study area, the occurrence of fire appeared to be 2.4 times more frequent in the Cook-Quentin study area.

The 1800-1900 fires caused low mortality in the majority of the Deer study area, although the Cook-Quentin study area experienced mainly moderate mortality (fig. 18). Because some evidence showed more extensive fires of higher severity in both study areas before 1800 and the fire-severity distribution may differ considerably from one fire to another, the distribution of fire severity cannot be assumed to remain constant through time.

The fire regime of the Cook-Quentin study area was characterized by fairly frequent, medium- to low-severity fires that have occasionally crowned out and created patches of even-aged stands; more commonly, these fires have thinned the pre-existing stand. The stands that have developed after these fires are generally multi-aged with an average of more than two age classes of early seral tree species. Regeneration from more than four fires was found at 16 percent of the sites.

Fire in the Deer study area was less frequent on the whole. Small fires of medium to low severity occurred periodically in upper elevation areas and larger, stand-replacement fires occurred infrequently. Most of this study area burned at least once during three fire episodes in 1480 to 1580.

Although the two study areas are in close proximity, some significant environmental, climatic, and physiographic differences may explain contrasts in their fire history. Because the Deer study area is at a higher elevation than the Cook-Quentin study area, it has a colder and wetter climate that may have lead to less frequent fires. Fuels under these conditions in the Deer Creek area may rarely be conducive to carrying fire. Fewer microsites of hot, dry fuels may exist in the relatively gentle topography of this area as compared to the Cook-Quentin study area. On the other hand, this gentle topography may facilitate the spread of large, stand-replacement fires when rare favorable climatic conditions prevail. This combination of factors would result in infrequent, but extensive stand-replacement fires observed in the lower elevations of the Deer study area.

In upper elevations of the Deer study area, lightning ignitions and exposure to desiccating east winds may be frequent; the resulting fires usually do not spread far because of the numerous nonforest wet areas. These factors could lead to more frequent, but less intense fires in the upper elevation parts of the Deer study area.

The complex topography of the Cook-Quentin study area forms many potential fire boundaries such as stream bottoms, sharp ridgetops, and changes in aspect and vegetation type. In this irregular landscape, great variation occurs in fuel ignition potential, rate of combustion, and rate of fire spread. Wind patterns are also highly irregular in complex topography. These factors alter fire behavior, producing patchy fires of variable severity.

Fire regime was expected to vary with aspect and elevation. In the data from both study areas, the low sample size and high variation in several aspect categories made it impossible to test for significant differences in fire history with respect to aspect. Low elevation sites burned more frequently than higher elevation sites, mostly as a result of more frequent low-severity fires.

In both study areas, the fire record shows great variability from site to site. Some sites burned every 20 years, although others were fire-free for 500 years. This variability is not explained by a simple analysis of aspect and elevation. A more complete analysis of topographic position, slope, aspect, and elevation may reveal relations between fire history and site characteristics that are not apparent here.

Fire History Scenarios for Old-growth Stand Initiation

Much of the forest of both study areas may be characterized as old-growth Douglas-fir similar to old-growth stands found elsewhere in the western Cascade Range (Franklin and others 1981, Franklin and Spies 1983). The circumstances surrounding the establishment and growth of these stands provide insight into the dynamics of old-growth stand development and maintenance.

We propose three scenarios to explain the origin of these old-growth stands. Each scenario would produce a distinctive signature in the forest age structure and tree-ring record, and examples of each can be found in the old-growth forests of the Cascade Range.

In one scenario, the fire regime consists of large, stand-replacement fires recurring every 200 to 400+ years. In this scenario, a fire might cause a pattern of moderate age-spread of Douglas-fir trees in some stands because of slow restocking, caused by lack of seed source, brush establishment, and other factors. Site-to-site uniformity in age structure with some variation related to distance from seed source would be expected. Fire scars on remnant trees from such an event would yield coincident dates. Subsequent development of such a stand would be controlled by intertree competition and mortality from disease, windthrow, and other processes of very local extent. Release of late seral trees in small gaps created by the above processes would be an important aspect of stand development. Some fire-sensitive, late seral trees would approach the age of the Douglas-fir trees. Some of the fires and stands described by Hemstrom and Franklin (1982) and Juday (1977) may represent examples of this scenario.

In a second scenario, fire regime is characterized by a large catastrophic fire followed by several reburns within a period of 50 years and then a long fire-free interval. The age distribution of Douglas-fir trees would be extended as a result of very slow restocking and patchy burning by the subsequent fires. In this case, the fire-scar record would yield some evidence of these reburns, and more site-to-site variation in age structure would be expected. Subsequent development of stands originating under this scenario would be similar to that described in the first scenario, except that the early development would be marked by substantial mortality in areas that were reburned. Establishment of fire-sensitive species would postdate the last reburn, creating more age spread between these trees and Douglas-firs that may have survived. Examples of this pattern are found in the Tillamook, Yacolt, and Seven-Mile Burns. Many of the old-growth stands within the Deer study area appear to have resulted from such a scenario.

In a third scenario, old-growth stands would result from a fire regime of multiple, patchy fires of varying severity recurring every 20 to 100 years. Narrow age spread of Douglas-fir trees in stand replacement patches would be caused by rapid regeneration made possible by abundant surrounding seed source. Very wide age spread of Douglas-fir trees within other stands would result from repeated low- and moderate-severity burns and subsequent regeneration. Development of such a stand would be controlled to a large extent by the thinning effects of low- and moderate-severity burns. Intertree competition and mortality from disease, windthrow, and other small-scale disturbances would also play important but diminished roles. Fire-sensitive species would be less abundant and markedly younger in such stands compared to stands operating under the first two senarios. Establishment of new Douglas-fir trees in gaps created by thinning fires would be an important aspect of stand development. A complex fire-scar record extending over many centuries would be a signature of this scenario. Most of the old-growth stands in the Cook-Quentin study area appear to have resulted from such a scenario.

Key to evaluating the fires that controlled establishment of old-growth stands was the fire-scar record found in the few trees older than 450 years. Evaluation of this information in the two study areas and in the large reconnaissance study area suggested that examples of each scenario may be found in the central-western Cascade Range. The first two scenarios were more prevalent in the rolling upland areas, and the third scenario was more prevalent in more dissected topography.

Persistence of Old-Growth Forests in the Natural Fire Regime

Many old-growth stands in both study areas have persisted through low- to moderate-severity fire. At 8 percent of the sites in the two study areas with old-growth trees (over 200 years old), a forest canopy persisted and stand-replacement fires were absent for at least 750 years. At 95 percent of the old-growth sites in the Cook-Quentin study area, a forest canopy persisted through low- to moderate-severity fires. In the Deer study area, a forest canopy remained through low- to moderate-severity fire at 52 percent of the sites with old-growth trees. This persistence of old-growth forest conditions despite repeated under burns has been observed elsewhere in the Pacific Northwest (Juday 1977; Means 1981; Stewart 1984, 1986; Yamaguchi 1986).

The physical characteristics of old-growth Douglas-fir stands explains their ability to withstand repeated fires. The height of the trees and the concentration of foliage in the upper 50 percent of the bole (above 25 m in height) make crown fires less probable because sufficient heat cannot easily reach the canopy to ignite the crowns. Where a fuel ladder is present, the crowns may ignite in patches. Thick bark and extensive root mass in mineral soil are other fire-resistant characteristics of old-growth Douglas-fir trees.

Little attention has been given to the role of under burns in old-growth Douglas-fir ecosystems. These fires influenced succession in some areas by periodically removing fire-sensitive, late-seral species, and they may be one factor in the long timelag before dominance is attained by climax species. Under burns undoubtedly added complexity to the structure of some old-growth Douglas-fir forests. On many sites in the study areas, new early seral trees established after low- to moderate-severity fires. These new trees grew in canopy openings in the thinned old-growth forest and lived to develop old-growth characteristics while their predecessors still form a significant component of the stand. Live old-growth trees, large snags, large logs, and high structural complexity may have been sustained in many sites for nearly 1,000 years under the natural fire regime. This pattern is radically different from the classic concept of cycles of complete stand destruction and a sequence of stand development in which old-growth stands occupy a site only a small percentage of the time (for example, 33 percent of the time, assuming a 300-year fire rotation and 200 years to achieve old-growth conditions). Although much of the Deer study area approximates this classic model, much of the Cook-Quentin study area fits the model of sustained old-growth conditions, based on the criteria of the Old-Growth Definition Task group (1986) and Franklin and Spies (1983).

Human Influence on the Fire Record

Aboriginal ignition of forests in the western Cascade Range through intentional or accidental means is probable, but poorly documented. The Kalapuya Indians intentionally burned grasslands of the Willamette Valley each fall (Burke 1979). Burke also notes that fire escape from aboriginal campfires was a probable cause of forest-fire ignition. Aboriginal huckleberry drying on smouldering fires probably resulted in periodic ignition of surrounding forests.[3] Archeological investigations in the Middle Fork of the Willamette River indicate that aboriginal burning may have been significant (Winkler 1984; Paul Baxter, personal communication[4]). Willamette National Forest archaeologists[5] have uncovered two aboriginal occupation sites in the Cook-Quentin study area and eight sites in the Deer study area, with numerous sites in surrounding areas.

Burke (1979) postulates that forest fire incidence increased during the Euro-American settlement period (1850-1910) because fires were started by trappers, miners, sheepherders, explorers, and others. During this period, however, the average natural fire rotation for both study areas was 213 years compared to 127 years for the 1750-1810 period. Fire was, thus, 1.7 times more prevalent during the aboriginal influence period than during the Euro-American settlement period. But, during the short interval from 1810 to 1850, when aboriginal populations were in decline from disease (Burke 1979, Dicken and Dicken 1979) and when settlers had not yet entered the area in large numbers, the average natural fire rotation for both areas was 72 years. Lightning may be responsible for igniting most of the fires during this period of low human influence. The short timespan of each of these three periods combined with the randomness of fire occurrence may be responsible for the observed variation between periods. Annual precipitation recorded by dendroclimatological reconstruction (Graumlich 1985) provides no evidence of a precipitation anomaly to explain this variation in the natural fire rotation between 1750 and 1910.

Kilgore and Taylor (1979) report a similar decrease in fire incidence in sequoia-mixed conifer forests of the western Sierra Nevada Mountains in the last half of the 1800's. Regular, intentional, aboriginal burning of the Sierran forests is documented. They suggest that aboriginal people were a significant ignition source in parts of the Sierras 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.

Lightning is an ample cause of ignition of fires documented in this study. Burke (1979) documents the equivalent of 0.6 lightning ignited fires per year per km^2 for 1910-77, and certainly more undetected ignitions occurred. This rate of ignition is sufficient to account for all fires documented in the study.

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[3] Personal communication, Don Minore, 1988, Pacific Northwest Research Station, Forestry Sciences Laboratory, 3200 S.W. Jefferson Way, Corvallis, OR 97331.

[4] Personal communication, Paul Baxter, 1988, Heritage Research Assoc., 1997 Garden Avenue, Eugene, OR 97403.

[5] Personal communication, Jim Cox, 1988, Pacific Northwest Region, Mt. Baker-Snoqualmie National Forest, 1022 First Avenue, Seattle, WA 98104.

Although several very small fires were caused by humans or lightning, no major fires have occurred in the study areas since 1910 (Burke 1979). Fire suppression efforts may have successfully reduced fire spread, but the length of record is too short to tell if major wildfires have been eliminated from this landscape.

Conclusions and Implications

The two areas studied in the central-western Cascade Range exhibited significant differences and similarities in their fire regimes. Fires were less frequent, larger, and more severe in the Deer study area than in the Cook-Quentin study area. The incidence of fire in both study areas was similar, averaging 15 years between fires during the 1796-1893 interval and 32 years between fires during the 1515-1893 interval. Many coincident dates of fire episodes between the two study areas indicated that fires were widespread.

The natural fire rotation between 1500 and 1910 for the Cook-Quentin study area was 95 years and 149 years for the Deer study area. The average site fire frequency was also less for the Cook-Quentin study area (96 years) than for the Deer study area (239 years). The natural fire rotation for the two areas as a whole was 119 years, and the average fire frequency for the sites was 168 years. Differences between fire regimes in the two study areas were, in part, because of differences in elevation and in topographic irregularity. The fire regimes of these study areas fit the general regional pattern where relatively infrequent, stand-replacement fires are typical in cold, wet climates and where more frequent, less severe fires are more common in warmer, drier areas. Data from the larger area of reconnaissance study, however, suggest that the Cook-Quentin study area is more representative of the central-western Cascade Range than the Deer study area. These values may underestimate fire frequency for two reasons. Early fires were poorly recorded because of tree mortality in later fires. Low-severity burns were also poorly recorded, and fires occurring at less than five sample sites were not included in the analysis. These factors biased our estimates toward a longer natural fire rotation and lower average fire frequency at each site.

The incidence of fire was highly variable from site to site. Some sites burned every 20 years on the average, and other sites burned once every 400 years. The fire regime has been apparently uniform for the last 600 years, except for some 50- to 100-year periods of low fire activity.

Old-growth forests in these study areas may have originated from a sequence of fires of variable severity. Old-growth forest conditions were sustained in parts of these study areas for many centuries despite repeated fires.

Human influence on the fire history is difficult to determine for the study areas. The highest fire frequency in both study areas was during a period of least human influence. Native people may have been responsible for some fire ignition. No major fires have occurred in either study area since 1893. Similar fire-free periods occurred in the past, possibly caused by climatic conditions or chance; the current fire-free period could be attributed to these factors or fire suppression.

Interest is rising in the influence of natural and human-created patches on the forest landscape (Franklin and Forman 1987, Harris 1984). To evaluate how patches from harvesting affect the dynamics of forest ecosystems, scientists, land managers, and others should consider the landscape pattern in the primeval landscape. Fires in the Cook-Quentin and Deer study areas during the 1800's created patches of high mortality ranging from less than 0.2 ha to about 100 ha, but 86 percent of these patches were less than 16 ha, the average size of a clearcut on Forest Service land in the region. Although a few large patches influenced more area, patches smaller than an average clearcut covered a large portion of the landscape. Although elsewhere in the Pacific Northwest, fires are known to have created some large, stand replacement patches, it is not known whether small or large patches are predominant. To an important extent, the scale of analysis determines the patch-size distribution and the density of stand edge that are discerned.

The patch-size distribution, the density o edge, and the dynamics of age-class patches in natural and managed forests influence the following: output of the sediment and streamflow from watersheds; the abundance and diversity of wildlife (Black and Thomas 1978, Thomas and others 1978, Welty 1982); effects of secondary disturbances, such as windthrow; and effects of interactions between patches in stand development. Fire suppression and possibly decline in aboriginal ignition greatly diminished the contrast between adjacent patches from the late 1800's until logging began in the 1950's. Just before logging, all of the edges in these study areas occurred between mature and old-growth stands, and contrast between patches was minor. Before 1900, contrast between patches created by fire and the surrounding forest was moderated by the presence of snags, logs, and remnant trees in fire-created patches. Today, contrasts between clearcut patches and remnant forests are more pronounced because these structural elements are scarce in clearcuts and second-growth stands.

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English Equivalents

1 square kilometer (km^2) = 0.39 square mile
1 hectare (ha) = 2.47 acres
1 millimeter (mm) = 0.039 inch
1 centimeter (cm) = 0.39 inch
1 meter (m) = 1.09 yards

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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 fires 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.

The **Forest Service** of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives—as directed by Congress—to provide increasingly greater service to a growing Nation.

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