Fire in riparian zones: a comparison of historical fire occurrence in riparian and upslope forests in the Blue Mountains and southern Cascades of Oregon

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This is to certify that I have examined this copy of a master's thesis by

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and have found that it is complete and satisfactory in all respects,
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Abstract

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Despite the ecological importance of fire in Pacific Northwest forests, its role in riparian forests is not well documented. This study reconstructed the historical occurrence of fire within riparian forests along different stream sizes within three different national forests in Oregon. Two study areas were located in mostly dry, low-severity fire regime forests in the Blue Mountains of northeastern Oregon (Dugout and Baker) and the third study area was located in more mesic, moderate-severity fire regime forests on the western slopes of the southern Oregon Cascades (Steamboat). Fire scar dates and tree establishment dates were determined from a total of 424 fire scarred tree wedges and 81 increment cores taken from 67 riparian and upslope plots. Based on the data from this study, fire was common historically in the riparian zones of all three study areas. Weibull median probability fire return intervals (WMPIs) for riparian forests in Dugout ranged between 13 and 14 years, and were only slightly longer than those for upslope forests (averaging one year longer). In Baker, differences between riparian and upslope forest WMPIs were greater, ranging between 13 and 36 years for riparian WMPIs, compared to 10 to 20 years for upslope WMPIs. However, further analyses suggested that forest type and slope aspect play a larger role than proximity to a stream when it came to differentiating fire regimes in this study area. For both Dugout and Baker it appeared that stream channels did not necessarily act as fire barriers during the more extensive fire years. Steamboat riparian WMPIs were somewhat longer (ranging from 35-39 years) than upslope WMPIs (ranging from 27-36), but these differences were not

significant. Fires were probably more moderate in severity and likely patchy, considering the incidence of fires occurring only at a riparian plot or an upslope plot within a pair, but not at both. It is possible that fire return interval lengths were associated with aspect, but more sampling would need to be done to show this. Based on the results from this study, it is evident that: 1) restoring fire, or at least conducting fuel reduction treatments, will be necessary to protect riparian forests in comparable forest ecosystems, 2) forests should be managed according to forest type, not just by proximity to a stream, and 3) historical recruitment of large woody debris was likely small but continuous for low-severity fire regime riparian forests, with a relatively short residence time, and patchy and more pulsed for the more moderate-severity fire regime forests.

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INTRODUCTION

Riparian zones are the interfaces between terrestrial and freshwater ecosystems (Gregory et al. 1991, Naiman and Decamps 1997) and they include an unusually diverse mosaic of landforms, biotic communities and physical environments relative to the rest of the landscape (Naiman et al. 1998). Recently, management of riparian forests has become a primary concern for Pacific Northwest forest managers (FEMAT 1993, USDA and USDI 1994, Sedell et al. 1997, USDA and USDI 1998, USDI et al. 1999) and managers have been required to focus on maintaining and restoring riparian forests as late successional species refugia and as salmonid habitat.

In the case of Pacific Northwest forests currently managed for timber production or slated for restoration, riparian zones have been granted certain levels of protection from the impacts of timber harvest and other forest management with the hope of maintaining some degree of ecological integrity. Depending on the size of the river or stream, whether it supports fish, and its ownership, levels of protection range from none to retaining large buffer strips with limited or no management (FEMAT 1993, USDA and USDI 1994, Sedell et al. 1997, USDI et al. 1999). Broad goals of the riparian forest protection measures include protecting streams from temperature extremes and erosion, providing organic input consumed by both aquatic vertebrates and invertebrates, and providing sources of large woody debris necessary for structural diversity within the streams. Goals also include reducing the impact of human activities on fish, amphibian and aquatic invertebrate habitat within and along the streams, maintenance of plant and animal species refugia, and maintenance of terrestrial and avian wildlife corridors.

This focus on riparian forests has raised questions about the ecological and physical processes associated with riparian zones and the subsequent impacts of current and historical management activities within and upslope of them (Agee 1988, Beschta 1990, Elmore et al. 1994, Wissmar et al. 1994, Fetherston et al. 1995, Kauffman et al. 1995, Naiman and Decamps 1997, Rieman and Clayton 1997, Benda et al. 1998, McClain et al. 1998, Gresswell 1999), whether these activities range from cattle grazing and timber production to the restoration of pre-Euroamerican settlement conditions. In order for protection measures to succeed, and in order to restore natural ecological processes in degraded riparian forests, it is necessary to understand how riparian forest ecosystems function. Naiman et al. (1993) suggest that ecologically diverse riparian corridors are maintained by an active natural disturbance regime operating over a wide range of spatial and temporal scales. One such disturbance is fire.

Pacific Northwest Forest Fire Regimes. Natural disturbance processes play an integral role in shaping forest ecosystems (White and Pickett 1985, Benda et al. 1998, Swanson et al. 1988, Sprugel 1991), and subsequently, they have become the focus of a great deal of research. Nearly every forest type in the Pacific Northwest has experienced a fire in the current millennium, some with frequent fire return intervals, some with intermediate fire return intervals, and others with extremely infrequent fire return intervals (estimates of mean or median fire return intervals range from 6 years to 937 years, Everett et al. 2000, Agee 1993). The existence of fire as a primary type of disturbance within forest ecosystems has been described throughout the region (Hemstrom and Franklin 1982, Cwynar 1987, Evans 1990, Morrison and Swanson 1990, Agee 1993, Maruoka 1994, Langston 1995, Wright 1996, Heyerdahl 1997, Taylor and Skinner 1998). Fire effects may range from the reduction of fine fuels in the forest understory and the occasional death of a senescing tree to a stand replacing event.

Forests can be classified in terms of their fire regimes (Agee 1990, 1993). A general method of fire regime classification assesses the impact of fire on the dominant vegetation. Based on the severity, frequency and extent of fires within them, forests are classified into low-, moderate- and high-severity fire regimes. A forest with a low-severity fire regime will encounter more frequent fires with less fire-induced mortality than a forest with a high-severity fire regime. Low-severity fire regime forests include drier forests dominated by oak (*Quercus garryana*) woodland, ponderosa pine (*Pinus ponderosa*) or mixed conifers. Moderate-severity fire regime forests include moister, more mesic forests, such as mixed-evergreen, dry Douglas-fir (*Pseudotsuga menziesii*) and red fir (*Abies magnifica*) dominated forests. Moderate-severity fire regime forests experience a mixture of stand replacement fires (i.e., high mortality, high-severity fires) and light surface, low-severity fires. High-severity fire regime forests experience infrequent, stand replacing fires and typically occur in the moister forests, such as western hemlock (*Tsuga heterophylla*)/ Douglas-fir and Pacific silver fir (*Abies amabilis*) dominated forests, along with subalpine forests.

Over the last two centuries, Euroamerican activities in the Pacific Northwest have produced unprecedented fuel loads and forest structures conducive to high intensity and high-severity fires within forests that historically experienced low-severity fire regimes (Barrett 1988, Schwantes 1989, Agee 1993, Covington and Moore 1994, Langston 1995, Agee 1996, 1998, Arno et al. 1997, Pyne 1997). Contributing factors include the reduction in Native American populations during the last couple centuries (and subsequently, a reduction in anthropogenic burning), vast increases in domestic livestock grazing toward the end of the 19th century, increasing large-scale timber harvest throughout the 20th century and, perhaps most notably, a policy of fire suppression since the first decade of the 20th century. Following a number of disastrous fires between 1900 and 1910, fire suppression became Forest Service policy, and over the next couple of decades, suppression became rather effective throughout the Pacific Northwest. Fire suppression likely has had much less impact on wet forests with histories of infrequent fires, however, in contrast to a dramatic impact on drier forest types, where fire was historically frequent. A relatively thick understory has been allowed to establish in the drier, historically open forests of the region. This undergrowth now provides a fuel structure that allows what would traditionally be a light surface fire to climb up into the tree crowns, thereby killing trees that have resisted fire mortality for hundreds of years. Such fire behavior converts fire regimes from low-severity to high-severity, increasing chances of catastrophic fire within forests that have traditionally been fire resistant (e.g., the 1994 Tyee Fire Complex in the Wenatchee National Forest of Washington). Subsequently, while a fire regime classification system based on the effects of fire on dominant vegetation may accurately describe pre-fire suppression forests, it may not be representative of current forests that historically experienced low- and moderate-severity fire regimes.

Riparian Forest Fire Regimes. It is likely that riparian forests experience different fire regimes than nearby upslope forest (Heinselman 1973, Agee 1994, Camp et al. 1997). The combined effects of topographical differences and higher moisture input, and the subsequent differences in vegetative communities, have been assumed to increase fire severity in riparian forests, vary fire intensity levels, and reduce fire frequency.

Fire severity is assumed to be greater within riparian zones. For example, a riparian zone along the Little French Creek in the Payette National Forest, Idaho, experienced a high-severity, stand replacement fire, while much of the adjacent lodgepole pine (*Pinus contorta*) forest did not even burn except for scattered small logs (Agee 1998, Williamson 1999). Similarly, the 1970 Entiat fires (Wenatchee National Forest, Washington) left almost no riparian zone along the Entiat River (excepting scattered western redcedars [*Thuja plicata*] along the bank). Nearby hillslopes showed evidence of historical fires that did not kill the ponderosa pine and Douglas-fir (fire scarred snags indicative of frequent, low intensity burning), yet historical fires appeared to have created even-aged classes of lodgepole pine in the riparian zone, suggesting a stand replacement fire near the stream (Agee 1994).

Topographically, riparian zones typically extend what are generally higher elevation plant series into lower elevations of a drainage (Crowe and Clausnitzer 1997). In addition to transporting water down the drainage, these zones act as a cold air drainages at night and receive less insolation during the day. The combined effects of higher moisture inputs and lower evaporation make the riparian forests cooler and moister than associated upslope forests (Brosofske et al. 1997, Naiman et al. 1998, Williamson 1999). Consequently, riparian zones are frequently dominated by vegetation requiring higher levels of moisture than neighboring upslope forest. Often this vegetation is more structurally complex than in corresponding upslope areas, with greater basal areas, tree densities and canopy foliage weight (Williamson 1999). There is also a higher proportion of multi-layered canopy (and sub-canopy) structure (Gregory et al. 1991, Agee 1994, Naiman and Decamps 1997). Many species with higher moisture requirements also generally have a lower resistance to fire. The greater complexity in vegetative structure, combined with a lowered resistance to fire, theoretically results in more severe fire effects for vegetation in riparian forests, thereby increasing rates of mortality.

Fire intensities are also assumed to vary between riparian and upslope forests. As a consequence of topography and increased moisture input, riparian zones should consequently retain moisture longer into the summer dry season. Moister conditions reduce flammability and subsequently reduce chances of fire ignition. Therefore, riparian zones should have a reduced flammability compared to corresponding upslope areas. Morse (1999) showed that fires in the 1994 Tyee Complex, Wenatchee National Forest, Washington, burned greater proportions of the tree crowns in upland areas relative to riparian areas. Also, fire ignition location influences initial fire behavior within a stand. Lightning is the primary natural source of forest fire in the Pacific Northwest (Morris 1934). Topographically, the upper one-third of hill slopes have the most ignitions by lightning. Slope position affects initial fire behavior since fires starting at the top of a slope are more likely to be dominated by backing and flanking fire behavior, while those starting at the bottom of the slope are more likely to be dominated by heading fire (Agee 1993, Pyne 1996). Heading fires typically have a higher intensity and a higher rate of spread than backing fires. A typical fire scenario is that a fire ignites from a lightning strike in the upper portion of a slope, burns to the ridge in a heading fire but does not necessarily back down the slope at the same rate or intensity, and then perhaps is extinguished once it reaches a zone of moister vegetation. The opposite behavior has also been shown, however. The channeling effect of wind within topographical constraints (e.g. along headwater riparian areas) can intensify fires within those areas, as was the case in some of the riparian areas within the 1988 Dinkelman fire near Wenatchee, Washington (Agee 1994).

Fires have been assumed to be less frequent in riparian forests than in neighboring upslope forests. Recent studies in the Pacific Northwest have reconstructed historical fire regimes at the stand and landscape level (e.g., Barrett 1982, Means 1982, Arno and Petersen 1983, Teensma 1987, Agee et al. 1990, Morrison and Swanson 1990, Agee 1991, Maruoka 1994, Wills and Stuart 1994, Garza 1995, Wright 1996, Heyerdahl 1997, Impara 1997, Taylor and Skinner 1998, Van Norman 1998, Weisberg 1998, Hadley 1999, Everett et al. 2000). Incidental results regarding historical fire within riparian forests have been mentioned in some of these studies. However, with the exception of Skinner's (1997) study in the Klamath Mountains of northern California, historical fire regime differences between riparian and upslope forests have not been explored.

Preliminary results from Skinner (1997) suggest that fire return intervals (the period of time between consecutive fires at a site, a measure of fire frequency) were approximately twice as long in riparian reserve sites than in upland forest sites. Incidental results from the other previously mentioned studies reinforce the assumption that fire return intervals are longer in riparian forests. Agee et al. (1990) found that Douglas-fir/grand fir (*Abies grandis*) communities in lower elevation draws had a mean fire return interval of 93 years, a longer fire return interval than surrounding drier communities (ponderosa pine/Douglas-fir and lodgepole pine/Douglas-fir, 52 and 76 years, respectively). In the central Cascades of Oregon, Teensma (1987) found that fire is "least frequent at lower elevations, in valley bottoms and streamsides, and where protected from east winds" (mean fire return interval of ≥150, as compared to 114 years for the entire study area). A study identifying historical fire refugia (areas less frequently disturbed than the surrounding landscape) in the grand fir and subalpine fir (*Abies lasiocarpa*) forest zones within the Swauk Late Successional Reserve of the Wenatchee National Forest, Washington (Camp et al. 1997) found a disproportionate amount of refugia along stream confluences, lower slopes, benches and headwalls. Hemstrom and Franklin (1982) also found that fire frequency varied with topographic position within forests of Mt. Rainier National Park. The park experiences catastrophic (high-severity and intensity) fires, leaving forests with a variety of different age classes, yet nearly every major river valley contains a streamside old-growth corridor. Additionally, according to Arno and Petersen (1983), fire return intervals, based on 1 acre plots, averaged 50-51 years in a "moist canyon" area along the lower portion of the Bitterroot River, compared to fire return intervals of 18 to 23 years in nearby areas (valley edge and montane slopes). Barrett (1982) found a mean fire return interval of 47.8 years within western redcedar/pachistima (*Pachistima* sp.) sites (>90% of which represented riparian communities) in the Clearwater National Forest of eastern Idaho, while mean fire return intervals decreased at nearby sites within the drier grand fir zone (28.7 years). Not all observations point to lower frequencies in riparian areas, however. Steve Arno (pers. comm. to M. Harrington, Dec. 14, 1993) has observed scarred stumps with multiple scars within riparian zones of ponderosa pine and western larch (*Larix occidentalis*) forests in western Montana (10 and 18 fire scars, in the "lower" part of the riparian area and 30 feet above it, respectively). While this does not necessarily indicate that fire frequency was similar within these riparian zones compared to the surrounding forest, it does imply an unexpectedly high fire frequency in riparian zones within some forest types.

Not only are fire return intervals assumed to be longer in riparian forests, another assumption is that the difference between riparian forest and upslope forest fire return intervals varies according to stream size. Larger streams are predicted to have larger fire return interval differences than smaller streams when compared to their adjacent upslope forests. No studies were found that directly related fire frequency to stream size, although fire extents measured from the 1988 Yellowstone fires were compared among different stream sizes (Minshall and Brock 1991). They found that when wildfires cover large areas, small stream (low stream order) watersheds tend to burn extensively or not at all, whereas large stream (higher stream order) watersheds tend to burn partially. This might counter the above assumption, perhaps suggesting that smaller streams experience larger, higher severity (lower frequency) fires and larger streams experience smaller, lower severity (higher frequency) fires.

Finally, less of a difference is expected between riparian and upslope forest fire return intervals in drier forest types than in moister forest types. Agee et al. (1990) suggested that small areas of cool, moist forest surrounded by larger areas of dry, warm forest, tended to have shorter fire return intervals than where that same cool, moist forest is widely distributed. However, once again, there are no apparent studies relating fire frequency differences between riparian zones and upslope forest across different types of forests.

Study Objectives

The conversion of historically low-severity fire regime forests to high-severity fire regimes, combined with concerns about the protection and restoration of riparian zones within these forests, requires a greater understanding of the historical role of fire within riparian zones. Brown (1989) stated that frequent, low intensity fires probably have little effect on aquatic systems, whereas infrequent, high-severity fires will have large effects. Where fire suppression has converted low-severity fire regimes to high severity, increased detrimental effects are likely in today's riparian ecosystems within the drier forest types.

Based on this need for more information about fire in riparian forests, the objectives of this study are: 1) to determine whether historical fire frequencies differ between riparian and corresponding upslope areas, and 2) if they differ, to determine whether fire frequency differences vary by stream size and general forest type (dry or mesic). This study is limited to comparing fire frequencies between riparian and upslope forests through the use of fire scars, restricting the comparison to only non-lethal fires. Estimates of historical fire severities are included as part of this study, but they are speculative since a reconstruction of species composition and stand structure was not within the scope of this study.

STUDY AREAS

This research is being conducted in study areas within three national forests in the Pacific Northwest (Figure 1). Two areas are within the Blue Mountains of northeastern Oregon: one is located in the Dugout Creek Research Natural Area of the Malheur National Forest (Dugout), and the other is located in the Baker City watershed in the Wallowa-Whitman National Forest (Baker). Landscape level fire histories were conducted in both of these study areas by Heyerdahl (1997). The third study area is located on the western slope of the southern Cascades of Oregon, within the Upper Steamboat watershed of the Umpqua National Forest (Steamboat).

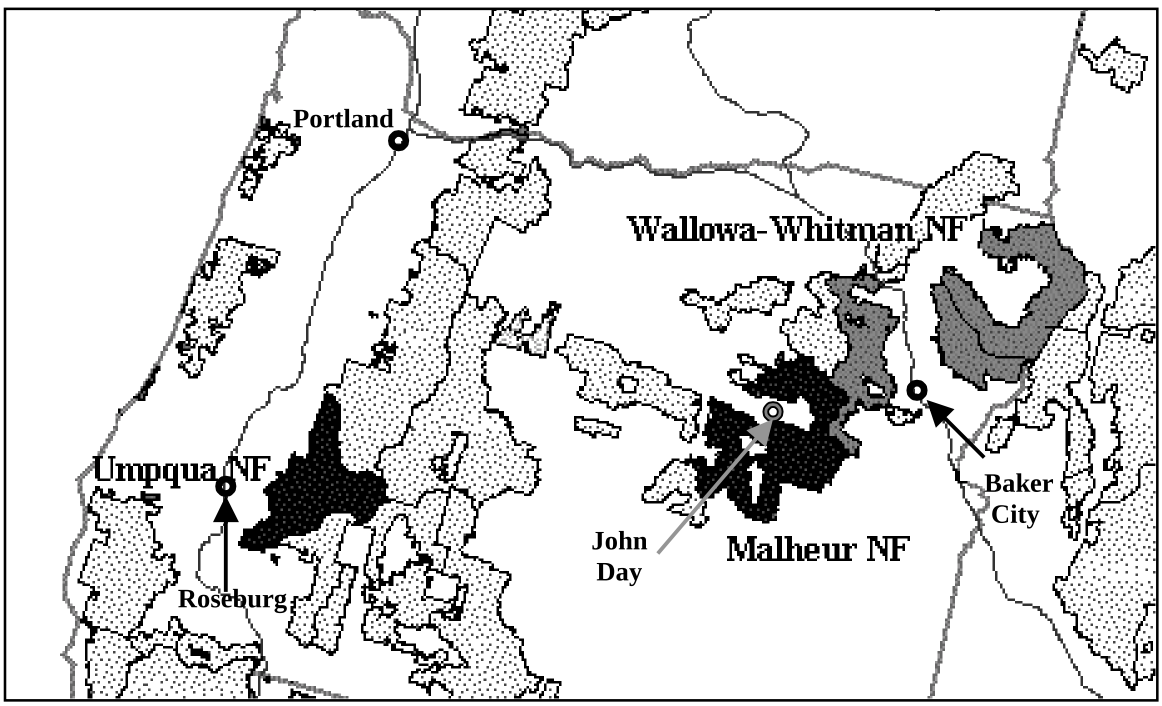

Figure 1. Locations of the three national forests in Oregon containing the three study areas (map modified from USDA 2000a).

Dugout Study Area. The Dugout study area is located in the southeastern Blue Mountains along the North Fork Malheur River, approximately 50 km southeast of John Day, Oregon. Its climate is well within the continental climate regime with maritime influences blocked by the Cascades to the west and the northern and central Blue Mountains. It is characterized by low precipitation and high evapotranspiration (Bryce and Omernik 1997) and summers are typically warm and dry with precipitation occurring primarily during the winter as snow (Johnson and Clausnitzer 1992). Temperatures (measured at John Day) range from -31°C to 44°C, with mean maximum August temperatures of 31°C and mean minimum January temperatures of -6°C. Annual precipitation ranges from 23 cm to 48 cm (NOAA 2000). Convective lightning storms are common in the summer and fall throughout the Blue Mountains (Morris 1934), resulting from cool masses of air crossing the Cascades and passing over high elevations of the Blue and Ochoco Mountains, then mixing violently with the hot, dry surface air (Johnson and Clausnitzer 1992).

The topography is undulating, with elevations ranging from 1,400 to 1,800 m. Slopes range from 0% to 100% in the riparian forests, averaging 48% (this study), and the average slope for upslope forests is 16% (Heyerdahl 1997). Soils are derived primarily from igneous rock, specifically rhyolites and ash flow tuffs from volcanics of the Pliocene. The weathering resistance of rhyolite contributes to typically shallow, cobbly (and therefore xeric) soil throughout the southern Blue Mountains (Bryce and Omernik 1997).

Heyerdahl (1997) assigned forests in her Blue Mountains study areas to two different categories: dry forest types and mesic forest types. Mesic forest types included all associations in the subalpine fir series and some of the associations in the grand fir series and lodgepole pine series. Dry forest types included all associations in the Douglas-fir and ponderosa pine series, as well as some associations in the grand-fir series. Plant associations for forests within Heyerdahl's study and this study were determined either from Johnson and Clausnitzer (1992) or Crowe and Clausnitzer (1997). Table 1 lists the dry and mesic forest type plant associations found in both the Dugout and Baker study areas.

Table 1. Plant associations found in the Dugout and Baker study areas, divided into dry and mesic forest types.

Dry forest types

Ponderosa Pine Series:

PIPO/CAGE: ponderosa pine/elk sedge (*Pinus ponderosa* /*Carex geyeri*)
PIPO/CARU: ponderosa pine/pine grass (*Pinus ponderosa* /*Calamagrostis rubescens*)
PIPO/SYAL-FLOODPLAIN: ponderosa pine/common snowberry-floodplain (*Pinus ponderosa* /*Symphoricarpos albus-floodplain*)

Douglas-fir Series:

PSME/CAGE: Douglas-fir/elk sedge (*Pseudotsuga menziesii* /*Carex geyeri*)
PSME/CARU: Douglas-fir/pine grass (*Pseudotsuga menziesii* /*Calamagrostis rubescens*)
PSME/SYAL-FLOODPLAIN: Douglas-fir/common snowberry-floodplain (*Pseudotsuga menziesii* /*Symphoricarpos albus-floodplain*)

Grand Fir Series:

ABGR/CAGE: grand fir/elk sedge (*Abies grandis* /*Carex geyeri*)
ABGR/CARU: grand fir/pine grass (*Abies grandis* /*Calamagrostis rubescens*)
ABGR/SYAL-FLOODPLAIN: grand fir/common snowberry-floodplain (*Abies grandis* /*Symphoricarpos albus-floodplain*)

Mesic forest types

Grand Fir Series:

ABGR/ACGL-FLOODPLAIN: grand fir/Rocky Mountain maple-floodplain (*Abies grandis* /*Acer glabrum-floodplain*)
ABGR/BRVU: grand fir/Columbia brome (*Abies grandis* /*Bromus vulgaris*)
ABGR/CLUN: grand fir/queen's cup beadlily (*Abies grandis* /*Clintonia uniflora*)
ABGR/LIBO2: grand fir/twinflower (*Abies grandis* /*Linnaea borealis*)
ABGR/VAME: grand fir/big huckleberry (*Abies grandis* /*Vaccinium membranaceum*)
ABGR/VASC: grand fir/grouse huckleberry (*Abies grandis* /*Vaccinium scoparium*)
PICO(ABGR)/VASC/CARU: lodgepole pine (grand fir)/grouse huckleberry/pinegrass plant community type (*Pinus contorta* [*Abies grandis*]/*Vaccinium scoparium* /*Calamagrostis rubescens*)

The Dugout study area is comprised mostly of dry forest types, typically ponderosa pine and dry Douglas-fir forest series. The entire area historically experienced a low-severity fire regime (Weibull median probability fire return intervals range from 9 to 32 years), and there was no consistent variation in fire return interval length with either aspect or elevation (Heyerdahl 1997).

The North Fork Malheur River system currently supports bull trout (*Salvelinus confluentus*) as well as other trout species, and traditionally supported an anadromous fishery (prior to dam placement along the Snake River; USDA 2000b).

Baker Study Area. The Baker study area is located at the southern end of the Powder River valley, approximately 5 km west of Baker City, Oregon. It is situated on the northeastern slope of the Elkhorn Mountains and it encompasses the lower portions of the Marble Creek watershed, extending northwest to the Mill Creek drainage and southeast to the Elk Creek drainage. It is located just beyond the zone strongly influenced by the Cascade rain shadow, where climate influenced by marine weather systems flowing up the Columbia River interfaces with the more continental climate found to the east and south (Bryce and Omernik 1997). Like the Dugout study area, summers are typically warm and dry with most precipitation falling during the winter (Johnson and Clausnitzer 1992) and convective lightning storms are common during the summer and fall (Morris 1934). According to Morris (1934), forest lands in what is now the Wallowa-Whitman N.F. experienced more than six lightning storms annually per 40,000 ha (compared to between three and four storms in the Malheur N.F.). Temperatures (measured at Baker City) range from -39°C to 41°C, with mean maximum August temperatures of 29°C and mean minimum January temperatures of -8°C. Annual precipitation ranges from 15 cm to 48 cm (NOAA 2000).

Soils are derived from both sedimentary and metamorphic parent materials, and ash deposits from the eruptions of Mount Mazama (6,600 y.b.p.) and Glacier Peak (12,000 y.b.p.) have been retained under the more mesic forests at middle and upper elevation, north-facing slopes. The onset of moisture stress in these forests during the summer is delayed by this moisture-retaining ash mantle. Elevations range from 1,250 to 1,600 m for the portion of the watershed included in this study. Slopes in the riparian forests range from 18% to 82%, averaging 67% (this study), and the average slope for the upslope forests is 40% (Heyerdahl 1997). The northwestern portion of the study area has rather steep and dissected topography, whereas the southeastern portion of the study area has a gentler topography, similar to that found in the Dugout study area. In the steeper, more dissected portions of this study area, the predominantly southwest to northeast orientation of the drainages plays a large role in determining forest composition. North- and east-facing aspects receive less solar radiation and therefore consistently have moister plant associations than south- and west-facing aspects. In steep terrain (45 degree slopes) at this latitude, southerly slopes receive nearly three times the direct solar energy that northerly slopes receive (Holland and Steyn 1975).

As with the Dugout study area, portions of the Baker study area are also representative of dry forest series, but with more area occurring within grand fir plant associations. Forest types range from dry grand fir series in the riparian forests and dry Douglas-fir series in the upslope forests at the lower elevations, to more mesic grand fir series in both riparian and upslope forests at the higher elevations (Figure 2). The mesic forest type extended lower in the watershed within riparian zones than it did in the upslope forest adjacent to the riparian zones. Dry forest types in the Baker study area generally occur on south and west aspects, and as with the Dugout study area, these dry forests historically experienced low-severity fire regimes (Weibull median probability fire return intervals range from 6 to 38 years) and north and east aspects above 1,500 m elevation tended to experience moderate- and high-severity fires (Heyerdahl 1997).

The upper portion of this study area serves as the water supply for Baker City, with water intake occurring at approximately 1,580 m in elevation throughout the study area. Bull trout as well as other trout species are present in the lower portions of the watershed, and suitable habitat is present at higher elevations (USDA 1998).

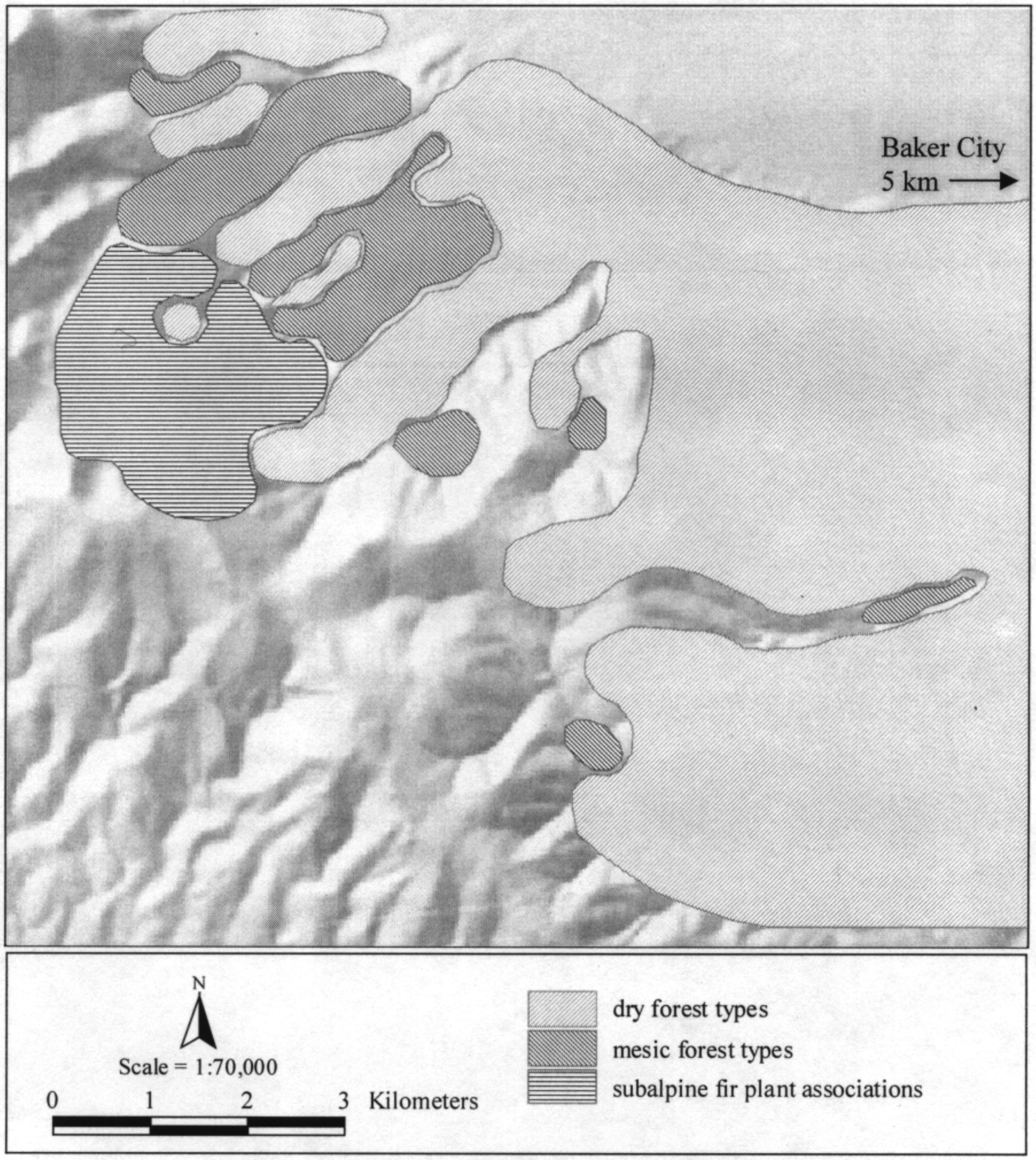

Figure 2. Approximate delineations of forest types for the Baker study area. Delineations were based on plant associations determined for each plot in this study and Heyerdahl (1997). Areas outside of the delineations did not contain any sampling plots.

Steamboat Study Area. The Steamboat study area is located in the Upper Steamboat watershed on the south facing slopes of the Calapooya Divide in the southern Cascades of

Oregon, approximately 70 km northeast of Roseburg. The Calapooya Divide is considered to be the boundary between the Mediterranean climate to the south (the result of the Siskiyou Mountains blocking marine influenced weather patterns) and a more moderate climate to the north (the result of moister, marine air flowing over the shorter Coast Range). East winds can occur periodically during the late summer and early fall, sustaining 50 to 60 km/h speeds and very low humidities, subsequently producing low fuel moisture levels (USDA and USDI 1998). Annual precipitation ranges from 120 to 200 cm, falling primarily between October and June. Winter temperatures average between -4 and 4°C and July maximum temperatures average between 18 and 32°C (USDA 1997). As in the Blue Mountains, convective lightning storms are also common during the summer and fall in the southern Oregon Cascades and the Upper Steamboat watershed is located within the zone described as having between 3 and 4 lightning storms annually per 40,000 ha (based on storms reported during a 7-year period from 1925 to 1931; Morris 1934).

Elevations range between 560 and 1,800 m and landforms within the watershed are the result of a deeply weathered volcanic landscape subjected to regional uplift over the past several million years. Landforms include steep slopes (averaging 71% slope; this study) and steep V-shaped canyon walls (averaging 71% slope; this study). Streams are characterized by generally steep-gradient bedrock and colluvial-constrained stream channels with most of the watershed's major channels converging within a short distance. Soils are derived primarily from igneous rock (USDA 1997).

The Steamboat study area is comprised of Douglas-fir plant associations, as well as relatively dry western hemlock and Pacific silver fir plant associations near the southern limit of their ranges (Atzet et al. 1996). In a preliminary investigation of riparian zone fire histories in the Klamath Mountains, Skinner (1997) found that mean fire return intervals for riparian reserve sites (between 16 and 42 years) were approximately twice as long as fire return intervals from nearby upland forests (between 7 and 13 years), with similar ranges (5 to 71 years for riparian sites compared to 3 to 64 years for upland sites). The data suggest that riparian fire return intervals tend to be longer and more variable than those in adjacent uplands. Taylor and Skinner (1998) found that median fire return intervals for Douglas-fir dominated forests in the Klamath Mountains of northern California varied by aspect. Median fire return intervals on south-facing slopes (8 years) and west-facing slopes (13 years) were shorter than on north-facing slopes (15 years) and east-facing slopes (16.5 years). Additionally, between 1850 and 1950, upper slopes, ridgetops, and south- and west-facing slopes appeared to experience higher severity fires relative to lower slopes and east- and north-facing slopes. In another study in the Klamath Mountains, Wills and Stuart (1994) found mean fire return intervals ranged between 10 and 17 years for a Douglas-fir/hardwood forest. And in a study in the Siskiyou Mountains, southwest of the Steamboat study area, fire frequencies ranged from 16 years in lower elevation, mixed evergreen forests to 64 years in higher elevation, white fir (*Abies concolor*) forests (Agee 1991).

Closer in proximity to the Steamboat study area, Van Norman (1998) found a composite median fire return interval of 123 years within moderate-severity fire regime forests in the Little River Watershed of the Umpqua National Forest, approximately 35 km southwest of the Steamboat study area. The Steamboat study area is also somewhat similar to two areas studied by Morrison and Swanson (1990) north of the Steamboat area in the central Oregon Cascades. These sites were located within the western hemlock zone, the Pacific silver fir zone and the transition zone between the two. Their lower elevation site (primarily in the western hemlock zone) had a mean fire return interval of 96 years and their higher elevation site (within the transition zone and the Pacific silver fir zone) had a mean fire return interval of 241 years. Both sites showed a mosaic of low-, moderate- and high-severity fire regime forests. Garza (1995) calculated an overall site mean fire return interval of 147 years at another site within the central western Cascades of Oregon, roughly 160 km north of the Steamboat site. The study occurred within western hemlock and Pacific silver fir zones, with median fire return intervals ranging between 93 years and 246 years as plant associations became progressively moister. And yet another nearby study in dry Douglas-fir dominated forest within the western hemlock zone of the Willamette National Forest, Oregon (Means 1982) found that stands within these forests burned at approximately 100 year intervals. Additionally, Teensma (1987) showed a mean fire return interval of 114 years within the H.J. Andrews Experimental Forest in the central Cascades of Oregon (still within the western hemlock and Pacific silver fir zones).

Impara (1997) found a mean fire return interval of 85 years for his study area in the central Oregon Coast Range, roughly 90 km northwest of the Steamboat study area. When the area was divided between the eastern portion along the margin of the Willamette Valley and the central and western portion within the interior of the range and along the coast, mean fire return intervals were 75 years and at least 115 years, respectively. Overall, the eastern portion of the study area experienced a moderate-severity fire regime, compared to the higher severity fire regime evident for the central and western portions of the study area, which resulted in a greater mixture of age classes. Additionally, both the severity and the frequency of fires were found to be greater for the upper portions of the hillslope compared to the middle and lower portions. And widespread, high-severity fires were more frequent on north-facing slopes than other aspects.

Weisberg (1998) studied the Blue River watershed, approximately 60 km north of the Steamboat study area. Weibull median probability fire return intervals ranged from 73 years to 91 years depending on whether low-severity fires were included or excluded. It appeared that fire severity was lower on more north-facing slopes and the proportion of low-severity fires was greater at lower slope positions. This suggests that fires burned continuously in terms of topographic features, but the higher moisture levels in the lower slope position and north-facing slopes reduced the severity of the fire in those locations.

METHODS

Fire scars were collected from plots located within riparian zones along small and large sized streams distributed throughout each study area. Maps were made for each fire year based on which plots recorded scars for that fire year.

Plot Size

Each plot covered an area no larger than one hectare, and no plot edges spanned more than 100m. By keeping the plot size small, a point fire frequency can be interpreted from the data, in contrast to an area frequency (Agee 1993). Theoretically, a single point on the landscape should be represented by a single tree. However, not every fire scars every tree, so when sampling fire scars, collecting samples from more than one tree within each sampling plot provides a more complete record of fires for that "point" on the landscape. Because fire return intervals decrease as sample unit size increases (Arno and Petersen 1983), it is important that the plot size is minimal in area, yet still captures the history of fires at that spot. Fire extents within the low-severity fire regime forests of the Dugout and Baker study areas are typically far greater than the size of the sampling point (Heyerdahl 1997). Based on fire extents in the study conducted by Morrison and Swanson (1990) north of the Steamboat study area, a one hectare plot size appears to suffice in moderate-severity fire regime forests, too.

Plot Selection

Riparian Zone Definition. The riparian zone has various definitions in the literature. Oregon's Riparian Task Force developed a structured definition of riparian ecosystems, recognizing three distinct zones: the aquatic zone (the wetted area of streams, lakes and wetlands up to the average high water level), the riparian zone (includes terrestrial areas where the vegetation and microclimate are influenced by perennial and/or intermittent water, associated with high water tables and soils which exhibit some wetness characteristics), and the riparian zone of influence (the transition area between the riparian zone and the upland cover type, identified by a change in plant composition, containing trees that may provide shade or contribute fine or large woody material to a stream) (Raedeke 1988). The definition of riparian zone used for this project includes the riparian zone of influence. This is measured in terms of site potential tree lengths from the edge of the stream channel, or, if applicable, the topographic edge of the floodplain. A site potential tree length (SPTL) represents the height of “a tree that has attained the average maximum height possible given site conditions where it occurs” (FEMAT 1993), which, for the purposes of this study, was determined to be approximately 45 m for the Dugout and Baker study areas and 50 m for the Steamboat study area. The Dugout and Baker study area SPTLs were based on ICBEMP definitions (Sedell et al. 1997) and were comparable to those found in PACFISH (USDA and USDI 1994). The Steamboat study area SPTL was based on the Northwest Forest Plan Riparian Reserve requirements (FEMAT 1993).

Riparian reserve requirements in the Northwest Forest Plan (FEMAT 1993) include retaining a forest buffer with a width equivalent to two SPTLs, or roughly 100 m, along each side of a fish-bearing stream. Along non-fish-bearing streams and intermittent streams, buffer widths ranging from one half to one SPTL (roughly 15 to 50 m) are required along each side of the stream. The Interior Columbia Basin Ecosystem Management Project (ICBEMP) and proposes similar dimensions: two SPTLs (roughly 90 m) along each side of perennial streams and one SPTL along each side of intermittent streams (roughly 45 m, Sedell et al. 1997). Subsequently, the riparian zone definition for this study was based on these dimensions. For small streams, the riparian zone spanned one SPTL from either side of the stream or floodplain, while larger stream riparian zones included forest within two SPTLs from the stream or floodplain.

The riparian plots were placed as close to the stream as possible. Riparian plots were roughly divided between small streams and large streams. Originally, large and small streams were defined based on stream order, with small streams including headwater streams, 1st and 2nd order streams, and large streams including 3rd and 4th order streams. Stream ordering was based on Brown (1985) and determined from 7.5' USGS quadrangle maps. However, because categorizing streams according to stream order has become nearly obsolete, bankfull widths were measured for each stream (Figure 3). Except for the large streams in the Baker study area, the bankfull width cutoff point between large and small streams is at approximately 6 m, and there is virtually no overlap between small and large stream bankfull widths. The Baker City water supply intake points are located upstream from the large stream riparian plots in the Baker study area, and have subsequently reduced water flow in the downstream reaches of the watershed. It is unlikely that current bankfull width measurements for these streams are representative of historical stream widths.

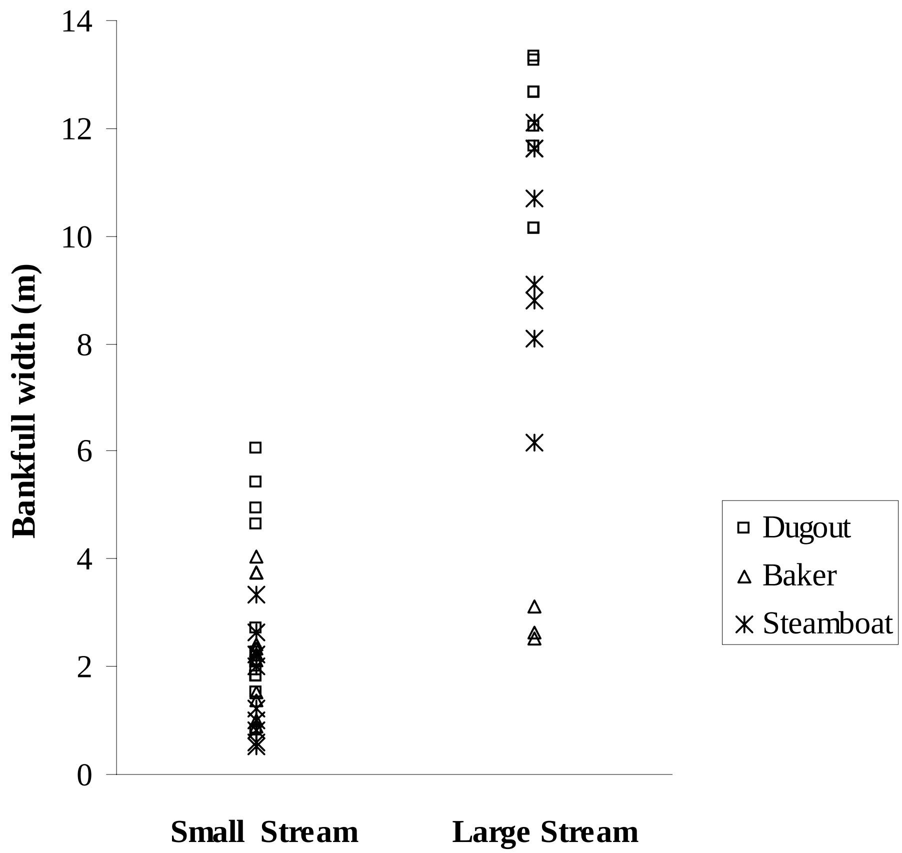

Figure 3. Bankfull widths categorized by stream size for all of the riparian plots in each of the three study areas.

Dugout Study Area. Nineteen riparian plots were located such that they coincided with upslope plots sampled by Heyerdahl (1997, Figure 4). The seven plots located along the North Fork Malheur River (categorized as a large stream) were restricted to just one side of the river, i.e., the plot did not span across the river. However, the plots were well distributed on both sides of the river. Twelve plots were distributed along smaller streams and included sampling on both sides of the stream.

Baker Study Area. As in the Dugout study area, riparian plots were located downslope from plots in the dry forest types (dry grand fir and Douglas-fir plant associations) sampled by Heyerdahl (1997, Figure 5). Of the sixteen plots sampled, three were along large streams and the other thirteen were along small streams. Samples were collected on both sides of the stream within all plots, with the goal of characterizing the role slope aspect played in historical fire occurrence.

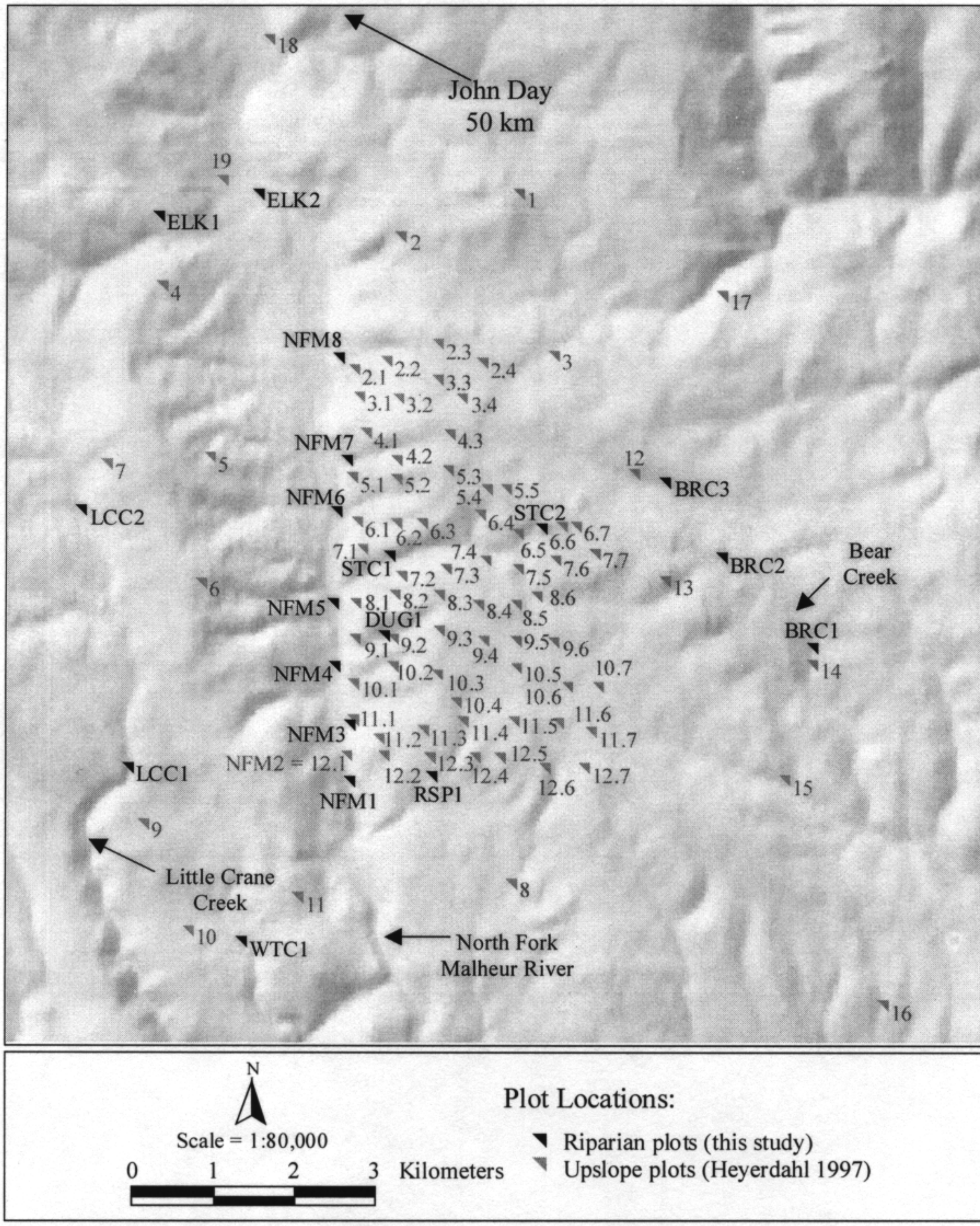

Figure 4. Plot locations for the Dugout study area, Malheur National Forest.

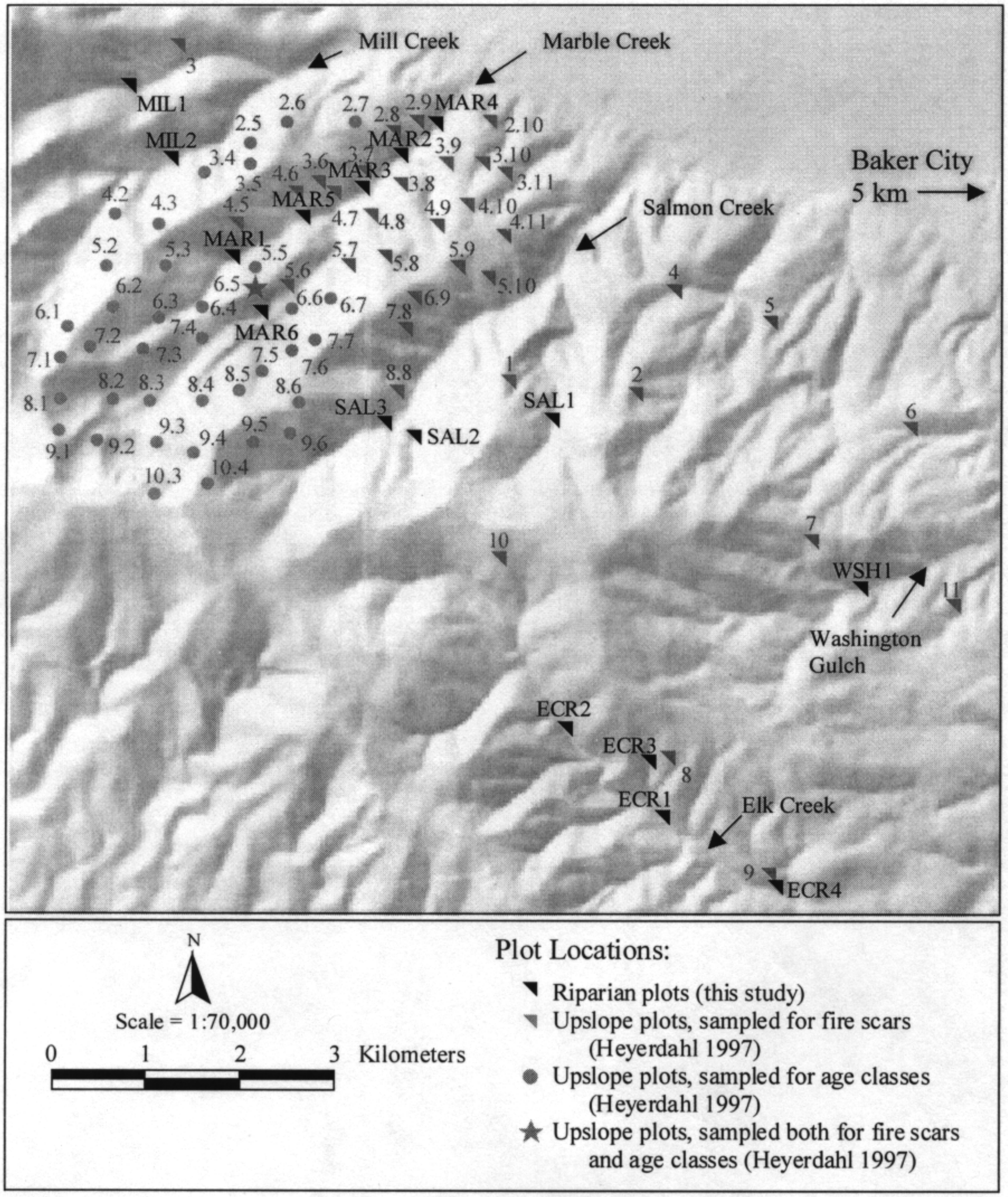

Figure 5. Plot locations for the Baker study area, Wallowa-Whitman National Forest.

Steamboat Study Area. Unlike the Blue Mountain study areas, no previous fire history sampling had occurred in the Steamboat study area, so it was necessary to sample upslope plots in addition to riparian plots. The primary species available for fire-scar sampling was Douglas-fir, which often heals over fire scars when fire return intervals are sufficiently long, making them difficult or impossible to detect in a live tree. This necessitated sampling in clearcuts, where evidence of scarring was observable on the stump surfaces. Subsequently, plot selection was limited to recent cuts (where the stumps had not experienced too much rot) that extended into the riparian zone. Seventeen riparian plots were paired with upslope plots, totaling 32 plots (Figure 6). Some riparian plots shared upslope plots. Eight of the 17 plots were located along large streams, and nine of the plots were located along small streams.

Four plots (2 pairs of riparian and upslope plots: CCR3 and 4, LRC1 and 2) from the Steamboat study area were not used in the data analysis, although their data were summarized in Appendix B and they were included in the fire maps (Appendix F). These two pairs of plots were located close to each other and were the highest elevation plots sampled in the watershed, occurring well within the Pacific silver fir series. This series is known to have a high-severity fire regime (Agee 1993), which was confirmed by the fact that the samples from three of the four plots did not have tree ring records prior to the middle of the 1800s, suggesting a stand replacing fire prior to that point. Consequently, these plots were not very comparable with the lower elevation plots. Additionally, as the only plots within this study area that were sampled within the Pacific silver fir series, they were not comparable to other locations sampled within the watershed.

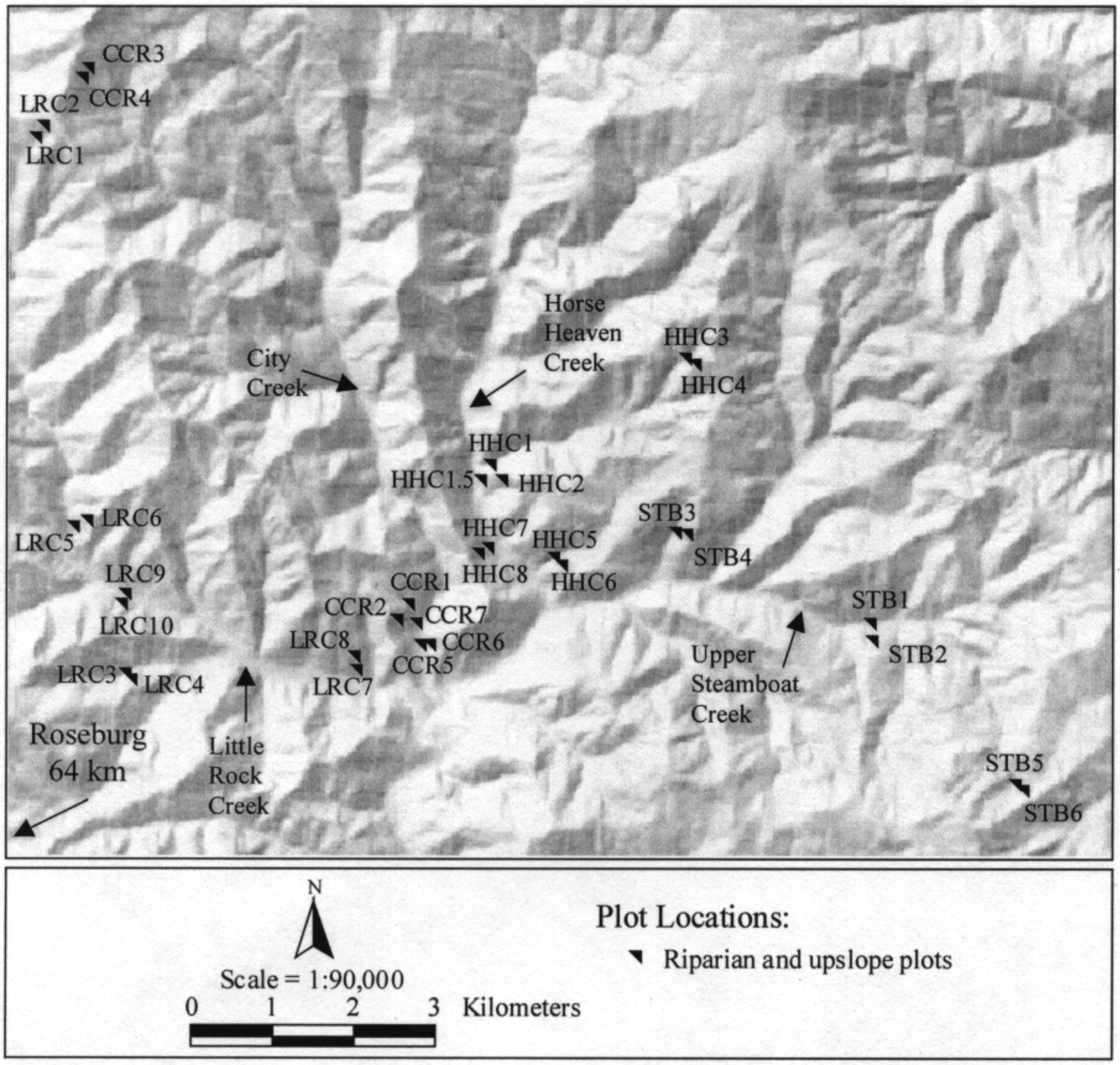

Figure 6. Plot locations for the Steamboat study area, Umpqua National Forest.

Plot Characteristics

Within each plot the plant association (based on potential vegetation; Atzet et al. 1996, Crowe and Clausnitzer 1997, Johnson and Clausnitzer 1992) was determined, the aspect and degree of the slope measured, and latitude/longitude readings were made using a Garmin GPS unit and verified on 7.5' USGS quadrangle maps. For riparian plots, bankfull, terrace and floodplain widths were each averaged from three measurements taken 20 m apart. Stream channel morphology was categorized based on Montgomery and Buffington (1993).

Fire Scars

Fire scars are created when a portion of the tree's cambium is heated beyond its threshold for survival. Heat-killed bark peels away from the xylem, revealing the woody core of the tree (Gill 1974). Subsequent years of growth by the adjacent live cambium gradually heal over the scar, resulting in rings curling along the edges of the scar. The scar location is susceptible to further scarring by successive fires (Johnson and Gutsell 1994) and frequently there is record of multiple fires within one scarred portion of a tree (Figure 7). Since other disturbance events can cause scars (humans, wildlife, insect attacks, diseases, sun scorch, scrape from nearby falling trees, broken branches and frost, to name a few) it is important to be able to differentiate a fire scar from other types of scars (Stokes 1980). For this study, a scar was considered a fire scar if the cross-section showed the classical curling, or if there was a large (or multiple small), pitchy split or break point along a ring that coincided with a nearby fire date. Additionally, evidence of suppression or release (abrupt increases or decreases in radial growth) events that coincided with a nearby fire date, numerous resin ducts within a ring that coincided with the year following a nearby fire date, or the presence of charring along a ring, were also considered evidence of fire. It is important to note, however, evidence of any sort of scarring, aside from the traditional curling scar, needed corroboration from other, nearby samples before it could be considered a fire scar. Based on this conservative determination of fire evidence, it is possible that the amount of fire scarring within the collected samples has been underestimated in this study.

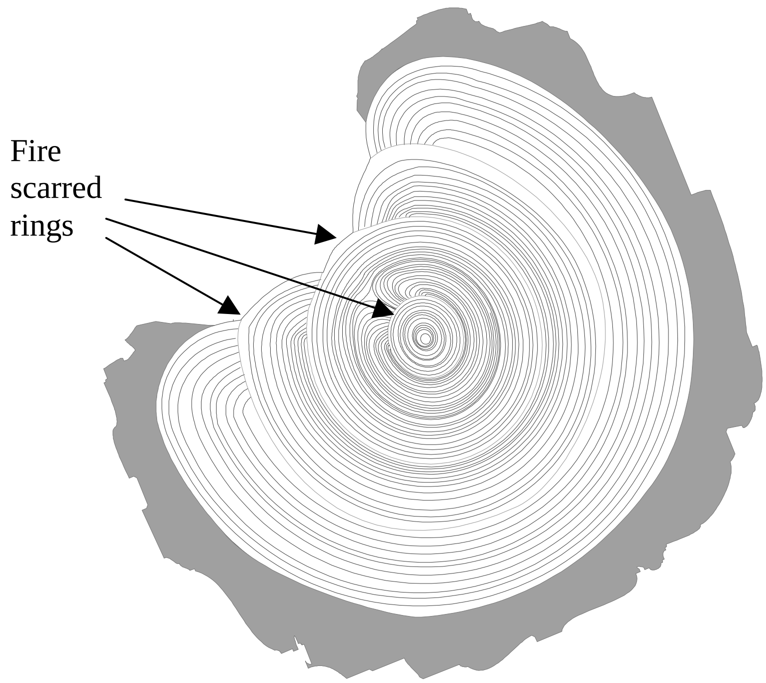

Figure 7. Schematic of the cross-section of a fire scarred tree (graphic originally created by K. Maruoka, University of Washington fire lab).

Within each one hectare plot, between three and 10 fire scarred partial cross-sections were removed from live trees, logs, stumps, and short snags using a chainsaw, following methods described by Arno and Sneck (1977). Samples were selected based on their quality: well-preserved, clearly distinguishable scars were chosen when they could be safely removed from the tree. Preference was given to taking samples out of dead material. For each fire scar sample collected, species, height of scar and scar position relative to topography was recorded and a diagram drawn relating it to other samples and topographic features (a stream, for example) at that plot.

A total of 424 fire scarred samples were brought back to the lab and each cross-section was sanded until individual cells were discernable (400 grit). Cross-sections were then crossdated against master tree-ring chronologies in order to associate a year with each fire scar. Out of the 424 fire scarred samples, 398 (94%) were successfully crossdated. Generally, dates could be determined based on visual crossdating, using a binocular microscope. However, for those samples where visual crossdating was too difficult, ring widths were measured and input into a crossdating software program (COFECHA; Holmes 1983). In addition to fire date determination, the use of a microscope allowed an approximate determination of the season of a fire's occurrence, depending on whether the scar is located within the earlywood portion of the tree-ring (spring), the latewood portion or at the boundary of the tree-ring (late summer), or at the boundary of the latewood and the following year's earlywood (fall or winter).

Master tree-ring chronologies were already available for the Dugout and Baker study areas (Heyerdahl 1997 and Swetnam 1993, respectively), however, it was necessary to create one for the Steamboat study area. To develop a chronology, 12 Douglas-firs and two sugar pines located along ridgetops within the Upper Steamboat watershed were cored twice at breast height. Cores were brought back to the lab, glued onto wooden mounts and sanded. Ring dates were determined based on counting back from the bark (i.e., the core date), then ring widths were measured and the cores combined to create a master ring-width chronology. This chronology coincided well with a Douglas-fir chronology developed by Graumlich (1983) for the Abbot Creek Research Natural Area, located approximately 70 km to the south. The Dugout chronology includes the past 400 years, the Baker chronology covers the past 500 years, and the chronology for the Steamboat study area goes back about 340 years.

Due to a paucity of fire scars within some riparian plots in the Baker study area, it was necessary to supplement fire scar samples with age class data. A total of 81 increment cores were taken from the largest early seral trees found in the plots (primarily western larch and lodgepole pine, occasionally ponderosa pine). If the establishment dates of these individuals occurred within a few years following a fire recorded at a neighboring plot, then it was assumed that the fire also occurred within that particular plot but no trees remained to record the scar. Cores were removed from trees using an 18 inch increment borer; generally this was sufficient to reach the pith of the tree. Trees were cored as close to the base of the tree as possible in order to reduce the amount of error involved with estimating the establishment date. When the core did not intersect the pith, the pith date was estimated using a pith indicator (Applequist 1958). The tree's establishment date was then estimated by subtracting from the pith date an adjustment for the height at which the tree was cored. For the Baker study area, one year was subtracted from the pith date for every five centimeter increment of the coring height (Maruoka 1994). Establishment dates were also determined for any fire scarred cross-sections that included or came close to the pith. The same adjustment for sampling height used in the Baker study area was also used for the Dugout study area. An adjustment was determined for the Steamboat study area based on data from dry Douglas-fir forests in the Pacific Northwest (Figure 8, extrapolated from McArdle and Meyer 1930).

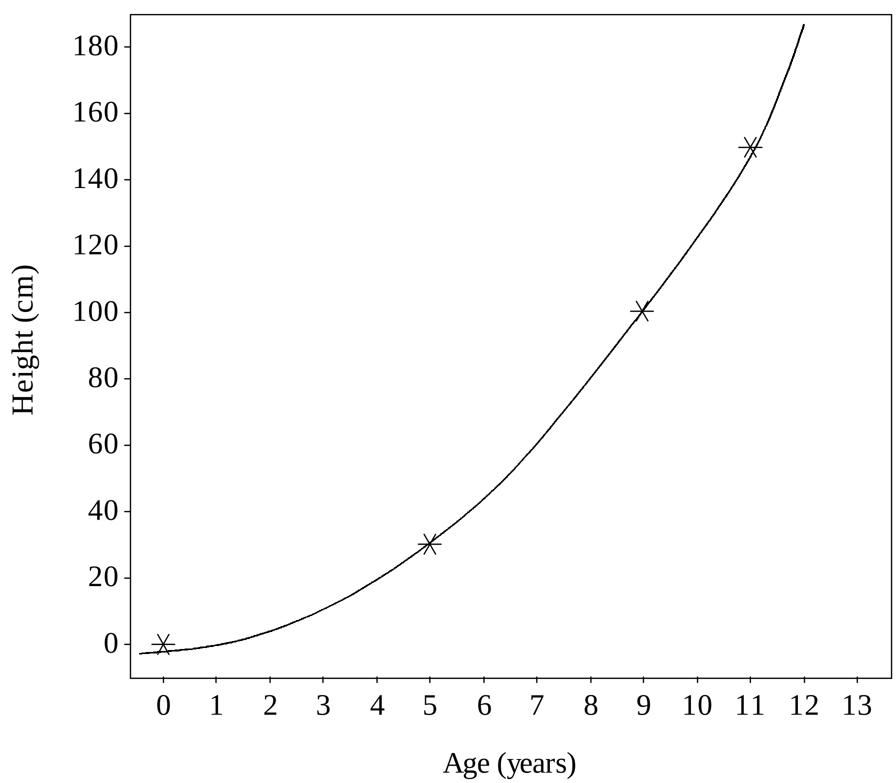

Figure 8. Age versus height curve for Douglas-fir, extrapolated from McArdle and Meyer (1930).

Fire Maps

Maps were created for each study area using ArcView GIS 3.2 (ESRI 1999) geographic information system (GIS) software. Sample plot latitude and longitude (or UTM) coordinates, and 1:24,000 Scale USGS Digital Elevation Models (DEMs), were corrected to the Albers Equal-Area Conic projection (units = meters, spheroid = Clarke 1866, datum = NAD27), in order to fit with Arc/Info (ESRI 1995) GIS data from Heyerdahl (1997). The projection is truest along the eastern Oregon state line, between the 43^{rd} and 48^{th} parallels. In addition to producing maps showing plot locations within each study area, maps were produced for each fire year within each study area (Appendices D, E, F).

Baker and Dugout Maps. For both the Dugout and Baker study areas, maps of plots sampled in this study were superimposed onto maps of plots sampled by Heyerdahl (1997). Additionally, fire year maps from this study were superimposed onto fire year maps from Heyerdahl (1997). For each fire year map, the original fire extent polygon drawn by Heyerdahl (1997) was kept, and an additional polygon was drawn to reflect fire extent changes based on data from this study. Heyerdahl (1997) drew fire boundaries approximately halfway between plots with fire records for a certain fire year and plots without evidence of fire for that year. When plots with fire records were located along the outer portion of the sampling grid, or had neighboring plots that were not capable of recording fires that year, then fire boundaries were either drawn as straight lines between two plots with fire records, or drawn along ridgelines and perennial streams. Since this study was designed to determine fire occurrence in riparian zones, the use of perennial streams as fire boundaries may be contradicted by the presence of fire in a riparian zone. Therefore, the fire polygons drawn for this study reflect whether or not there was evidence of a fire burning on both sides of a stream. And when there was no other physical evidence available for bounding a fire, then the boundary was drawn as a straight line between the outer plots with fire records. Finally, as in Heyerdahl (1997), if plots with fire records were separated by more than 3 plots without fire evidence or were farther than 1.5 km from the nearest plot, then boundaries were simply drawn as a circle around the plot. New fire polygons were drawn in this study simply for the sake of visualizing fires. Fire extents were not recalculated because it was not the focus of this study.

Steamboat Maps. Unlike the Dugout and Baker study areas, fire polygons were not drawn around plots with fire records because the sampling scheme was not designed to determine fire extent. Therefore the fire year maps simply indicate which plots had fire records and which plots did not.

DATA ANALYSIS

Determination of the Time Period of Analysis

The time period used in this study was somewhat arbitrarily chosen to be 1650-1900, in order to get a fire record length throughout each study area that is long enough to be able to characterize historical fire frequency, but not so long that the sample depth is overly compromised. The early constraint of this time period (1650) is based loosely on the number of plots in the Dugout and Baker study areas that had at least one sample recording fires, and on the number of plots in the Steamboat study area that had at least one sample (or a combination of samples) with a tree ring record extending throughout the time period. In order to be considered capable of recording fires, at least a portion of a tree's cambium needs to be exposed from a previous disturbance (Grissino-Mayer 1995). Therefore, at least in the case of the Dugout and Baker study areas, the recording period for a sample typically begins on the date of the first fire. In Steamboat, however, the concept of recording trees is complicated by the fact that trees sampled in this area (typically Douglas-fir) grow over fire scarred cambium quite rapidly, and sometimes do not even appear to have an open scar face at any point after a fire (i.e., the tree puts on an ring for the entire circumference of the tree the year after the fire). Therefore, the date of the first fire record does not necessarily signify the beginning of the site's ability to record fires. In this case, the length of tree ring records was used, rather than the length of fire records. The choice of 1900 as the cutoff year for this fire history is intended to avoid the impact of Euroamerican settlement and the subsequent land use practices (like fire exclusion) on the fire record.

During the 1650-1900 period, 13 of 20 riparian plots (65%) in the Dugout study area have fire records spanning the entire time period. Six of the 16 riparian plots (38%) in the Baker study area have fire records spanning the entire 1650-1900 time period and 17 of the 28 riparian and upslope plots (61%) in the Steamboat study area have tree ring records spanning the entire 1650-1900 time period. Previous studies have utilized time periods when 30% of the plots had fire records during the entire time period (Heyerdahl 1997) or when 25% of the plots had at least one tree with a tree ring record extending back to the beginning of the chosen time period (Wright 1996), so the 1650-1900 time period seems to be an acceptable choice for this study.

Methods of Data Analysis

Data were summarized for each category of plot (e.g., riparian plots vs. upslope plots, small stream riparian plots vs. large stream riparian plots, etc.) using three different methods: 1) composite fire return interval calculations for each plot, 2) number of fires per plot, and 3) individual fire return intervals grouped by plot categories.

Composite fire return interval calculations for each plot. This is one of the more common approaches to calculating fire return intervals (e.g., Barrett 1982, Means 1982, Arno and Petersen 1983, Teensma 1987, Agee et al. 1990, Morrison and Swanson 1990, Agee 1991, Maruoka 1994, Wills and Stuart 1994, Garza 1995, Wright 1996, Heyerdahl 1997, Impara 1997, Taylor and Skinner 1998, Van Norman 1998, Weisberg 1998, Hadley 1999, Everett et al. 2000, and numerous other studies within and outside of the Pacific Northwest). Fire years derived from all of the samples in one plot are combined into one master chronology of fire dates for that plot. Individual fire return intervals are then determined by calculating the period of time between each of the fires occurring at the plot. Once the fire return intervals have been calculated, they are grouped for that plot and the fire history software program FHX2 (Grissino-Mayer 1995) then calculates the mean and median fire return interval, based on both a normal distribution and a Weibull distribution, calculates confidence intervals based on a Weibull distribution, and shows how well the data fit both the normal and Weibull distributions. The Weibull distribution is frequently used in fire history studies because it is a flexible distribution that allows the tendency of fire return interval distributions skewed to the right to be represented mathematically. The Weibull median probability fire return interval (WMPI) provides a least biased measure of central tendency in skewed distributions of fire return interval data (Grissino-Mayer 1995).

The resulting calculations represent fire return intervals from that particular plot. The composite fire return interval calculations for each plot are then used as replicates within each category of plot (e.g., a riparian plot along a small stream, a plot upslope from a large stream, etc.). Then comparisons are made between the different types of categories (e.g., riparian vs. upslope plots, riparian plots along small streams vs. riparian plots along large streams). A problem with this analysis method is that the FHX2 program requires at least four fires, and subsequently three fire return intervals, for each plot in order to calculate a Weibull distribution mean, median and confidence interval. In this study, all of the riparian plots (i.e., the ones sampled for this study) in the Dugout study area, except for one (19 of 20), have at least four fires recorded during the 1650-1900 time period. However, in the Baker study area, only 10 of the 16 plots sampled in this study recorded four or more fires, and in the Steamboat study area, only 12 of 32 plots recorded four or more fires. Clearly, ignoring six of 16 and 20 of 32 plots will affect the comparisons between categories of plots. Therefore, other analysis methods were explored.

Number of fires per plot. Heyerdahl (1997) analyzed fire frequency based on fire recurrence over a particular time period, using the number of fires that occurred at each plot during that period as the basis of her comparisons, rather than calculating and comparing fire return intervals. This method works well if all or most of the plots have tree ring records that extend throughout the chosen time period and the trees within the plots were able to record fires during that period. However, if the trees sampled within a plot do not have combined tree ring records extending throughout the time period being analyzed, or if they were not recording fires during that entire time period, then this method does not work as well. For example, suppose two plots have a sufficient number of fire scars to perform plot-based fire return interval calculations, and those plots have similar mean fire return intervals calculated for the time period of 1650-1900. The plot with the shorter fire record (suppose one of the plots does not start recording fires until the mid-1700s) will have fewer fires recorded for that plot during the 1650-1900 time period than the plot with a fire record spanning the entire 1650-1900 time period, and therefore appear to be have less frequent fires during the 1650-1900 time period. A solution to this would be to chose a shorter time period for comparison, one that coincides with the plot having the shortest fire recording period. However, in the Dugout study area, this would limit the time period to 1780-1900. The Baker study area would be limited to 1872-1900 and the Steamboat study area tree ring recording period would be limited to 1736-1900. Therefore, the original time period of 1650-1900 is used for the sake of both consistency and having a reasonable period of time to analyze. Comparisons of the number of fires per plot between different categories of plots were conducted in this study in order to be consistent with Heyerdahl (1997), but these comparisons are presented in Appendix C rather than in the main body of the thesis.

Individual fire return intervals grouped by plot categories. As with the plot-based fire return interval calculations method, fire dates are combined for all of the samples taken from one plot, a master chronology of fire dates is produced, and the time intervals between those fire dates are calculated. Unlike the plot-based fire return interval calculations method, however, the fire return intervals determined at each plot are not summarized into mean or median fire return intervals for that plot. Instead, the group of fire return intervals from each plot are pooled with fire return intervals from other plots within the same category (based on similar topographical characteristics). For example, suppose site A is a riparian plot along a small stream. It has records of 3 fires and therefore 2 fire return intervals. Site B is also a riparian plot along a small stream, with records of 12 fires and 11 fire return intervals. Site C is the upslope plot that corresponds with site A, with records of 8 fires and 7 fire return intervals, and site D is the upslope plot corresponding to site B, with records of 11 fires and 10 fire return intervals. Using the more traditional plot-based fire return interval calculation method, a WMPI would be calculated for each plot, then the WMPIs for sites A and B would be compared to those for sites C and D in order to determine if there was a difference between fire return intervals at riparian plots along small streams compared to their upslope counterparts. However, in this scenario, a WMPI could not be calculated for site A because it had only 2 fire return intervals, which would exclude it from the WMPI comparisons. But if the individual fire return intervals from site A (2) were pooled with those from site B (11, for a total of 13 fire return intervals), and then the fire return intervals from site C (7) were pooled with those from site D (10, for a total of 17 fire return intervals), then a comparison could be made between all the data in the small stream riparian plot category (sites A and B) and all the data in the corresponding upslope plots category (sites C and D). Additionally, normal distribution means, medians and confidence intervals can be calculated for these pooled fire return intervals, as well as Weibull distribution means, medians and confidence intervals. This method of analysis allows for the inclusion of fire return intervals from all of the plots in each of the study areas, and minimizes the bias based on the length of the tree ring or fire record because the fire return interval derivations are independent of the length of the time period being considered. Keep in mind that in this analysis approach, fire return intervals are calculated from the fire years recorded at a particular plot, then pooled with fire return intervals calculated from other plots within the same category. Fire return intervals are not calculated from fire years pooled from all the plots within a particular category. Therefore the fire return intervals are still representative of a point fire frequency, as opposed to an area fire frequency. A comparison between the plot-based fire return interval calculation method and the individual fire return intervals grouped by plot categories method, using the Dugout study area data, is included in the results section.

Statistical Analyses

Fire return interval calculations and statistical tests were performed using a variety of software. Plot-based fire return interval calculations based on both the normal distribution and the Weibull distribution were produced using the statistical function of the FHX2 fire history software (Grissino-Mayer 1995). Then the remainder of the statistical tests and calculations based on the normal distribution were performed using the Statistix for Windows statistical software package (Analytical Software 1998) and additional calculations were made based on the Weibull distribution.

For each plot used in this study, which includes plots sampled during this study and plots sampled by Heyerdahl (1997), the following descriptive statistics were calculated: the number of fires recorded per plot, the minimum and maximum fire return intervals, the WMPI, the Weibull 80% confidence interval (the 10^{th} percentile fire return interval subtracted from the 90^{th} percentile fire return interval), and the mean, median, standard deviation, and coefficient of variation based on the normal distribution. For each category of plots (e.g., riparian, small stream upslope, etc.), the minimum and maximum fire return interval (or WMPI, or number of fires, depending on the type of analysis) were calculated, as well as the mean and median (based on the normal distribution), and the Weibull mean, median and 80% confidence interval. The statistics not included in the main body of this thesis are shown in Appendices A, B and C.

Once the fire scar data were summarized, whether in the form of plot-based fire return interval calculations, number of fires per plot, or individual fire return intervals grouped by plot categories, the data were tested for normality using the Wilk-Shapiro procedure in the Statistix for Windows statistical software package (Analytical Software 1998). Since the data typically did not fit the normal distribution, categories were compared using the equivalent non-parametric tests: the Wilcoxon signed rank test (instead of the paired t-test), the Mann-Whitney U-test for unmatched samples (instead of the two-sample t-test) and the Kruskal-Wallis one-way analysis of variance (instead of the parametric one-way analysis of variance). In addition to testing whether the fire return interval data fit a normal distribution, the data were tested for fit along a Weibull distribution. For the fire return intervals calculated at each plot, the FHX2 fire history software calculates a Kolmogorov-Smirnov d-statistic in order to determine the goodness-of-fit of the fire return interval distribution from that plot to both a normal distribution and a Weibull distribution. Similarly, for each category of fire return intervals, a Chi-square statistic was calculated to determine the goodness-of-fit of the fire return interval data or number of fires data to a Weibull distribution. For this study, an alpha value of 0.05 or less was used to determine the level of significance.

Category Comparisons

Within each of the three study areas, at least three category comparisons were made: 1) riparian fire return intervals from the entire study area were compared to corresponding upslope fire return intervals, 2) riparian fire return intervals categorized according to large and small stream sizes were compared to corresponding upslope fire return intervals, and 3) large stream riparian fire return intervals were compared to small stream riparian fire return intervals. Except for the comparison between the plot-based fire return interval calculation data analysis method and the individual fire return intervals grouped by plot categories data analysis method for the Dugout study area, only results using the individual fire return intervals grouped by plot categories data analysis method were reported for each study area.

Dugout Study Area. These were the only three comparisons made for the Dugout study area, since the study area was rather homogeneous in terms of topography (Figure 4). However, additional comparisons were made for both the Baker and Steamboat study areas.

Baker Study Area. In addition to stream size comparisons, riparian and upslope plots in the Baker study area were analyzed in terms of forest type (dry compared to mesic), and slope aspect (north compared to south). Because drainages in the study area tend to flow from west to east, plots in the study area were only divided into north and south aspects (as opposed to dividing plots into north, south, east and west aspects). North aspects were defined as the range from 271° to 90°, and south aspects were defined as the range from 91° to 270°. Riparian plots in the Baker study area were placed in riparian zones such that half of the plot was located on one side of the stream and half on the other, allowing fire return intervals to be distinguished according to aspect.

Categorizing fire return intervals simply in terms of large and small streams did not necessarily represent what fire regime differences could be occurring in the Baker study area. Only 3 of the 16 riparian plots were located along a large stream because the study area is not large enough for streams to consistently reach a large size before they flow out of the study area. As a consequence, the sample size for this category is small, and all of the large stream plots were located in the lower elevations of the study area. Furthermore, both riparian and upslope forests in the lower elevations of the study area generally coincided with less dissected terrain as well as drier forest types compared to the higher elevation forests (Figures 2 and 5). Fire return interval lengths were not analyzed directly in terms of elevation because differences in forest types seemed to override elevational differences. For example, forest stands with north-facing aspects at the same elevation as forest stands with south-facing aspects can support fairly different types of forests, and moister forest types extend into lower elevations in riparian forests than they do in upslope forests.

Three different subsets of the Baker study area data were analyzed in order to characterize potential differences in aspect. First, just the riparian fire return intervals from the entire study area were analyzed, then both riparian and upslope fire return intervals from only the Marble Creek drainage were analyzed, and finally the riparian and upslope fire return intervals from just the mid-elevation portion of the Marble Creek drainage were analyzed.

Differences in forest composition relative to aspect are visually apparent in the Marble Creek drainage, which is located in the northwestern portion of the study area. The Marble Creek drainage has a more dissected topography than the southeastern portion of the study area, and subsequently has greater differentiation between forest types on its north-facing slopes compared to its south-facing slopes (Figure 2) . It also happens to be the drainage located within the intensive sampling grid from Heyerdahl (1997), and therefore has the largest concentration of plots in the study area, with both north- and south-facing slopes well represented in the plot grid.

Comparing fire return intervals according to aspect within the entire Marble Creek drainage still does not take into account how topography differs within the drainage. The lower elevations are less dissected than the upper elevations. The final aspect analysis focused on just the mid-elevational range of the Marble Creek drainage. This was done in order to characterize the aspect differences in fire return intervals that can occur within a small elevational range without differences in steepness. The north- and south-facing halves of two riparian plots (plots Mar3 and Mar5) and their corresponding upslope sites (plots 4.8, 4.7, 5.7 and 4.6, Heyerdahl 1997) were compared. These plots ranged between 1380m and 1560m in elevation. The mid-elevational range was selected for a couple of reasons. First, the riparian plots had corresponding upslope plots on both north- and south-facing aspects that had been sampled for fire scars (Heyerdahl 1997). Second, these sites appear to be located at a transitional point within the drainage. Above and below this area, upslope plots from opposite-facing slopes have similarly dry or mesic plant associations. Above this point, north- and south-facing plant associations are generally in the mesic category, whereas below this point, associations are generally in the dry category. Within the mid-elevational range, however, upslope plots were located within different plant associations because of their aspect, with drier associations occurring on the south-facing slopes and more mesic associations occurring on the north-facing slopes.

Steamboat Study Area. Not only were comparisons made between riparian and upslope plots along different sizes of streams in the Steamboat study area, but an additional analysis was performed to determine the importance of a pair of plots' overall proximity to large streams versus small streams (not based on strictly on riparian zone width). Riparian and upslope fire dates were combined for pairs of plots along small streams and for pairs of plots along large streams, plot fire return intervals were calculated, and then these combined plot fire return intervals were compared between large streams and small streams.

In addition to stream size comparisons, fire return intervals in the Steamboat study area were analyzed in terms of slope aspect. These analyses were performed because variations due to aspect had been found in nearby study areas (Impara 1997, Taylor and Skinner 1998, Van Norman 1998, Weisberg 1998). First, comparisons were made according to aspect alone, i.e., fire return intervals were not differentiated by riparian versus upslope locations. Then riparian and upslope plots were compared according to aspect. North aspects were defined as the range from 316° to 45°, east aspects were defined as the range from 46° to 135°, south aspects were defined as the range from 136° to 225°, and west aspects were defined as the range from 226° to 315°.

Fire Map Analysis

Fire maps are provided to visually represent the fires in each study area. Comparisons were essentially qualitative in nature, as statistical tests were not used in the fire map analysis.

Dugout and Baker Study Areas. For both the Dugout and Baker study areas, the fire maps were analyzed by tallying the number of riparian plots that recorded fire scars during a particular fire year (as well as those plots capable of recording a fire but did not). The tallies were then categorized by the spatial extent of the fire. Classification according to fire extent was possible because Heyerdahl (1997) determined fire extents for these two study areas. Fire extents were divided into different sizes classes based on a classification used by the U.S. Forest Service, which divides fires into 7 size classes: A=<0.10 ha, B=0.11-4 ha, C=5-40 ha, D=41-121 ha, E=122-404 ha, F=405-2300 ha, and G=>2300 ha (USDA 1993). For the sake of this study, these size classes were modified to: <122 ha, 122-404 ha, 405-799 ha, 800-2299 ha and >2300 ha. Classes A through D were combined because the resolution of fire extent was not reliable enough to separate those classes. And Category F was split into two size classes because results showed there was a transitional point in how riparian plots burned relative to the extent of the fire at around 800 ha. Only fire years with extents calculated in Heyerdahl (1997) were used for this analysis. Fire years that did not have enough records to determine an extent (at least two fire scarred samples) were not included, and additional fire years determined by this study were not included.

The North Fork Malheur river riparian zone became the focus of the fire map analysis for the Dugout study area because it appeared that the river may act as a fire barrier in some circumstances. So in addition to simply tallying the number of riparian plots recording a particular fire in terms of the extent of the fire, riparian plots with evidence of fire were also categorized in terms of where the plot was located (i.e., in the riparian zone of the North Fork Malheur river or elsewhere) and whether or not a fire burned in riparian plots within both sides of the North Fork Malheur river riparian zone.

The fact that riparian plots in the Baker study area were partitioned according to aspect allowed a similar analysis with regard to streams acting as a fire barrier. Additionally, the analysis was more comprehensive than that for Dugout because fires along all streams, not just the largest stream, were analyzed in terms of whether the fire burned within both sides of a riparian plot.

Steamboat Study Area. The fire map analysis for the Steamboat study area was restricted to comparing whether particular fires were recorded in both the riparian and upslope plots within a pair, and how many pairs of plots recorded a particular fire within at least one of the plots (either riparian or upslope). Because the sampling in the Steamboat study are was not designed to determine fire extents, only a rough examination of fire size was possible based on the number of pairs of plots recording the fire and the distance between the farthest pairs of plots recording the fire.

Aside from the fire map analysis, an additional examination of the earliest tree ring records or establishment dates recorded for each site was conducted, but since sampling was not designed to determine stand age structures, the examination was limited in what it could imply about fire history.

RESULTS

Dugout Study Area

Stream Size Comparisons. In general, fire return interval lengths were similar for riparian and upslope forests (Figure 9). While statistically significant differences were found between fire return interval lengths in riparian zones compared to upslope forests, these differences were small (1 to 2 years).

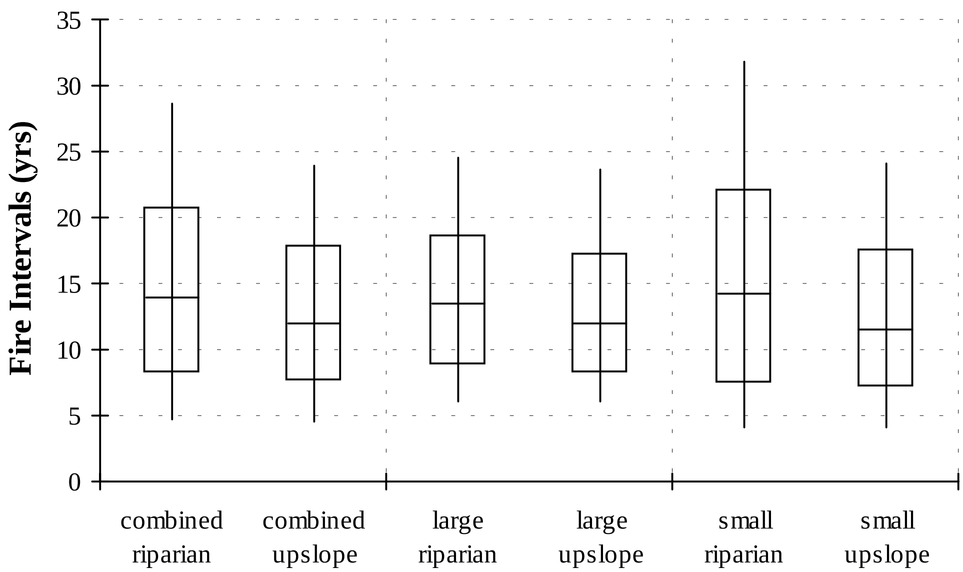

Figure 9. Fire return interval ranges for combined riparian and combined upslope plot categories, large stream riparian and upslope plot categories, and small stream riparian and upslope plot categories, Dugout. Box plots represent, from top to bottom: 90th percentile and 75th percentile exceedance levels, WMPI, 25th percentile and 10th percentile exceedance levels (all percentiles calculated from the Weibull distribution).

When analyzed in terms of individual fire return intervals grouped by plot categories, fire return intervals are statistically longer in the riparian category (14 year WMPI) compared to the upslope category (12 year WMPI, $p = 0.01$, two-tailed Mann-Whitney U-Test for unmatched samples), and riparian fire return intervals from the small stream category (14 year WMPI) are statistically longer than corresponding upslope fire return intervals (12 year WMPI, p = 0.03, two-tailed Mann-Whitney U-Test for unmatched samples). The 80% confidence interval for all riparian fire return intervals is 5 to 29 years (with an minimum fire interval of 1 year and a maximum interval of 65 years), compared to 5 to 24 years for all upslope fire return intervals (with a minimum interval of 1 year and a maximum interval of 49 years). The 80% confidence interval for small riparian fire return intervals is 4 to 32 years (with a minimum interval of 1 year and a maximum interval of 65 years), compared to 4 to 24 years for the corresponding upslope fire return intervals (with a minimum interval of 1 year and a maximum interval of 49 years).

No statistical differences were found when large stream riparian fire return intervals were compared to corresponding upslope fire return intervals (13 and 12 year WMPIs, respectively, p = 0.33, two-tailed Mann-Whitney U-Test for unmatched samples), or when large stream riparian fire return intervals were compared to small stream fire return intervals (13 and 14 year WMPIs, respectively, p = 0.75, two-tailed Mann-Whitney U-Test for unmatched samples).

Fire Maps. Fire return interval calculations and fire maps (Appendix D) indicate that fires in the Dugout study area typically included riparian zones. Fifty-two out of the 71 fires that occurred between 1650 and 1900 (for which fire extents were determined by Heyerdahl 1997) showed evidence of burning in riparian plots. Also, whether or not the fires burned within both sides of the North Fork Malheur riparian zone seemed to correlate with the extent of the fire.

A greater number of fire years occurred within the largest fire extent class (>2300 ha) than any other size class, and all of the fires within this class also recorded fires in riparian plots (Figure 10). Additionally, most of the fires in the >2300 ha size class showed evidence of burning in riparian plots within both sides of the North Fork Malheur river riparian zone, indicating that the North Fork Malheur river may not have acted as a fire barrier for these fires. This is the only size class where evidence of fire was found along both sides of the North Fork Malheur riparian zone within the same fire year. The rest of the fires were recorded along just one side of the North Fork Malheur riparian zone, or within other riparian plots in the study area.

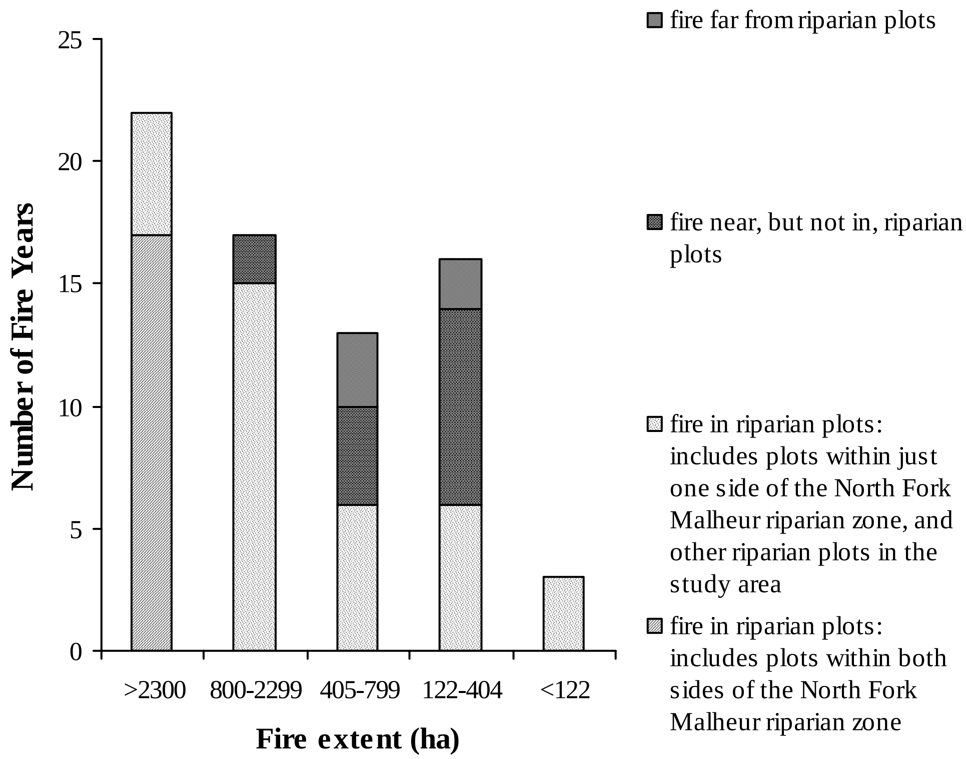

Figure 10. Number of fires that burned in Dugout riparian plots, categorized by fire extent size classes and the location of the riparian plot relative to the North Fork of the Malheur river.

An interesting side note is that visual examination of the fire maps indicated that in at least one instance (during the 1793 and 1794 fire years, Figure 11), there appeared to be a fire that began during the late summer or early fall of one year, then either that same fire or a separately ignited fire proceeded to burn throughout the following spring and summer. There is no way to know whether the fire actually continued to burn at some location within the study area throughout the winter, but it is intriguing that there are two plots within the study area (an upslope plot in the northern portion and a riparian plot in the southern portion) that had fire scars recording during both late season of 1793 and early season of 1794. Based on the fire maps, it seems that the fire from the fall of 1793 could have started in the western portion of the study area, burned toward the east until it reached the North Fork Malheur river, smoldered throughout the winter, then resumed burning during the early season of 1794.

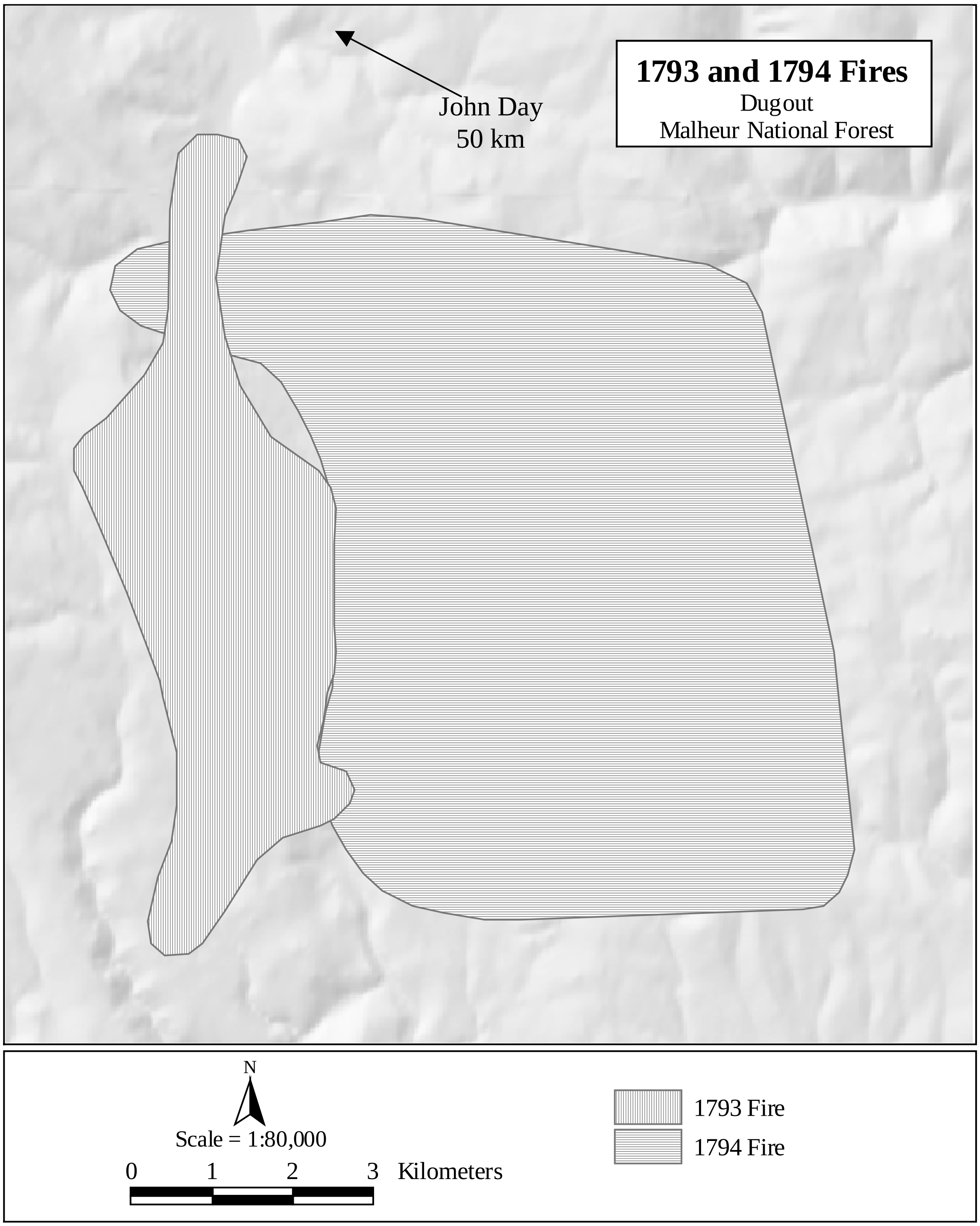

Figure 11. Map of 1793 and 1794 fires, Dugout.

Comparison of Fire Return Interval Data Analysis Methods Using Dugout Data. The two different data analysis methods for calculating fire return intervals (the composite fire return interval calculations for each plot method and the individual fire return intervals grouped by plot categories method) resulted in comparable WMPIs (Table 2). For each category of plot, the two-tailed Mann-Whitney U-Test for unmatched samples was used to compare the plot-based WMPIs calculated for each plot within that category to the pool of individual fire return intervals grouped by plot category. There were no statistical differences between the two calculation methods, with p-values of 0.32, 0.19, 0.59, 0.42, 0.42, and 0.32 for the comparison of methods between fire return intervals from all riparian plots, all upslope plots, large stream riparian plots, large stream upslope plots, small stream riparian plots, and small stream upslope plots, respectively. Note that, as mentioned in the Dugout results section, significant differences between combined riparian fire return intervals and combined upslope fire return intervals, and between small stream riparian fire return intervals and small stream upslope fire return intervals, are found using the individual fire return intervals grouped by plot category method. The differences between fire return intervals for these categories are not significant in the plot-based fire return interval calculation method, however. Considering the difference in sample sizes for the composite fire return interval calculations compared to the individual fire return interval calculations (e.g., 11 plot WMPIs compared to 127 fire return intervals for the small stream riparian plot category), it is likely that the difference in sample sizes explains the difference in levels of significance.

Table 2. Comparison of the two fire return interval data analysis methods, using Dugout data. Statistical tests are the two-tailed Mann-Whitney U-Test for unmatched samples, unless otherwise noted. The Weibull median probability fire return intervals (WMPIs) calculated by each method are highlighted for the sake of comparison.

	Plot-based WMPIs							**Individual Fire Return Intervals Grouped by Plot Category**							
	Number			**Weibull**				**Number of**				**Weibull**			
plot category	**of plots**	**min.**	**max.**	**mean**	**median**	**80% CI**	**Fit[2]**	**plots**	**intervals**	**min.**	**max.**	**mean**	**median**	**80% CI**	**Fit[2]**
combined riparian	19	11	32	15.8	13.9	11-23	0.42	20	237	1	65	15.5	13.8	5-29	0.18
combined upslope	17	9	21	12.9	12.6	10-17	0.01	18	292	1	49	13.4	12.1	5-24	<.001
statistics		riparian = upslope, p = 0.14								riparian > upslope, **p = 0.01**					
large stream, riparian	8	12	17	14.0	13.6	12-17	0.02	8	110	3	54	14.5	13.3	6-24	0.06
large stream, upslope	6	12	15	13.2	12.8	12-15	0.047	6	95	4	39	13.7	12.1	6-24	<.001
statistics		riparian = upslope, p = 0.41[1]								riparian = upslope, p = 0.33					
small stream, riparian	11	11	32	17.3	13.8	11-28	0.26	12	127	1	65	16.3	13.8	4-32	0.10
small stream, upslope	11	9	21	12.8	12.1	9-18	0.03	12	197	1	49	13.2	11.7	4-24	<.001
statistics		riparian = upslope, p = 0.13								riparian > upslope, **p = 0.03**					
large stream, riparian	8	12	17	14.0	13.6	12-17	0.02	8	110	3	54	14.5	13.3	6-24	0.06
small stream, riparian	11	11	32	17.3	13.8	11-28	0.26	12	127	1	65	16.3	13.8	4-32	0.10
statistics		small = large, p = 0.85[1]								small = large, p = 0.75					

[1] One-tailed Mann-Whitney U-Test for unmatched samples

[2] The Weibull Fit is a p-value derived from a Chi-squared goodness of fit analysis of the actual data compared to the predicted distribution of data. The null hypothesis is that the data fit the Weibull distribution. Therefore, a p-value greater than 0.05 means that the null hypothesis that the data fit the Weibull distribution is accepted. A p-value less than 0.05 means the null hypothesis is rejected, and that the data do NOT fit the Weibull distribution.

Baker Study Area

The results of the fire return interval analyses for this study area are separated into three different categories: stream size comparisons, forest type comparisons, and slope aspect comparisons.

Stream Size Comparisons. Overall, riparian fire return intervals in the Baker study area are longer than upslope fire return intervals (Figure 12), although, depending on how the fire return intervals are categorized, the differences in fire return interval lengths may or may not be statistically significant or ecologically relevant. When fire return intervals from both large and small streams are combined, riparian fire return intervals are statistically longer than upslope fire return intervals (15 year and 11 year WMPIs, respectively, $p = 0.001$, two-tailed Mann-Whitney U-Test for unmatched samples). As with the Dugout study area, however, the difference between the WMPIs is small (4 years) and unlikely to represent a biological difference.

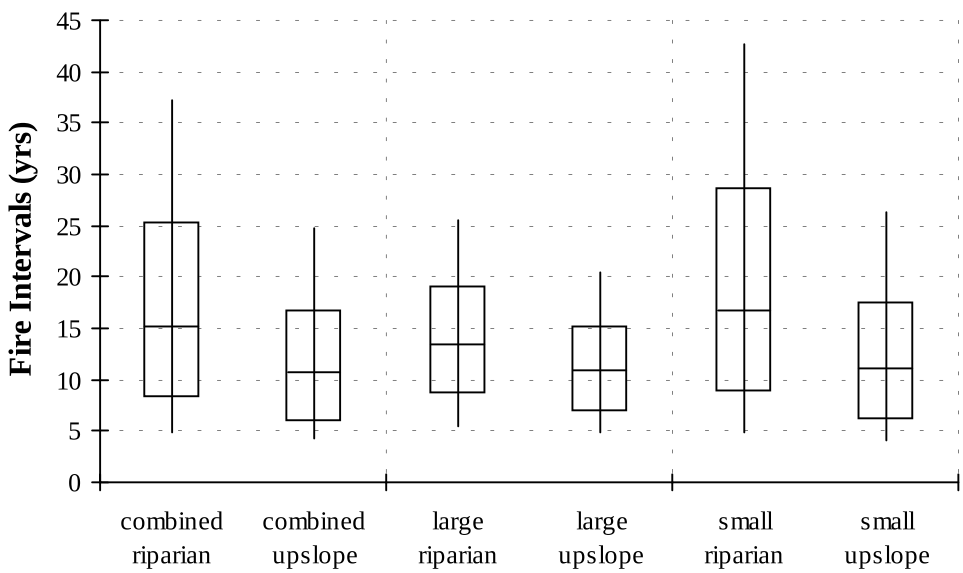

Figure 12. Fire return interval ranges for combined riparian and combined upslope plot categories, large stream riparian and upslope plot categories, and small stream riparian and upslope plot categories, Baker. Box plots represent, from top to bottom: 90th percentile and 75th percentile exceedance levels, WMPI, 25th percentile and 10th percentile exceedance levels (all percentiles calculated from the Weibull distribution).

There is no significant difference between large stream riparian fire return intervals and their corresponding upslope fire return intervals (13 year and 10 year WMPIs, respectively, $p = 0.10$, two-tailed Mann-Whitney U-Test for unmatched samples), yet there is a difference between small stream riparian fire return intervals and their corresponding upslope fire return intervals. Small stream riparian fire return intervals are statistically longer than upslope fire return intervals (17 year and 10 year WMPIs, respectively, $p = 0.0002$, two-tailed Mann-Whitney U-Test for unmatched samples) and the confidence interval is wider for small stream riparian fire return intervals compared to small stream upslope fire return intervals. Finally, the large stream riparian fire return intervals are slightly shorter but not significantly different from small stream riparian fire return intervals (13 year and 17 year WMPIs, respectively, $p = 0.15$, two-tailed Mann-Whitney U-Test for unmatched samples), yet the confidence interval for small riparian fire return intervals is considerably wider than the confidence interval for large riparian fire return intervals.

Forest Type Comparisons. Fire return interval lengths within riparian plots varied according to forest type. Riparian fire return intervals within dry forest types were significantly shorter than those within mesic forest types (12 year and 19 year WMPIs, respectively, p = 0.01, two-tailed Mann-Whitney U-Test for unmatched samples) and had a much narrower confidence interval (Figure 13).

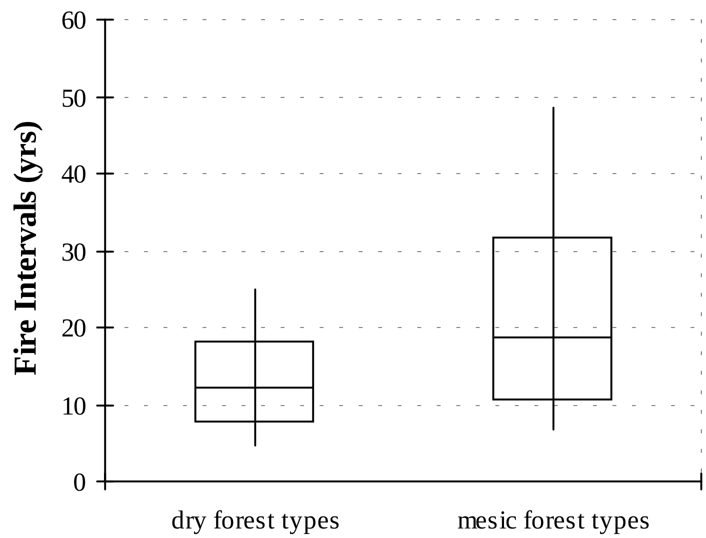

Figure 13. Fire return interval ranges for mesic forest type riparian fire return intervals compared to dry forest type riparian fire return intervals, Baker. Box plots represent, from top to bottom: 90th percentile and 75th percentile exceedance levels, WMPI, 25th percentile and 10th percentile exceedance levels (all percentiles calculated from the Weibull distribution).

Slope Aspect Comparisons. Fire return interval lengths also differed according to slope aspect. When all of the riparian plots in the Baker study area were analyzed, riparian fire return intervals from the north-facing halves of the plots were significantly longer than those from the south-facing halves of the plots (21 year and 16 year WMPIs, respectively, p = 0.02, two-tailed Mann-Whitney U-Test for unmatched samples) and had a somewhat wider confidence interval (Figure 14).

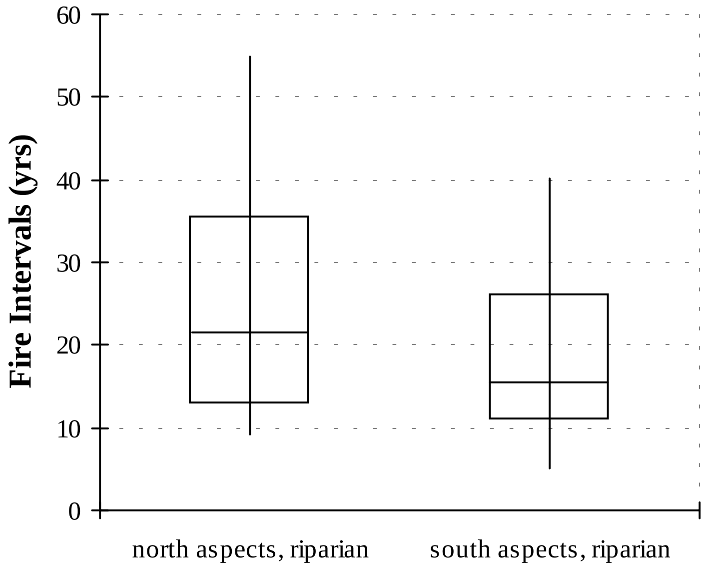

Figure 14. Fire return interval ranges for riparian fire return intervals from north aspects compared to south aspects, Baker. Box plots represent, from top to bottom: 90th percentile and 75th percentile exceedance levels, WMPI, 25th percentile and 10th percentile exceedance levels (all percentiles calculated from the Weibull distribution).

When both riparian and upslope plots within only the Marble Creek drainage were analyzed, only the riparian fire return intervals from the north-facing halves of the riparian plots stood out as being different than the other aspect categories (Figure 15). They were significantly longer than their upslope counterparts (26 year and 15 year WMPIs, respectively, p = 0.01, two-tailed Mann-Whitney U-Test for unmatched samples) and were also significantly longer than fire return intervals from the south-facing halves of the riparian plots (15 year WMPI, p = 0.01, two-tailed Mann-Whitney U-Test for unmatched samples). Additionally, the range of north-facing riparian fire return intervals is wider than ranges for other categories of fire return intervals. No significant difference was found between riparian fire return intervals from the south-facing halves of the riparian plots compared to their upslope counterparts (both had 15 year WMPIs, p = 0.53, two-tailed Mann-Whitney U-Test for unmatched samples), nor was there a significant difference between north- and south-facing upslope fire return intervals (again, both had 15 year WMPIs, p = 0.78, two-tailed Mann-Whitney U-Test for unmatched samples).

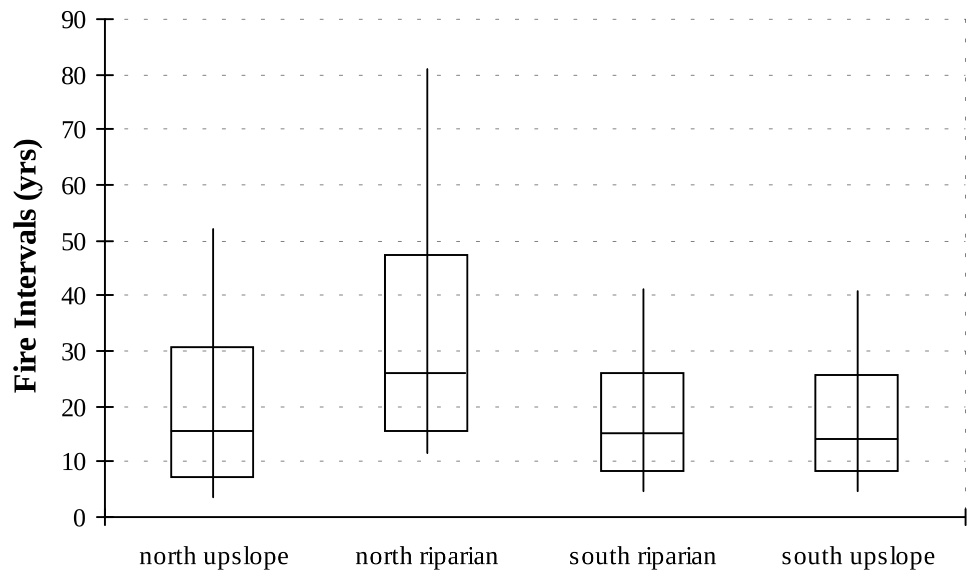

Figure 15. Fire return interval ranges for riparian and upslope fire return intervals from north- and south-facing aspects in the Marble Creek drainage, Baker. Box plots represent, from top to bottom: 90th percentile and 75th percentile exceedance levels, WMPI, 25th percentile and 10th percentile exceedance levels (all percentiles calculated from the Weibull distribution).

In contrast to the analysis of the larger portion of the Marble Creek drainage, when just the middle elevations of the watershed were analyzed, the south-facing upslope fire return intervals were shorter (12 year WMPI) than the other categories of fire return intervals (Figure 16). They were significantly shorter than the riparian fire return intervals from the south-facing halves of the riparian plots (19 year WMPIs, p = 0.03, two-tailed Mann-Whitney U-Test for unmatched samples) and were also significantly shorter than north-facing upslope fire return intervals (20 year WMPI, p = 0.02, two-tailed Mann-Whitney U-Test for unmatched samples). Additionally, the range of south-facing upslope fire return intervals is much narrower than the ranges from other categories of fire return intervals. There were not enough fire return intervals to calculate a WMPI for the riparian fire return intervals from the north-facing halves of the riparian plots. However, no significant difference was found between riparian fire return intervals from the north-facing halves of the riparian plots compared to their upslope counterparts (p = 0.12, one-tailed Mann-Whitney U-Test for unmatched samples), nor was there a significant difference between riparian fire return intervals from the north- and south-facing halves of the riparian plots (p = 0.08, one-tailed Mann-Whitney U-Test for unmatched samples).

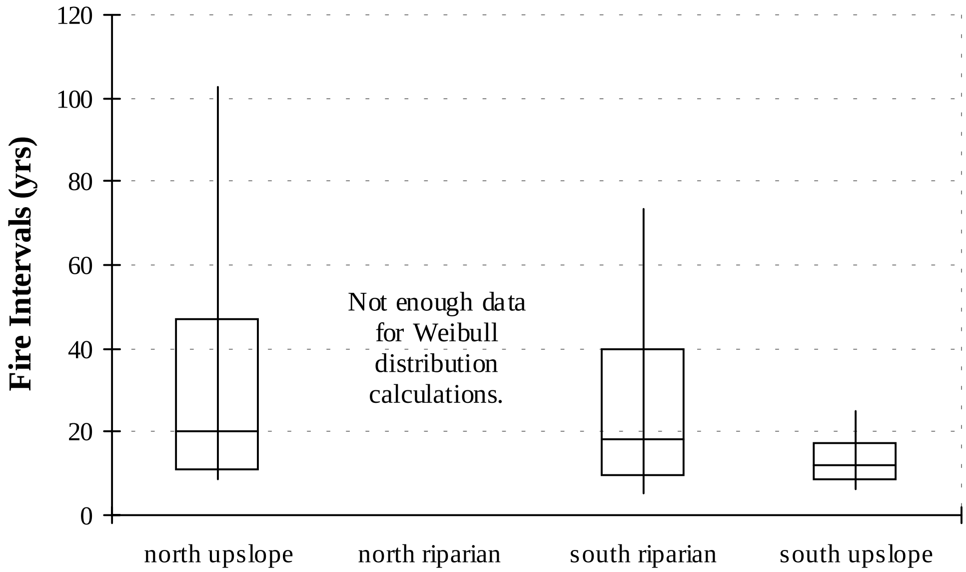

Figure 16. Fire return interval ranges for riparian and upslope fire return intervals from north- and south-facing aspects in the mid-elevational range of the Marble Creek drainage, Baker. Box plots represent, from top to bottom: 90th percentile and 75th percentile exceedance levels, WMPI, 25th percentile and 10th percentile exceedance levels (all percentiles calculated from the Weibull distribution). There were not enough fire return intervals in the north-facing riparian fire return interval category to determine a WMPI or confidence intervals.

Fire Maps. Fires in the Baker study area burned frequently in the riparian zones. Forty of the 52 fires that occurred between 1650 and 1900 (for which fire extents were determined by Heyerdahl 1997) showed evidence of fire in riparian plots. Fire evidence from riparian plots was recorded as occurring on one or both sides of the stream. This helped identify fires where the stream did or did not act as a fire barrier. It was also useful to help determine the influence of aspect on fire in riparian zones.

All of the fires within the largest fire extent class showed riparian plots recording fires somewhere within the fire's boundaries (Figure 17), and most of those fires showed evidence of the fire burning on both sides of the stream within at least one of the riparian plots. Fires burned on both sides of the stream within the same riparian plot for the three largest size classes, but not the smaller size classes. More fires burned into the south aspects of the riparian plots than fires that burned into the north aspects of the riparian plots, and this is true for all fire extent size classes. This may indicate that fires on south-facing slopes tended to back down into the riparian zone and then stop along the creek, whereas either fewer fires occurred on north-facing slopes, or they were less likely to back down into the riparian zone.

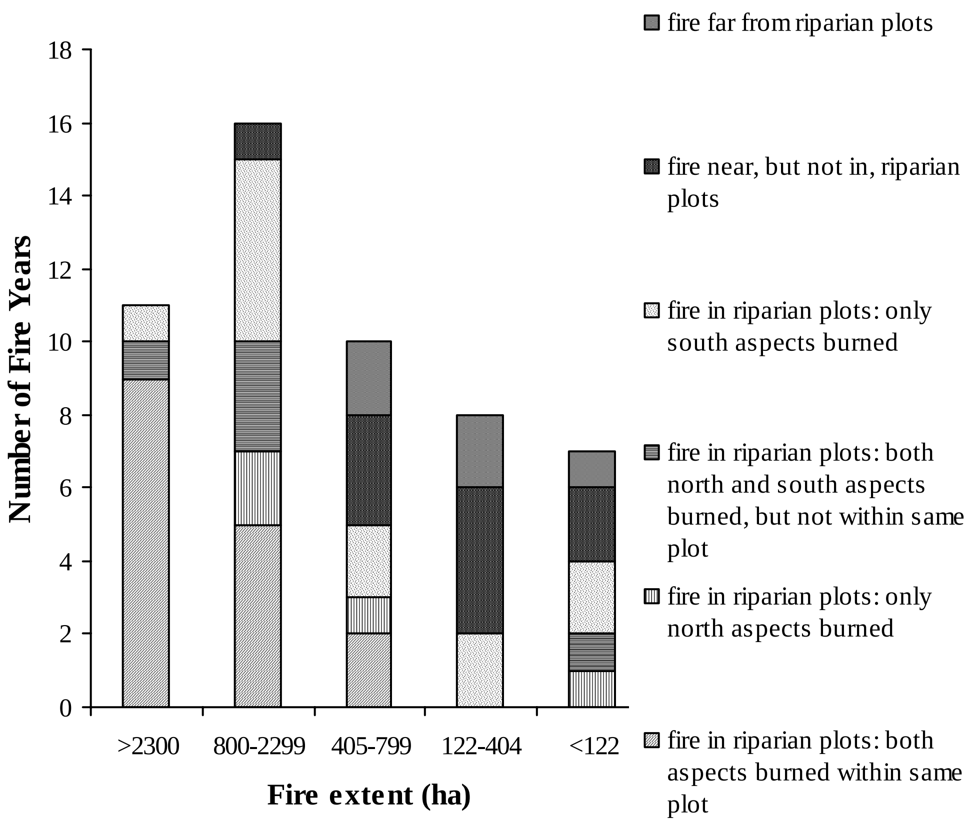

Figure 17. Number of fires that burned in Baker riparian plots, categorized by fire extent size classes and the aspect within the riparian plot.

Steamboat Study Area

The results of the fire return interval analyses for this study area are separated into two different categories: stream size comparisons and slope aspect comparisons.

Stream Size Comparisons. Fire return interval lengths in riparian forests are slightly longer but not statistically different from fire return interval lengths in upslope forests, and this is consistent for plots along both large and small streams. When fire return intervals from both large and small streams are combined, riparian fire return intervals are statistically similar to upslope fire return intervals (38 year and 29 year WMPIs, respectively, $p = 0.15$, two-tailed Mann-Whitney U-Test for unmatched samples) and they have similarly wide confidence intervals (Figure 18). There is no significant difference between large stream riparian fire return intervals and their corresponding upslope fire return intervals (35 year and 27 year WMPIs, respectively, $p = 0.13$, two-tailed Mann-Whitney U-Test for unmatched samples), or between small stream riparian fire return intervals and their corresponding upslope fire return intervals (39 year and 36 year WMPIs, respectively, $p = 0.80$, two-tailed Mann-Whitney U-Test for unmatched samples). Additionally, there is no difference between large stream riparian fire return intervals and small stream riparian fire return intervals (35 year and 39 year WMPIs, respectively, $p = 0.27$, two-tailed Mann-Whitney U-Test for unmatched samples). Confidence intervals for both small riparian fire return intervals and their corresponding upslope fire return intervals are similar in width, yet they appear to be wider than the confidence intervals for both large riparian fire return intervals and their corresponding upslope fire return intervals (which are also similar in width).

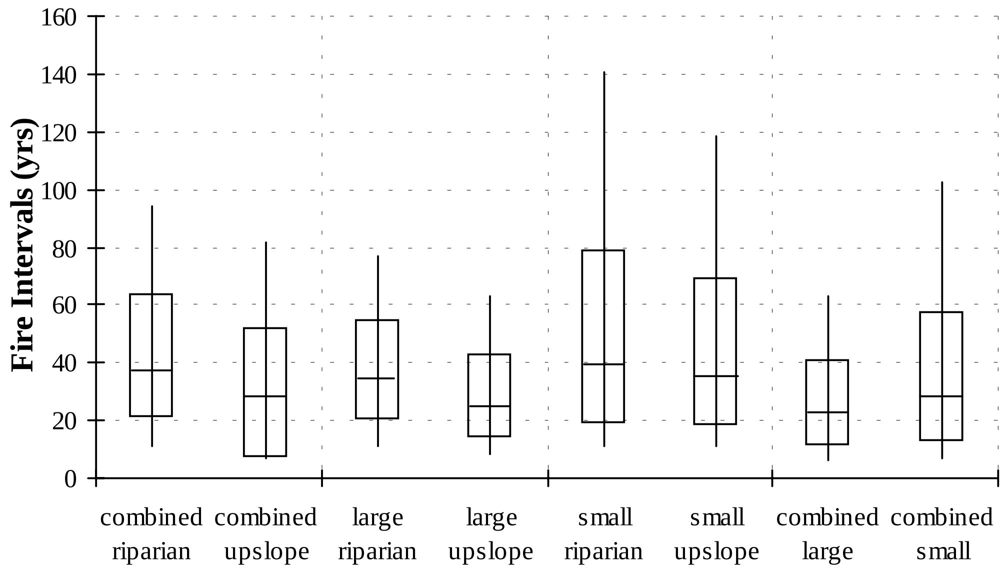

Figure 18. Fire return interval ranges for combined riparian and combined upslope plot categories, large stream riparian and upslope plot categories, small stream riparian and upslope plot categories, and combined large stream and combined small stream plot categories, Steamboat. Box plots represent, from top to bottom: 90th percentile and 75th percentile exceedance levels, WMPI, 25th percentile and 10th percentile exceedance levels (all percentiles calculated from the Weibull distribution).

When pairs of plots were combined into a single plot, and interval calculations were made from these combined pairs, no significant differences were found between large stream pair fire return intervals and small stream pair fire return intervals (23 year vs. 29 year WMPIs, respectively, $p = 0.28$, two-tailed Mann-Whitney U-Test for unmatched samples, Figure 18), yet the confidence interval for the combined small stream fire return intervals still appears to be wider than the confidence interval for the combined large stream fire return intervals. So the vicinity to a large stream or a small stream may play a role in how fire regimes vary within the Steamboat study area.

Slope Aspect Comparisons. Fire return interval lengths do not differ by aspect, either when fire return intervals from riparian and upslope plots are combined or compared separately. Although fire return intervals from west-facing plots were slightly longer than those from east facing plots, which were slightly longer than those from north-facing plots, there were no significant differences between the fire return intervals (45 year, 36 year and 27 year WMPIs, respectively, p = 0.34, Kruskal-Wallis one-way nonparametric analysis of variance, Figure 19).

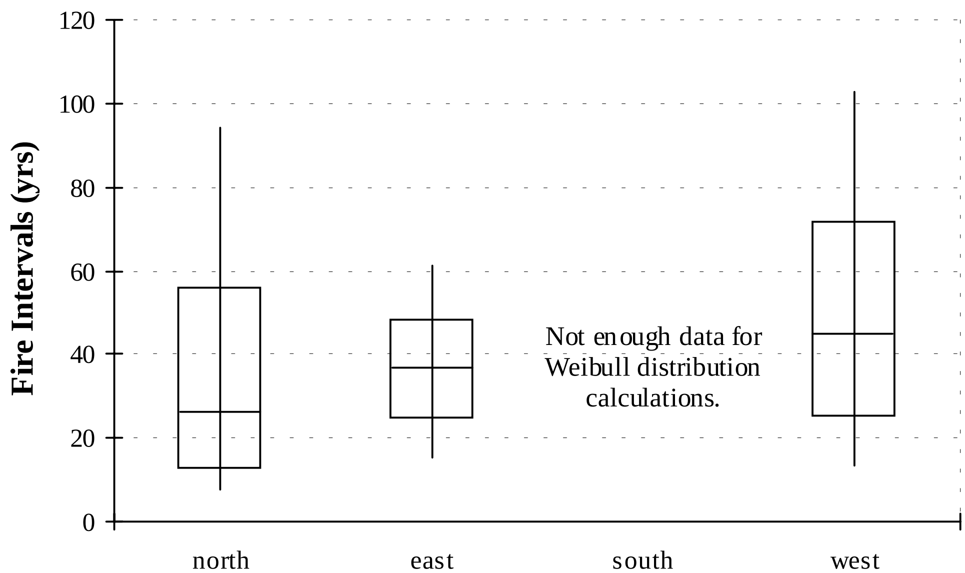

Figure 19. Fire return interval ranges for combined riparian and upslope fire return intervals from north, east, south and west aspects, Steamboat. Box plots represent, from top to bottom: 90th percentile and 75th percentile exceedance levels, WMPI, 25th percentile and 10th percentile exceedance levels (all percentiles calculated from the Weibull distribution). There were not enough fire return intervals in the south-facing fire return interval category to determine a WMPI or confidence intervals.

When the aspects were differentiated by riparian and upslope fire return intervals, no statistical differences were present (p = 0.46, Kruskal-Wallis one-way nonparametric analysis of variance, Figure 20) except when the west-facing riparian fire return intervals were compared to the west-facing upslope fire return intervals. West-facing riparian fire return intervals are longer than their upslope counterparts (56 year vs. 30 year WMPIs, respectively, p = 0.02, one-tailed Mann-Whitney U-Test for unmatched samples) and the confidence interval for west-facing riparian fire return intervals is considerably wider than the confidence interval for west-facing upslope fire return intervals. Sample sizes for these aspect categories are very small, however, and based on a non-statistical analysis, riparian fire return intervals appear to be somewhat longer than upslope fire return intervals for each of these three aspects, and the differences between the riparian and upslope fire return intervals may also be decreasing from west-facing plots to east-facing plots to north-facing plots.

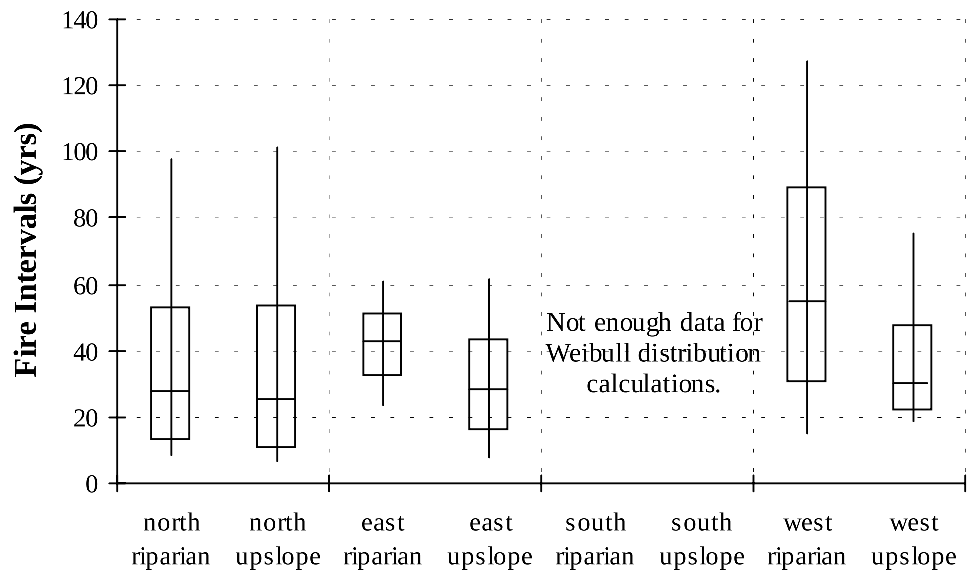

Figure 20. Fire return interval ranges for riparian and upslope fire return intervals from north, east, south and west aspects, Steamboat. Box plots represent, from top to bottom: 90th percentile and 75th percentile exceedance levels, WMPI, 25th percentile and 10th percentile exceedance levels (all percentiles calculated from the Weibull distribution). There were not enough fire return intervals in the south-facing riparian and upslope fire return interval categories to determine WMPIs or confidence intervals.

Fire Maps. Most fire years did not appear to be burning much of the study area, as they were recorded only in one pair of plots (32 out of 47 of the fires occurring between 1650 and 1900). But 11 fire years included two pairs of plots, and there were individual fire years where three, four, five and 11 pairs of plots burned during the year (Figure 21).

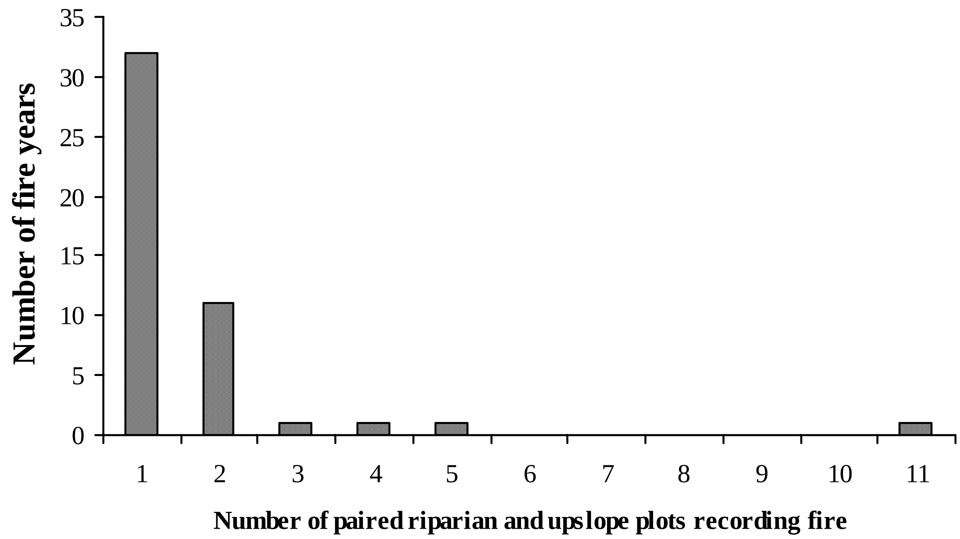

Figure 21. Number of fire years in the Steamboat study area between 1650 and 1900, in relation to the number of paired riparian and upslope plots recording each fire.

Figure 22 can be interpreted as an indication as to how widespread fires might have been within the study area. When the 15 fire years that included two or more pairs of plots are graphed in terms of distance between the farthest plots against the total number of pairs burned, there is a wide range of distances between pairs during fire years when just two pairs burned, but there may be an overall trend of increasing distance between pairs and number of pairs that burned. This would be expected for years where either an extensive, contiguous fire burned within the study area, or for years where conditions within the study area were suitable to multiple fires from multiple ignitions. Two fire years outside of the 1650-1900 time period also appear to have large fires. The 1568 fire may have ranged over 6.4 km, if evidence of possible post-fire tree establishment is included. And the 1615 fire year had 3 pairs of plots recording fire ranging over 2.9 km. This increases to 5 pairs over 5.0 km, if evidence of possible post-fire tree establishment is included.

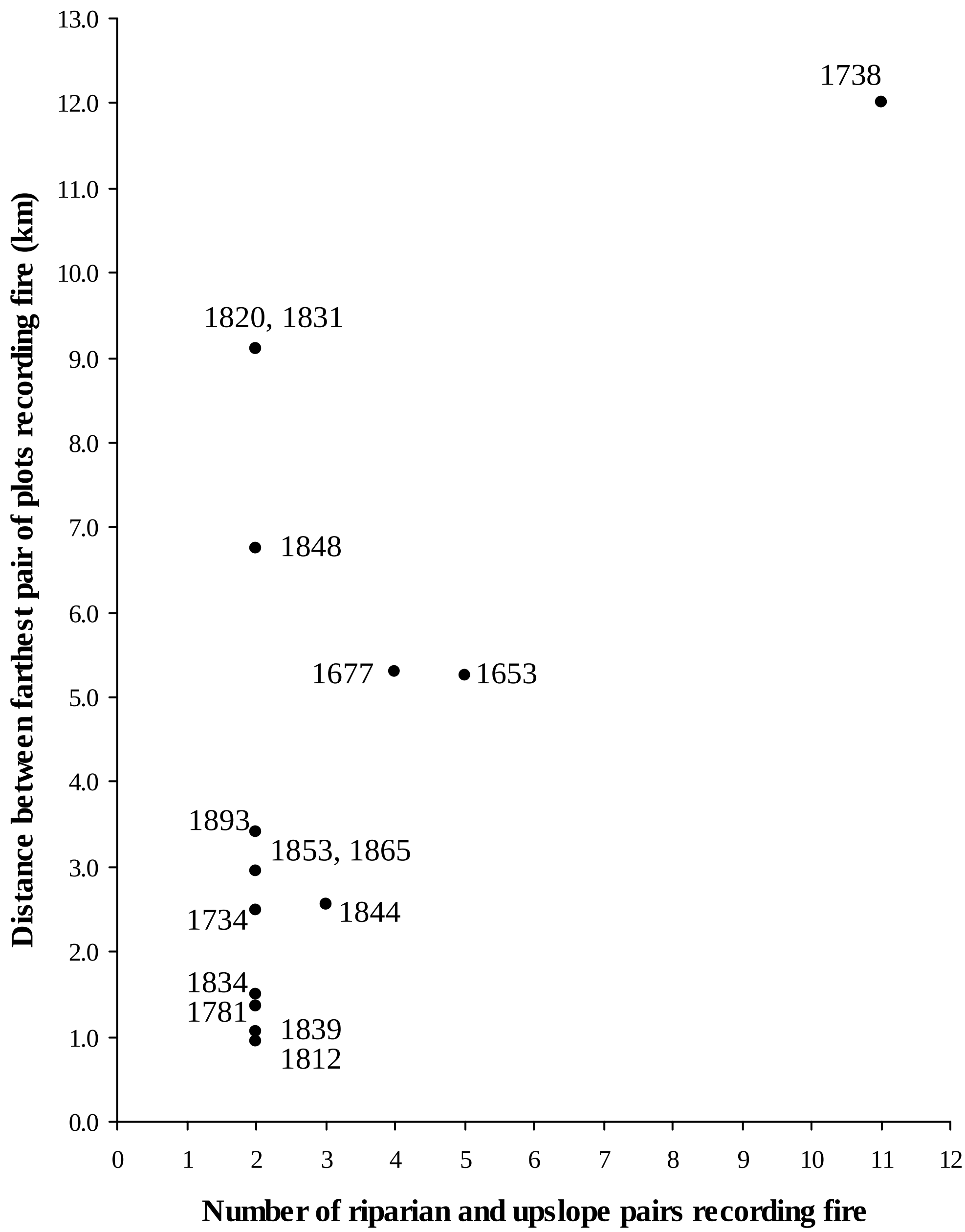

Figure 22. Fire years between 1650 and 1900 showing evidence of fire in two or more pairs of plots, and the distance between the two farthest plots recording each fire, Steamboat.

Another fire map analysis looked at whether there were fire scars in both riparian and upslope plots within a pair during a fire year. Throughout the 47 fire years, there were 77 incidences of fire scars occurring within at least one plot of a pair. Only 33 of the 77 incidences included fire scars in both plots, while 21 included fire scars in only the riparian plot, and 23 included fire scars in only the upslope plot (Figure 23).

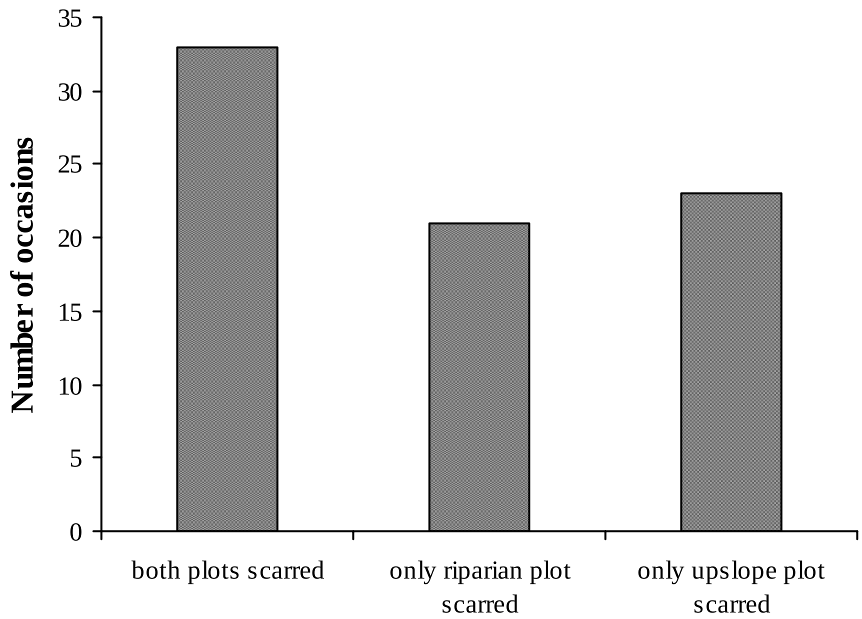

Figure 23. The number of occasions where fires scarred both riparian and upslope plots, compared to occasions where fires scarred only the riparian plot or only the upslope plot, Steamboat.

Examination of the earliest tree ring records or establishment dates for each site revealed no clear trends (Figure 24), although it is possible that riparian plots generally showed older tree ring records than upslope plots. Since this information was only incidental to the study and not part of the sampling scheme, only limited interpretations can be made. It is apparent, however, that records generally extend farther back than 1700, and aspect does not seem to influence the length of record within a plot.

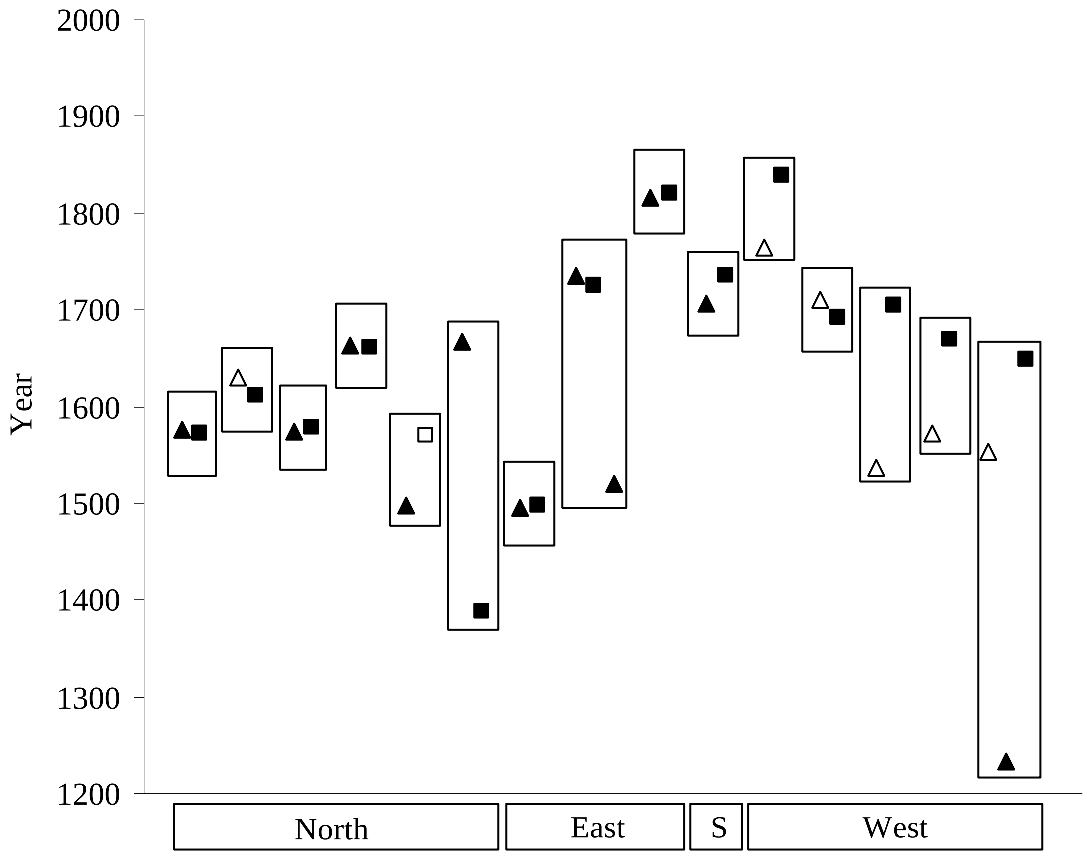

Figure 24. Earliest tree ring records or establishment dates recorded for each of the riparian and upslope plots, according to aspect. Boxes were placed around paired riparian and upslope plots. Triangles represent riparian plots and squares represent upslope plots. Blackened shapes indicate estimated tree establishment dates and hollow shapes indicate the earliest tree ring for that site (establishment dates could not be estimated).

DISCUSSION

Dugout Study Area. Although statistical differences were found between riparian and upslope fire return intervals for both the combined stream size and small stream size categories, the small WMPI differences (one to two years) suggests that the significant differences between fire return interval categories has little ecological significance. The statistically significant differences may be due to the fact that fire return intervals in riparian zones in both the combined stream size and small stream size categories have slightly wider confidence intervals for riparian fire return intervals compared to upslope fire return intervals. These significant differences may also be explained by the large sample size of fire return intervals (237 and 292 for combined stream size riparian and combined stream size upslope fire return intervals, respectively, and 127 and 197 for small stream size riparian and small stream size upslope fire return intervals, respectively), which may allow even small differences in fire return interval lengths to be statistically significant.

Regardless of whether there were significant differences between fire return intervals for the different riparian and upslope categories, fires occurred frequently in riparian forests, averaging every 13 or 14 years. These results definitely put riparian forests in the Dugout study area well within what is considered to be a low-severity, high frequency fire regime. And they show that fires are more common in the riparian forests than had previously been documented. Because there was so little overall variation in fire return interval lengths across the different categories, the only additional analysis that was made was the fire map analysis. Terrain in this study area is gentle and the forests rather homogeneous in terms of vegetation and structure. Because Heyerdahl (1997) found that fire recurrence in the Dugout study area did not vary according to topography, additional analyses with respect to topography or forest type were not done.

The fire map analysis revealed what would be expected: large fires included riparian plots more often than smaller fires. This is intuitive based on the fact that larger fires will cover an area that includes more riparian zones. What was interesting about the results, however, was that only the largest fire extent class (>2300 ha) showed evidence of burning in riparian plots within both sides of the North Fork Malheur river riparian zone. Other fire extent classes showed evidence of a fire burning within upslope plots on either side of the river, or within riparian plots within one side of the riparian zone and in upslope plots on the other side of the river, but did not indicate that the fire burned within both sides of the riparian zone. This suggests that the fires in the smaller extent classes may not have been as contiguous across the landscape and the river may have acted as a fire barrier.

Baker Study Area. As with the Dugout study area, fires were also frequent historically in the riparian forests of the Baker study area, averaging between 12 and 26 years, depending on how the fire return intervals were categorized. Generally, fire return intervals were slightly longer and have a wider variation in riparian forests than in upslope forests. Although statistically significant, there was little difference (4 years) between the average fire return intervals in riparian forests as a whole, relative to neighboring upslope forest. And when fire return intervals from large stream riparian forests are separated from those from small stream riparian forests, the only significant difference in fire return intervals is that small stream riparian fire return intervals are longer than their corresponding upslope fire return intervals. This result contradicts the original expectation that riparian forests along small streams would be more similar to upslope forests than riparian forests along large streams. It is important to note, however, that the larger streams occur only at the lower elevations of the watershed, where topography tends to be flatter and forests are generally categorized as drier forest types, and conversely smaller streams had a greater representation at the higher elevations. Therefore it was necessary to take other factors into account besides simply the proximity to large or small streams.

Heyerdahl (1997) determined that fire recurrence decreased as elevation increased. She did not, however, find a difference in fire recurrence according to aspect. But since forest types tend to differ in the Baker study area according to aspect (Figure 2), both forest type and aspect were analyzed in terms of riparian fire return intervals.

Based on data from just the riparian forests in this study, it was found that fire return interval lengths varied by both forest type and by aspect. Dry forest types not only experienced shorter fire return intervals, they also showed less variation in fire return interval length, compared to mesic forests. Although most of the riparian forests sampled in this study had mesic forest type plant associations, which would be expected for areas with higher moisture levels, four of the 16 plots had dry forest type plant associations, including one of the three plots along large sized streams. Additionally, dry forest type riparian average fire return intervals (12 year WMPI) were nearly identical to the upslope average fire return intervals used in this study (10 and 11 year WMPIs, calculated from Heyerdahl 1997), most of which occurred in dry forest type plant associations. This similarity helps explain why differentiating fire return intervals according to proximity to a stream is less indicative of fire regime variations than differentiating according to forest type.

Forest types are correlated with slope aspect (Holland and Steyn 1975), and this is especially evident for the Baker study area (Figure 2). When riparian forests were analyzed in terms of aspect, fire return intervals were longer in the north-facing portions of the riparian zone. This makes sense in terms of reduced insolation and subsequently higher moisture levels. Even though Heyerdahl (1997) did not find differences in fire recurrence according to aspect for the upslope forests in the Baker study area, the riparian forests logically occur in the most incised portions of the landscape and should therefore show the greatest differences in insolation relative to aspect.

When aspect analyses were narrowed to just the Marble Creek drainage, fire return intervals from the south-facing portions of the riparian forests and the north- and south-facing portions of the upslope forests were all similar, with only the north-facing riparian fire return intervals standing out as being longer and more variable. Fire return intervals from north-facing upslope forests still are not being differentiated from south-facing upslope forests at this scale. This is likely due to the fact that north-facing slopes in lower elevations of drainage are still dry forest (comparable to their cross drainage, south-facing counterparts) and therefore have short fire return intervals. However, the differentiation of fire return intervals between north-facing riparian forests and north-facing upslope forests suggests that fires entered the riparian forests less frequently than they burned upslope forests on just the north-facing aspects, whereas this did not appear to be the case for south-facing aspects. Unfortunately, this result cannot be corroborated at this time with a comparable forest type analysis for each portion of the riparian plots, because riparian plant associations were not differentiated according to north- or south-facing portions of the plot. The plant associations represent an average of both portions of the plot.

The final aspect analysis looked only at plots within the middle elevations of the Marble Creek watershed. This is the transitional point within the watershed where mesic forests dominate both aspects above this elevation and dry forests dominate both aspects below this elevation. It was at this scale where differences in fire return intervals for different upslope forest aspects began to be teased out of the data. The fact that south-facing upslope fire return intervals were significantly shorter than both south-facing riparian fire return intervals and north-facing upslope fire return intervals (neither of which were significantly different than north-facing riparian fire return intervals) indicates that this point in the watershed is where fires on south-facing upslopes were less likely to enter riparian forests. And this is likely due to the fact that at this elevation, mesic forest types occur in the riparian zones and on the north-facing aspects, while dry forest types still occur on the south-facing aspects. Above this elevation, the influence of aspect is likely overridden by elevational effects, and below this elevation, aspect is likely overridden by both elevation and the degree of topographical dissection.

As with the Dugout study area, the Baker study area fire map analysis showed that large fires included riparian plots more often than smaller fires. There was also evidence that fires commonly burned both sides of riparian plots in the three largest fire extent classes (encompassing 405 ha fires to >2300 ha fires). Unlike the Dugout study area where only the North Fork Malheur river was analyzed, all riparian plots in the Baker study area were analyzed in terms of whether a fire burned on both sides of the stream, therefore the results are not directly comparable between the study areas. Regardless, the Baker fire map analysis supports the conclusion that fires frequently entered riparian forests, and during the larger fire extent years, streams did not appear to act as fire barriers.

Steamboat Study Area. Fire return interval lengths in the Steamboat study area are representative of a moderate-severity fire regime, with average fire return intervals ranging between 23 and 56 years, depending on how the study plots are categorized. And the overall range of fire return intervals was between 3 and 167 years, showing a wide variation in length, which is consistent with moderate-severity fire regime forests (Agee 1993). Fire return intervals were found to be statistically similar for riparian and upslope forests, even when the riparian plots were categorized according to whether they occurred in riparian zones along small or large streams. The only indication of a possible difference is that the confidence intervals for small riparian and small upslope fire return intervals are wider than those for large riparian and large upslope fire return intervals. This suggests that fire regimes in the Steamboat study area may be less influenced by whether the plots are located in riparian or upslope forests than by whether they are located in the vicinity of large streams or small streams. However, when paired plots were combined into a single plot and categorized according to the combined plot's proximity to large or small streams, the average fire return interval from plots along small streams was not statistically different than the average fire return interval from plots along large streams. Nevertheless, the confidence interval for small stream fire return intervals was still wider than that for large stream fire return intervals. Perhaps with a larger sample size, the two categories may have been statistically different. Regardless, it is still apparent that fire return intervals in riparian forests and upslope forests are similar, and that some other variable may be what differentiates fire return intervals in this study area.

Perhaps the lack of differentiation between the riparian fire return interval and upslope fire return interval lengths is a result of a flawed riparian zone definition. The upslope plot locations may in reality not experience conditions different enough from the riparian plot locations to change the fire regime. Riparian plots tended to over represent the outer portion of the riparian zone. There were no samples taken immediately adjacent to large streams due to buffers left at the time of cutting, most of the samples were at least 30 m from large streams. Samples were taken closer to smaller streams, since buffers were typically smaller or non-existent along these streams. A more realistic definition of a riparian zone may be narrower than what was used for this study, or perhaps the zone extends into what was considered upslope for this study. Either way, it is clear that fires occurred at similar fire return intervals within the managerial definition of a riparian zone as they did outside of that zone. The riparian plot locations in this study are likely comparable to the lower regions of what other researchers have termed "lower slope positions" (Impara 1997, Weisberg 1998). Many of the upslope plots also may fall within that category, since they rarely extended farther upslope than the middle of the slope.

As expected, fire return intervals in the Steamboat study area are shorter than those determined by Means (1982), Teensma (1987), Morrison and Swanson (1990), Garza (1995), Impara (1997), Van Norman (1998), and Weisberg (1998) for western Oregon Cascades forests to the north and Oregon Coast Range forests to the west. These other studies found average fire return intervals ranging between 73 years and 246 years for forests within the western hemlock and Pacific silver fir zones. Furthermore, the average fire return intervals found in the Steamboat study area are longer than those found by Wills and Stuart (1994), Skinner (1997), and Taylor and Skinner (1998) in Douglas-fir forests of the Klamath Mountains of northern California, south of the study area. Fire return intervals in these forests were found to average between 8 and 42 years. And the average fire return intervals from this study were comparable to the range of fire frequencies found for the Siskiyou Mountains (16 to 64 years, Agee 1991).

When fire return intervals were separated according to aspect, no significant differences in fire return interval lengths were found between aspects. When riparian and upslope fire return intervals were compared within each aspect, the only significant difference was that west-facing riparian fire return intervals were longer and had a wider confidence interval than west-facing upslope fire return intervals. It is very likely that the results of aspect analyses suffer from a small sample size. Perhaps with a larger sample size more significant differences would have been found between the different aspects, since it appears there may be a trend of decreasing fire return interval lengths from west-facing plots to east-facing plots to north-facing plots (Figure 19). Additionally, riparian fire return intervals appear to be somewhat longer than upslope fire return intervals for each of these three aspects, and the difference between the riparian and upslope fire return intervals may be decreasing from west-facing plots to east-facing plots to north-facing plots. There are too few fire return intervals from south-facing plots to comment on where they fall within the trend.

In their Klamath Mountains study, Taylor and Skinner (1998) found that average fire return intervals on south- and west-facing slopes were shorter than on north- and east-facing slopes. If the trend of differences between aspects from the Steamboat study area is in fact a real one, it is then essentially opposite the trend found in the Klamath Mountains. Additionally, based on establishment dates of Douglas-firs, Taylor and Skinner (1998) found that the upper slopes and ridgetops throughout their study area, and intermediate south- and west-facing slopes, appeared to experience larger patches of higher severity fires relative to lower slopes and east- and north-facing slopes. Similarly, Weisberg (1998) found that north-facing slopes in the Blue River watershed experienced lower severity fires, and lower slope positions experienced lower severity fires. Impara (1997) found both severity and frequency were higher for the upper slope positions. And Van Norman (1998) found south-facing aspect fire return intervals were longer than those on north-facing aspects, which was interpreted by Agee (pers. comm. 2000) as higher severity fire on south aspects, resulting in fewer fire scars.

It is unclear how results from these other studies relate to those from the Steamboat study area. Perhaps, in general, fires in the Steamboat study area were patchier in terms of high-severity patches intermingling with low-severity patches, and the sampling scheme was effective at capturing the overall frequency of fires but not the spatial variability. Moister conditions on north- and east-facing slopes may have caused fire intensity to be lower within these areas. Maybe the drier conditions on south- and west-facing slopes were dry enough that fires were of higher intensity and, based on the complex stand structure in these forests, consequently higher severity (leaving fewer fire scarred trees).

As with results from the fire return interval analyses, results from the fire maps support the classification of the Steamboat forests as having a moderate-severity fire regime. Based on the number of occasions where a fire scarred only plot within a pair of riparian and upslope plots, either 1) most fires were small in terms of the size of the study area, or 2) fires were very patchy either in continuity across the landscape or in severity. The fact there is not a predominance of fire scars in riparian plots or upslope plots supports the previous finding that fires occur at similar intervals in riparian forests compared to upslope forests, although it is surprising that the similarity in fire return intervals is not necessarily due to both plots burning at the same time, but rather often burning at different times with a similar frequency. This again supports the suggestion that fires were patchy. It is also possible that fires were not always recorded on trees. Mature

Douglas-fir have extremely thick bark, therefore some individuals may not scar during a fire. Or perhaps some fires were not recorded on trees within the plots. If a fire is able to scorch or torch the crown of a tree, the tree usually dies and once it decays will subsequently be lost in terms of recording that fire.

Weisberg (1998) summarized fire history studies in the Washington and Oregon Cascades, and determined there is considerable evidence supporting two periods of widespread fire, one roughly between 1450 and 1650, and the other roughly between 1800 and the early 1900s. Two of the four potentially large fire years in the Steamboat study area (fires that burned at three or more pairs of plots), 1653 and 1844 fall within these periods. If the 1568 and 1615 fire years are also assumed to be large fire years, then four of the six largest fires in the study area occur within these time periods.

Finally, examination of the earliest tree ring records or establishment dates for each site suggested that, although riparian plots may tend to have older tree ring records than upslope plots, records were generally long (extending farther back than 1700), and aspect does not seem to influence the length of record within a plot. Although limited interpretation can be made from these results, it is clear that none of these sites experienced strictly high-severity fires since at least the early 1700s, and many sites had records extending back more than 400 years. This supports the conclusion that the higher severity and intensity portions of fires were generally either small or patchy, not continuous across large portions of the landscape.

Study Area Comparisons. Historical fires were common in the riparian zones of all three study areas. The study areas seem to represent a gradient of low- to moderate-severity fire regimes, ranging from Dugout, which is essentially entirely a low-severity fire regime forest, to Steamboat, which is representative of a moderate-severity fire regime. Baker shows a greater similarity to Dugout than to Steamboat, which is expected considering its proximity to Dugout. The lower portions of the Baker study area are categorized by a low-severity fire regime, but as elevation increases and the topography becomes more dissected, so does the severity of the fire regime, and perhaps the patchiness of individual fires.

When forests occur where climate and topography interact such that riparian forests reflect large vegetational differences relative to upslope forests, then fire return intervals differ, suggesting that forest composition plays a larger role than just whether or not a forest is located within a riparian zone.

Dry forests in the Dugout and Baker study areas experienced large, frequent fires that burned consistently across the landscape, including the riparian zones. Riparian forests within these dry forest types burned at essentially the same frequency as upslope forests. The dry forest types and subsequent low-severity fire regime are likely due to the gentle topography and dry climatic conditions present throughout the entire Dugout study area (only two riparian plots, out of all of the riparian and upslope plots, were mesic forest types) and the lower portions of the Baker study area. The similarity between riparian and upslope fire return intervals in the Dugout study area and in the drier, lower portions of the Baker study area is consistent with Heyerdahl's (1997) findings that fire recurrence in the Dugout study area did not vary according to topography (either aspect or elevation) and that fire recurrence in the Baker study area varied only according to elevation.

However, as elevation increases and terrain becomes more dissected in the Baker study area, longer and more variable fire return interval lengths begin to emerge. This is likely a result of forest composition changes related to both topography and elevational changes in temperature. Insolation differences are greater in terms of aspect in these steeper forests. Riparian valleys are deeper and therefore receive less insolation, and subsequently the forest composition on north-facing slopes and riparian zones is more mesic than on south-facing upslope forests. This study shows that more mesic conditions result in longer fire return intervals and perhaps patchier fires, suggesting a more moderate-severity fire regime.

Within both the Dugout and Baker study areas, the characteristics of the fires within the different fire extent classes may be representative of the overall fuel moisture conditions within the study area during the year of the fire. If it can be assumed that years with large fires had continuously dry fuels, then it appears that moisture levels during those years were not high enough to inhibit fire spread from the upslope forests to the riparian zones in either the Dugout study area or the lower portions of the Baker study area. Additionally, streams did not appear to act as fire barriers during these large extent fire years. Fire years where extents fell within smaller size classes may have had patchier fuel dryness conditions across the study area, and fuel moisture levels may have varied enough within and between riparian zones and upslope forests, resulting in smaller fires and greater variations in burning.

The Steamboat study area, on the other hand, is located within an extremely dissected landscape. It experiences a moister, more maritime climate than do the Blue Mountains. All of the riparian and upslope plots occur either within the dry end of the western hemlock forest series or the wet end of the Douglas-fire forest series. Fire return intervals are longer and appear to be more variable than in both the Dugout and Baker study areas, undoubtedly because the climate is moister. Like the Dugout study area, however, the topography in the Steamboat study area is consistent throughout the study area and forest composition is similar between riparian and upslope forests. Fire return intervals are also similar between riparian and upslope forests, and perhaps according to aspect, suggesting that topographical variation influences the fire regime in this area less than climate.

Overall, it appears that fire return intervals are influenced more by forest composition and overall climate than they are by whether they occur in riparian forests or upslope forests.

When the moisture gradient from the riparian zone to the upslope forest is large enough to allow a mesic riparian forest type to occur adjacent to a dry upslope forest type, then there will be a difference between fire return intervals in the riparian forest relative to the upslope forest. But when forest compositions are similar between riparian and upslope forests, the are likely to be the result of similar moisture levels within each of the forests, and they subsequently will experience similar fire return intervals.

MANAGEMENT IMPLICATIONS

Fire was a common occurrence in the riparian forests of all three study areas. Therefore, if the goal of forest management within these three areas is to restore forests to historical conditions, then reintroducing fire to riparian forests needs to be a part of that management. If the goal is to maintain these forests as they stand today, it is important to recognize the role that fire played in determining the structure and vegetational composition within these forests. Keeping fire out of the ecosystem will not only continue to alter the structure and vegetational composition of these riparian forests, but will also allow the buildup of fuels that could result in unprecedented fire intensities, and subsequently higher fire severities, than were present in the system historically. If the goal of forest management is to restore historical disturbance regimes to these forests, results from this study indicate riparian forests should be managed according to the historical fire regime of the forest type rather than distance from a stream. In both the Dugout and Baker study areas, drier forest conditions similar to adjacent upslope forests can occur well within the current managerial definition of a riparian zone, and this may be true for the Steamboat study area as well.

Understandably, reintroducing fire to riparian forests is not necessarily a feasible management option when there are concerns about threatened and endangered species (e.g., bull trout) within the streams or streamside forests. In a synthesis of literature about fire and aquatic ecosystems, Gresswell (1999) concluded that salmonid species have evolved strategies to survive disturbances occurring at the frequency of historical fires, but that local populations may have been ephemeral. At present, long term detrimental effects of high-severity fires are generally limited to areas where native populations have either declined or become isolated due to human influences. Therefore, although fire was common in riparian forests within these study areas, it may be necessary to totally protect some of these streamside forests. Historically, it is likely that riparian fires were a result of upslope fires backing down into the riparian zone. Subsequently, if upslope forests are treated for fuels reduction, either with prescribed fire or other silvicultural treatments, then perhaps a wildfire ignited within the upslope forests would be less likely to gain the intensity needed to burn within the wetter portion of the riparian zone. However, the possibility that entire riparian zones may have burned historically in the Dugout and Baker study areas during the larger fire years suggests that, if fuel conditions are dry enough, these forests may be susceptible to ignition even from a relatively low intensity fire. Williamson (1999) found that nearly 95% of the riparian forests sampled in the vicinity of the Dugout study area were currently at risk to crown fire ignition under 90^{th} percentile weather conditions. Therefore, it may be necessary to reduce current fuel loads within riparian forests in order to protect them from crown fire ignition.

In terms of coarse woody debris recruitment within these riparian forests, and the subsequent addition of large woody debris to the streams, it is likely that inputs followed cycles comparable to the length of the historical fire return intervals. Within the drier forests of the Dugout and Baker study areas, coarse woody debris input into the system was likely to be rather small but continuous, with a rather short residence time. Fires occurred roughly every 12 to 14 years but seldom killed large trees. Therefore, when trees died and snags eventually fell down, it was likely due to synergistic effects between fire and other disturbance processes, such as insects or pathogens. Once logs were on the ground, they were likely consumed by the frequently occurring fires. Within the more mesic forest types of the Baker study area, as well as the moister forests in the Steamboat study area, fire intervals were longer and more variable in length, and appeared to include at least patches of higher severity fire. The higher severity patches within these fires would have resulted in higher amounts of tree mortality in these forests. So it is possible that coarse woody debris creation could have occurred patchily and in pulses (lagging a few years after fires, accounting for the time it takes for the snag to fall) roughly every 19 years in the mesic riparian forests of the Baker study area, and roughly every 38 years in the riparian forests of the Steamboat study area.

RECOMMENDATIONS FOR FURTHER RESEARCH

The paired plot approach to sampling riparian forests and upslope forests was a logical first step to studying the fire history of riparian zones, because it allowed sampling at multiple locations throughout each study area. However, based on the general lack of differentiation of fire return intervals between riparian zones and upslope forests as they are defined in this study, it would be interesting to hone in on a few locations within the Baker and Steamboat study areas and sample plots along a transect from the stream edge to the ridgetop. It would also be useful to do an age class analysis and thorough sampling of species composition along with the fire scar sampling in order to address historical fire severities. In study areas such as the Steamboat study area, where stumps are necessary to locate fire scars, it will be important to sample the fire scars before the stumps have decayed. I had difficulty cleanly removing scars from stumps in clearcuts greater than 15 years old. Since the Steamboat study is part of the Northwest Forest Plan's system of Late Successional Reserves, clearcutting ceased in 1994. Therefore, it is important to recognize that the window of opportunity for fire scar collection off of stumps is passing quickly, in this study area as well as similar areas within the western Cascades.

In the Baker study area there are growth suppression events apparent within increment cores from larch, focused roughly around 1914 and 1980, perhaps from a larch defoliator. Considering the current mortality levels and the resulting large amounts of fuel from the spruce budworm and Douglas-fir tussock moth outbreaks in the 1980s, it would be useful to design a study to look at the synergism between different types of disturbances and how they relate to topography and forest composition.

Additionally, it would be interesting to look at what sorts of historical anthropogenic influences could be associated with fires in the riparian plots within these three study areas. For example, could the interesting patterns of the 1793 and 1794 fires in the Dugout study area be correlated with known Native American cultural sites? Could the unexpectedly short fire return intervals found along large streams in all three study areas represent higher numbers of Native American ignitions along travel corridors? Understandably, this type of study would be extremely speculative. However, considering the known use of fire by Native Americans, and the fact that streamside forests would likely have been attractive locations when it came to proximity to water, both in terms of camp location as well as hunting grounds, it is possible that the historical presence of fire in riparian zones was not strictly a result of upslope, lightning-ignited fires backing down into the riparian forest.

Finally, it would be useful to study the physical, chemical and biological processes involved with reintroducing fire into riparian forests. It is often assumed that the short term detrimental impacts of intense silvicultural treatments such as prescribed fire or understory thinning on the survival of threatened fish and wildlife populations would surpass the positive impacts associated with the reduction of fuels. However, Gresswell (1999) notes that local extirpation of fishes is often patchy in the case of extensive high-severity fires, and that recolonization is rapid. If this is indeed the case, perhaps a series of carefully designed and implemented fuels reduction treatments within riparian forests could elucidate how effectively fire can be reintroduced to these forests.

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APPENDIX A. Plot and stream characteristics tables by study area.

Appendix A summarizes the plot and stream characteristics for each of the three study areas. Riparian plant associations in the Dugout and Baker study areas were determined from Crowe and Clausnitzer (1997) and upslope plant associations were determined from Johnson and Clausnitzer (1992). Both riparian and upslope plant associations were determined from Atzet et al. (1996) for the Steamboat study area. Stream descriptions were based on classifications in Montgomery and Buffington (1993).

Table 3. Dugout riparian plot and stream characteristics (bold, this study) and characteristics of the corresponding upslope sites (Heyerdahl 1997).

Plot ID	Plant Association	Forest Type	Elev. (m)	Aspect (degree)	Slope (degree)	Longitude (degree)	Latitude (degree)	stream order	stream description	bankfull avg. (m)	floodplain avg. (m)
NFM1	**Psme/Syal floodplain**	**dry**	**1390**	**258**	**33**	**-118.380**	**44.183**	**4**	**regime**	**12.0**	**37.9**
11.2	Psme/Caru	dry	1520	--	0	-118.374	44.189	--	--	--	--
NFM2 (12.1)	**Psme/Syal floodplain**	**dry**	**1400**	**280**	**23**	**-118.379**	**44.187**	**4**	**regime**	**(12.7)**	**(49.8)**
11.2	Psme/Caru	dry	1520	--	0	-118.374	44.189	--	--	--	--
NFM3	**Psme/Syal floodplain**	**dry**	**1410**	**274**	**34**	**-118.381**	**44.189**	**4**	**regime**	**(12.7)**	**(49.8)**
11.1	Psme/Caru	dry	1490	340	9	-118.378	44.191	--	--	--	--
NFM4	**Pipo/Syal floodplain**	**dry**	**1410**	**72**	**26**	**-118.383**	**44.196**	**4**	**regime**	**13.3**	**61.8**
6	Abgr/Caru	dry	1720	107	10	-118.402	44.206	--	--	--	--
NFM5	**Pipo/Syal floodplain**	**dry**	**1430**	**263**	**27**	**-118.382**	**44.204**	**4**	**regime**	**13.3**	**82.4**
6	Abgr/Caru	dry	1720	107	10	-118.402	44.206	--	--	--	--
NFM6	**Pipo/Caru**	**dry**	**1440**	**76**	**10**	**-118.383**	**44.215**	**4**	**regime**	**11.7**	**63.2**
5	Abgr/Caru	dry	1690	40	12	-118.401	44.220	--	--	--	--
NFM7	**Psme/Syal floodplain**	**dry**	**1460**	**240**	**38**	**-118.382**	**44.220**	**4**	**braided**	**10.2**	**55.0**
4.1	Psme/Caru	dry	1600	260	11	-118.377	44.223	--	--	--	--
NFM8	**Pipo/Syal floodplain**	**dry**	**1480**	**255**	**28**	**-118.384**	**44.233**	**4**	**regime**	**10.2**	**78.8**
2.1	Psme/Caru	dry	1590	280	10	-118.379	44.230	--	--	--	--
ELK1	**Abgr/Vasc**	**mesic**	**1590**	**63/250**	**2/38**	**-118.409**	**44.248**	**2**	**step-pool**	**4.9**	**5.4**
4	Abgr/Caru	dry	1720	69	5	-118.409	44.239	--	--	--	--
ELK2	**Pipo/Syal floodplain**	**dry**	**1490**	**349/171**	**5/5**	**-118.392**	**44.249**	**2**	**plane-bed**	**6.1**	**10.1**
19	Abgr/Cage	dry	1520	65	3	-118.400	44.251	--	--	--	--
STC1	**Abgr/Syal floodplain**	**dry**	**1470**	**328/143**	**30/38**	**-118.377**	**44.208**	**1**	**step-pool**	**1.5**	**2.8**
7.1	Psme/Caru	dry	1600	--	3	-118.377	44.210	--	--	--	--
STC2	**Psme/Syal floodplain**	**dry**	**1700**	**21/250**	**21/18**	**-118.334**	**44.211**	**1**	**step-pool**	**2.1**	**5.5**
6.6	Psme/Caru	dry	1760	170	5	-118.346	44.213	--	--	--	--
DUG1	**Psme/Syal floodplain**	**dry**	**1480**	**332/172**	**29/24**	**-118.377**	**44.199**	**1**	**step-pool**	**1.8**	**2.2**
9.2	Psme/Caru	dry	1610	324	9	-118.372	44.200	--	--	--	--
RSP1	**Pipo/Syal floodplain**	**dry**	**1520**	**302/138**	**23/22**	**-118.371**	**44.184**	**1**	**step-pool**	**0.8**	**2.6**
11.4	Psme/Cage	dry	1640	220	7	-118.361	44.191	--	--	--	--

Table 3 (continued). Dugout riparian plot and stream characteristics (bold, this study) and characteristics of the corresponding upslope sites (Heyerdahl 1997).

Plot ID	Plant Association	Forest Type	Elev. (m)	Aspect (degree)	Slope (degree)	Longitude (degree)	Latitude (degree)	stream order	stream description	bankfull avg. (m)	floodplain avg. (m)
LCC1	**Abgr/Syal floodplain**	**dry**	**1640**	**279/99**	**26/26**	**-118.414**	**44.185**	**2**	**step-pool**	**5.4**	**6.3**
9	Psme/Caru	dry	1620	--	0	-118.410	44.179	--	--	--	--
LCC2	**Pico(Abgr)/Vasc/Caru pct**	**mesic**	**1730**	**45/249**	**24/12**	**-118.422**	**44.214**	**2**	**plane-bed**	**2.7**	**6.1**
7	Abgr/Caru	dry	1810	190	8	-118.417	44.219	--	--	--	--
WTC1	**Psme/Syal floodplain**	**dry**	**1530**	**91/229**	**18/19**	**-118.396**	**44.166**	**1**	**step-pool**	**2.3**	**6.0**
10	Psme/Caru	dry	1560	65	8	-118.403	44.167	--	--	--	--
BRC1	**Pipo/Syal floodplain**	**dry**	**1610**	**86/260**	**22/17**	**-118.308**	**44.200**	**2**	**plane-bed**	**1.9**	**5.6**
14	Pipo/Caru	dry	1550	261	21	-118.307	44.198	--	--	--	--
BRC2	**Pipo/Syal floodplain**	**dry**	**1640**	**12/194**	**2/18**	**-118.322**	**44.211**	**1**	**pool-riffle**	**1.8**	**17.0**
13	Pipo/Caru	dry	1590	150	15	-118.330	44.207	--	--	--	--
BRC3	**Pipo/Syal floodplain**	**dry**	**1660**	**346/194**	**19/18**	**-118.323**	**44.219**	**1**	**pool-riffle**	**4.6**	**13.0**
12	Pipo/Cage	dry	1610	190	8	-118.335	44.219	--	--	--	--

Table 4. Baker riparian plot and stream characteristics (bold, this study), including characteristics split by aspect, and characteristics of the corresponding upslope sites (Heyerdahl 1997).

Plot ID	Plant Association	Forest Type	Elev. (m)	Aspect (degree)	Slope (degree)	Longitude (degree)	Latitude (degree)	stream order	stream description	bankfull avg. (m)	floodplain avg. (m)
MAR1	**Abgr/Acgl-floodplain**	**mesic**	**1620**	--	--	**-118.019**	**44.790**	**2**	**cascade**	**1.4**	**3.4**
MAR1N	--	--	--	**356**	**30**	--	--	--	--	--	--
MAR1SE	--	--	--	**135**	**42**	--	--	--	--	--	--
4.5	Psme/Caru	dry	1660	170	23	-118.018	44.793	--	--	--	--
5.5	Abgr/Libo2	mesic	1620	10	20	-118.015	44.789	--	--	--	--
MAR2	**Abgr/Acgl-floodplain**	**mesic**	**1310**	--	--	**-117.997**	**-44.800**	**3**	**step-pool**	**3.1**	**11.1**
MAR2N	--	--	--	**351**	**32**	--	--	--	--	--	--
MAR2SE	--	--	--	**133**	**25**	--	--	--	--	--	--
2.8	Psme/Caru	dry	1430	135	25	-117.997	44.802	--	--	--	--
3.9	Psme/Caru	dry	1480	5	17	-117.990	44.799	--	--	--	--
MAR3	**Abgr/Acgl-floodplain**	**mesic**	**1380**	--	--	**-118.001**	**44.796**	**3**	**cascade**	**2.6**	**5.1**
MAR3N	--	--	--	**2**	**33**	--	--	--	--	--	--
MAR3SE	--	--	--	**128**	**37**	--	--	--	--	--	--
4.7	Psme/Caru	dry	1520	180	20	-118.005	44.796	--	--	--	--
4.8	Abgr/Libo2	mesic	1470	13	30	-118.000	44.794	--	--	--	--
MAR4	**Abgr/Syal-floodplain PCT**	**dry**	**1270**	--	--	**-117.993**	**44.803**	**3**	**step-pool**	**2.5**	**10.2**
MAR4NE	--	--	--	**318**	**30**	--	--	--	--	--	--
MAR4SE	--	--	--	**123**	**30**	--	--	--	--	--	--
2.9	Psme/Caru	dry	1360	135	9	-117.994	44.803	--	--	--	--
2.10	Psme/Caru	dry	1320	85	19	-117.984	44.803	--	--	--	--
MAR5	**Abgr/Acgl-floodplain**	**mesic**	**1490**	--	--	**-118.010**	**44.793**	**2**	**cascade**	**1.5**	**5.6**
MAR5N	--	--	--	**354**	**32**	--	--	--	--	--	--
MAR5SE	--	--	--	**149**	**28**	--	--	--	--	--	--
4.6	Psme/Caru	dry	1560	170	20	-118.010	44.796	--	--	--	--
5.7	Abgr/Libo2	mesic	1540	330	16	-118.003	44.789	--	--	--	--

Table 4 (continued). Baker riparian plot and stream characteristics (bold, this study), including characteristics split by aspect, and characteristics of the corresponding upslope sites (Heyerdahl 1997).

Plot ID	Plant Association	Forest Type	Elev. (m)	Aspect (degree)	Slope (degree)	Longitude (degree)	Latitude (degree)	stream order	stream description	bankfull avg. (m)	floodplain avg. (m)
MAR6	**Abgr/Acgl-floodplain**	**mesic**	**1700**	--	--	**-118.016**	**44.784**	**2**	**cascade**	**2.3**	**5.8**
MAR6N	--	--	--	**350**	**32**	--	--	--	--	--	--
MAR6SE	--	--	--	**142**	**34**	--	--	--	--	--	--
5.6	Psme/Caru	dry	1670	125	18	-118.011	44.787	--	--	--	--
6.6	Abgr/Brvu	mesic	1650	290	20	-118.010	44.785	--	--	--	--
MIL1	**Abgr/Acgl-floodplain**	**mesic**	**1640**	--	--	**-118.030**	**44.806**	**1**	**step-pool**	**4.0**	7.7
MIL1NE	--	--	--	**42**	**37**	--	--	--	--	--	--
MIL1SE	--	--	--	**138**	**32**	--	--	--	--	--	--
3	Abgr/Caru	dry	1550	132	24	-118.026	44.810	--	--	--	--
MIL2	**Abgr/Clun**	**mesic**	**1610**	--	--	**-118.026**	**44.799**	**2**	**cascade**	**3.7**	**8.2**
MIL2NW	--	--	--	**335**	**30**	--	--	--	--	--	--
MIL2SE	--	--	--	**128**	**28**	--	--	--	--	--	--
3.4	Abgr/Vame	mesic	1620	350	25	-118.022	44.798	--	--	--	--
SAL1	**Abgr/Acgl-floodplain PCT**	**mesic**	**1600**	--	--	**-117.973**	**44.774**	**2**	**cascade**	**2.2**	3.3
SAL1NW	--	--	--	**302**	**30**	--	--	--	--	--	--
SAL1E	--	--	--	**82**	**36**	--	--	--	--	--	--
1	Abgr/Caru	dry	1660	59	24	-117.981	44.778	--	--	--	--
SAL2	**Abgr/Acgl-floodplain**	**mesic**	**1610**	--	--	**-117.995**	**44.773**	**1**	**cascade**	**1.0**	**2.0**
SAL2NW	--	--	--	**310**	**37**	--	--	--	--	--	--
SAL2E	--	--	--	**74**	**33**	--	--	--	--	--	--
SAL3	**Abgr/Acgl-floodplain**	**mesic**	**1610**	--	--	**-117.999**	**43.773**	**2**	**cascade**	**2.2**	**3.6**
SAL3N	--	--	--	**356**	**36**	--	--	--	--	--	--
SAL3SE	--	--	--	**139**	**34**	--	--	--	--	--	--
8.8	Abgr/Caru	dry	1610	45	24	-117.996	44.777	--	--	--	--

Table 4 (continued). Baker riparian plot and stream characteristics (bold, this study), including characteristics split by aspect, and characteristics of the corresponding upslope sites (Heyerdahl 1997).

Plot ID	Plant Association	Forest Type	Elev. (m)	Aspect (degree)	Slope (degree)	Longitude (degree)	Latitude (degree)	stream order	stream description	bankfull avg. (m)	floodplain avg. (m)
ECR1	**Abgr/Cage**	**dry**	**1470**	--	--	**-117.959**	**44.736**	**2**	**step-pool**	**3.7**	**14.6**
ECR1NE	--	--	--	**62**	**32**	--	--	--	--	--	--
ECR1SW	--	--	--	**236**	**32**	--	--	--	--	--	--
8	Psme/Cage	dry	1550	130	10	-117.959	44.742	--	--	--	--
ECR2	**Abgr/Libo2**	**mesic**	**1560**	--	--	**-117.971**	**44.745**	**2**	**step-pool**	**2.1**	**5.1**
ECR2E	--	--	--	**86**	**28**	--	--	--	--	--	--
ECR2SW	--	--	--	**242**	**29**	--	--	--	--	--	--
8	Psme/Cage	dry	1550	130	10	-117.959	44.742	--	--	--	--
ECR3	**Abgr/Cage**	**dry**	**1540**	--	--	**-117.961**	**44.742**	**1**	**cascade**	**0.9**	**2.5**
ECR3E	--	--	--	**110**	**34**	--	--	--	--	--	--
ECR3SW	--	--	--	**240**	**32**	--	--	--	--	--	--
8	Psme/Cage	dry	1550	130	10	-117.959	44.742	--	--	--	--
ECR4	**Abgr/Syal-floodplain PCT**	**dry**	**1380**	--	--	**-117.944**	**44.728**	**2**	**very altered**	--	
ECR4NE	--	--	--	**26**	**25**	--	--	--	--	--	--
ECR4S	--	--	--	**194**	**26**	--	--	--	--	--	--
9	Pipo/Cage	dry	1380	200	11	-117.945	44.731	--	--	--	--
WSH1	**Abgr/Acgl-floodplain**	**mesic**	**1390**	--	--	**-117.933**	**44.759**	**2**	**plane-bed**	**2.4**	**13.6**
WSH1N	--	--	--	**8**	**21**	--	--	--	--	--	--
WSH1S	--	--	--	**169**	**26**	--	--	--	--	--	--
7	Psme/Cage	dry	1500	221	10	-117.940	44.763	--	--	--	--
11	Psme/Cage	dry	1370	94	20	-117.757	44.757	--	--	--	--

Table 5. Steamboat riparian plot and stream characteristics (bold) and characteristics of their paired upslope sites.

Plot ID	Plant Association	Elev. (m)	Aspect (degree)	Slope (degree)	Longitude (degree)	Latitude (degree)	stream order	stream description	bankfull avg. (m)	floodplain avg. (m)
HHC1	**Tshe/Acci-Gash-SWO**	**700**	**298**	**40**	**-122.593**	**43.527**	**2**	**step-pool**	**3.3**	**6.1**
HHC1.5	**Tshe/Gash-Rhma3-SWO**	**670**	**278**	**42**	**-122.594**	**43.526**	**3**	**step-pool**	**8.1**	**10.6**
HHC2	Psme/Arne-SWO?	790	260	36	-122.592	43.526	--	--	--	--
HHC3	**Tshe/Acci-Rhma3**	**980**	**349**	**26**	**-122.563**	**43.540**	**1**	**colluvial**	**0.6**	**4.2**
HHC4	Tshe/Acci-Rhma3	1030	336	25	-122.563	43.540	--	--	--	--
HHC5	**Thpl/Bene2/Pomu**	**680**	**0**	**34**	**-122.578**	**43.517**	**1**	**step-pool**	**2.6**	**7.1**
HHC6	Tshe/Gash-Rhma3-SWO	730	334	42	-122.576	43.517	--	--	--	--
HHC7	**Tshe-Thpl/Rhma3**	**640**	**64**	**28**	**-122.599**	**43.518**	**3**	**step-pool**	**9.1**	**12.3**
HHC8	Tshe/Gash-Rhma3-SWO	700	64	38	-122.600	43.518	--	--	--	--
CCR1	**Psme/Acci-Bene2**	**740**	**53**	**41**	**-122.604**	**43.510**	**1**	**bedrock**	**2.0**	**3.2**
CCR2	Psme/Gash-Rhma3	800	78	42	-122.605	43.511	--	--	--	--
CCR7	**Tshe/Gash-Pomu-SWO**	**630**	**95**	**35**	**-122.601**	**43.508**	**3**	**step-pool**	**11.6**	**14.1**
CCR3	**Abam/Rogy/Actr**	**1490**	**118**	**40**	**-122.648**	**43.568**	**1**	**colluvial**	**1.0**	**2.6**
CCR4	Abam/Tshe/Vame/Actr	1540	125	30	-122.659	43.565	--	--	--	--
CCR5	**Tshe/Gash-Rhma3-SWO**	**610**	**240**	**25**	**-122.598**	**43.506**	**3**	**step-pool**	**10.7**	**14.1**
CCR6	Psme/Acci-Bene2	670	232	30	-122.597	43.506	--	--	--	--
LRC1	**Abam/Rogy/Actr**	**1470**	**224**	**39**	**-122.661**	**43.560**	**0**	**colluvial**	**0.5**	**1.8**
LRC2	Abam/Rogy/Actr	1550	230	24	-122.621	43.561	--	--	--	--
LRC3	**Tshe-Thpl/Rhma3**	**720**	**356**	**35**	**-122.636**	**43.501**	**1**	**step-pool**	**2.2**	**3.6**
LRC4	Tshe/Rhma3-Gash-SWO	780	354	22	-122.643	43.500	--	--	--	--
LRC5	**Tshe/Gash-Rhma3-SWO**	**720**	**272**	**35**	**-122.654**	**43.516**	**3**	**step-pool**	**8.8**	**10.7**
LRC6	Tshe-Cach6/Gash-Rhma3	800	286	40	-122.653	43.516	--	--	--	--
LRC7	**Psme/Acci-Bene2**	**610**	**194**	**35**	**-122.611**	**43.503**	**4**	**step-pool**	**12.1**	**18.2**
LRC8	Psme/Acci-Bene2	670	204	30	-122.611	43.504	--	--	--	--
LRC9	**Tshe-Thpl/Rhma3**	**670**	**40**	**8**	**-122.636**	**43.509**	**4**	**step-pool**	**11.6**	**11.8**
LRC10	Tshe-Cach6/Gash-Rhma3	740	24	45	-122.645	43.508	--	--	--	--

Table 5 (continued). Steamboat riparian plot and stream characteristics (bold) and characteristics of their paired upslope sites.

Plot ID	Plant Association	Elev. (m)	Aspect (degree)	Slope (degree)	Longitude (degree)	Latitude (degree)	stream order	stream description	bankfull avg. (m)	floodplain avg. (m)
STB1	**Tshe/Gash-Rhma3-SWO**	**760**	**343**	**37**	**-122.524**	**43.512**	**3**	**step-pool**	**6.2**	**7.8**
STB2	Psme/Gash-Rhma3	850	343	26	-122.523	43.511	--	--	--	--
STB3	**Tshe/Gash-Rhma3-SWO**	**790**	**278**	**35**	**-122.786**	**43.520**	**1**	**bedrock**	**0.8**	**1.7**
STB4	Psme/Acci-Bene2	890	278	32	-122.785	43.520	--	--	--	--
STB5	**Tshe/Gash-Rhma3-SWO**	**1180**	**339**	**38**	**-122.509**	**43.496**	**0**	**step-pool**	**1.2**	**2.3**
STB6	Psme/Acci-Bene2	1240	319	28	-122.507	43.496	--	--	--	--

APPENDIX B. Plot statistics tables by study area.

Appendix B summarizes fire return interval statistics for each of the plots in the three study areas. "Oldest tree ring record" represents either the pith date for a sample or the earliest ring recorded for a sample. The rest of the statististics were output from the FHX2 fire history software developed by Grissino-Mayer (1995), with the exception of plots where the degrees of freedom were less than three. In these cases, the mean was calculated by hand.

Table 6. Dugout plot statistics (1650-1900), riparian plots (bold, this study) paired with closest upslope site (Heyerdahl 1997). A "--" indicates there is not enough data to calculate the value.

Plot ID	Oldest tree ring record	Number of fires	Interval						Std. Dev.	Coeff. of Var.	Deg. Freedom
			Min.	Max.	WMPI	80% CI	Mean	Median			
NFM1	**1433**	**13**	**7**	**31**	**16**	**8-27**	**17**	**15**	**8**	**0.47**	**12**
11.2	1547	17	5	31	13	5-23	13	12	7	0.55	16
NFM2 (12.1)	**1454**	**16**	**7**	**25**	**14**	**7-22**	**14**	**12**	**6**	**0.41**	**15**
11.2	1547	17	5	31	13	5-23	13	12	7	0.55	16
NFM3	**1665**	**12**	**5**	**30**	**15**	**7-25**	**15**	**14**	**8**	**0.49**	**11**
11.1	1625	17	5	25	12	5-21	13	11	7	0.53	16
NFM4	**1493**	**16**	**5**	**25**	**12**	**5-21**	**13**	**11**	**6**	**0.49**	**15**
6	1539	18	5	31	13	5-23	14	12	8	0.55	17
NFM5	**1613**	**15**	**5**	**23**	**13**	**7-19**	**13**	**13**	**5**	**0.37**	**14**
6	1539	18	5	31	13	5-23	14	12	8	0.55	17
NFM6	**1515**	**13**	**3**	**29**	**17**	**9-26**	**18**	**19**	**7**	**0.37**	**12**
5	1507	19	5	23	13	6-20	13	12	5	0.41	18
NFM7	**1447**	**14**	**4**	**54**	**12**	**3-30**	**14**	**11**	**13**	**0.90**	**13**
4.1	1640	15	4	39	15	6-28	16	13	9	0.58	14
NFM8	**1565**	**19**	**6**	**29**	**13**	**6-21**	**13**	**11**	**6**	**0.46**	**18**
2.1	1603	15	6	32	14	6-25	14	13	8	0.54	14
ELK1	**1748**	**7**	**12**	**44**	**22**	**9-38**	**23**	**19**	**13**	**0.55**	**6**
4	1616	14	6	31	14	6-25	14	13	8	0.54	13
ELK2	**1672**	**12**	**5**	**32**	**16**	**6-28**	**17**	**13**	**9**	**0.56**	**11**
19	1542	17	2	31	12	5-23	13	12	7	0.54	16
STC1	**1603**	**17**	**2**	**33**	**11**	**3-24**	**13**	**11**	**9**	**0.69**	**16**
7.1	1454	20	4	23	11	5-19	11	11	6	0.50	19
STC2	**1602**	**13**	**1**	**35**	**15**	**4-33**	**17**	**17**	**11**	**0.65**	**12**
6.6	1592	16	5	30	15	6-26	16	14	8	0.52	15
DUG1	**1589**	**14**	**2**	**43**	**14**	**4-31**	**16**	**13**	**11**	**0.69**	**13**
9.2	1454	16	5	30	14	6-24	14	12	7	0.51	15
RSP1	**1579**	**9**	**1**	**25**	**16**	**7-27**	**17**	**18**	**8**	**0.45**	**8**
11.4	1656	10	5	49	21	6-45	24	23	16	0.68	9
LCC1	**1539**	**7**	**11**	**57**	**32**	**14-54**	**34**	**36**	**17**	**0.51**	**6**
9	1619	16	2	34	13	4-28	15	12	10	0.65	15
LCC2	**1712**	**6**	**7**	**65**	**27**	**8-58**	**31**	**25**	**23**	**0.74**	**5**
7	1506	16	7	29	14	6-23	14	12	7	0.47	15
WTC1	**1345**	**20**	**3**	**25**	**11**	**4-21**	**12**	**8**	**7**	**0.61**	**19**
10	1454	20	3	25	11	4-20	12	10	6	0.55	19
BRC1	**1762**	**3**	**19**	**30**	**--**	**--**	**25**	**--**	**--**	**--**	**2**
14	1528	19	4	25	12	6-19	13	13	5	0.42	18
BRC2	**1424**	**14**	**5**	**34**	**11**	**4-22**	**12**	**10**	**8**	**0.65**	**13**
13	1625	22	3	25	9	3-17	9	8	6	0.64	21
BRC3	**1360**	**17**	**3**	**30**	**12**	**4-25**	**13**	**11**	**9**	**0.67**	**16**
12	1592	23	2	30	9	3-20	11	9	8	0.75	22

Table 7. Baker plot statistics (1650-1900), entire riparian plots (bold, this study) paired with closest upslope site (Heyerdahl 1997). A "--" indicates there is not enough data to calculate the value.

Plot ID	Oldest tree ring record	Number of fires	Interval						Std. Dev.	Coeff. of Var.	Deg. Freedom
			Min.	Max.	WMPI	80% CI	Mean	Median			
MAR1	**1808**	**3**	**30**	**53**	**--**	**--**	**42**	**--**	**--**	**--**	**2**
4.5	1636	9	12	43	24	12-37	24	23	10	0.42	8
MAR2	**1638**	**12**	**11**	**28**	**19**	**12-27**	**19**	**22**	**6**	**0.33**	**11**
2.8	1633	12	3	25	9	3-20	10	7	8	0.73	11
MAR3	**1580**	**13**	**4**	**30**	**14**	**6-25**	**15**	**13**	**8**	**0.51**	**12**
4.7	1516	15	6	24	11	5-19	12	11	5	0.47	14
MAR4	**1624**	**18**	**3**	**25**	**11**	**4-21**	**12**	**10**	**7**	**0.61**	**17**
2.9	1694	13	7	31	13	6-22	14	11	7	0.49	12
MAR5	**1551**	**6**	**32**	**64**	**48**	**32-62**	**47**	**43**	**13**	**0.27**	**5**
4.6	1622	10	6	34	17	7-31	18	18	10	0.55	9
MAR6	**1799**	**3**	**6**	**10**	**--**	**--**	**8**	**--**	**--**	**--**	**2**
5.6	1610	5	15	104	42	12-94	49	38	39	0.81	4
MIL1	**1697**	**7**	**9**	**45**	**20**	**8-39**	**22**	**18**	**14**	**0.63**	**6**
3	1675	19	3	23	9	4-16	10	10	5	0.50	18
MIL2	**1794**	**2**	**11**	**11**	**--**	**--**	**--**	**--**	**--**	**--**	**1**
3	1675	19	3	23	9	4-16	10	10	5	0.50	18
SAL1	**1808**	**0**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**
1	1584	11	7	43	21	8-37	22	24	12	0.54	10
SAL2	**1799**	**1**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**0**
8.8	1622	6	12	56	38	20-59	39	43	10	0.45	5
SAL3	**1796**	**1**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**0**
8.8	1622	6	12	56	38	20-59	39	43	10	0.45	5
ECR1	**1617**	**9**	**5**	**31**	**20**	**11-29**	**20**	**23**	**8**	**0.38**	**8**
8	1463	18	5	23	11	5-17	11	10	5	0.41	17
ECR2	**1577**	**5**	**5**	**56**	**32**	**10-65**	**36**	**42**	**23**	**0.63**	**4**
8	1463	18	5	23	11	5-17	11	10	5	0.41	17
ECR3	**1329**	**14**	**5**	**38**	**16**	**6-28**	**16**	**14**	**9**	**0.55**	**13**
8	1463	18	5	23	11	5-17	11	10	5	0.41	17
ECR4	**1510**	**20**	**2**	**27**	**10**	**4-20**	**11**	**10**	**7**	**0.58**	**19**
9	1482	20	3	27	10	4-17	10	10	5	0.48	19
WSH1	**1496**	**9**	**5**	**95**	**22**	**5-58**	**27**	**19**	**28**	**1.04**	**8**
7	1580	27	3	20	8	3-14	8	8	4	0.51	26

Table 8. Baker plot statistics (1650-1900), riparian plots (bold, this study) split by aspect, paired with closest upslope site that has a similar aspect (Heyerdahl 1997). A "--" indicates there is not enough data to calculate the value.

Plot ID	Oldest tree ring record	Number of fires	Interval						Std. Dev.	Coeff. of Var.	deg. freedom
			Min.	Max.	WMPI	80% CI	Mean	Median			
MAR1N	**1808**	**3**	**30**	**53**	**--**	**--**	**42**	**--**	**--**	**--**	**2**
5.5	1791	--	--	--	--	--	--	--	--	--	--
MAR1SE	**1865**	**1**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**0**
4.5	1636	9	12	43	24	12-37	24	23	10	0.42	8
MAR2N	**1868**	**2**	**14**	**14**	**--**	**--**	**--**	**--**	**--**	**--**	**1**
3.9	1645	12	5	110	13	2-46	20	12	30	1.53	11
MAR2SE	**1638**	**10**	**11**	**28**	**20**	**12-27**	**19**	**22**	**7**	**0.34**	**9**
2.8	1633	12	3	25	9	3-20	10	7	8	0.73	11
MAR3N	**1580**	**4**	**13**	**88**	**45**	**14-94**	**50**	**50**	**38**	**0.75**	**3**
4.8	1729	4	12	46	24	9-45	25	18	18	0.72	3
MAR3SE	**1711**	**10**	**4**	**30**	**17**	**7-29**	**18**	**19**	**9**	**0.50**	**9**
4.7	1516	15	6	24	11	5-19	12	11	5	0.47	14
MAR4NE	**1639**	**5**	**22**	**39**	**30**	**20-38**	**29**	**28**	**8**	**0.27**	**4**
2.10	1669	22	2	17	9	4-14	9	9	4	0.43	21
MAR4SE	**1625**	**17**	**3**	**25**	**11**	**4-22**	**12**	**12**	**7**	**0.59**	**16**
2.9	1694	13	7	31	13	6-22	14	11	7	0.49	12
MAR5N	**1809**	**2**	**73**	**73**	**--**	**--**	**--**	**--**	**--**	**--**	**1**
5.7	1558	6	8	88	40	12-86	46	43	33	0.72	4
MAR5SE	**1551**	**4**	**43**	**105**	**68**	**35-104**	**68**	**57**	**33**	**0.48**	**3**
4.6	1622	10	6	34	17	7-31	18	18	10	0.55	9
MAR6N	**1802**	**2**	**10**	**10**	**--**	**--**	**--**	**--**	**--**	**--**	**1**
6.6	1893	--	--	--	--	--	--	--	--	--	--
MAR6SE	**1799**	**2**	**16**	**16**	**--**	**--**	**--**	**--**	**--**	**--**	**1**
5.6	1610	5	15	104	42	12-94	49	38	39	0.81	4
MIL1NE	**1714**	**4**	**9**	**63**	**24**	**6-62**	**30**	**17**	**29**	**0.98**	**3**
N/A	--	--	--	--	--	--	--	--	--	--	--
MIL1SE	**1697**	**6**	**17**	**45**	**26**	**13-41**	**26**	**20**	**12**	**0.45**	**5**
3	1675	19	3	23	9	4-16	10	10	5	0.50	18
MIL2NW	**1831**	**1**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**0**
3.4	1793	--	--	--	--	--	--	--	--	--	--
MIL2SE	**1794**	**1**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**0**
N/A	--	--	--	--	--	--	--	--	--	--	--

Table 8 (continued). Baker plot statistics (1650-1900), riparian plots (bold, this study) split by aspect, paired with closest upslope site that has a similar aspect (Heyerdahl 1997). A "--" indicates there is not enough data to calculate the value.

Plot ID	Oldest tree ring record	Number of fires	Interval						Std. Dev.	Coeff. of Var.	deg. freedom
			Min.	Max.	WMPI	80% CI	Mean	Median			
SAL1NW	**1822**	**0**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**
N/A	--	--	--	--	--	--	--	--	--	--	--
SAL1E	**1808**	**0**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**
1	1584	11	7	43	21	8-37	22	24	12	0.54	10
SAL2NW	**1806**	**0**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**
N/A	--	--	--	--	--	--	--	--	--	--	--
SAL2E	**1799**	**1**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**0**
N/A	--	--	--	--	--	--	--	--	--	--	--
SAL3N	**1804**	**1**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**0**
N/A	--	--	--	--	--	--	--	--	--	--	--
SAL3SE	**1796**	**1**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**0**
8.8	1622	6	12	56	38	20-59	39	43	10	0.45	5
ECR1NE	**1617**	**7**	**22**	**38**	**27**	**18-35**	**27**	**24**	**6**	**0.24**	**6**
N/A	--	--	--	--	--	--	--	--	--	--	--
ECR1SW	**1707**	**6**	**5**	**70**	**27**	**7-65**	**32**	**23**	**26**	**0.80**	**5**
8	1463	18	5	23	11	5-17	11	10	5	0.41	17
ECR2E	**1767**	**1**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**0**
N/A	--	--	--	--	--	--	--	--	--	--	--
ECR2SW	**1577**	**5**	**5**	**56**	**32**	**10-65**	**36**	**42**	**23**	**0.63**	**4**
8	1463	18	5	23	11	5-17	11	10	5	0.41	17
ECR3E	**1840**	**0**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**
N/A	--	--	--	--	--	--	--	--	--	--	--
ECR3SW	**1329**	**14**	**5**	**38**	**16**	**6-28**	**16**	**14**	**9**	**0.55**	**13**
8	1463	18	5	23	11	5-17	11	10	5	0.41	17
ECR4NE	**1661**	**12**	**7**	**27**	**16**	**8-24**	**16**	**15**	**7**	**0.41**	**11**
N/A	--	--	--	--	--	--	--	--	--	--	--
ECR4S	**1510**	**16**	**5**	**27**	**13**	**5-23**	**13**	**12**	**7**	**0.54**	**15**
9	1482	20	3	27	10	4-17	10	10	5	0.48	19
WSH1N	**1496**	**7**	**16**	**95**	**31**	**9-70**	**35**	**26**	**30**	**0.85**	**6**
11	1552	20	5	27	11	5-19	11	10	6	0.49	19
WSH1S	**1828**	**2**	**27**	**27**	**--**	**--**	**--**	**--**	**--**	**--**	**1**
7	1580	27	3	20	8	3-14	8	8	4	0.51	26

Table 9. Steamboat plot statistics (1650-1900), riparian plots (bold) paired with closest upslope site. A "--" indicates there is not enough data to calculate the value.

Plot ID	Earliest date[1]	Number of fires	Interval Min.	Interval Max.	Interval WMPI	Interval 80% CI	Interval Mean	Interval Median	Std. Dev.	Coeff. of Var.	Deg. Freedom
HHC1	**(1553)**	**2**	**106**	**106**	**--**	**--**	**--**	**--**	**--**	**--**	**1**
HHC1.5	**1234**	**4**	**4**	**131**	**48**	**6-171**	**72**	**81**	**64**	**0.89**	**3**
HHC2	1648	2	25	25	--	--	--	--	--	--	1
HHC3	**1574**	**4**	**18**	**48**	**37**	**21-53**	**37**	**44**	**16**	**0.44**	**3**
HHC4	1579	3	17	110	--	--	64	--	--	--	2
HHC5	**1497**	**3**	**24**	**167**	**--**	**--**	**96**	**--**	**--**	**--**	**2**
HHC6	(1569)	3	21	106	--	--	64	--	--	--	2
HHC7	**1496**	**5**	**46**	**61**	**55**	**46-61**	**54**	**55**	**7**	**0.13**	**4**
HHC8	1498	8	3	61	28	7-68	34	40	24	0.69	7
CCR1	**1736**	**3**	**24**	**56**	**--**	**--**	**40**	**--**	**--**	**--**	**2**
CCR2	1725	5	23	41	31	20-40	30	29	8	0.28	4
CCR7	**1520**	**7**	**23**	**57**	**36**	**21-52**	**36**	**37**	**12**	**0.34**	**6**
CCR3	**1817**	**0**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**
CCR4	1821	1	--	--	--	--	--	--	--	--	0
CCR5	**(1710)**	**3**	**43**	**53**	**--**	**--**	**48**	**--**	**--**	**--**	**2**
CCR6	1693	4	29	53	38	22-52	37	30	14	0.36	3
LRC1	**(1765)**	**1**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**0**
LRC2	1838	2	2	2	--	--	--	--	--	--	1
LRC3	**1664**	**3**	**8**	**82**	**--**	**--**	**45**	**--**	**--**	**--**	**2**
LRC4	1661	3	8	61	--	--	35	--	--	--	2
LRC5	**(1537)**	**3**	**32**	**60**	**--**	**--**	**46**	**--**	**--**	**--**	**2**
LRC6	1705	5	18	34	27	19-33	27	27	7	0.25	4
LRC7	**1707**	**3**	**14**	**38**	**--**	**--**	**26**	**--**	**--**	**--**	**2**
LRC8	1735	3	11	102	--	--	57	--	--	--	2
LRC9	**1667**	**6**	**13**	**61**	**34**	**15-58**	**35**	**37**	**19**	**0.53**	**5**
LRC10	1389	6	6	61	30	11-58	33	37	20	0.61	5
STB1	**(1630)**	**6**	**7**	**57**	**21**	**6-49**	**25**	**18**	**20**	**0.82**	**5**
STB2	1612	8	5	74	20	4-54	25	22	24	0.93	7
STB3	**(1572)**	**3**	**49**	**110**	**--**	**--**	**80**	**--**	**--**	**--**	**2**
STB4	1670	3	49	106	--	--	155	--	--	--	2
STB5	**1576**	**3**	**13**	**91**	**--**	**--**	**52**	**--**	**--**	**--**	**2**
STB6	1572	2	110	110	--	--	--	--	--	--	1

[1] Earliest establishment date (extrapolated from a pith date) from the samples at that plot. If the year is in parentheses, then the date represents the oldest ring sampled at that site, but the ring was not close enough to the pith of the tree to determine an establishment date.

APPENDIX C. Statistical test tables by study area.

As mentioned in the Data Analysis section, only non-parametric statistical test were used in this study. These tables summarize all of the statistics done for each category of plots. The Mann-Whitney U-Test for unmatched samples was the most common statistical test used. Use of other tests is mentioned for each table whenever applicable.

Table 10. Dugout statistical tests for differences between fire interval lengths grouped by different categories of plot types, 1650-1900. Tests are the two-tailed Mann-Whitney U-Test for unmatched samples, unless otherwise noted.

			Fire Intervals									
					Distribution Type:							
	Number of:				Normal			Weibull				
plot category	**plots**	**intervals**	**min.**	**max.**	**mean**	**median**	**Fit**[1]	**mean**	**median**	**CI**[2]	**Fit**[3]
all plots	38	529	1	65	14	12	0.89	14	13	5-26	<.001
combined riparian	20	237	1	65	15	13	0.88	15	14	5-29	0.18
combined upslope	18	292	1	49	13	11	0.90	13	12	5-24	<.001
statistics	riparian > upslope, **p = 0.01**										
large stream, riparian	8	110	3	54	14	13	0.88	14	13	6-24	0.06
large stream, upslope	6	95	4	39	14	12	0.90	14	12	6-24	<.001
statistics	riparian = upslope, p = 0.33										
small stream, riparian	12	127	1	65	16	14	0.89	16	14	4-32	0.10
small stream, upslope	12	197	1	49	13	11	0.90	13	12	4-24	<.001
statistics	riparian > upslope, **p = 0.03**										
large stream, riparian	8	110	3	54	14	13	0.88	14	13	6-24	0.06
small stream, riparian	12	127	1	65	16	14	0.89	16	14	4-32	0.10
statistics	small = large, p = 0.75										

[1] Wilk-Shapiro normality statistic: a value less than 0.95 accepts the hypothesis that the data does not fit a normal distribution.
[2] 80% Confidence Interval: the range between the 10th and 90th percentile values of the Weibull distribution.
[3] P-value from a Chi-square analysis of how well the data fits the predicted data in a Weibull distribution: a value greater than 0.05 accepts the hypothesis that the actual distribution fits a Weibull distribution.

Table 11. Dugout statistical tests for differences between composite Weibull median probability fire return interval lengths (calculated for each plot), grouped by different categories of plot types, 1650-1900. Tests are the two-tailed Mann-Whitney U-Test for unmatched samples, unless otherwise noted.

		Composite Weibull Median Probability Fire Intervals									
				Distribution Type:							
	Number			Normal			Weibull				
plot category	**of plots**	**min.**	**max.**	**mean**	**median**	**Fit[1]**	**mean**	**median**	**CI[2]**	**Fit[3]**
all plots	36	9	32	14	13	0.74	14	14	10-20	0.003
combined riparian	19	11	32	16	14	0.76	16	14	11-23	0.42
combined upslope	17	9	21	13	13	0.85	13	13	10-17	0.01
statistics	riparian = upslope, p = 0.14									
large stream, riparian	8	12	17	14	13	0.89	14	14	12-17	0.02
large stream, upslope	6	12	15	13	13	0.93	13	13	12-15	0.047
statistics	riparian = upslope, p = 0.41[4]									
small stream, riparian	11	11	32	17	15	0.82	17	14	11-28	0.26
small stream, upslope	11	9	21	13	13	0.88	13	12	9-18	0.03
statistics	riparian = upslope, p = 0.13									
large stream, riparian	8	12	17	14	13	0.89	14	14	12-17	0.02
small stream, riparian	11	11	32	17	15	0.82	17	14	11-28	0.26
statistics	small = large, p = 0.85[4]									

[1] Wilk-Shapiro normality statistic: a value less than 0.95 accepts the hypothesis that the data does not fit a normal distribution.
[2] 80% Confidence Interval: the range between the 10th and 90th percentile values of the Weibull distribution.
[3] P-value from a Chi-square analysis of how well the data fits the predicted data in a Weibull distribution: a value greater than 0.05 accepts the hypothesis that the actual distribution fits a Weibull distribution.
[4] One-tailed Mann-Whitney U-Test for unmatched samples.

Table 12. Dugout statistical tests for differences between the number of fires per plot, grouped by different categories of plot types, 1650-1900. Tests are the two-tailed Mann-Whitney U-Test for unmatched samples, unless otherwise noted.

		Number of Fires Per Plot								
				Distribution Type:						
	Number			Normal			Weibull			
plot category	**of plots**	**min.**	**max.**	**mean**	**median**	**Fit[1]**	**mean**	**median**	**CI[2]**	**Fit[3]**
all plots	38	3	23	15	16	0.95	15	15	9-20	0.10
combined riparian	20	3	20	13	14	0.95	13	13	7-18	0.07
combined upslope	18	10	23	17	17	0.96	17	17	13-21	0.12
statistics	riparian < upslope, **p = 0.002**									
large stream, riparian	8	12	19	15	15	0.93	15	14	12-18	0.18
large stream, upslope	6	15	19	17	17	0.93	17	16	15-20	0.18
statistics	riparian < upslope, **p = 0.04**[4]									
small stream, riparian	12	3	20	12	13	0.97	11	11	5-19	0.25
small stream, upslope	12	10	23	17	17	0.96	17	17	12-22	0.03
statistics	riparian < upslope, **p = 0.01**									
large stream, riparian	8	12	19	15	15	0.93	15	14	12-18	0.18
small stream, riparian	12	3	20	12	13	0.97	11	11	5-19	0.25
statistics	small = large, p = 0.13[4]									

[1] Wilk-Shapiro normality statistic: a value less than 0.95 accepts the hypothesis that the data does not fit a normal distribution.

[2] 80% Confidence Interval: the range between the 10th and 90th percentile values of the Weibull distribution.

[3] P-value from a Chi-square analysis of how well the data fits the predicted data in a Weibull distribution: a value greater than 0.05 accepts the hypothesis that the actual distribution fits a Weibull distribution.

[4] One-tailed Mann-Whitney U-Test for unmatched samples.

Table 13. Baker statistical tests for differences between fire interval lengths grouped by different categories of plot types, 1650-1900. Tests are the nonparametric two-tailed Mann-Whitney U-Test for unmatched samples, unless otherwise noted.

			Fire Intervals								
					Distribution Type:						
	Number of:				Normal			Weibull			
plot category	**plots**	**intervals**	**min.**	**max.**	**mean**	**median**	**Fit**[1]	**mean**	**median**	**CI**[2]	**Fit**[3]
all plots	27	246	2	104	15	12	0.71	15	13	4-31	<.001
combined riparian	15	108	2	95	19	14	0.80	19	15	5-37	0.001
combined upslope	12	138	3	104	13	11	0.60	13	11	4-25	<.001
statistics	riparian > upslope, **p = 0.001**										
large stream, riparian	3	40	3	30	15	12	0.94	15	13	6-25	0.003
large stream, upslope	3	37	3	31	12	11	0.83	12	10	5-20	0.002
statistics	riparian = upslope, p = 0.10										
small stream, riparian	15	68	2	95	13	11	0.81	21	17	5-43	0.03
small stream, upslope	9	101	3	104	21	16	0.58	13	10	4-26	<.001
statistics	riparian > upslope, **p = 0.0002**										
large stream, riparian	3	40	3	30	15	12	0.94	15	13	6-25	0.003
small stream, riparian	15	68	2	95	13	11	0.81	21	17	5-43	0.03
statistics	small = large, p = 0.15										
dry forest, riparian	4	57	2	38	14	12	0.93	14	12	5-25	0.02
mesic forest, riparian	11	51	4	95	24	21	0.84	24	19	7-49	0.07
statistics	dry < mesic, **p = 0.01**										
north aspects, riparian	15	36	7	95	28	23	0.76	28	21	9-55	0.09
south aspects, riparian	15	64	3	105	20	17	0.72	20	16	5-40	0.002
statistics	north > south, **p = 0.02**										

[1] Wilk-Shapiro normality statistic: a value less than 0.95 accepts the hypothesis that the data does not fit a normal distribution

[2] 80% Confidence Interval: the range between the 10th and 90th percentile values of the Weibull distribution

[3] P-value from a Chi-square analysis of how well the data fits the predicted data in a Weibull distribution: a value greater than 0.05 accepts the hypothesis that the actual distribution fits a Weibull distribution.

Table 14. Baker statistical tests for differences between the number of fires per plot, grouped by different categories of plot types, 1650-1900. Tests are the nonparametric two-tailed Mann-Whitney U-Test for unmatched samples, unless otherwise noted.

		Number of Fires Per Plot							
				Distribution Type:					
	Number			**Normal**		**Weibull**			
plot category	**of plots**	**min.**	**max.**	**mean**	**median**	**mean**	**median**	**CI**[1]	**Fit**[2]
all plots	28	0	27	10	10	11	9	3-20	0.66
combined riparian	16	0	20	8	7	9	5	1-22	0.18
combined upslope	12	5	27	14	13	14	12	6-23	0.49
statistics				riparian < upslope, **p = 0.03**					
large stream, riparian	3	12	18	14	13	not enough data			
large stream, upslope	3	12	15	13	13	not enough data			
statistics				riparian = upslope, p = 0.35[3]					
small stream, riparian	16	0	20	6	5	8	3	1-19	0.05
small stream, upslope	9	5	27	14	11	14	10	5-29	0.05
statistics				riparian < upslope, **p = 0.02**					
large stream, riparian	3	12	18	14	13	not enough data			
small stream, riparian	16	0	20	6	5	8	3	1-19	0.05
statistics				small < large, **p = 0.03**[3]					
dry forest types, riparian	4	9	20	15	16	not enough data			
mesic forest types, riparian	12	0	13	5	4	7	3	1-16	0.16
statistics				dry > mesic, **p = 0.002**[3]					
north aspects, riparian	16	0	12	3	2	5	2	1-11	0.06
south aspects, riparian	16	0	17	6	5	9	3	1-21	0.01
statistics				north < south, **p = 0.02**[4]					

[1] 80% Confidence Interval: the range between the 10th and 90th percentile values of the Weibull distribution

[2] P-value from a Chi-square analysis of how well the data fits the predicted data in a Weibull distribution: a value greater than 0.05 accepts the hypothesis that the actual distribution fits a Weibull distribution.

[3] One-tailed Mann-Whitney U-Test for unmatched samples

[4] One-tailed Wilcoxon Signed Rank Test (for matched samples)

Table 15. Baker statistical tests for differences between fire interval lengths in the Marble Creek drainage, grouped by different categories of plot types, 1650-1900. Tests are the nonparametric two-tailed Mann-Whitney U-Test for unmatched samples, unless otherwise noted.

			Fire Intervals								
					Distribution Type:						
	Number of:				**Normal**			**Weibull**			
plot category	**plots**	**intervals**	**min.**	**max.**	**mean**	**median**	**Fit[1]**	**mean**	**median**	**CI[2]**	**Fit[3]**
north riparian	6	12	10	88	37	31	0.92	38	26	11-81	0.16
north upslope	7	57	2	112	23	12	0.69	23	15	4-52	<.001
statistics					riparian > upslope, **p = 0.01**						
south riparian	5	38	3	105	20	16	0.66	20	15	5-41	0.004
south upslope	9	75	3	104	19	12	0.63	20	15	5-41	<.001
statistics					riparian = upslope, p = 0.53						
north riparian	6	12	10	88	37	31	0.92	38	26	11-81	0.16
south riparian	5	38	3	105	20	16	0.66	20	15	5-41	0.004
statistics					north > south, **p = 0.01**						
north upslope	7	57	2	112	23	12	0.69	23	15	4-52	<.001
south upslope	9	75	3	104	19	12	0.63	20	15	5-41	<.001
statistics					north = south, p = 0.78						
mid elev. north riparian	2	4	13	88	56	62	not enough data				
mid elev. north upslope	2	7	8	88	37	43	0.88	43	20	8-103	0.15
statistics					riparian = upslope, p = 0.12[4]						
mid elev. south riparian	2	12	4	105	30	22	0.77	31	19	5-73	0.25
mid elev. south upslope	2	23	6	34	14	11	0.85	14	12	6-25	0.01
statistics					riparian > upslope, **p = 0.03**						
mid elev. north riparian	2	4	13	88	56	62	not enough data				
mid elev. south riparian	2	12	4	105	30	22	0.77	31	19	5-73	0.25
statistics					north = south, p = 0.08[4]						
mid elev. north upslope	2	7	8	88	37	43	0.88	43	20	8-103	0.15
mid elev. south upslope	2	23	6	34	14	11	0.85	14	12	6-25	0.01
statistics					north > south, **p = 0.02**						

[1] Wilk-Shapiro normality statistic: a value less than 0.95 accepts the hypothesis that the data does not fit a normal distribution

[2] 80% Confidence Interval: the range between the 10th and 90th percentile values of the Weibull distribution

[3] P-value from a Chi-square analysis of how well the data fits the predicted data in a Weibull distribution: a value greater than 0.05 accepts the hypothesis that the actual distribution fits a Weibull distribution.

[4] One-tailed Mann-Whitney U-Test for unmatched samples

Table 16. Steamboat statistical tests for differences between fire interval lengths grouped by different categories of plot types, 1650-1900. Tests are the two-tailed Mann-Whitney U-Test for unmatched samples, unless otherwise noted.

	Number of:		Fire Intervals		Distribution Type: Normal			Weibull			
plot category	plots	intervals	min.	max.	mean	median	Fit[1]	mean	median	CI[2]	Fit[3]
all plots	28	86	2	167	43	37	0.88	43	34	9-88	0.10
combined riparian	15	43	4	167	47	43	0.87	47	38	11-95	0.23
combined upslope	13	43	2	110	38	29	0.87	38	29	7-82	0.05
statistics	riparian = upslope, p = 0.15										
large riparian	8	29	4	131	41	38	0.88	41	35	11-77	0.08
large upslope	8	33	3	102	32	27	0.90	32	27	8-63	0.005
statistics	riparian = upslope, p = 0.13										
small riparian	7	14	8	167	60	49	0.91	62	39	11-141	0.62
small upslope	7	14	8	110	52	37	0.84	53	36	11-119	0.05
statistics	riparian = upslope, p = 0.80										
large riparian	8	29	4	131	41	38	0.88	41	35	11-77	0.08
small riparian	7	14	8	167	60	49	0.91	62	39	11-141	0.62
statistics	small = large, p = 0.27										
combined large	8	49	3	106	30	27	0.90	30	23	11-41	0.04
combined small	5	16	4	106	44	34	0.89	45	29	13-58	0.05
statistics	small = large, p = 0.28										

[1] Wilk-Shapiro normality statistic: a value less than 0.95 accepts the hypothesis that the data does not fit a normal distribution.
[2] 80% Confidence Interval: the range between the 10th and 90th percentile values of the Weibull distribution.
[3] P-value from a Chi-square analysis of how well the data fits the predicted data in a Weibull distribution: a value greater than 0.05 accepts the hypothesis that the actual distribution fits a
[4] One-tailed Mann-Whitney U-Test for unmatched samples.
[5] Kruskal-Wallis One-Way Nonparametric Analysis of Variance.

Table 17. Steamboat statistical tests for differences between fire interval lengths grouped by aspect and plot type, 1650-1900. Unless otherwise noted, tests are the two-tailed Mann-Whitney U-Test for unmatched samples. If a comparison is not listed, there were no significant differences between the category types (e.g., north aspect riparian plots = north aspect upslope plots, p = 0.90).

			Fire Intervals									
					Distribution Type:							
	Number of:				**Normal**			**Weibull**				
plot category	**plots**	**intervals**	**min.**	**max.**	**mean**	**median**	**Fit**[1]	**mean**	**median**	**CI**[2]	**Fit**[3]
north aspect	12	38	5	167	41	28	0.84	42	27	8-94	0.28
east aspect	5	23	3	61	38	40	0.95	37	36	15-61	0.13
south aspect	2	4	11	102	41	26	not enough data				
west aspect	9	20	4	131	53	46	0.89	53	45	13-103	0.02
statistics			no significant differences according to aspect, p = .34[5]								
north riparian	6	19	7	167	42	30	0.78	43	26	9-97	0.20
north upslope	6	19	5	110	41	25	0.85	43	24	6-101	0.27
east riparian	3	12	23	61	43	44	0.93	42	42	24-61	0.16
east upslope	2	11	3	61	33	33	0.97	32	28	8-61	0.047
south riparian	1	2	14	38	26	26	not enough data				
south upslope	1	2	11	102	57	57	not enough data				
west riparian	5	10	4	131	67	57	0.97	65	56	15-127	0.18
west upslope	4	10	18	106	40	30	0.70	41	30	19-75	0.02
statistics					west riparian > west upslope, **p = 0.02**[4]						

[1] Wilk-Shapiro normality statistic: a value less than 0.95 accepts the hypothesis that the data does not fit a normal distribution.
[2] 80% Confidence Interval: the range between the 10th and 90th percentile values of the Weibull distribution.
[3] P-value from a Chi-square analysis of how well the data fits the predicted data in a Weibull distribution: a value greater than 0.05 accepts the hypothesis that the actual distribution fits a
[4] One-tailed Mann-Whitney U-Test for unmatched samples.
[5] Kruskall-Wallis One-Way Nonparametric Analysis of Variance.

APPENDIX D. Dugout study area fire maps.

Fire years were mapped for every year there was clear evidence of fire scarring. The Dugout fire maps show the fire scar data from this study (black) superimposed onto the fire scar data from Heyerdahl (gray, 1997). The intra-annular position of the scar is shown for both data sets. "No record for this year" indicates that there were no trees sampled that were recording during that year. "No evidence of fire" indicates that at least one tree at the plot was recording during that year, but there was no evidence of fire in any of the samples within that plot for that year. "Probable evidence of fire" indicates that there was some sort of disruption in the rings of a sample at that site for that year (e.g., an abrupt increase or decrease in ring widths), but it could not definitely be attributed to fire scarring. The fire boundaries are based on those determined by Heyerdahl (1997, see the Methods section). If data from this study indicated a different fire boundary, the fire boundaries were adjusted accordingly.

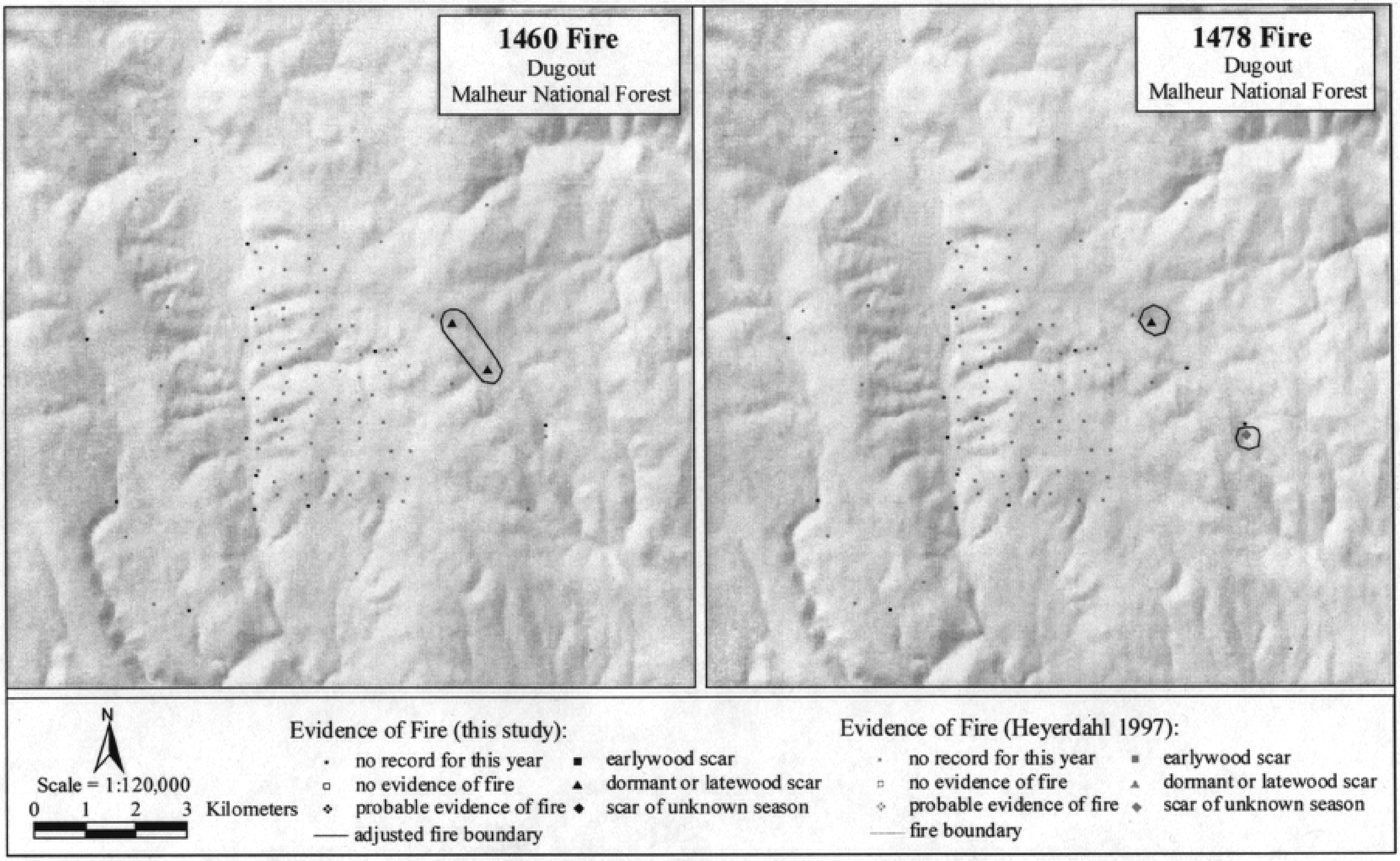

Figure 25. Dugout fire maps for 1460 (left) and 1478 (right).

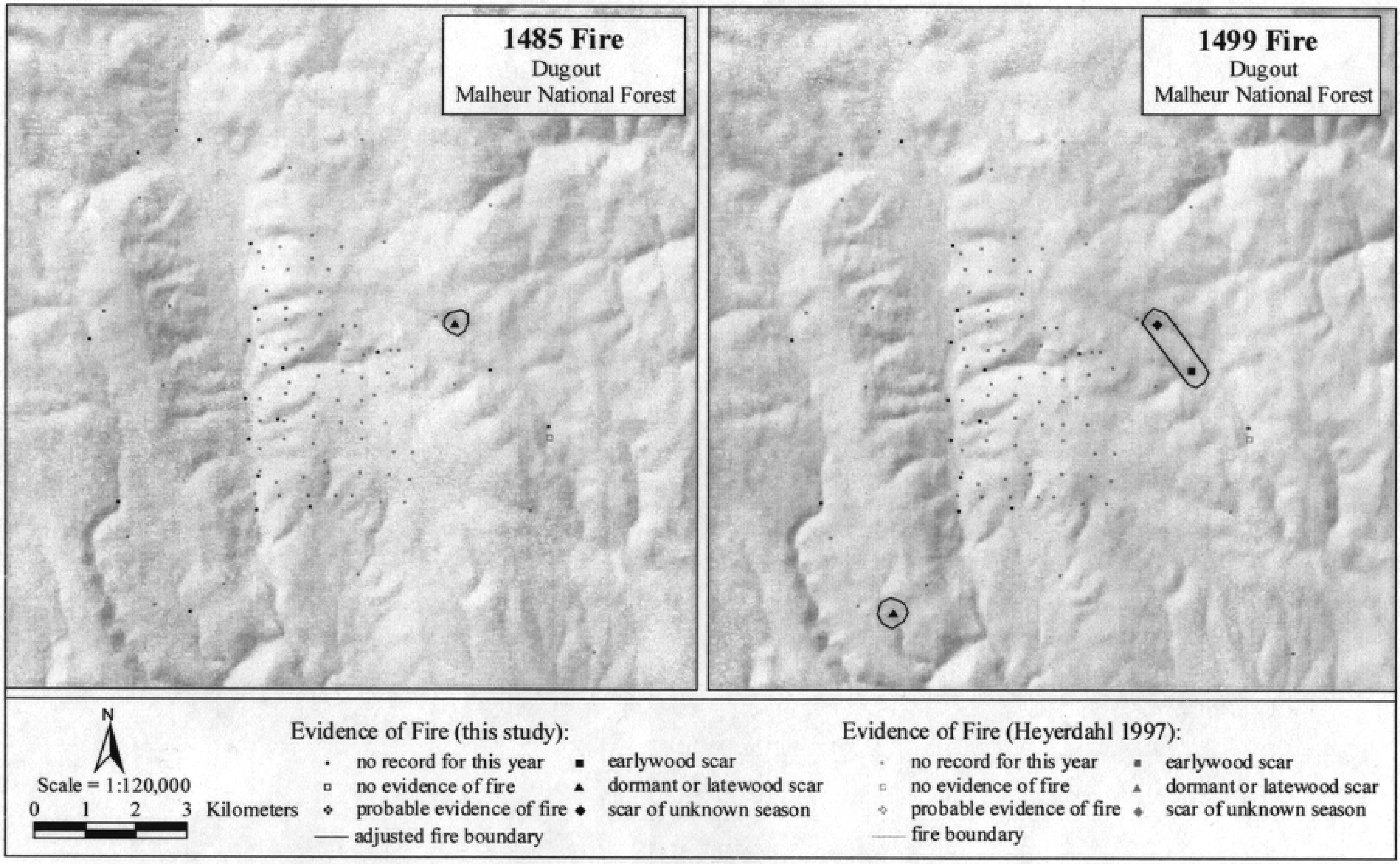

Figure 26. Dugout fire maps for 1485 (left) and 1499 (right).

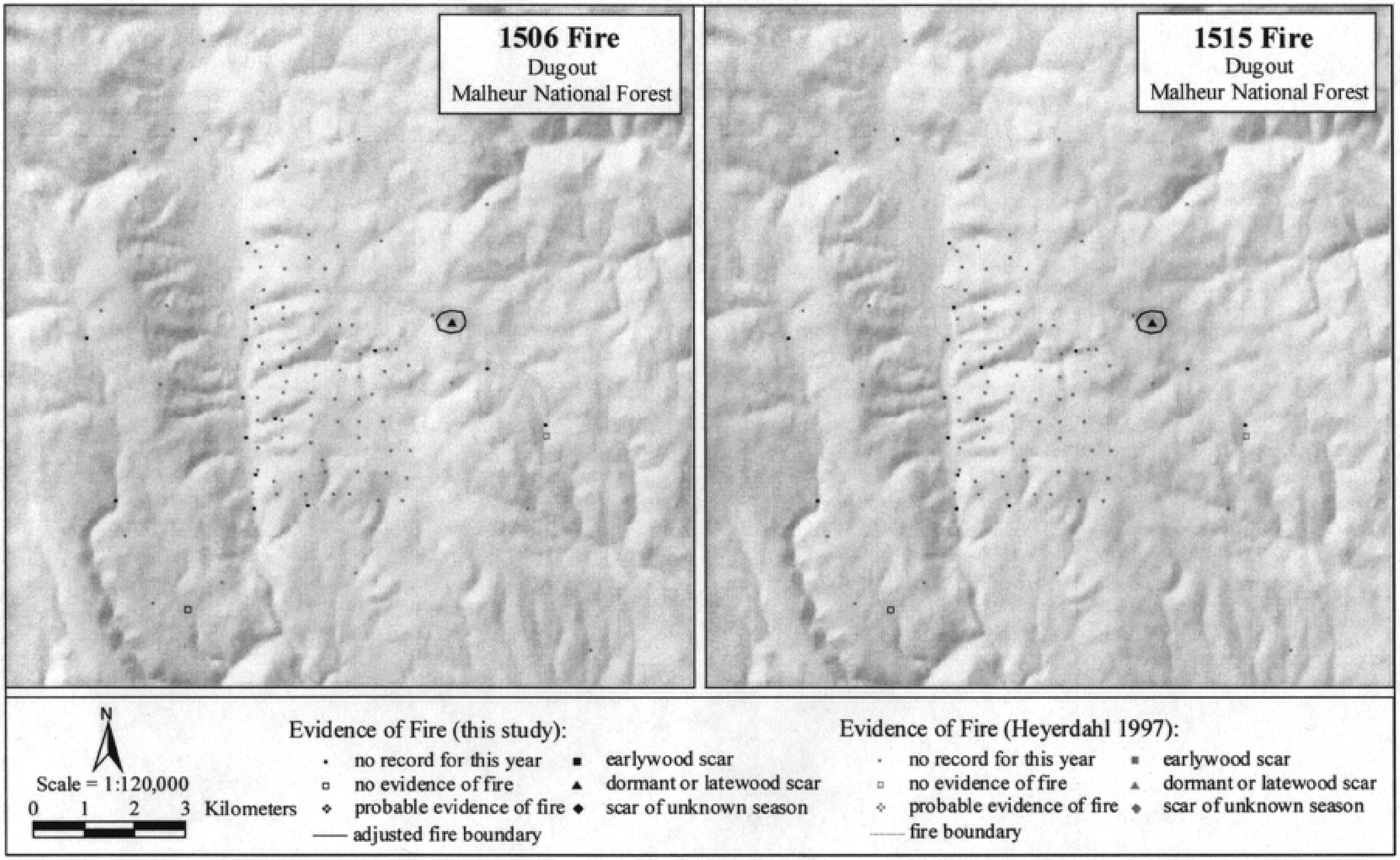

Figure 27. Dugout fire maps for 1506 (left) and 1515 (right).

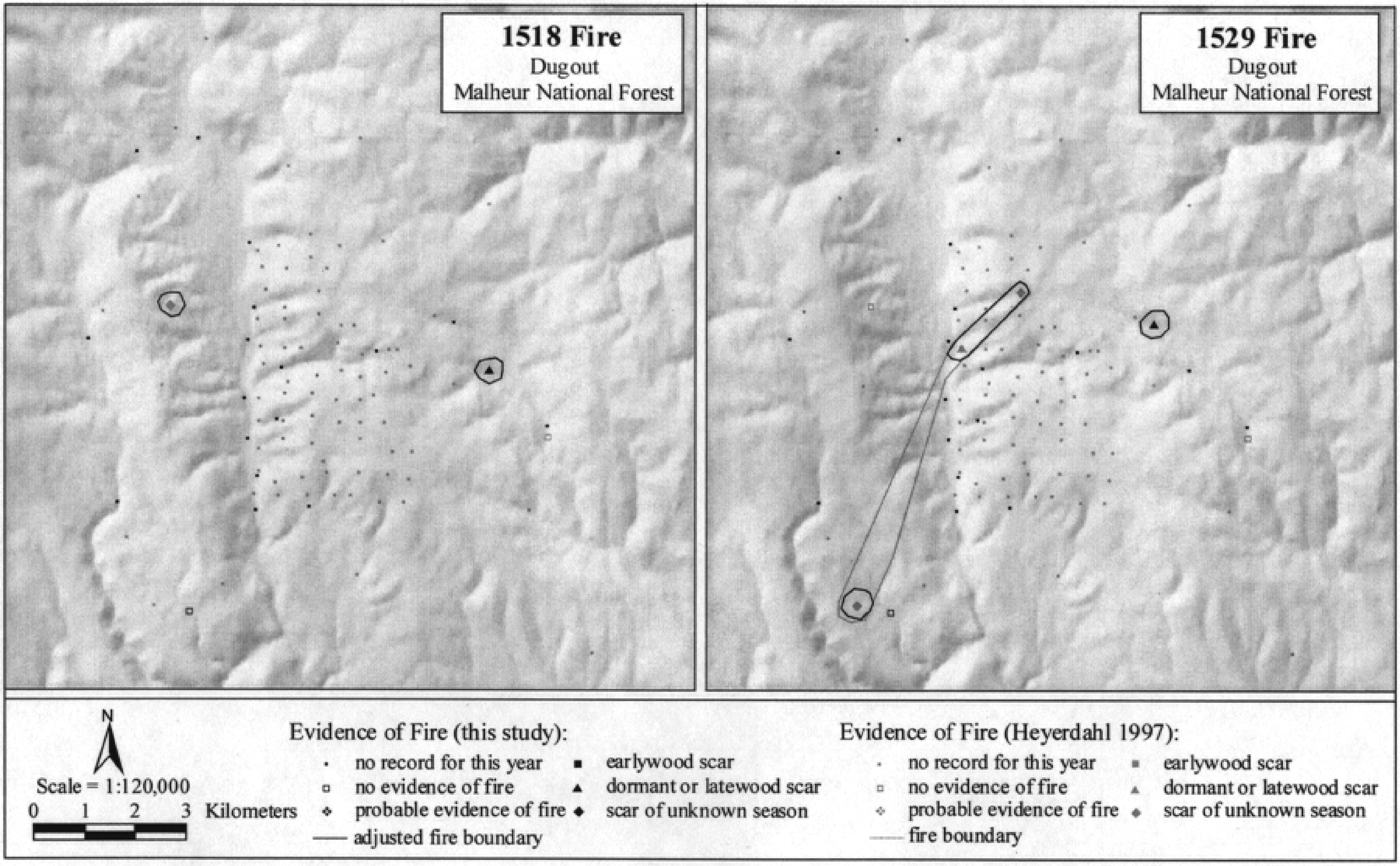

Figure 28. Dugout fire maps for 1518 (left) and 1529 (right).

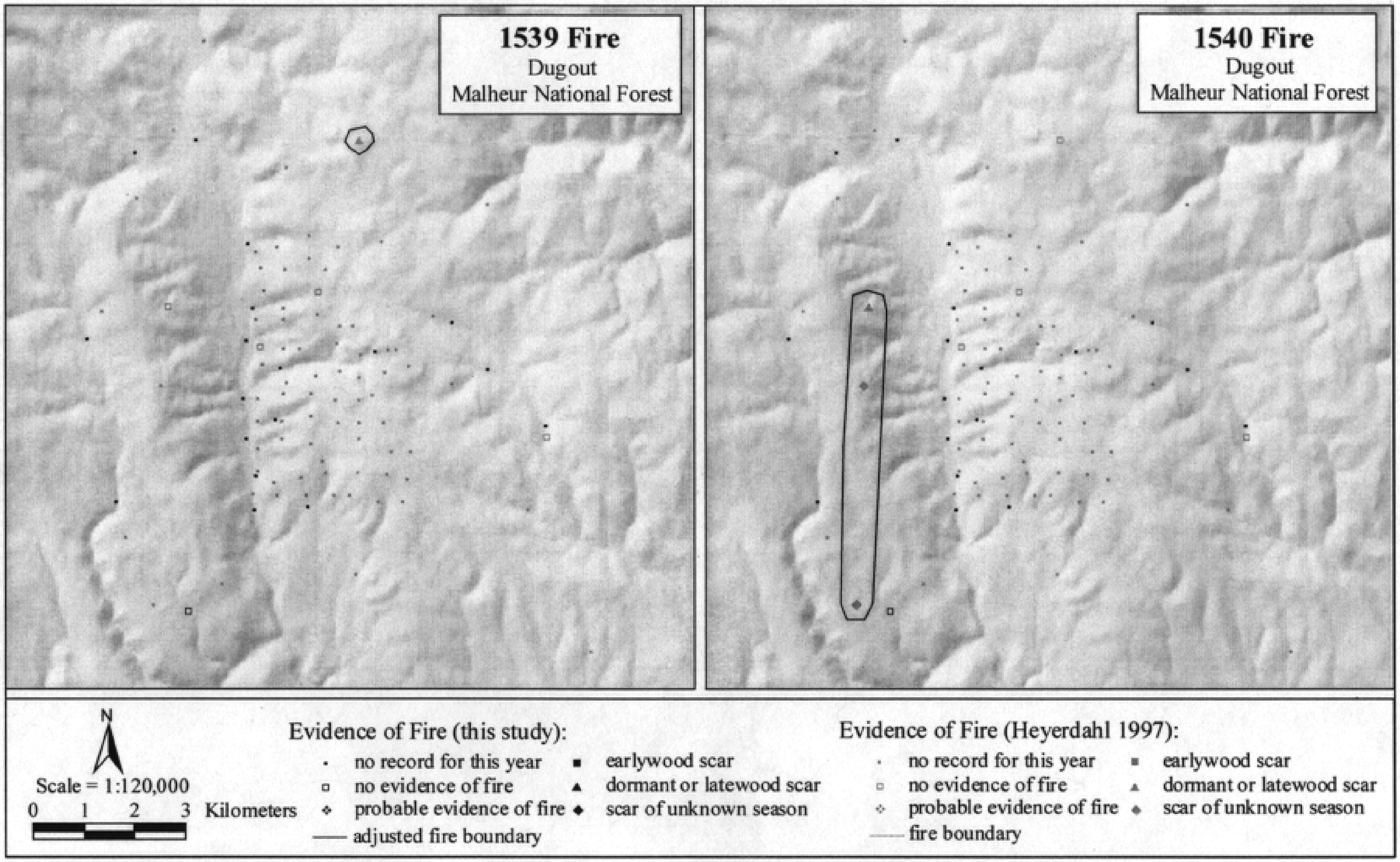

Figure 29. Dugout fire maps for 1539 (left) and 1540 (right).

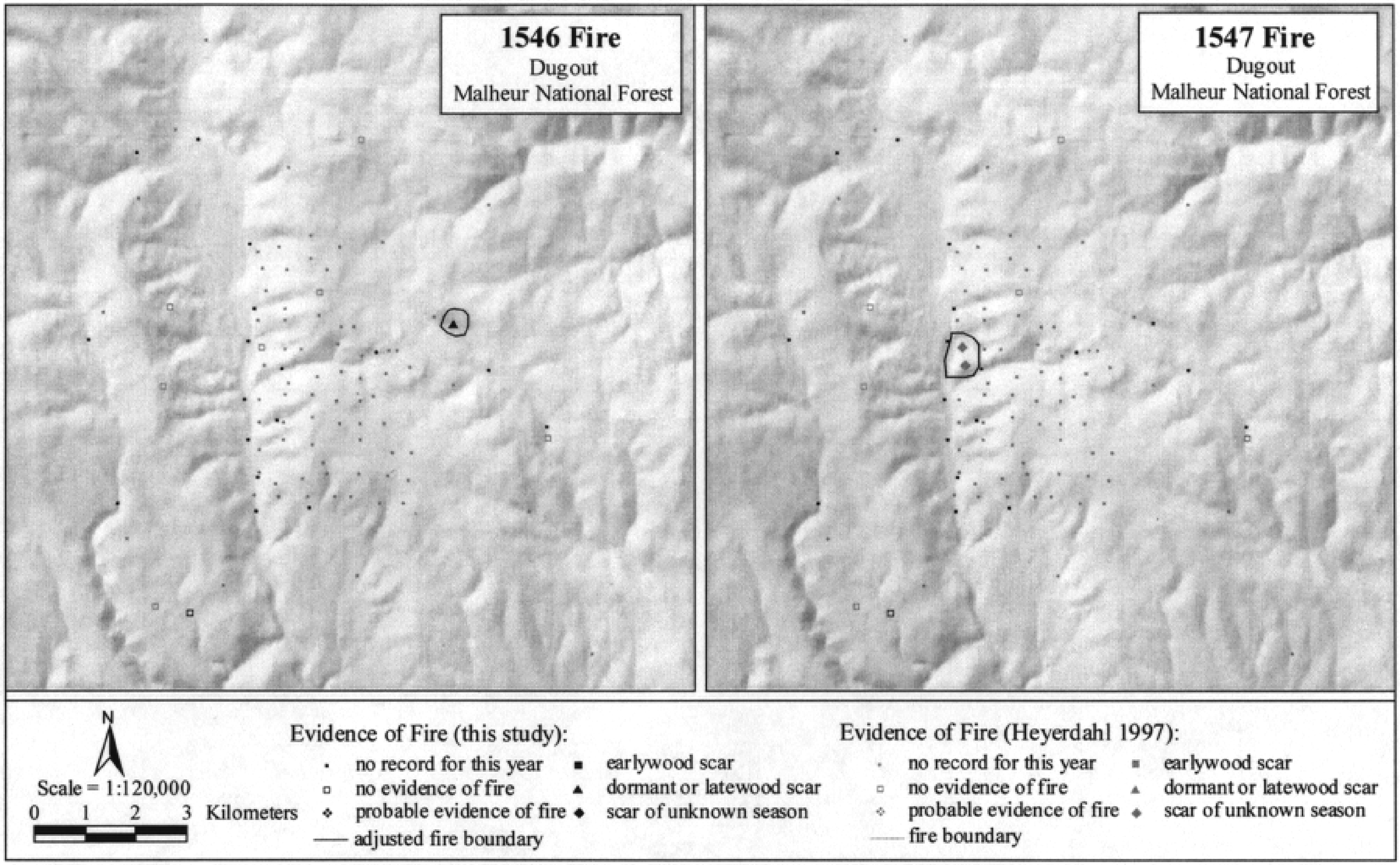

Figure 30. Dugout fire maps for 1546 (left) and 1547 (right).

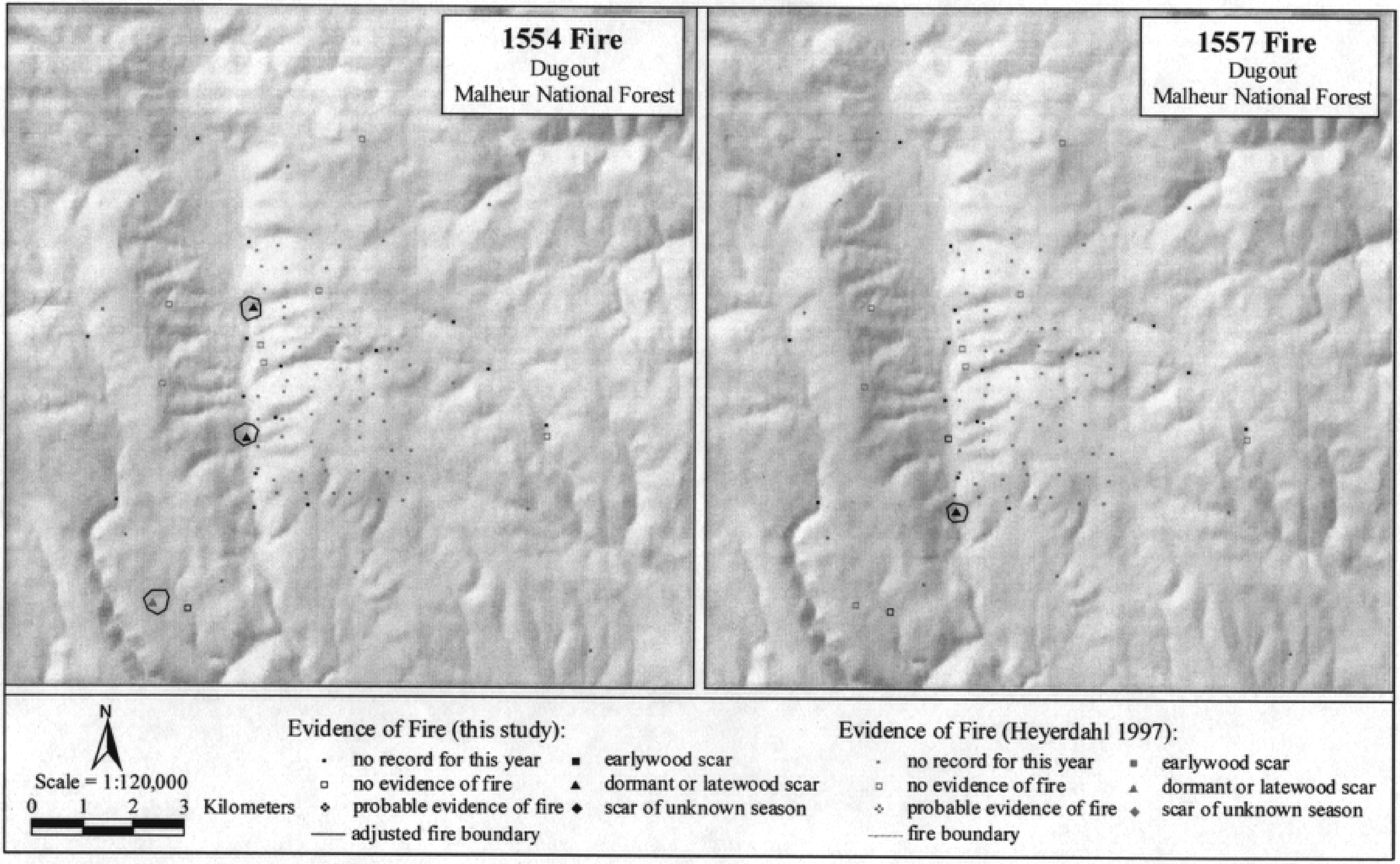

Figure 31. Dugout fire maps for 1554 (left) and 1557 (right).

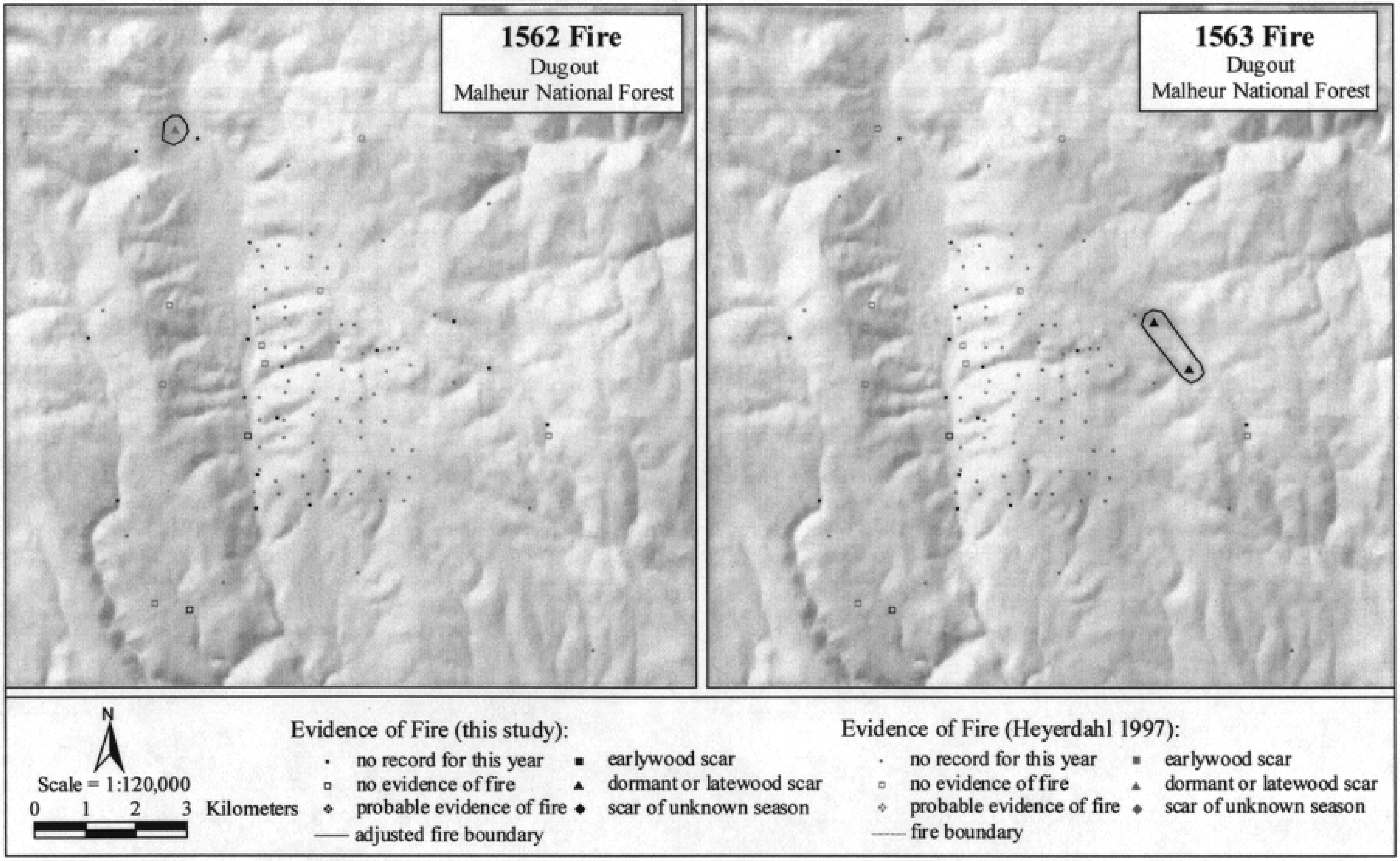

Figure 32. Dugout fire maps for 1562 (left) and 1563 (right).

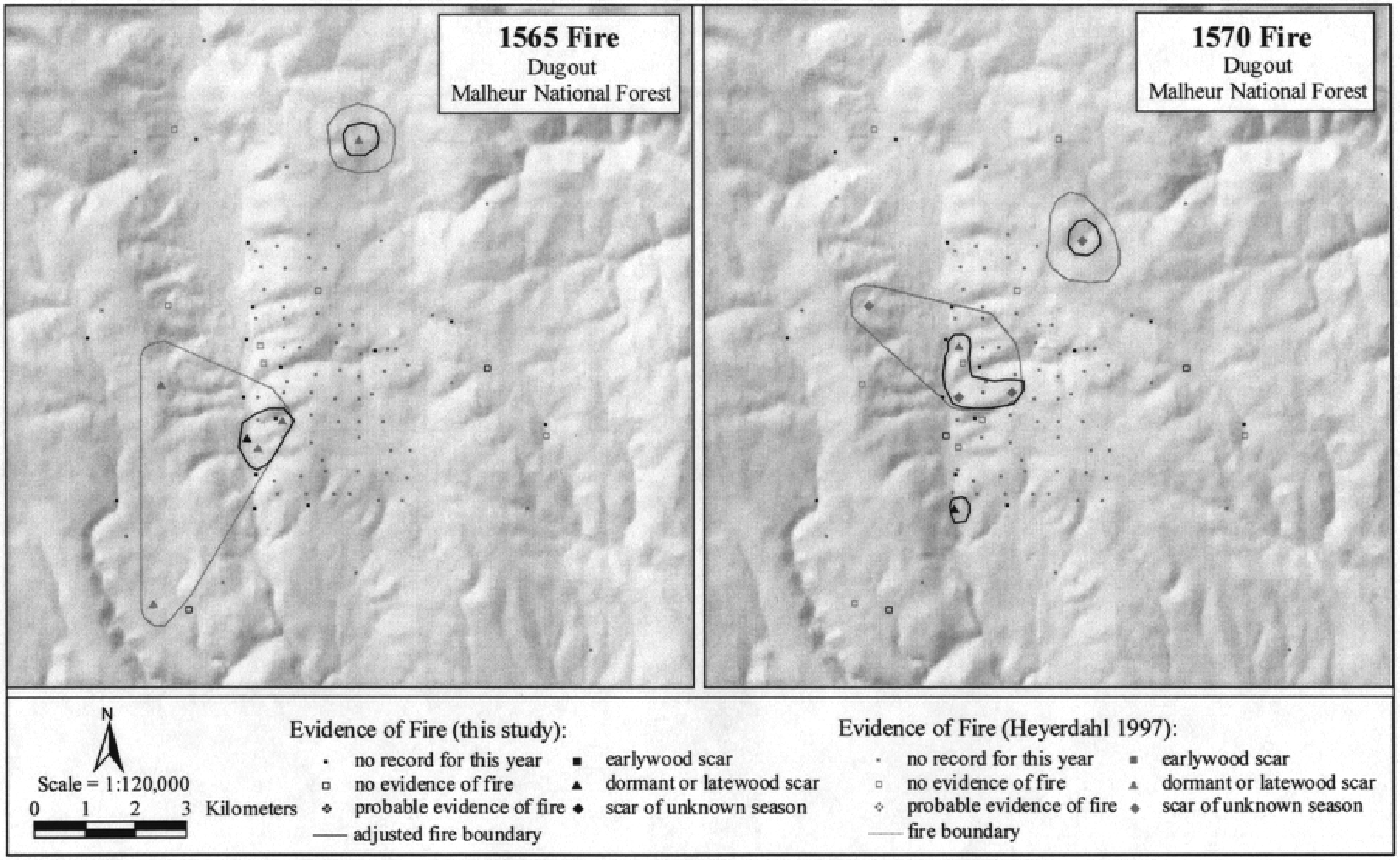

Figure 33. Dugout fire maps for 1565 (left) and 1570 (right).

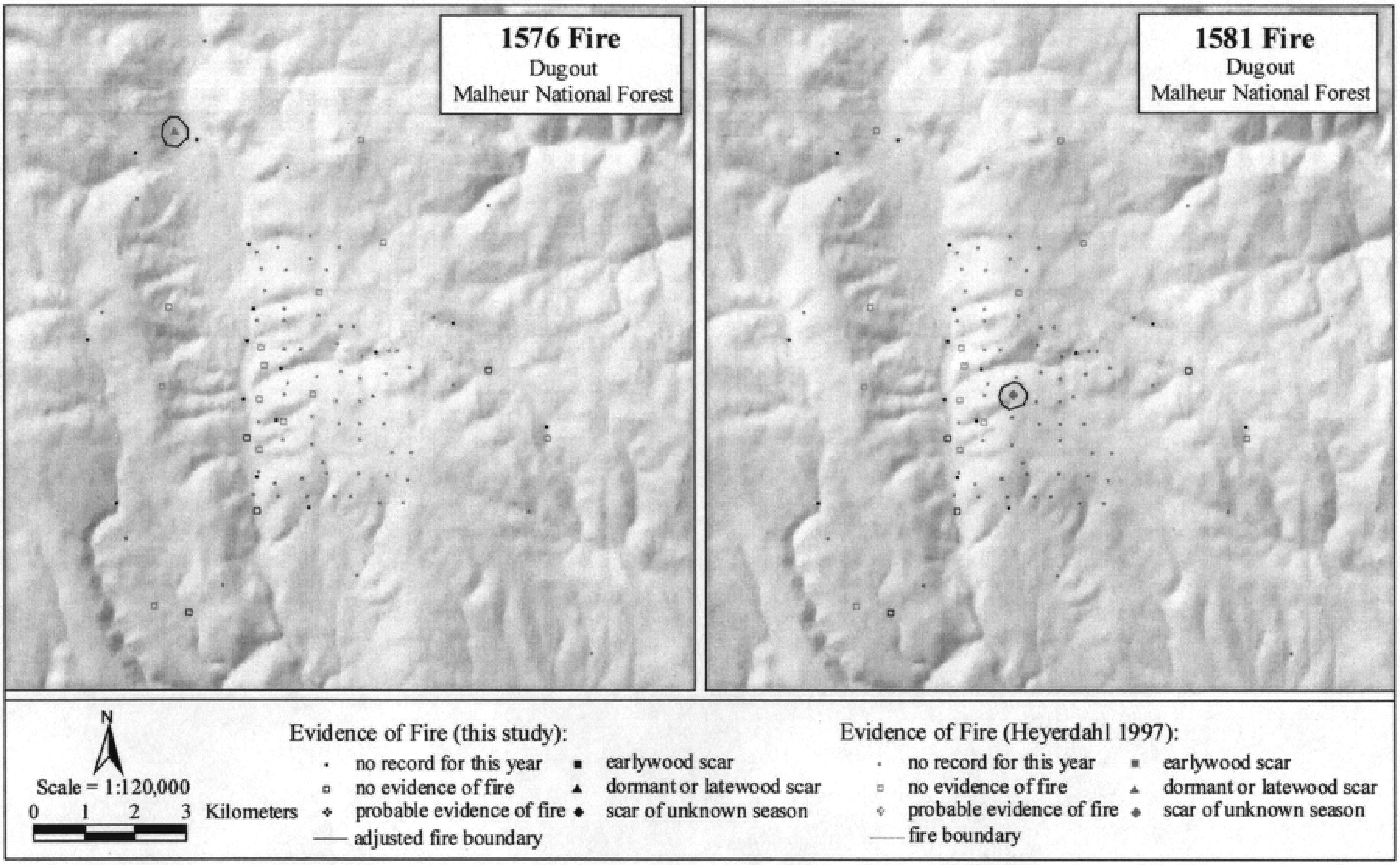

Figure 34. Dugout fire maps for 1576 (left) and 1581 (right).

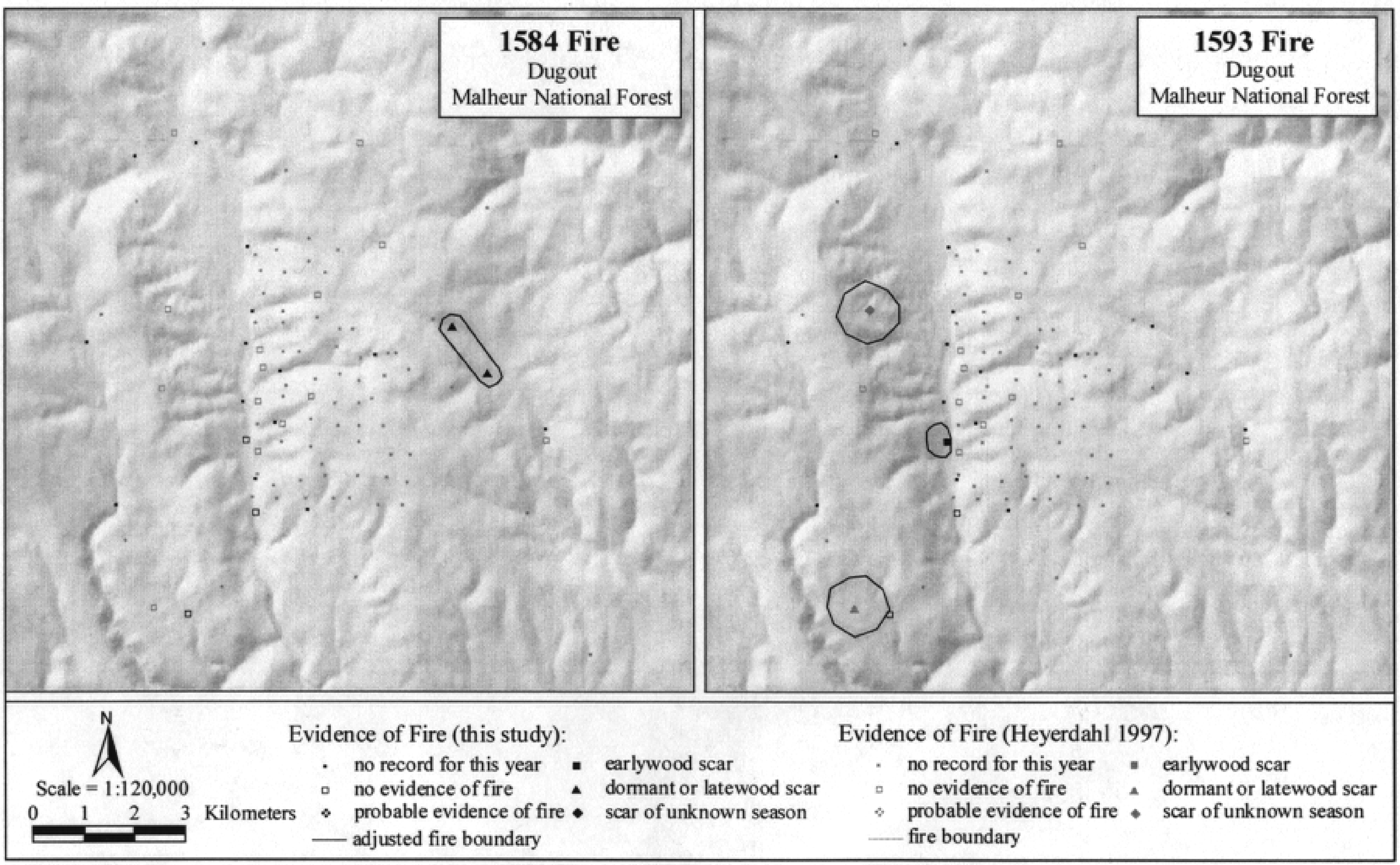

Figure 35. Dugout fire maps for 1584 (left) and 1593 (right).

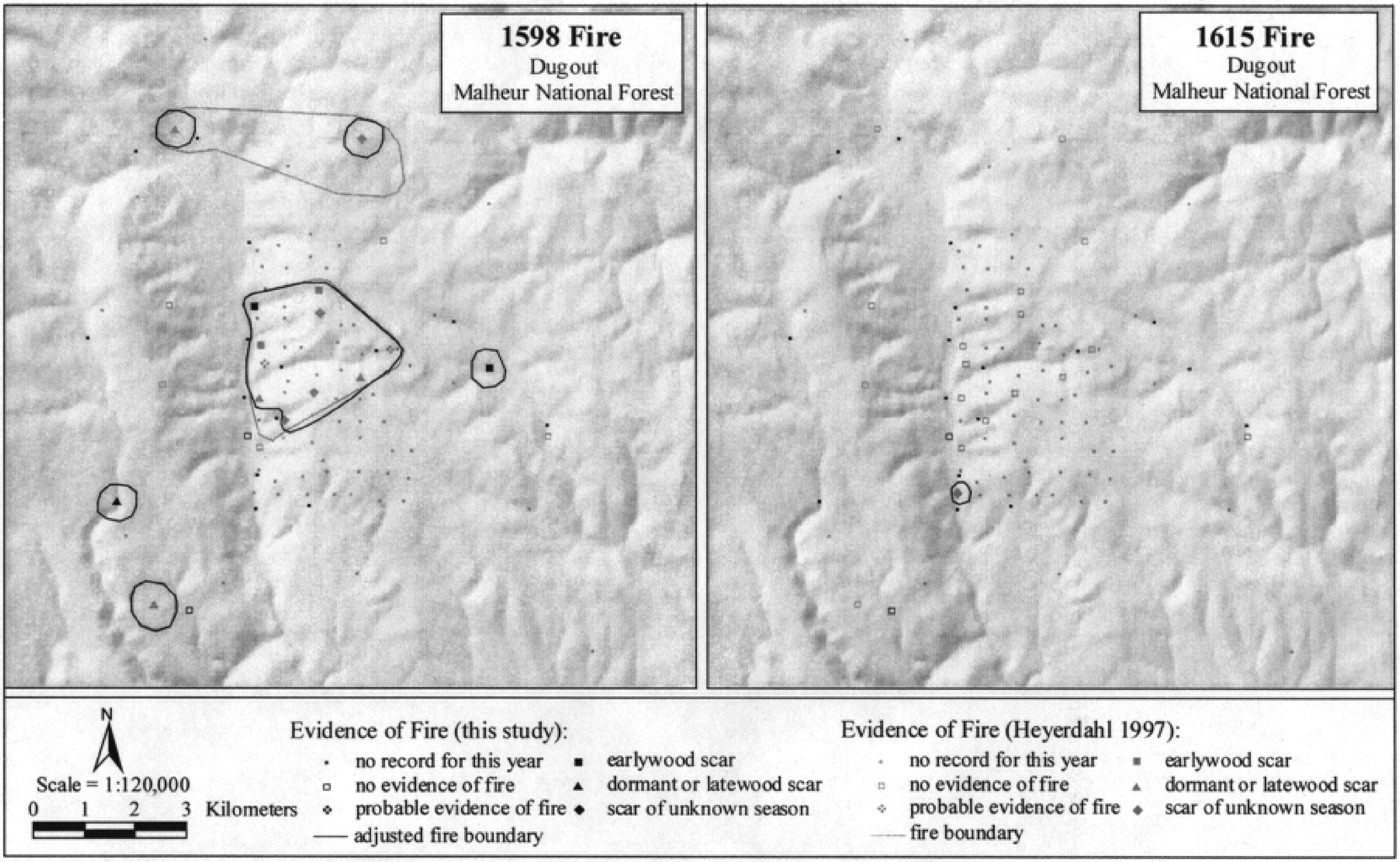

Figure 36. Dugout fire maps for 1598 (left) and 1615 (right).

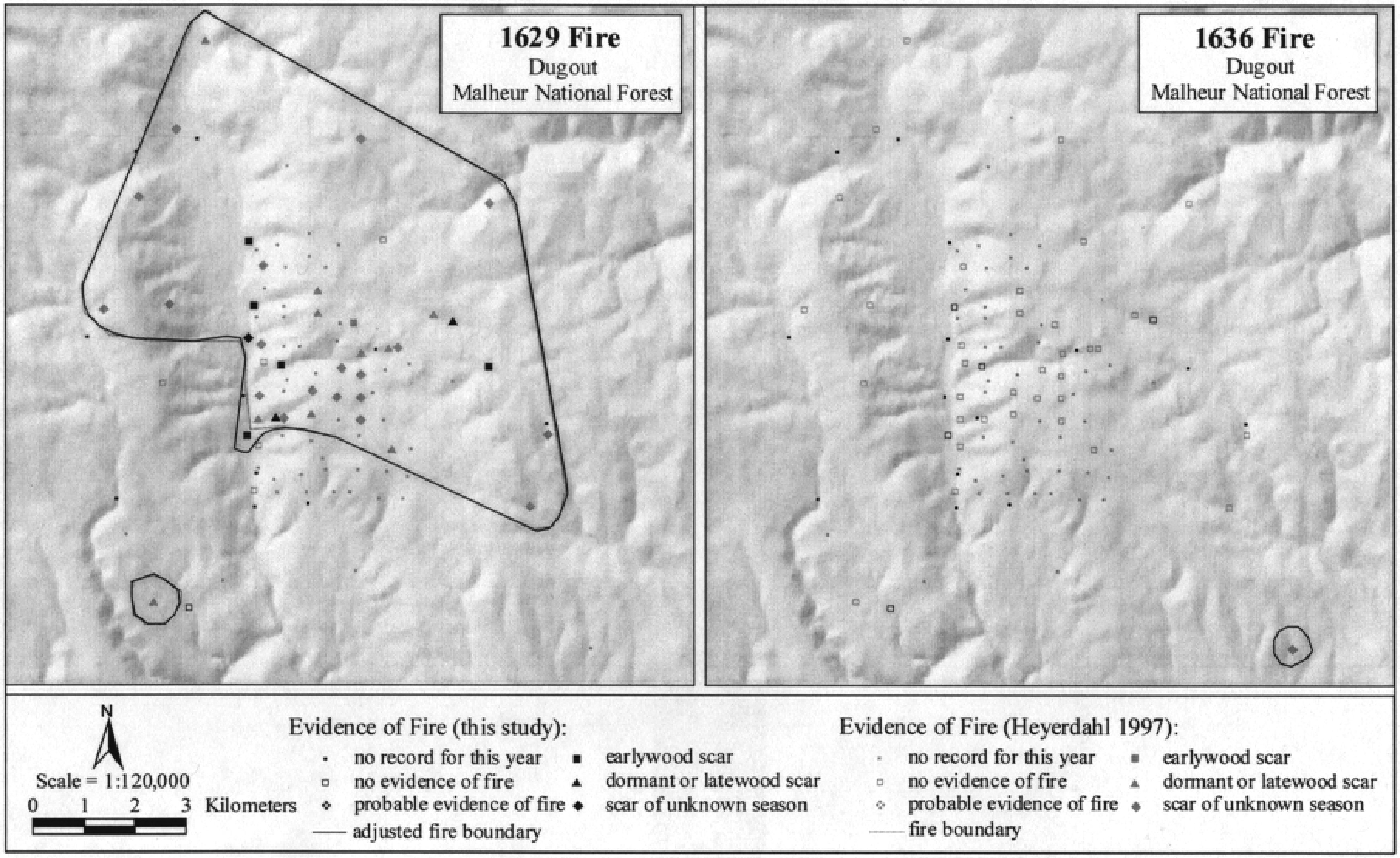

Figure 37. Dugout fire maps for 1629 (left) and 1636 (right).

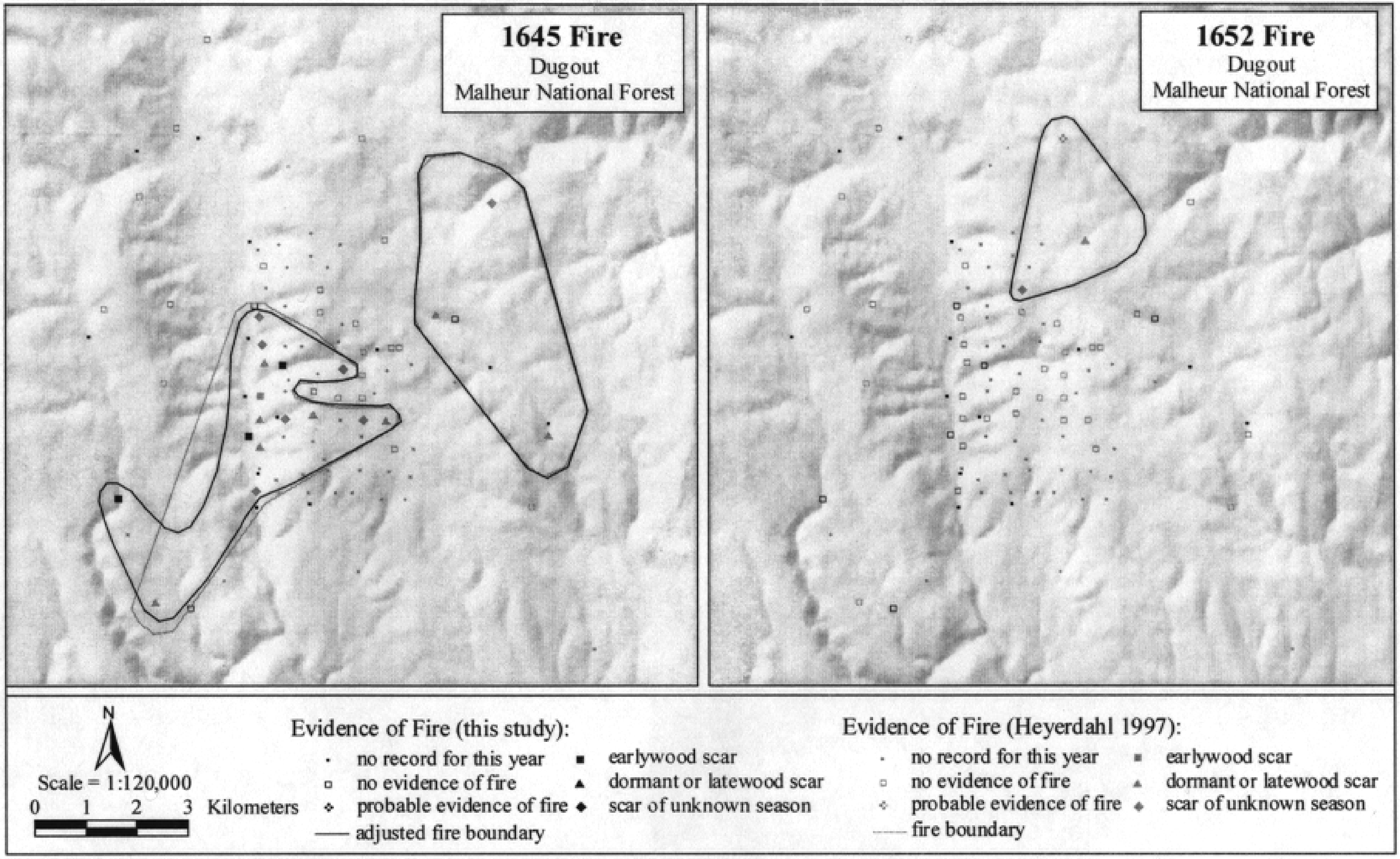

Figure 38. Dugout fire maps for 1645 (left) and 1652 (right).

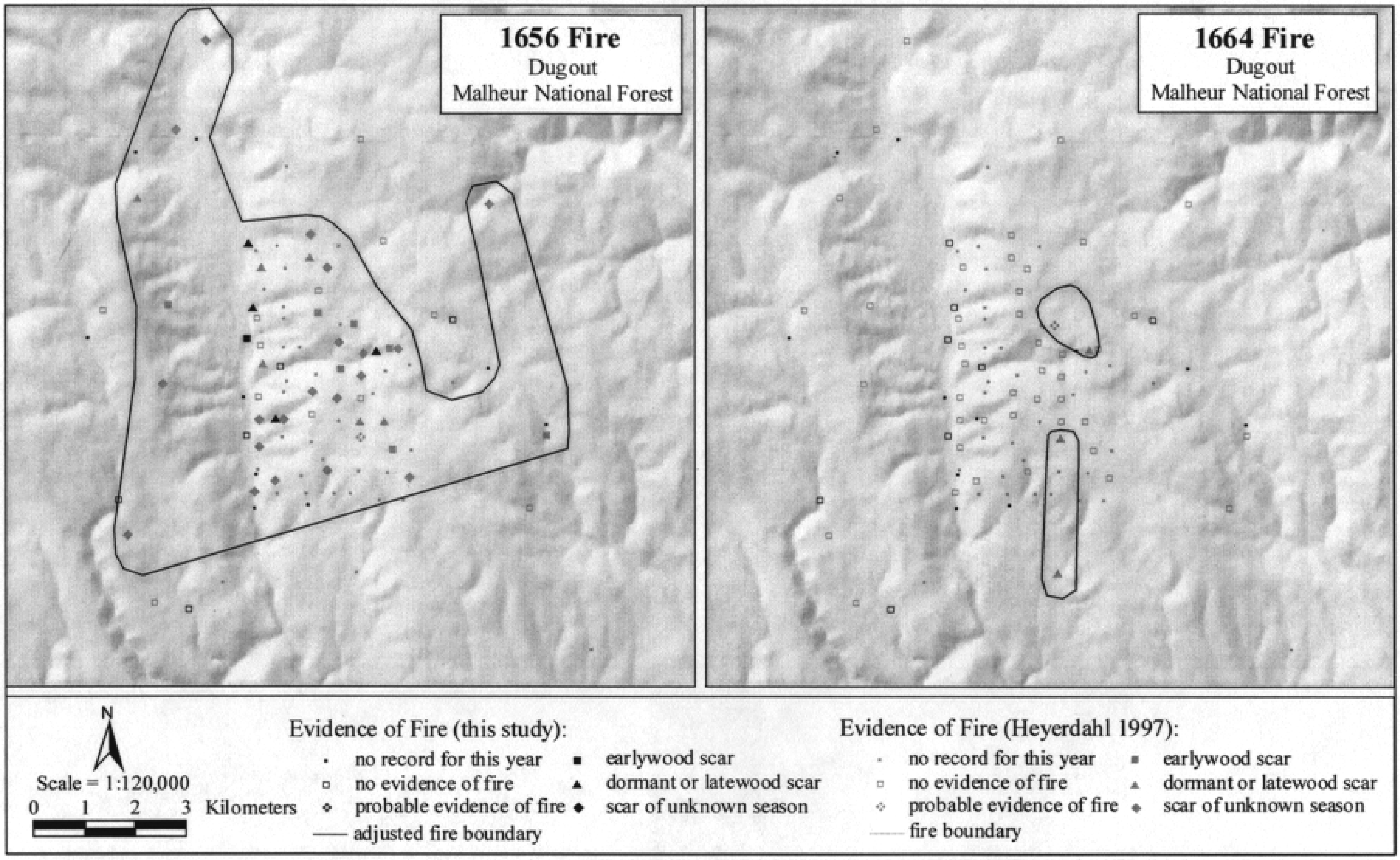

Figure 39. Dugout fire maps for 1656 (left) and 1664 (right).

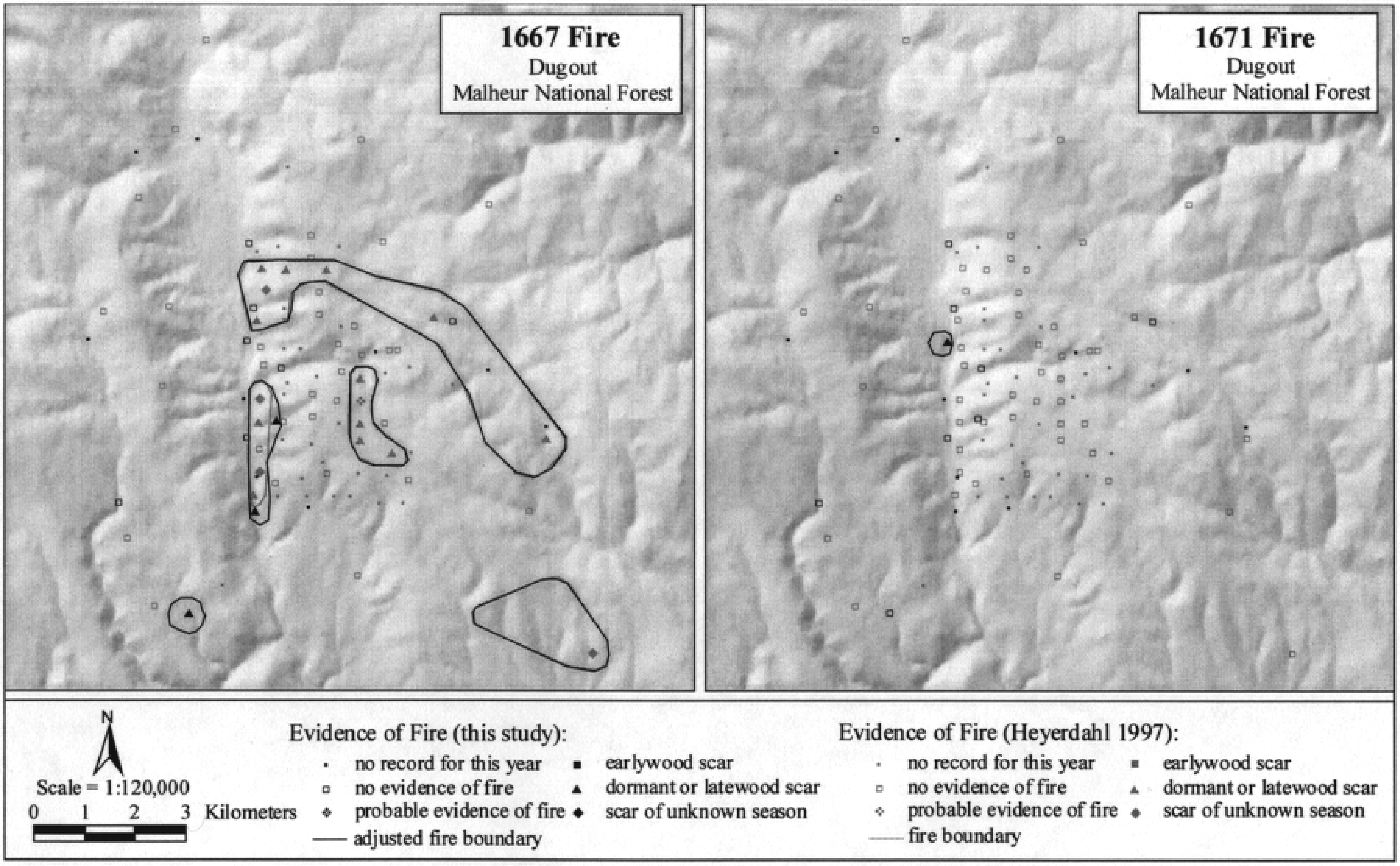

Figure 40. Dugout fire maps for 1667 (left) and 1671 (right).

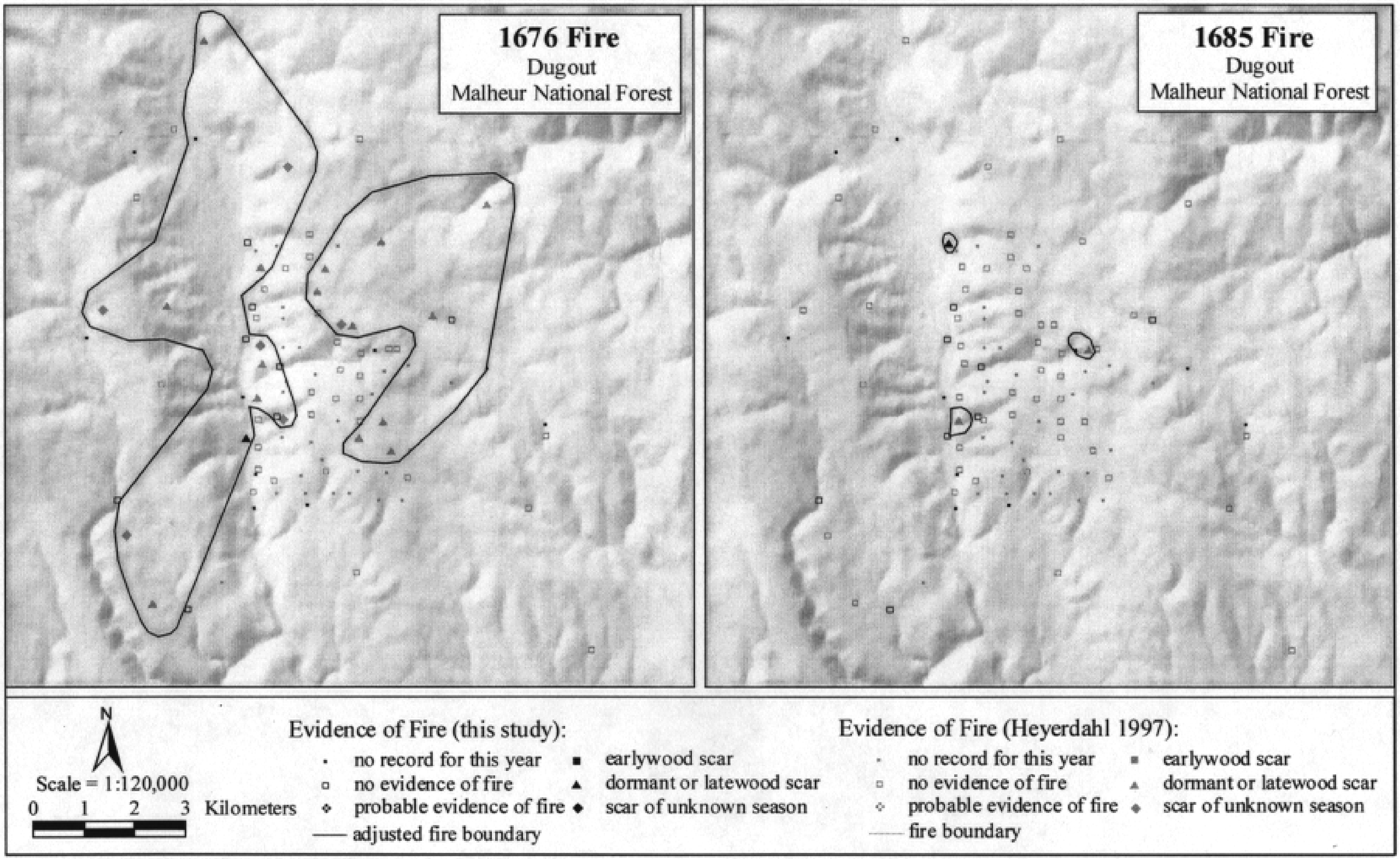

Figure 41. Dugout fire maps for 1676 (left) and 1685 (right).

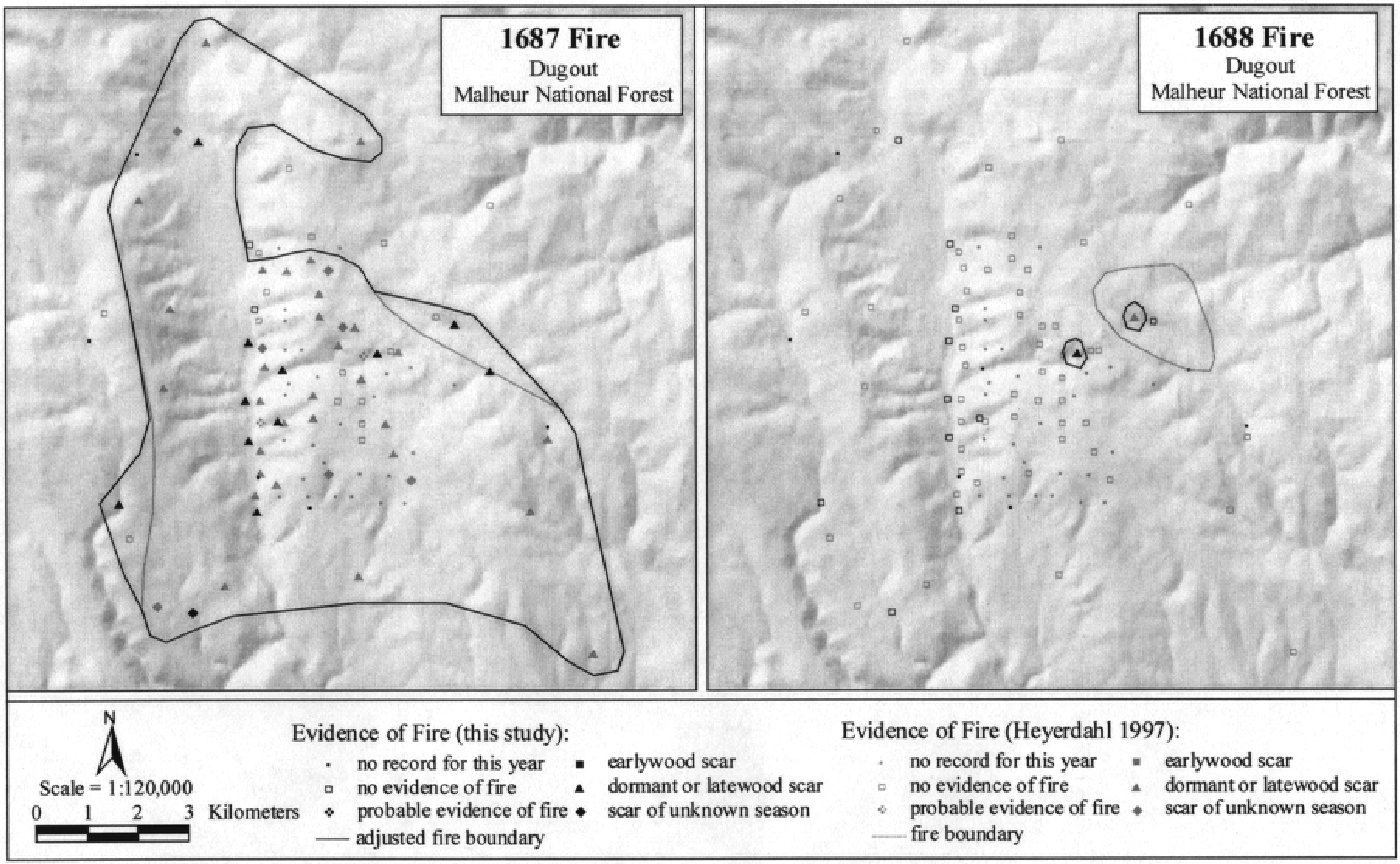

Figure 42. Dugout fire maps for 1687 (left) and 1688 (right).

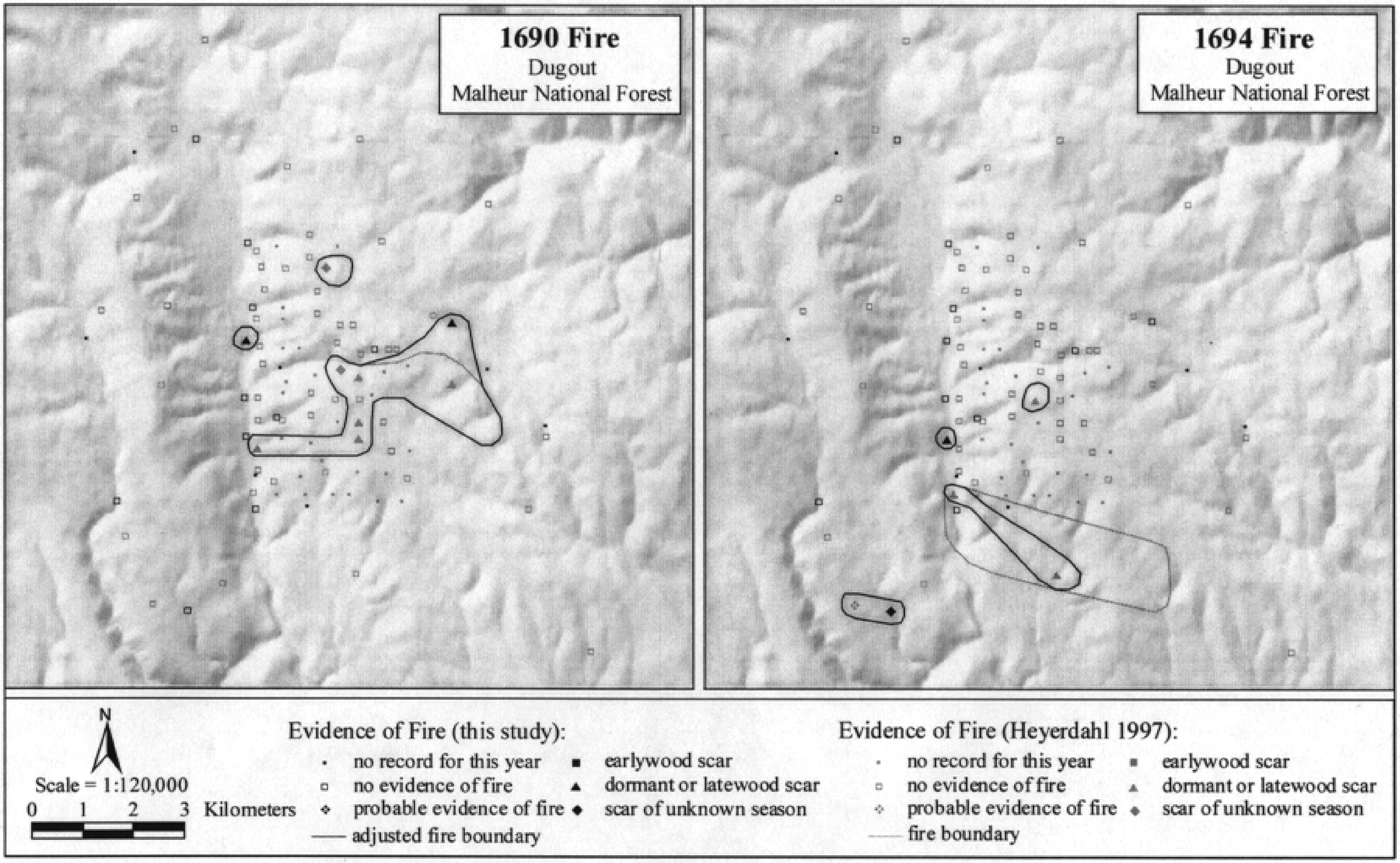

Figure 43. Dugout fire maps for 1690 (left) and 1694 (right).

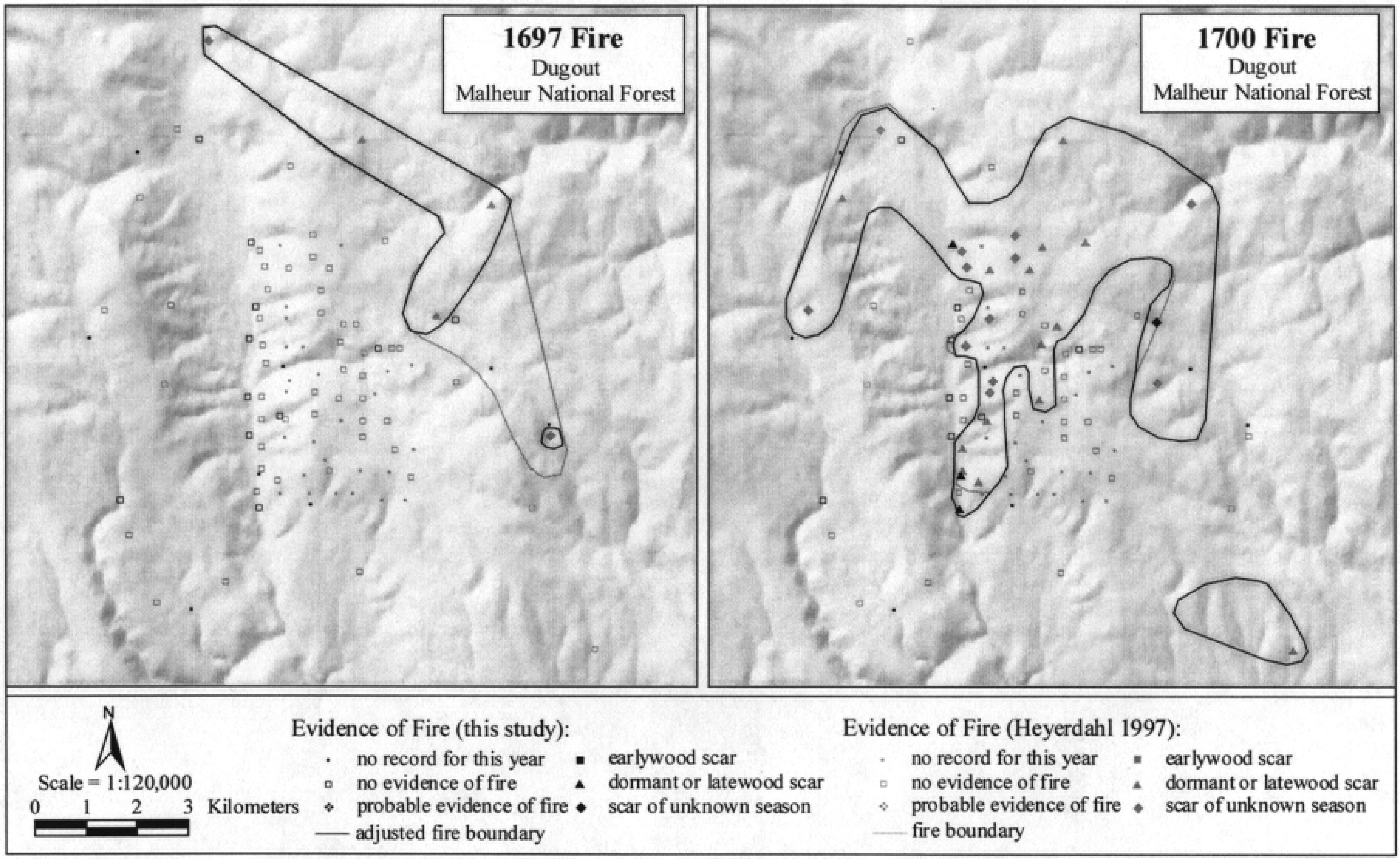

Figure 44. Dugout fire maps for 1697 (left) and 1700 (right).

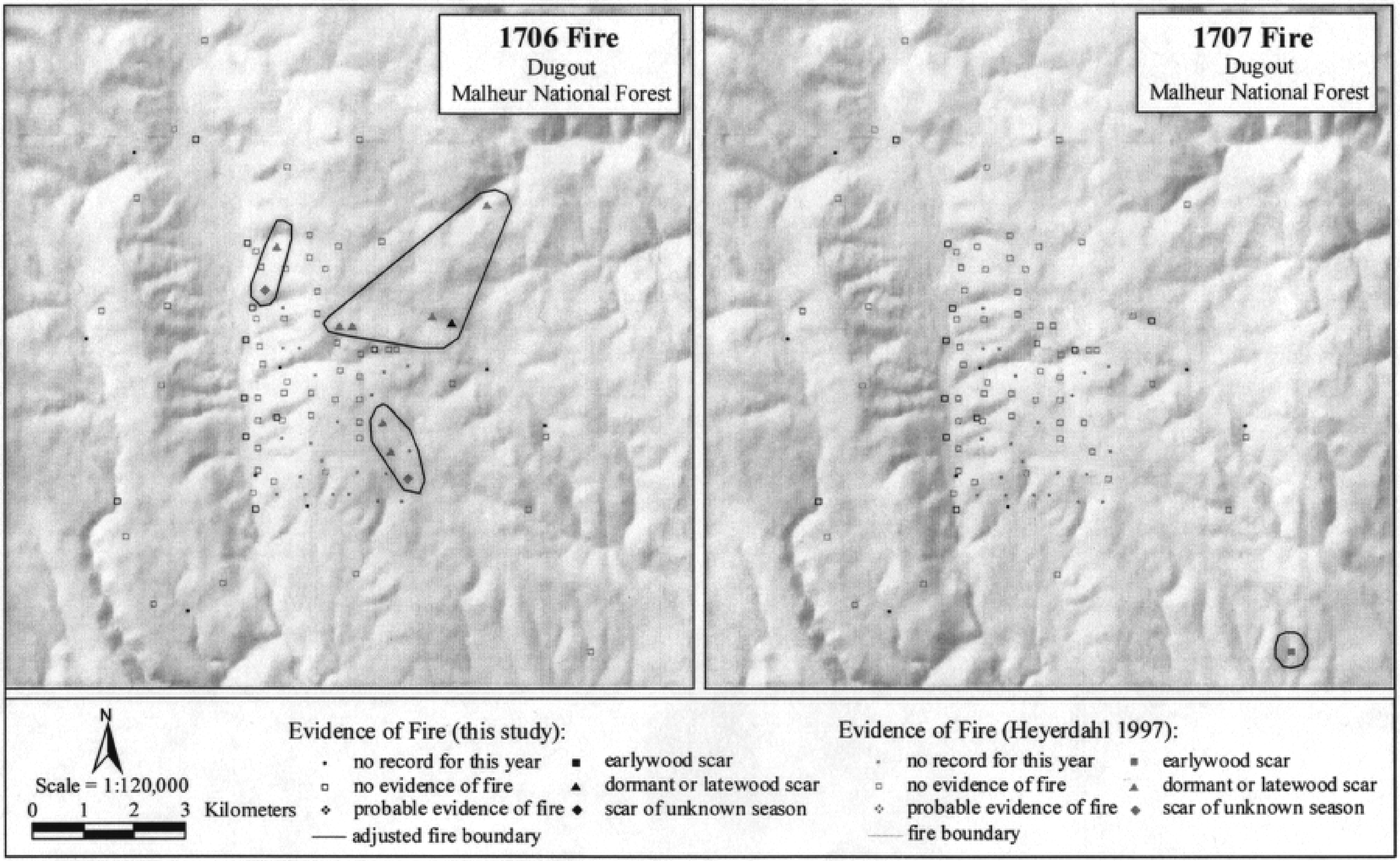

Figure 45. Dugout fire maps for 1706 (left) and 1707 (right).

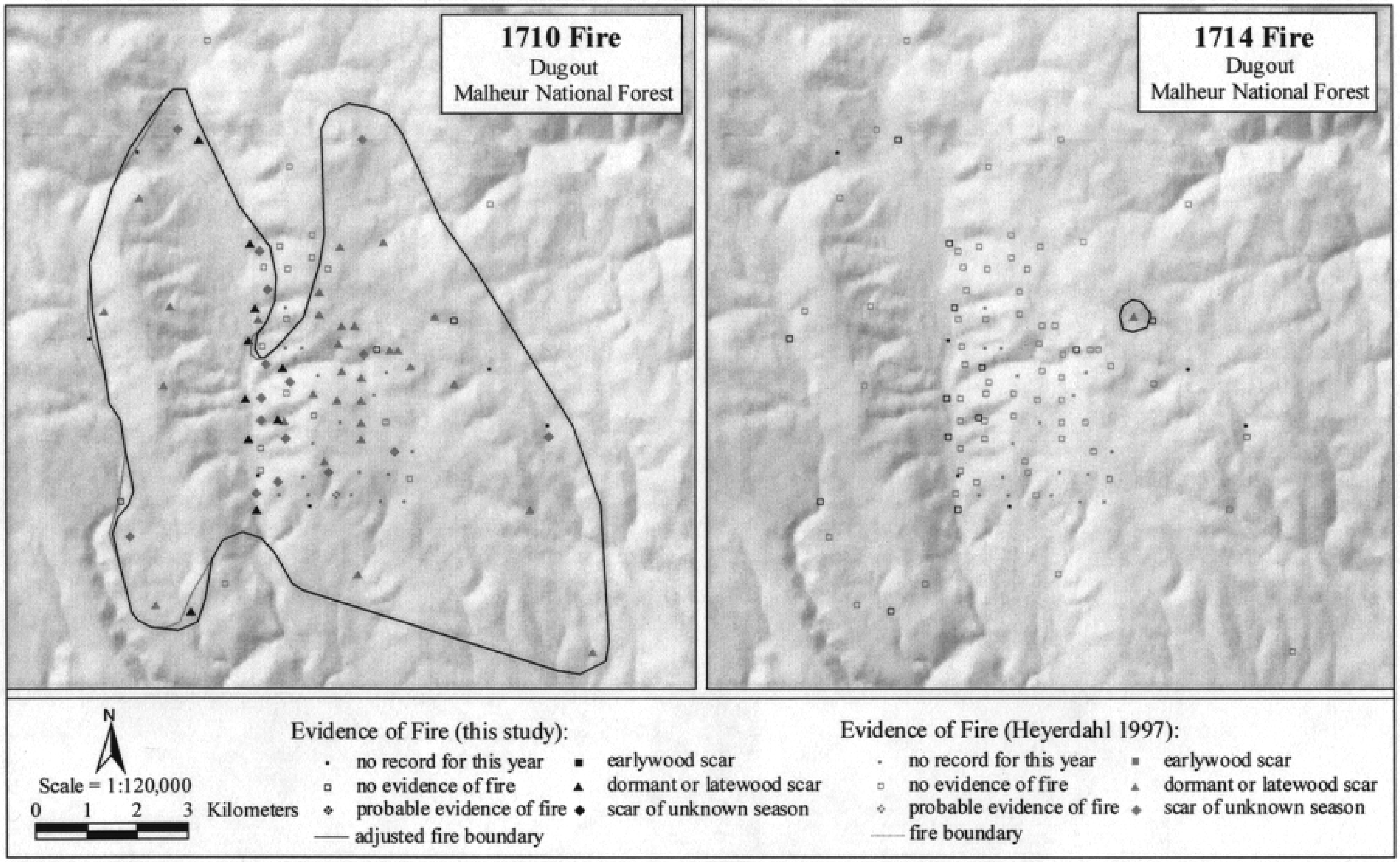

Figure 46. Dugout fire maps for 1710 (left) and 1714 (right).

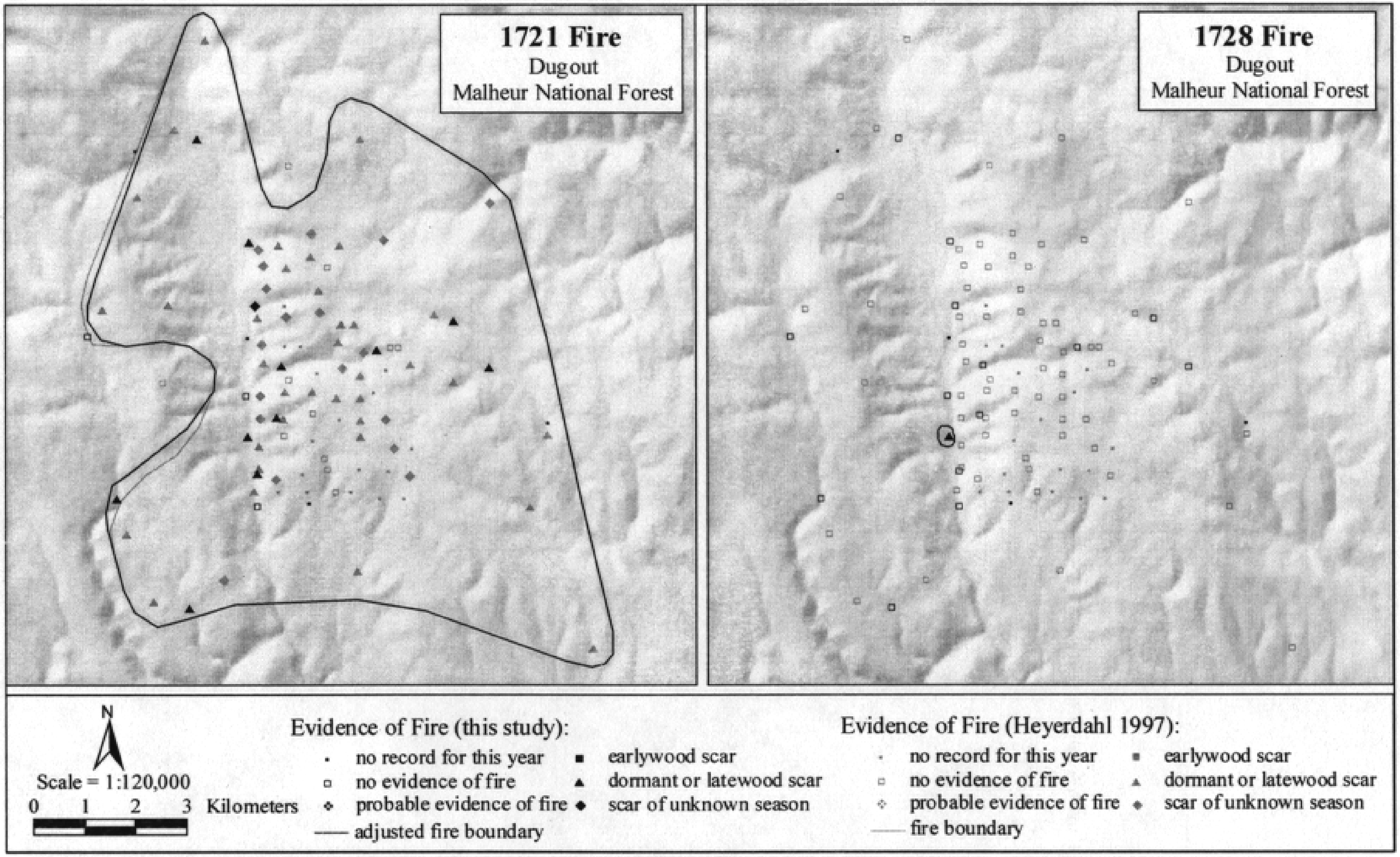

Figure 47. Dugout fire maps for 1721 (left) and 1728 (right).

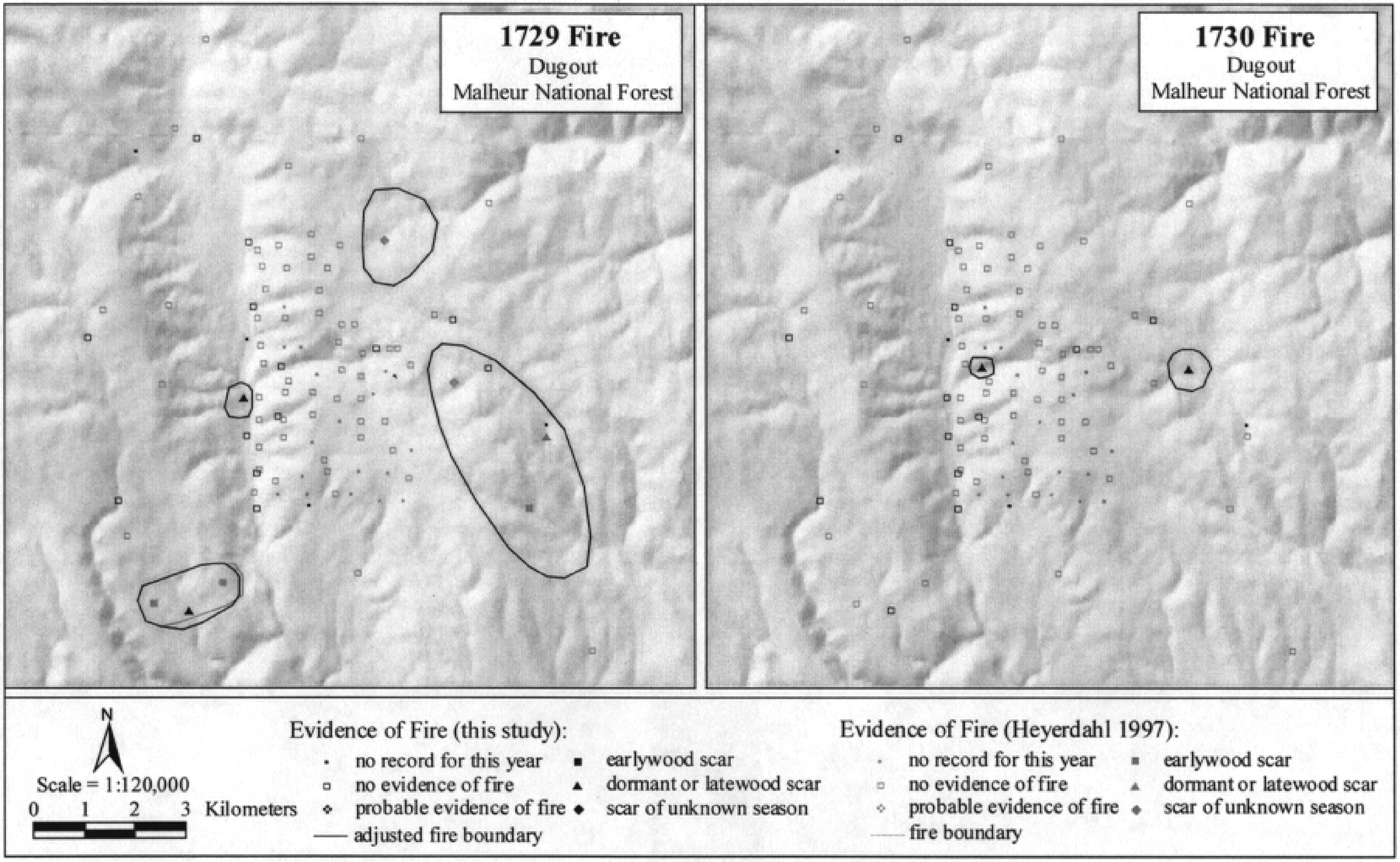

Figure 48. Dugout fire maps for 1729 (left) and 1730 (right).

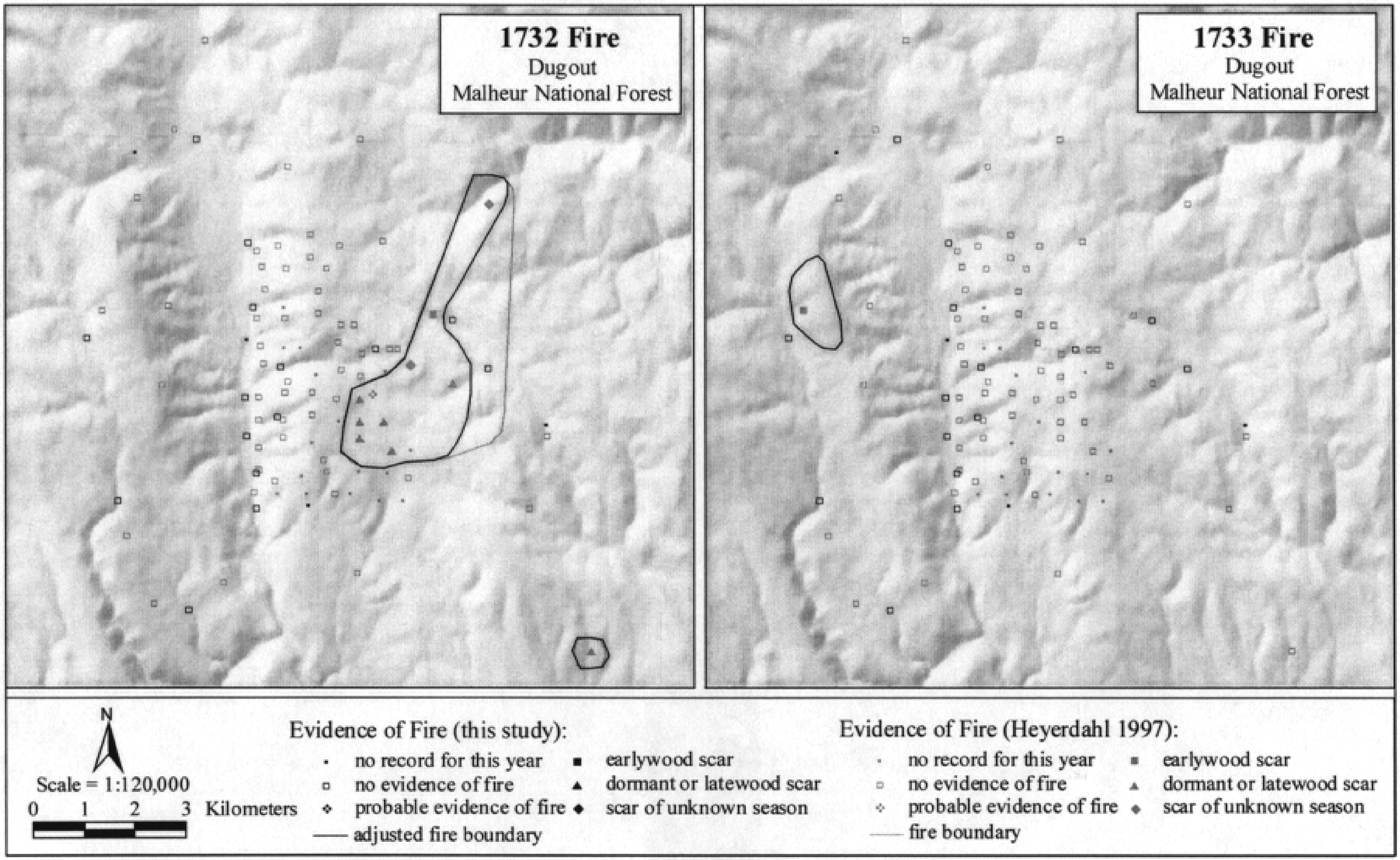

Figure 49. Dugout fire maps for 1732 (left) and 1733 (right).

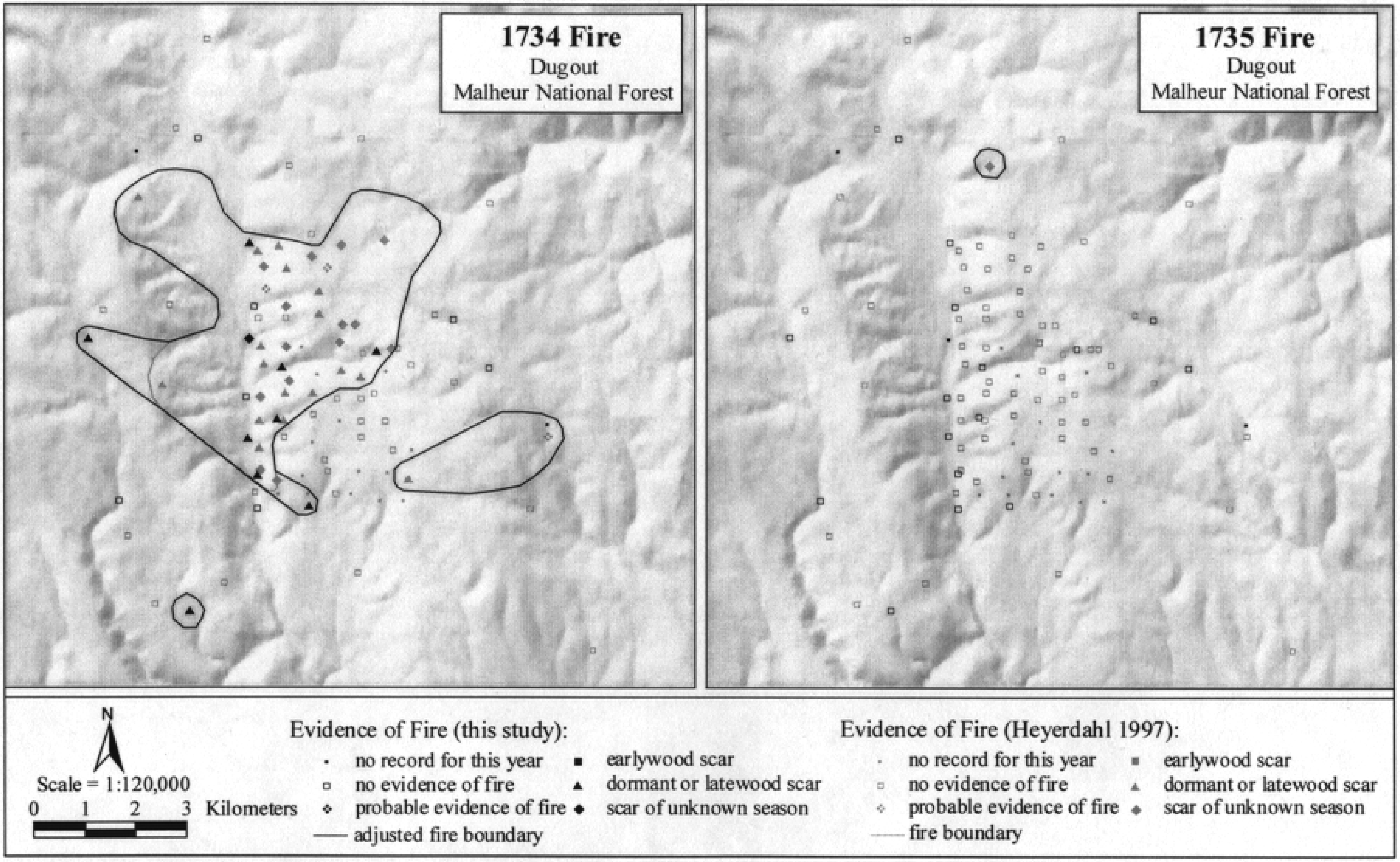

Figure 50. Dugout fire maps for 1734 (left) and 1735 (right).

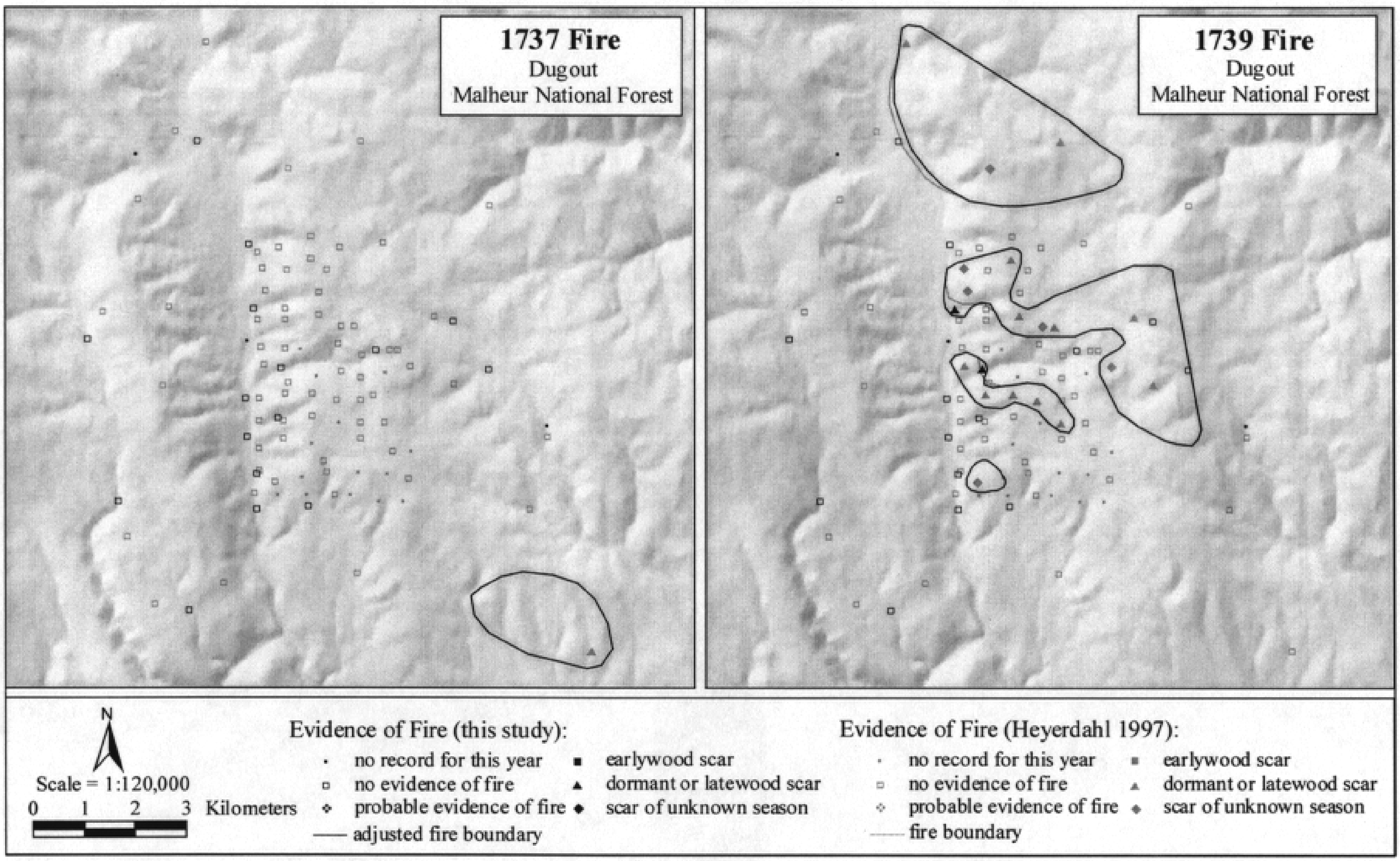

Figure 51. Dugout fire maps for 1737 (left) and 1739 (right).

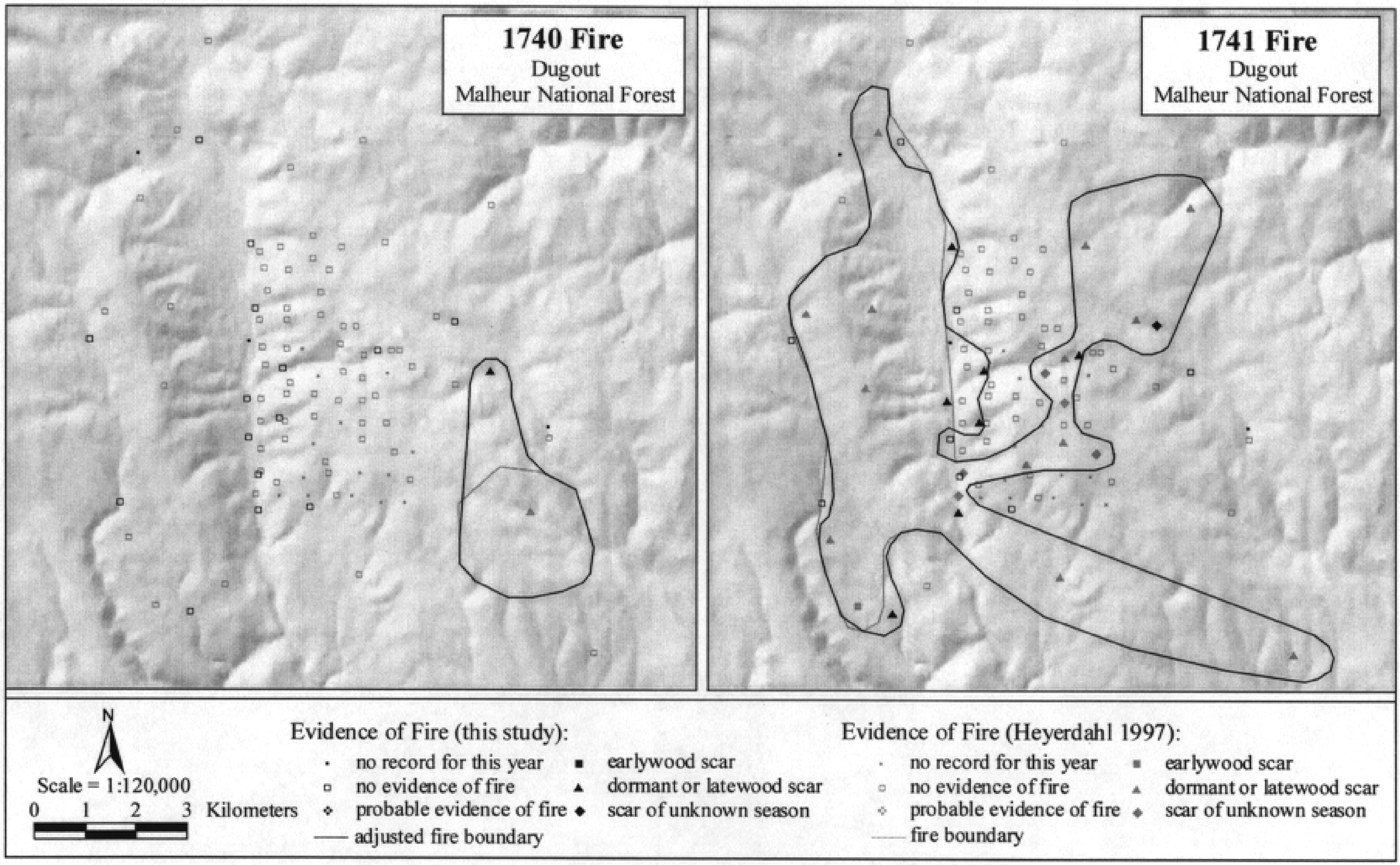

Figure 52. Dugout fire maps for 1740 (left) and 1741 (right).

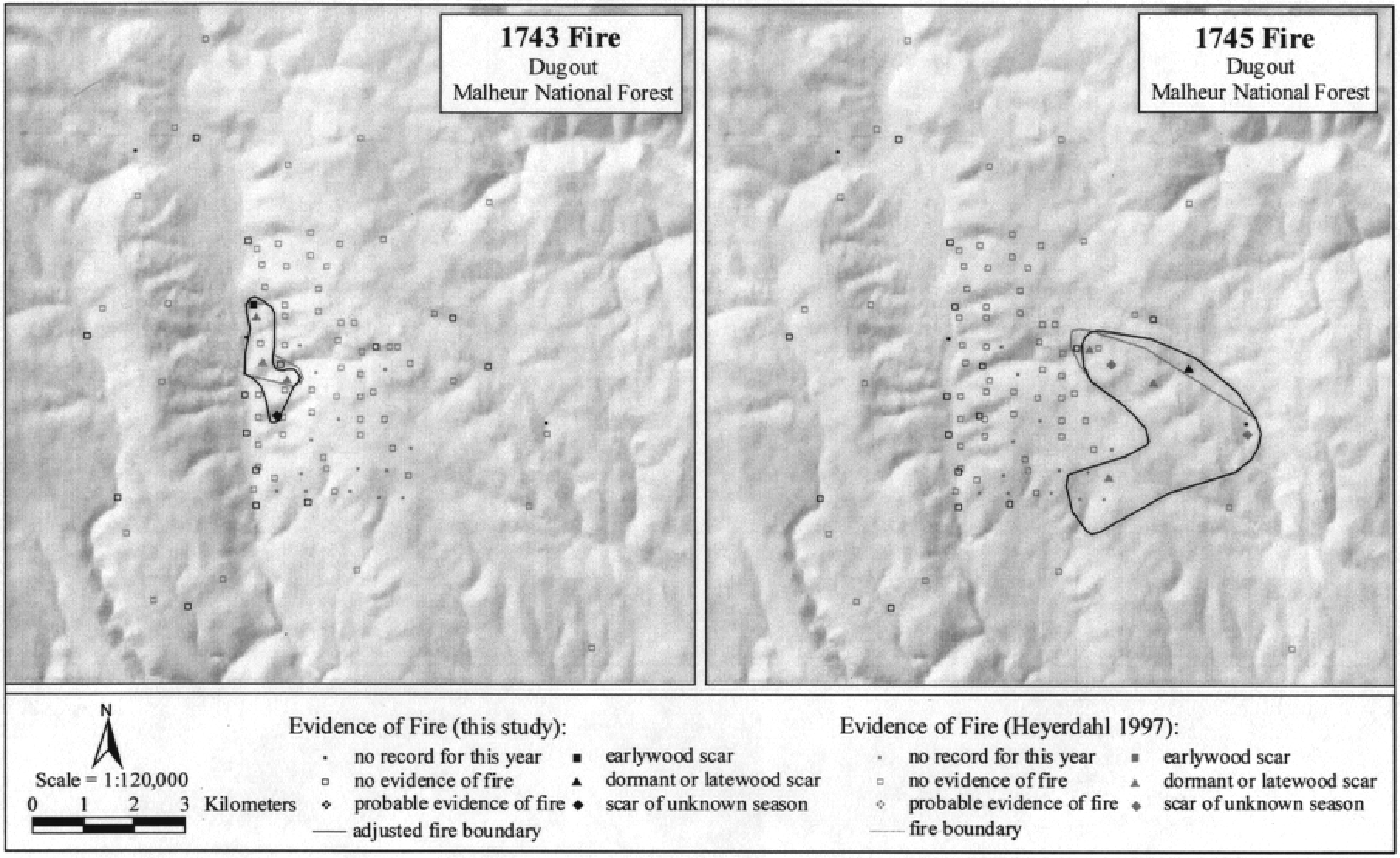

Figure 53. Dugout fire maps for 1743 (left) and 1745 (right).

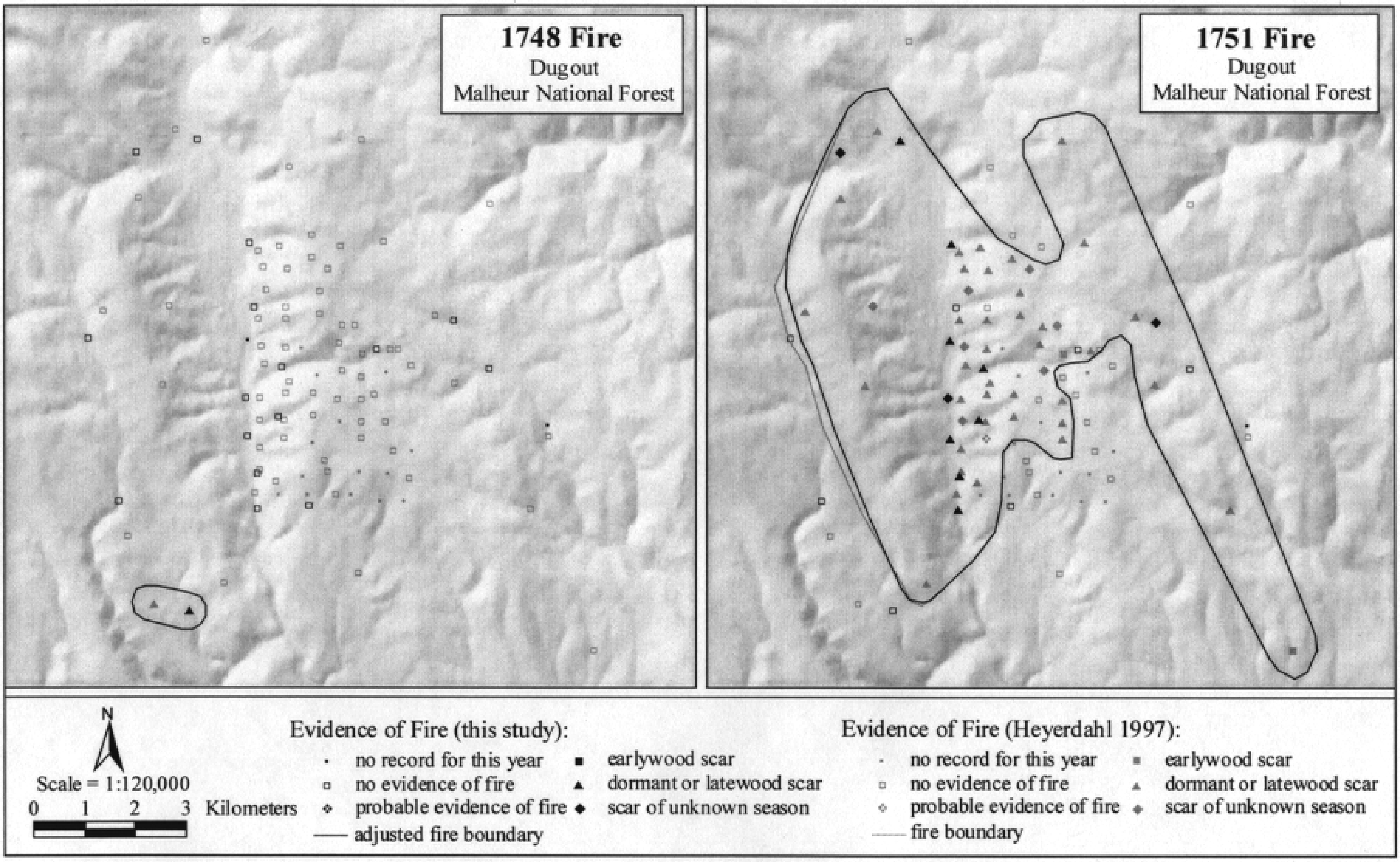

Figure 54. Dugout fire maps for 1748 (left) and 1751 (right).

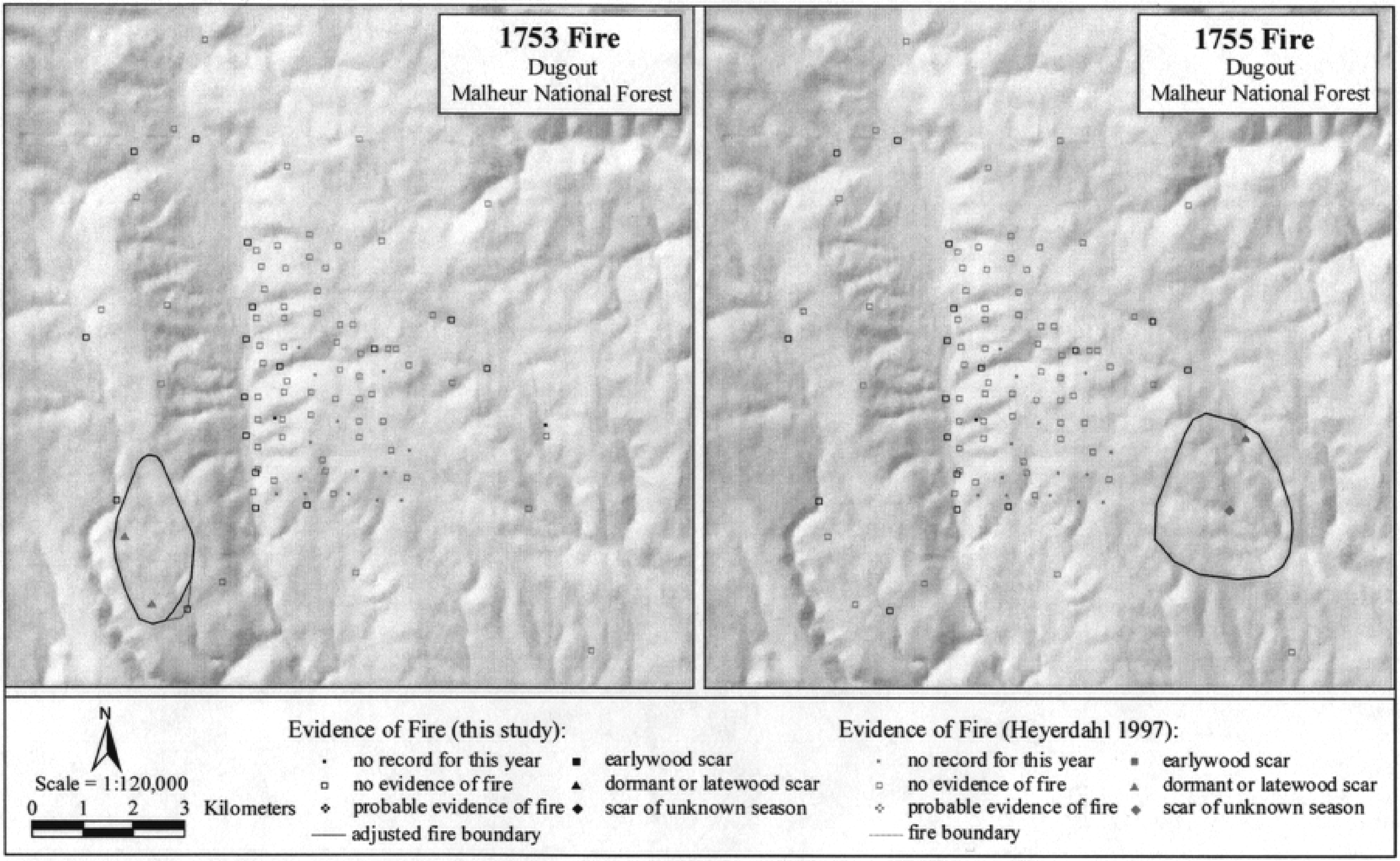

Figure 55. Dugout fire maps for 1753 (left) and 1755 (right).

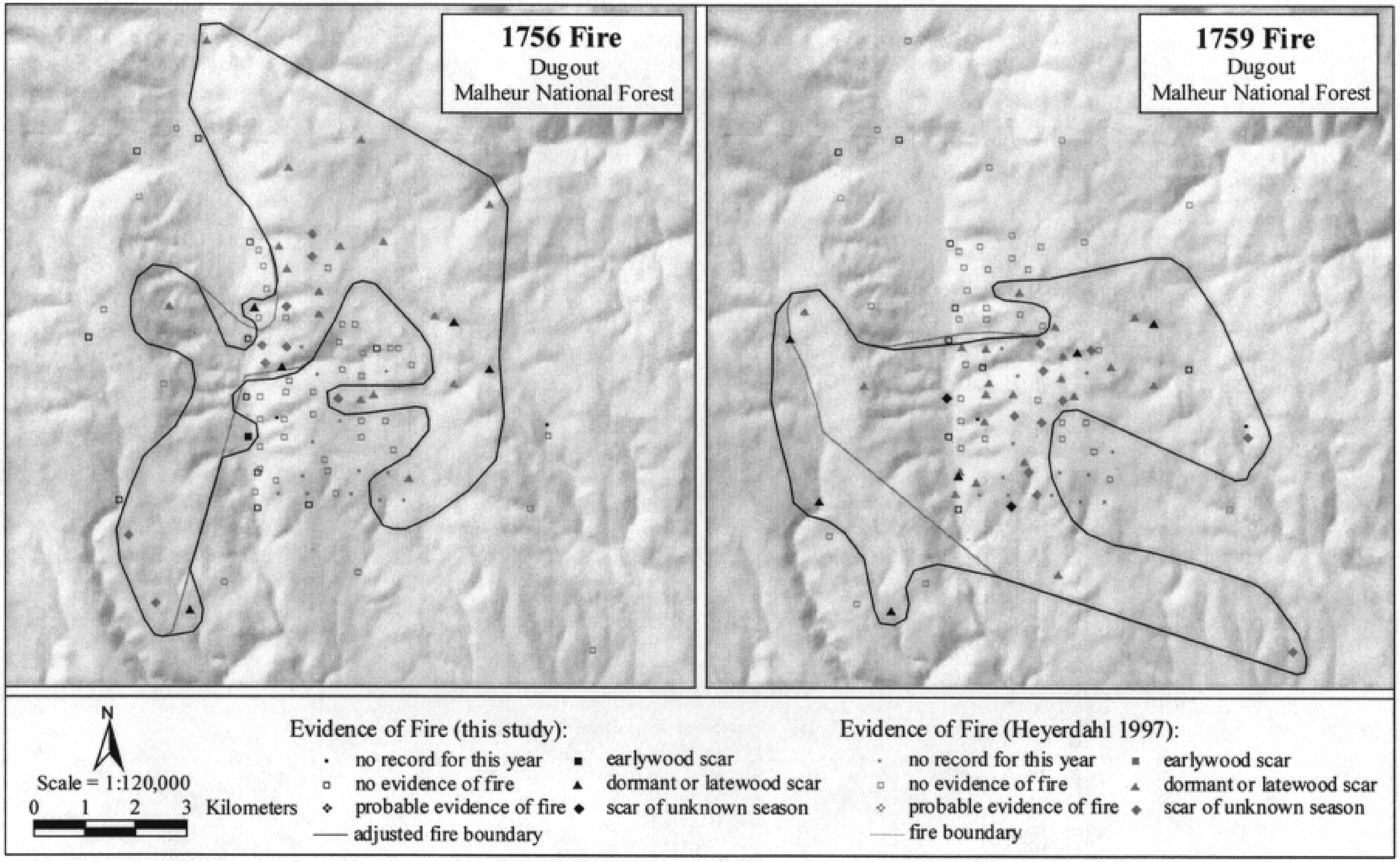

Figure 56. Dugout fire maps for 1756 (left) and 1759 (right).

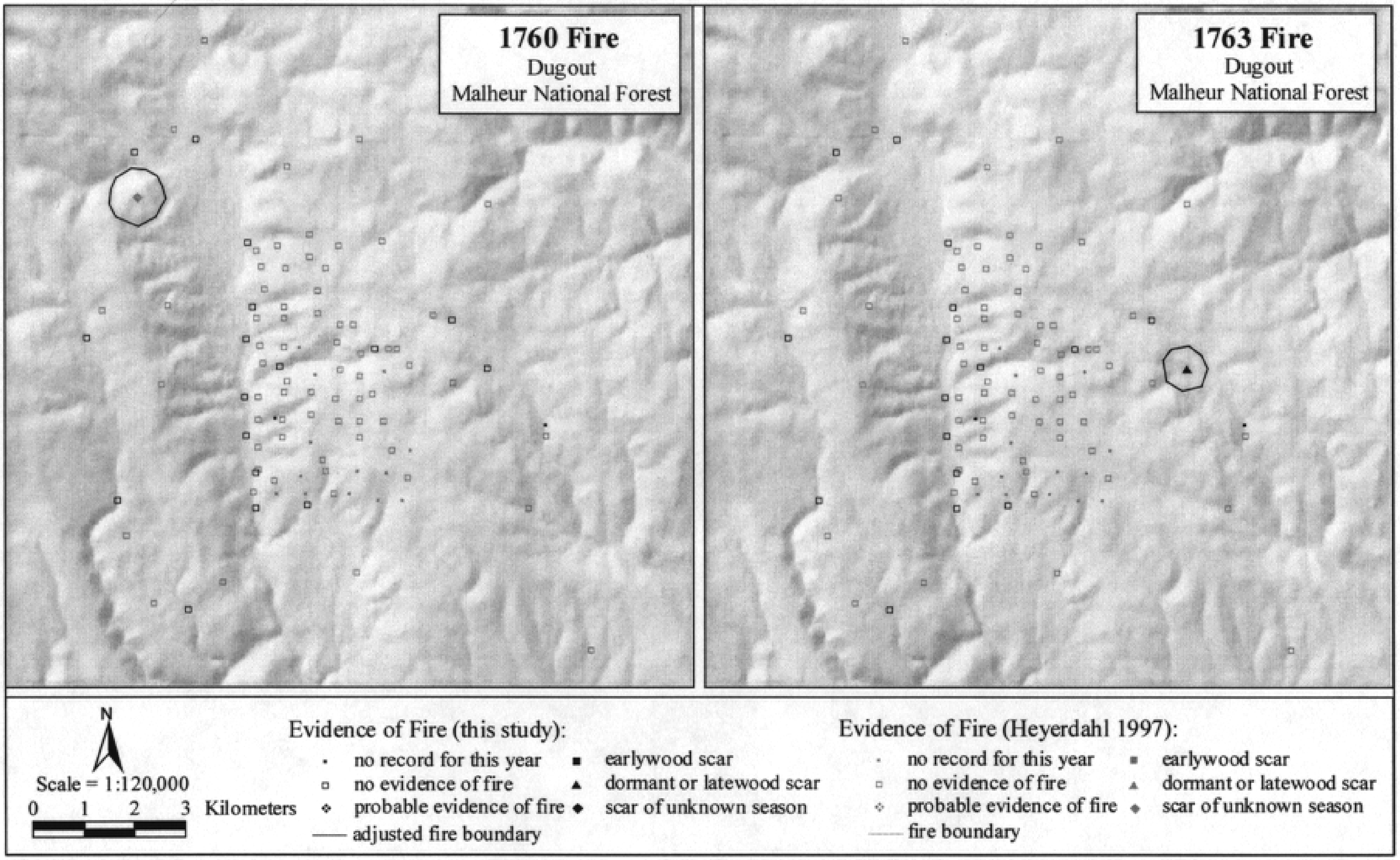

Figure 57. Dugout fire maps for 1760 (left) and 1763 (right).

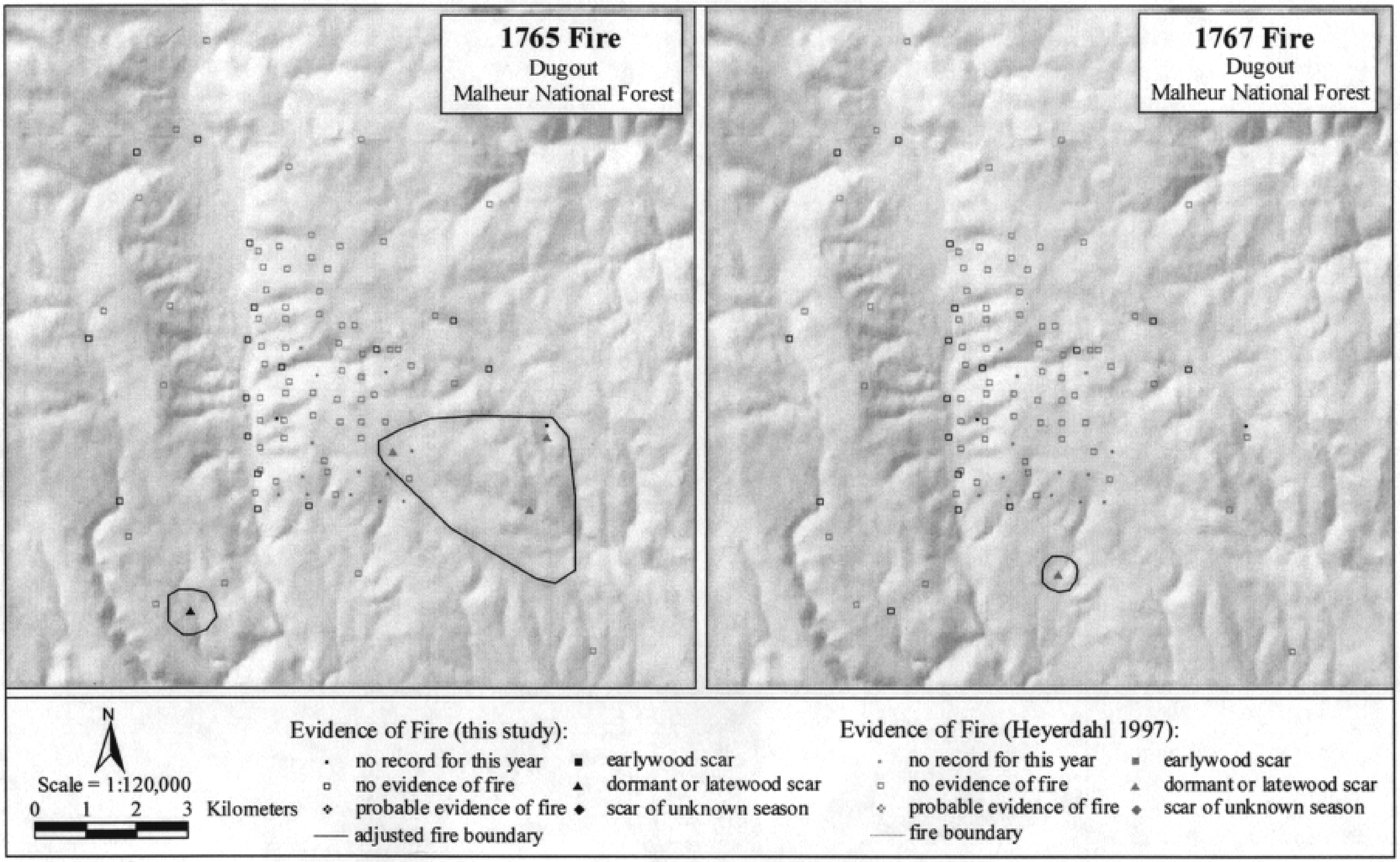

Figure 58. Dugout fire maps for 1765 (left) and 1767 (right).

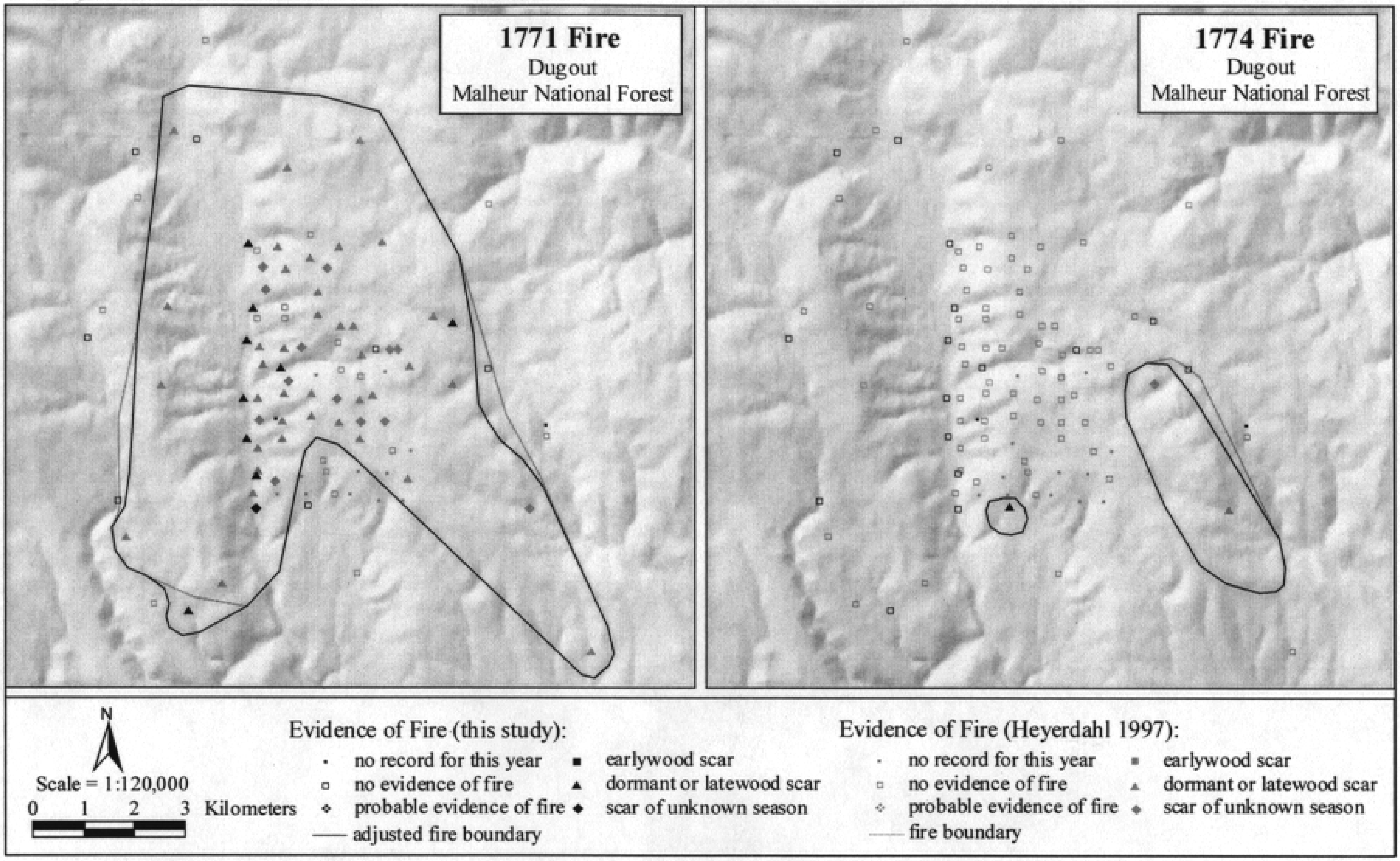

Figure 59. Dugout fire maps for 1771 (left) and 1774 (right).

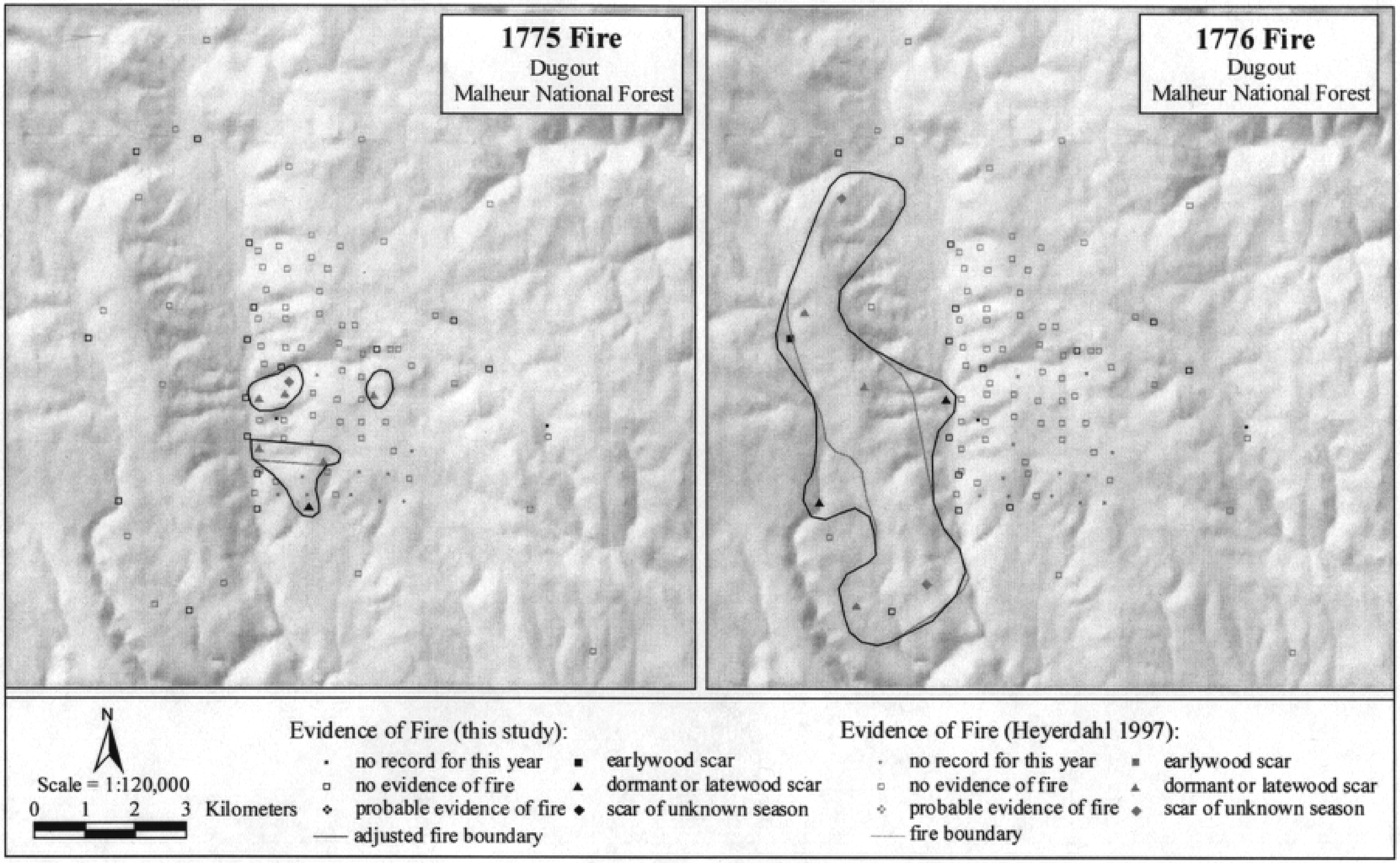

Figure 60. Dugout fire maps for 1775 (left) and 1776 (right).

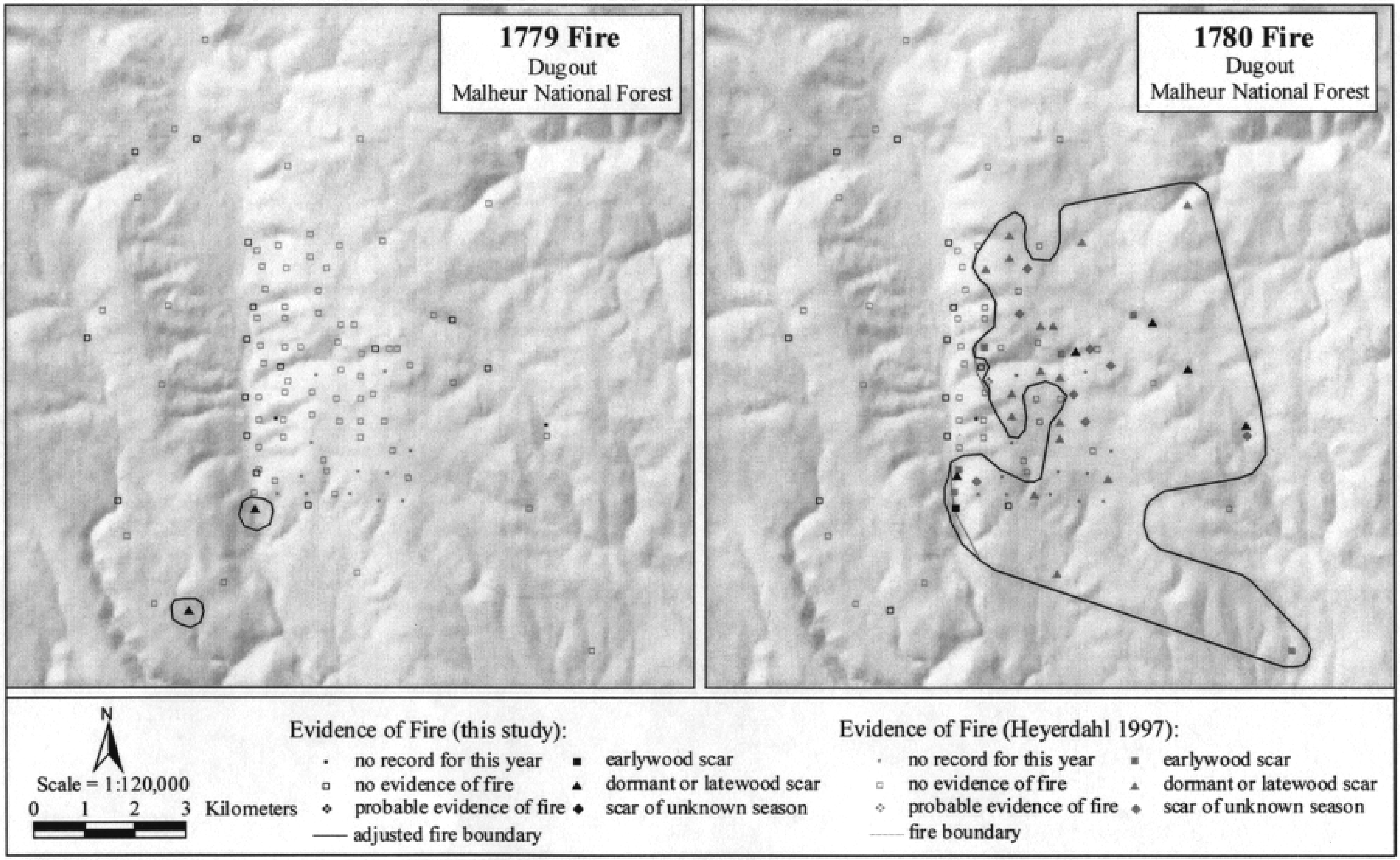

Figure 61. Dugout fire maps for 1779 (left) and 1780 (right).

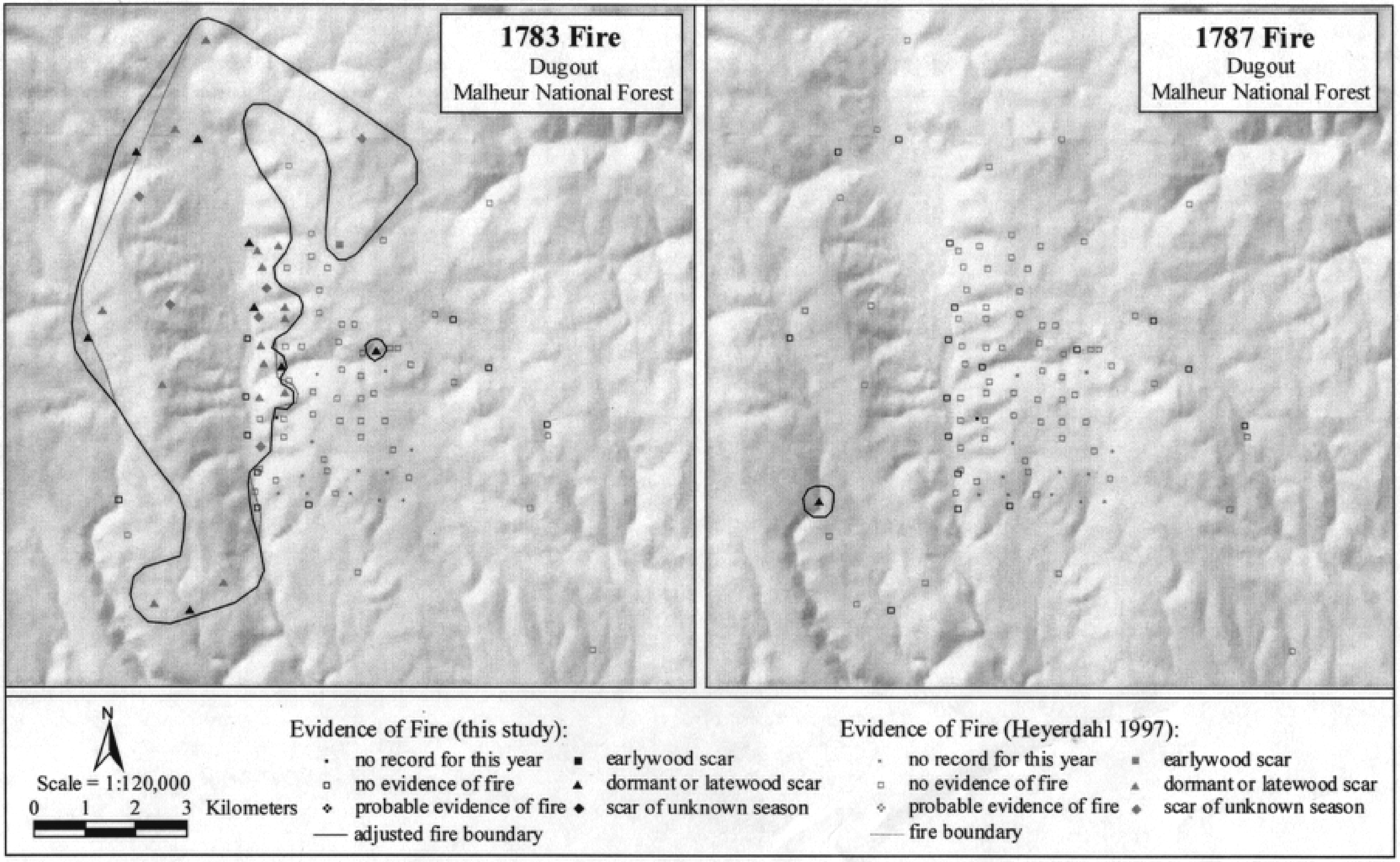

Figure 62. Dugout fire maps for 1783 (left) and 1787 (right).

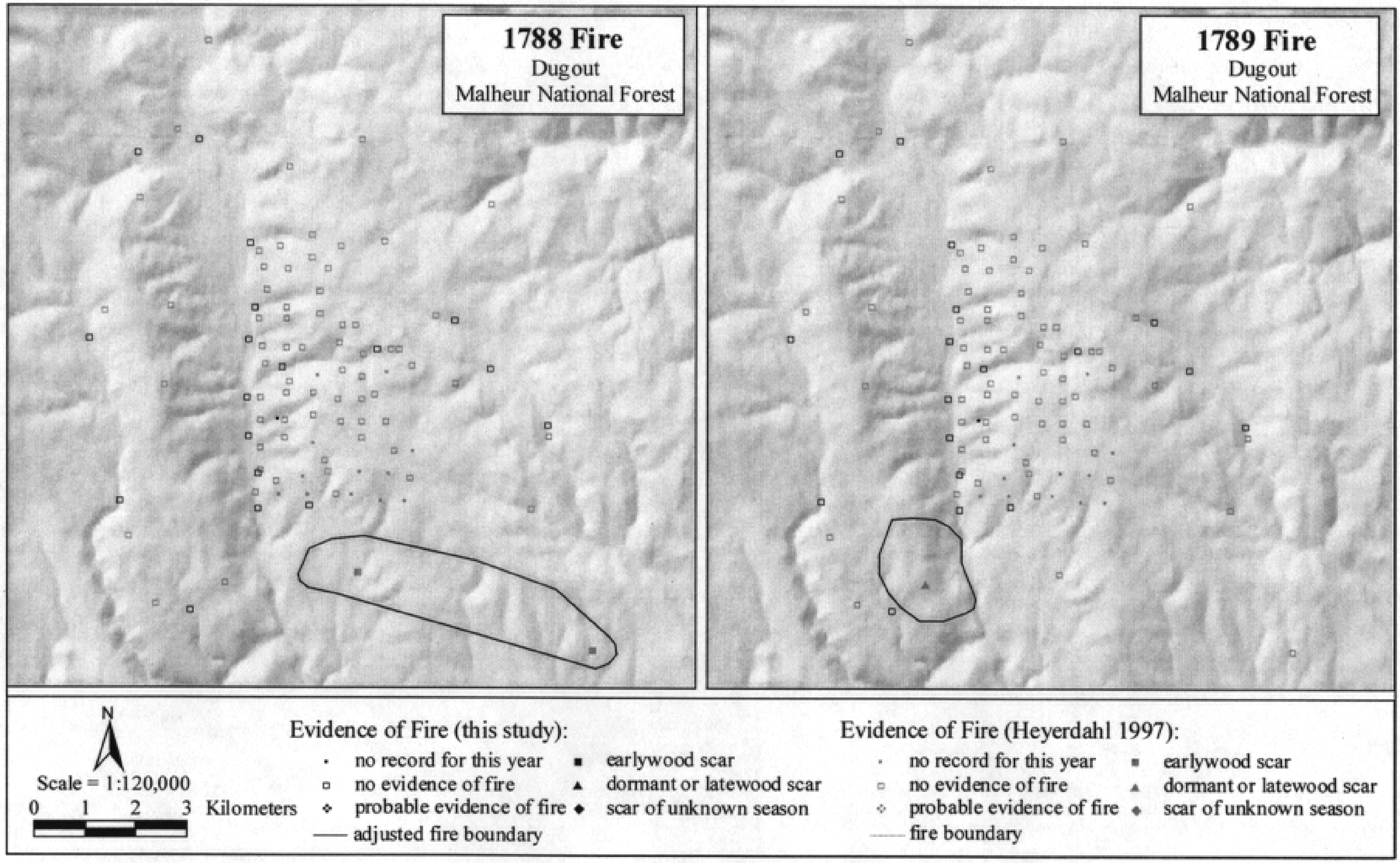

Figure 63. Dugout fire maps for 1788 (left) and 1789 (right).

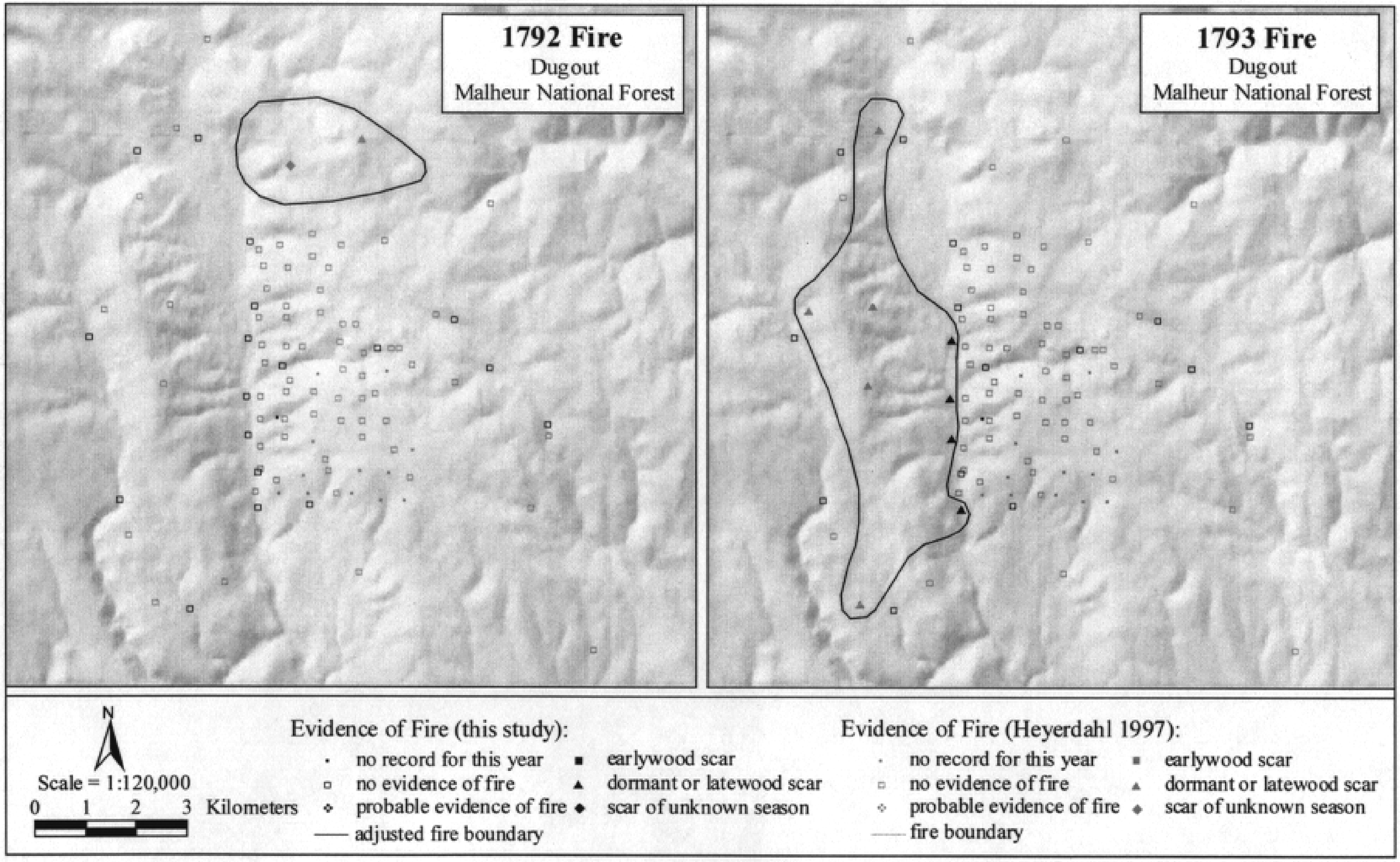

Figure 64. Dugout fire maps for 1792 (left) and 1793 (right).

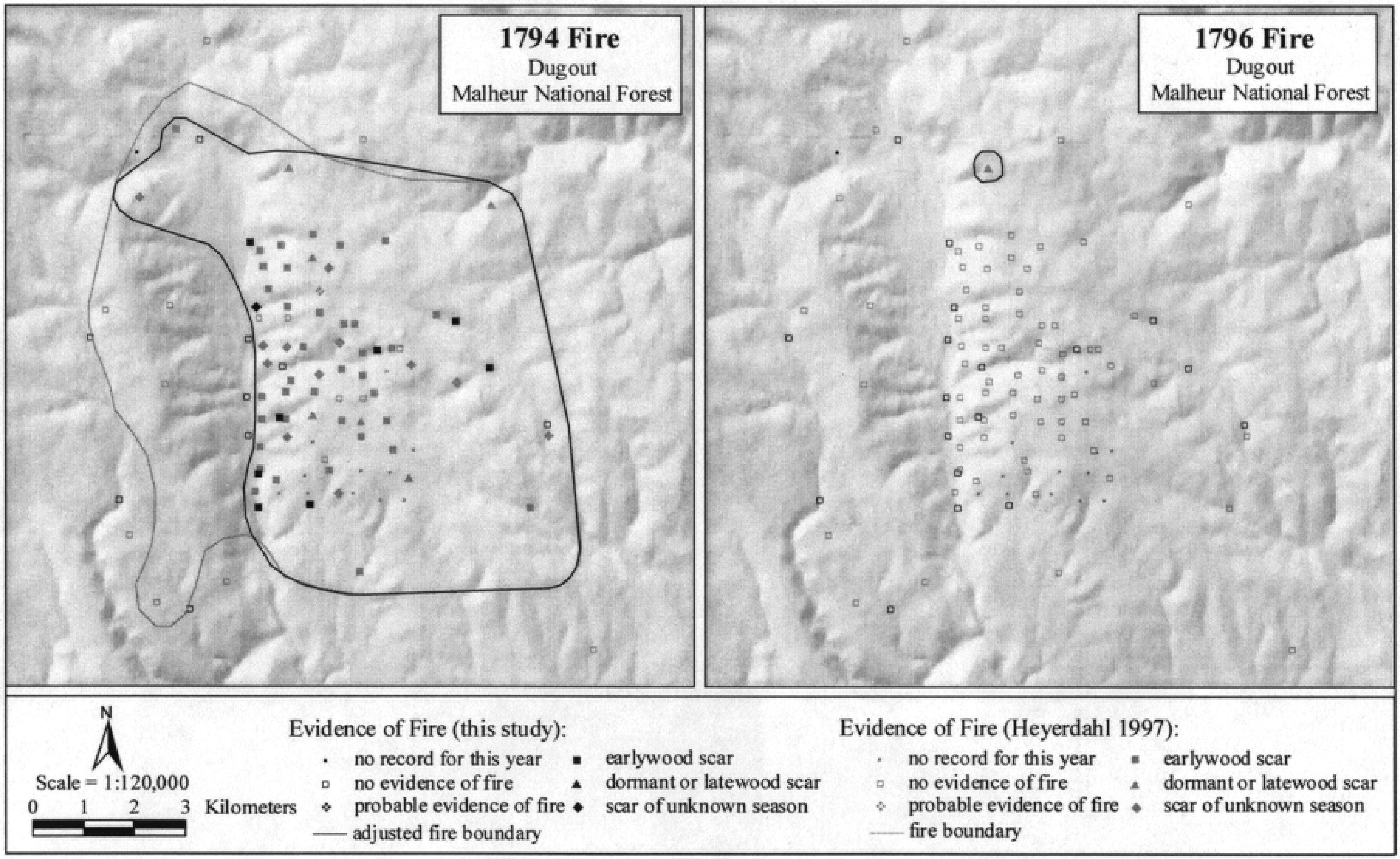

Figure 65. Dugout fire maps for 1794 (left) and 1796 (right).

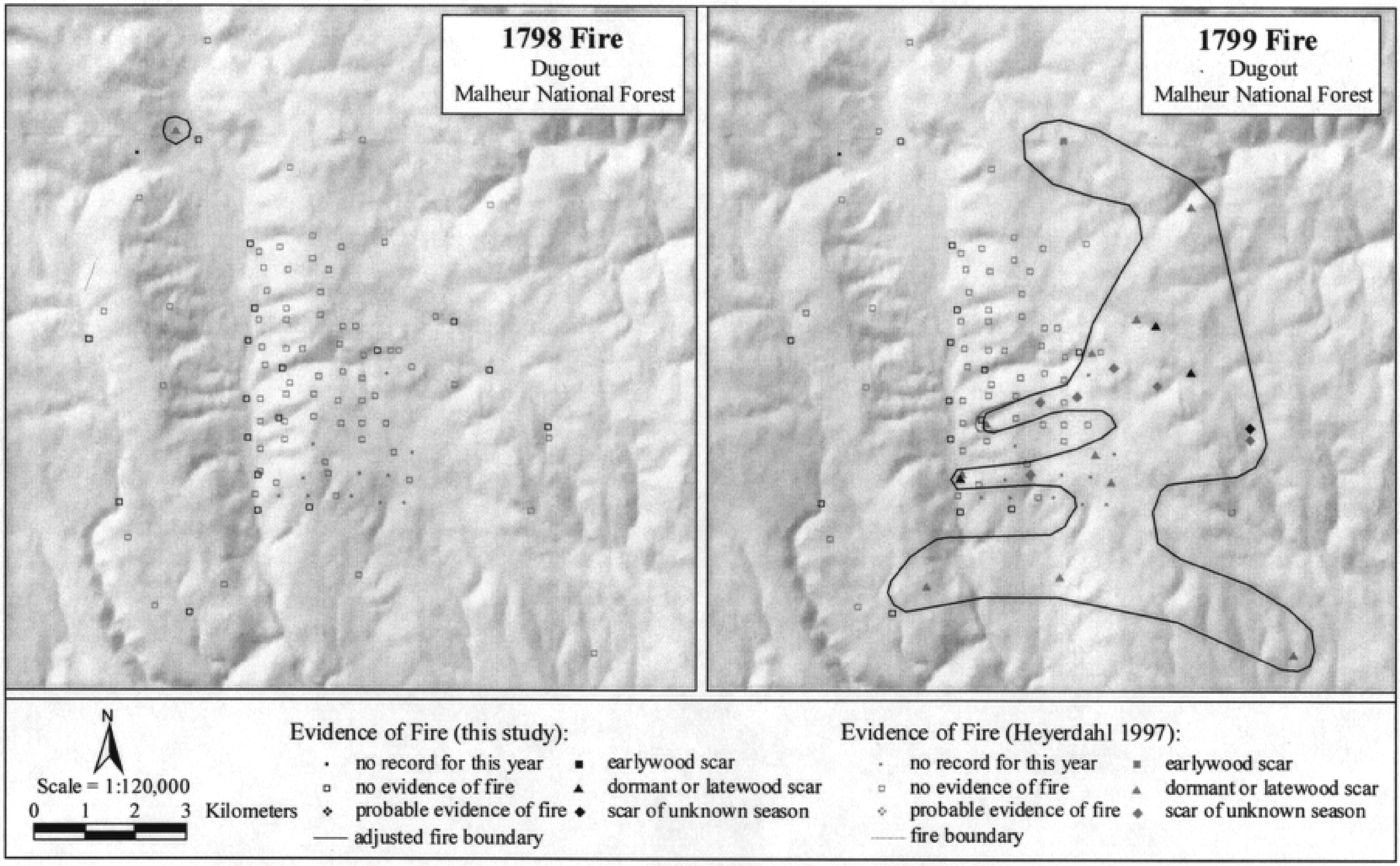

Figure 66. Dugout fire maps for 1798 (left) and 1799 (right).

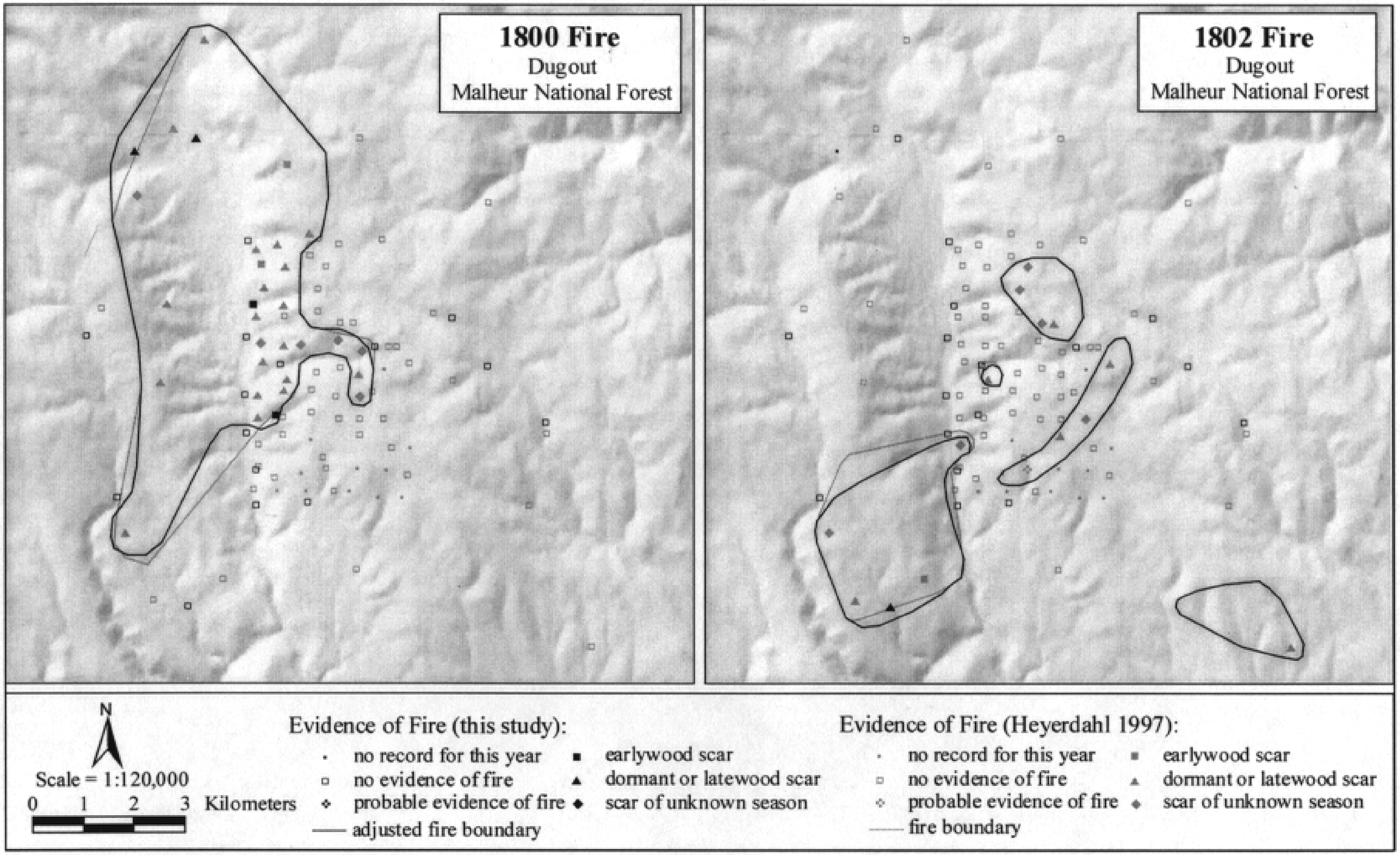

Figure 67. Dugout fire maps for 1800 (left) and 1802 (right).

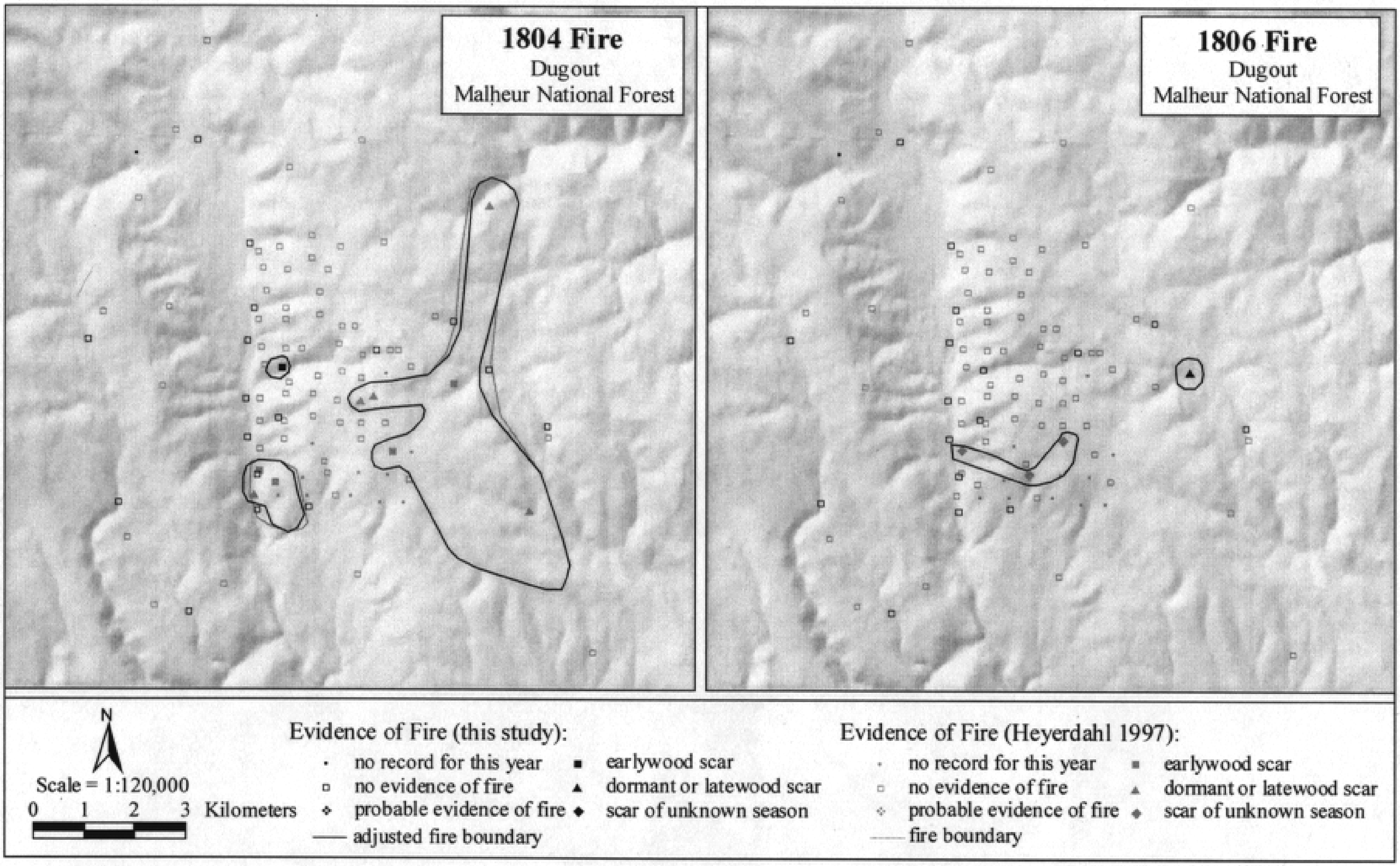

Figure 68. Dugout fire maps for 1804 (left) and 1806 (right).

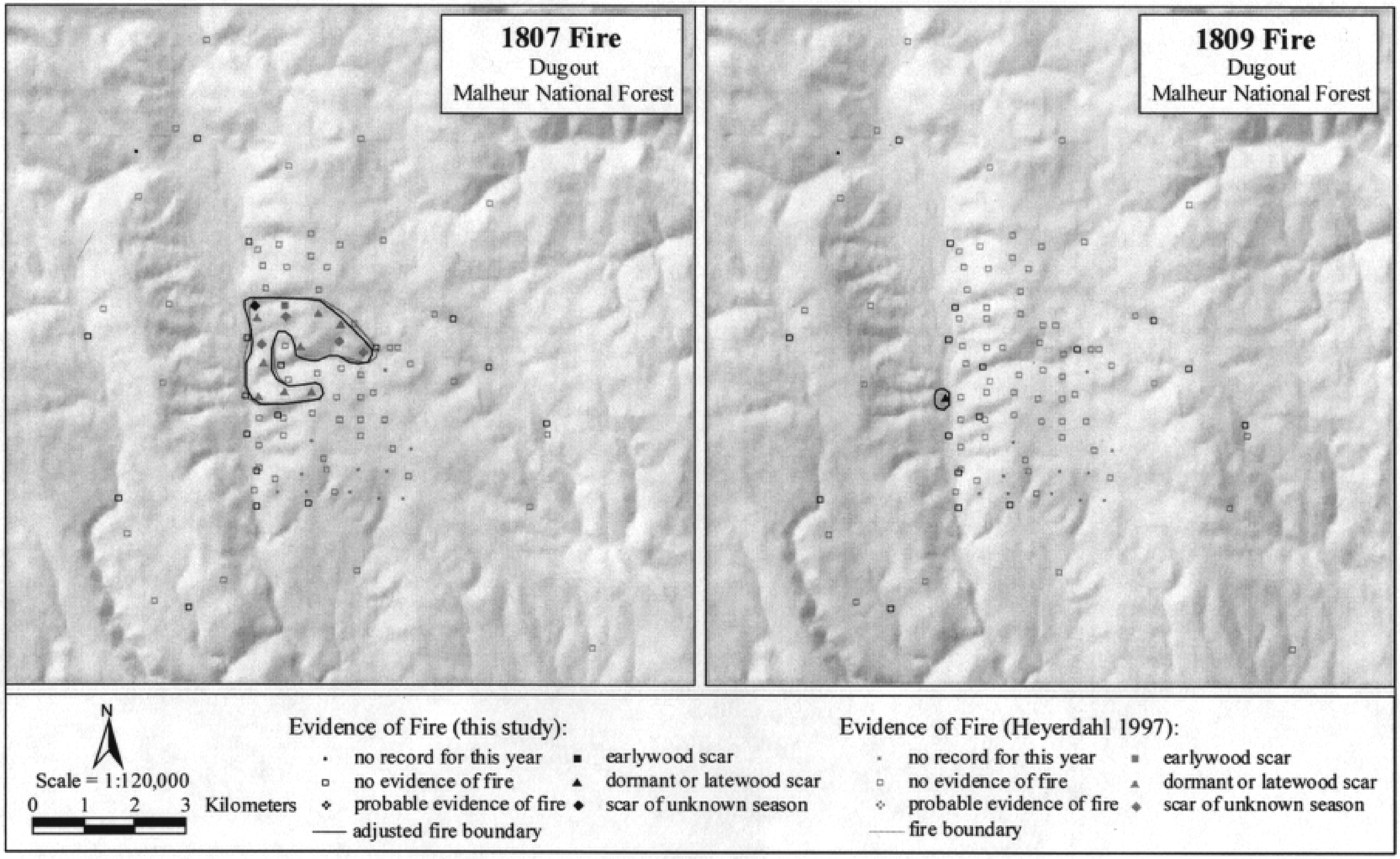

Figure 69. Dugout fire maps for 1806 (left) and 1809 (right).

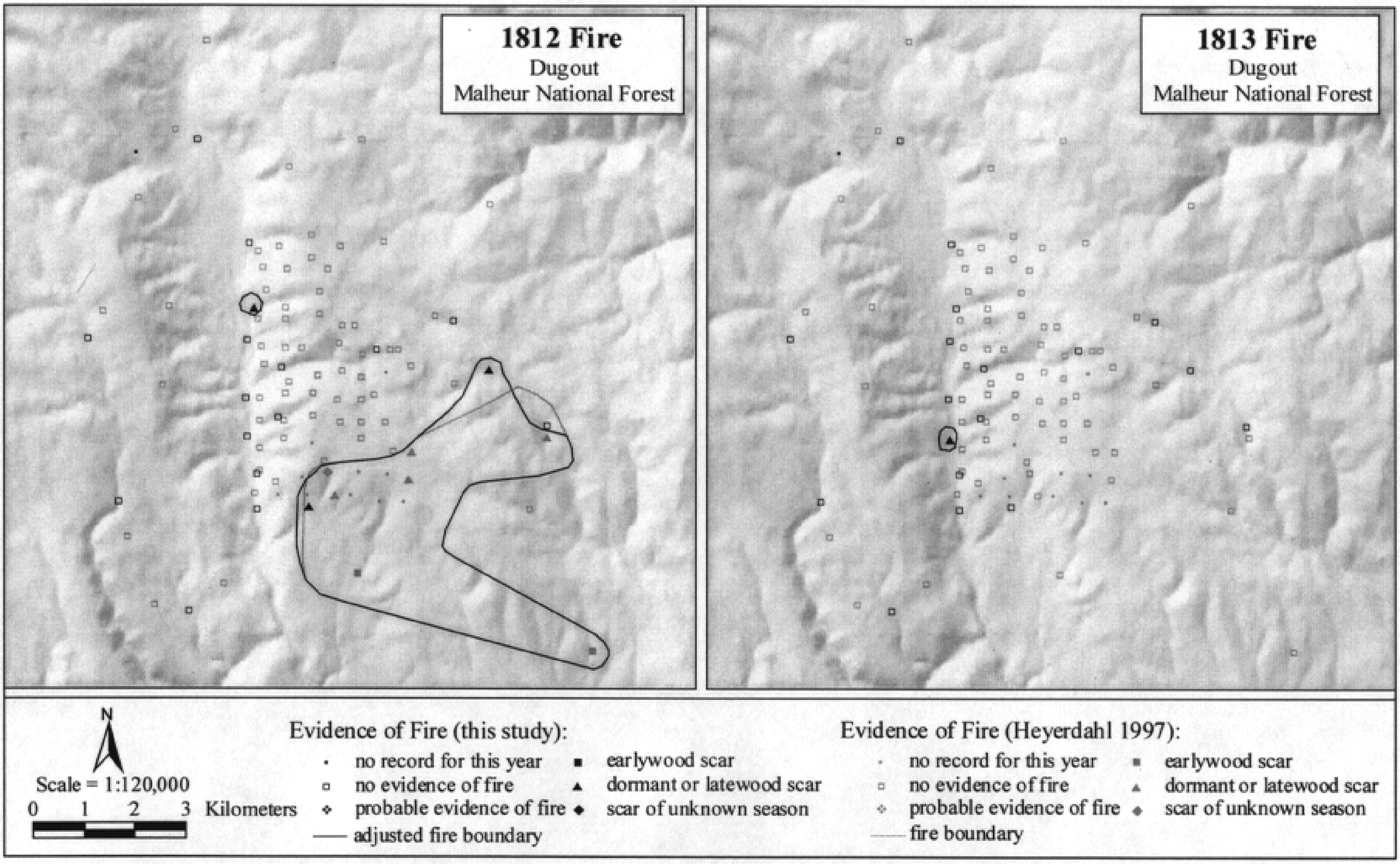

Figure 70. Dugout fire maps for 1812 (left) and 1813 (right).

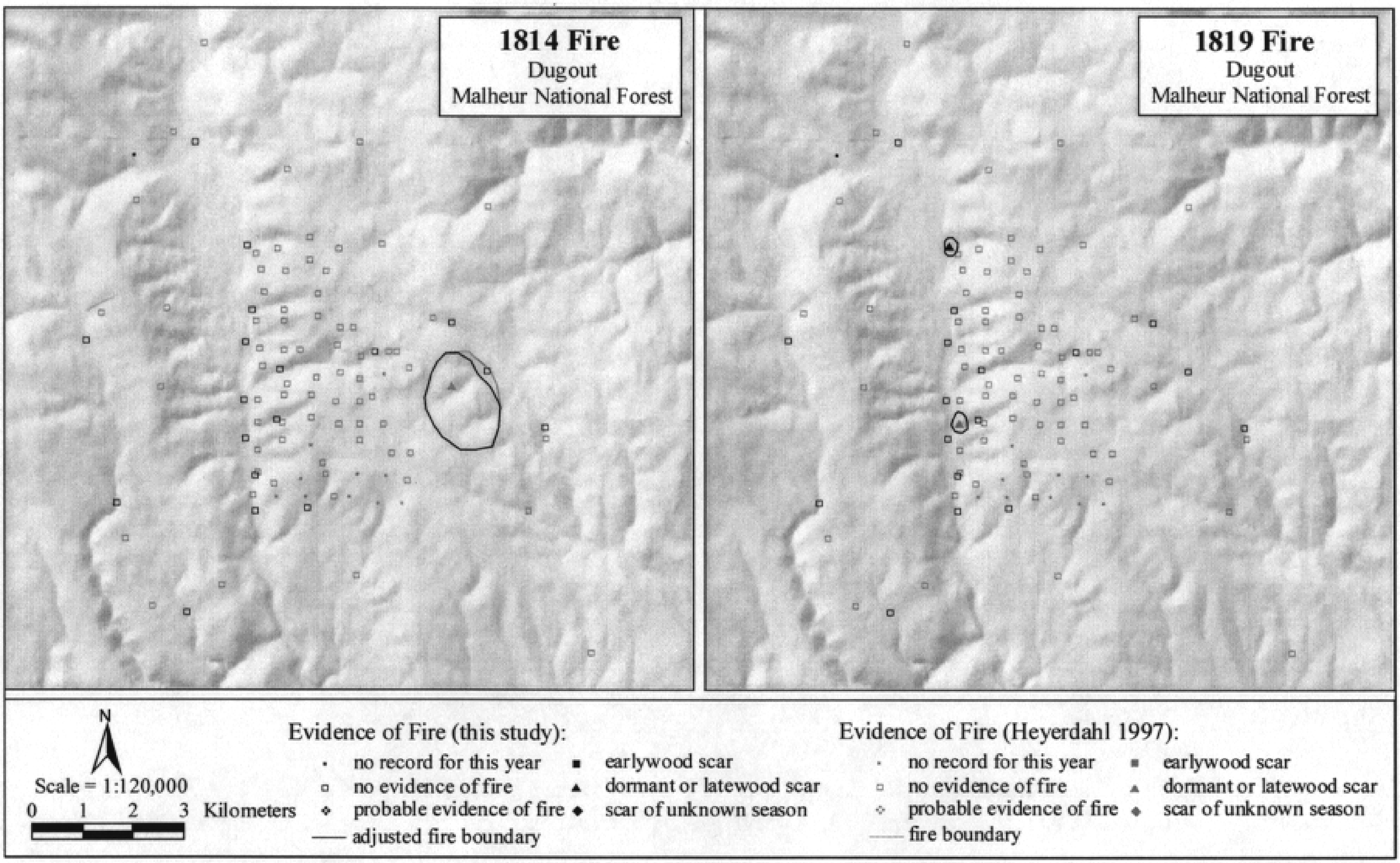

Figure 71. Dugout fire maps for 1814 (left) and 1819 (right).

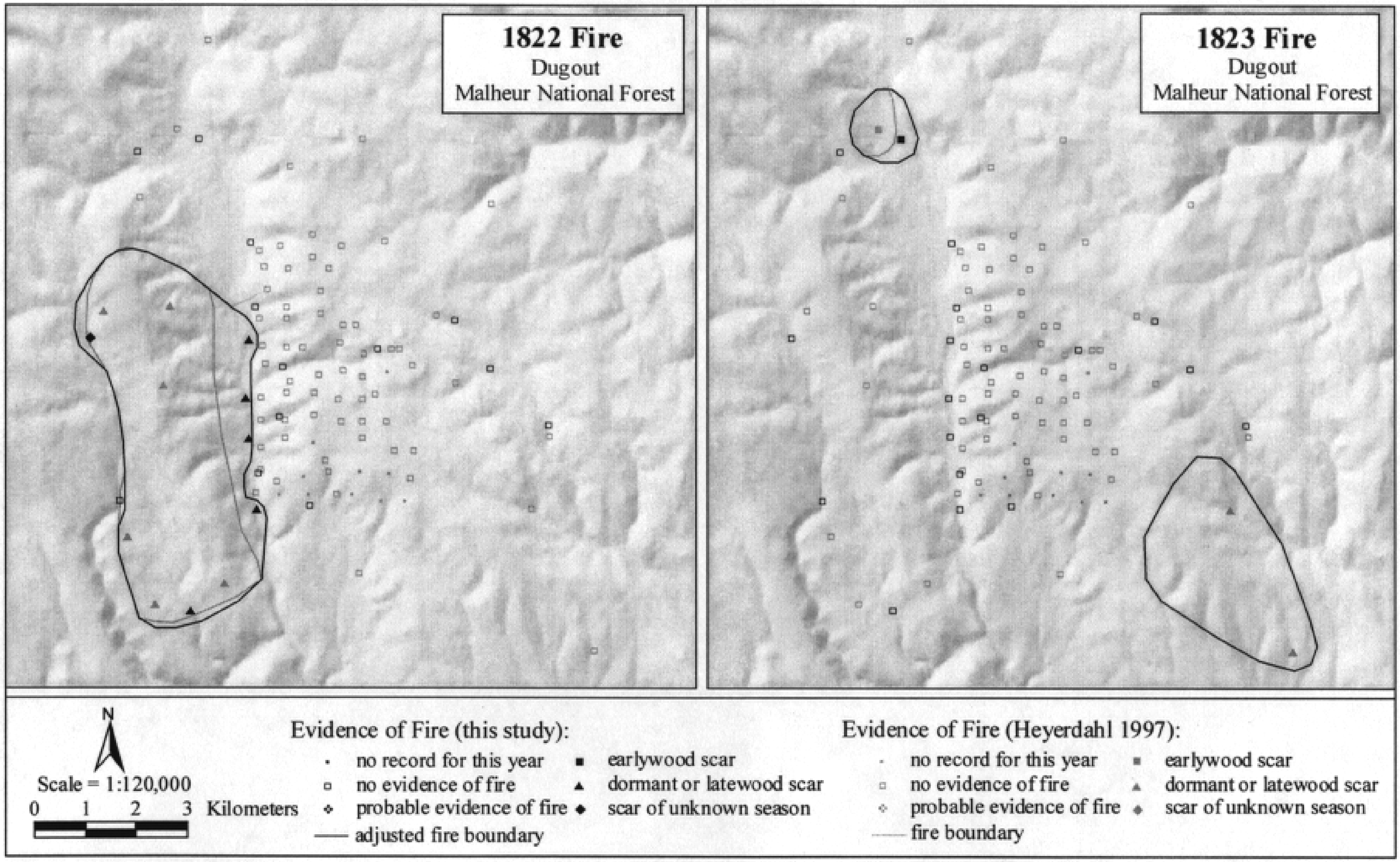

Figure 72. Dugout fire maps for 1822 (left) and 1823 (right).

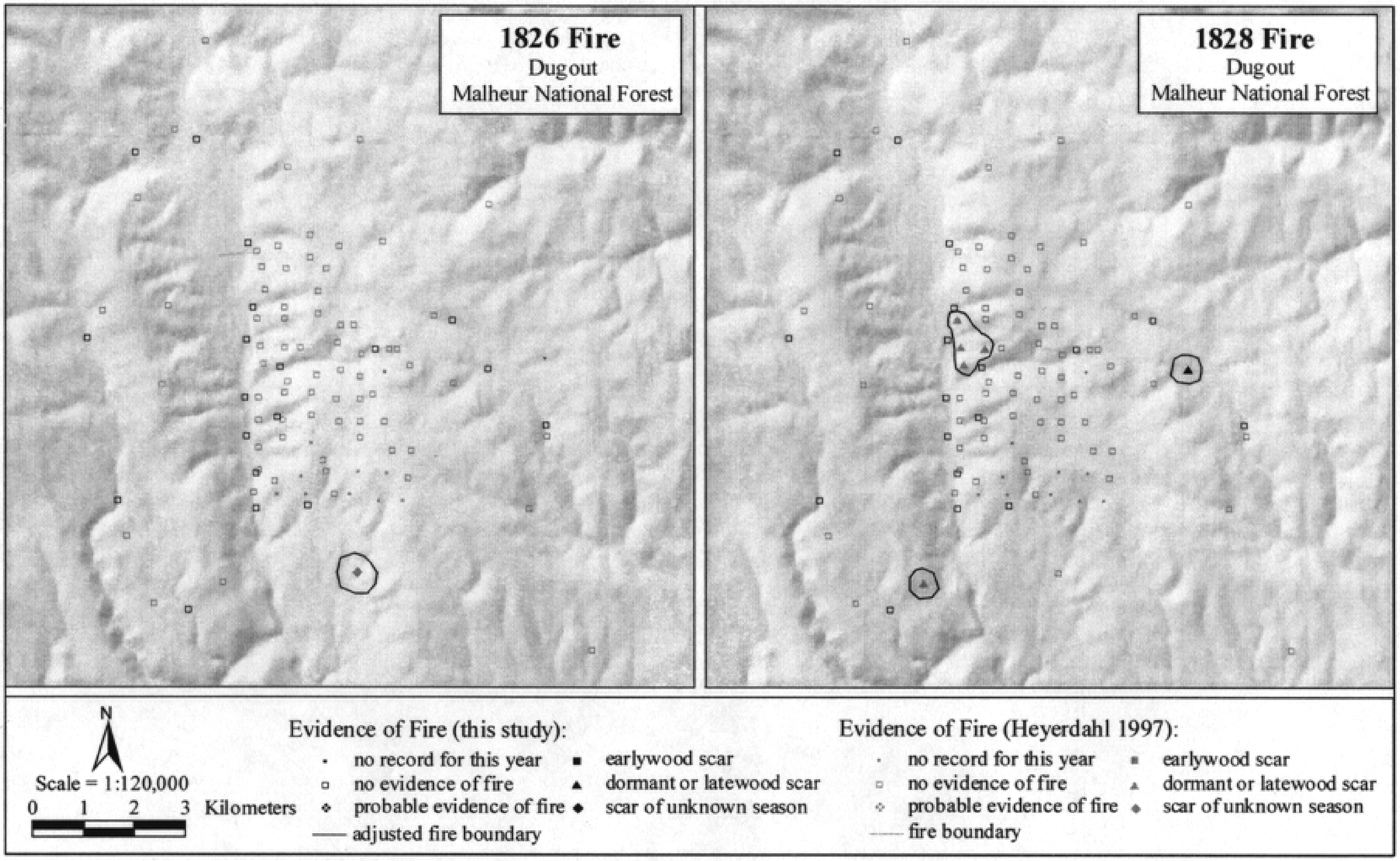

Figure 73. Dugout fire maps for 1826 (left) and 1828 (right).

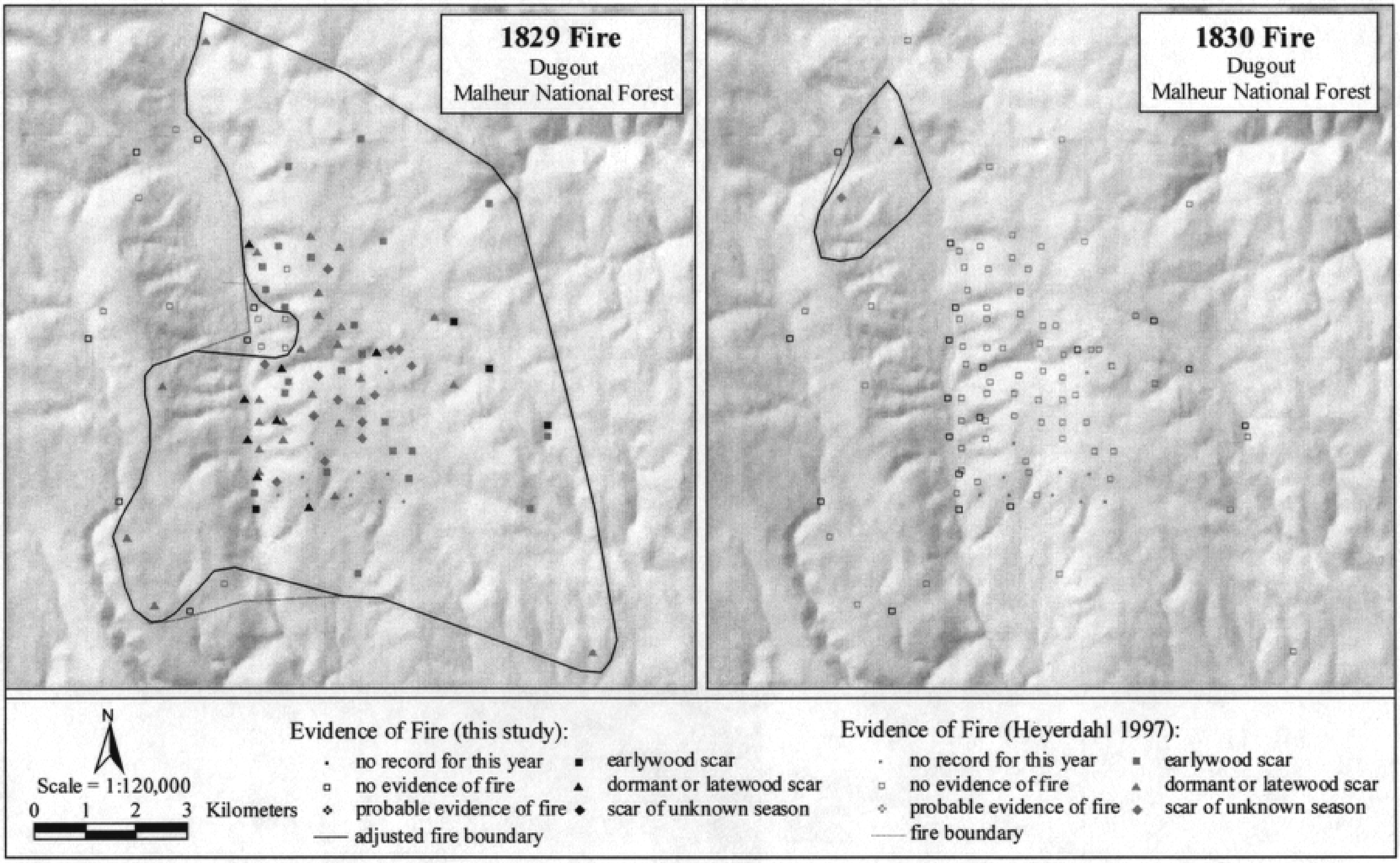

Figure 74. Dugout fire maps for 1829 (left) and 1830 (right).

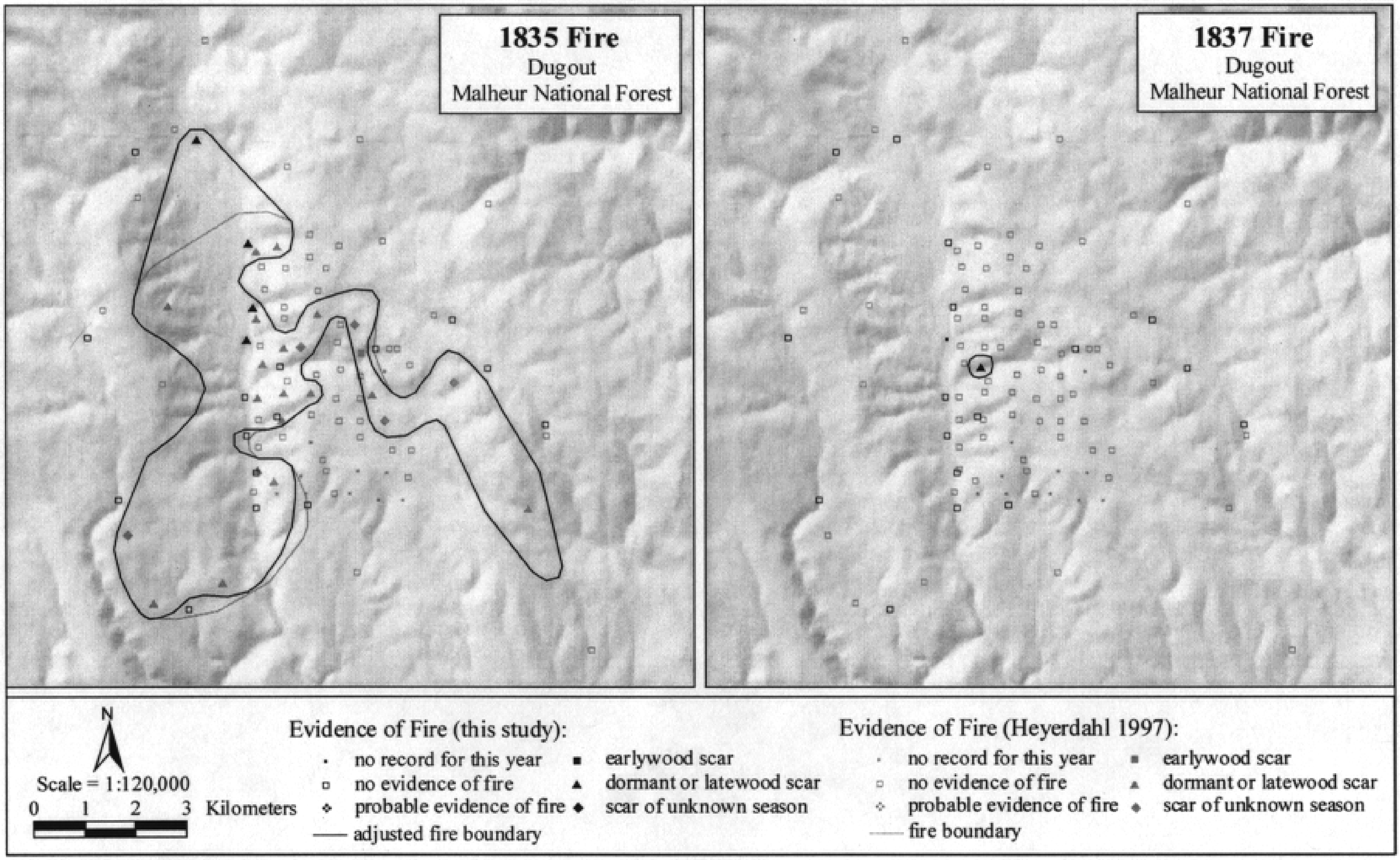

Figure 75. Dugout fire maps for 1835 (left) and 1837 (right).

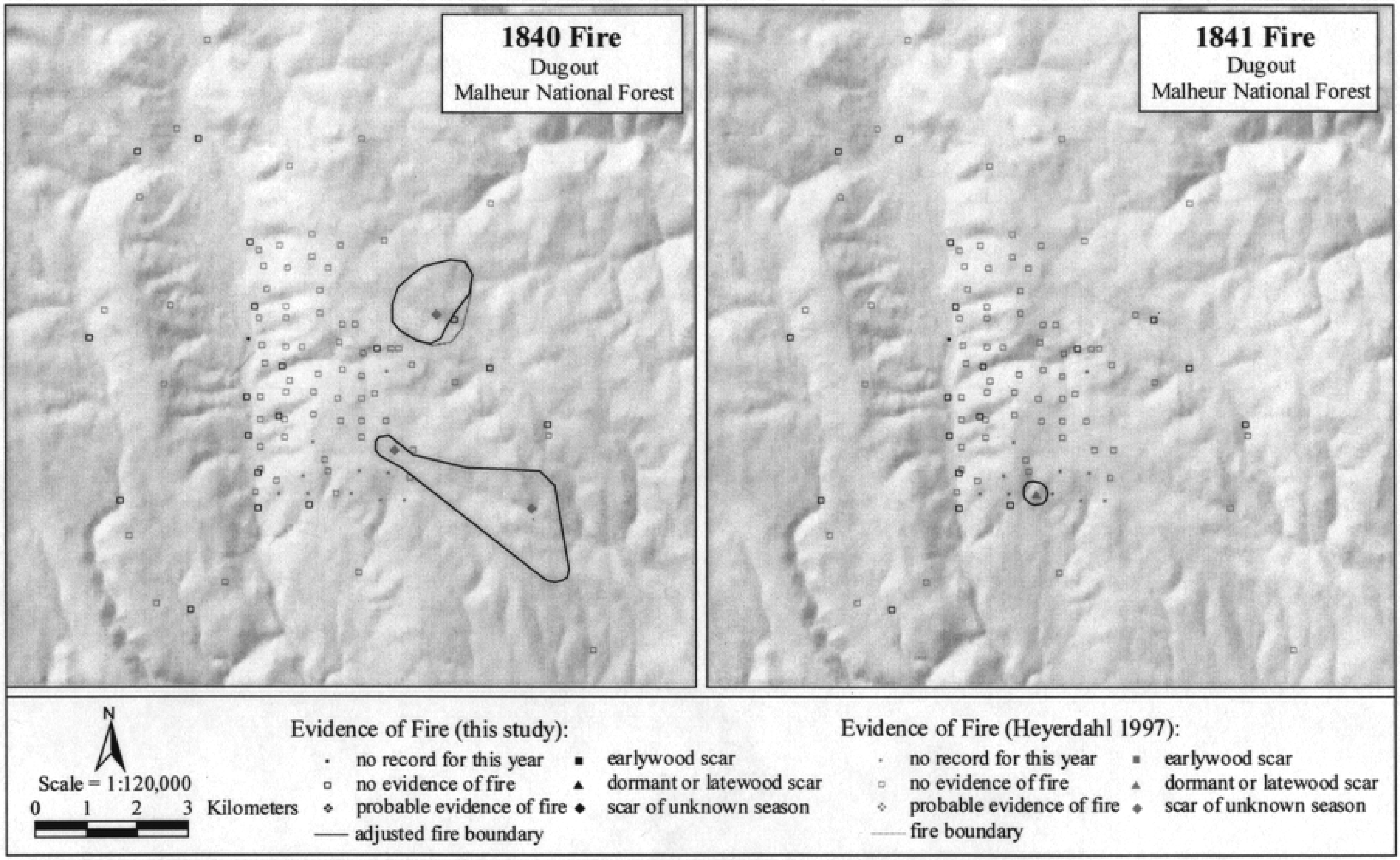

Figure 76. Dugout fire maps for 1840 (left) and 1841 (right).

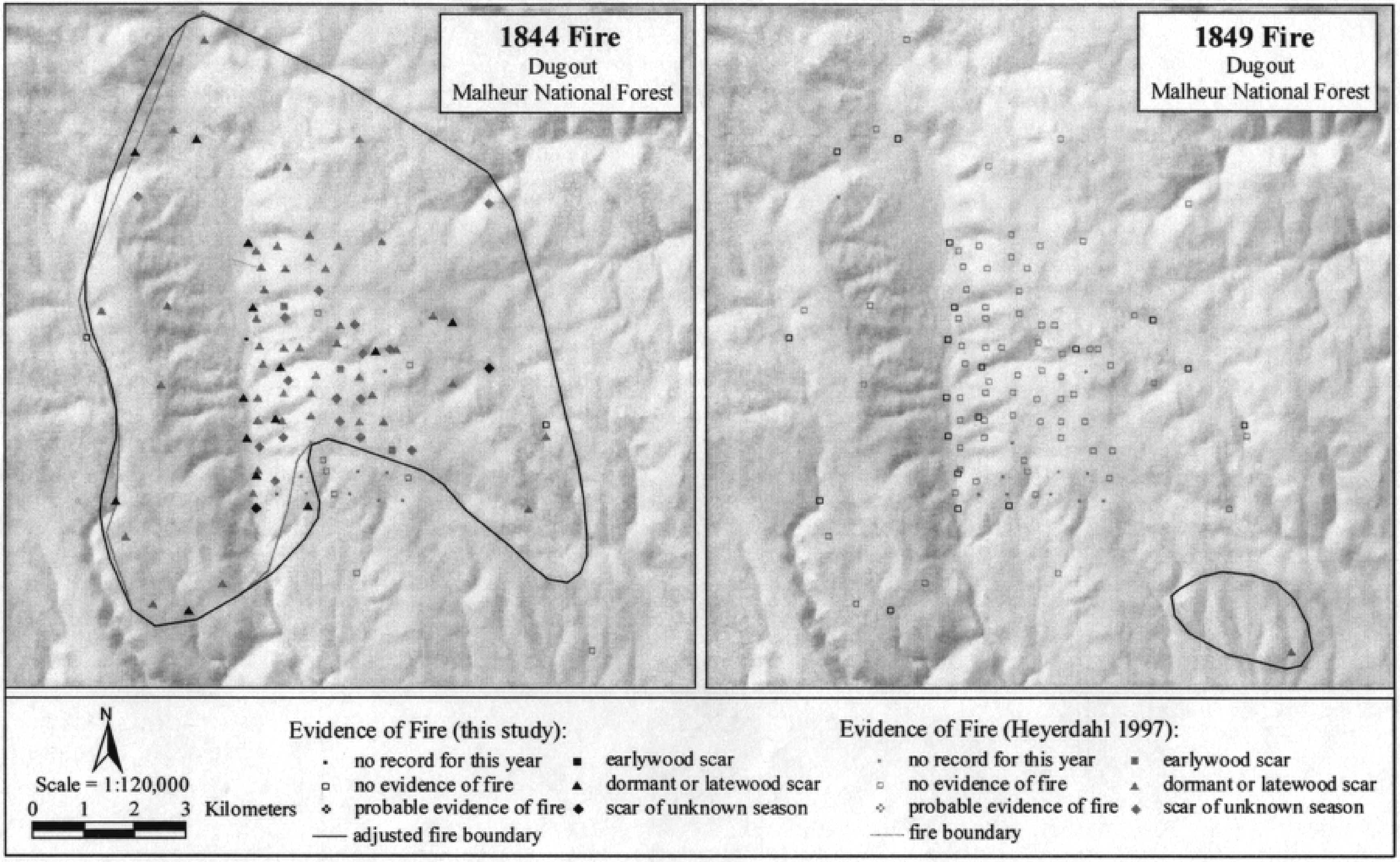

Figure 77. Dugout fire maps for 1844 (left) and 1849 (right).

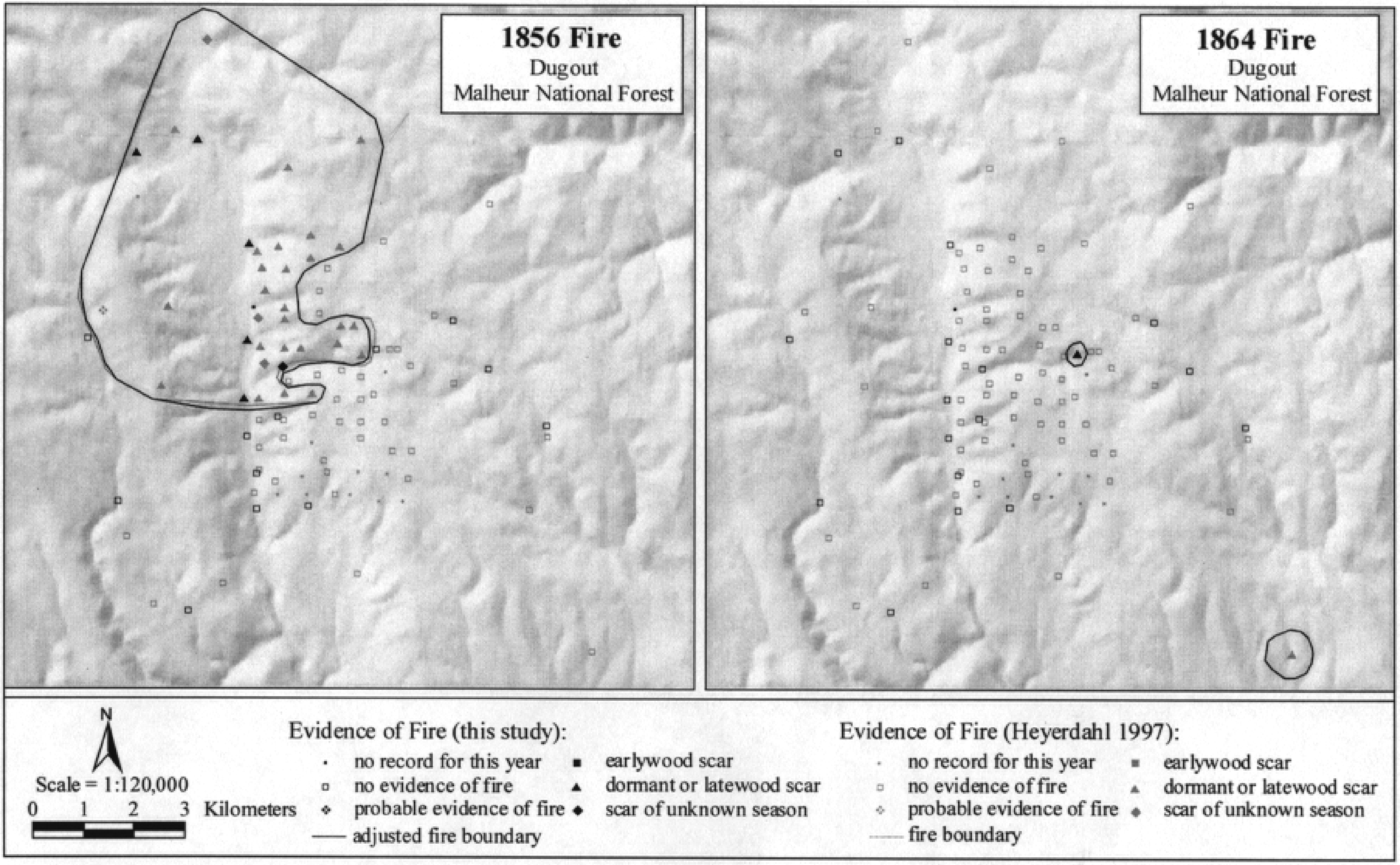

Figure 78. Dugout fire maps for 1856 (left) and 1864 (right).

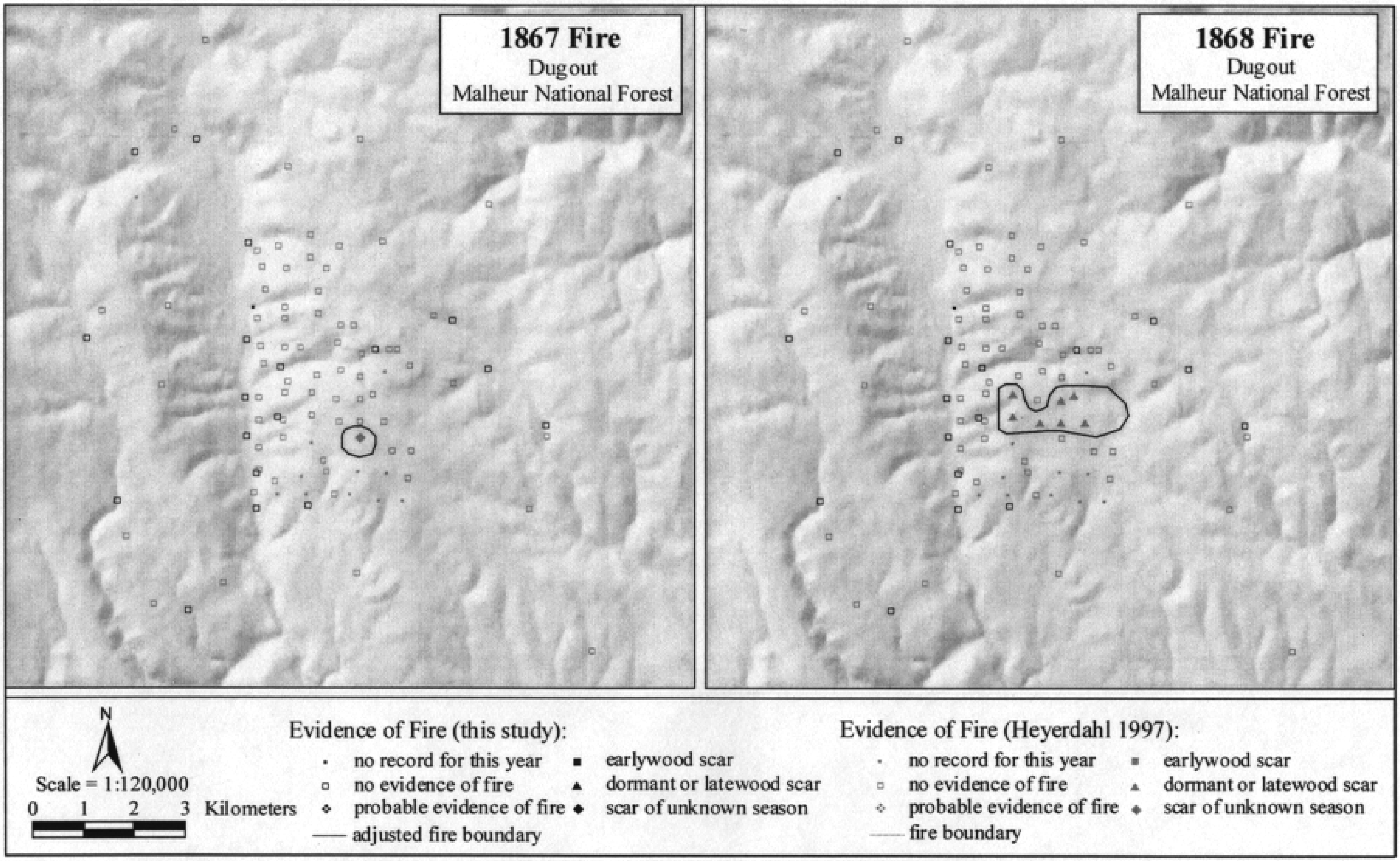

Figure 79. Dugout fire maps for 1867 (left) and 1868 (right).

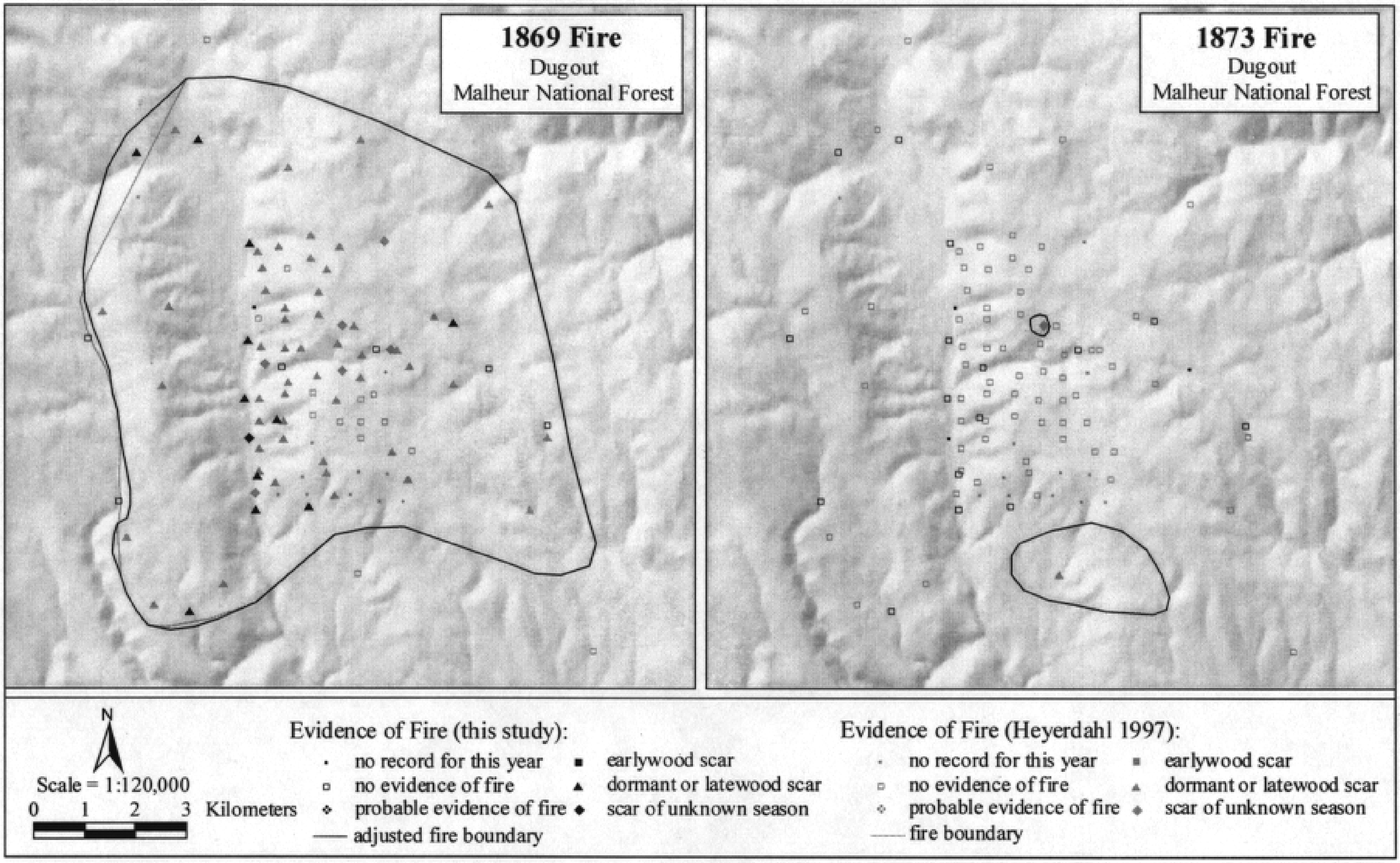

Figure 80. Dugout fire maps for 1869 (left) and 1873 (right).

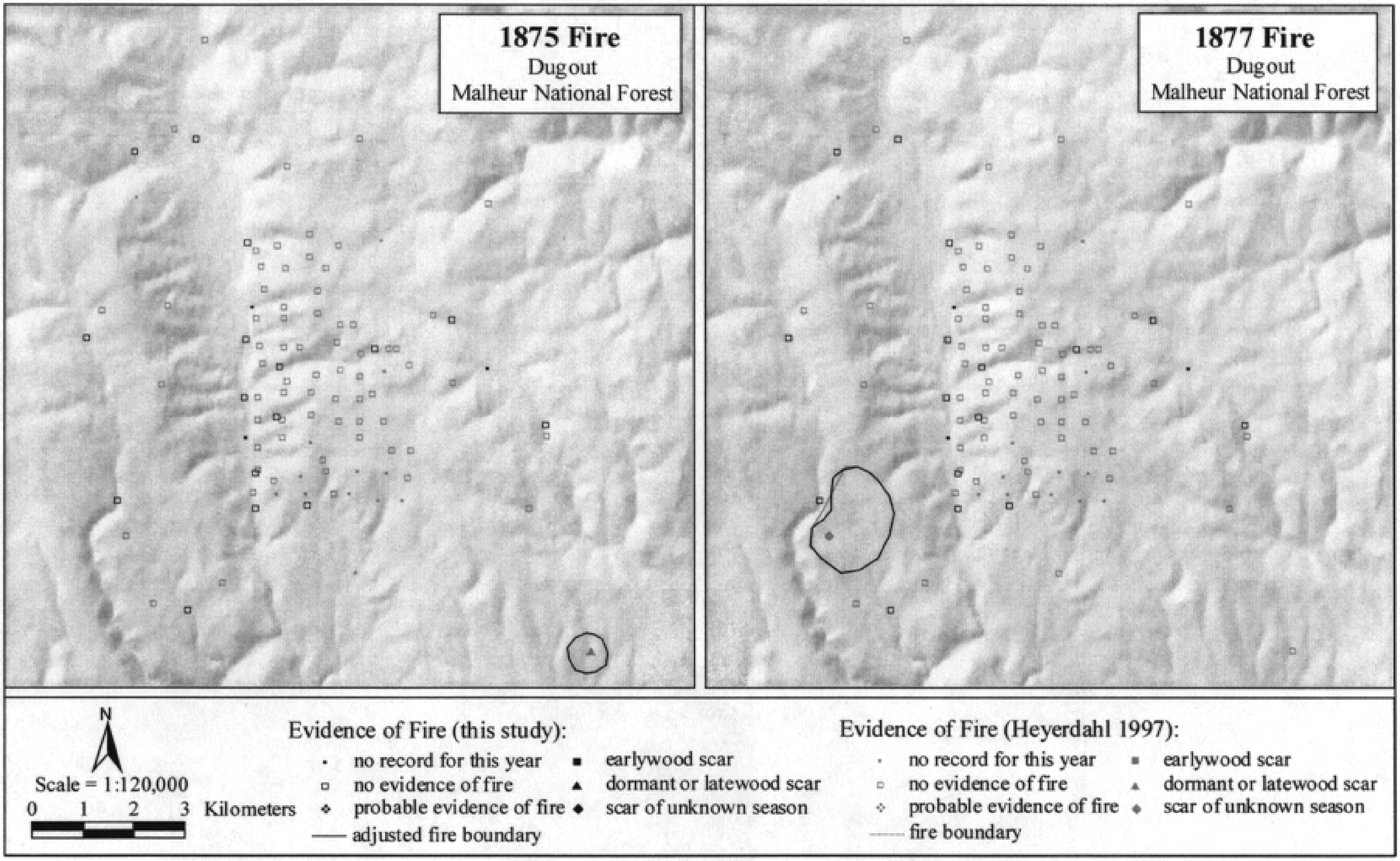

Figure 81. Dugout fire maps for 1875 (left) and 1877 (right).

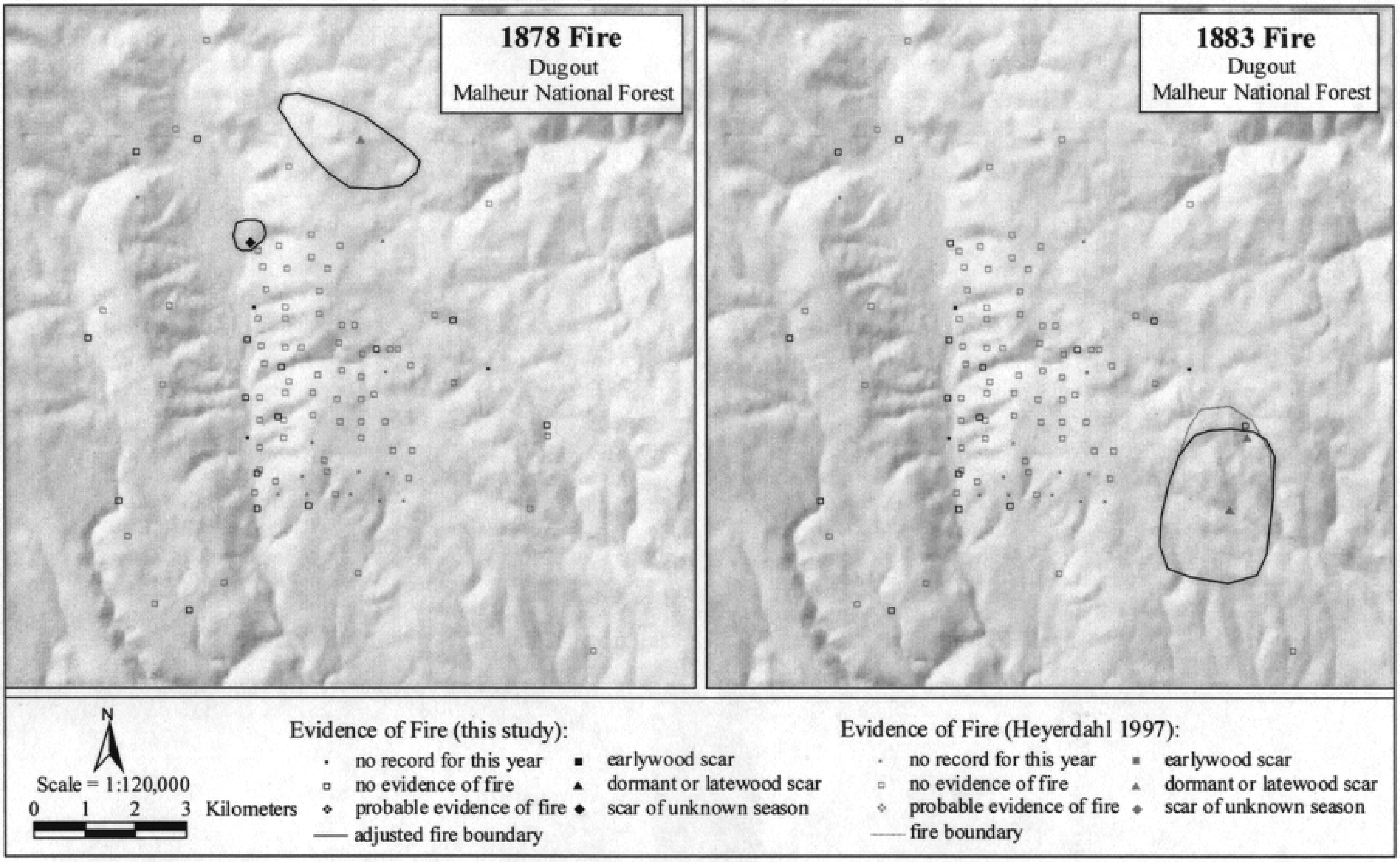

Figure 82. Dugout fire maps for 1878 (left) and 1883 (right).

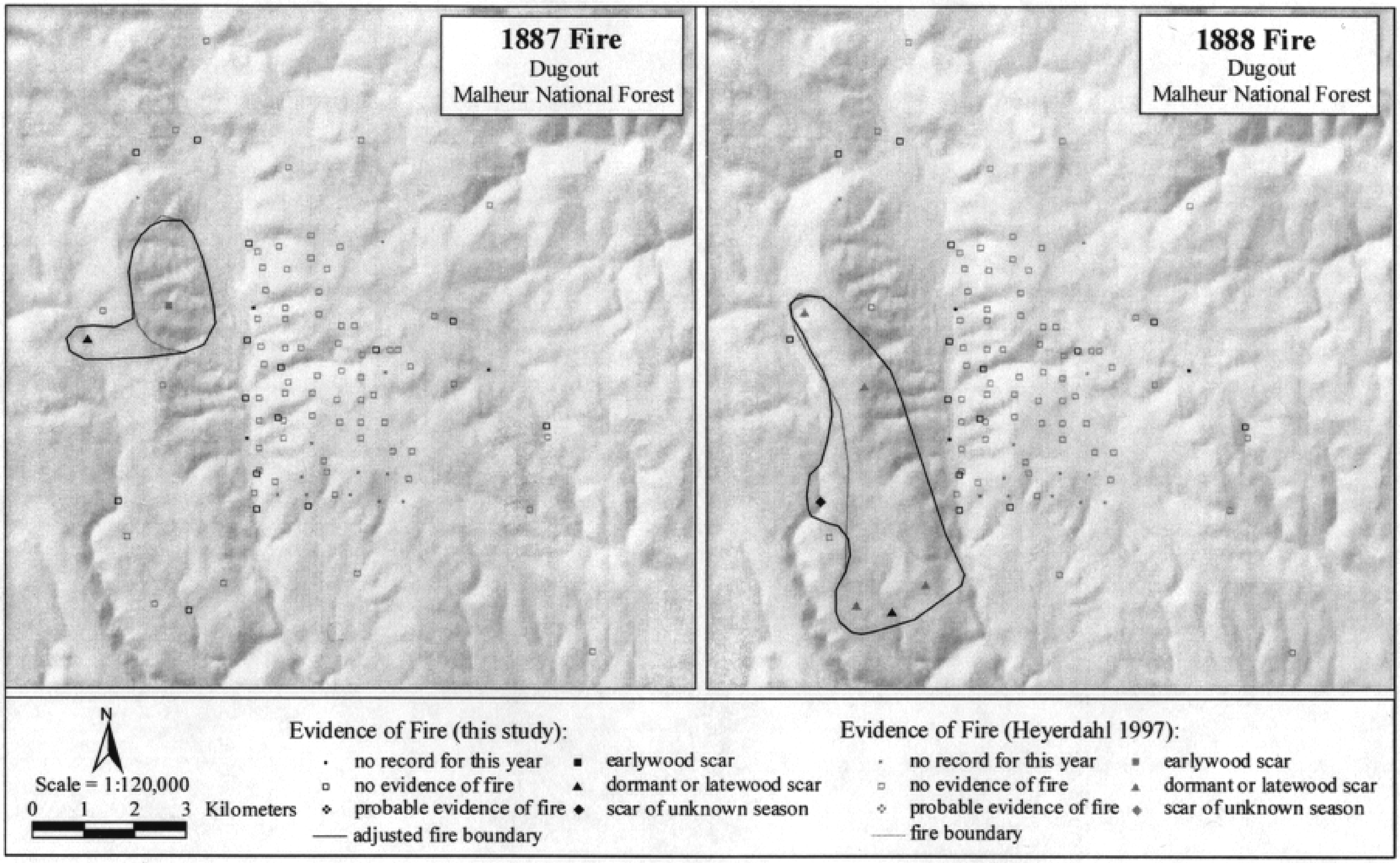

Figure 83. Dugout fire maps for 1887 (left) and 1888 (right).

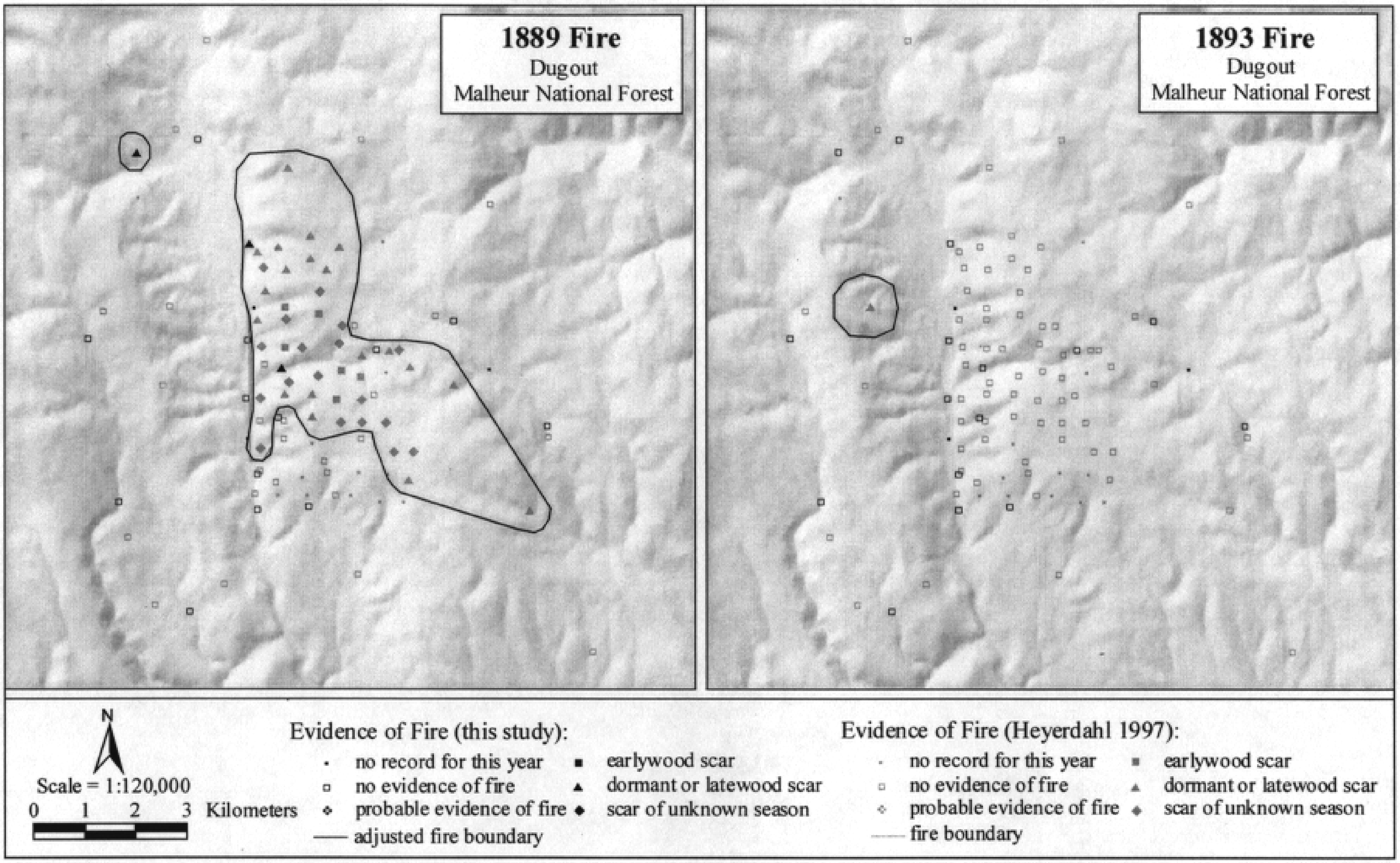

Figure 84. Dugout fire maps for 1889 (left) and 1893 (right).

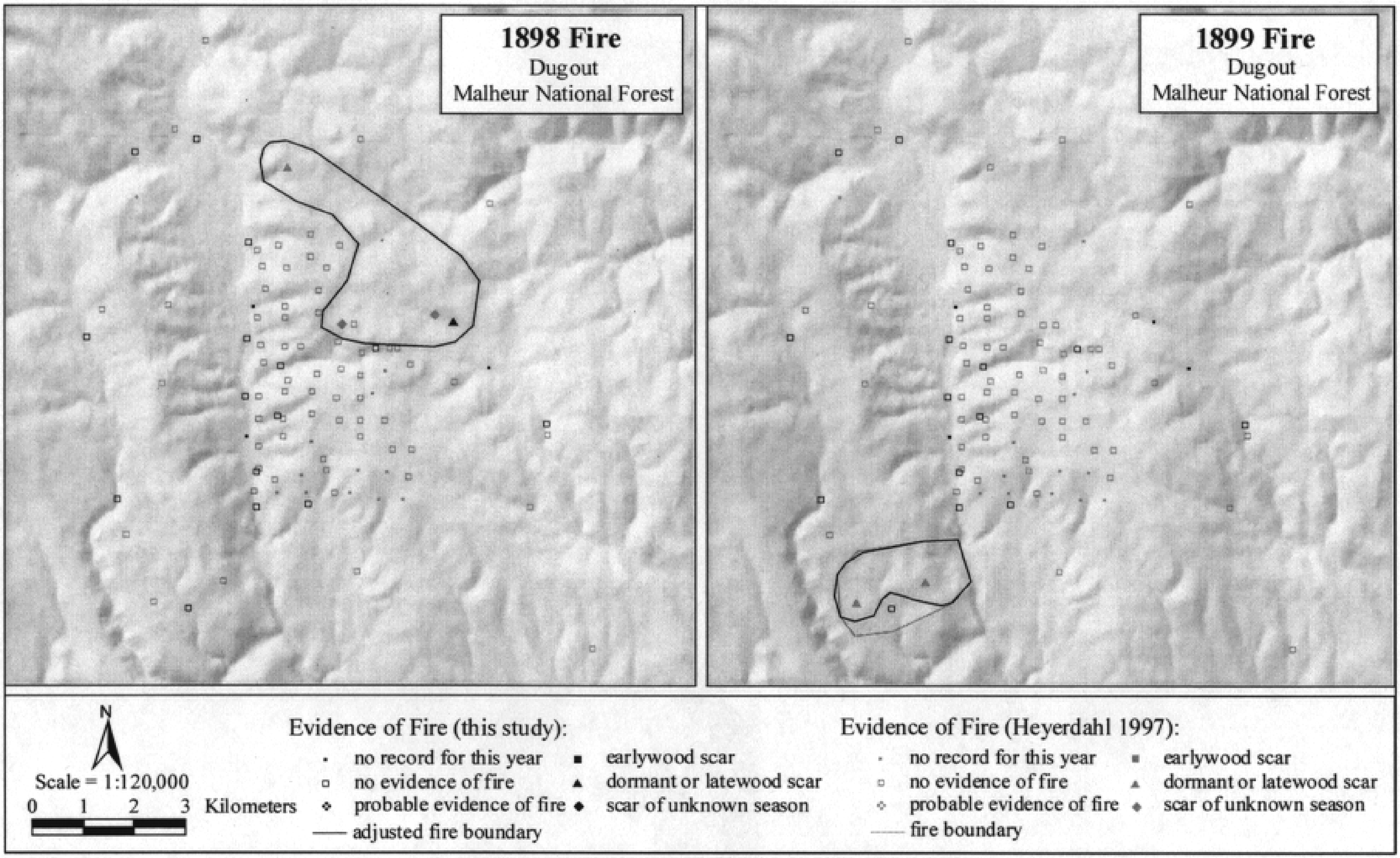

Figure 85. Dugout fire maps for 1898 (left) and 1899 (right).

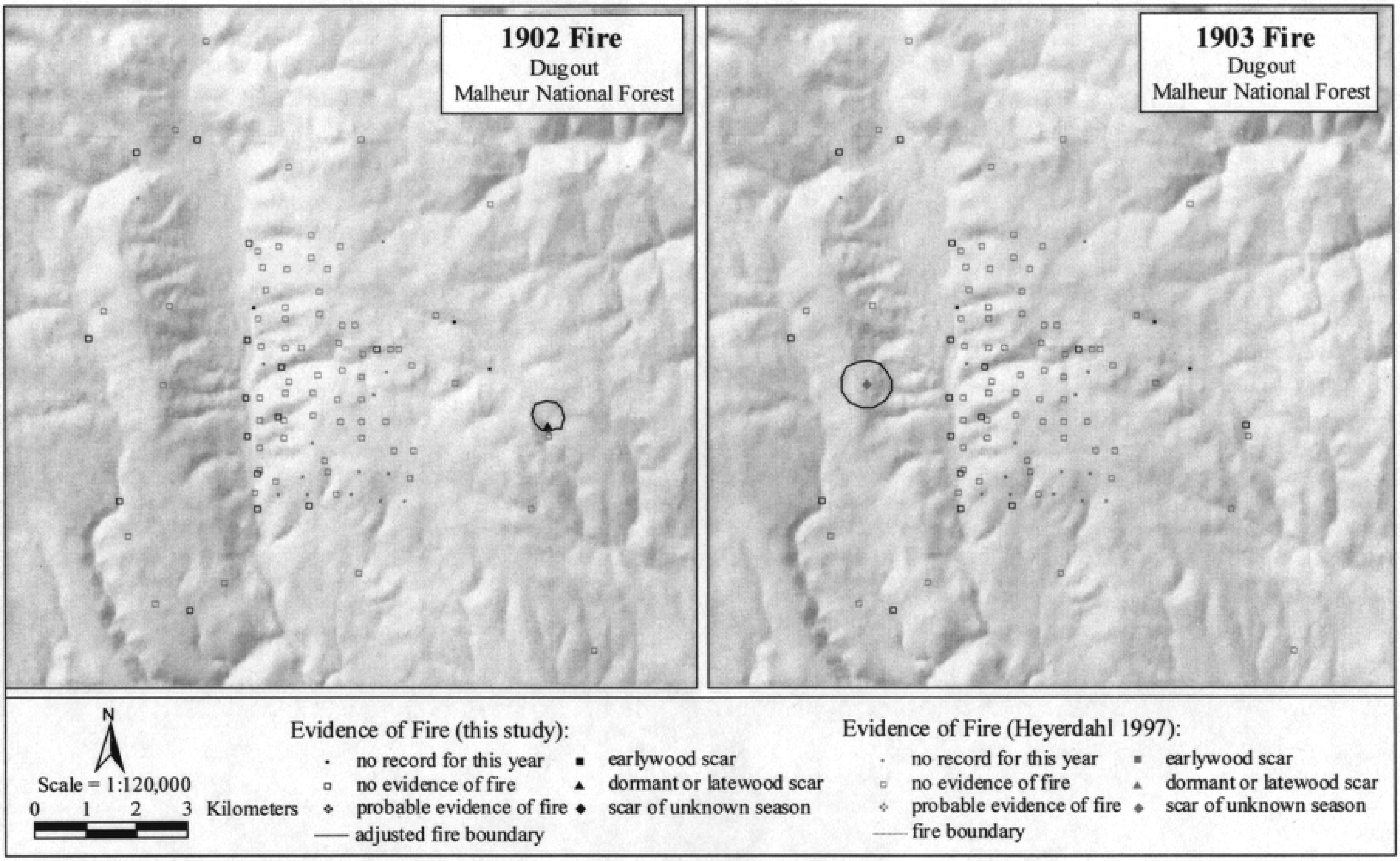

Figure 86. Dugout fire maps for 1902 (left) and 1903 (right).

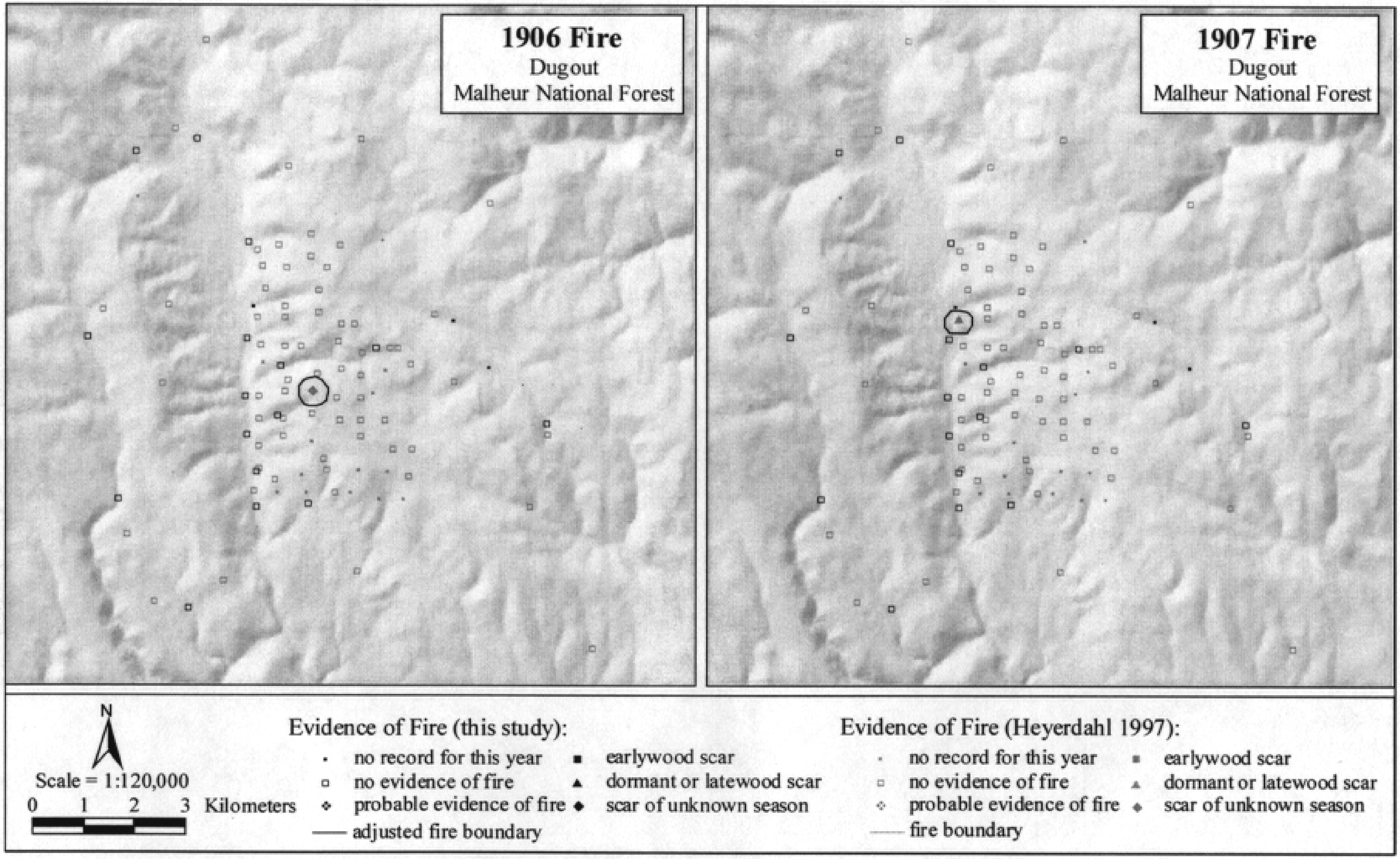

Figure 87. Dugout fire maps for 1906 (left) and 1907 (right).

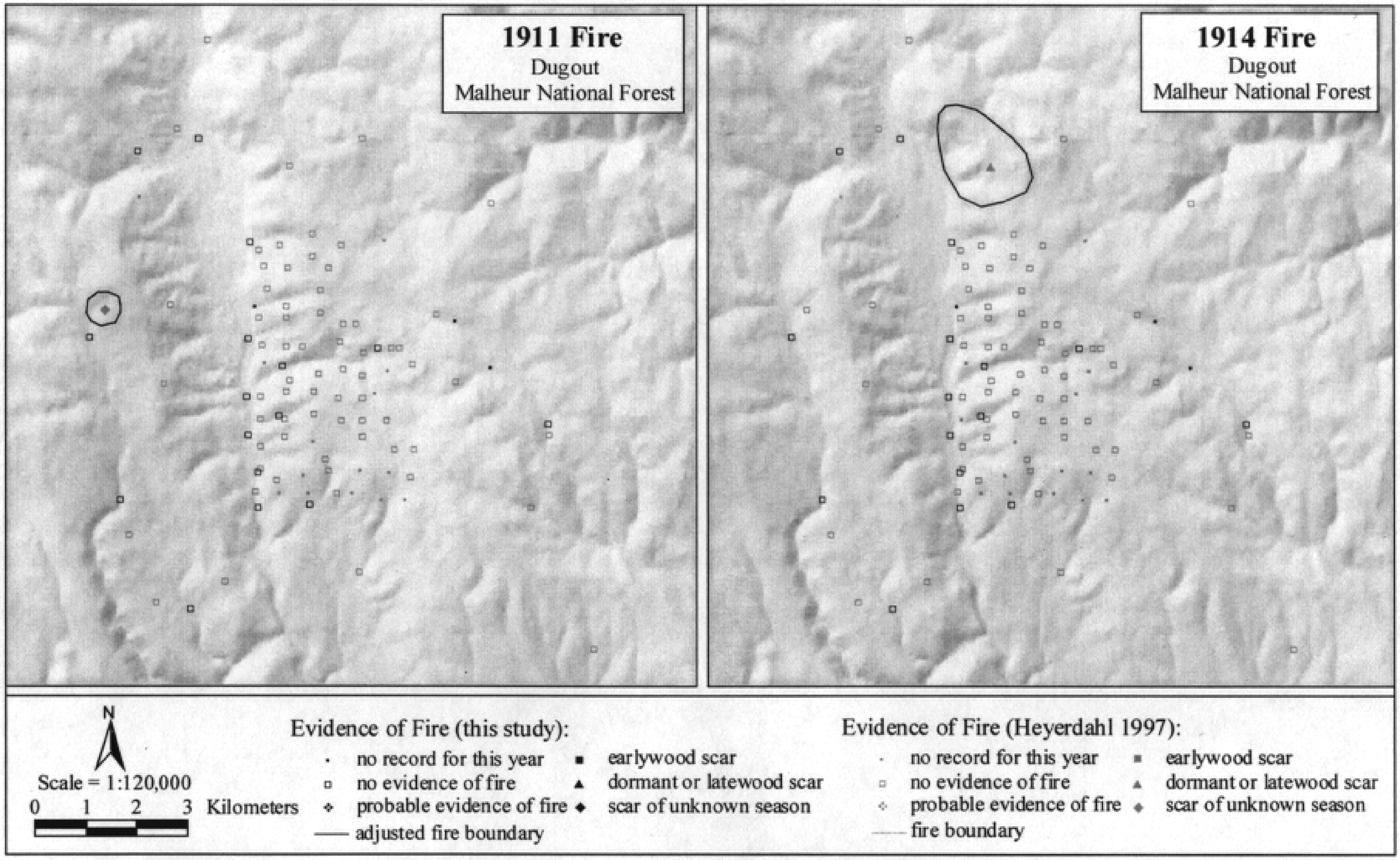

Figure 88. Dugout fire maps for 1911 (left) and 1914 (right).

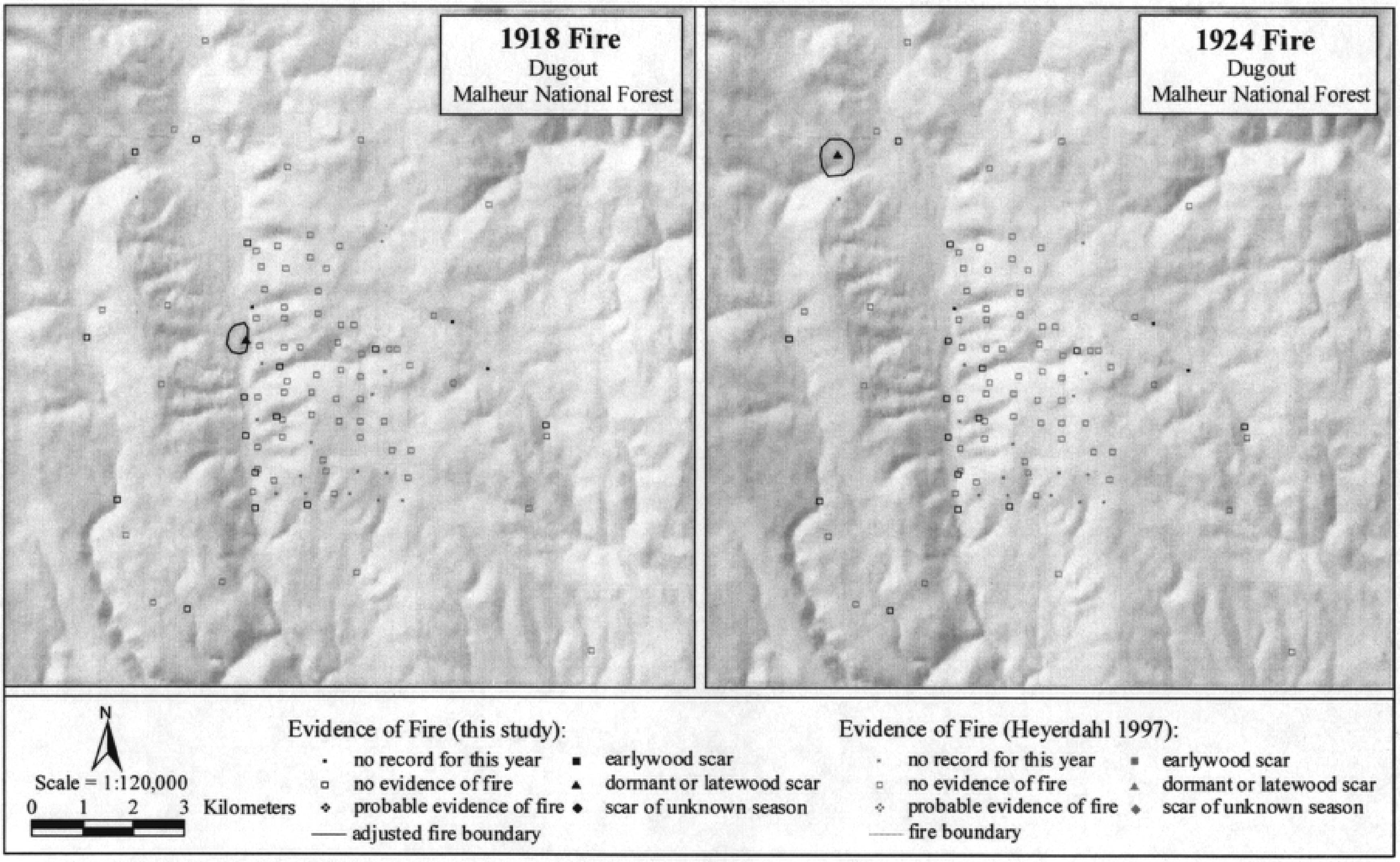

Figure 89. Dugout fire maps for 1918 (left) and 1924 (right).

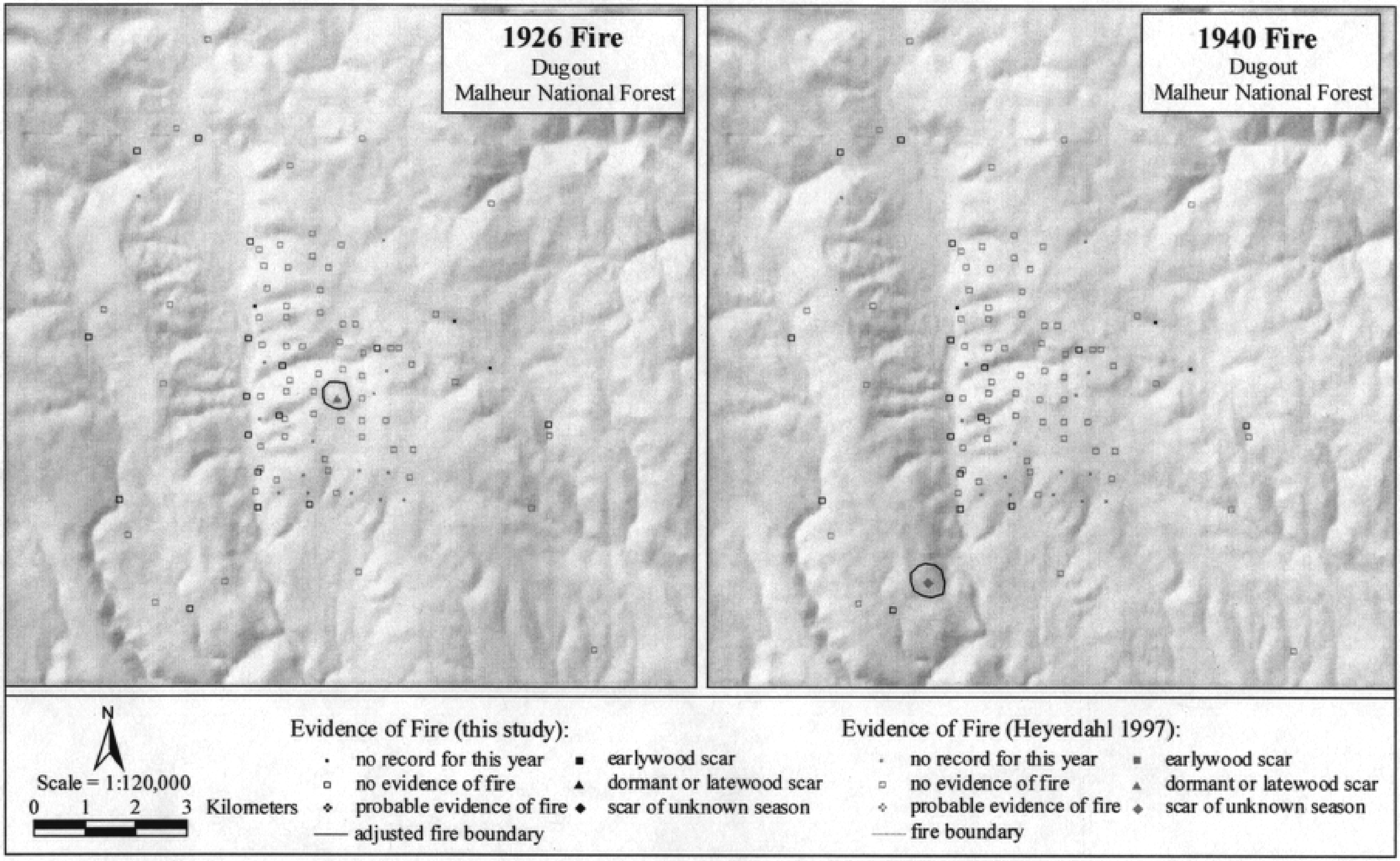

Figure 90. Dugout fire maps for 1926 (left) and 1940 (right).

APPENDIX E. Baker study area fire maps.

Fire years were mapped for every year there was clear evidence of fire scarring. The Baker fire maps show the fire scar data from this study (black) superimposed onto the fire scar data from Heyerdahl (gray, 1997). The intra-annular position of the scar is shown for both data sets. "No record for this year" indicates that there were no trees sampled that were recording during that year. "No evidence of fire" indicates that at least one tree at the plot was recording during that year, but there was no evidence of fire in any of the samples within that plot for that year. "Probable evidence of fire" indicates that there was some sort of disruption in the rings of a sample at that site for that year (e.g., an abrupt increase or decrease in ring widths), but it could not definitely be attributed to fire scarring. "Possible post-fire age class" indicates that establishment dates of more than two early seral trees (e.g. western larch, lodgepole pine) were determined to be roughly within 10 to 15 years of the fire date and could possibly be a post-fire cohort. It is important to note, however, that this was a very loose definition, and the data should be interpreted accordingly. The short fire return intervals in this study area obscure the determination of age cohorts (Heyerdahl 1997). The fire boundaries are based on those determined by Heyerdahl (1997, see the Methods section). If data from this study indicated a different fire boundary, the fire boundaries were adjusted accordingly.

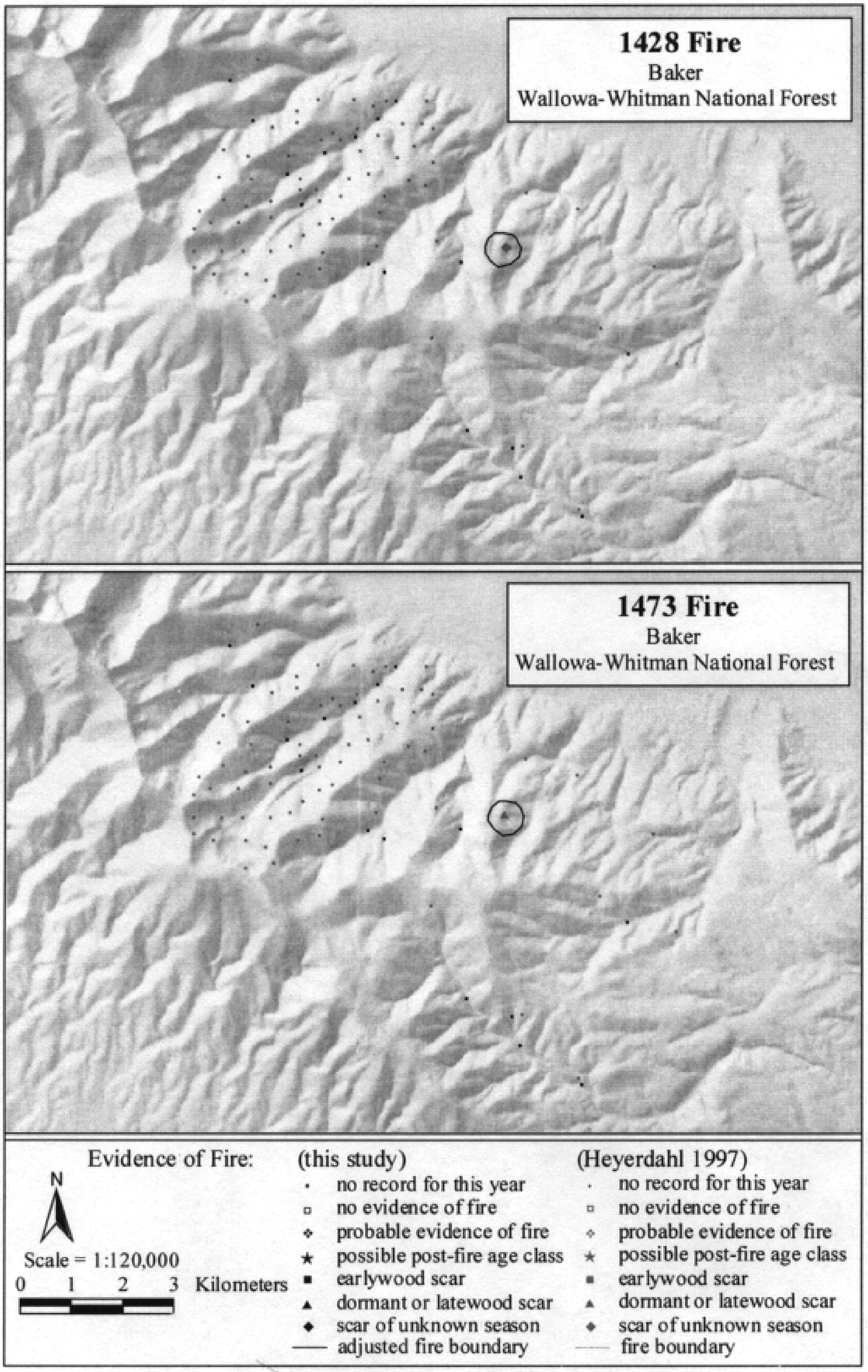

Figure 91. Baker fire maps for 1428 (top) and 1473 (bottom).

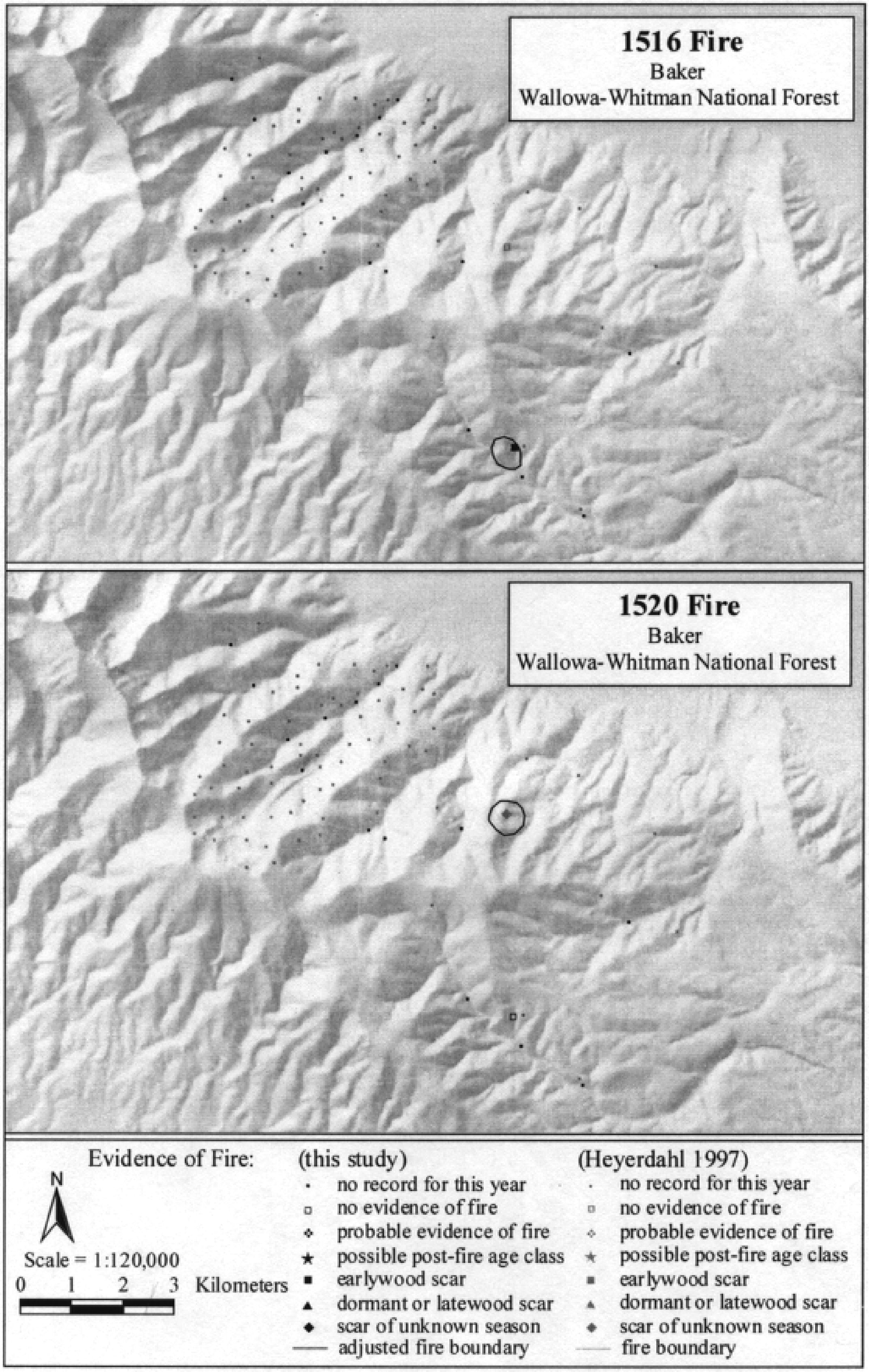

Figure 92. Baker fire maps for 1516 (top) and 1520 (bottom).

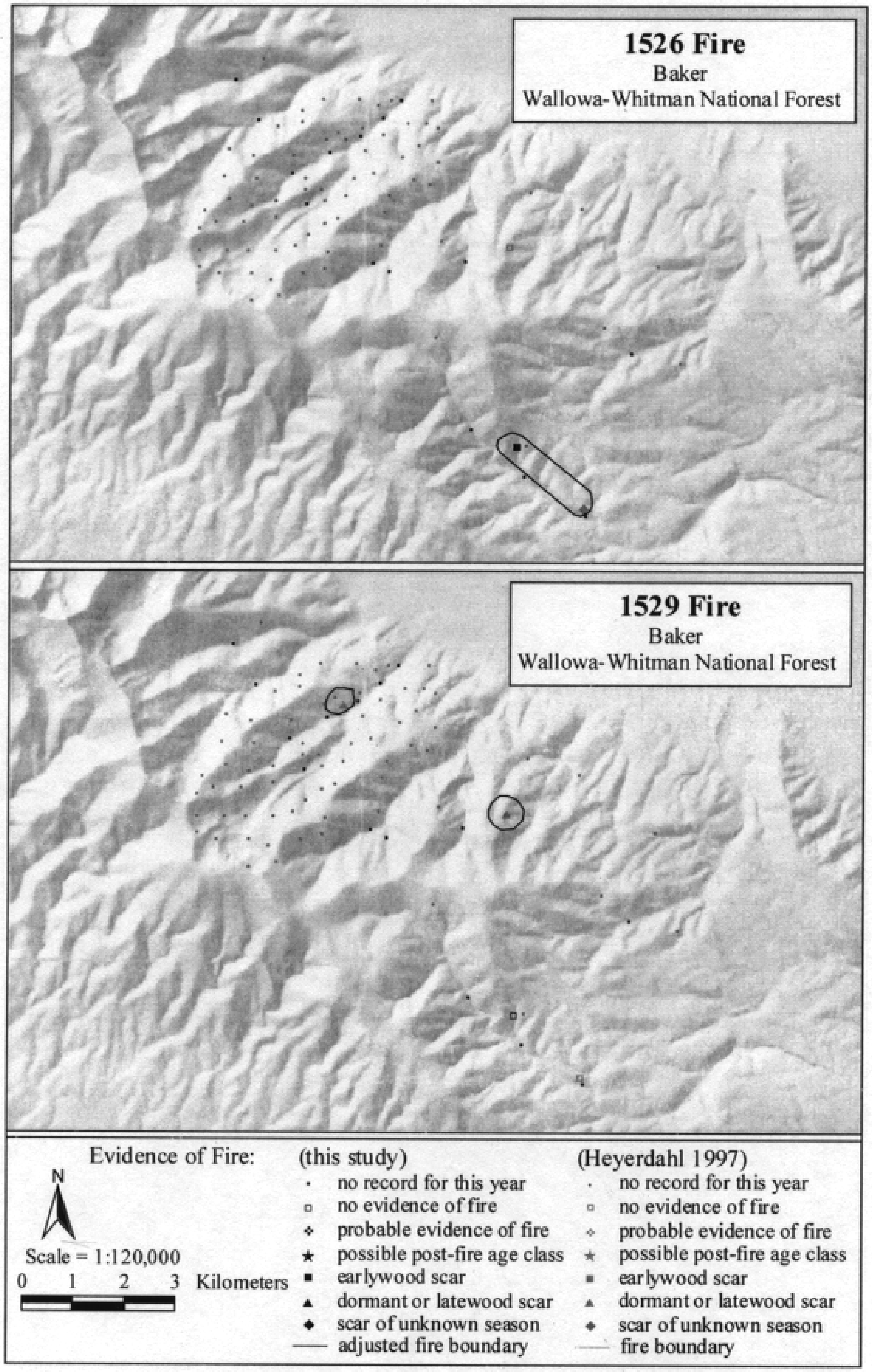

Figure 93. Baker fire maps for 1526 (top) and 1529 (bottom).

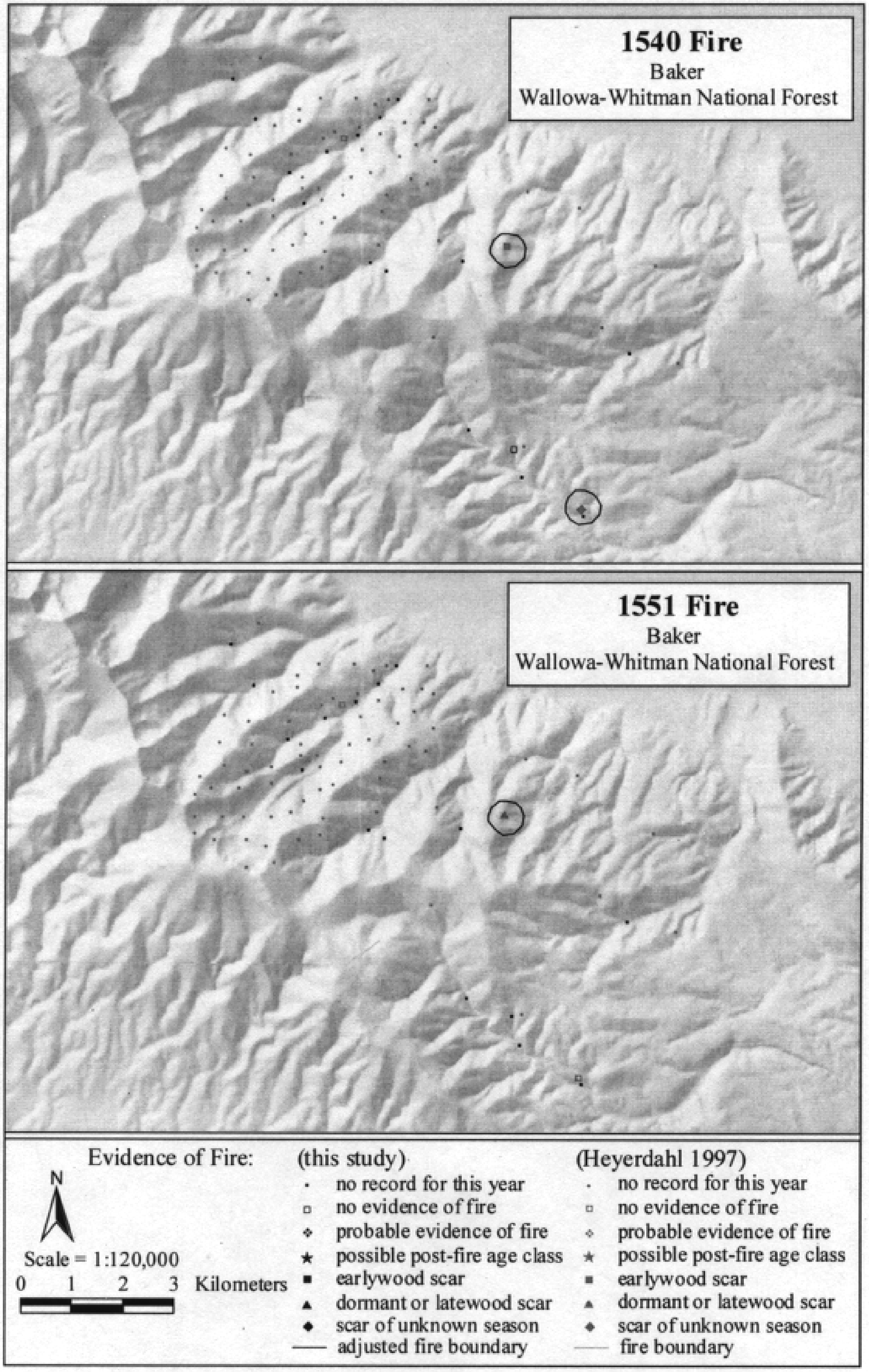

Figure 94. Baker fire maps for 1540 (top) and 1551 (bottom).

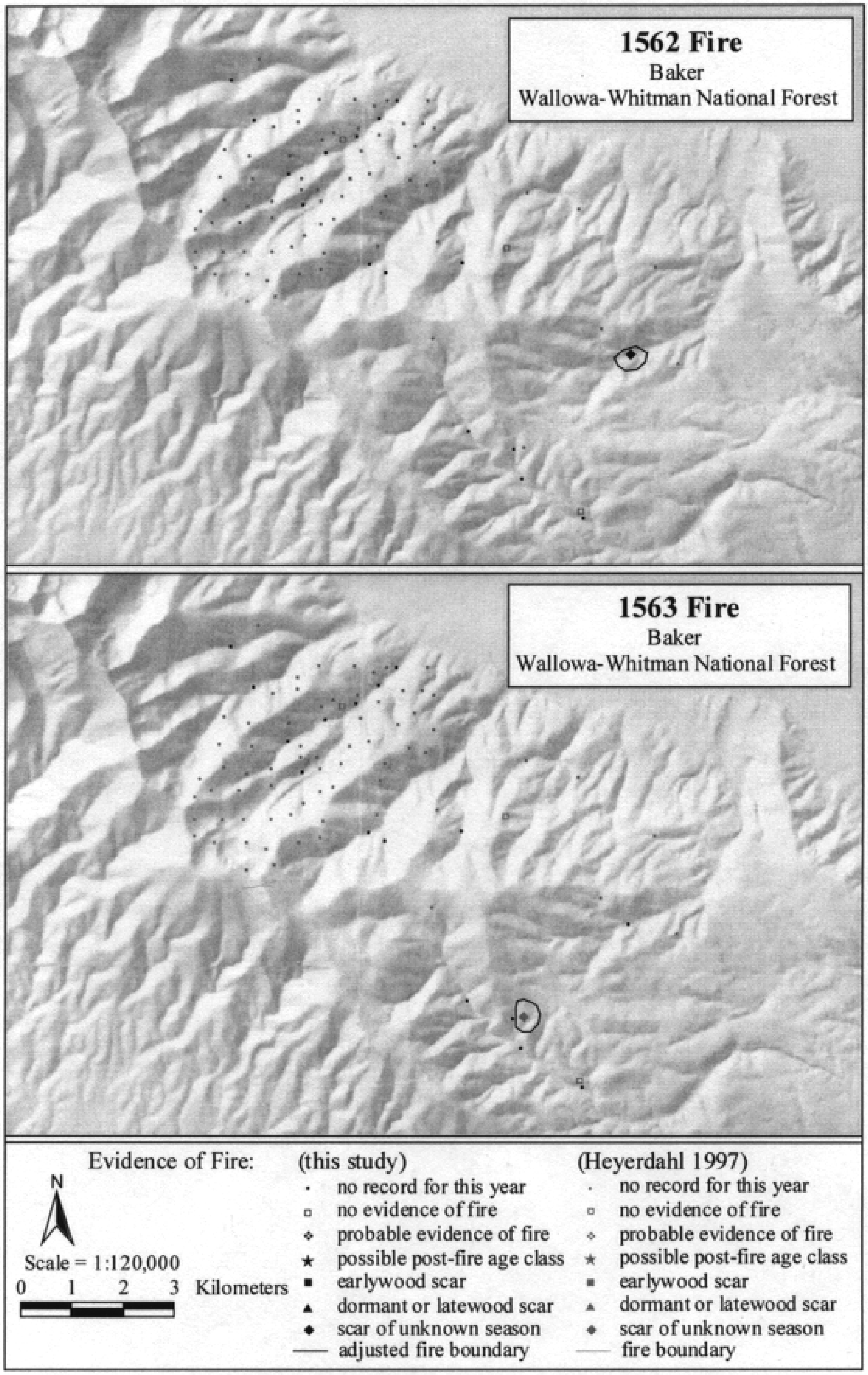

Figure 95. Baker fire maps for 1562 (top) and 1563 (bottom).

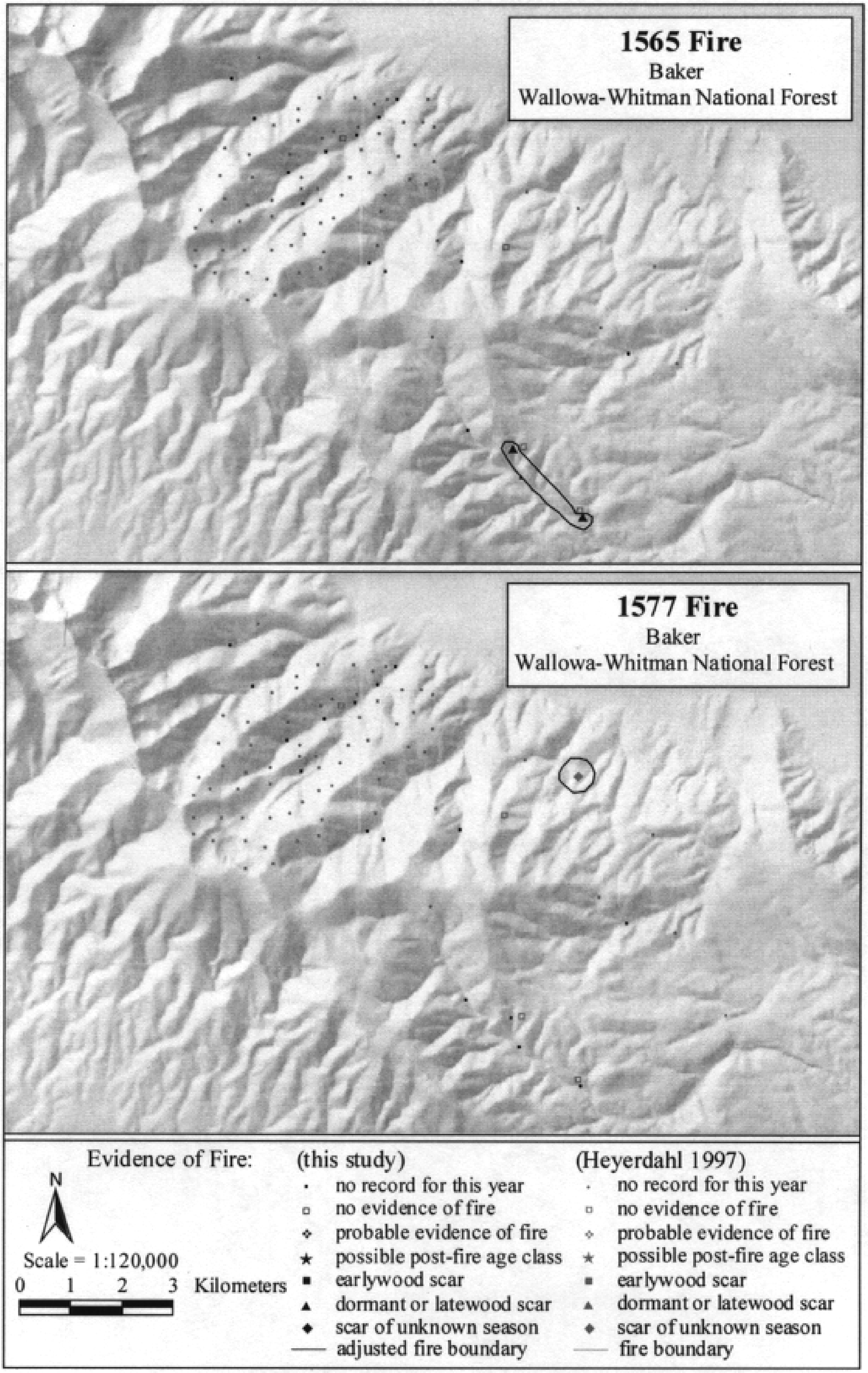

Figure 96. Baker fire maps for 1565 (top) and 1577 (bottom).

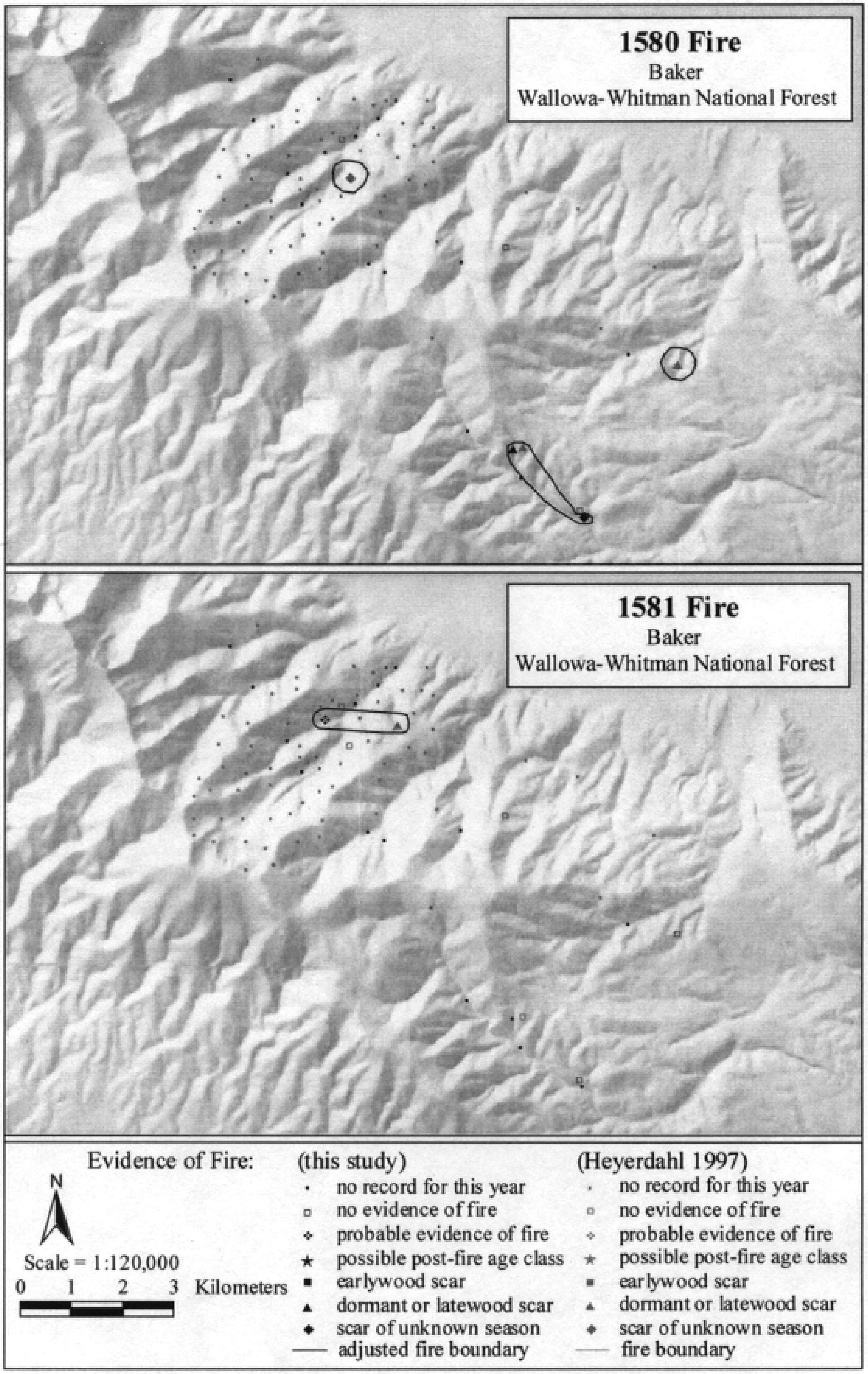

Figure 97. Baker fire maps for 1580 (top) and 1581 (bottom).

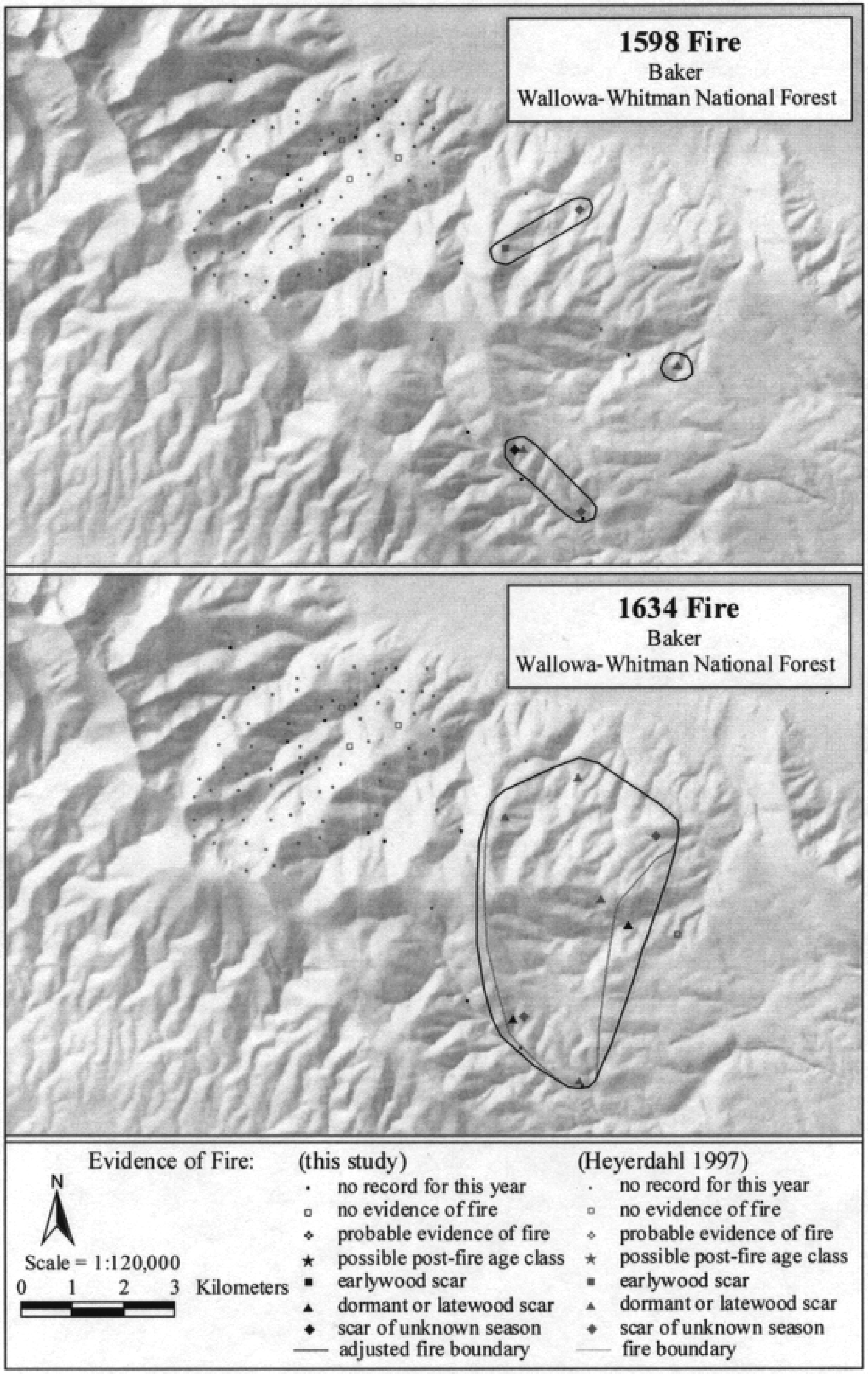

Figure 98. Baker fire maps for 1598 (top) and 1634 (bottom).

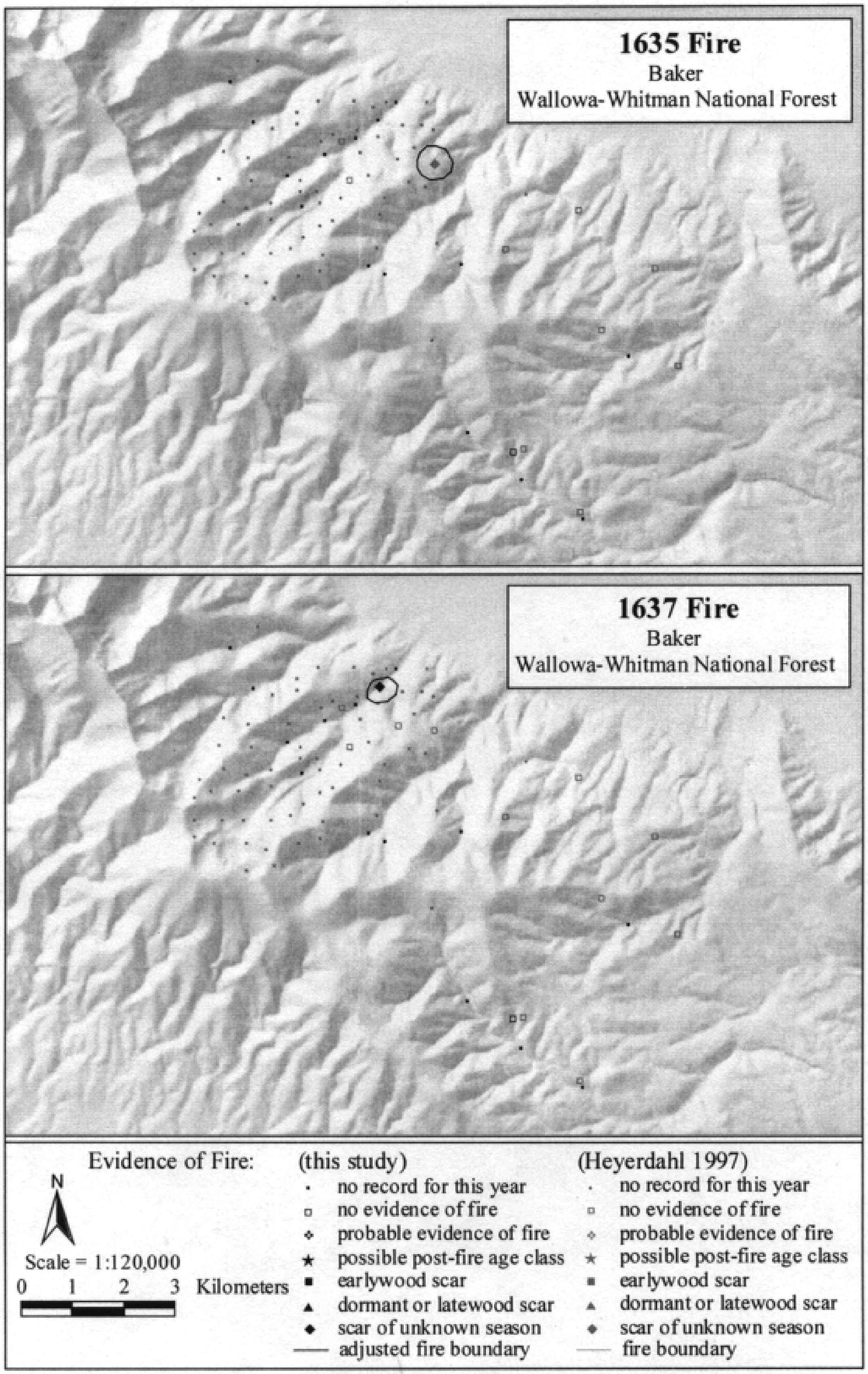

Figure 99. Baker fire maps for 1635 (top) and 1637 (bottom).

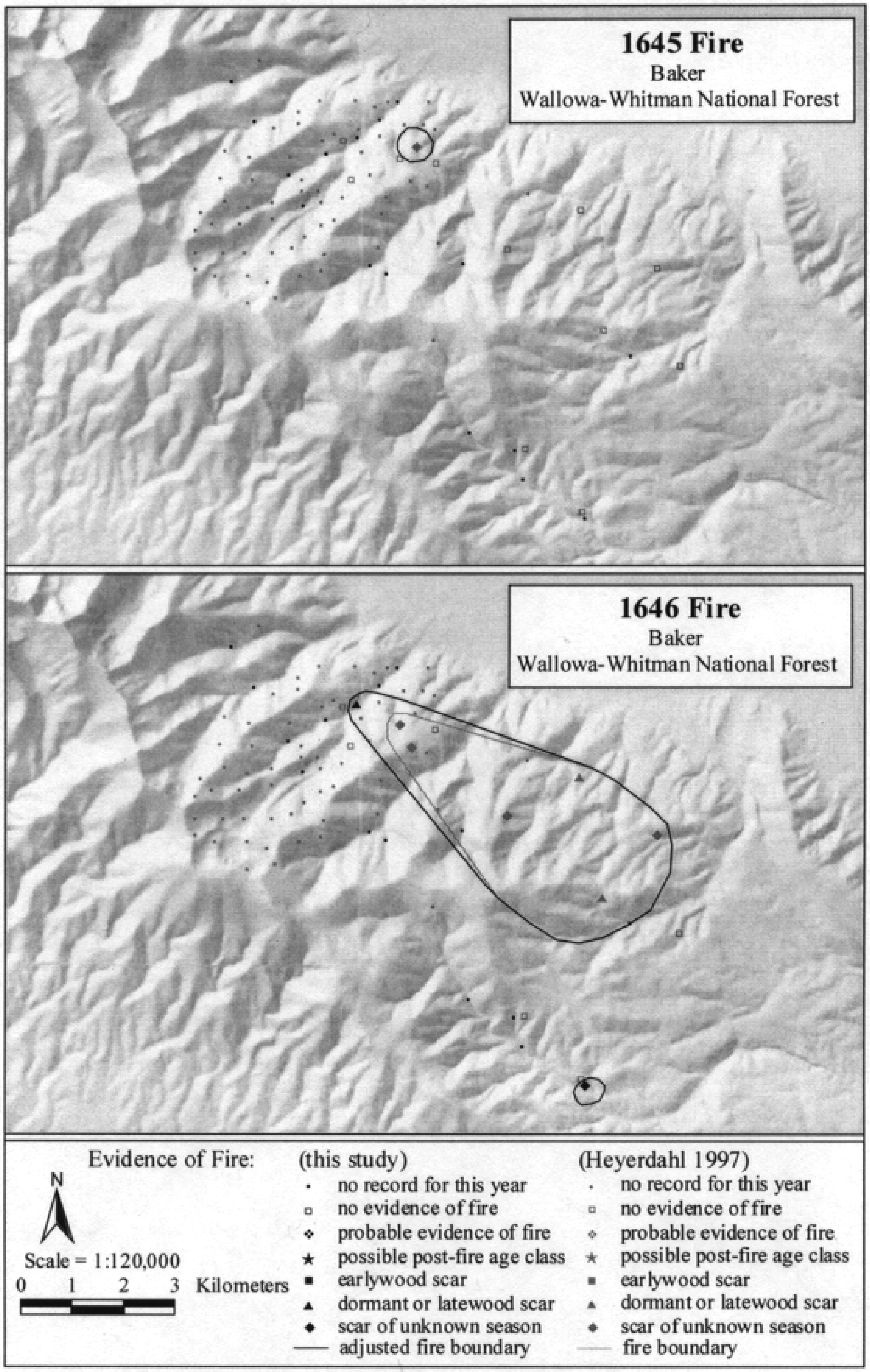

Figure 100. Baker fire maps for 1645 (top) and 1646 (bottom).

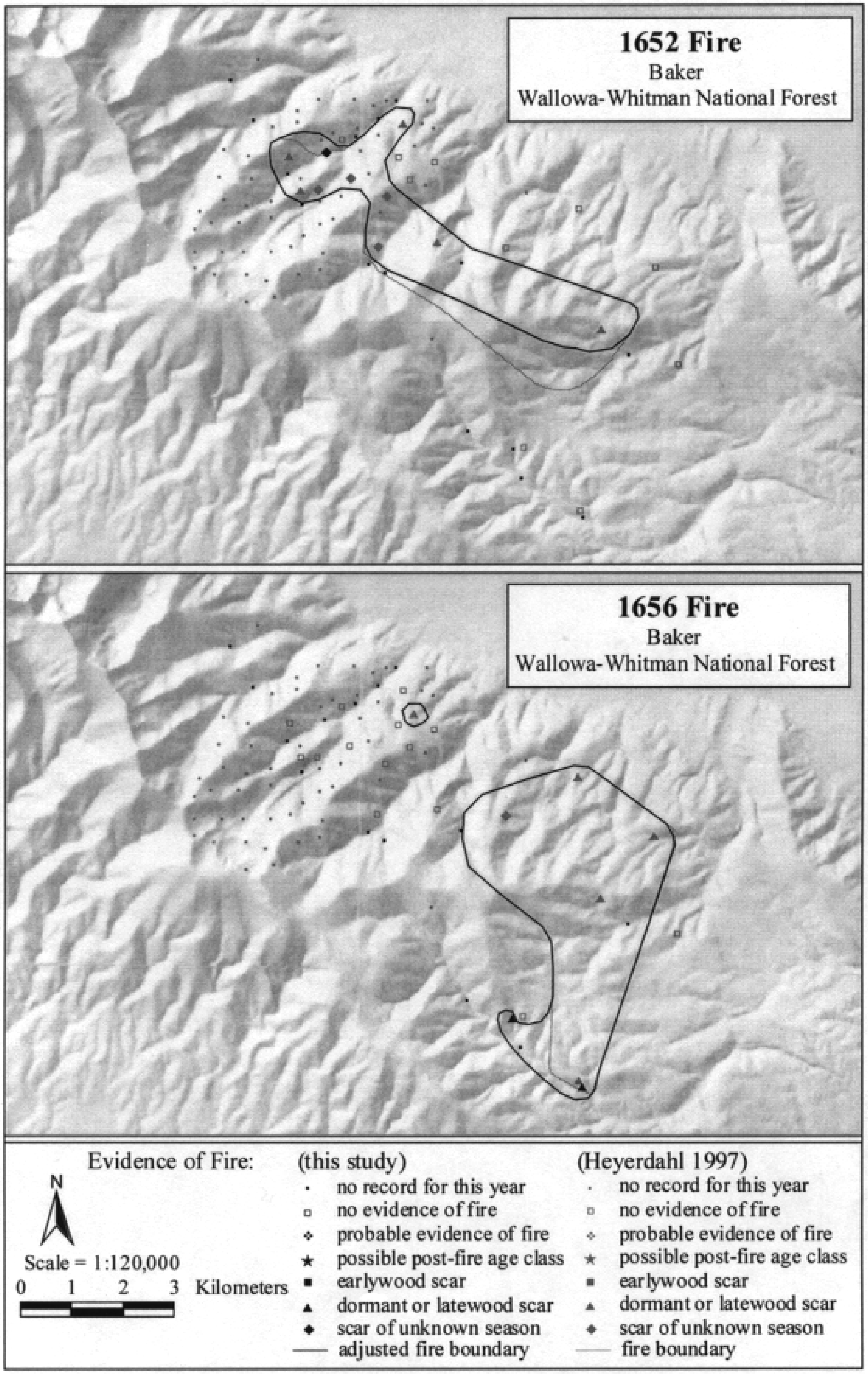

Figure 101. Baker fire maps for 1652 (top) and 1656 (bottom).

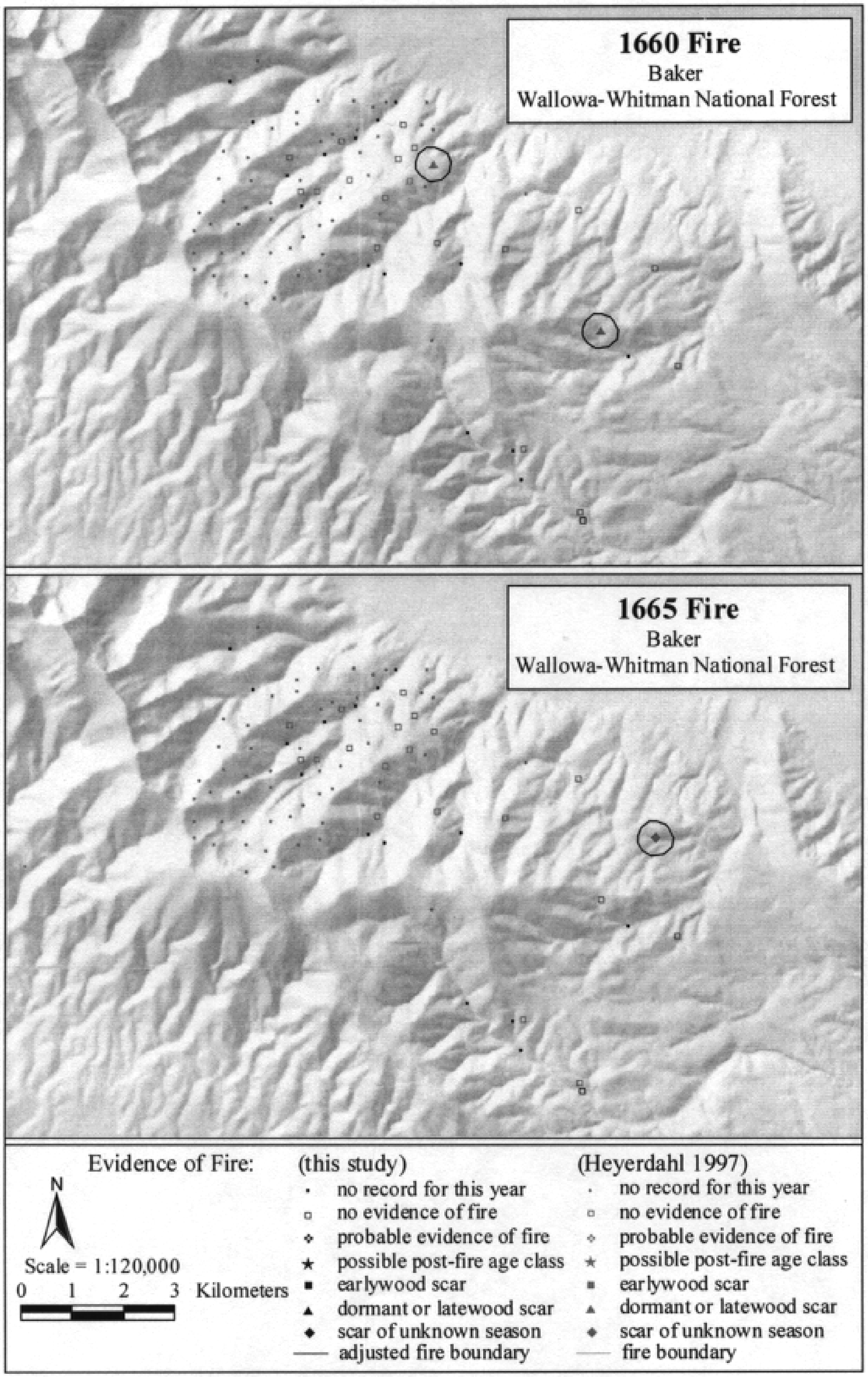

Figure 102. Baker fire maps for 1660 (top) and 1665 (bottom).

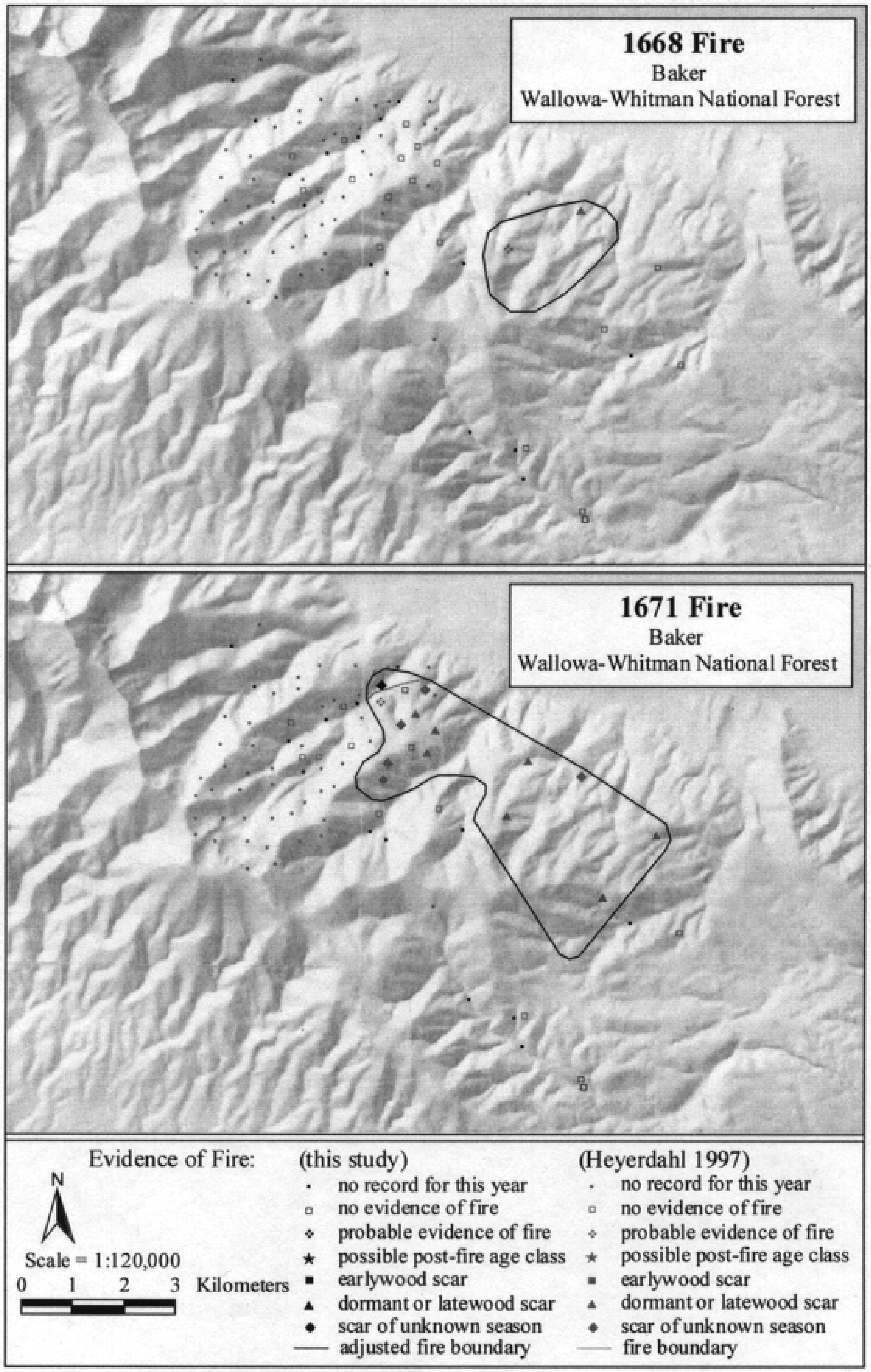

Figure 103. Baker fire maps for 1668 (top) and 1671 (bottom).

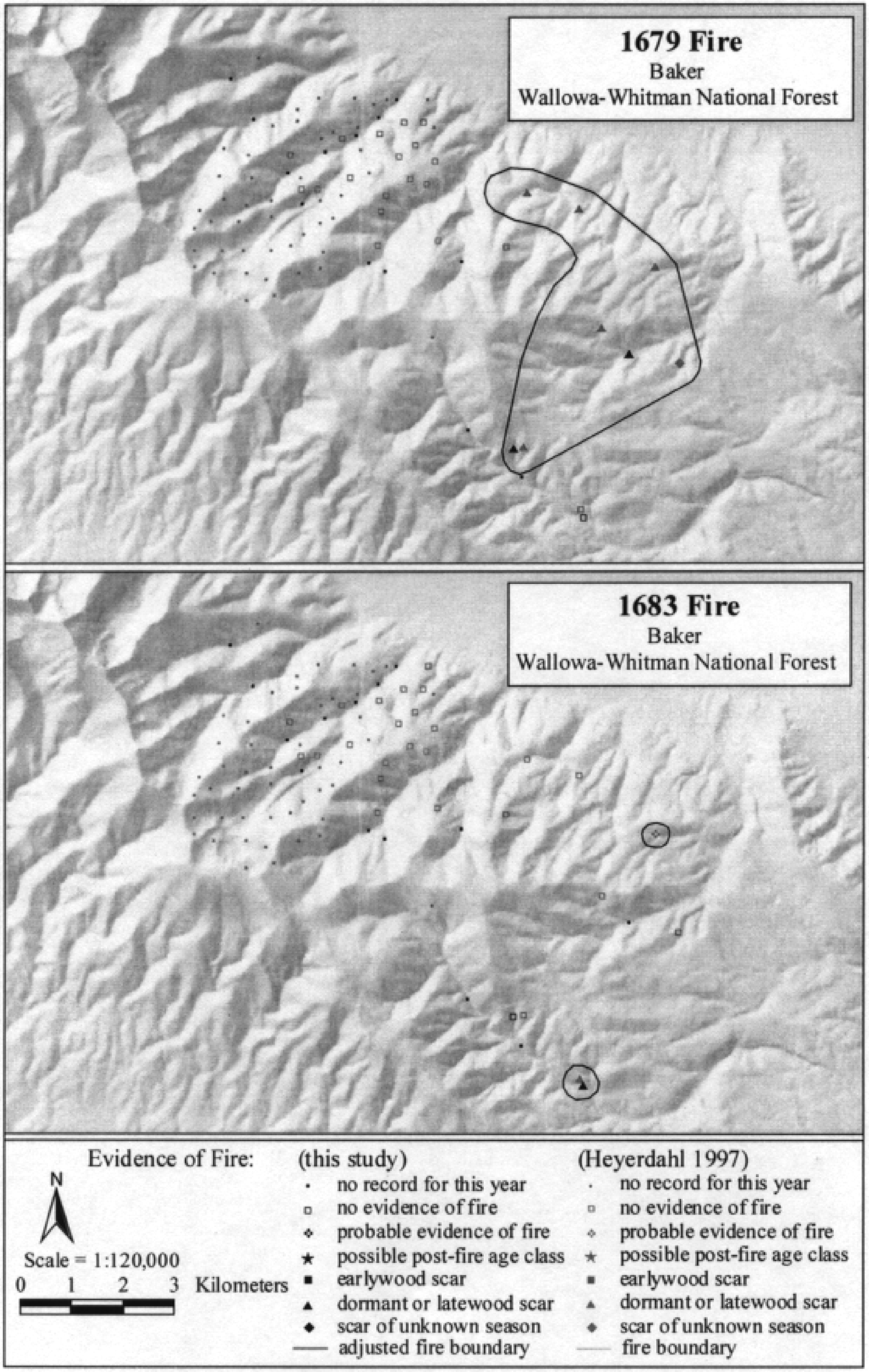

Figure 104. Baker fire maps for 1679 (top) and 1683 (bottom).

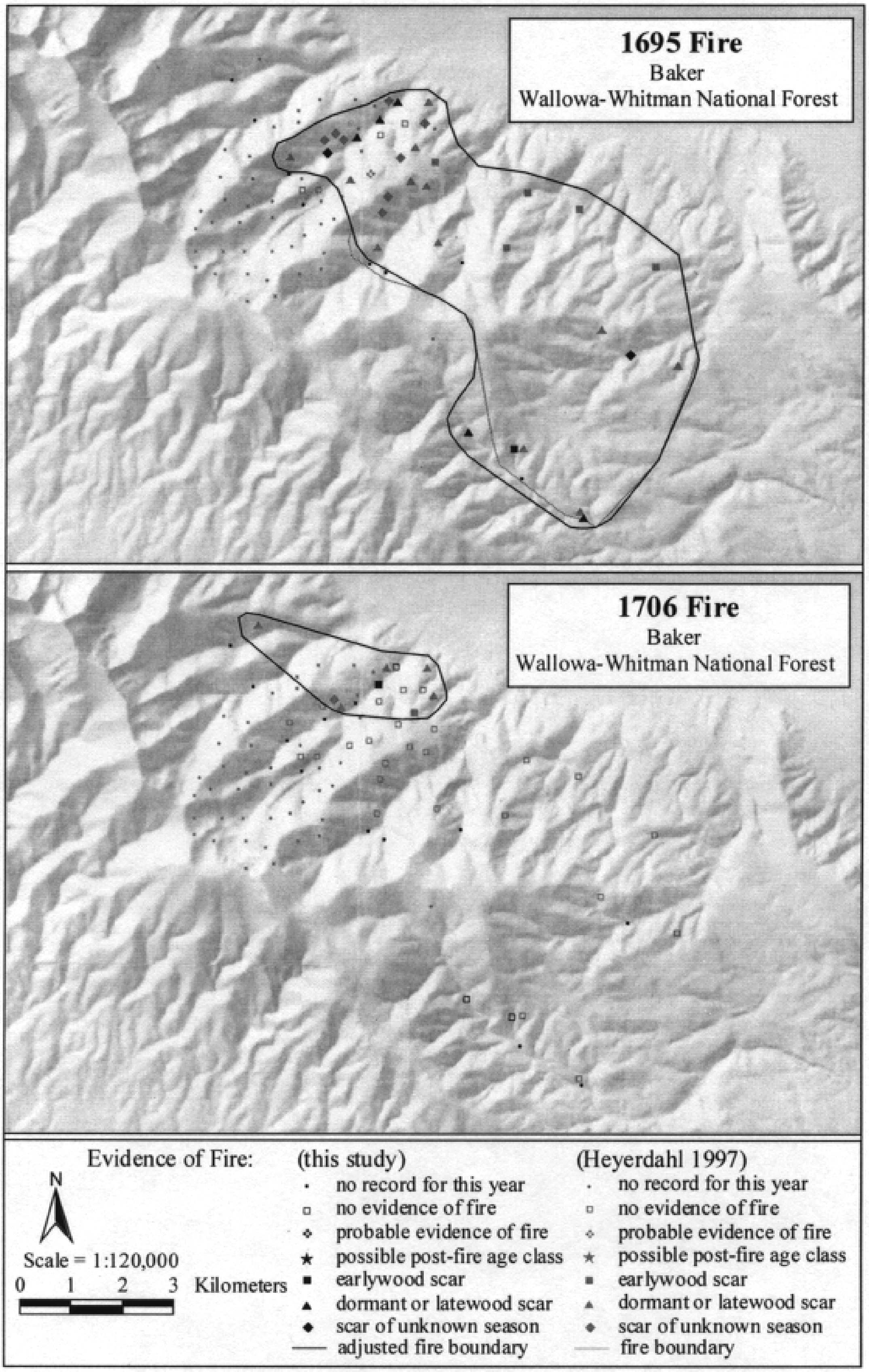

Figure 105. Baker fire maps for 1695 (top) and 1706 (bottom).

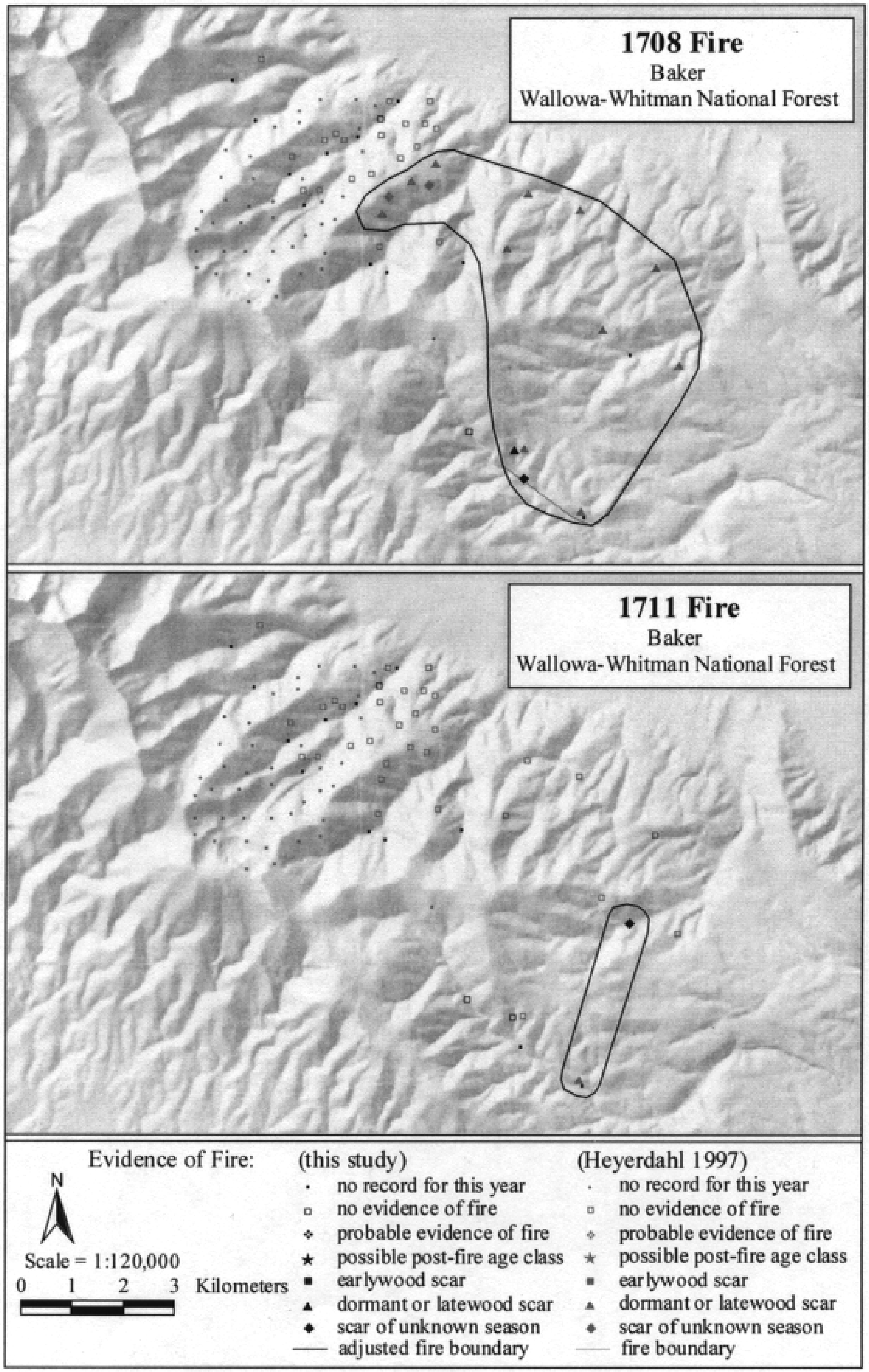

Figure 106. Baker fire maps for 1708 (top) and 1711 (bottom).

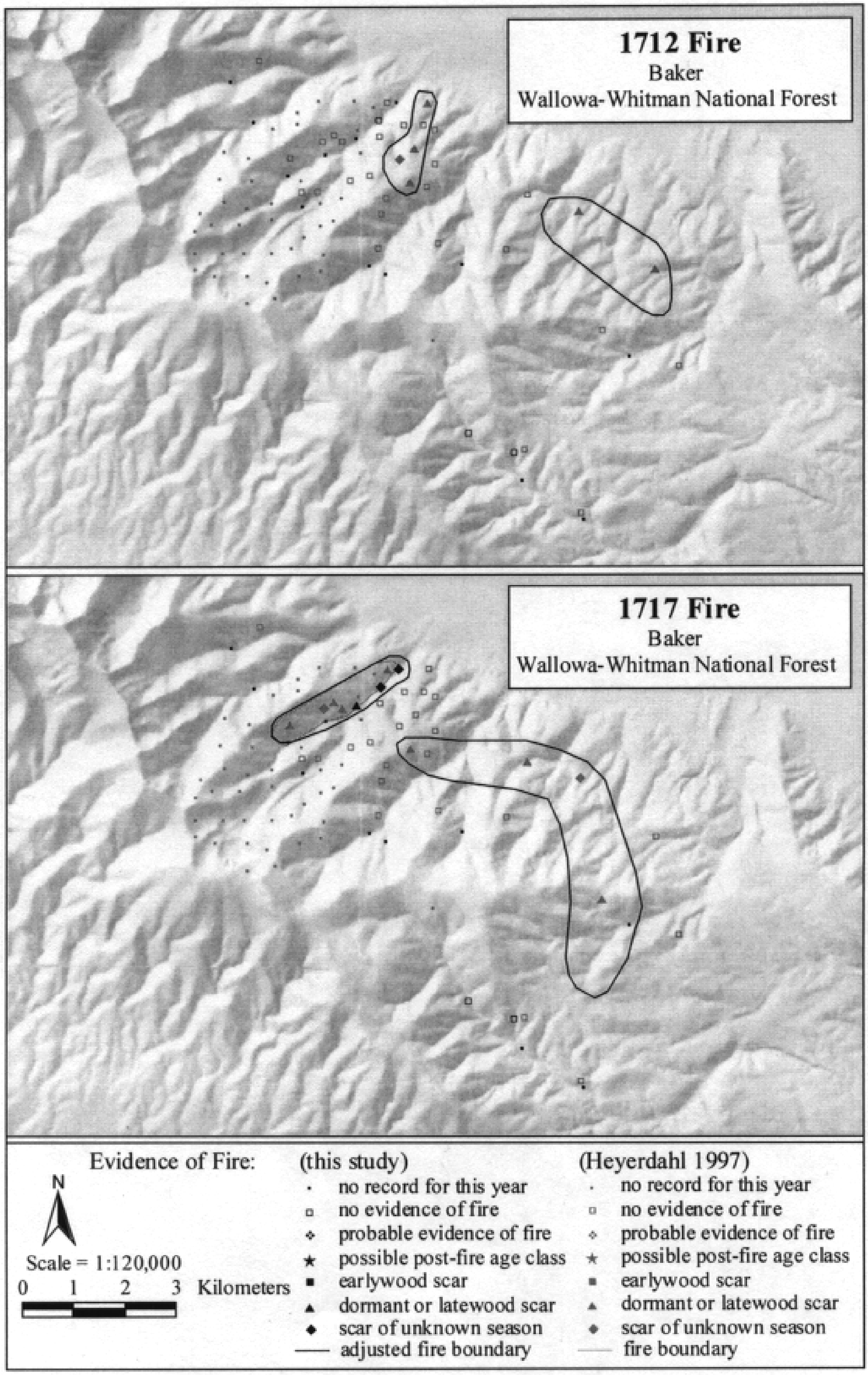

Figure 107. Baker fire maps for 1712 (top) and 1717 (bottom).

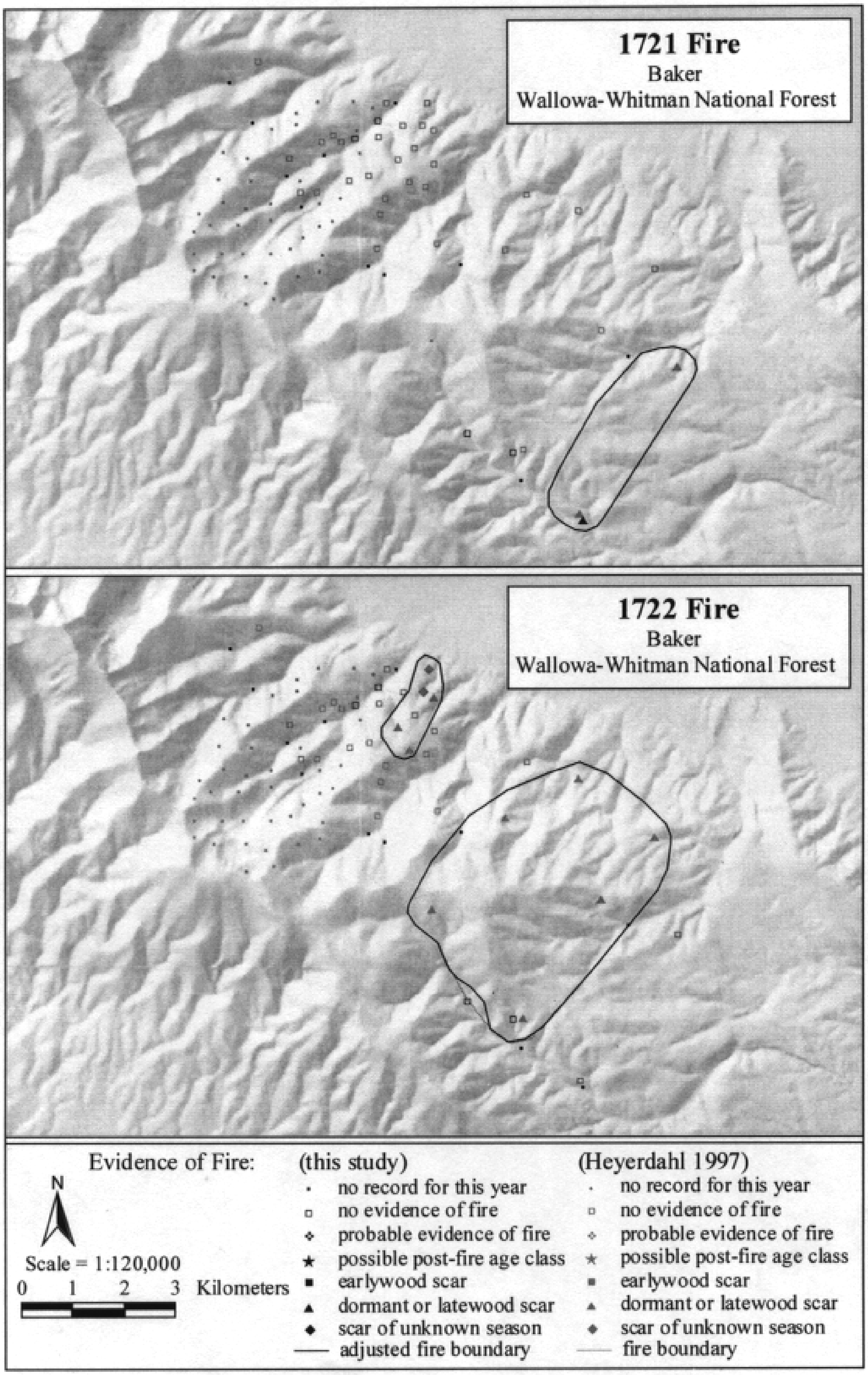

Figure 108. Baker fire maps for 1721 (top) and 1722 (bottom).

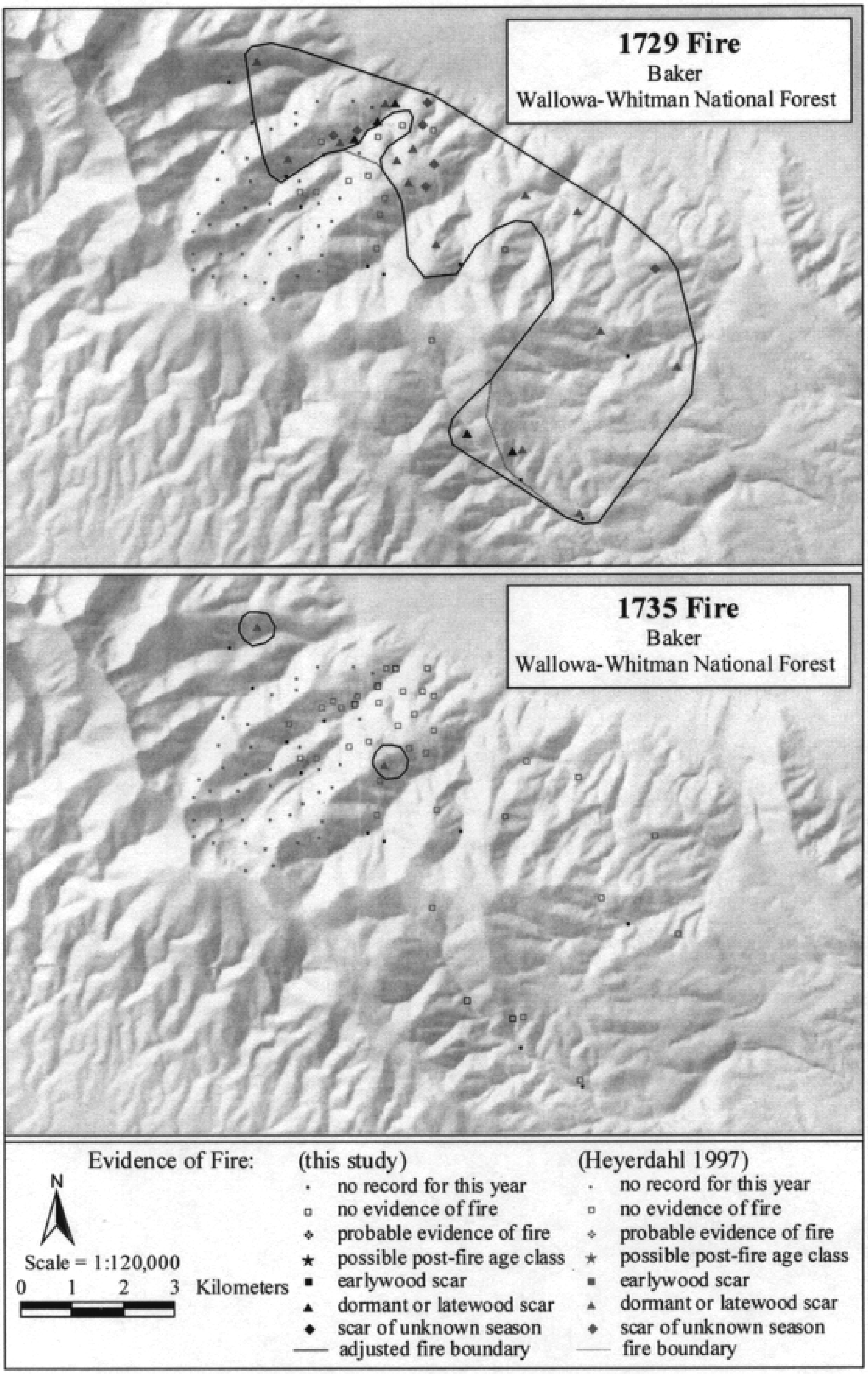

Figure 109. Baker fire maps for 1729 (top) and 1735 (bottom).

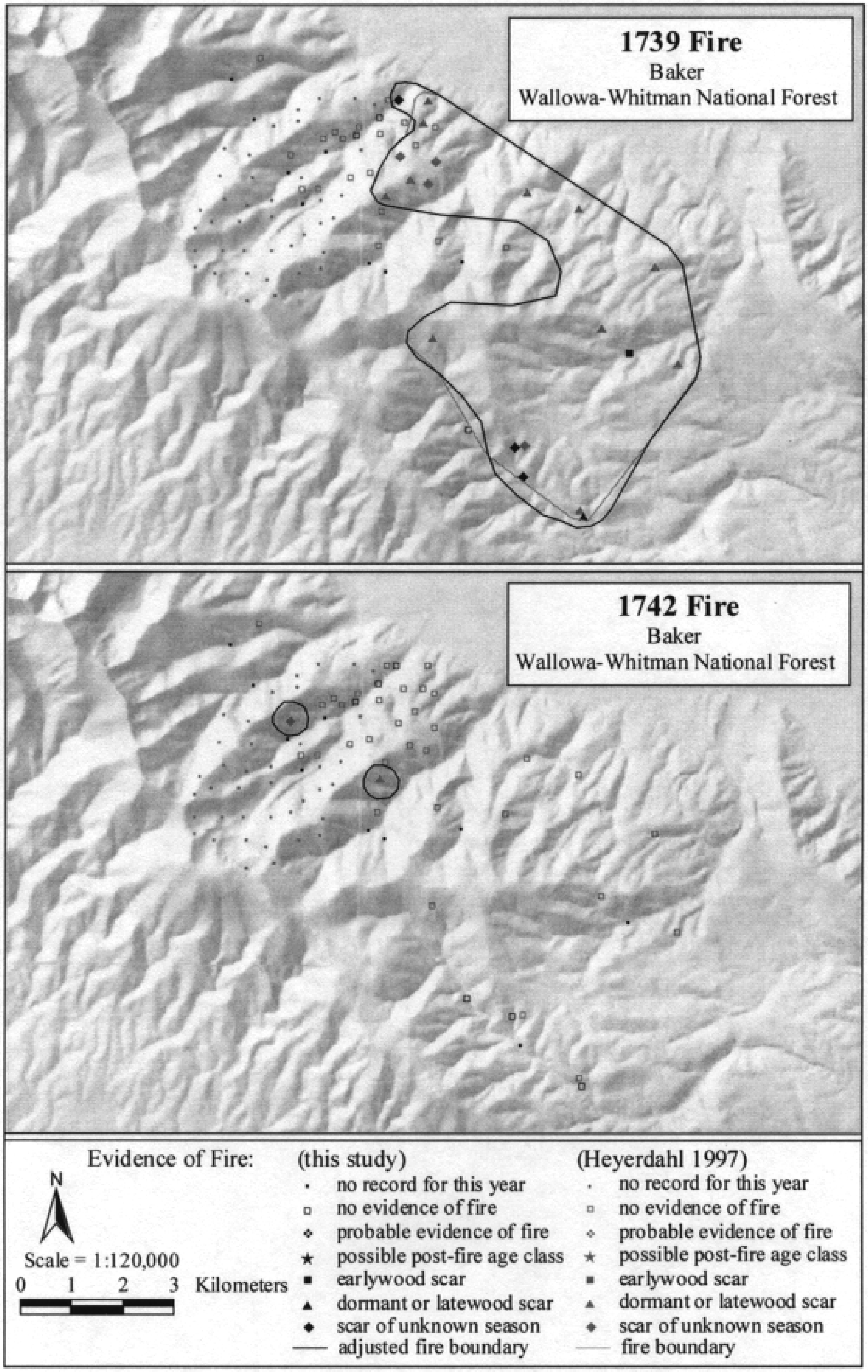

Figure 110. Baker fire maps for 1739 (top) and 1742 (bottom).

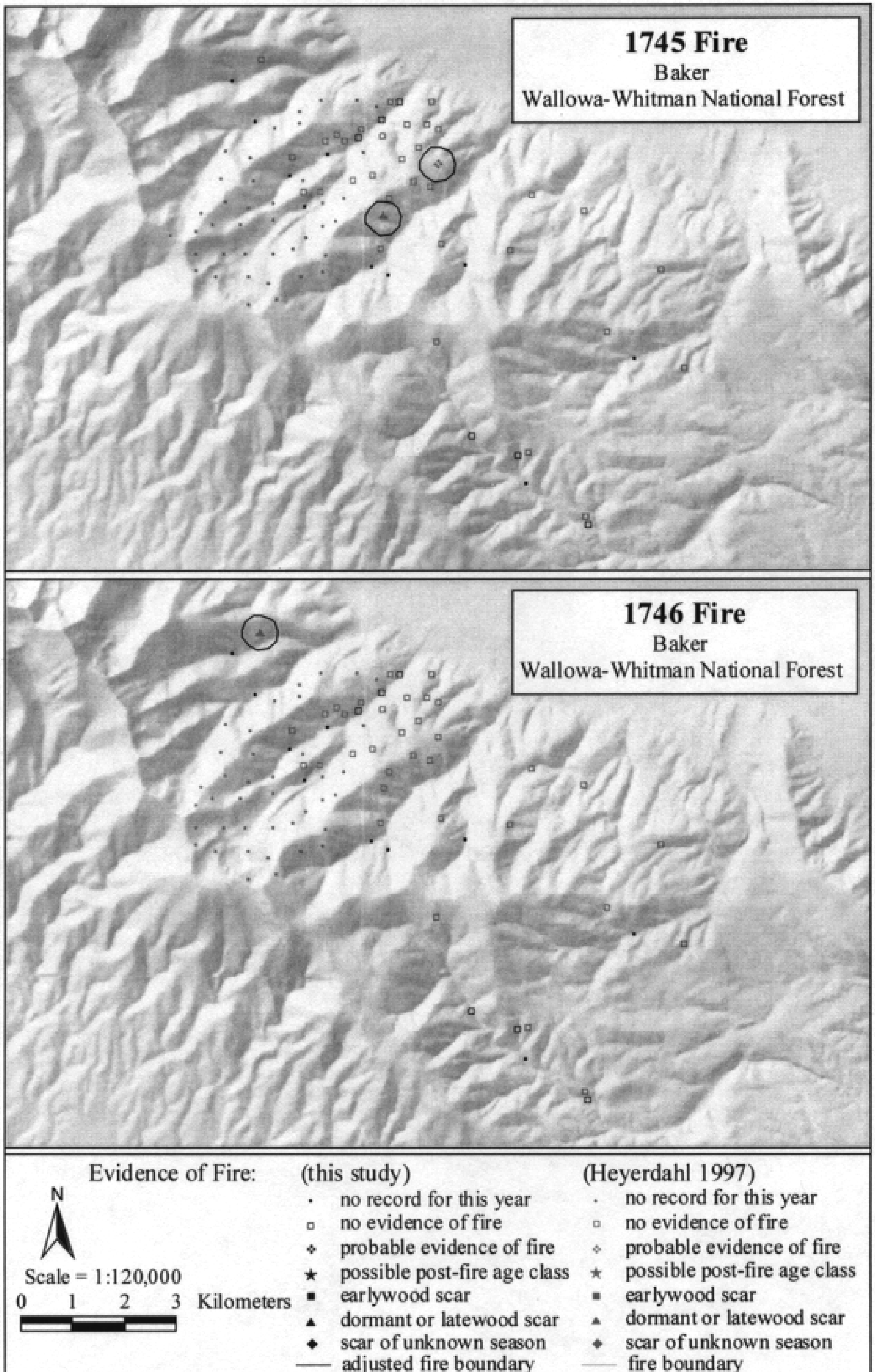

Figure 111. Baker fire maps for 1745 (top) and 1746 (bottom).

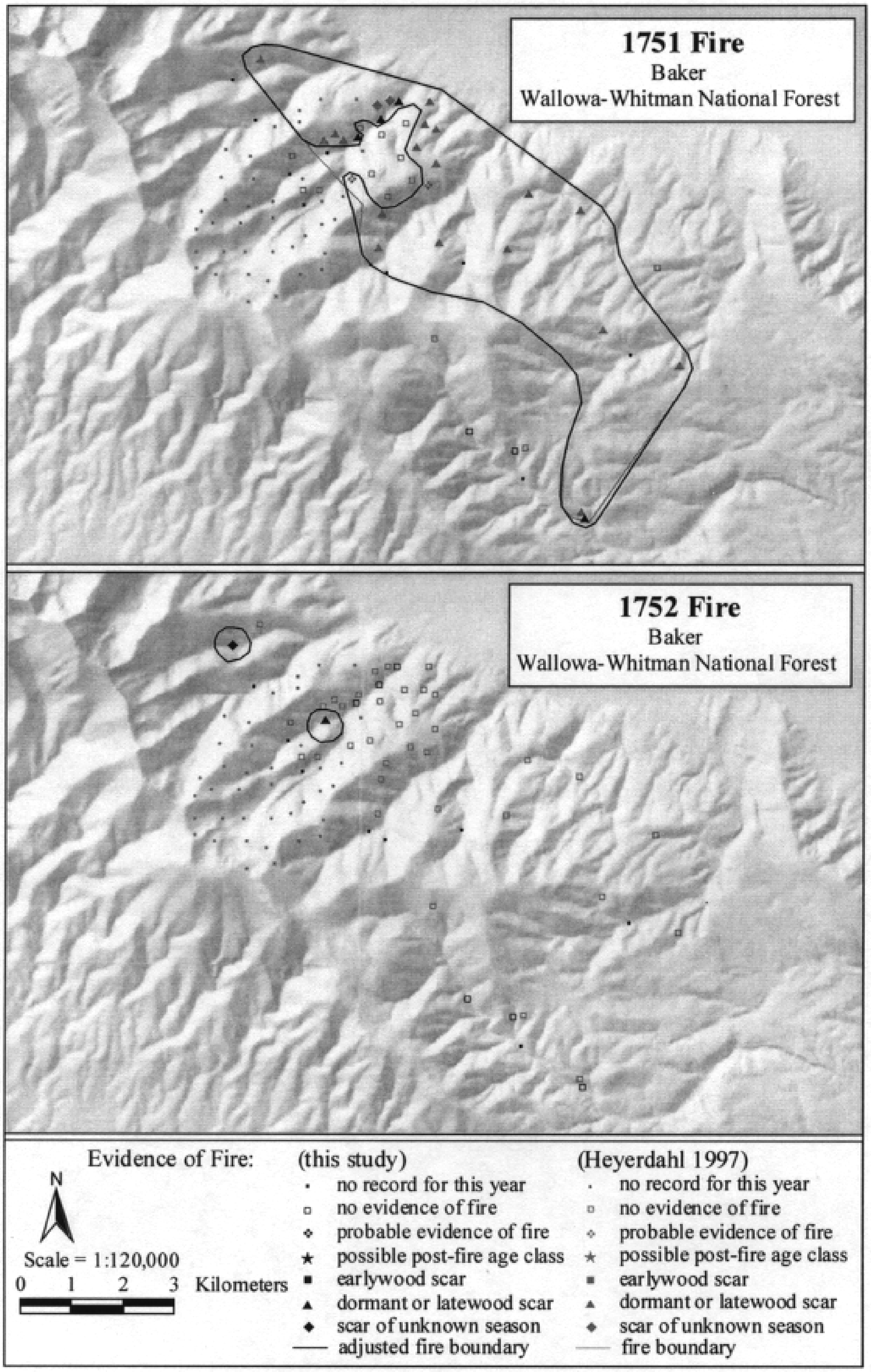

Figure 112. Baker fire maps for 1751 (top) and 1752 (bottom).

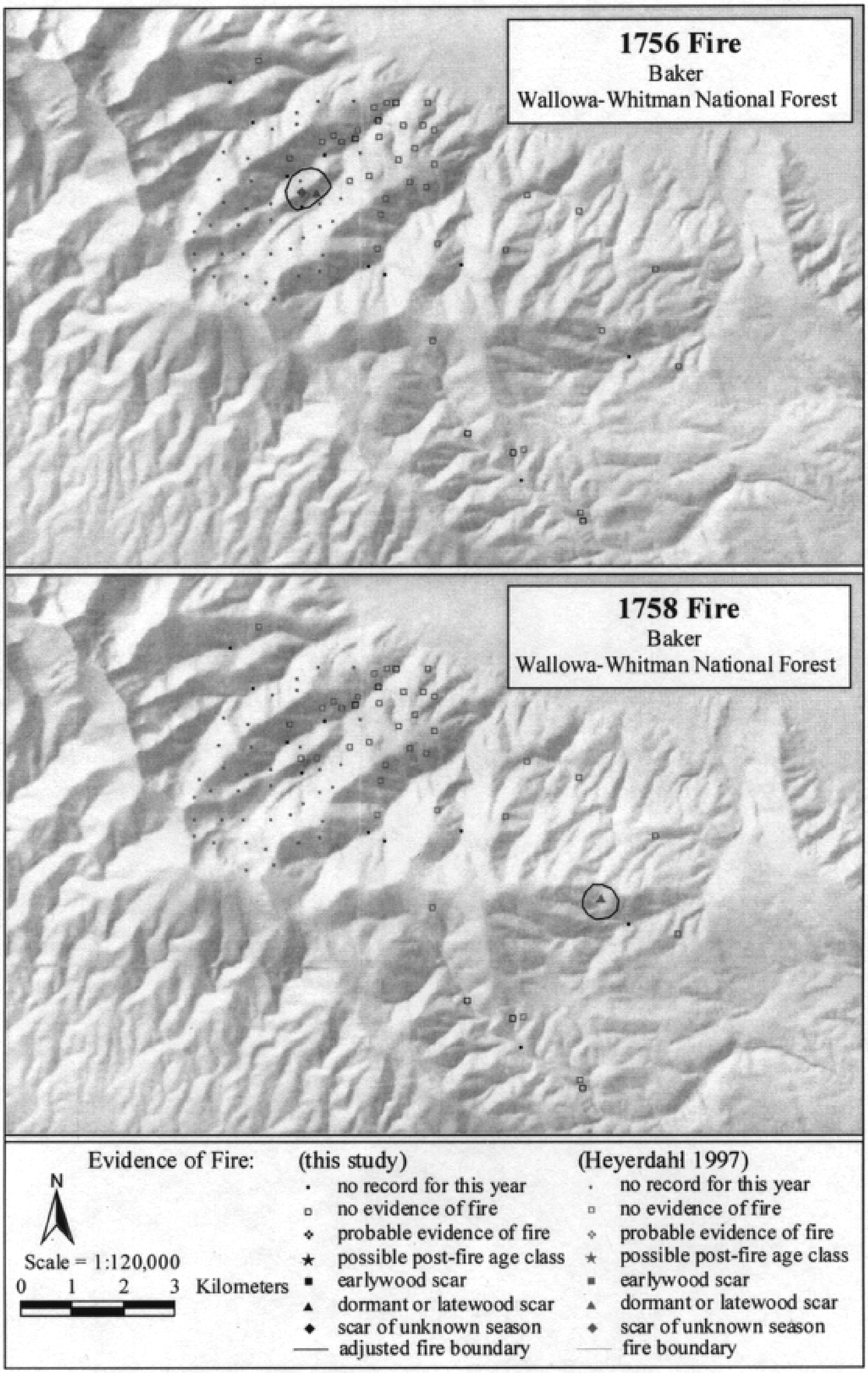

Figure 113. Baker fire maps for 1756 (top) and 1758 (bottom).

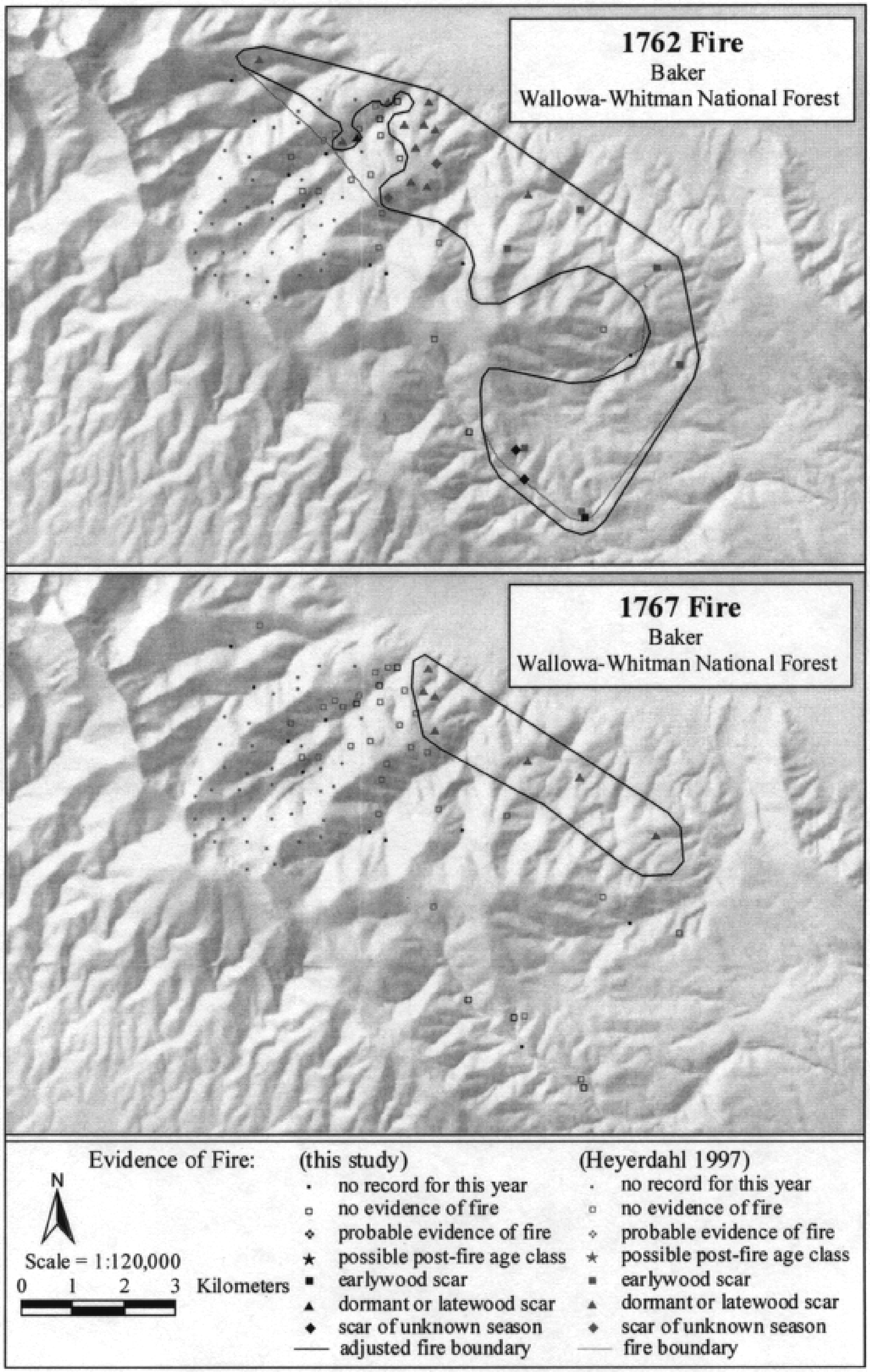

Figure 114. Baker fire maps for 1762 (top) and 1767 (bottom).

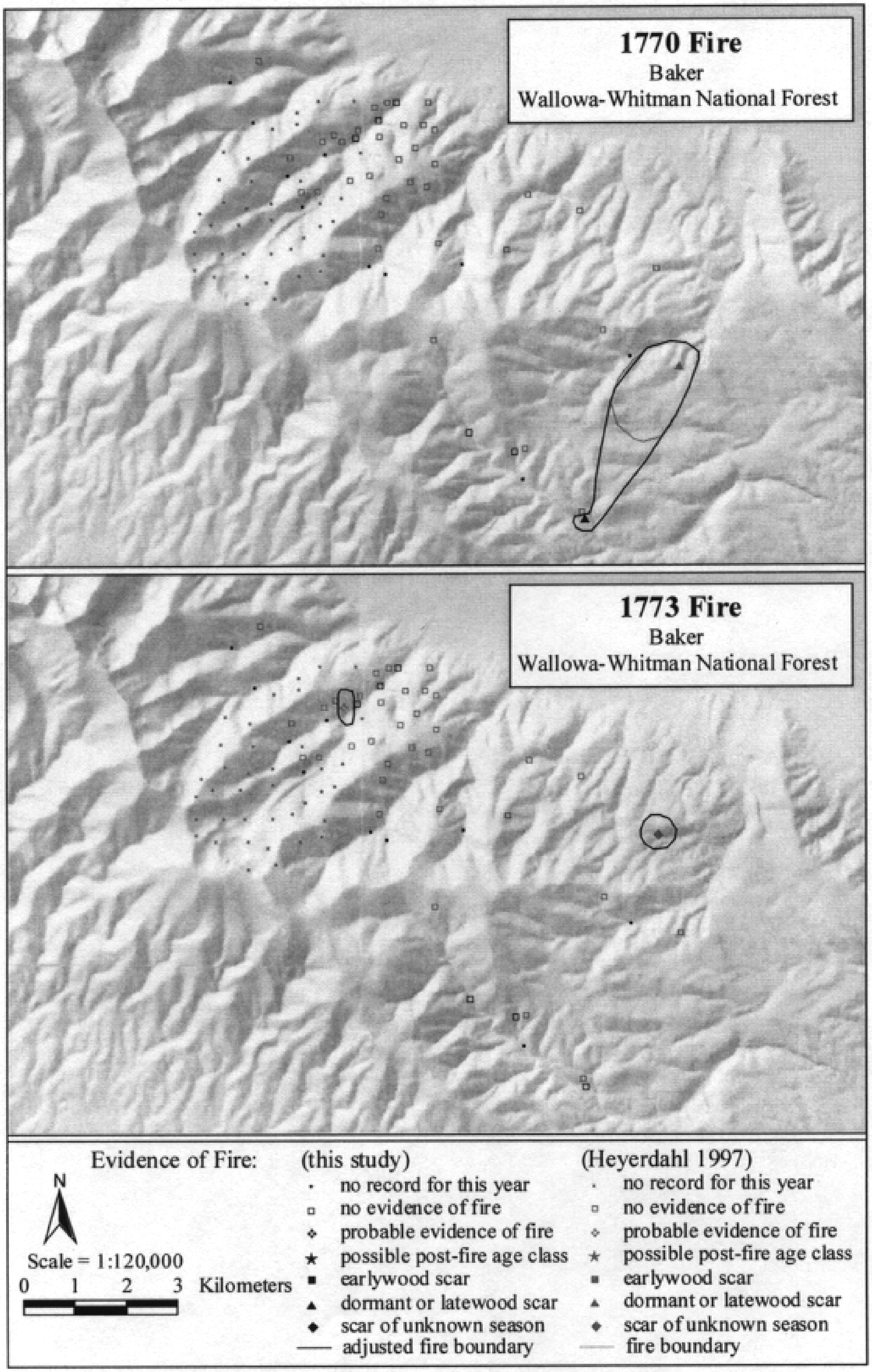

Figure 115. Baker fire maps for 1770 (top) and 1773 (bottom).

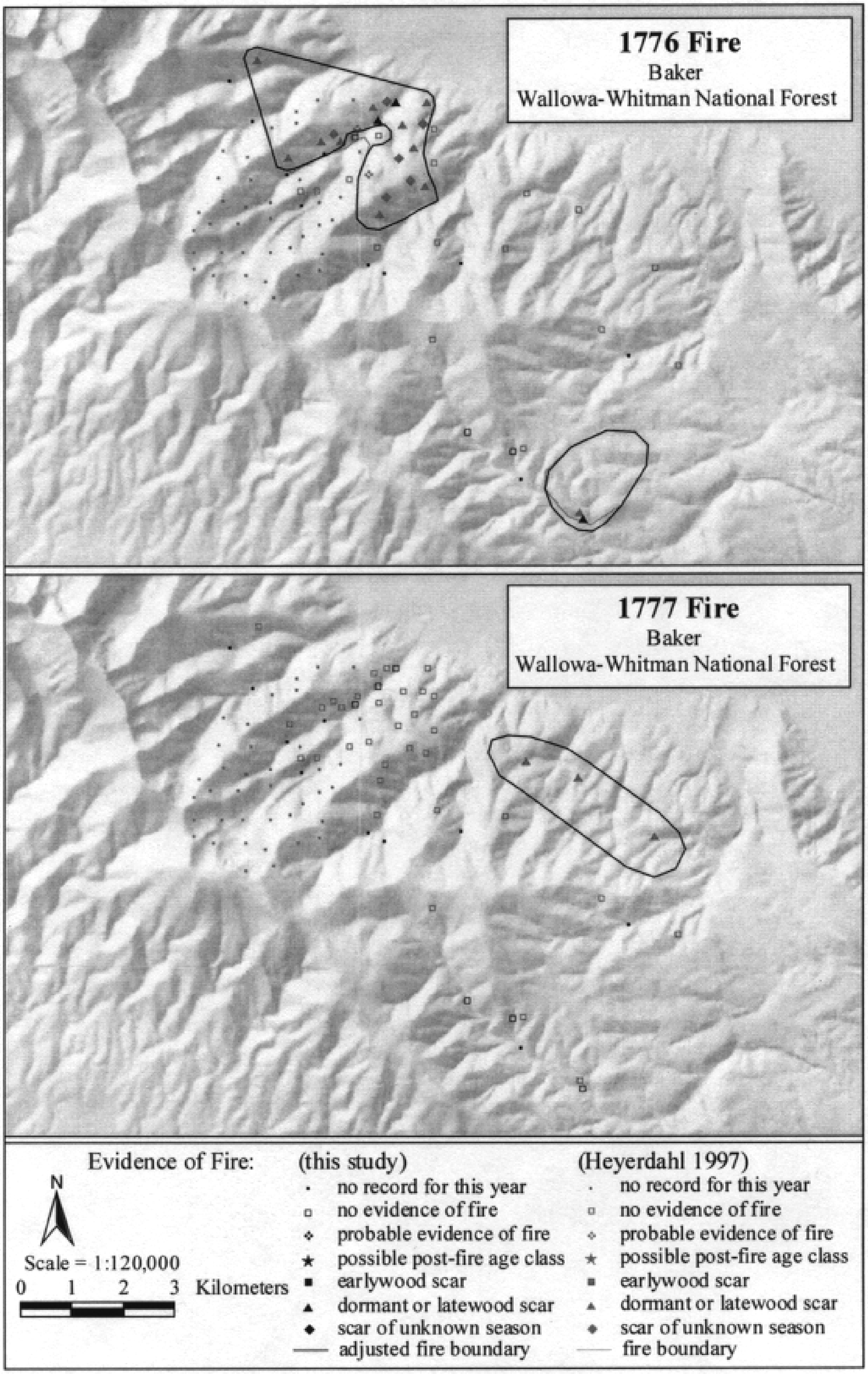

Figure 116. Baker fire maps for 1776 (top) and 1777 (bottom).

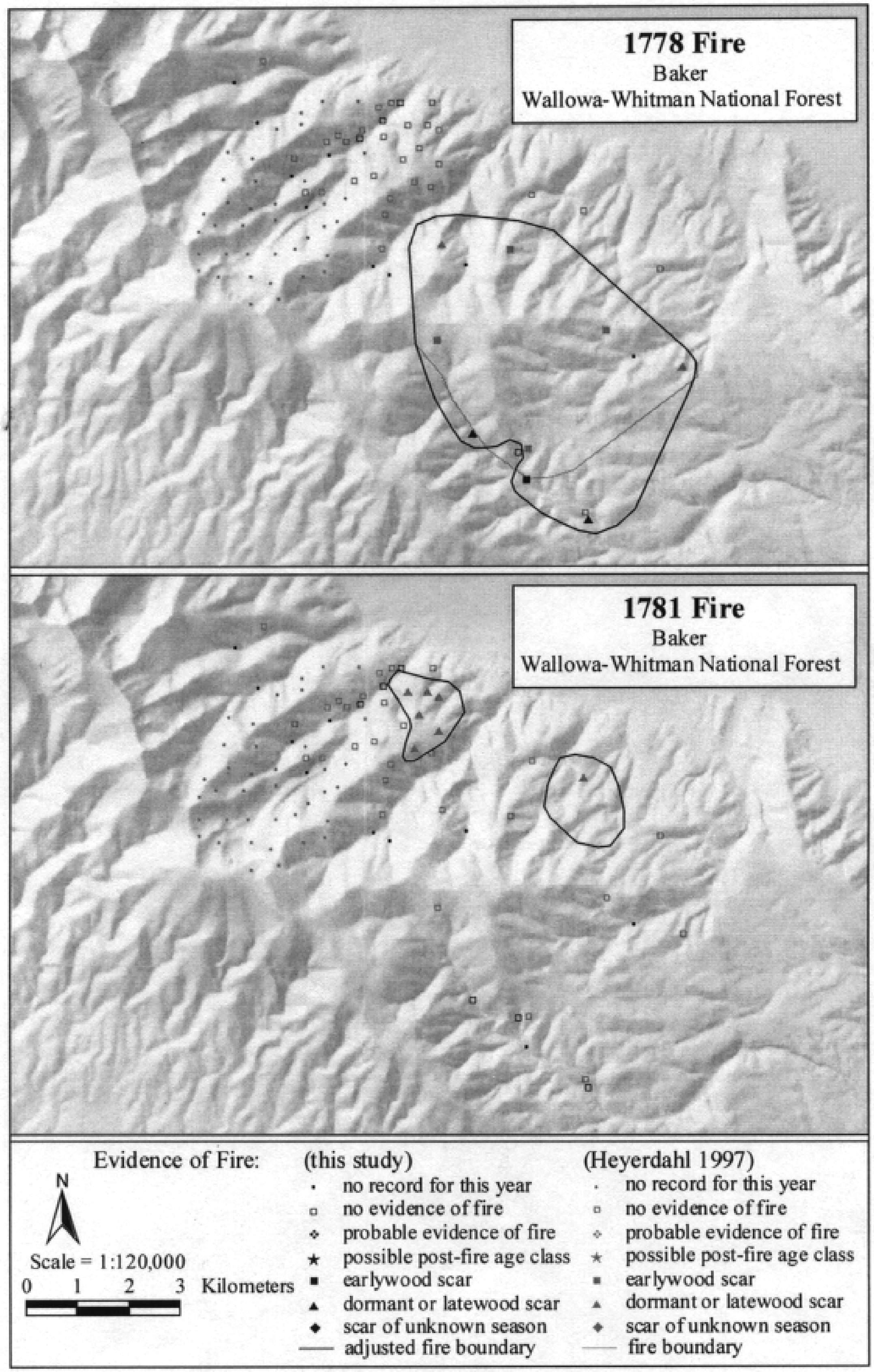

Figure 117. Baker fire maps for 1778 (top) and 1781 (bottom).

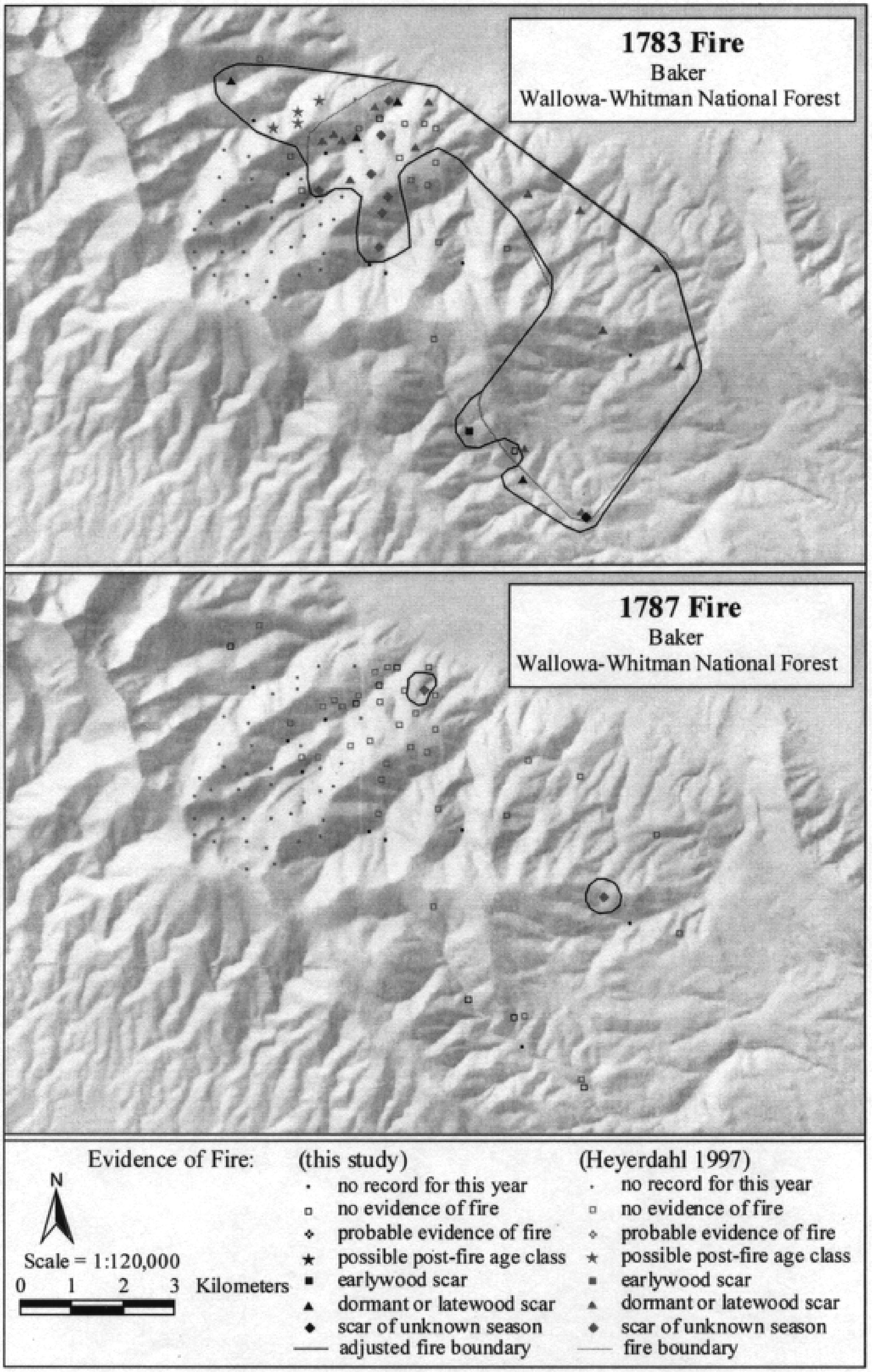

Figure 118. Baker fire maps for 1783 (top) and 1787 (bottom).

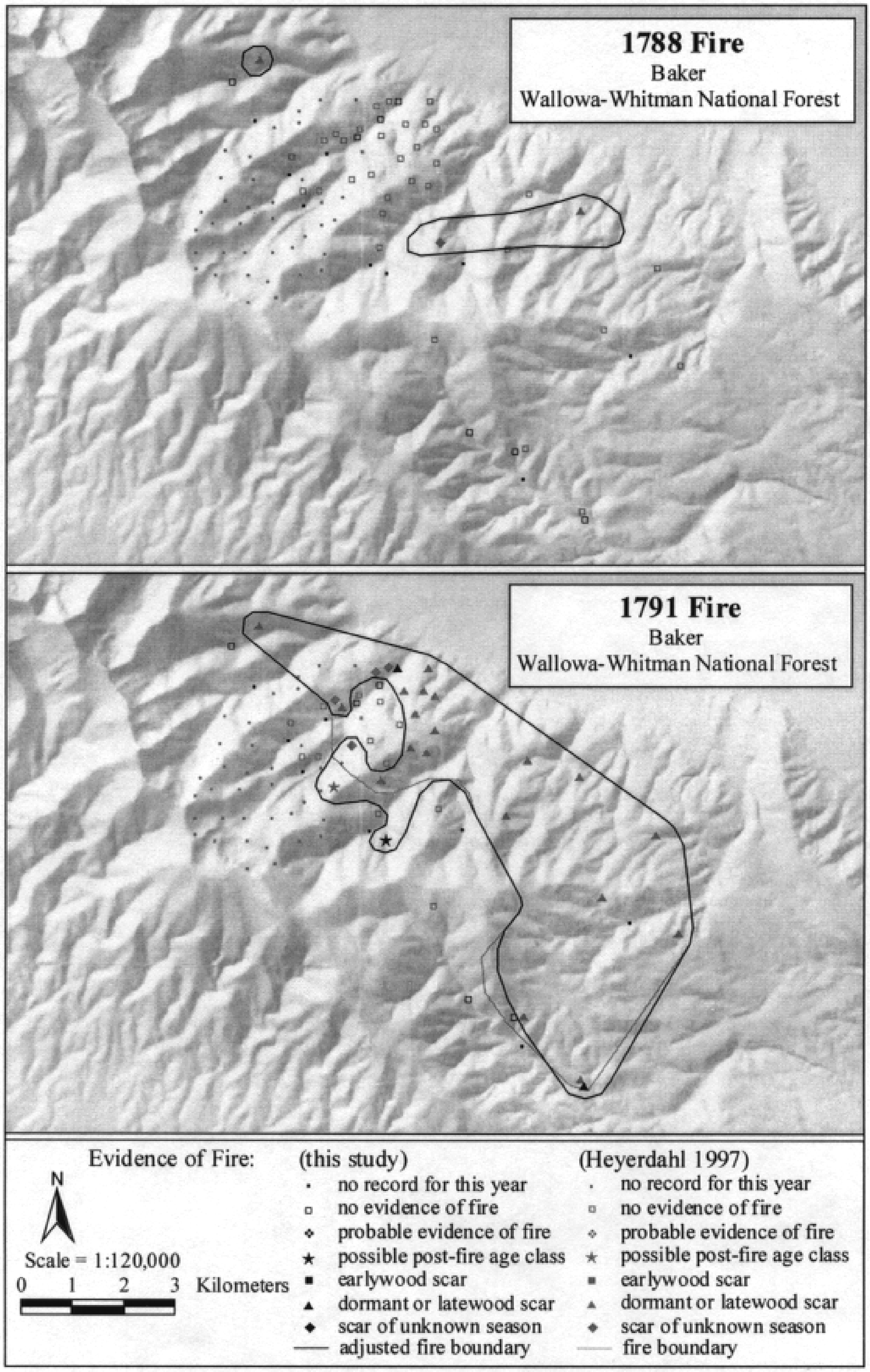

Figure 119. Baker fire maps for 1788 (top) and 1791 (bottom).

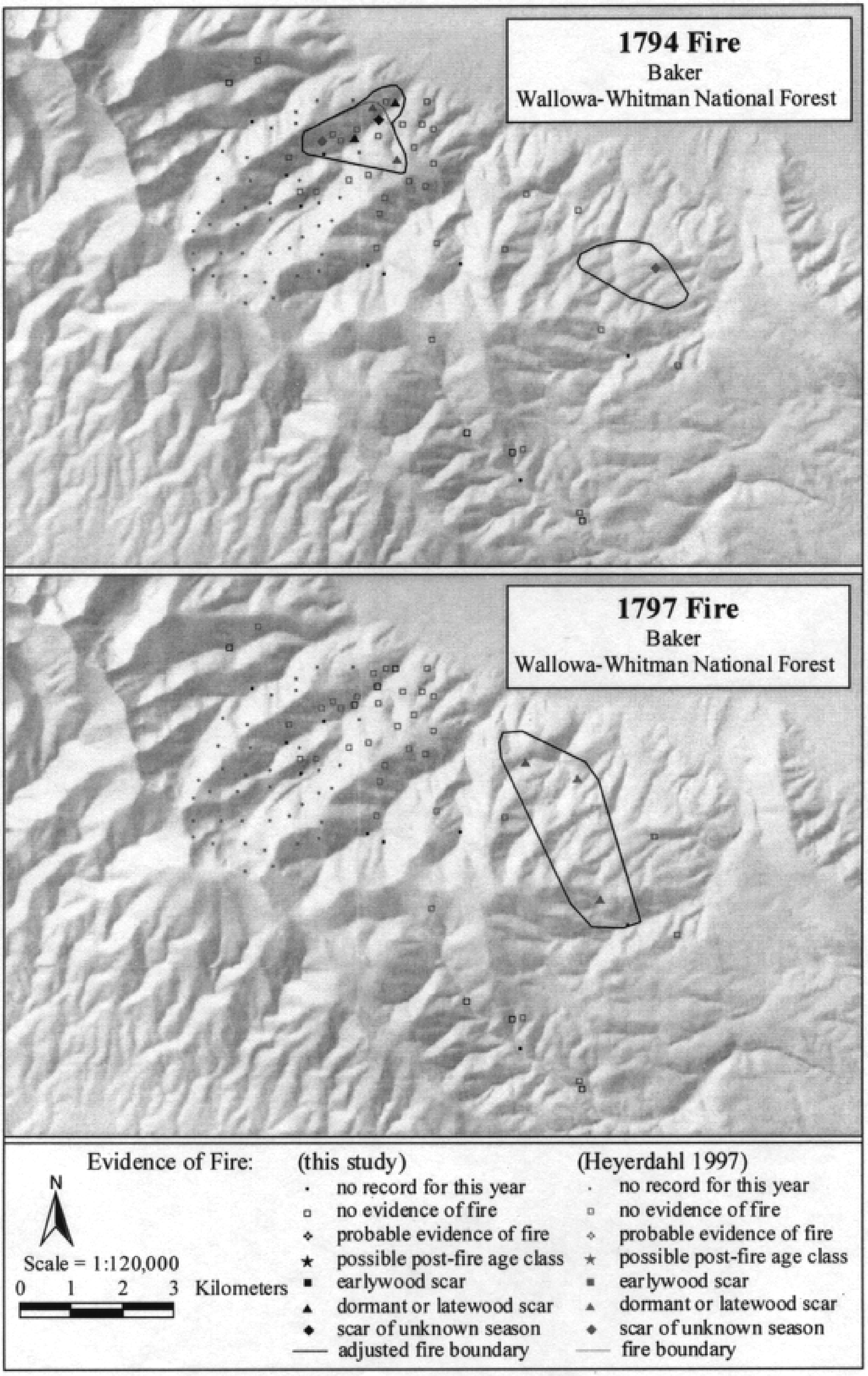

Figure 120. Baker fire maps for 1794 (top) and 1797 (bottom).

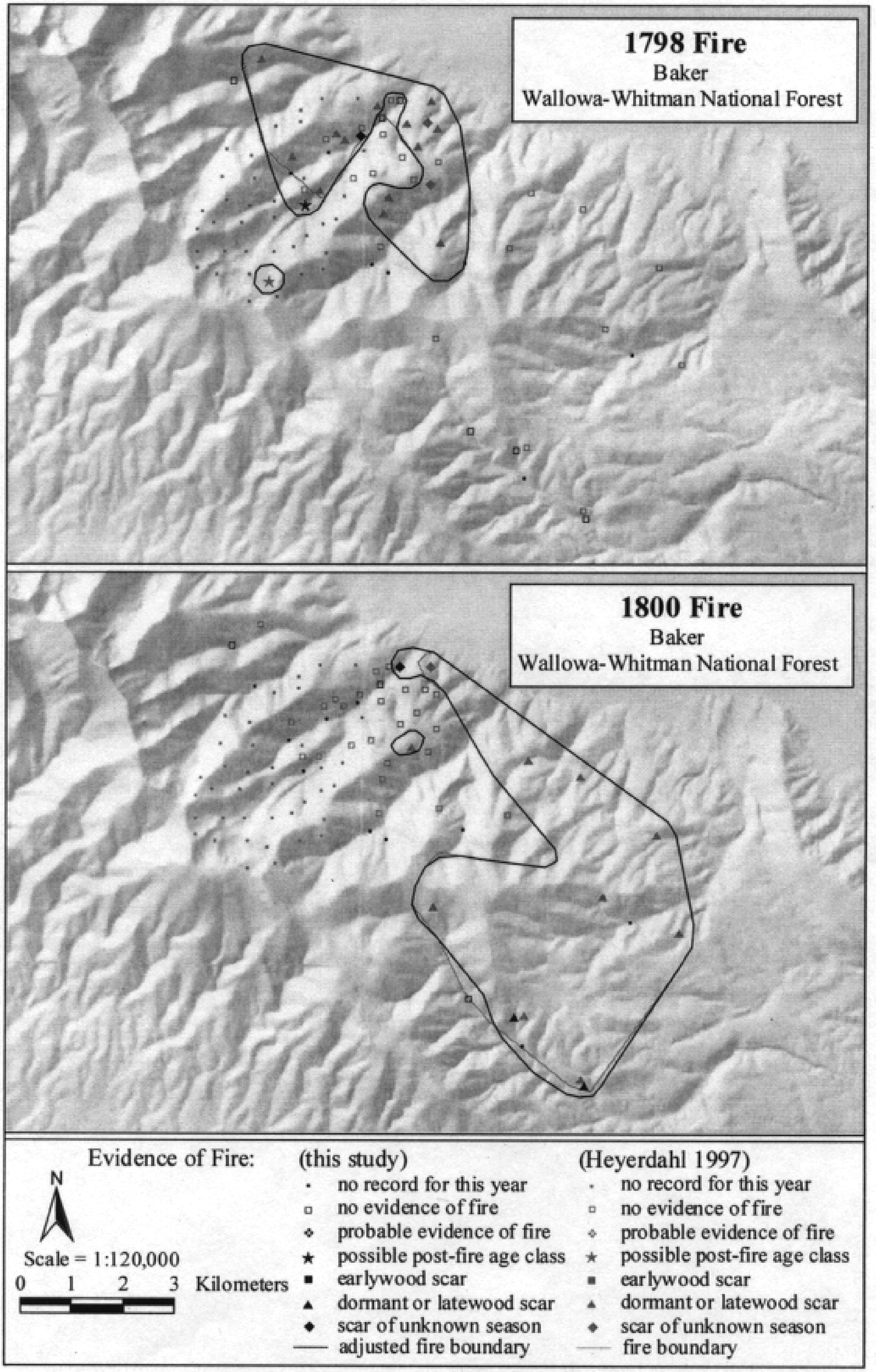

Figure 121. Baker fire maps for 1798 (top) and 1800 (bottom).

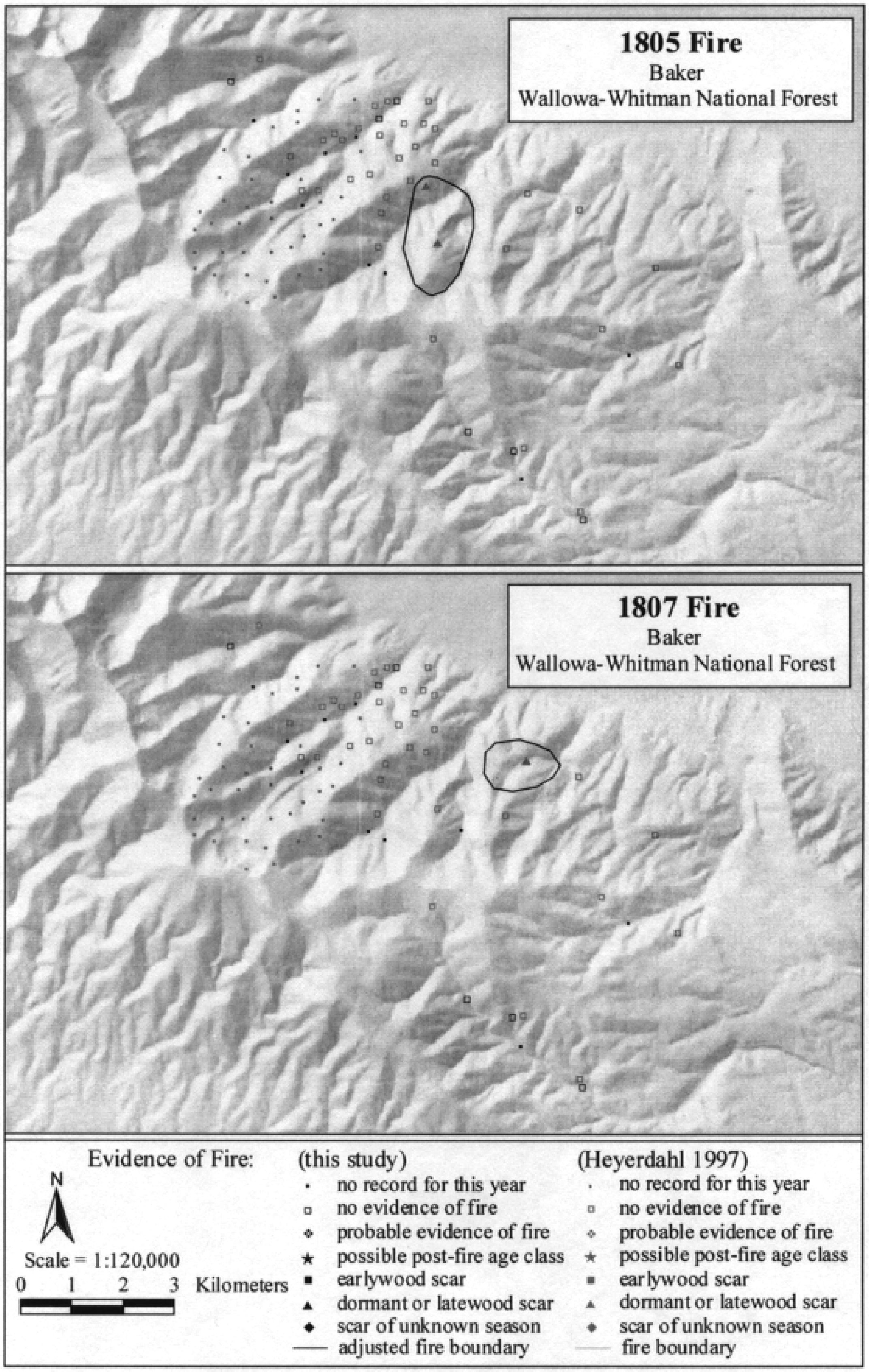

Figure 122. Baker fire maps for 1805 (top) and 1807 (bottom).

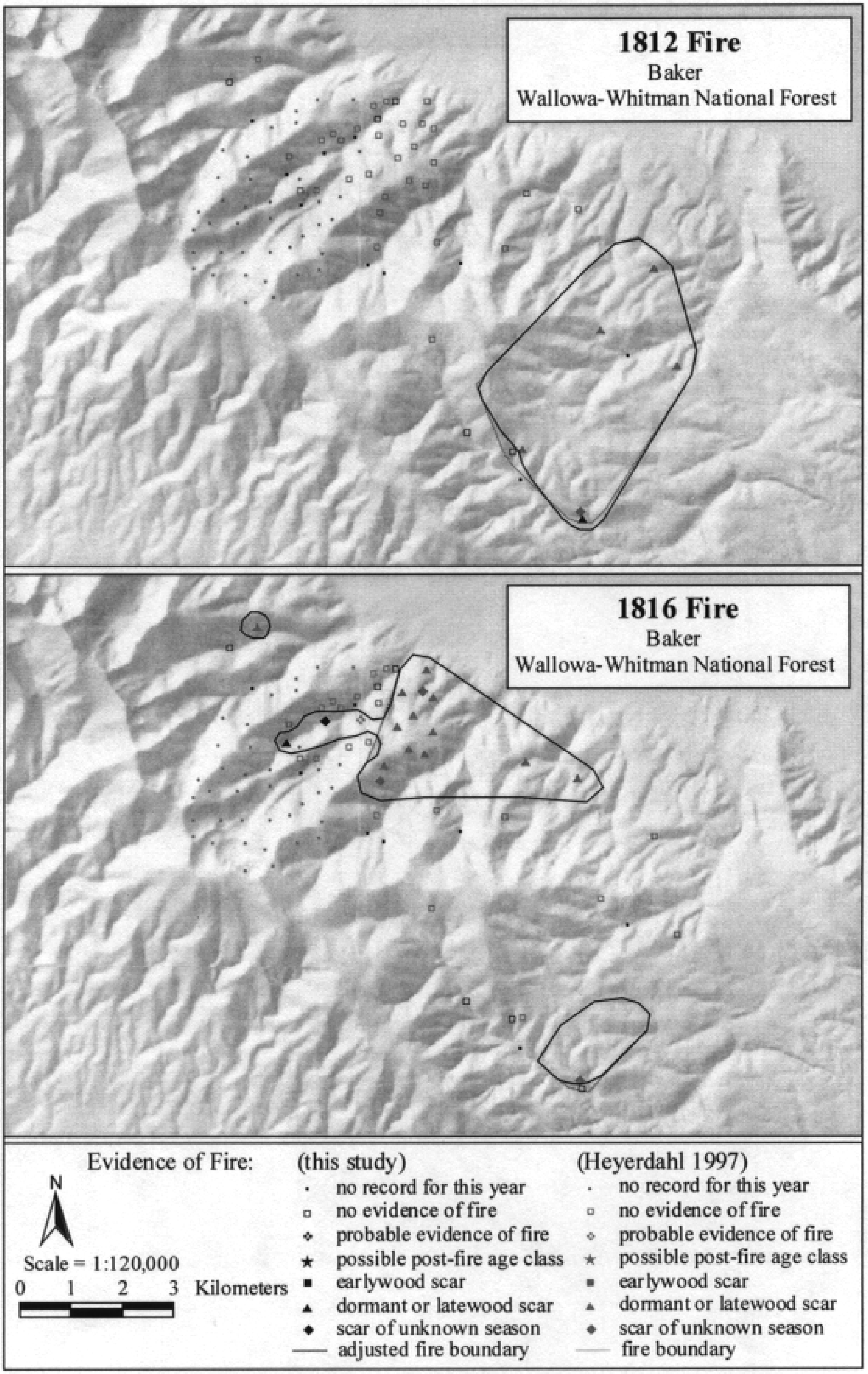

Figure 123. Baker fire maps for 1812 (top) and 1816 (bottom).

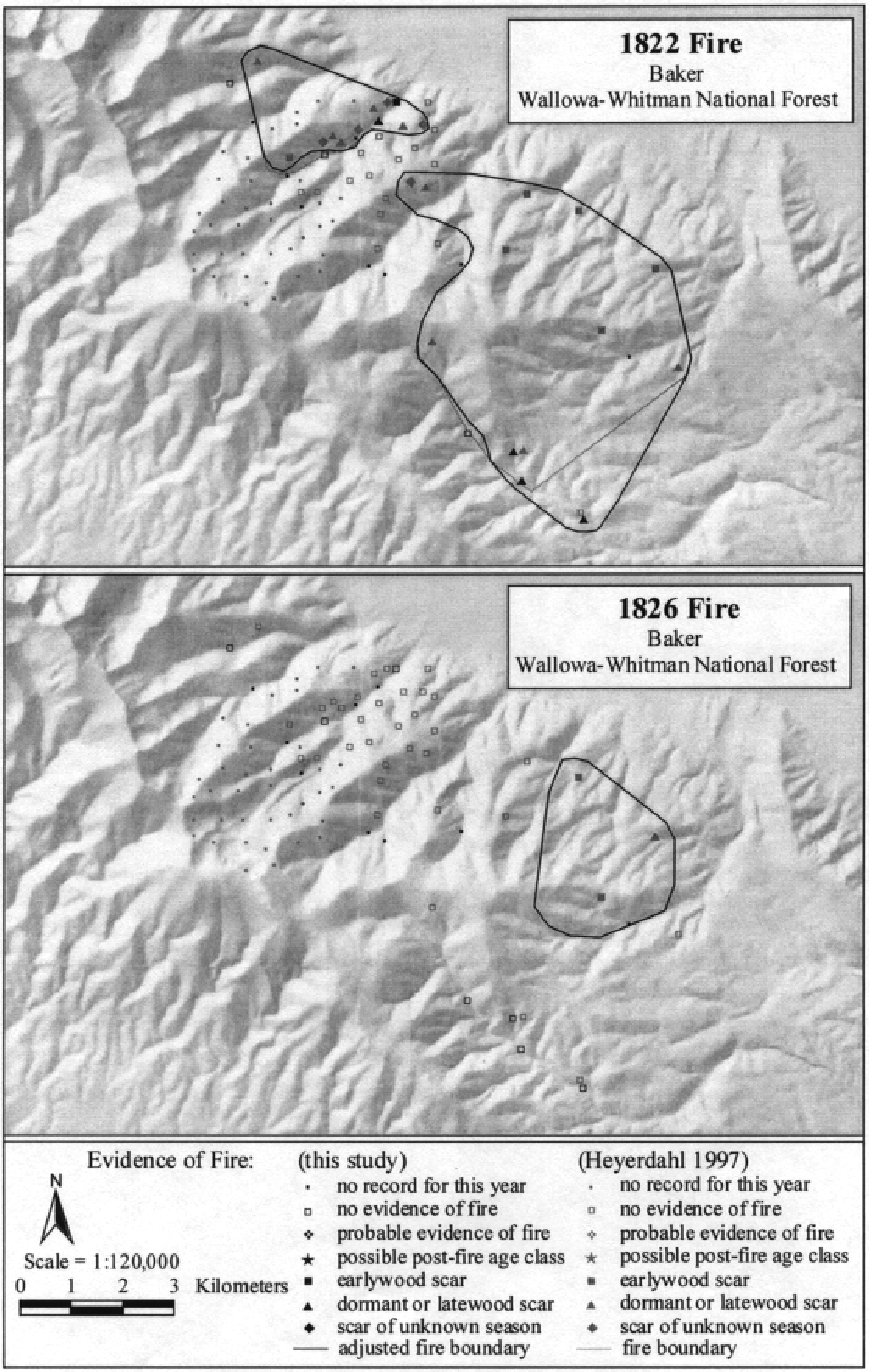

Figure 124. Baker fire maps for 1822 (top) and 1826 (bottom).

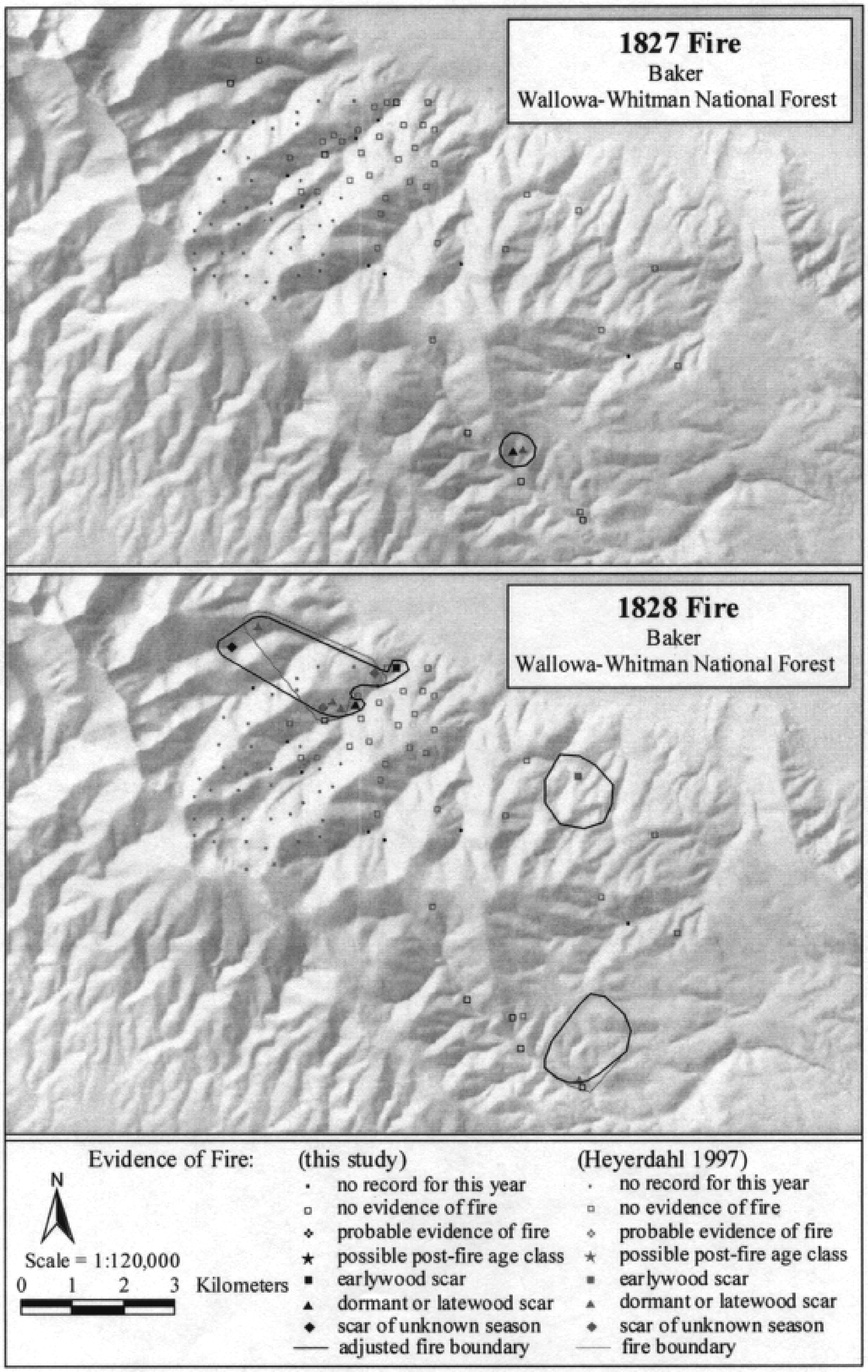

Figure 125. Baker fire maps for 1827 (top) and 1828 (bottom).

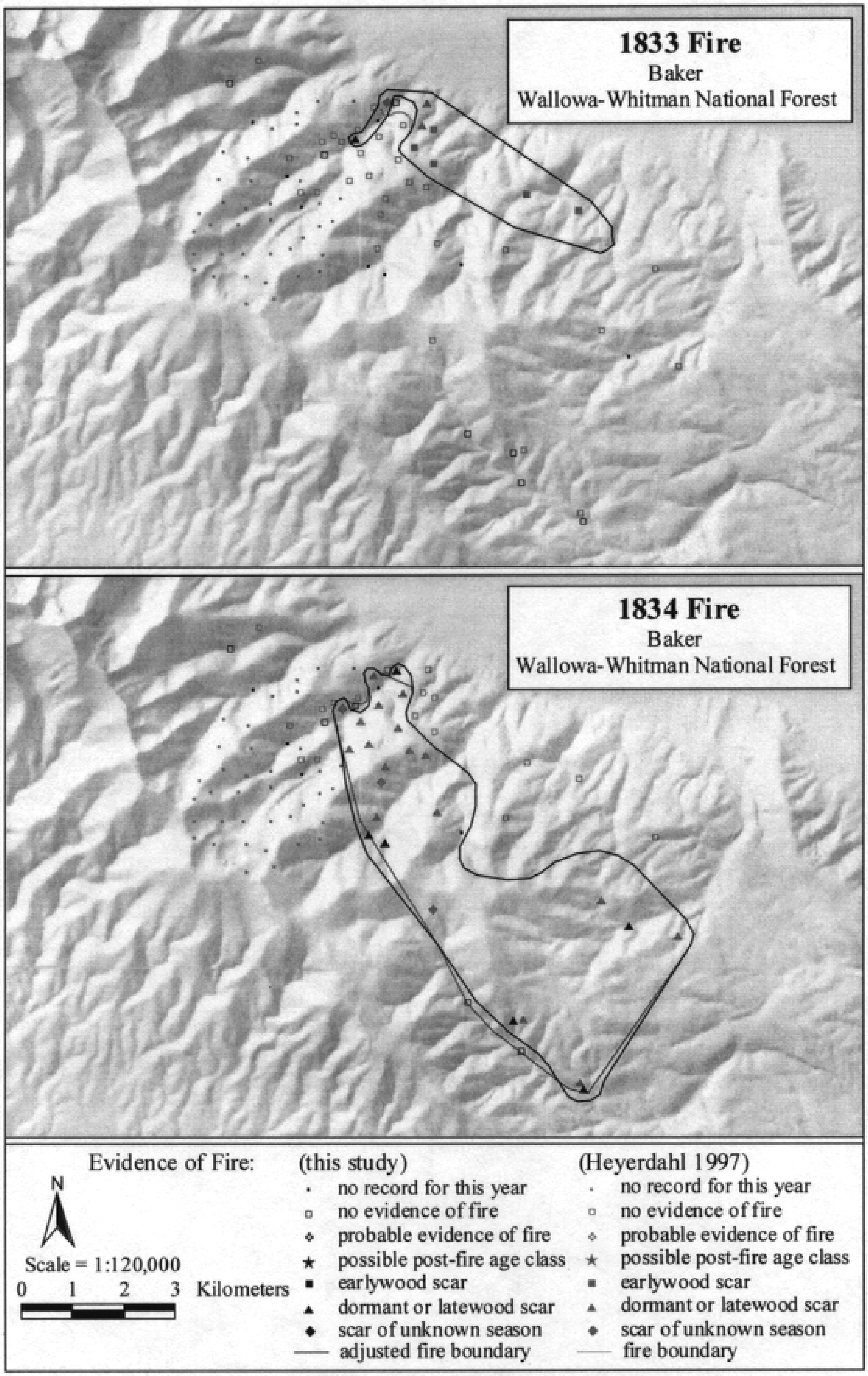

Figure 126. Baker fire maps for 1833 (top) and 1834 (bottom).

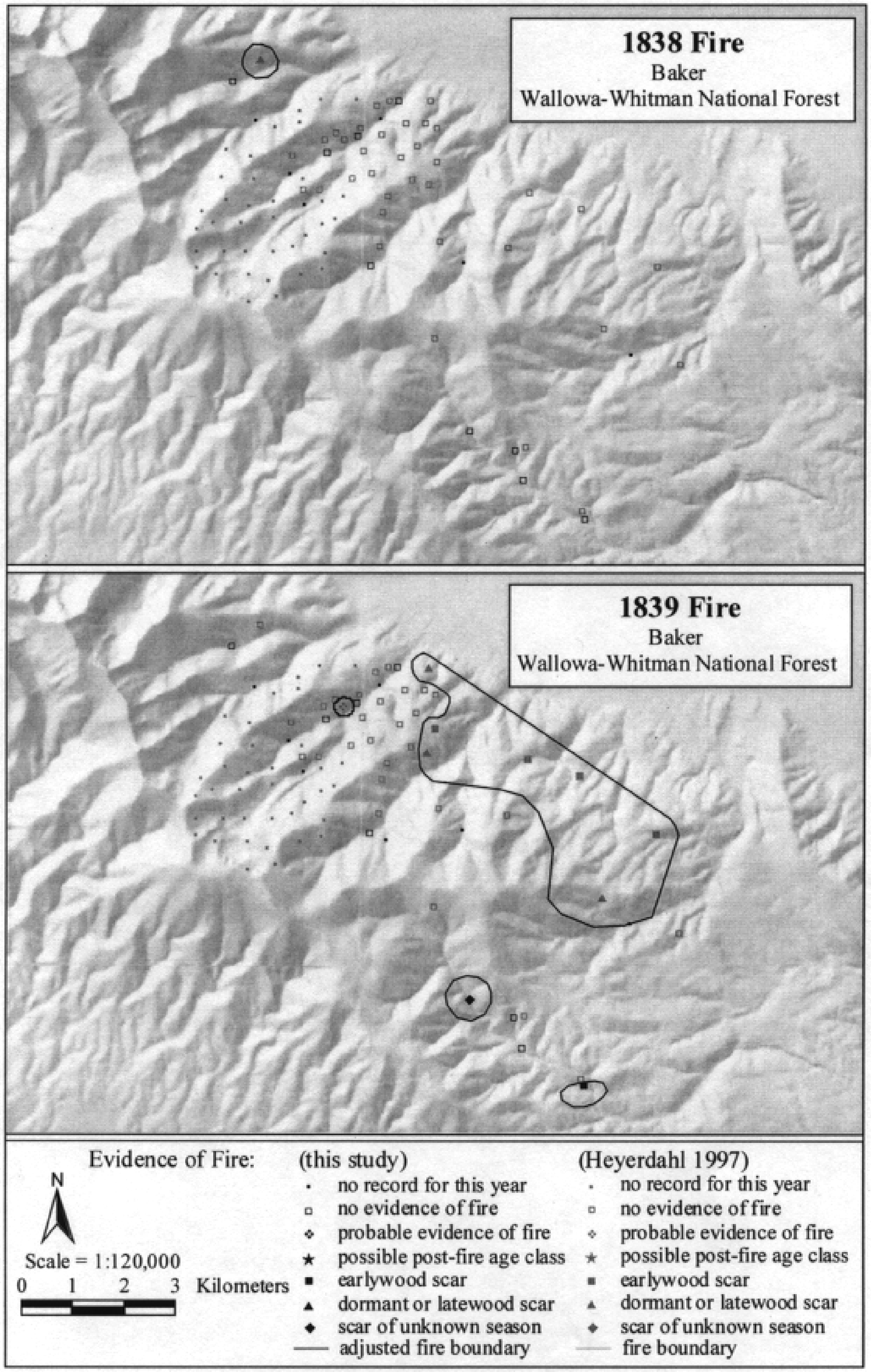

Figure 127. Baker fire maps for 1838 (top) and 1839 (bottom).

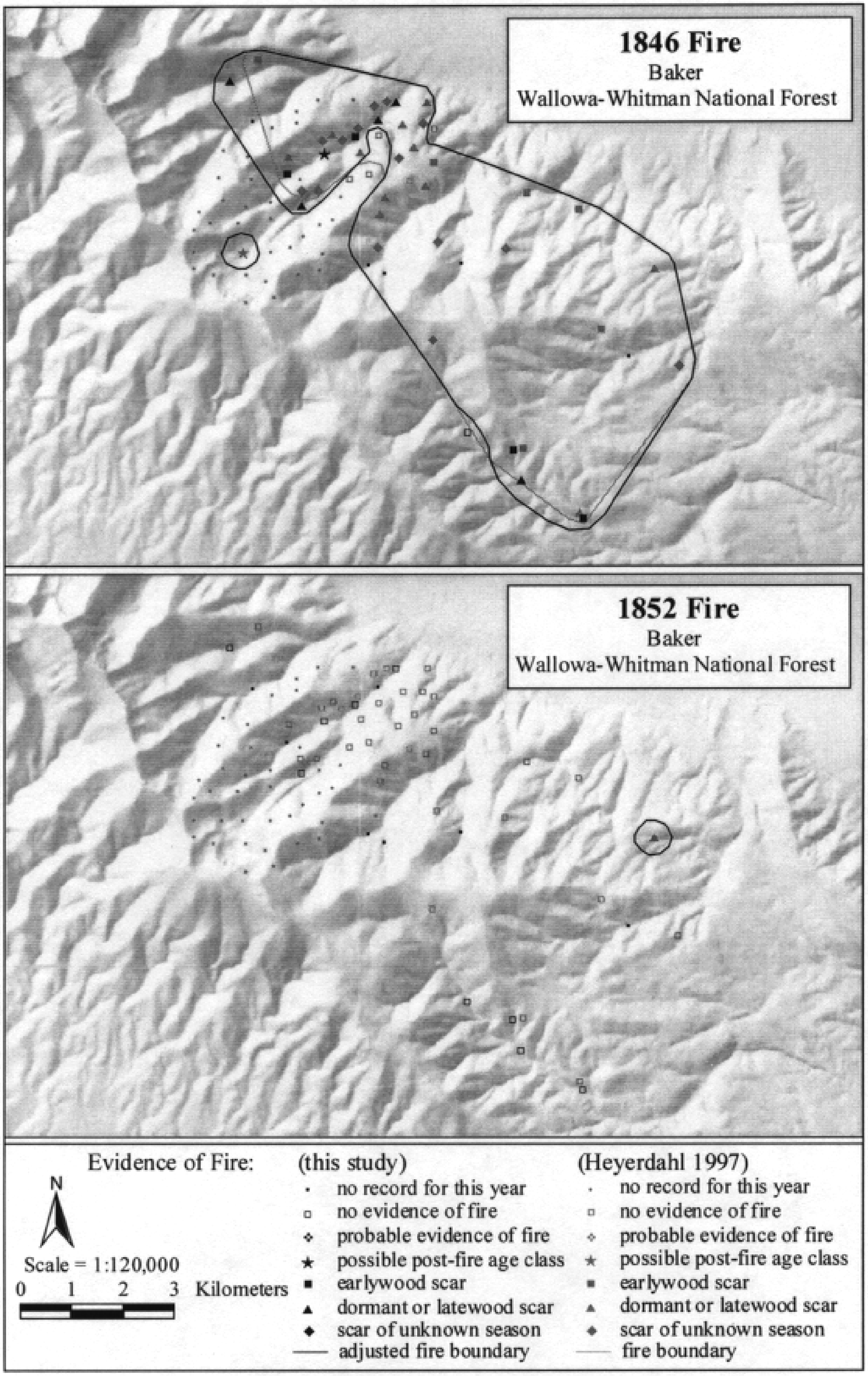

Figure 128. Baker fire maps for 1846 (top) and 1852 (bottom).

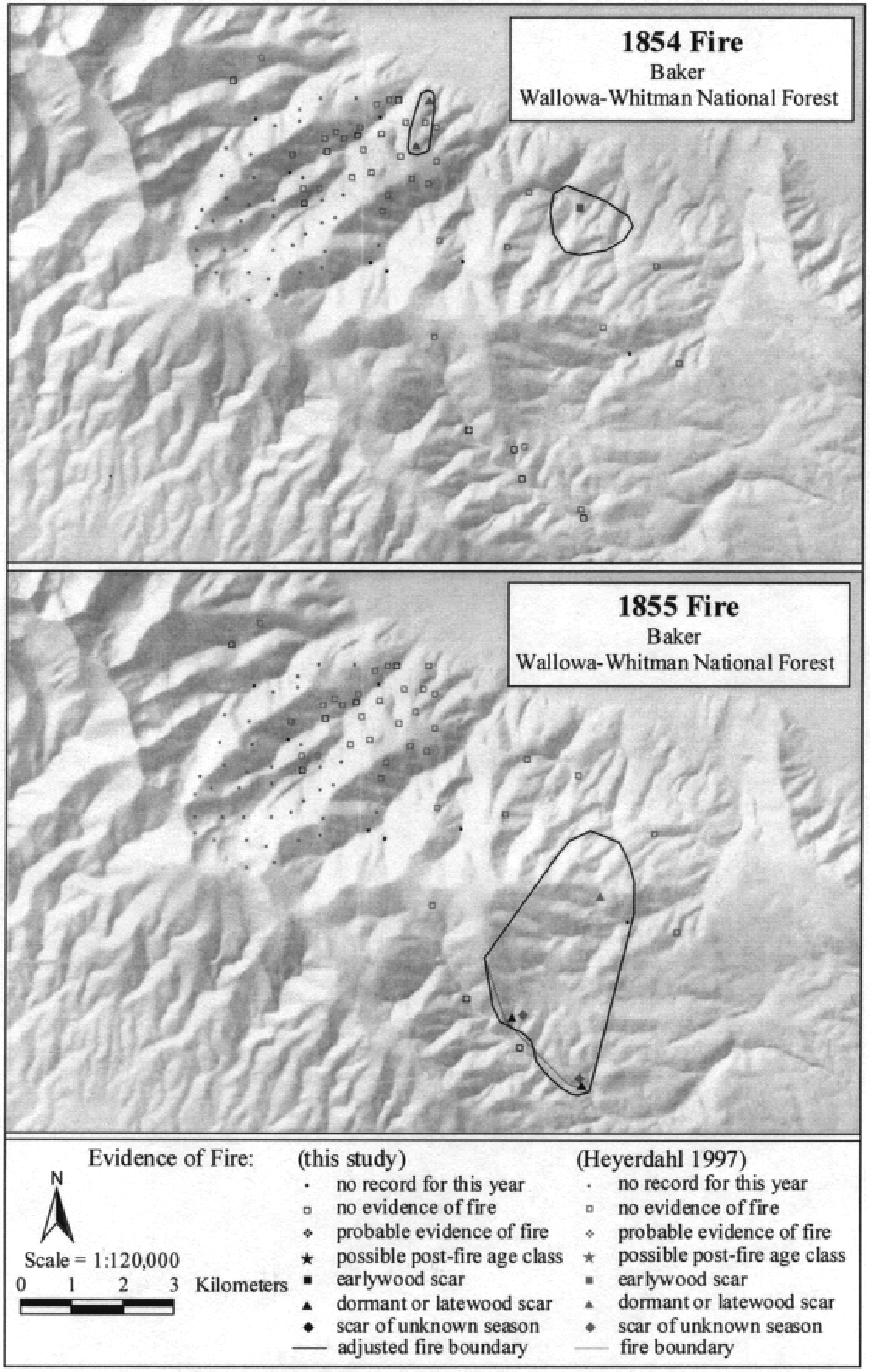

Figure 129. Baker fire maps for 1854 (top) and 1855 (bottom).

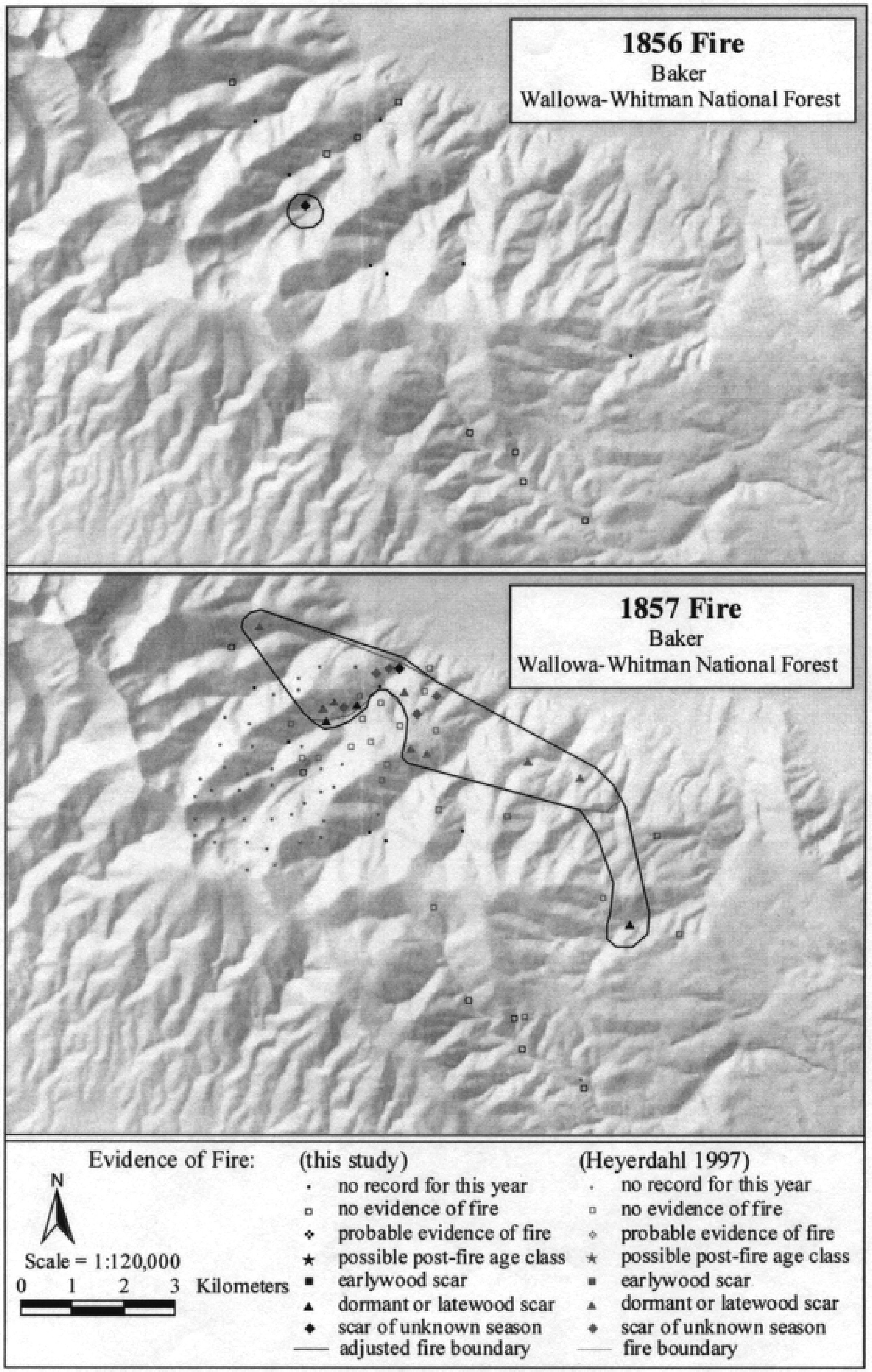

Figure 130. Baker fire maps for 1856 (top) and 1857 (bottom).

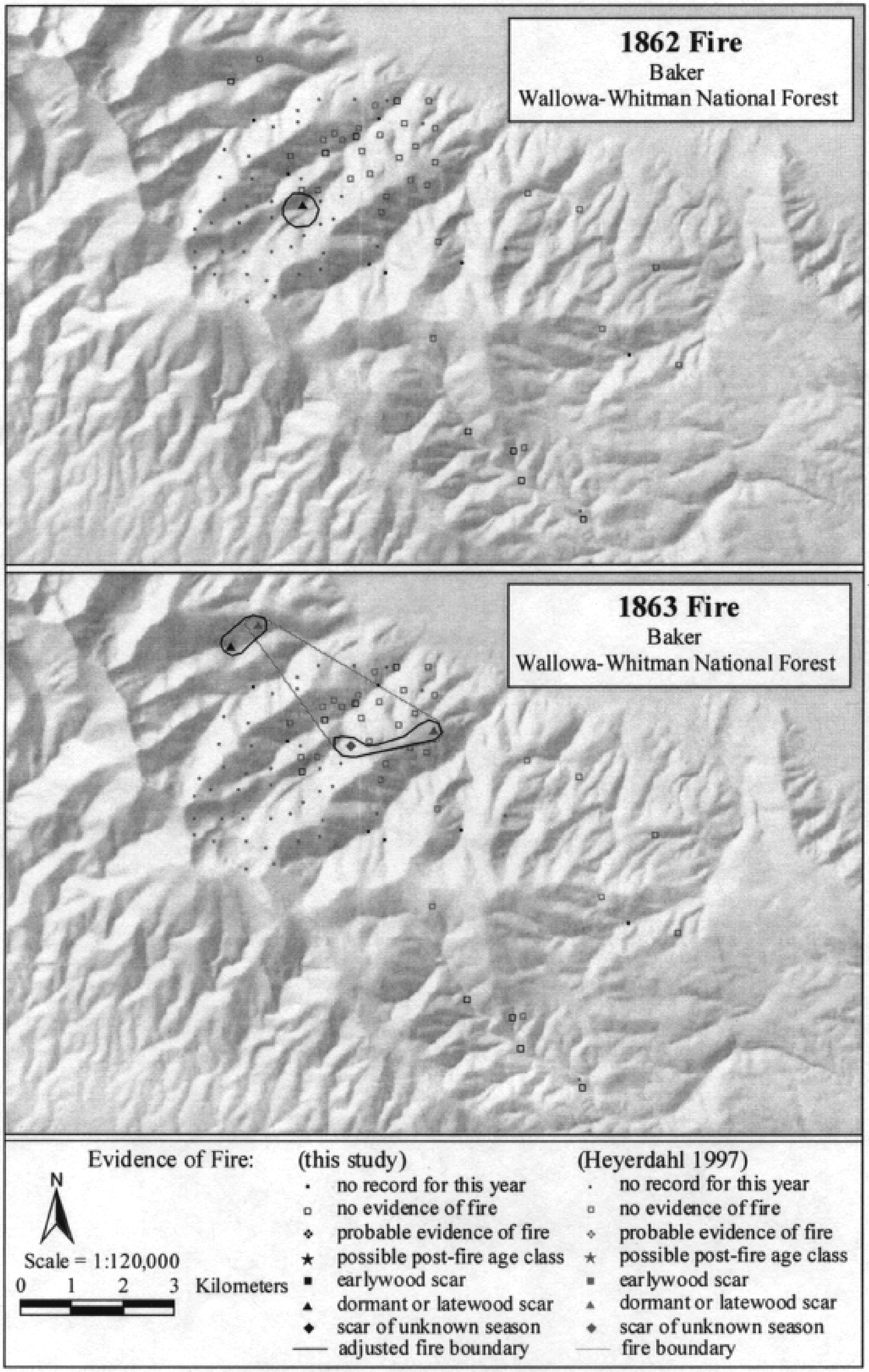

Figure 131. Baker fire maps for 1862 (top) and 1863 (bottom).

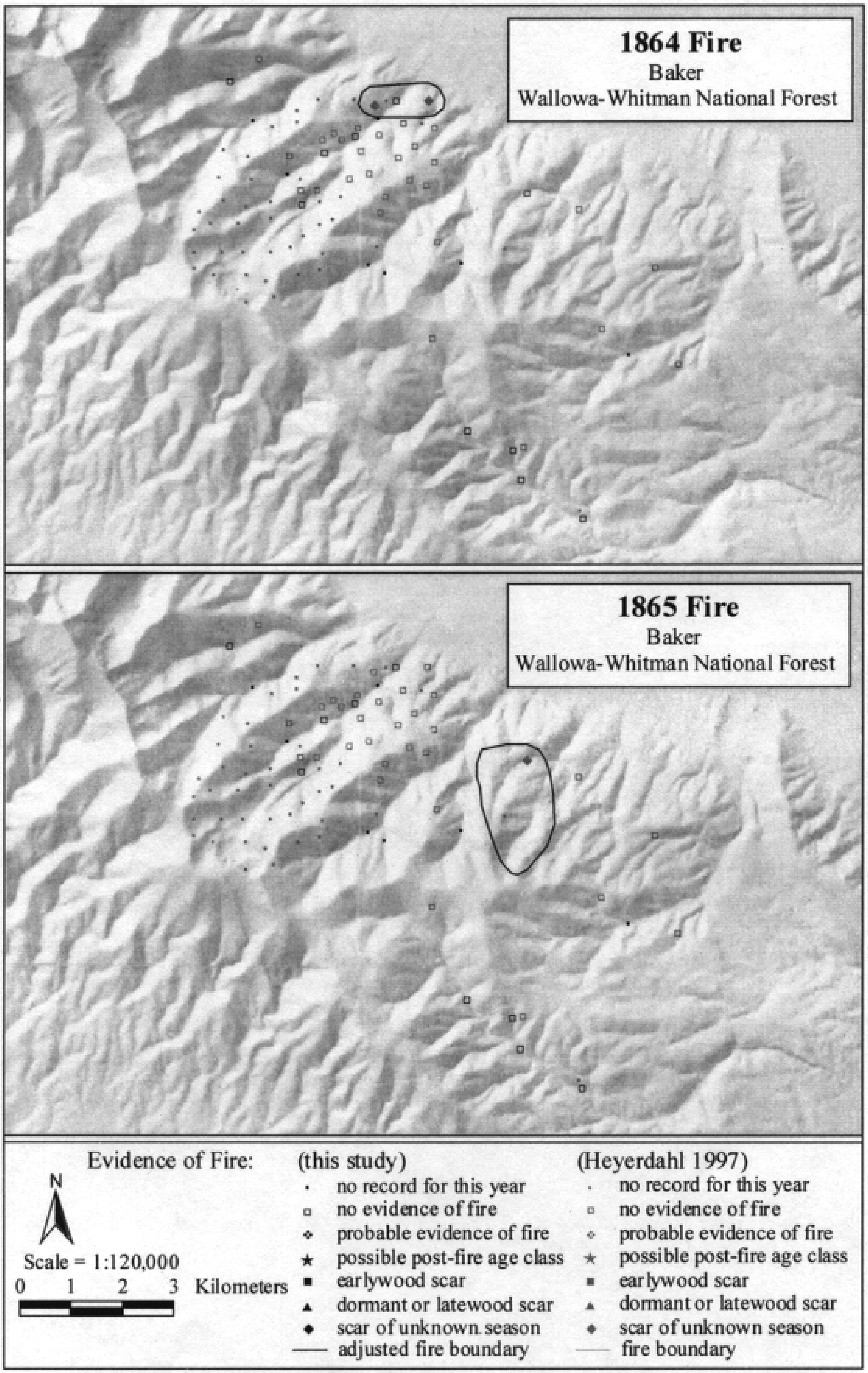

Figure 132. Baker fire maps for 1864 (top) and 1865 (bottom).

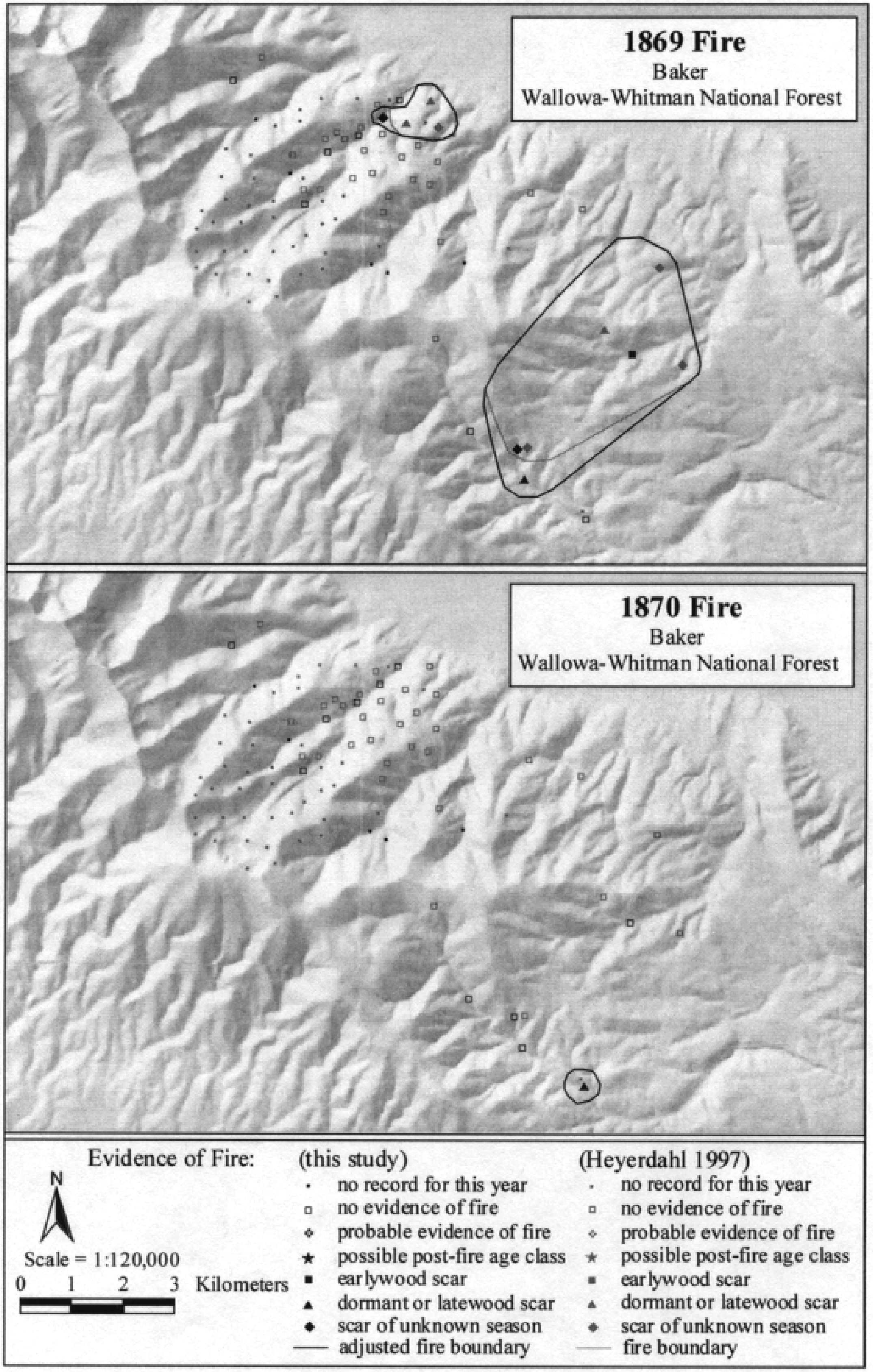

Figure 133. Baker fire maps for 1869 (top) and 1870 (bottom).

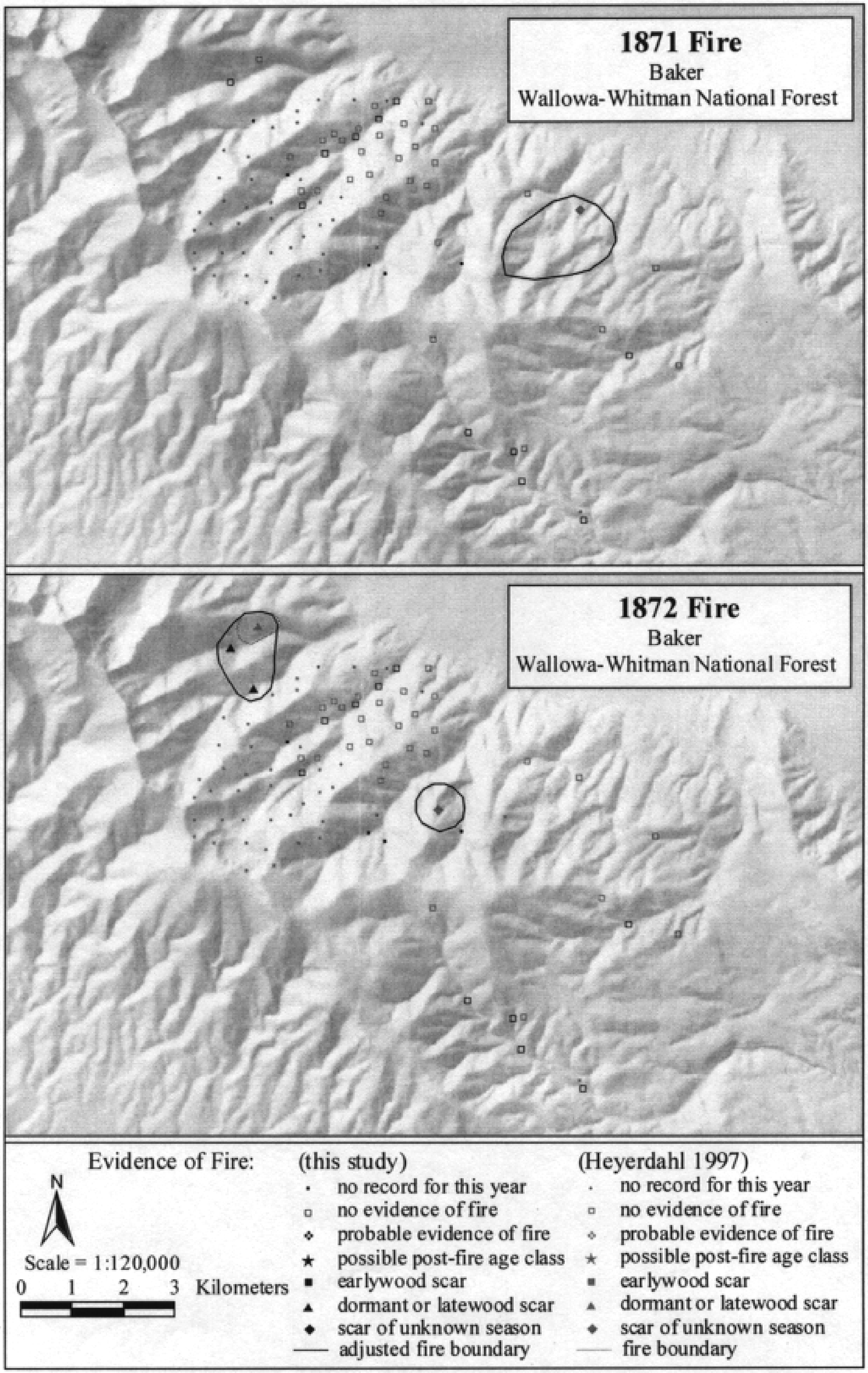

Figure 134. Baker fire maps for 1871 (top) and 1872 (bottom).

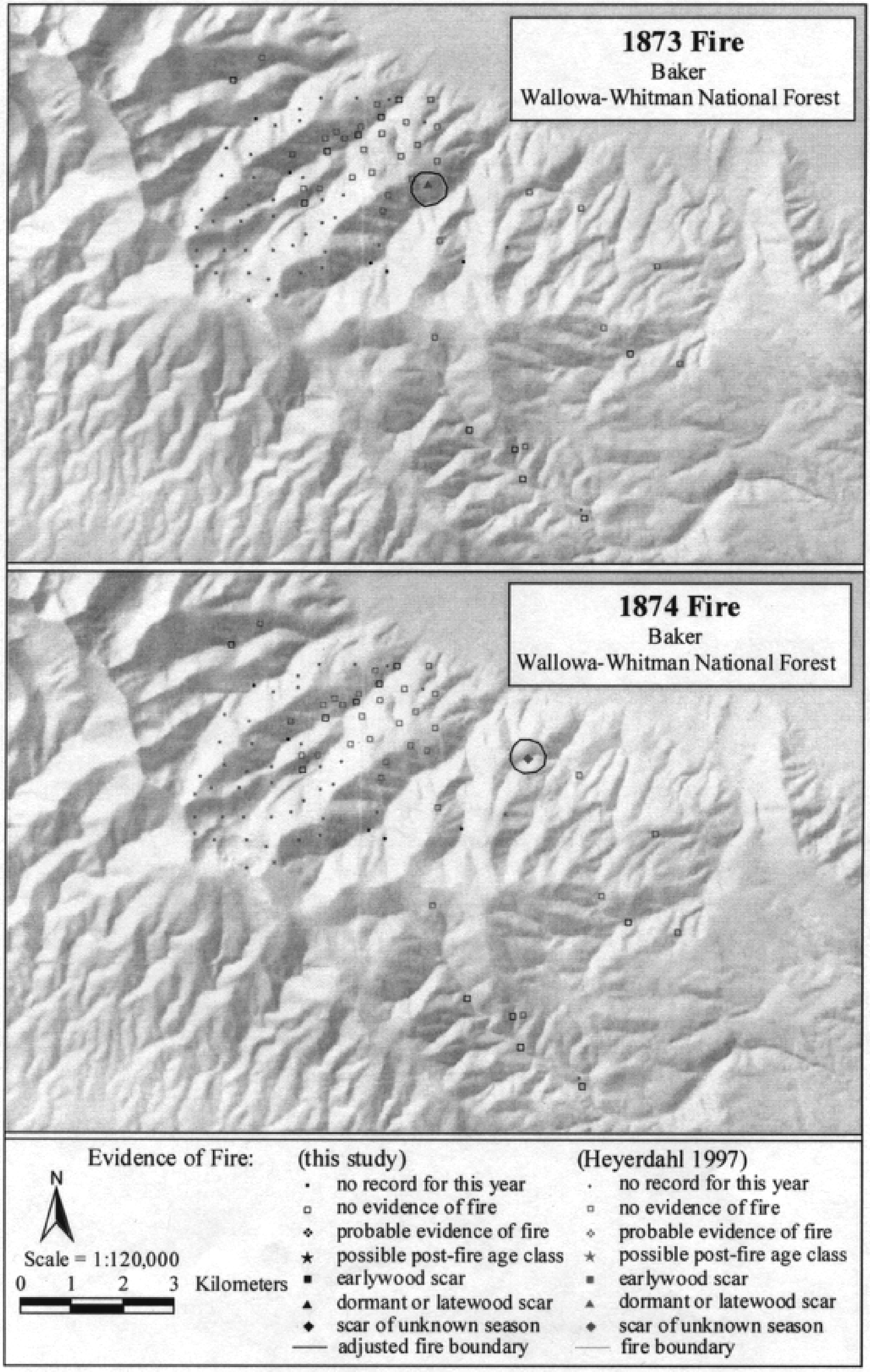

Figure 135. Baker fire maps for 1873 (top) and 1874 (bottom).

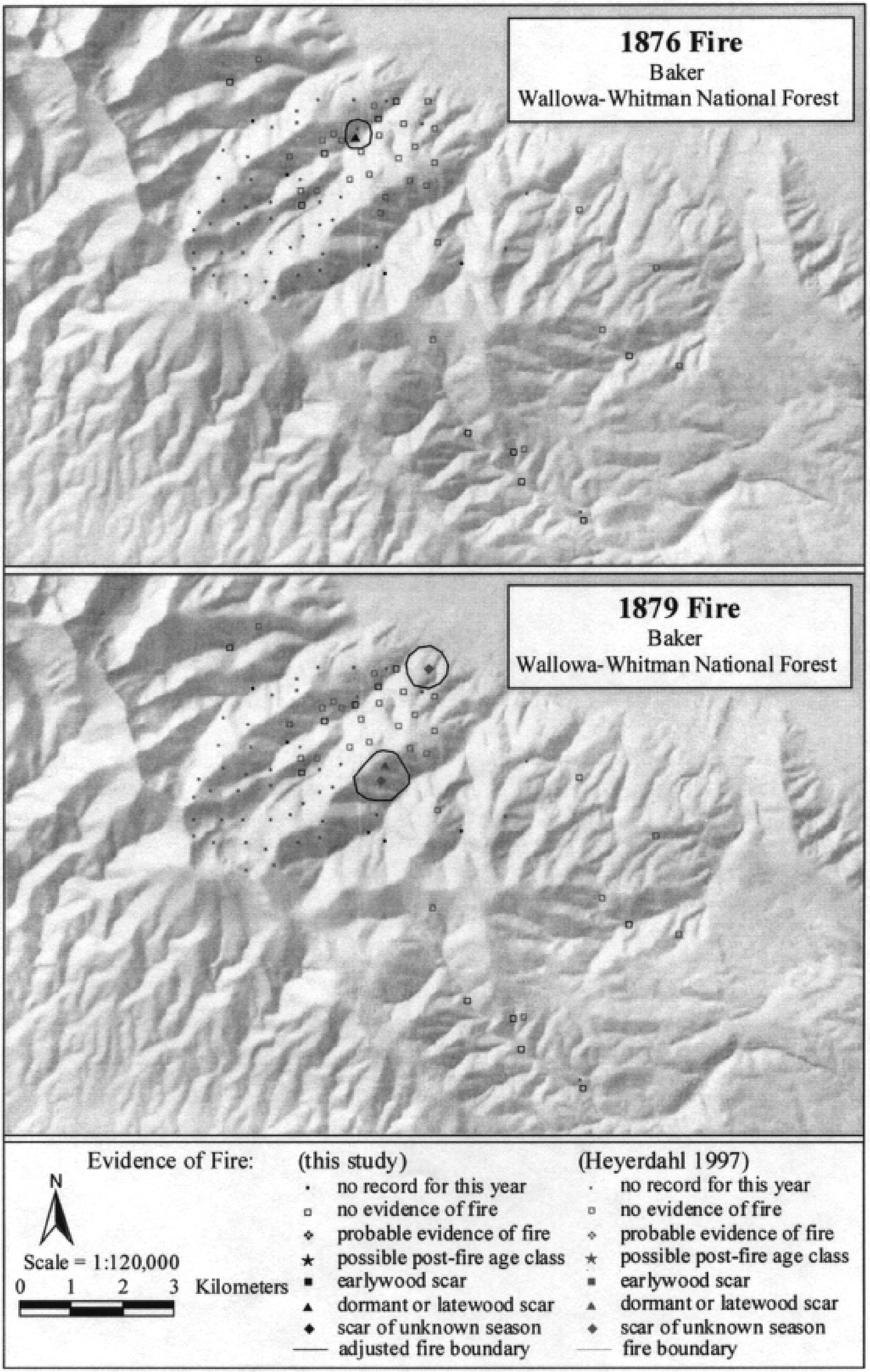

Figure 136. Baker fire maps for 1876 (top) and 1879 (bottom).

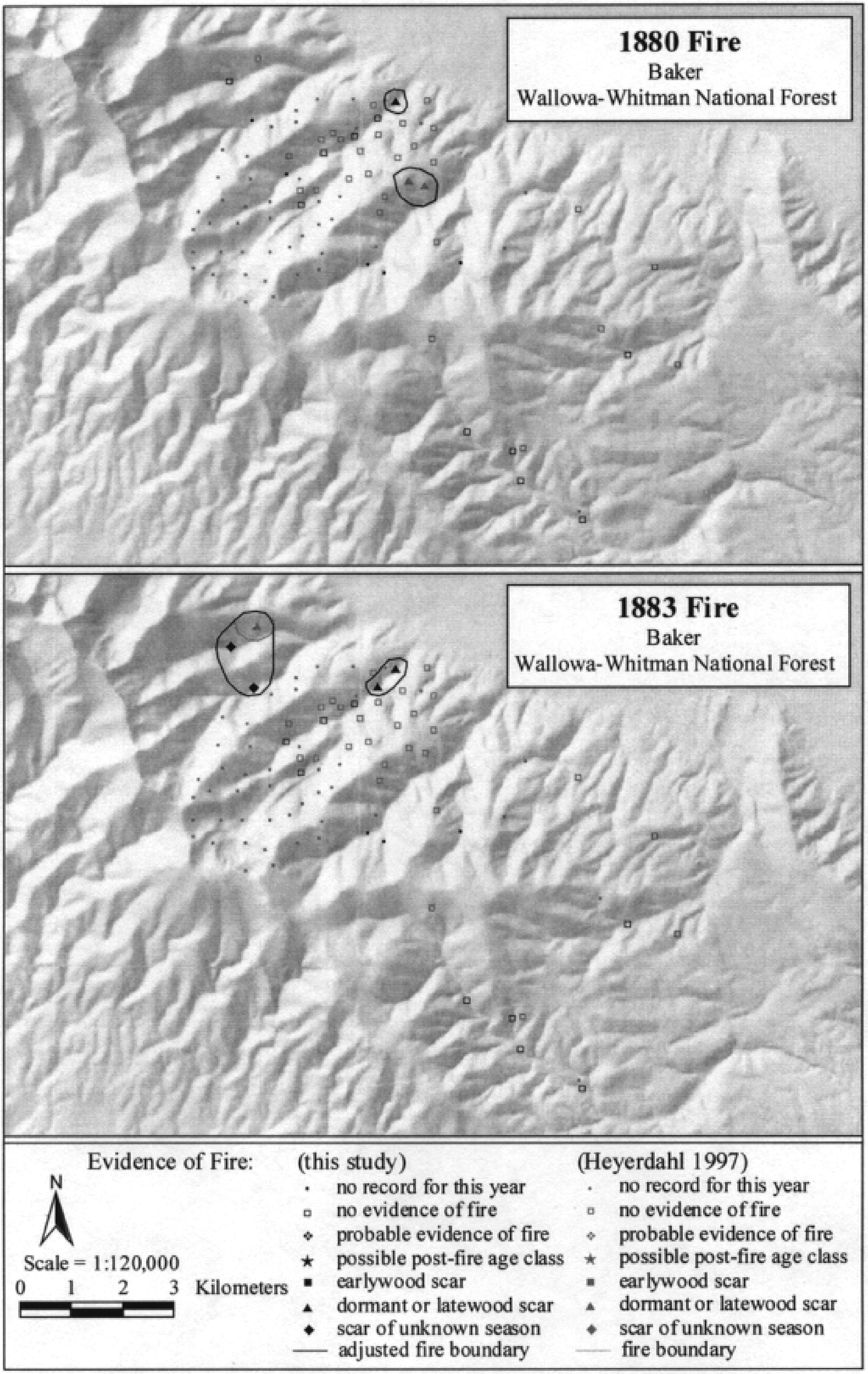

Figure 137. Baker fire maps for 1880 (top) and 1883 (bottom).

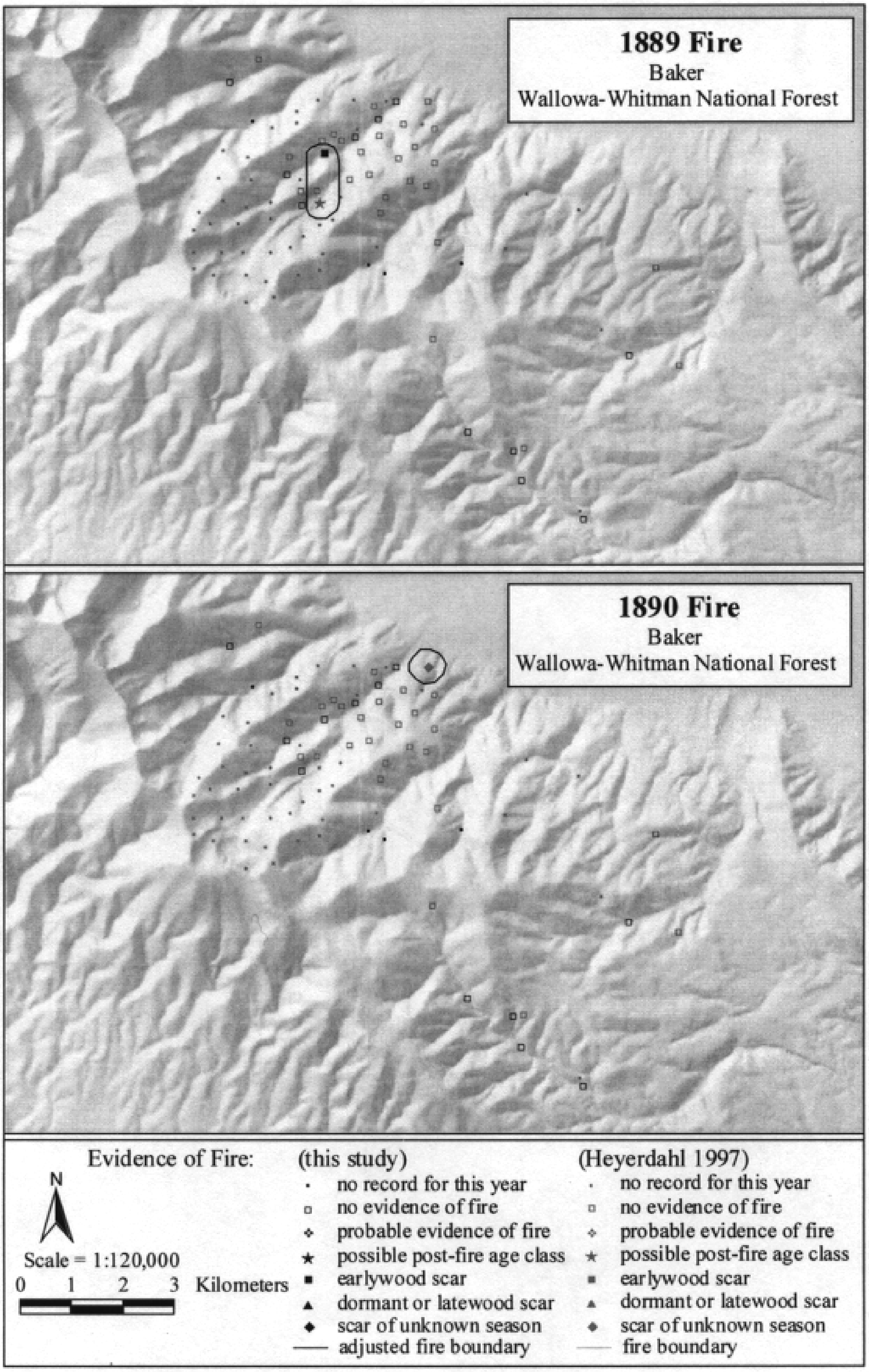

Figure 138. Baker fire maps for 1889 (top) and 1890 (bottom).

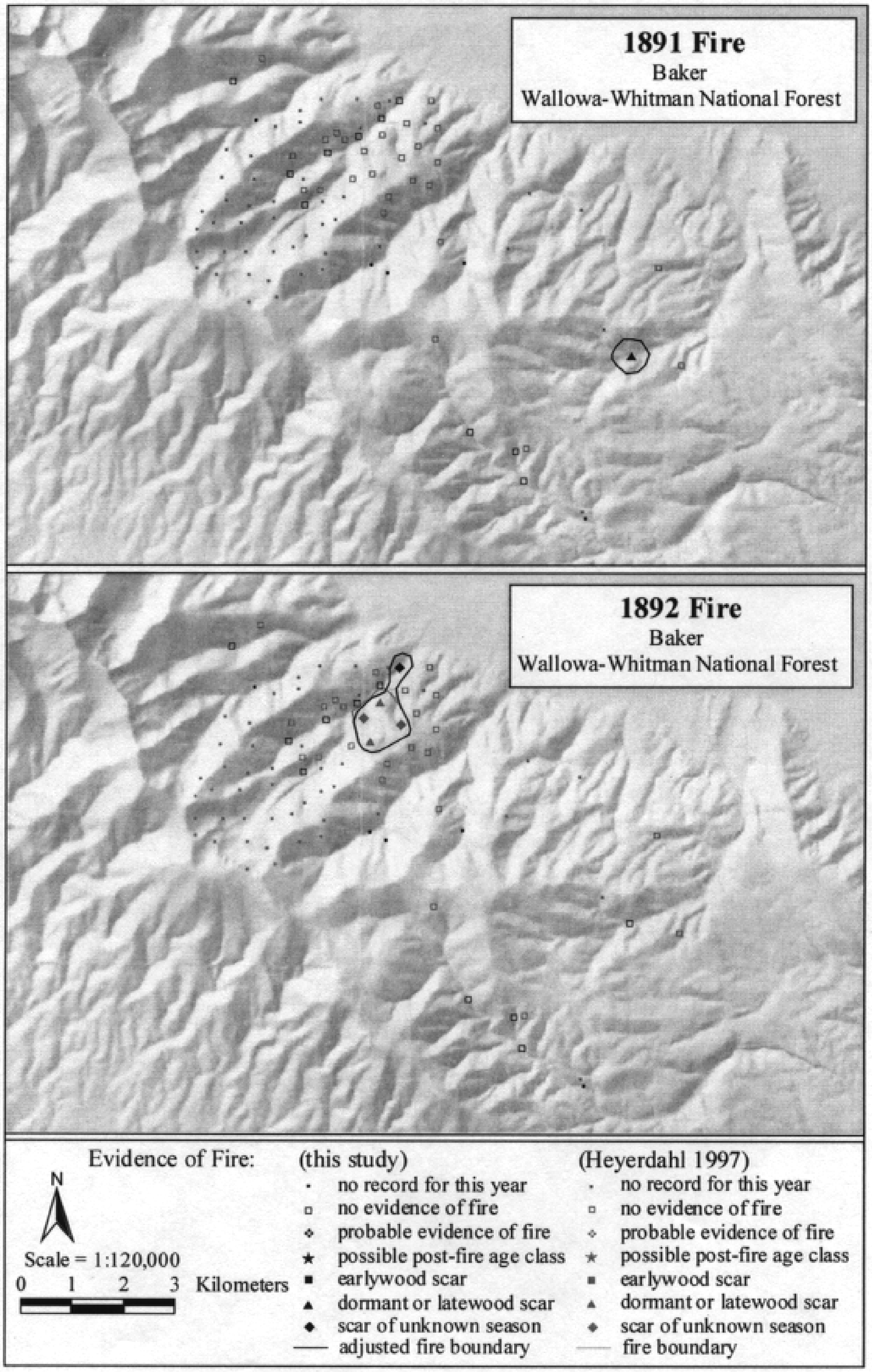

Figure 139. Baker fire maps for 1891 (top) and 1892 (bottom).

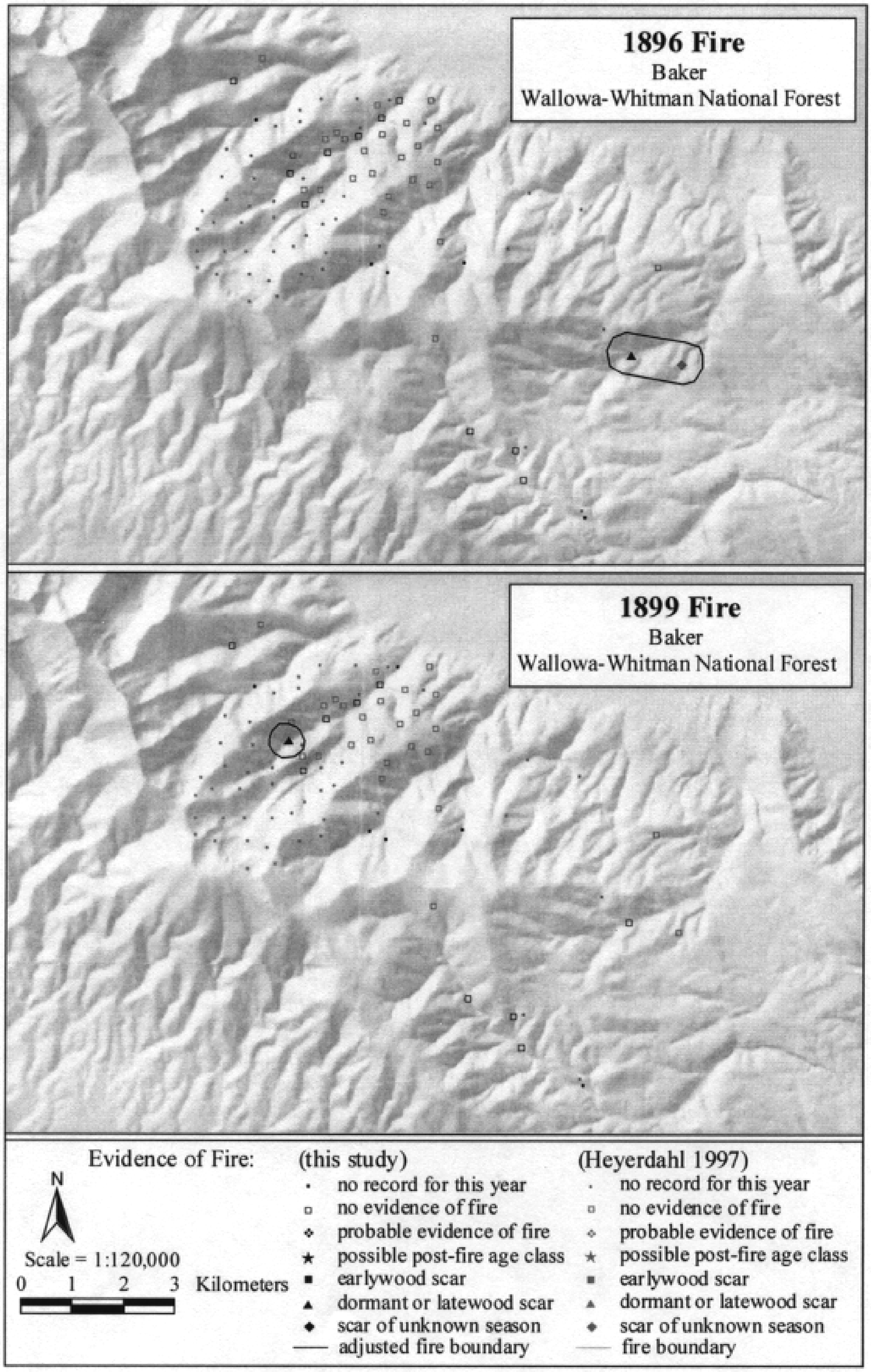

Figure 140. Baker fire maps for 1896 (top) and 1899 (bottom).

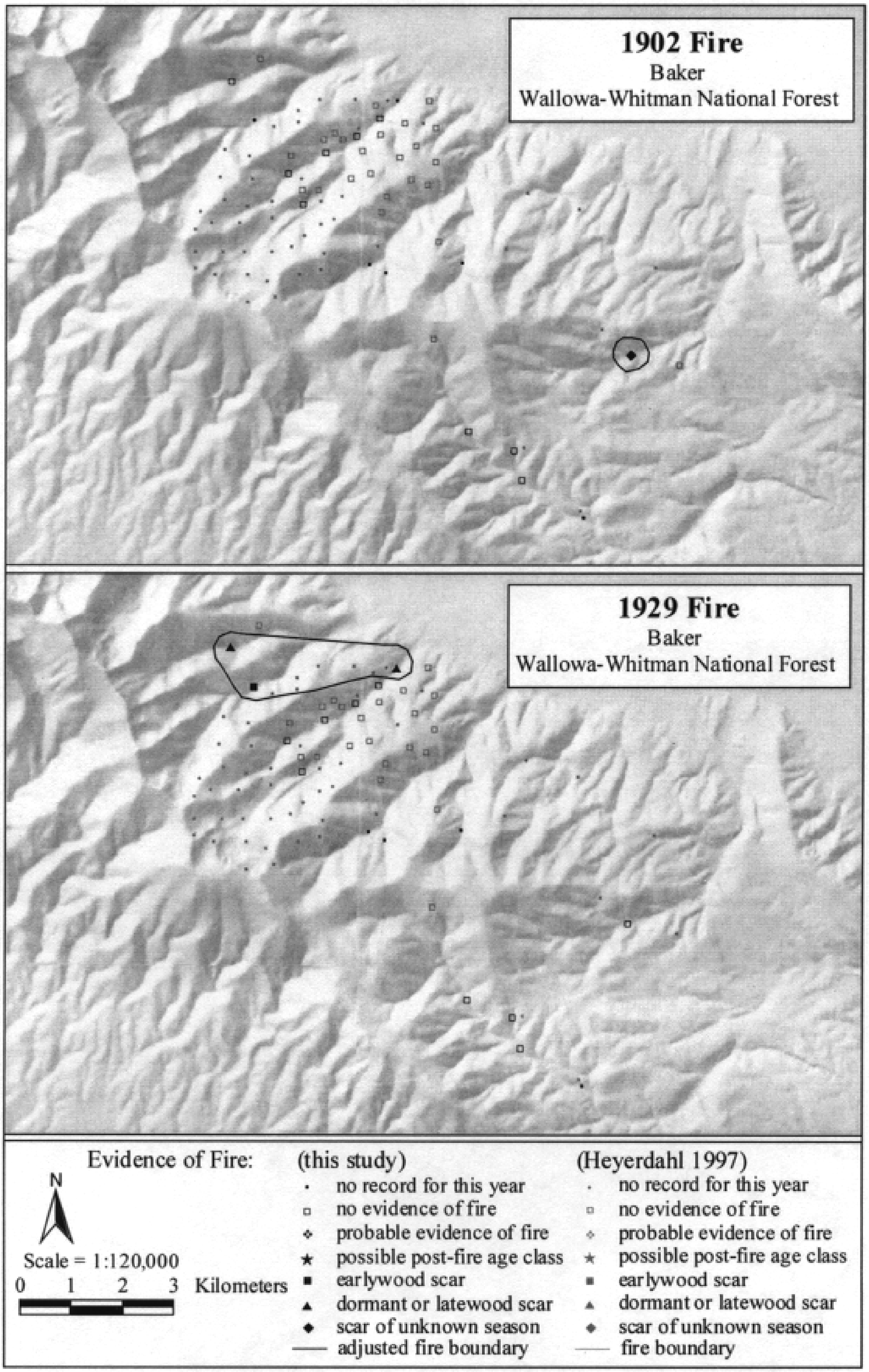

Figure 141. Baker fire maps for 1902 (top) and 1929 (bottom).

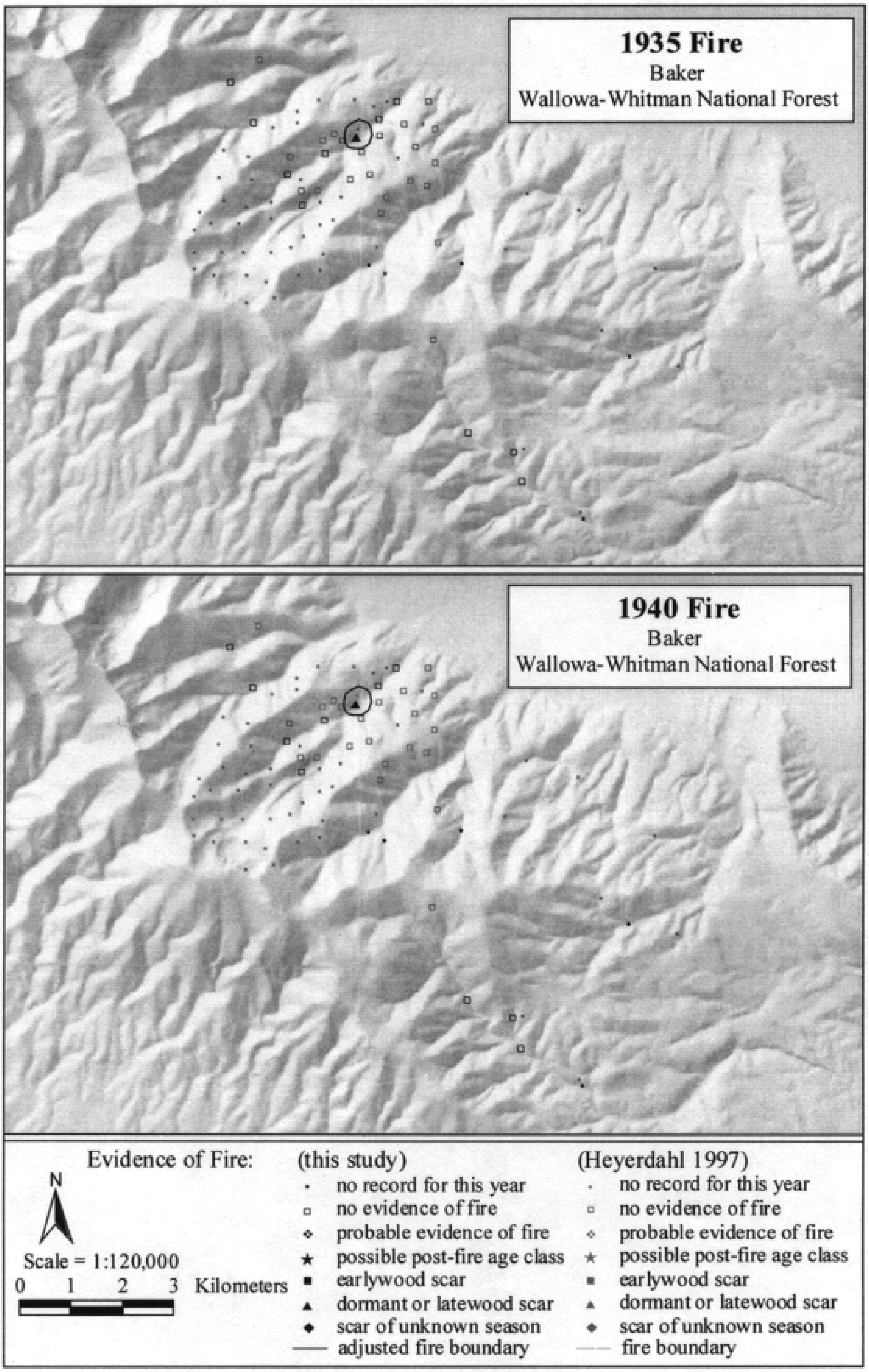

Figure 142. Baker fire maps for 1935 (top) and 1940 (bottom).

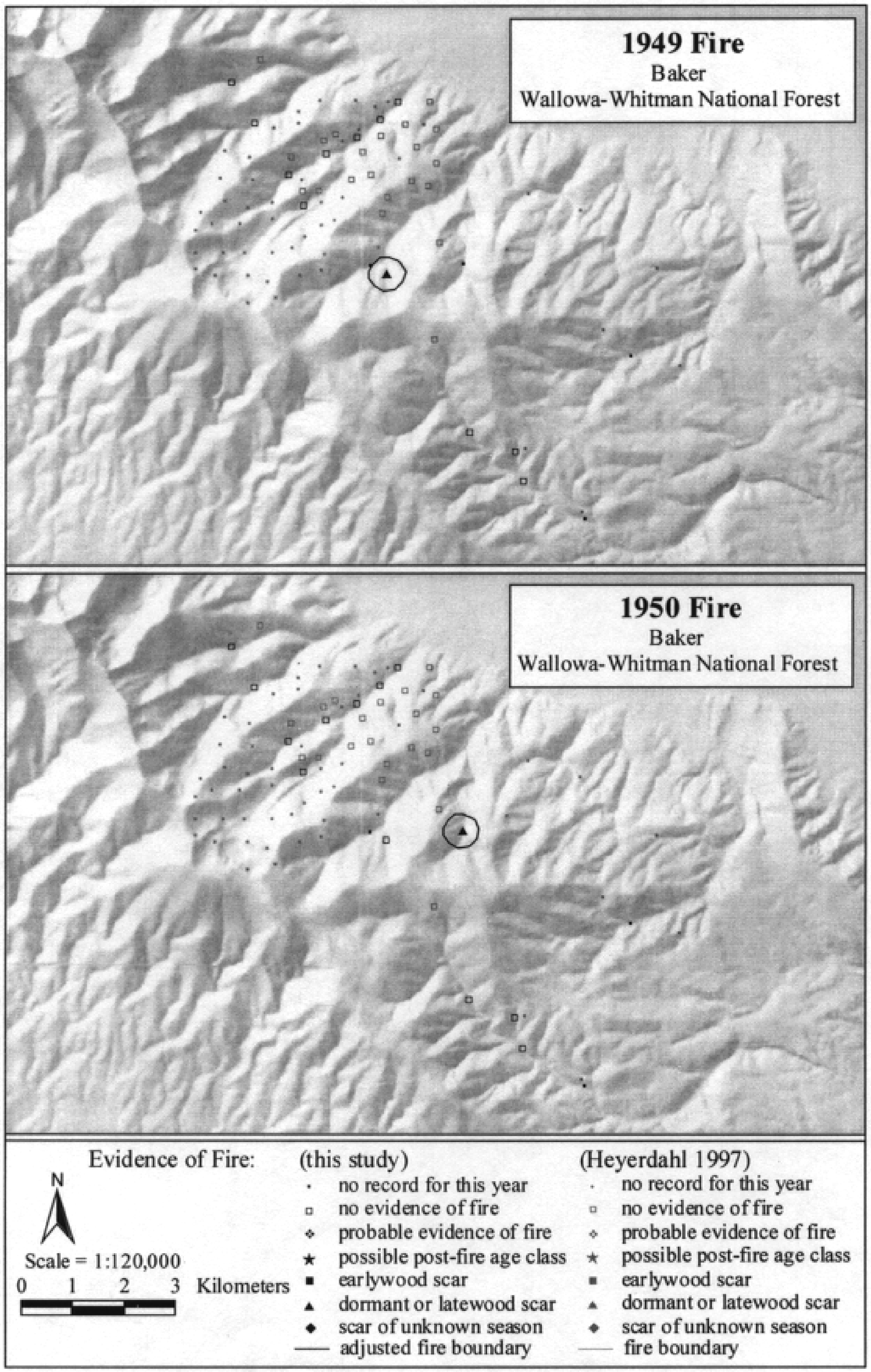

Figure 143. Baker fire maps for 1949 (top) and 1950 (bottom).

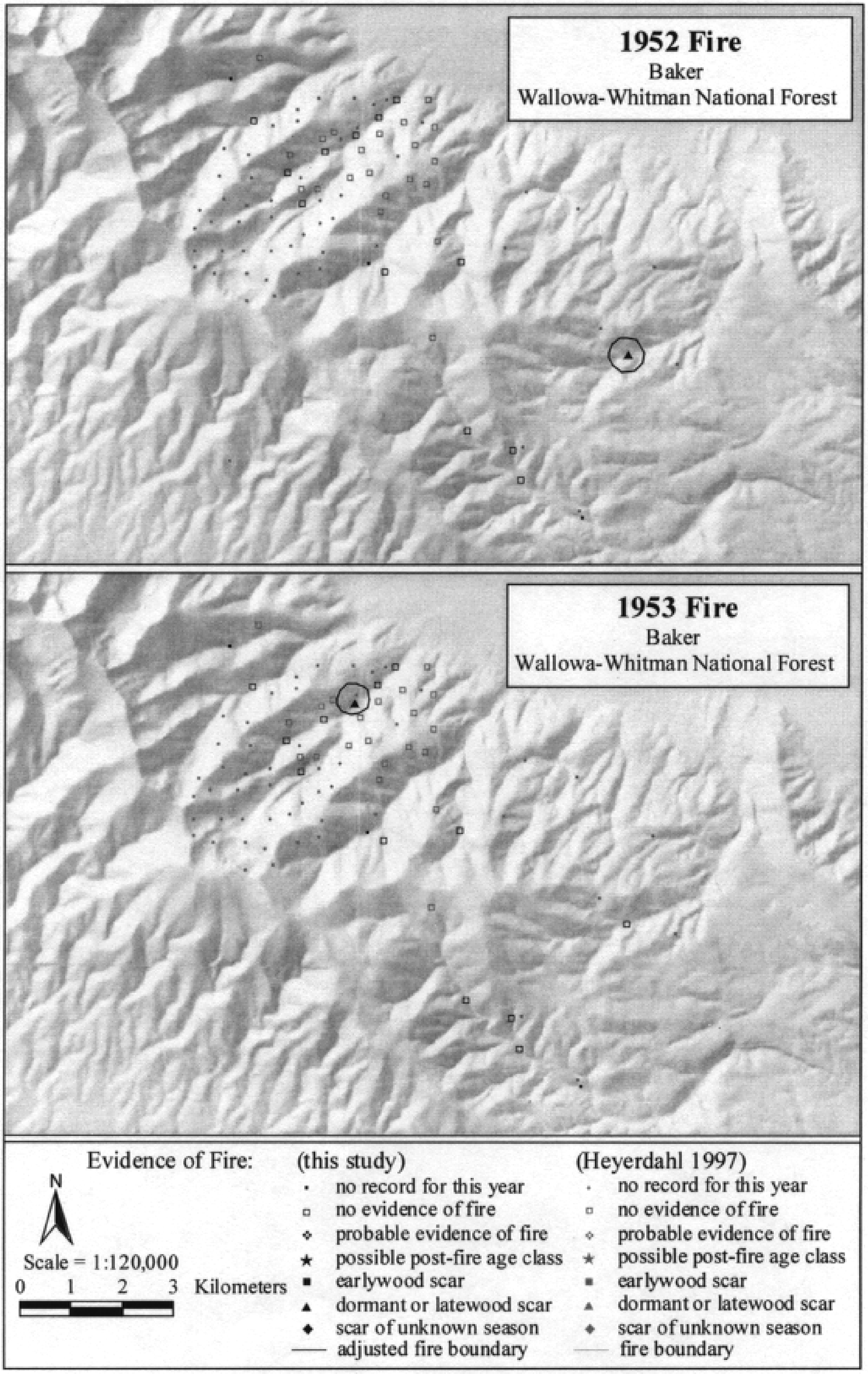

Figure 144. Baker fire maps for 1952 (top) and 1953 (bottom).

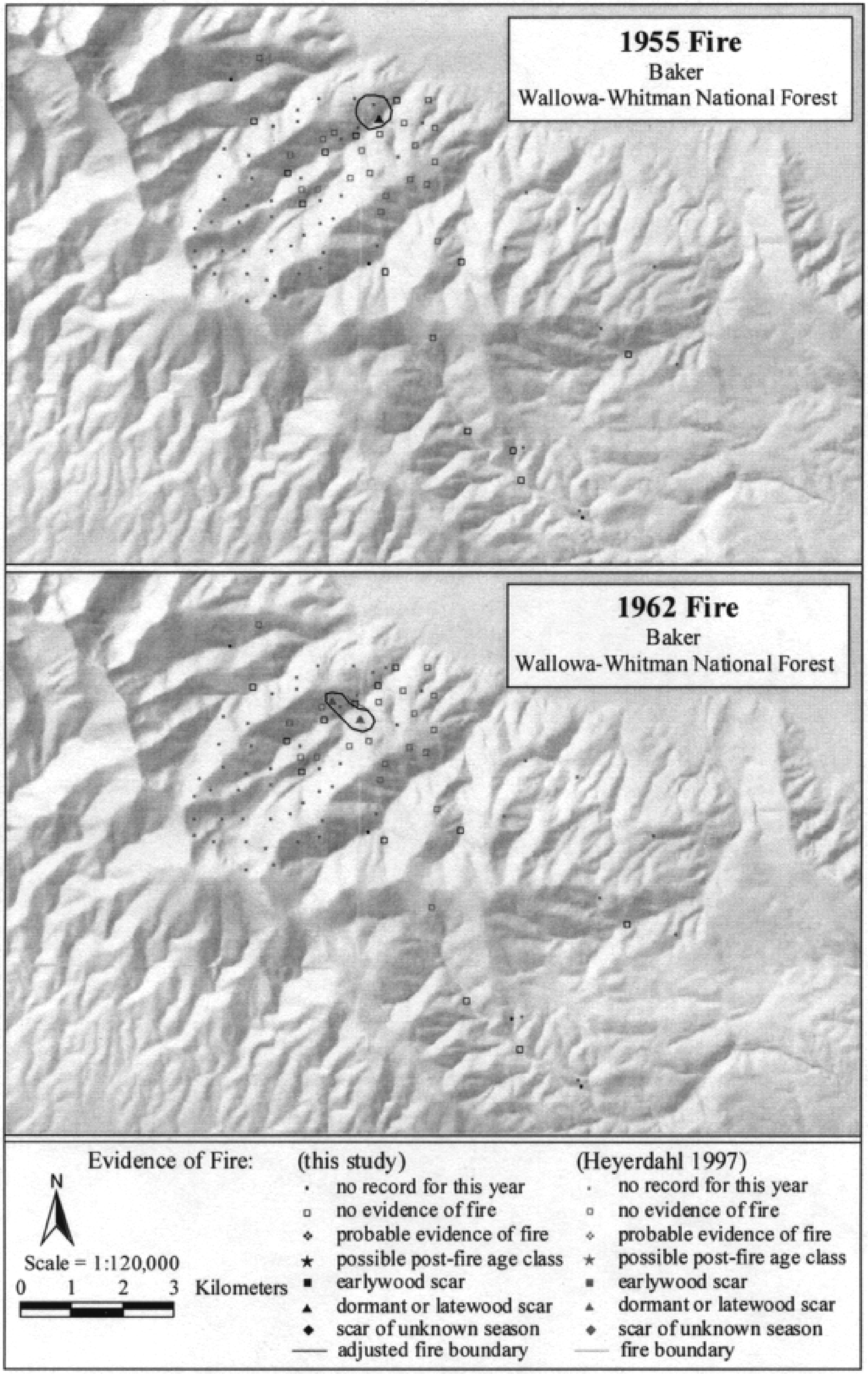

Figure 145. Baker fire maps for 1955 (top) and 1962 (bottom).

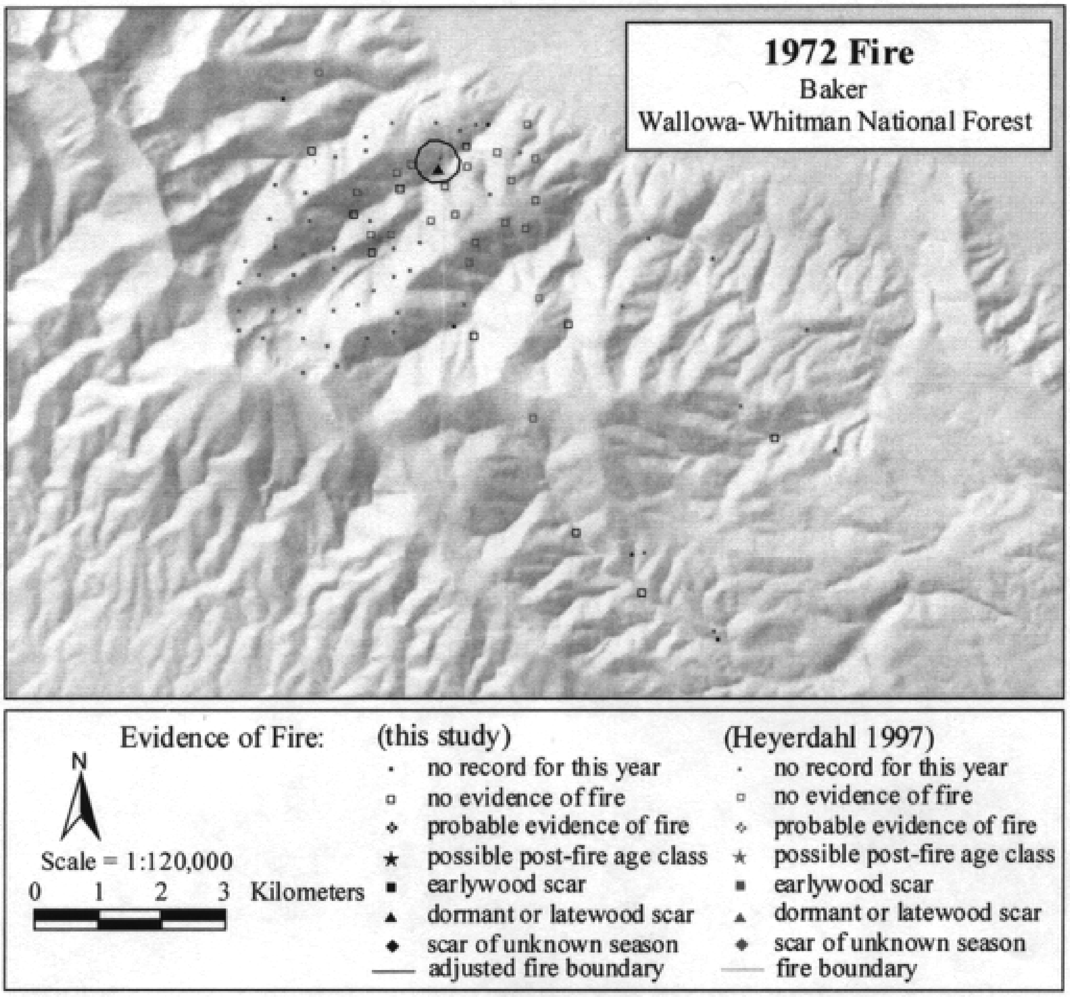

Figure 146. Baker fire map for 1972.

APPENDIX F. Steamboat study area fire maps.

Fire years were mapped for every year there was clear evidence of fire scarring. The Steamboat fire maps show the fire scar data from this study only. The intra-annular position of the scar is shown. "No record for this year" indicates that there were no trees sampled that were recording during that year. "No evidence of fire" indicates that at least one tree at the plot was recording during that year, but there was no evidence of fire in any of the samples within that plot for that year. Fire boundaries were not drawn for this study area because the sampling design for this study area was not comprehensive enough to determine fire boundaries.

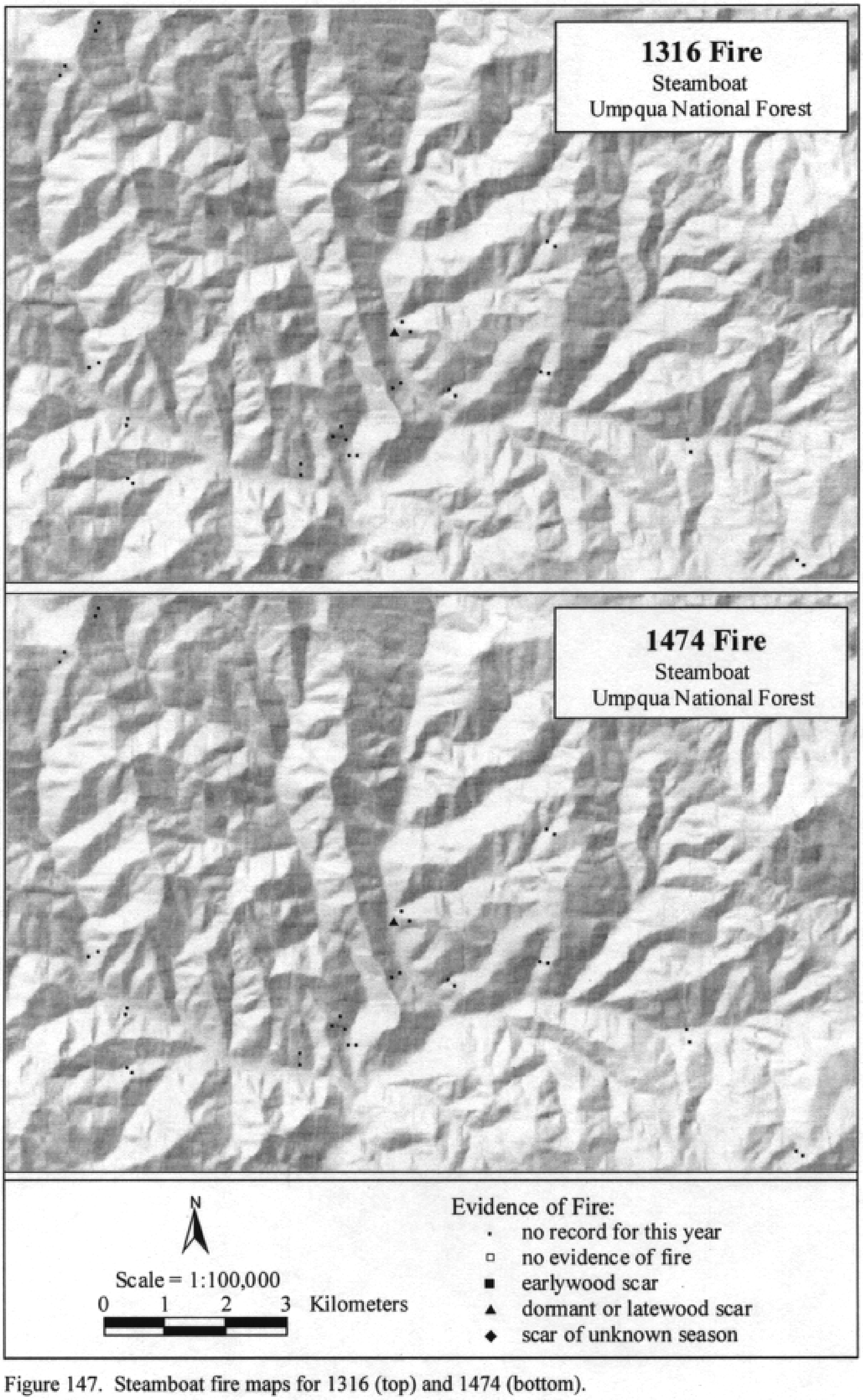

Figure 147. Steamboat fire maps for 1316 (top) and 1474 (bottom).

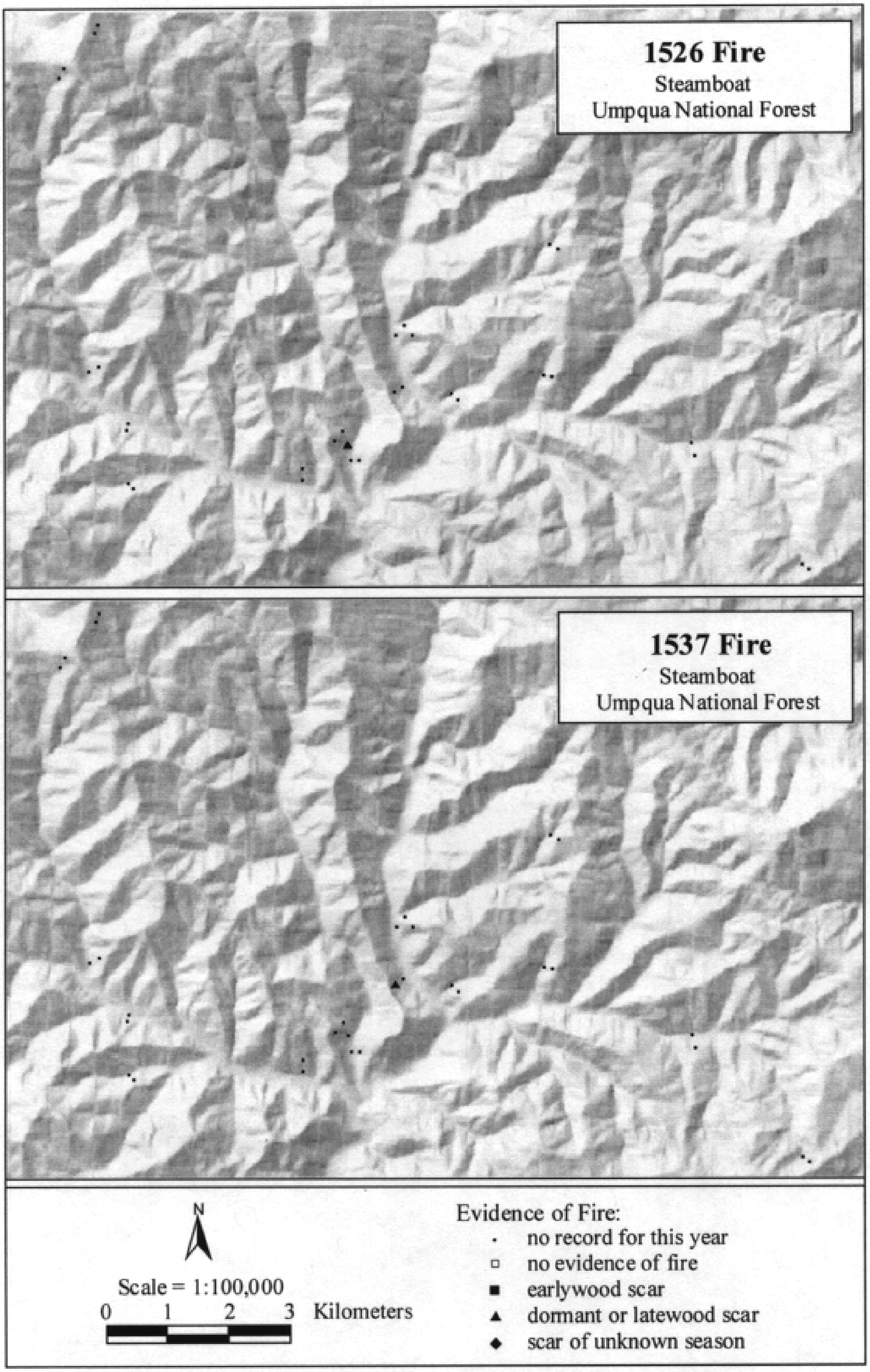

Figure 148. Steamboat fire maps for 1526 (top) and 1537 (bottom).

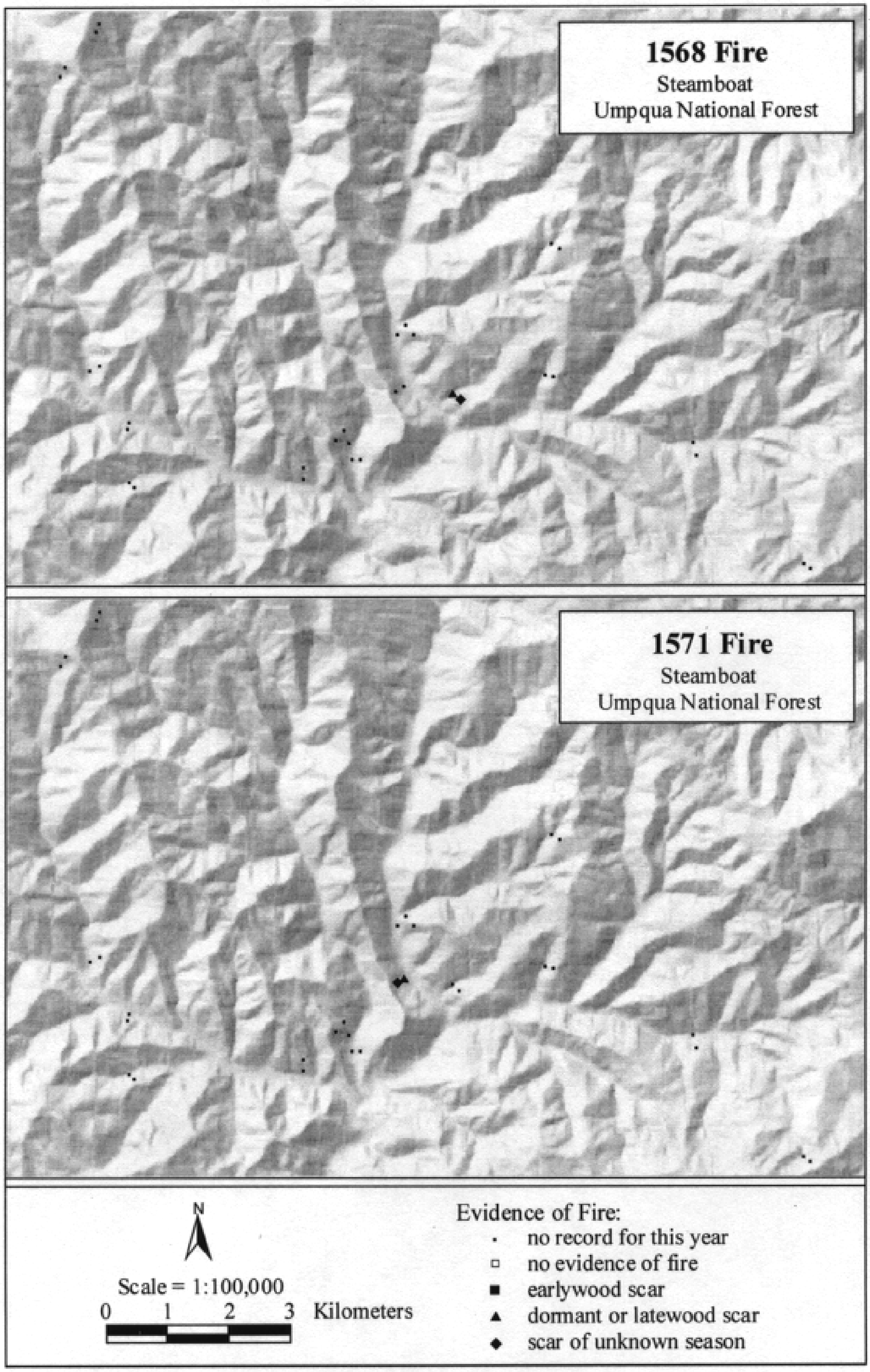

Figure 149. Steamboat fire maps for 1568 (top) and 1571 (bottom).

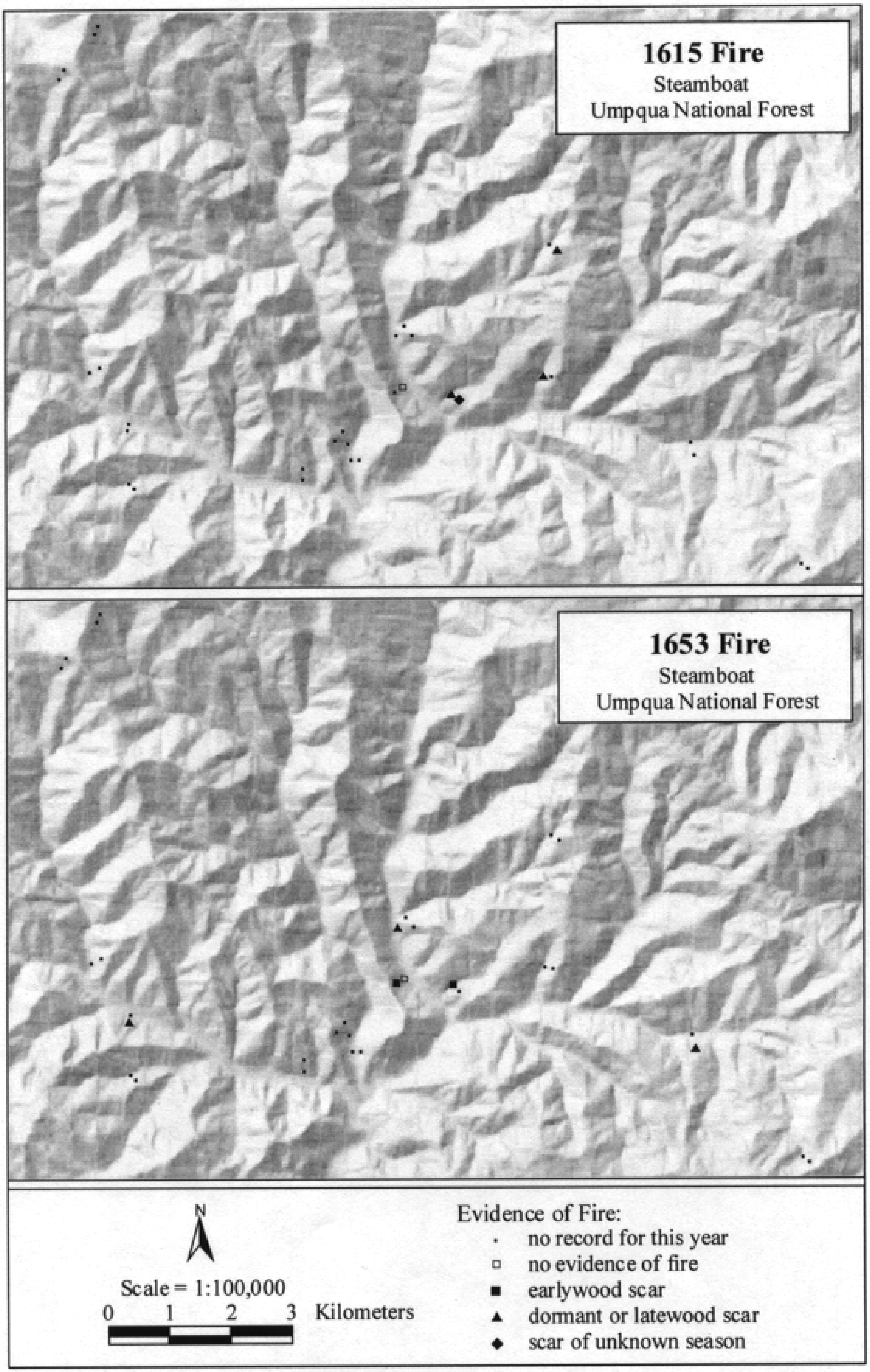

Figure 150. Steamboat fire maps for 1615 (top) and 1653 (bottom).

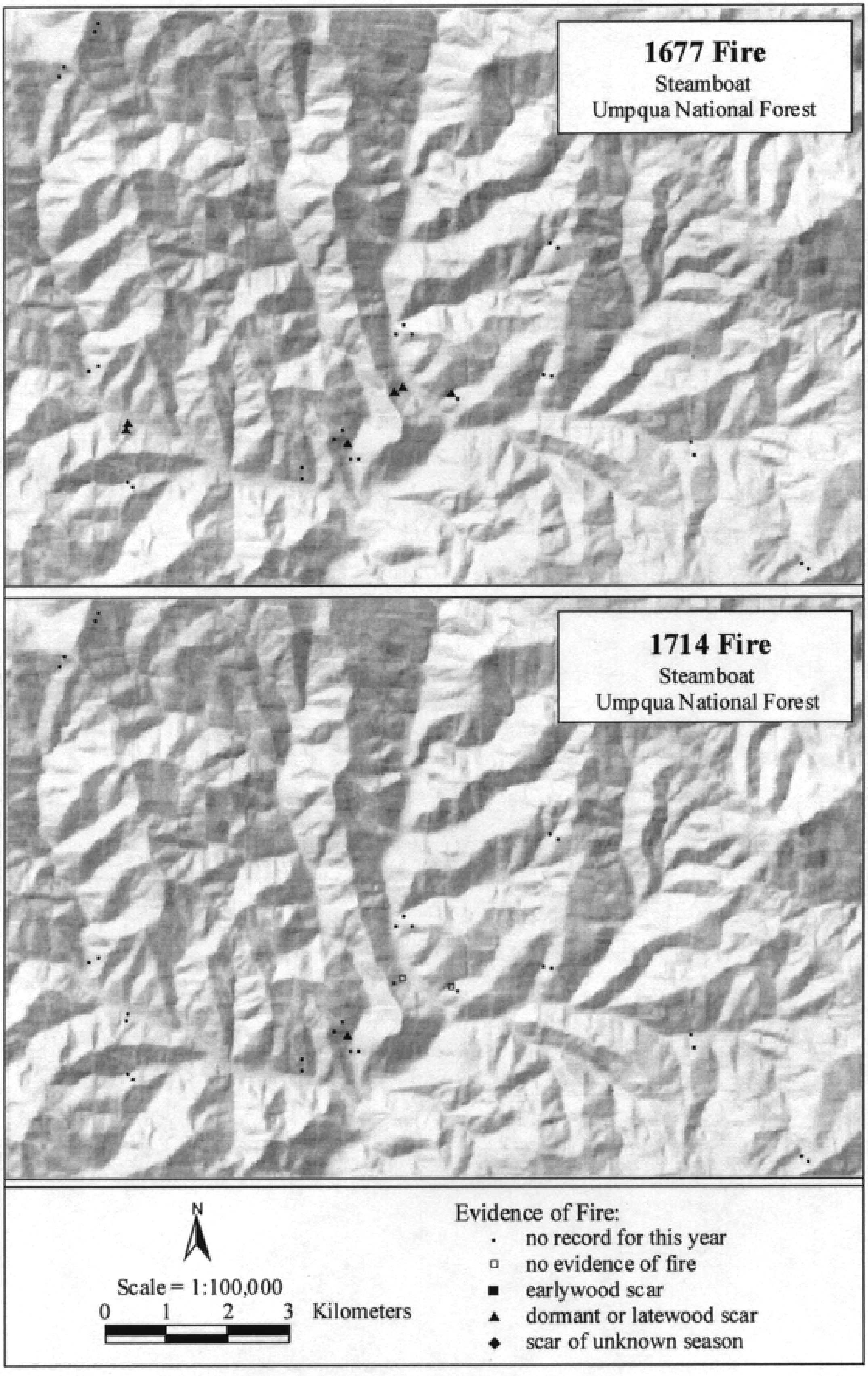

Figure 151. Steamboat fire maps for 1677 (top) and 1714 (bottom).

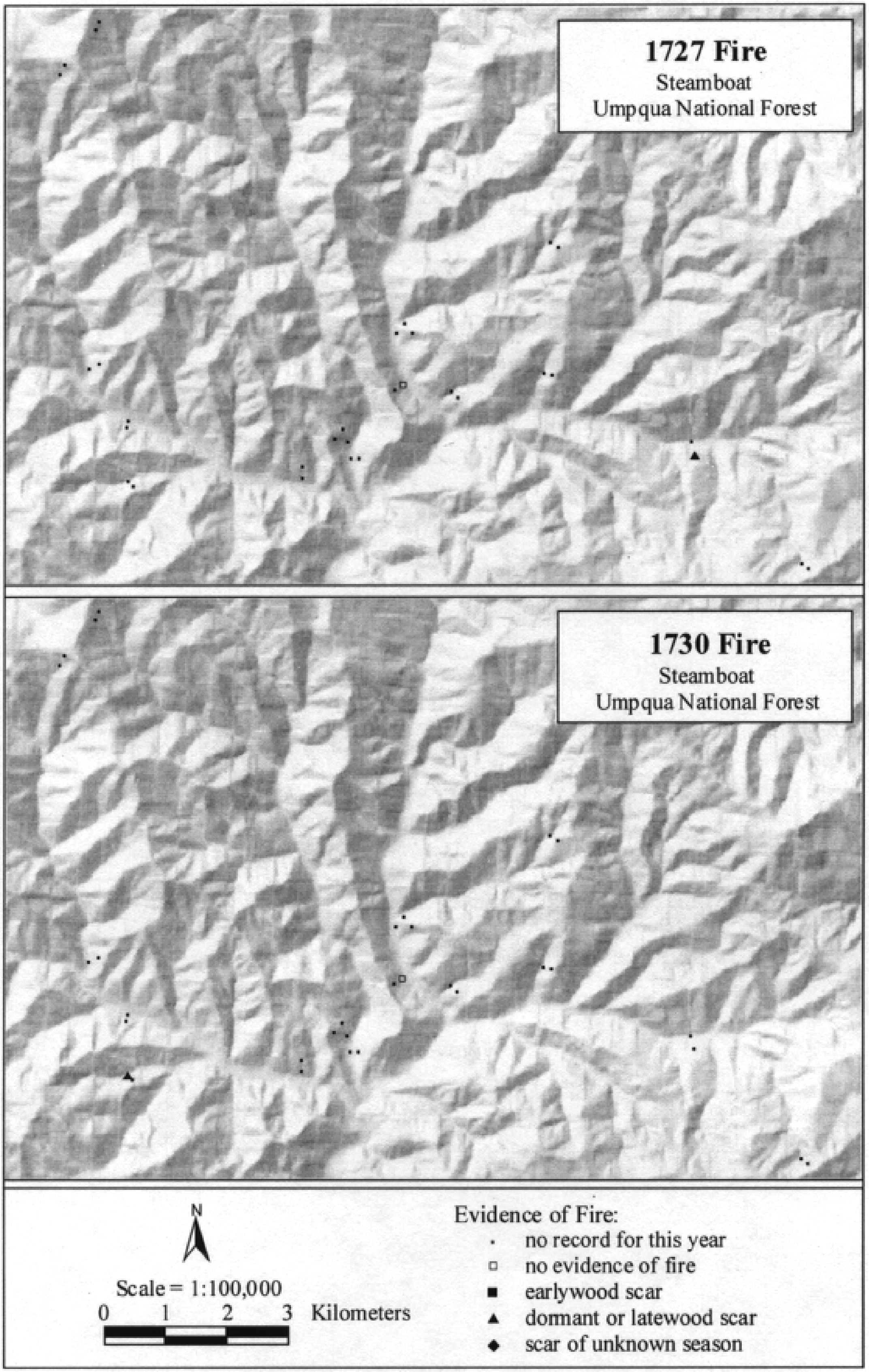

Figure 152. Steamboat fire maps for 1727 (top) and 1730 (bottom).

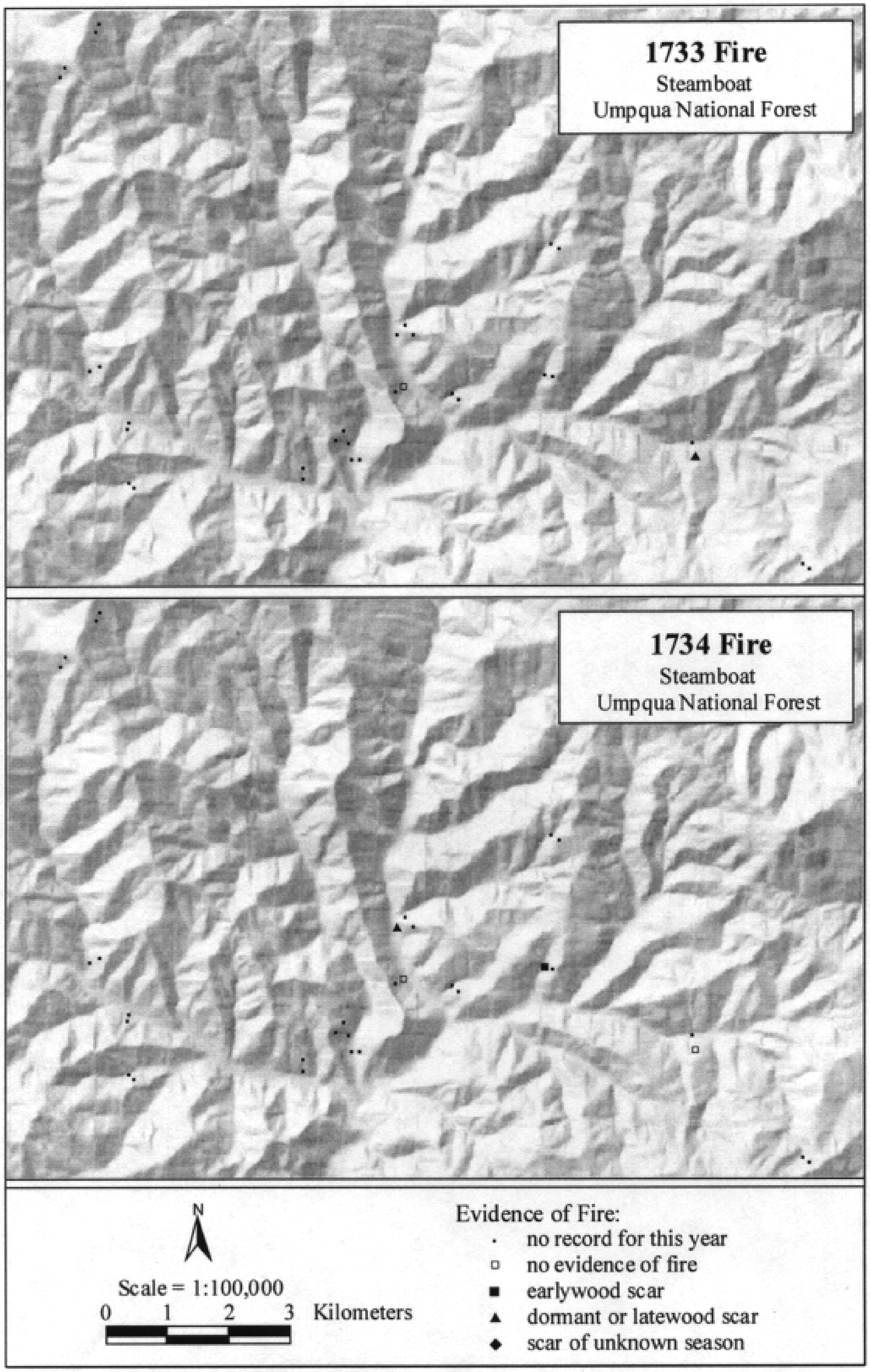

Figure 153. Steamboat fire maps for 1733 (top) and 1734 (bottom).

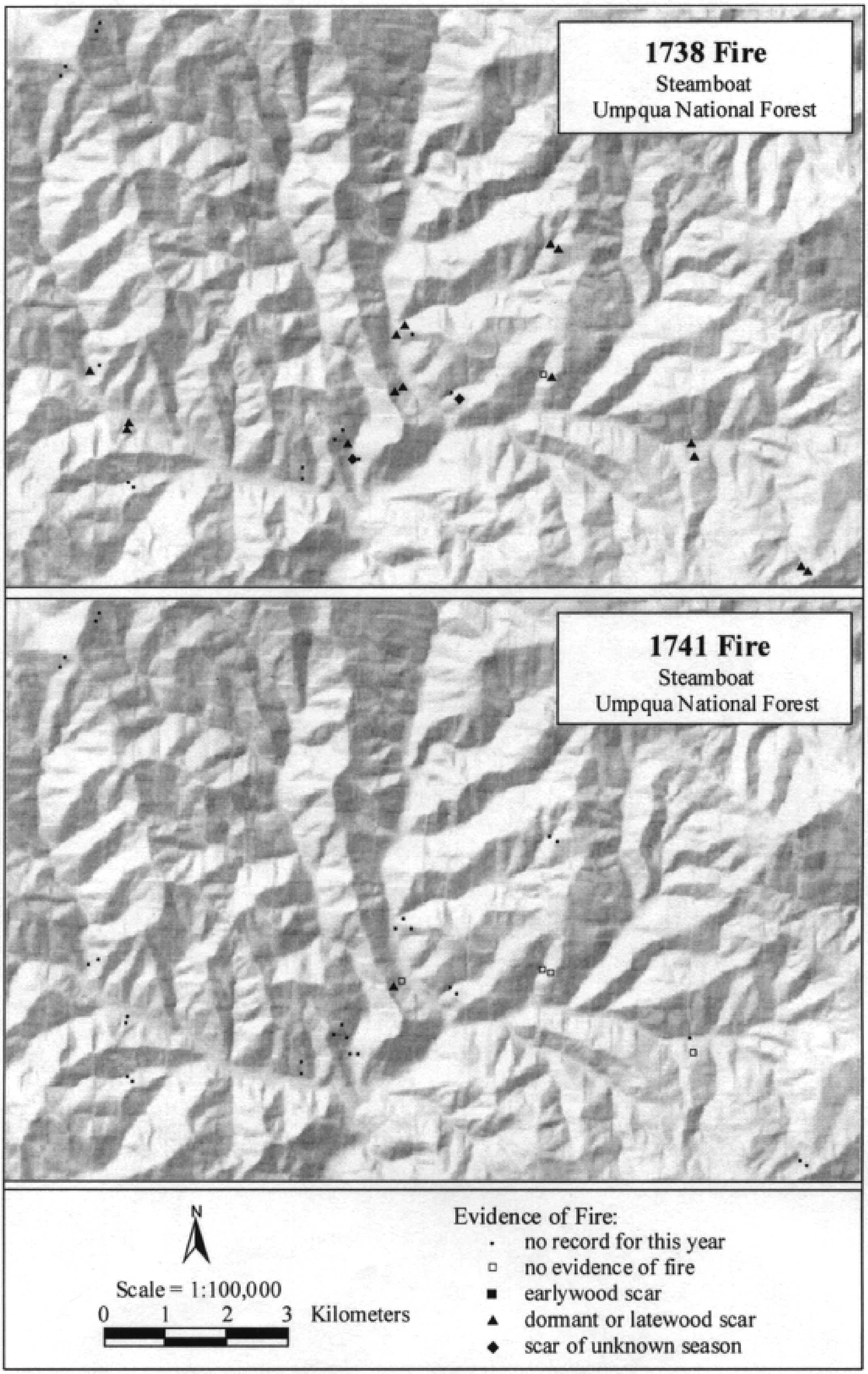

Figure 154. Steamboat fire maps for 1738 (top) and 1741 (bottom).

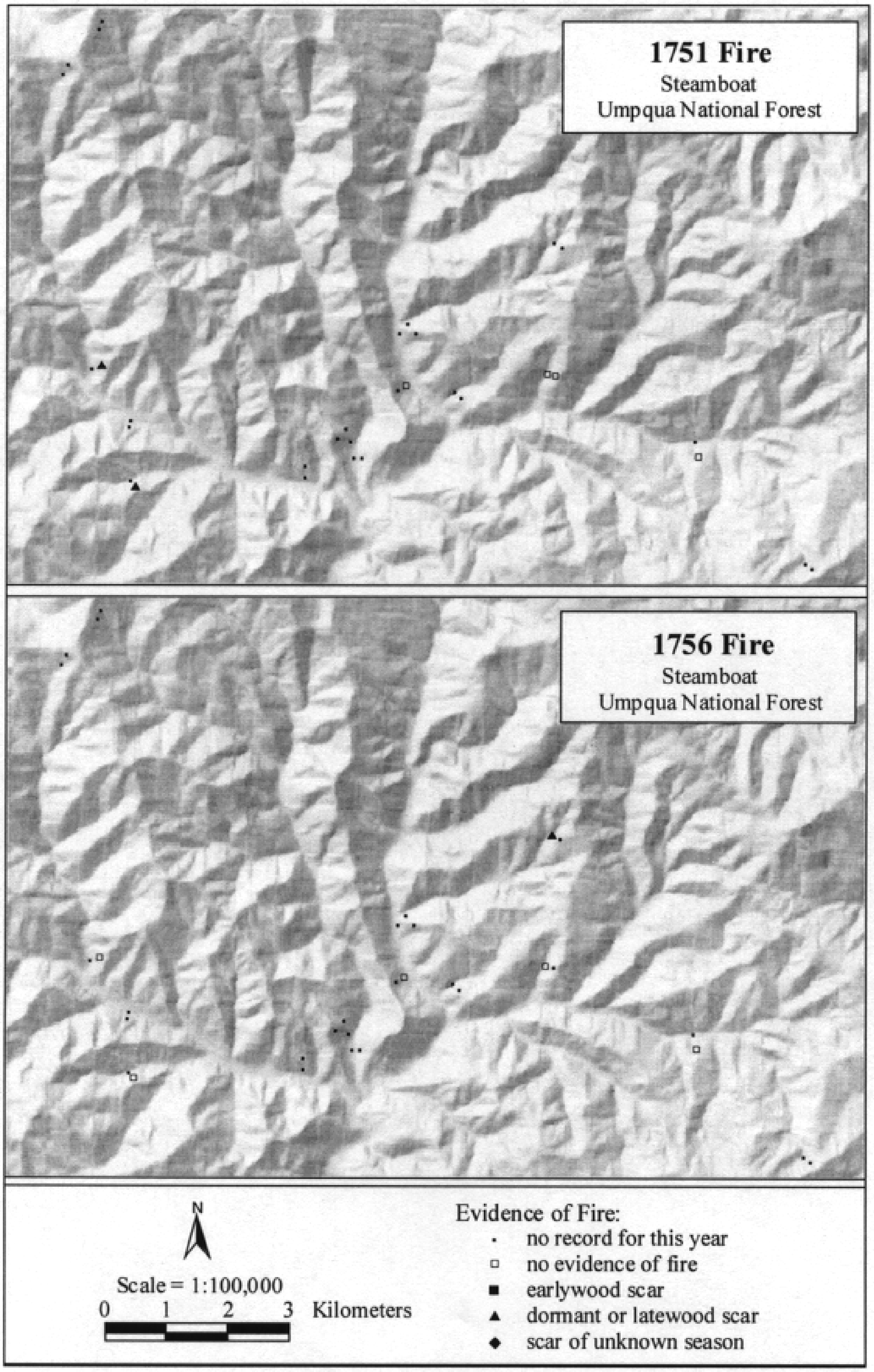

Figure 155. Steamboat fire maps for 1751 (top) and 1756 (bottom).

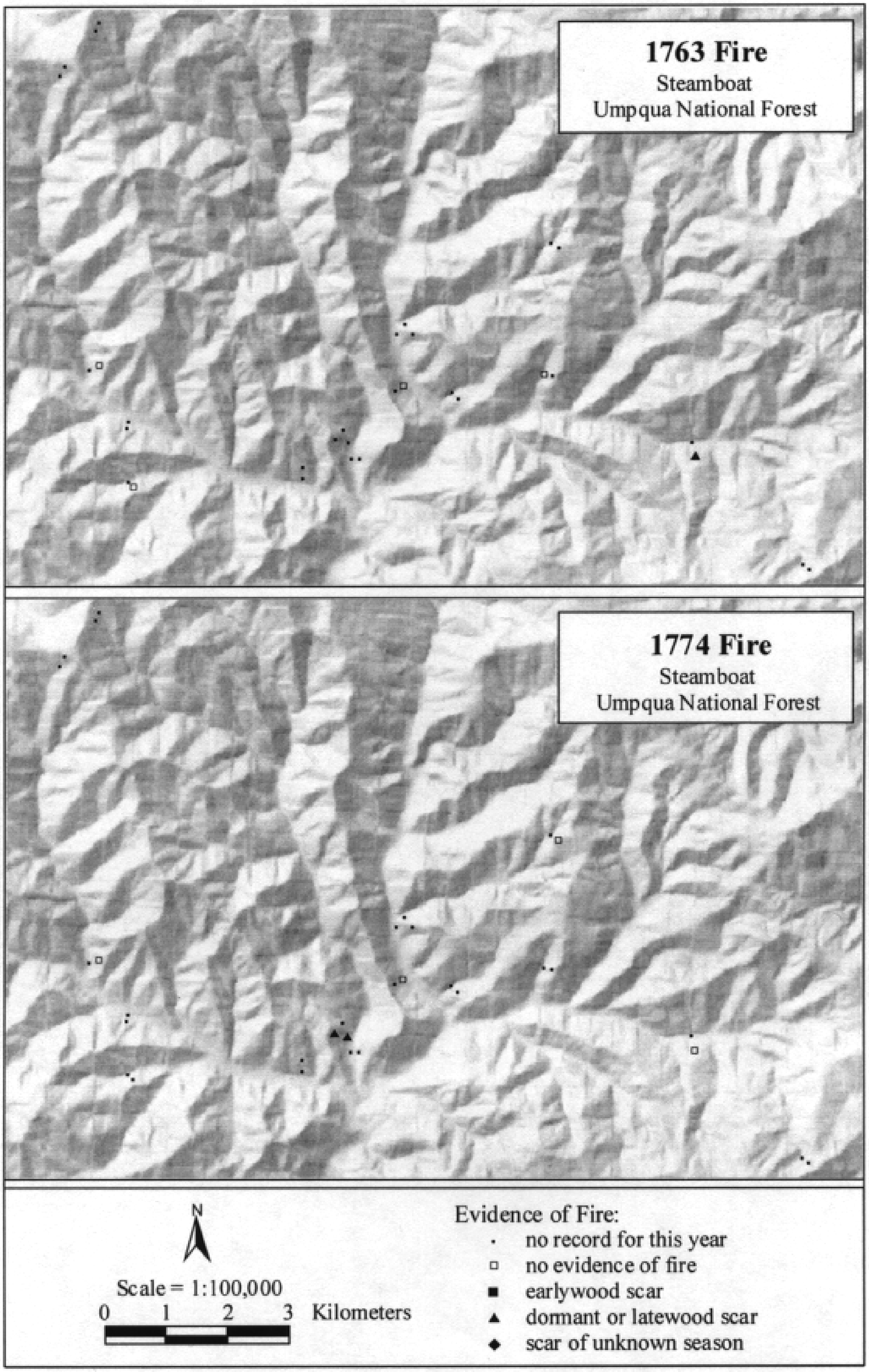

Figure 156. Steamboat fire maps for 1763 (top) and 1774 (bottom).

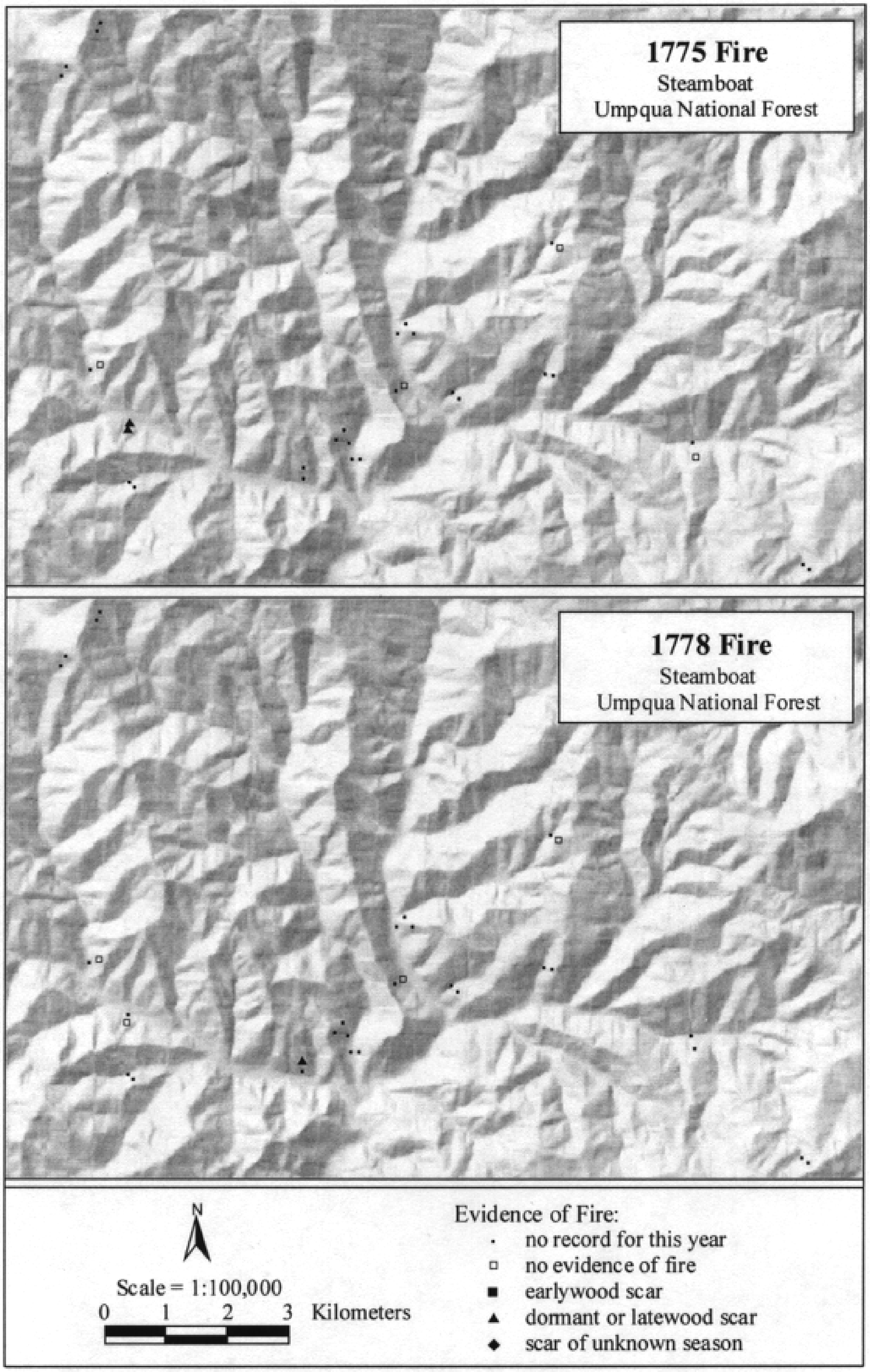

Figure 157. Steamboat fire maps for 1775 (top) and 1778 (bottom).

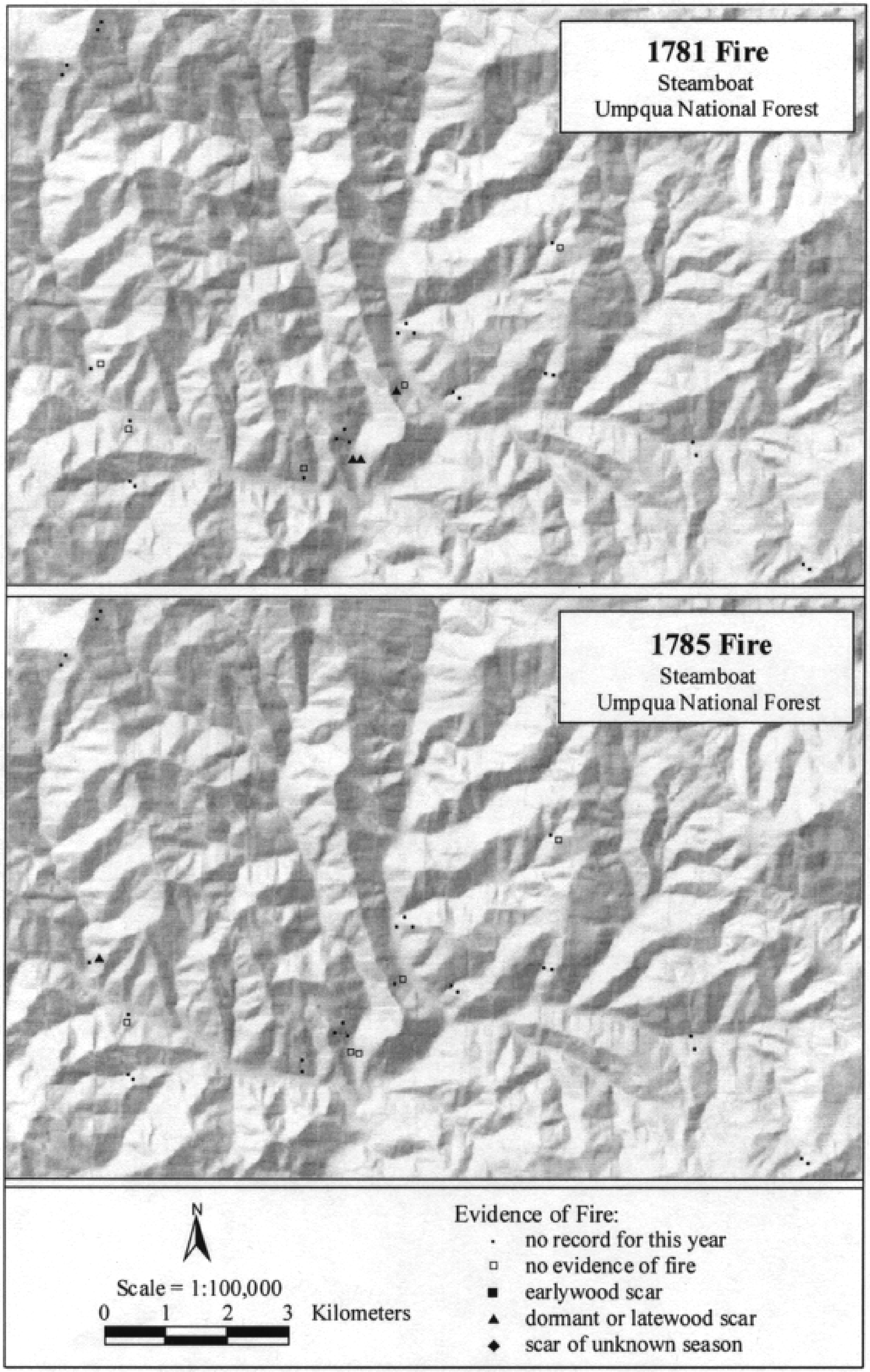

Figure 158. Steamboat fire maps for 1781 (top) and 1785 (bottom).

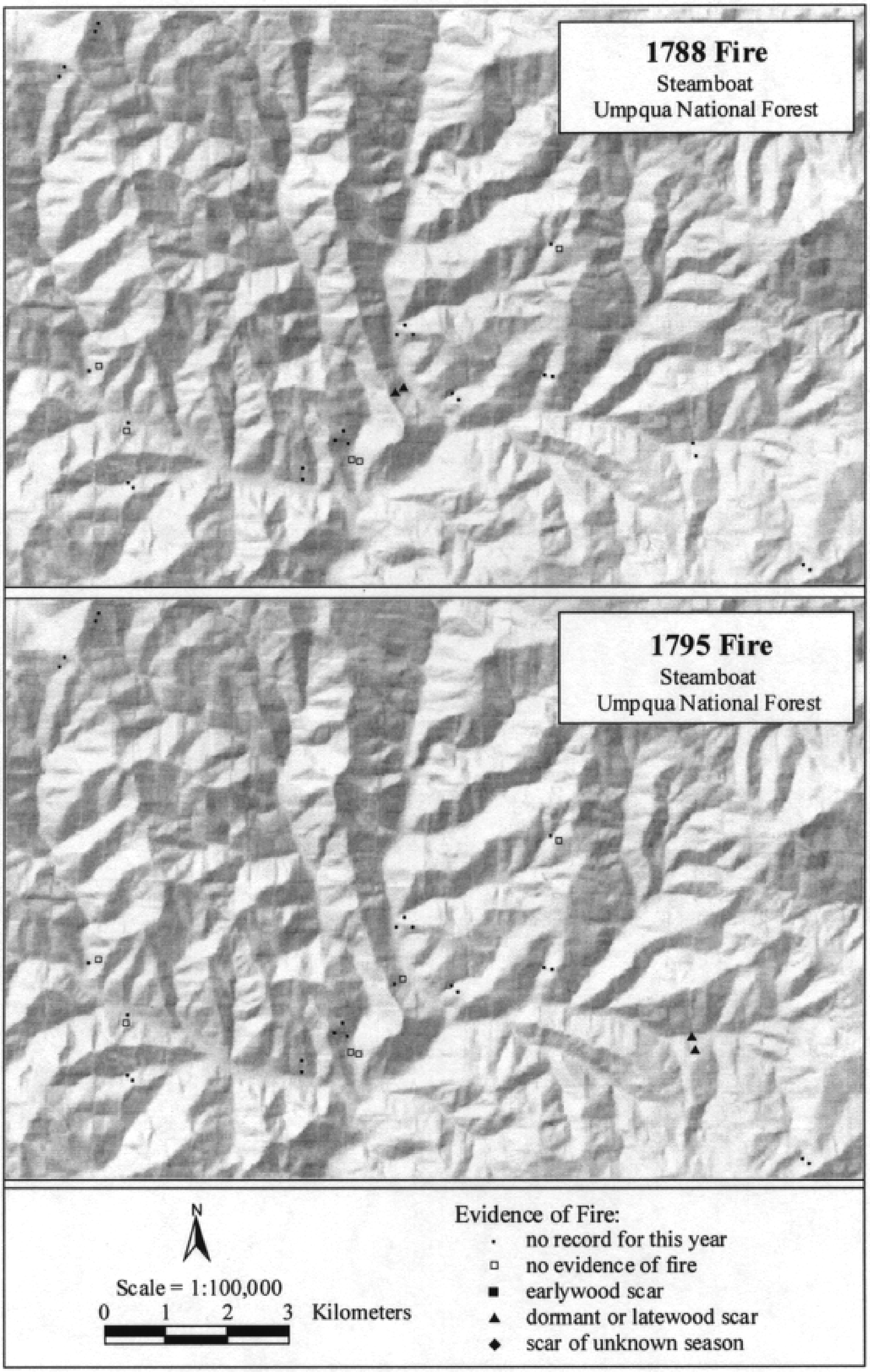

Figure 159. Steamboat fire maps for 1788 (top) and 1795 (bottom).

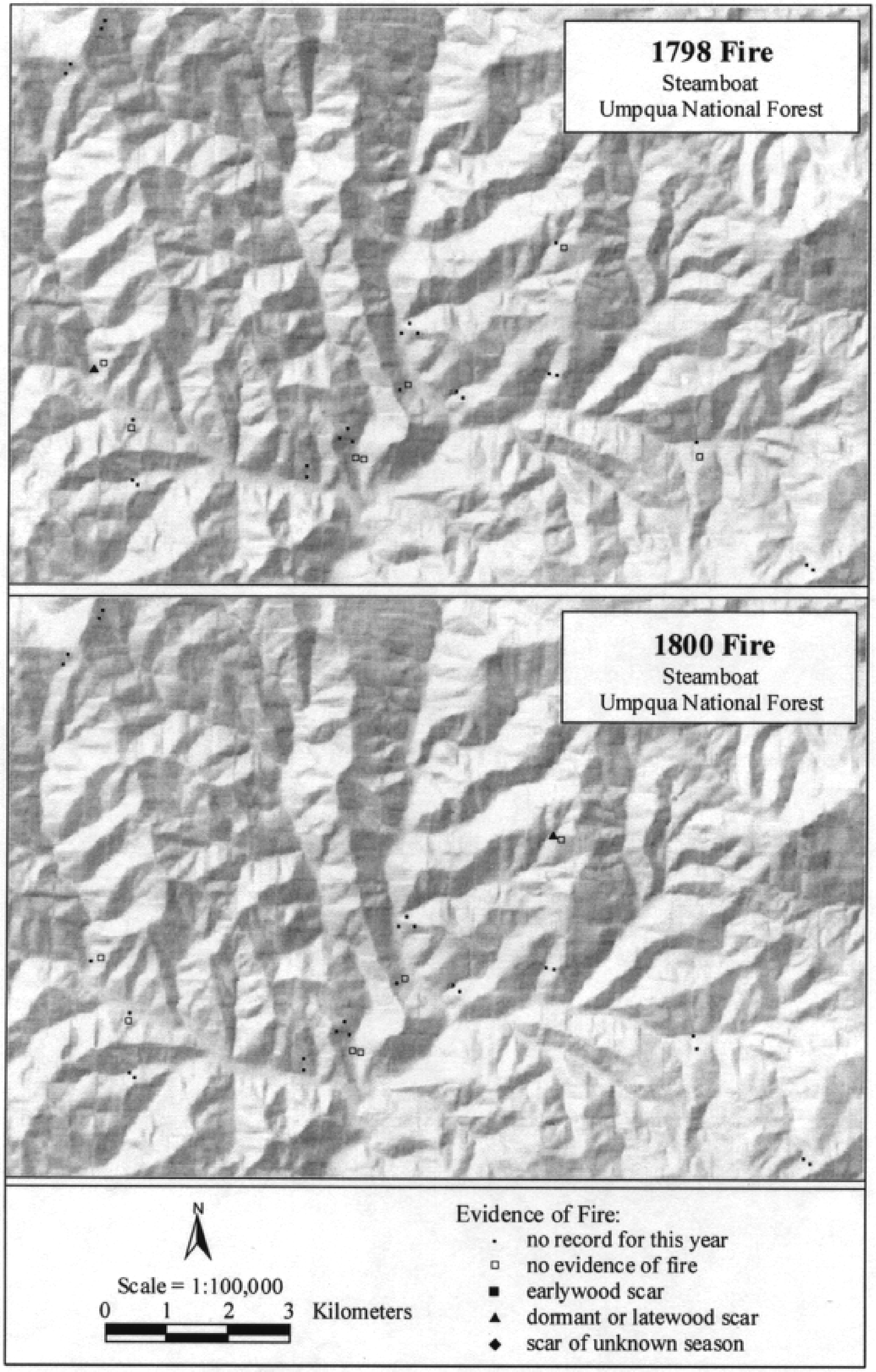

Figure 160. Steamboat fire maps for 1798 (top) and 1800 (bottom).

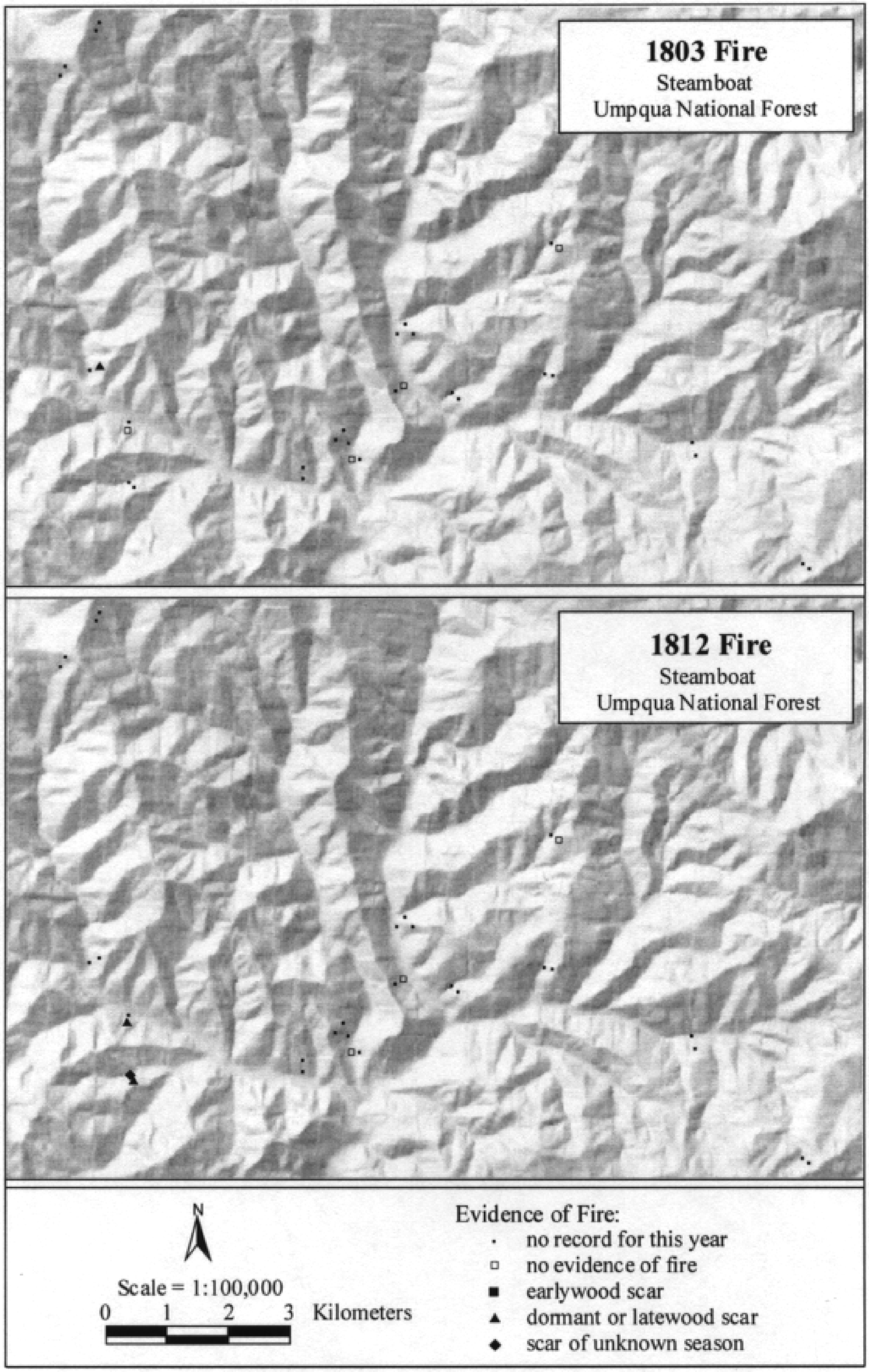

Figure 161. Steamboat fire maps for 1803 (top) and 1812 (bottom).

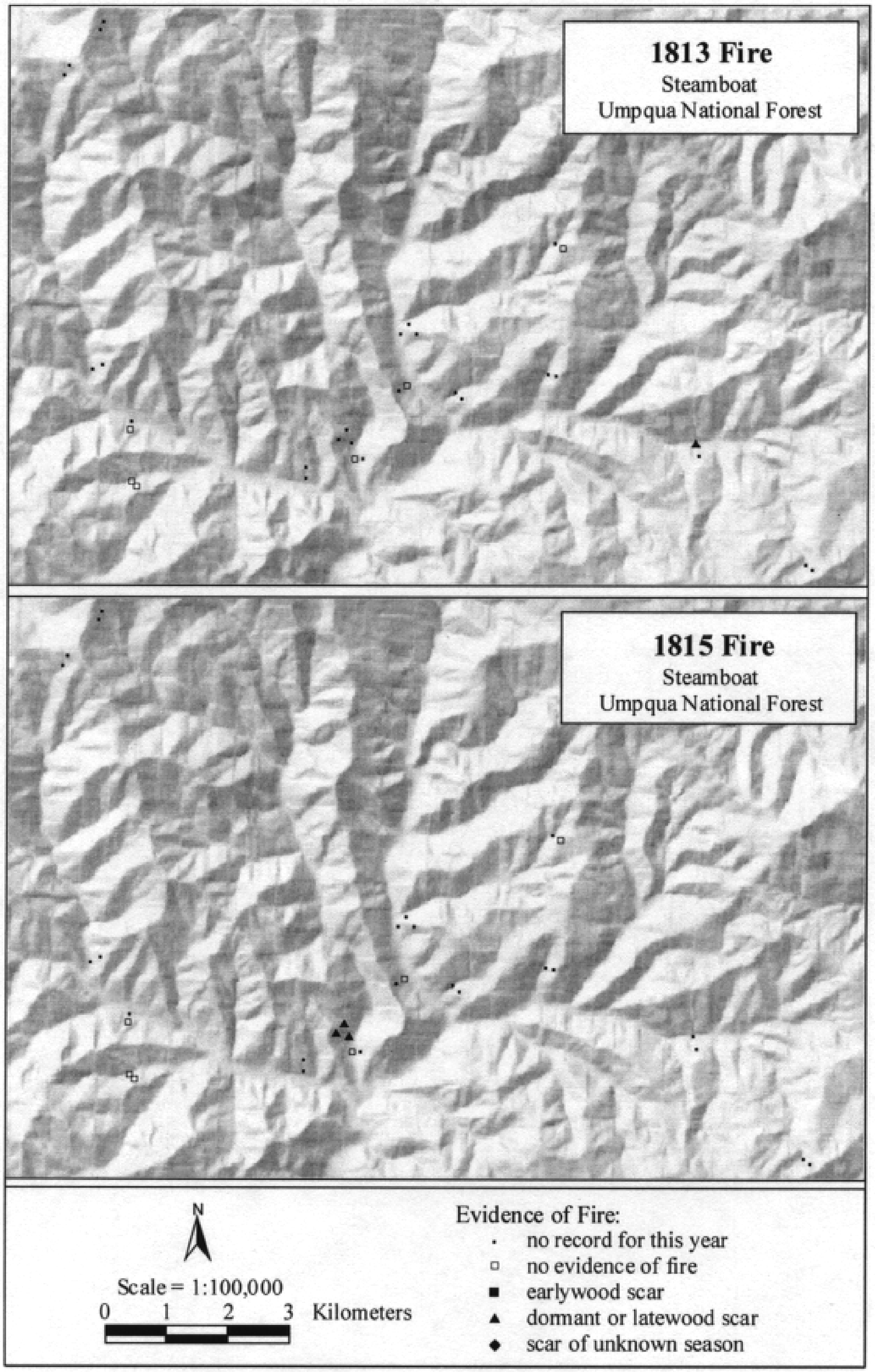

Figure 162. Steamboat fire maps for 1813 (top) and 1815 (bottom).

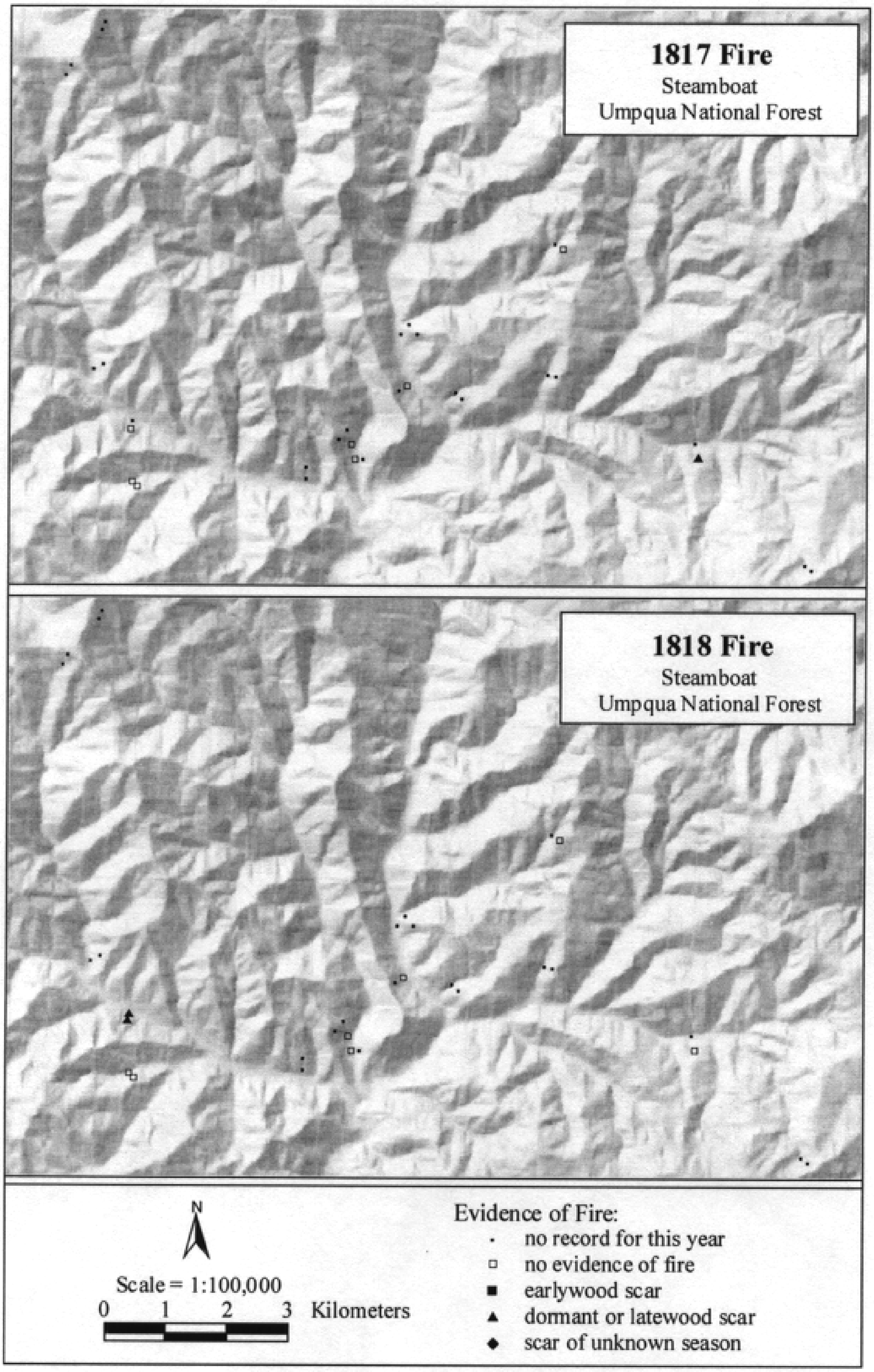

Figure 163. Steamboat fire maps for 1817 (top) and 1818 (bottom).

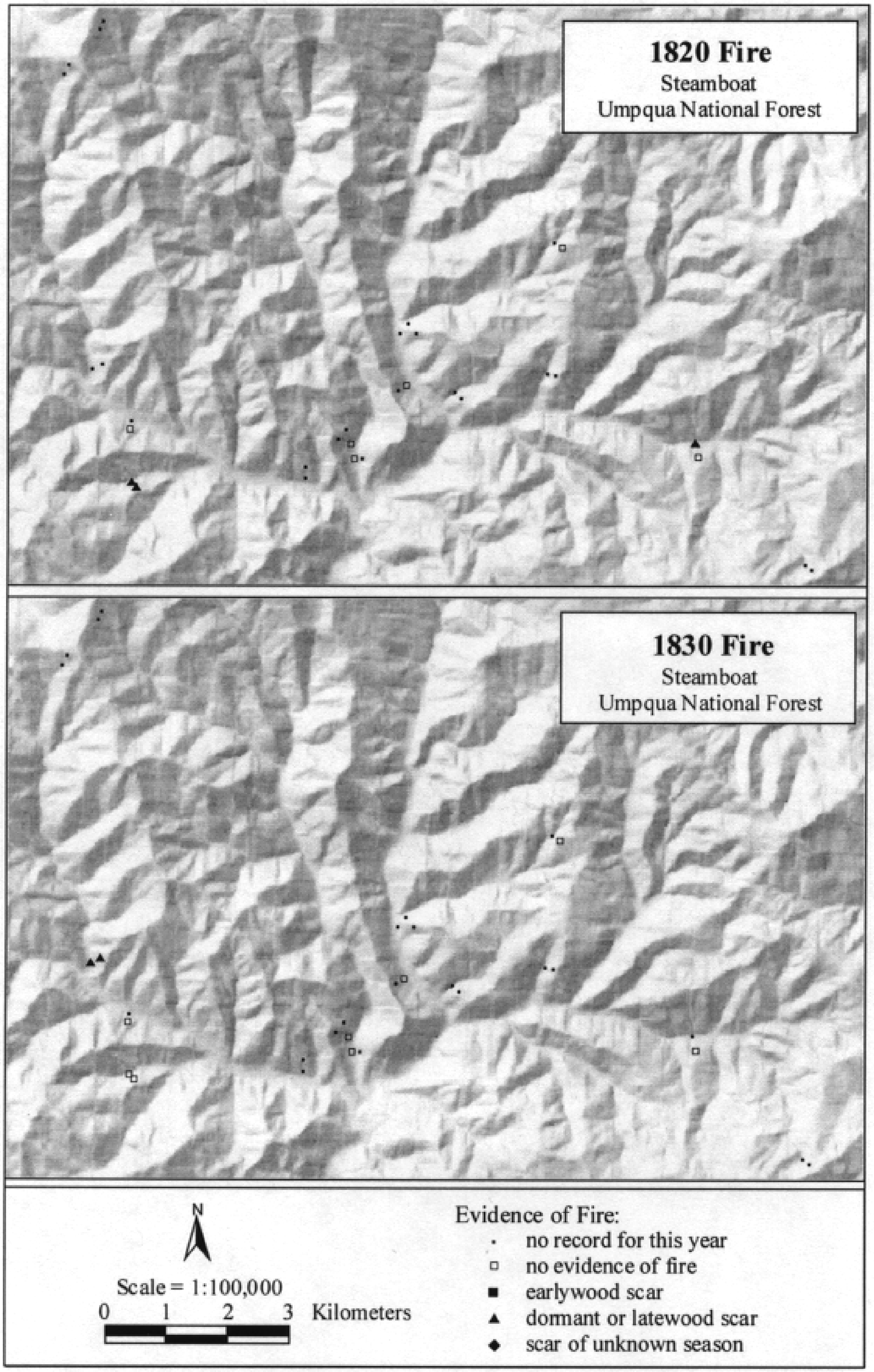

Figure 164. Steamboat fire maps for 1820 (top) and 1830 (bottom).

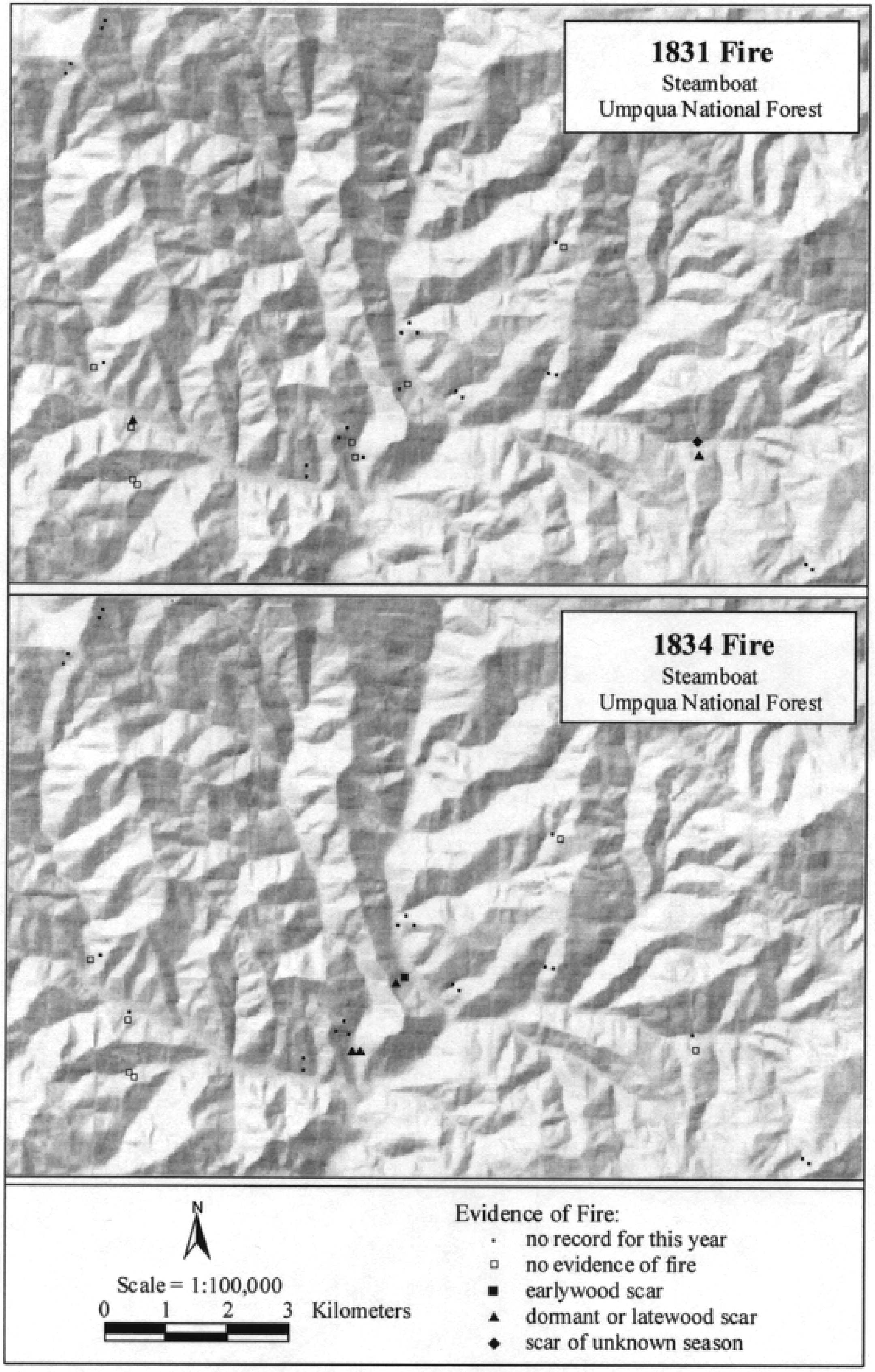

Figure 165. Steamboat fire maps for 1831 (top) and 1834 (bottom).

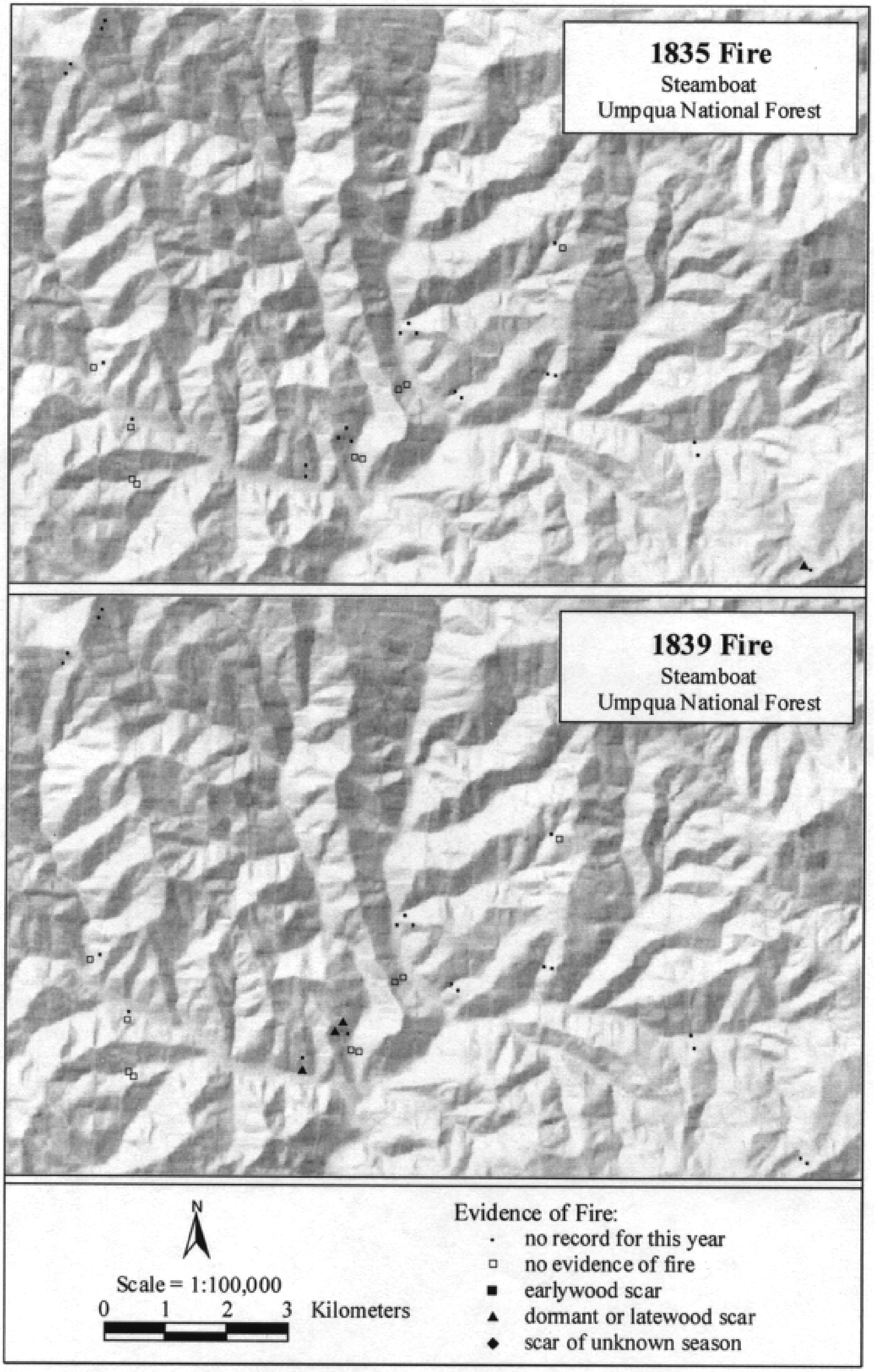

Figure 166. Steamboat fire maps for 1835 (top) and 1839 (bottom).

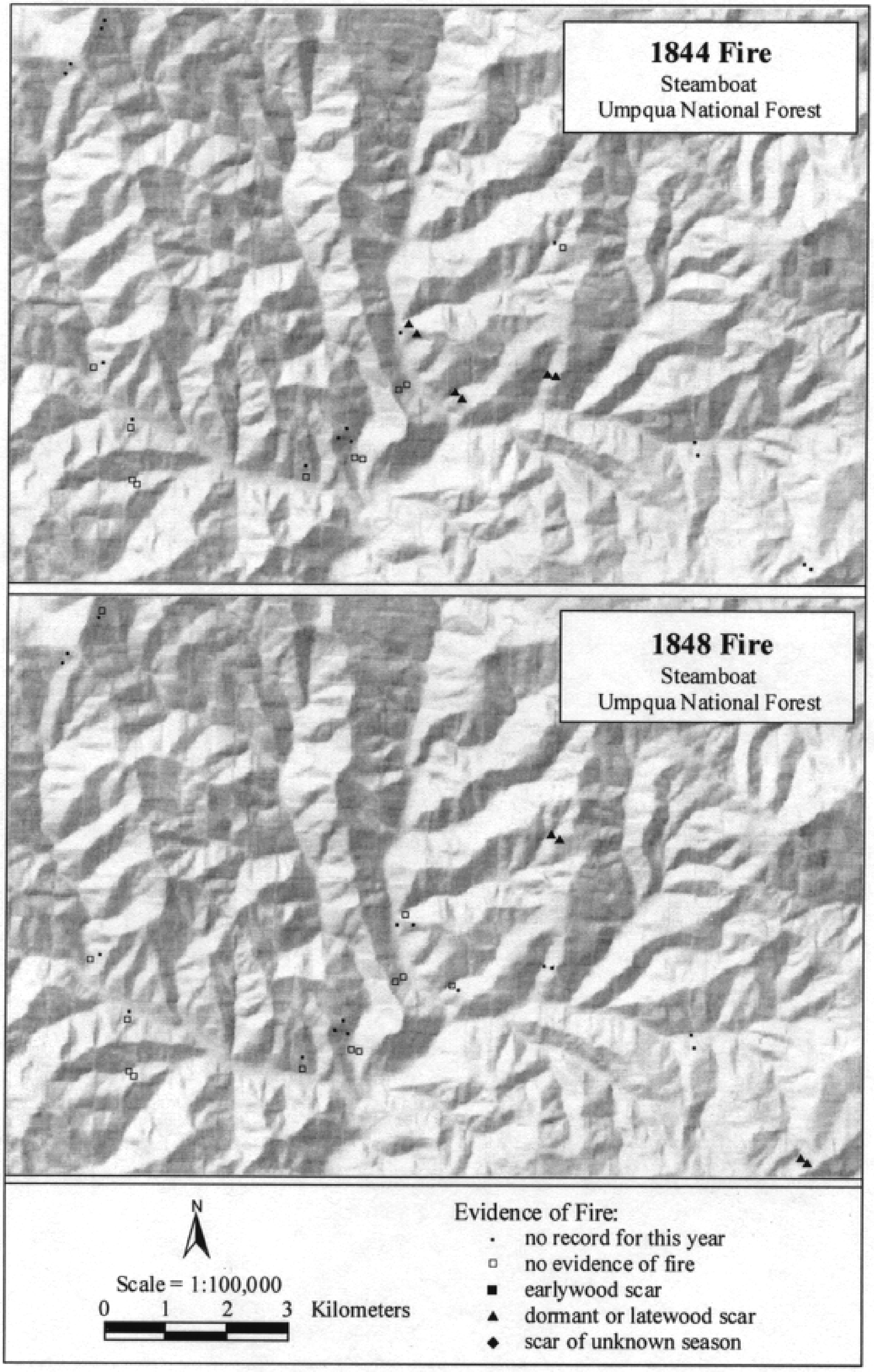

Figure 167. Steamboat fire maps for 1844 (top) and 1848 (bottom).

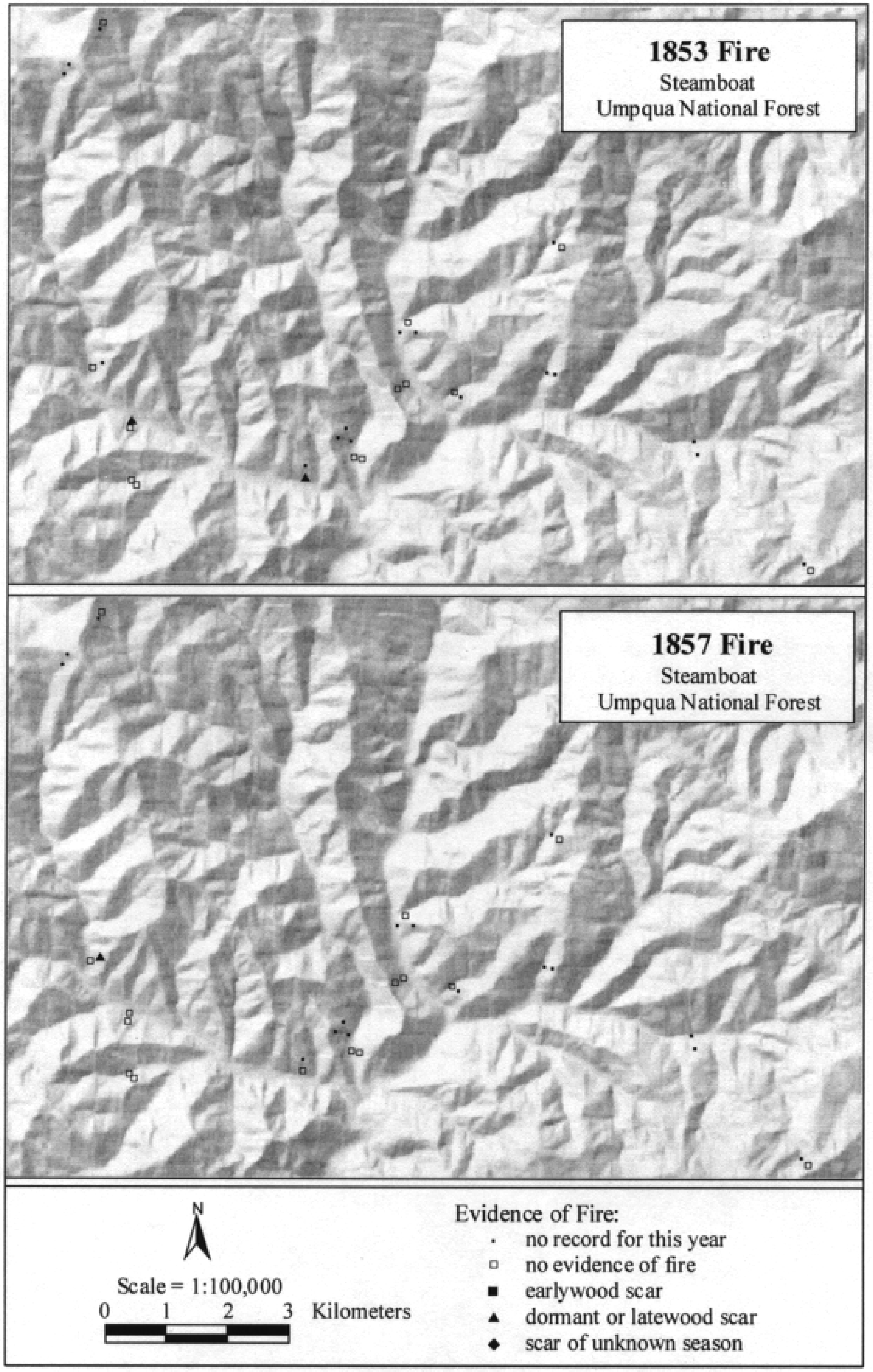

Figure 168. Steamboat fire maps for 1853 (top) and 1857 (bottom).

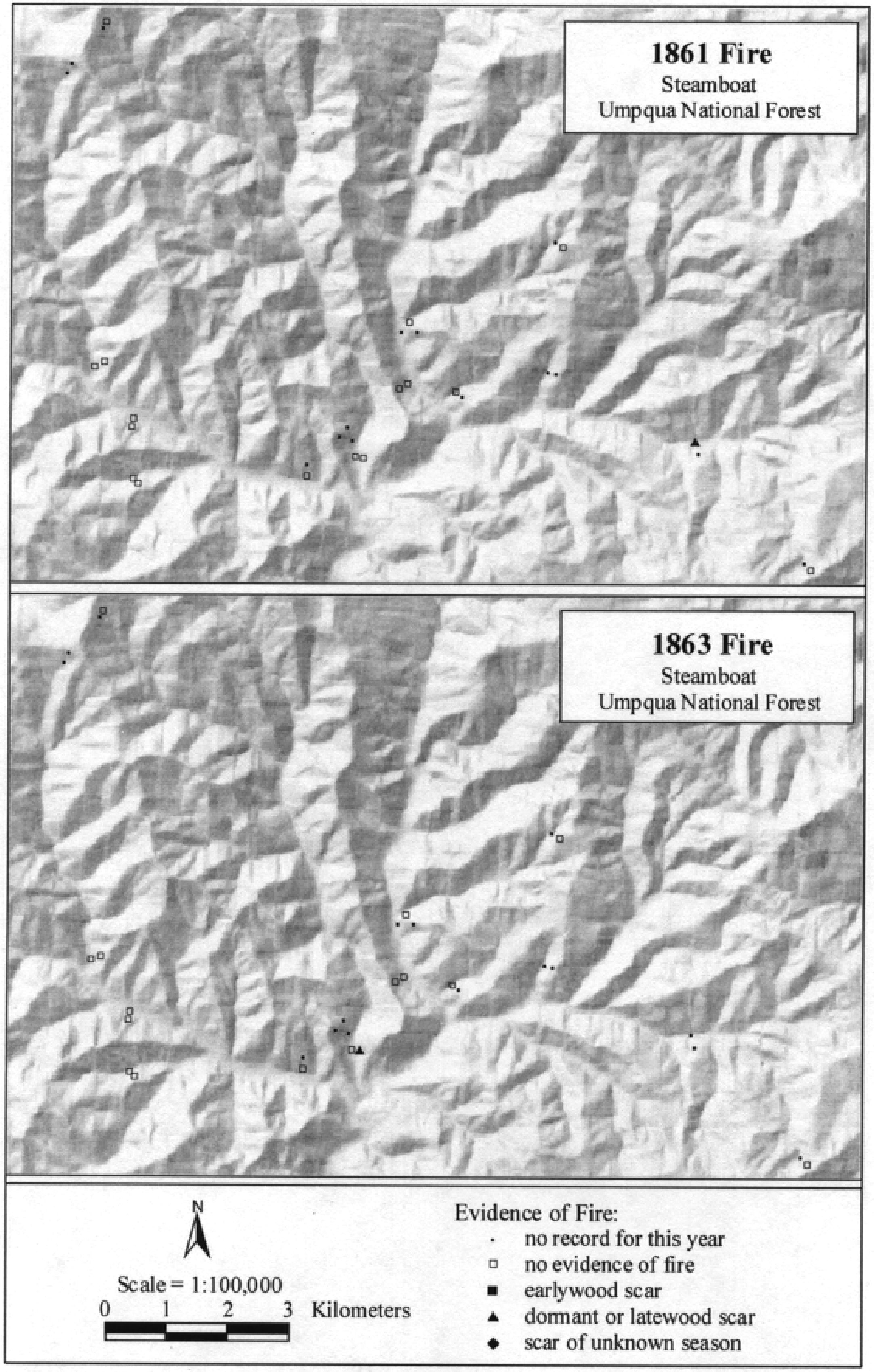

Figure 169. Steamboat fire maps for 1861 (top) and 1863 (bottom).

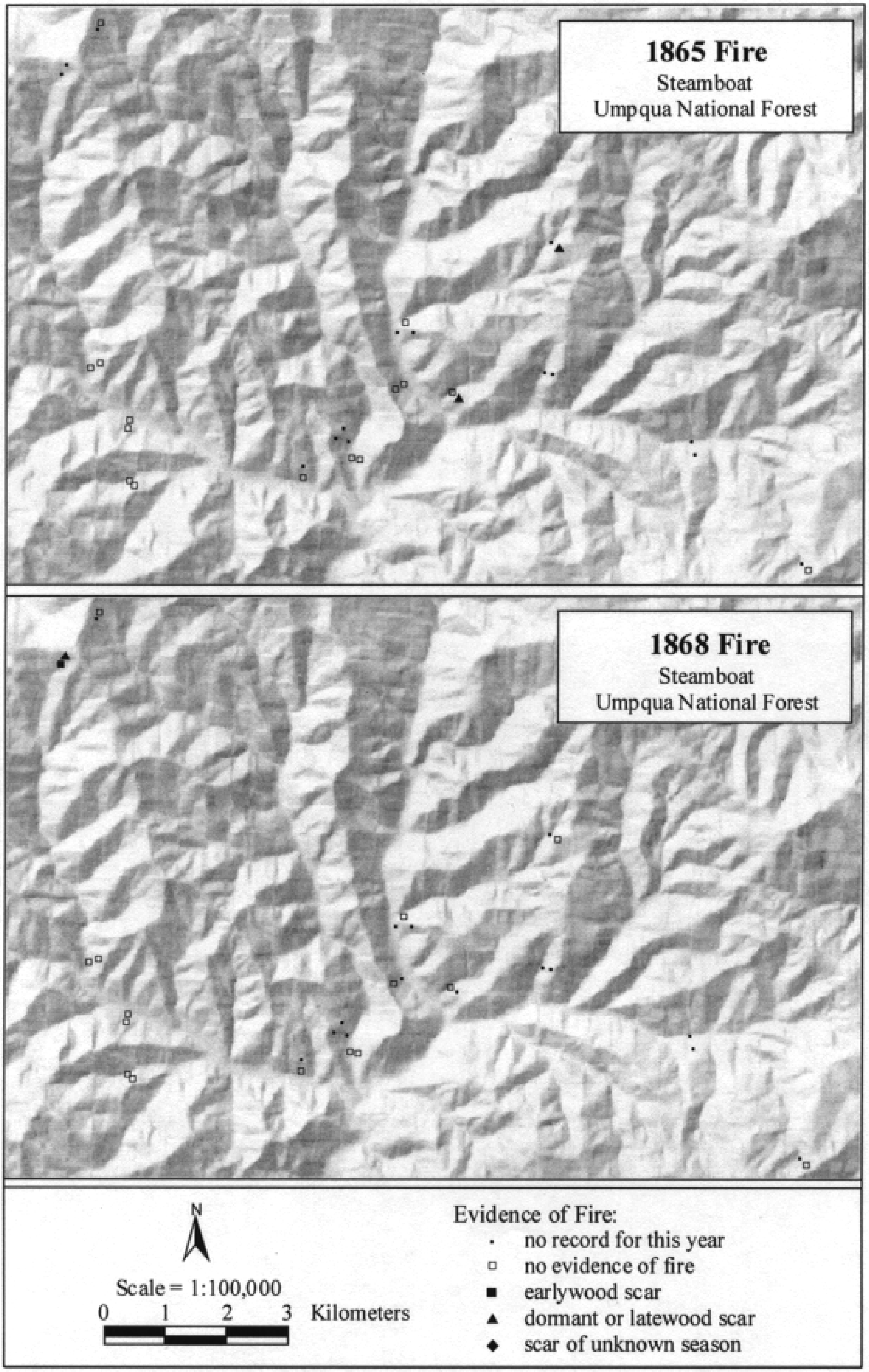

Figure 170. Steamboat fire maps for 1865 (top) and 1868 (bottom).

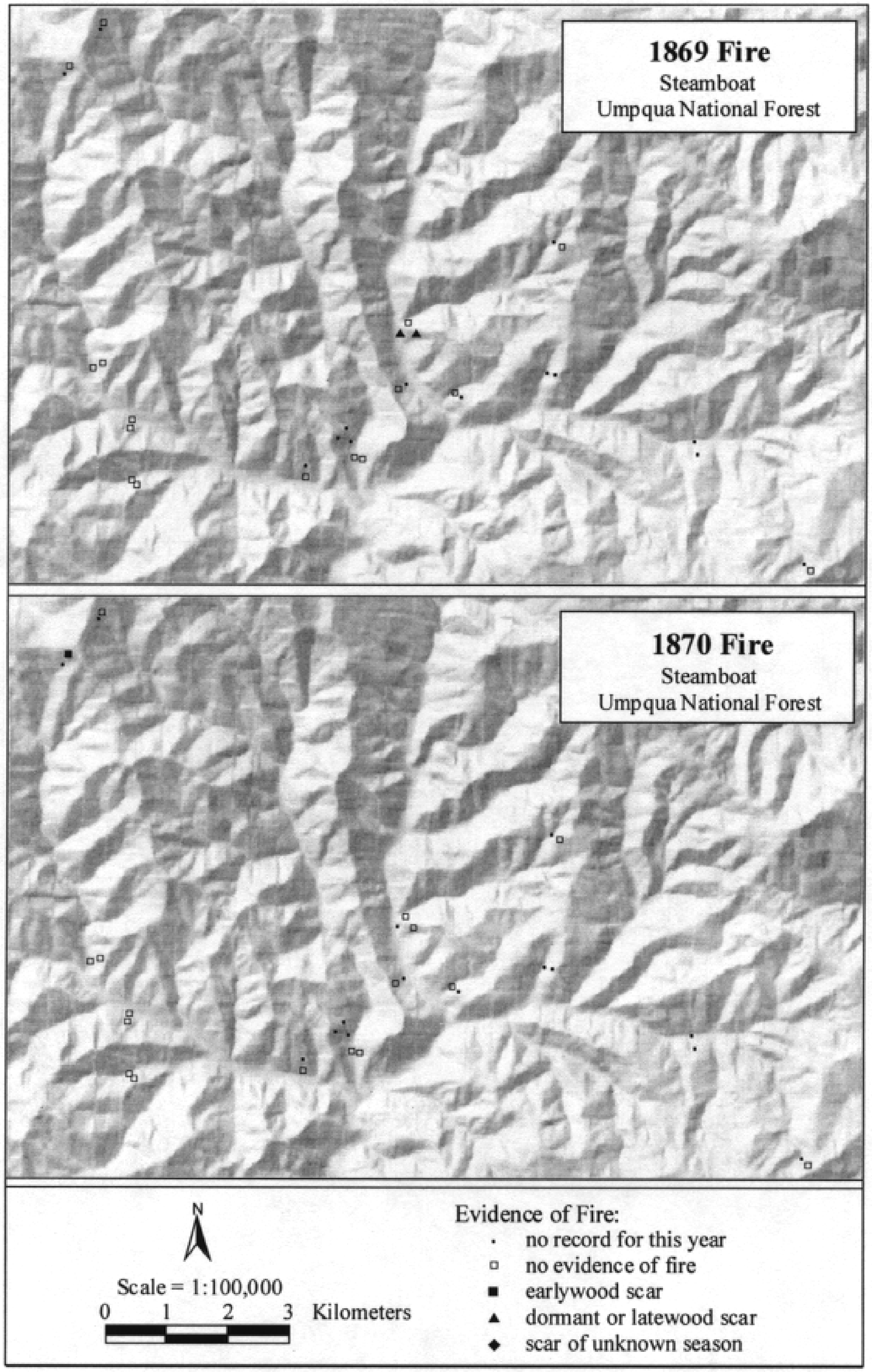

Figure 171. Steamboat fire maps for 1869 (top) and 1870 (bottom).

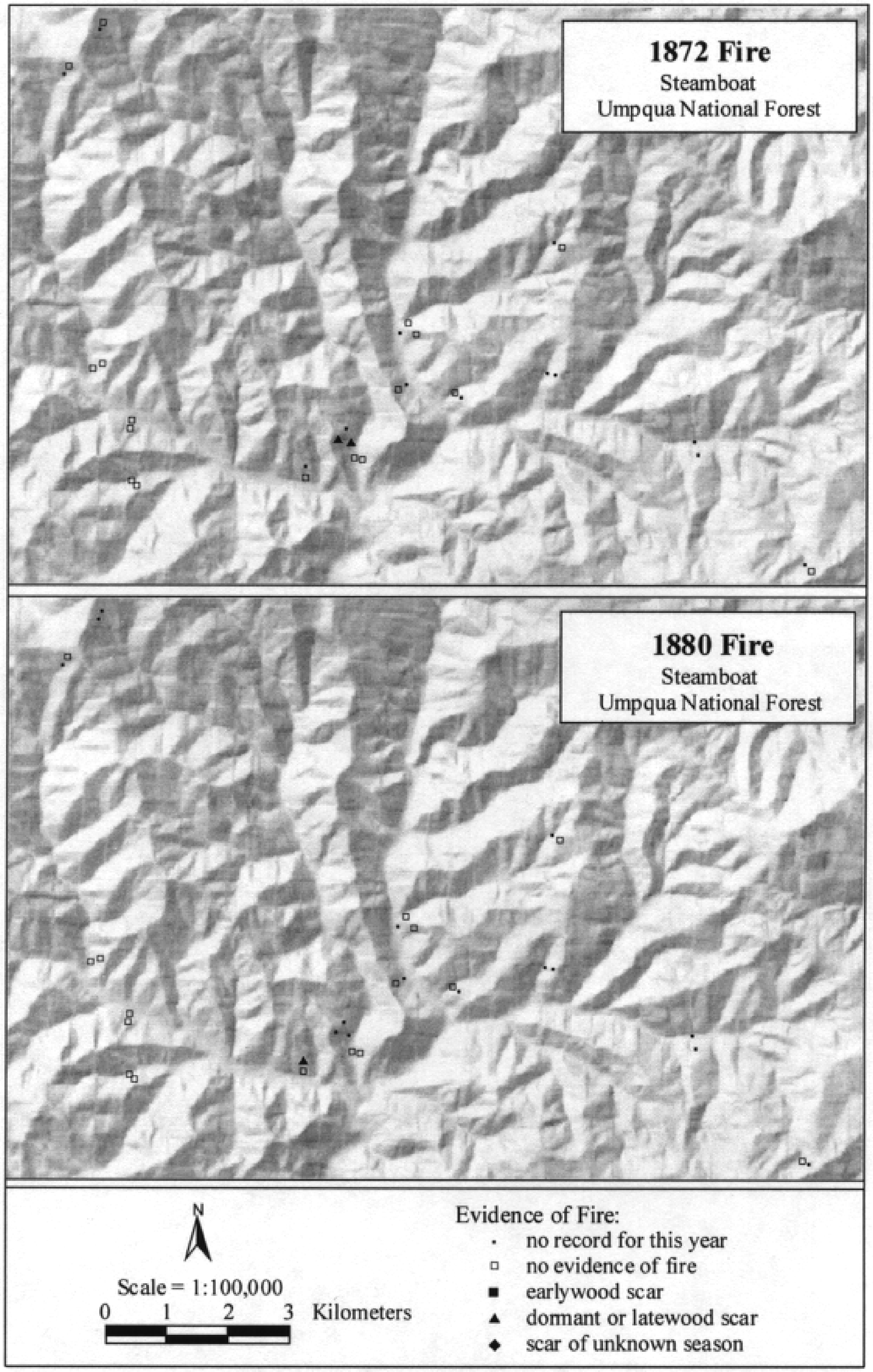

Figure 172. Steamboat fire maps for 1872 (top) and 1880 (bottom).

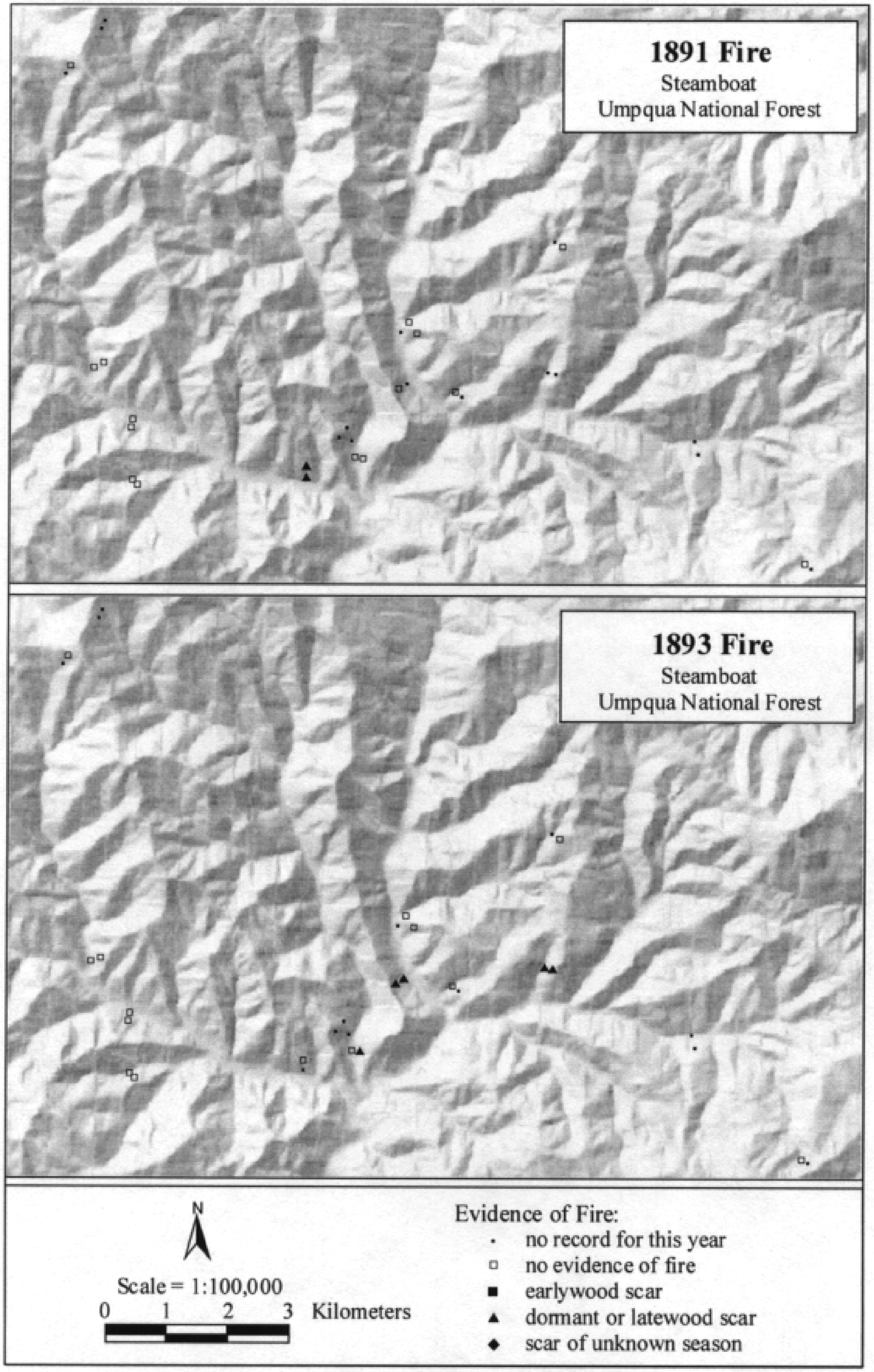

Figure 173. Steamboat fire maps for 1891 (top) and 1883 (bottom).

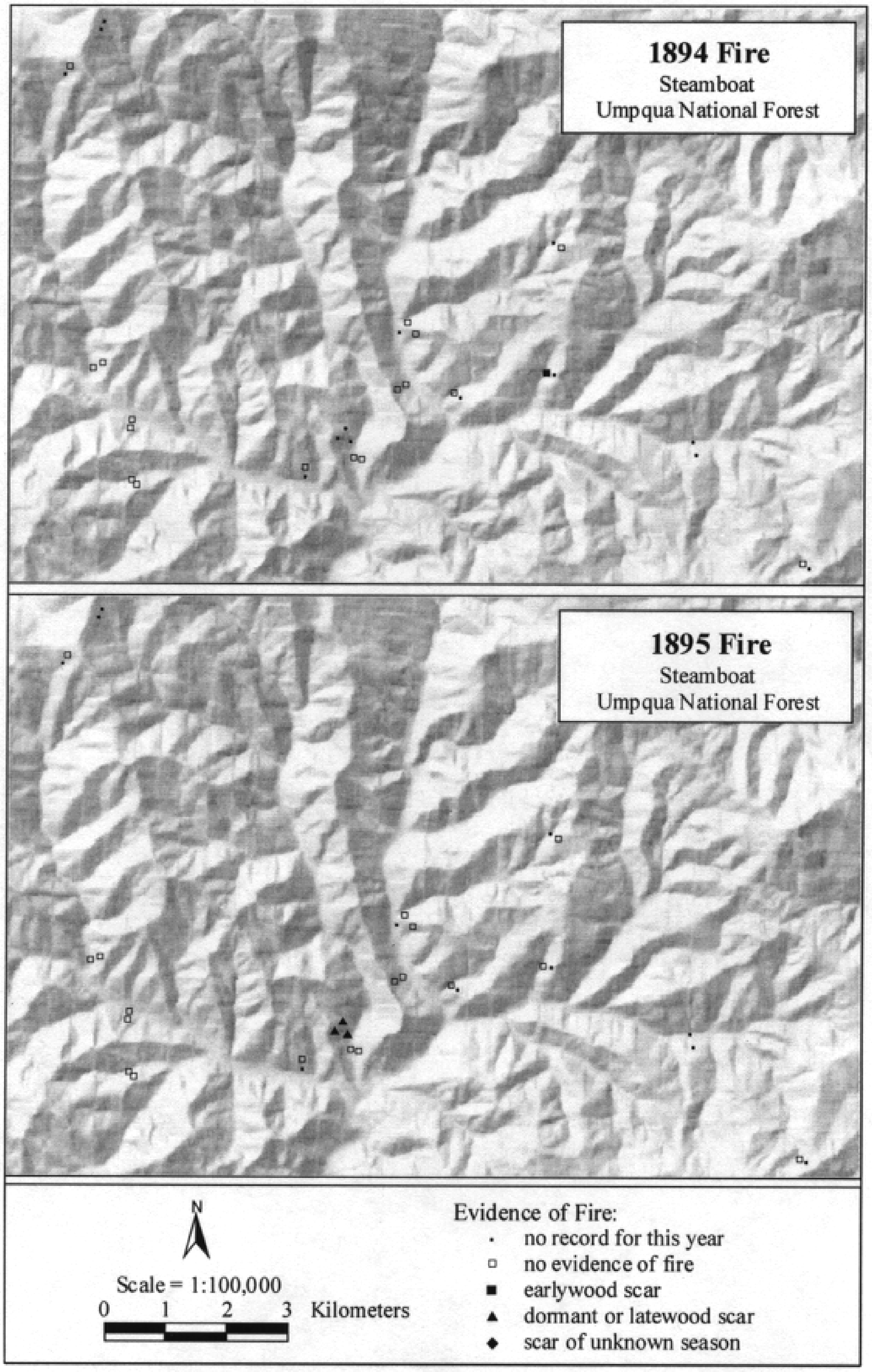

Figure 174. Steamboat fire maps for 1894 (top) and 1895 (bottom).

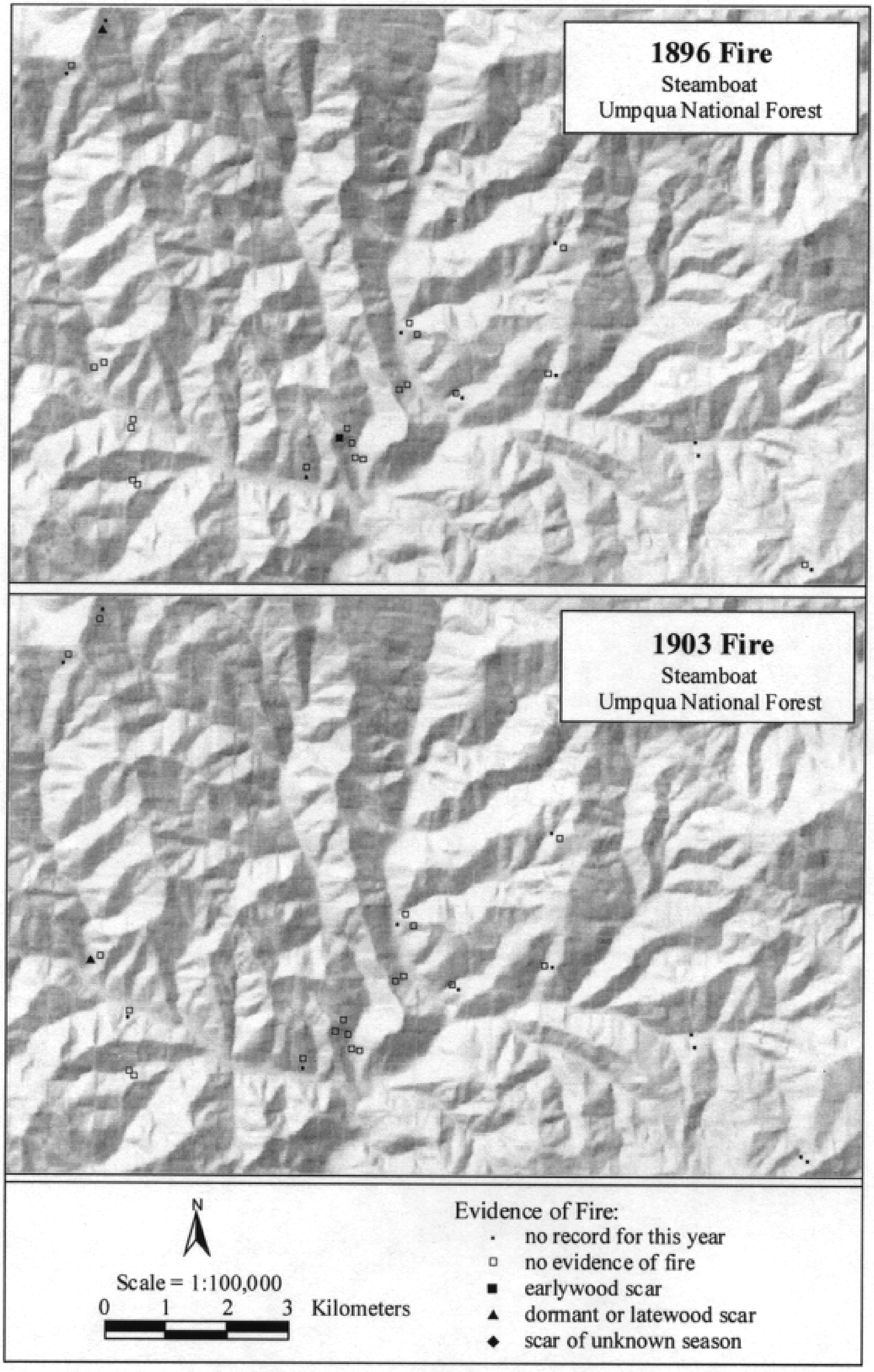

Figure 175. Steamboat fire maps for 1896 (top) and 1903 (bottom).

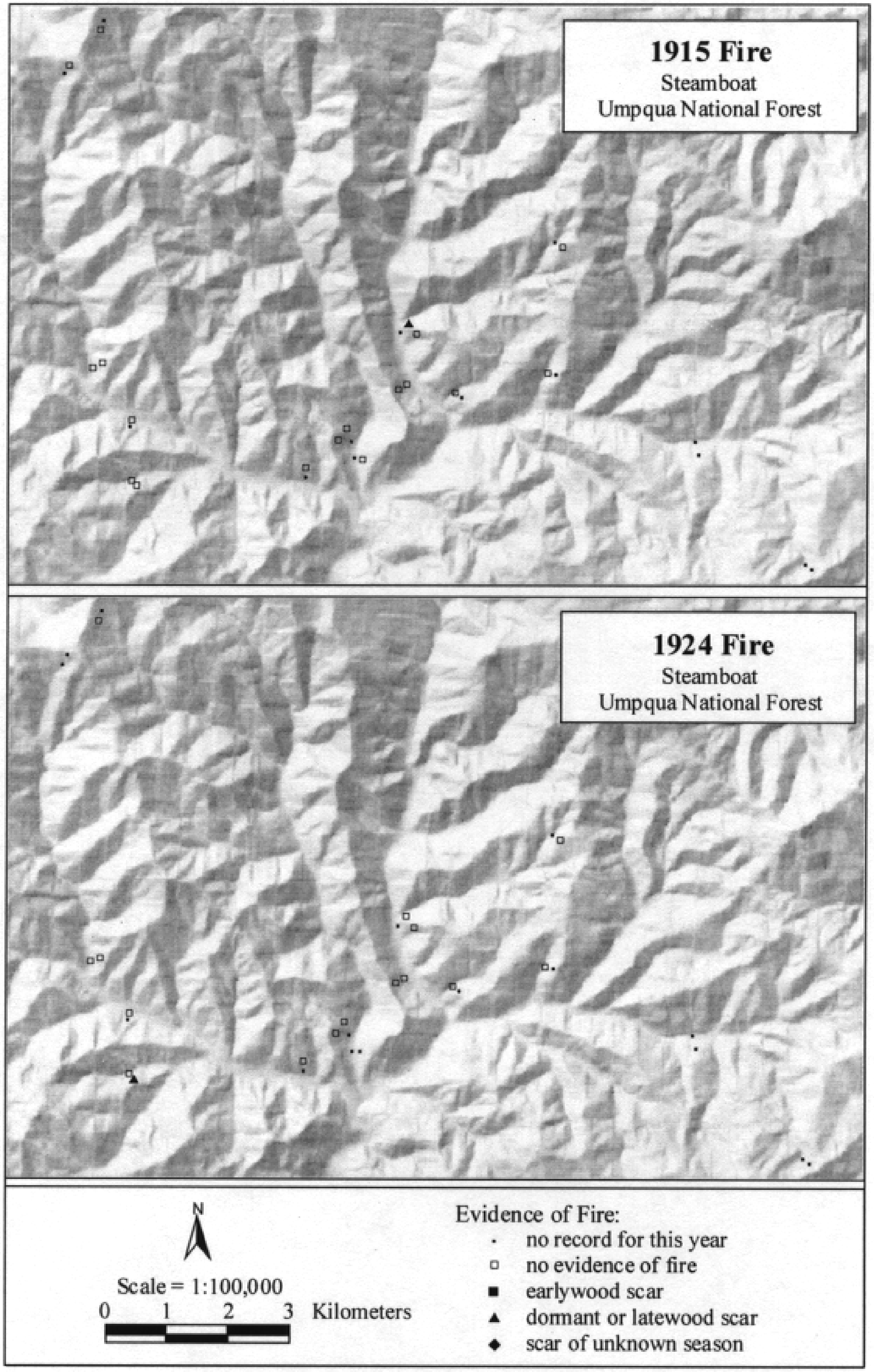

Figure 176. Steamboat fire maps for 1915 (top) and 1924 (bottom).

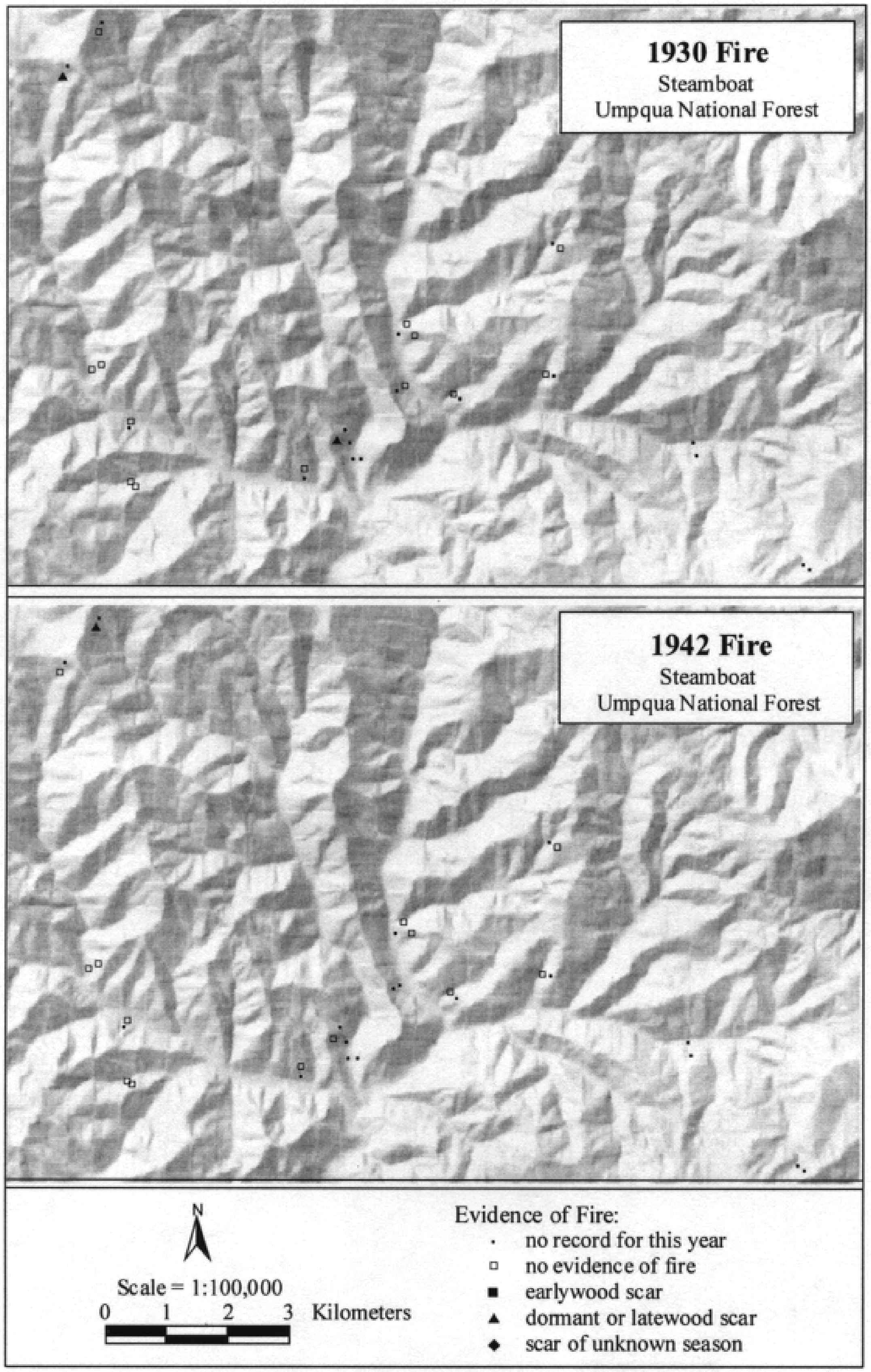

Figure 177. Steamboat fire maps for 1930 (top) and 1942 (bottom).

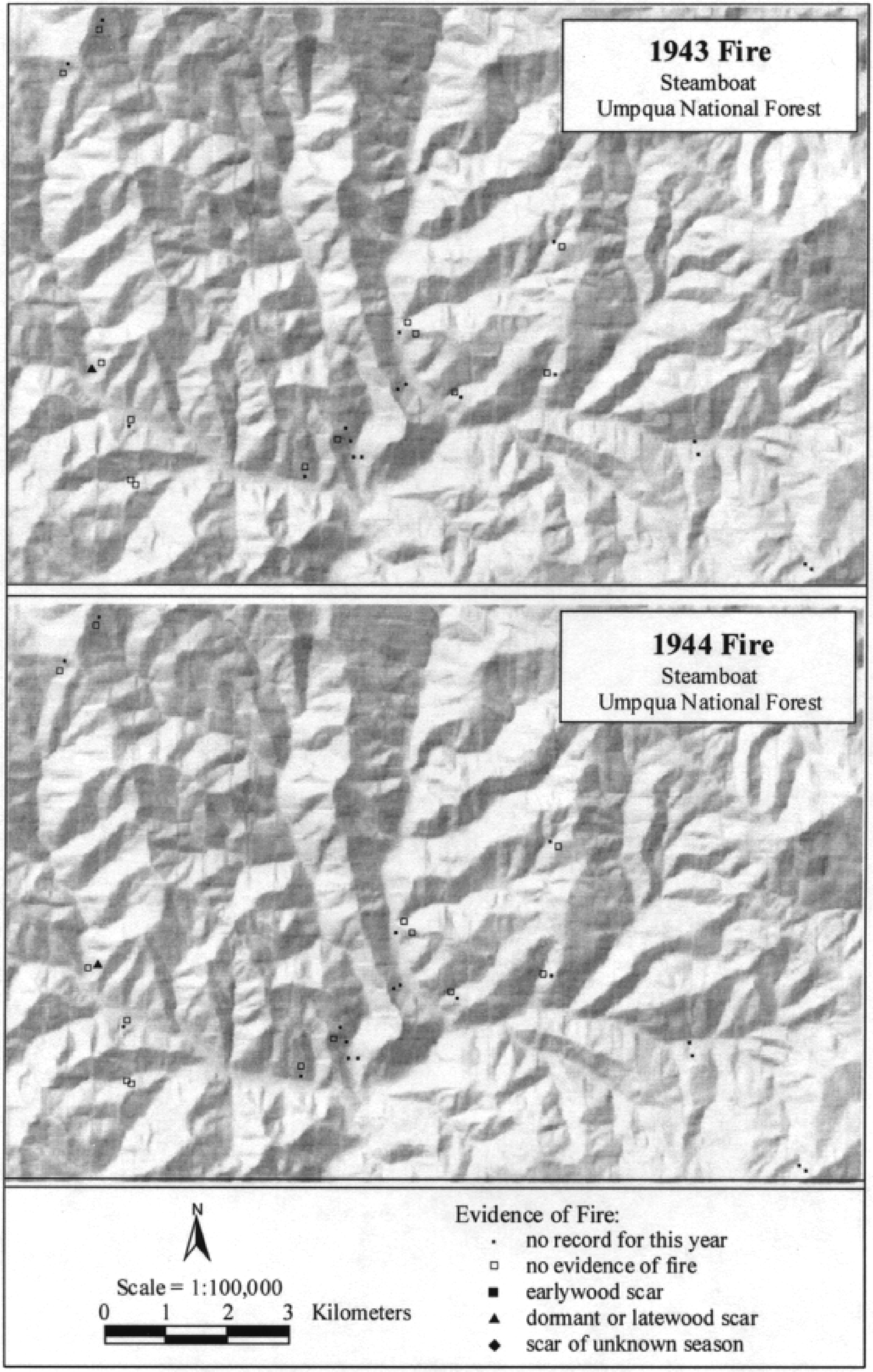

Figure 178. Steamboat fire maps for 1943 (top) and 1944 (bottom).

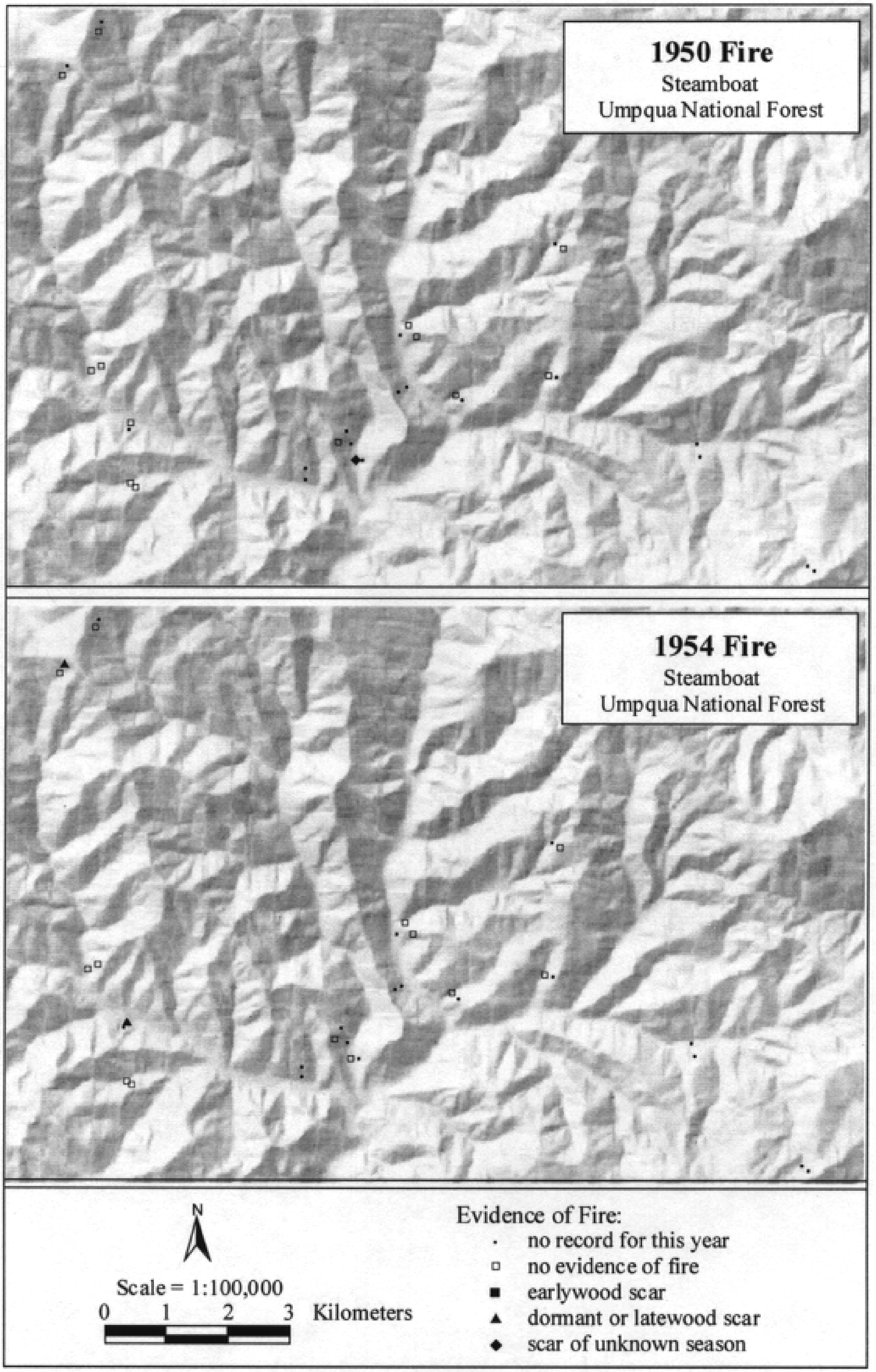

Figure 179. Steamboat fire maps for 1950 (top) and 1954 (bottom).

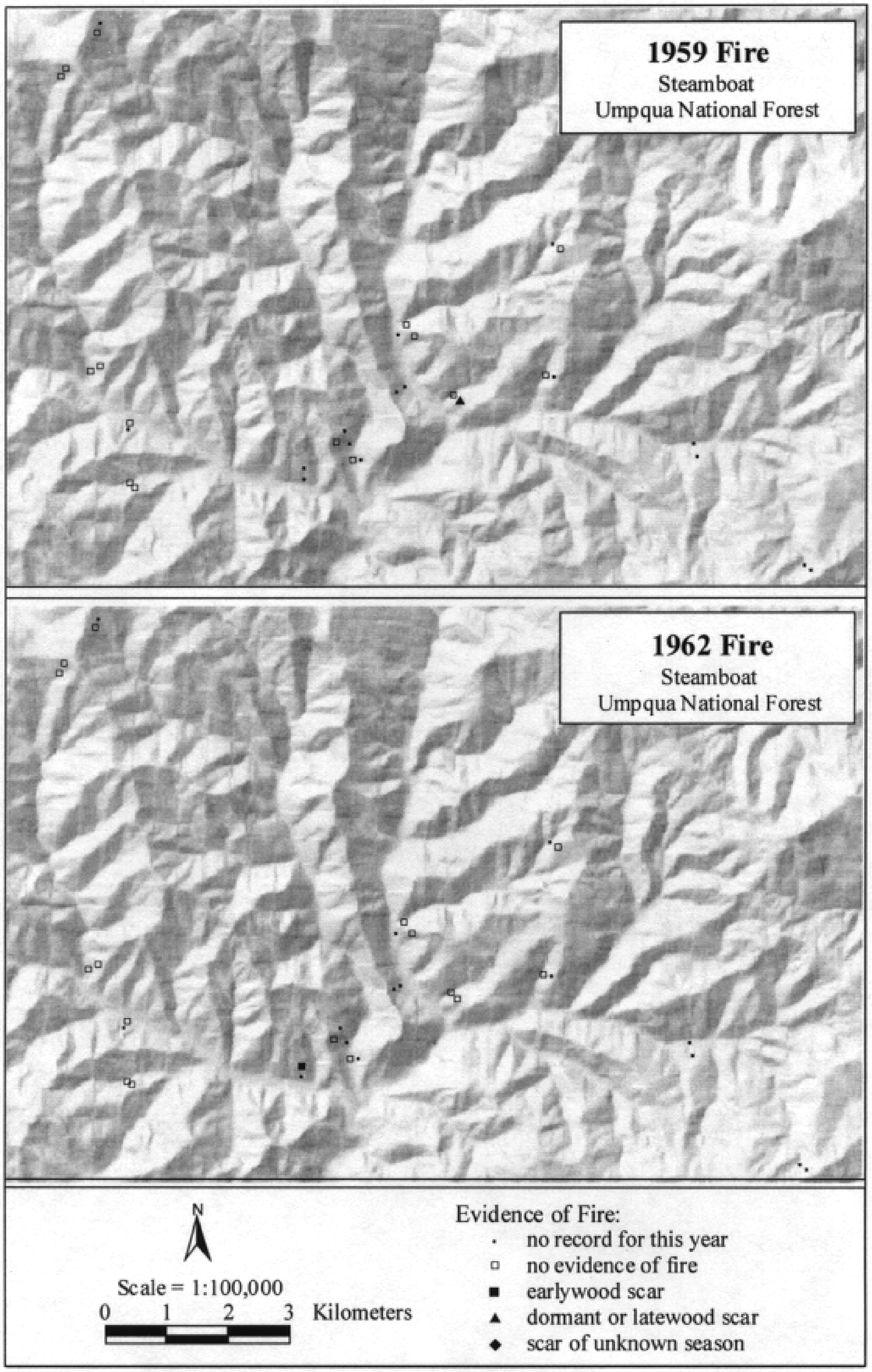

Figure 180. Steamboat fire maps for 1959 (top) and 1962 (bottom).

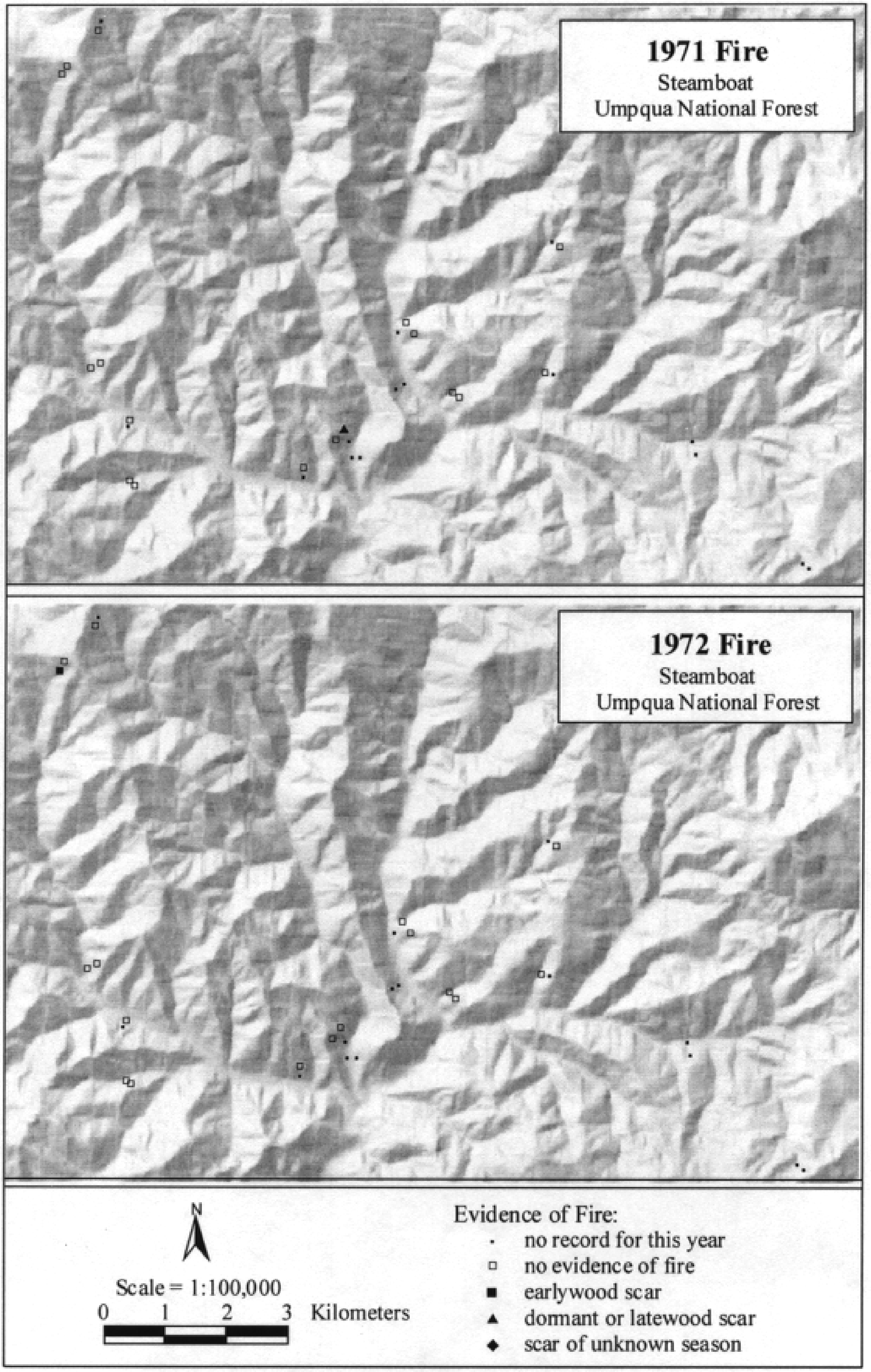

Figure 181. Steamboat fire maps for 1971 (top) and 1972 (bottom).

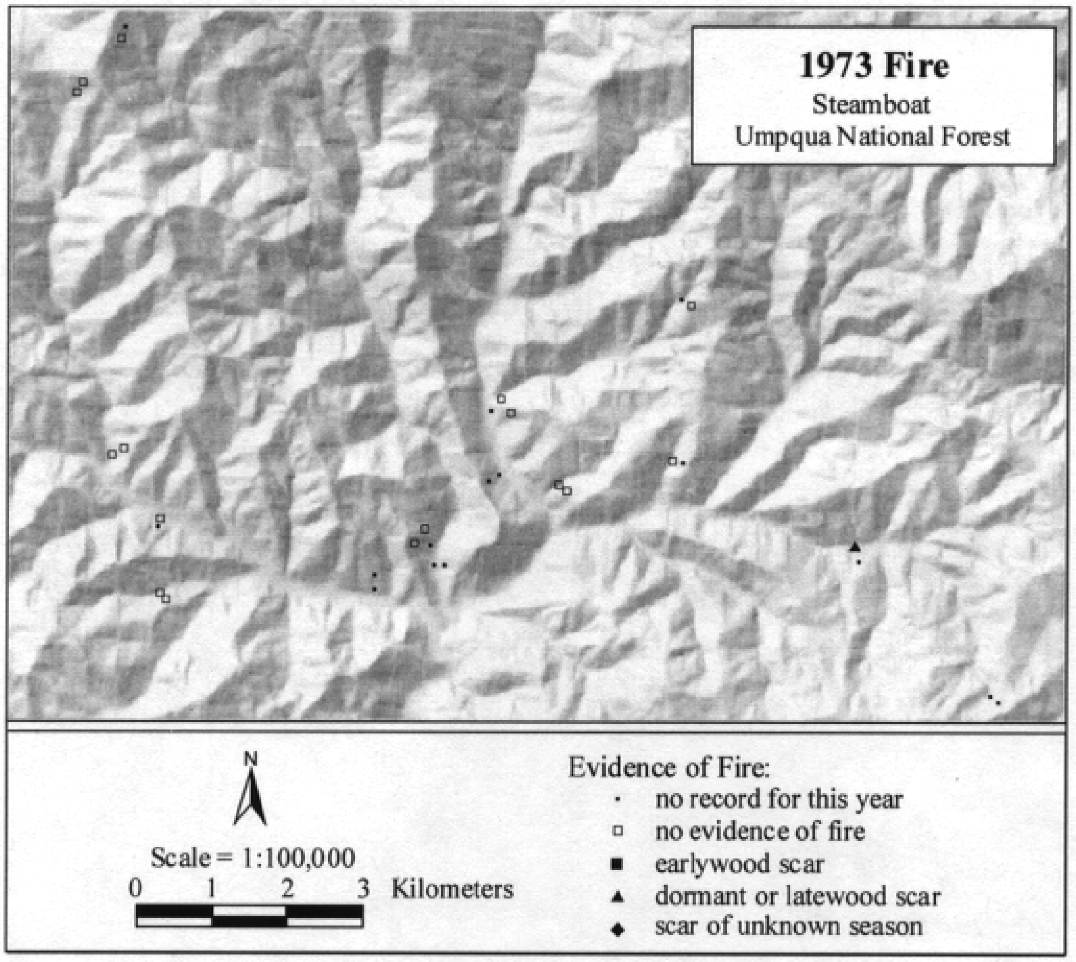

Figure 182. Steamboat fire map for 1973.