# 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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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 19$^{th}$ century, increasing large-scale timber harvest throughout the 20$^{th}$ century and, perhaps most notably, a policy of fire suppression since the first decade of the 20$^{th}$ 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).

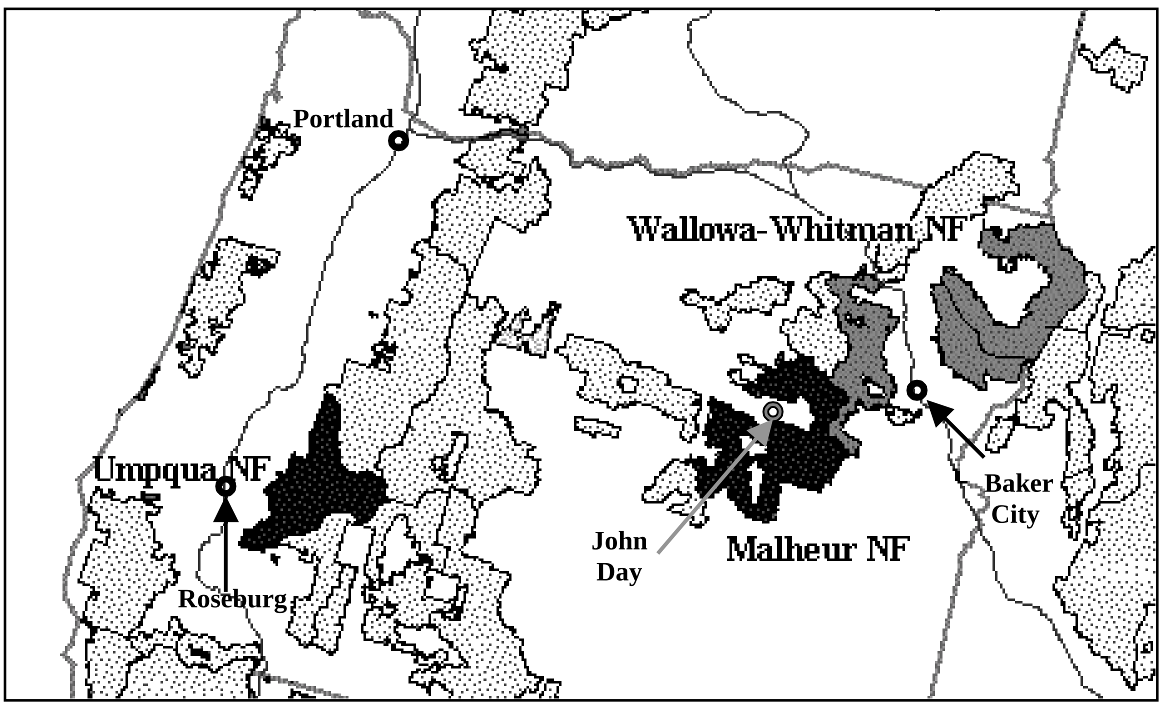


Figure 1. Locations of the three national forests in Oregon containing the three study areas (map modified from USDA 2000a).

**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).

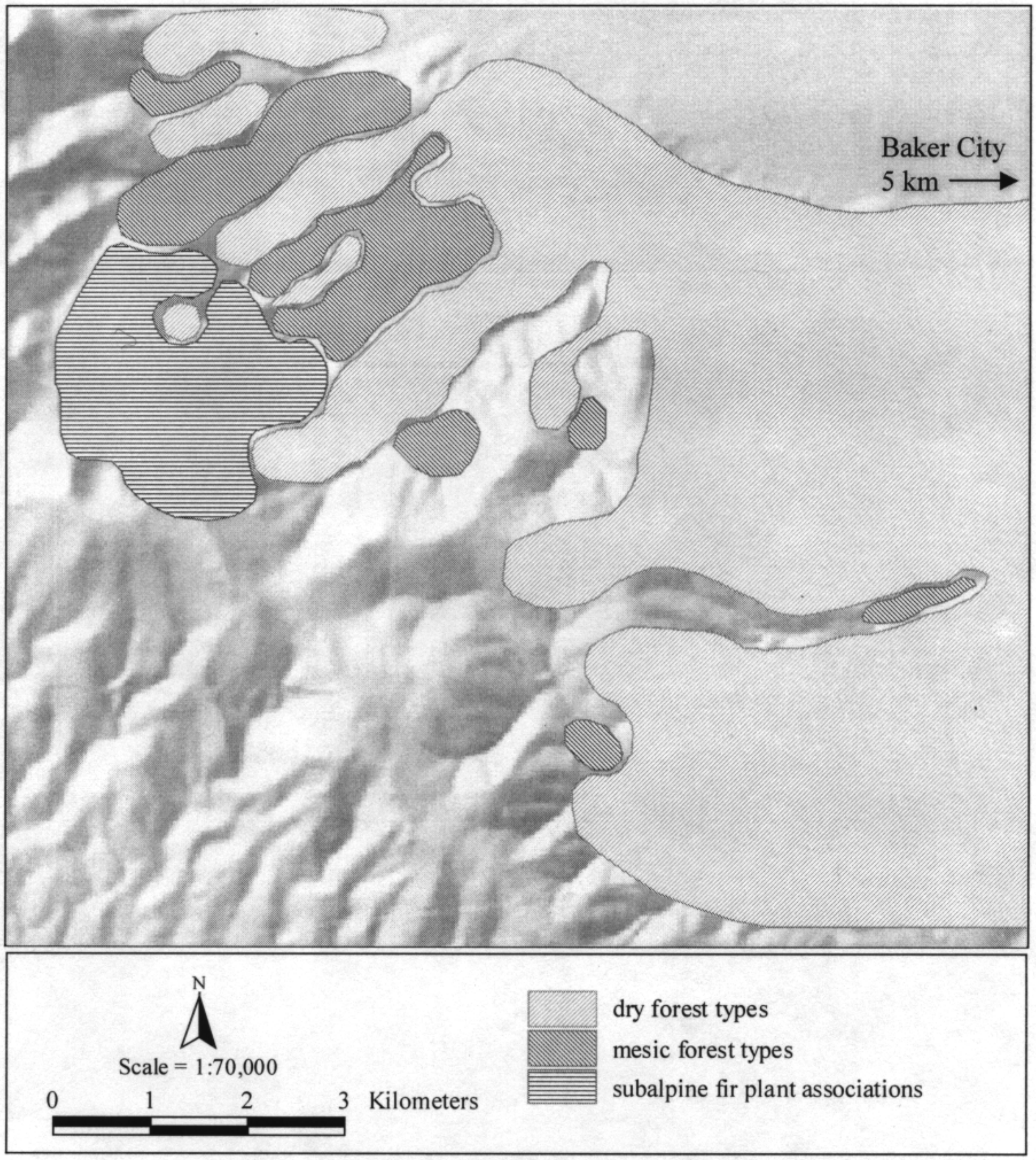


Figure 2. Approximate delineations of forest types for the Baker study area. Delineations were based on plant associations determined for each plot in this study and Heyerdahl (1997). Areas outside of the delineations did not contain any sampling plots.

**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.

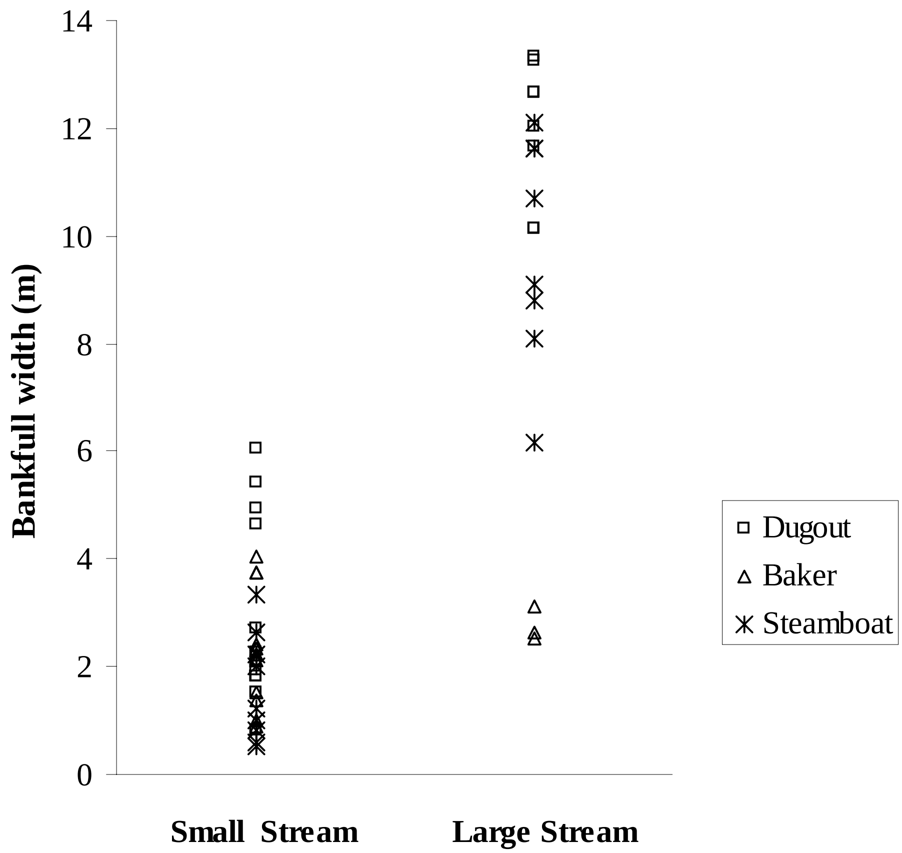


Figure 3. Bankfull widths categorized by stream size for all of the riparian plots in each of the three study areas.

**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.

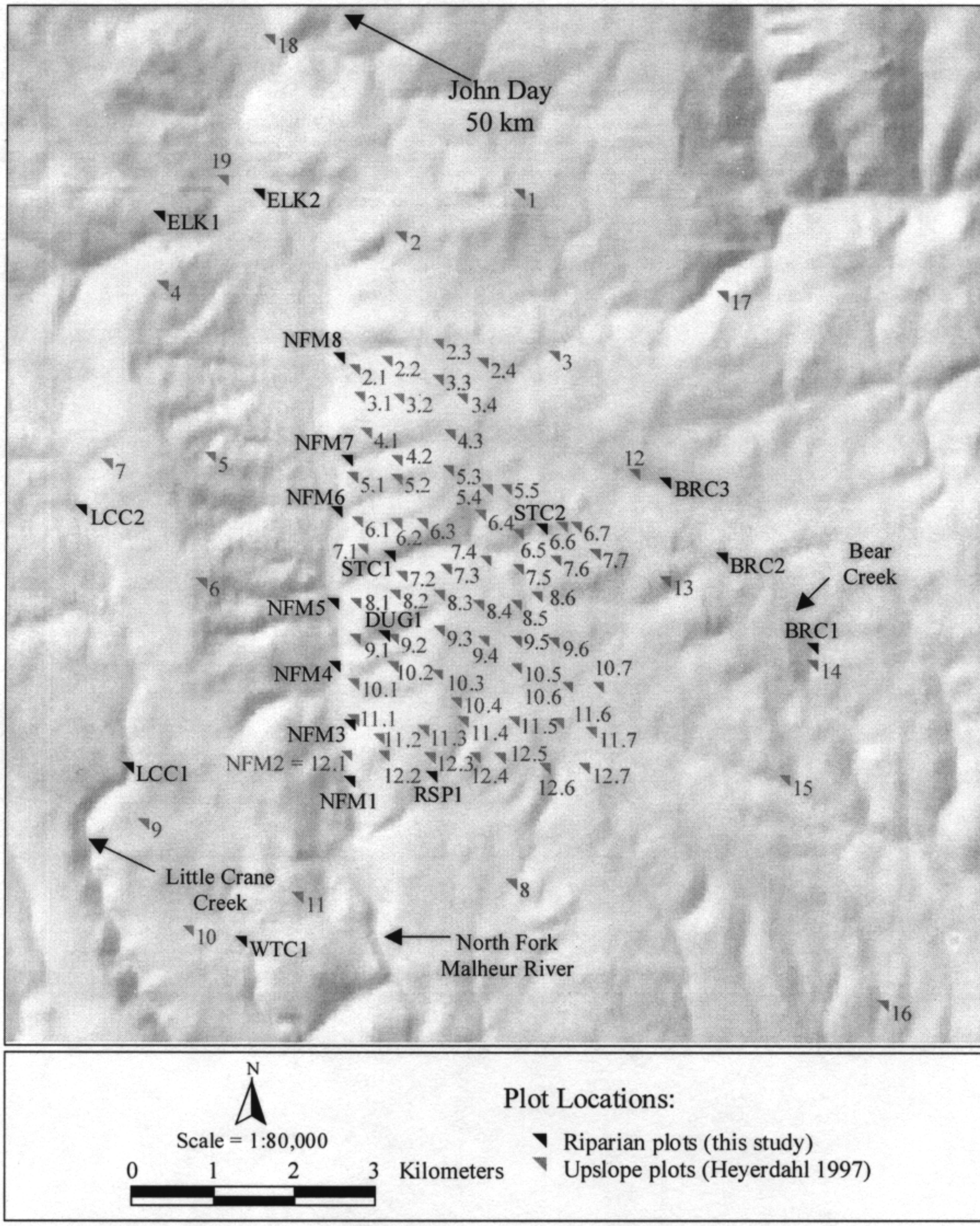


Figure 4. Plot locations for the Dugout study area, Malheur National Forest.

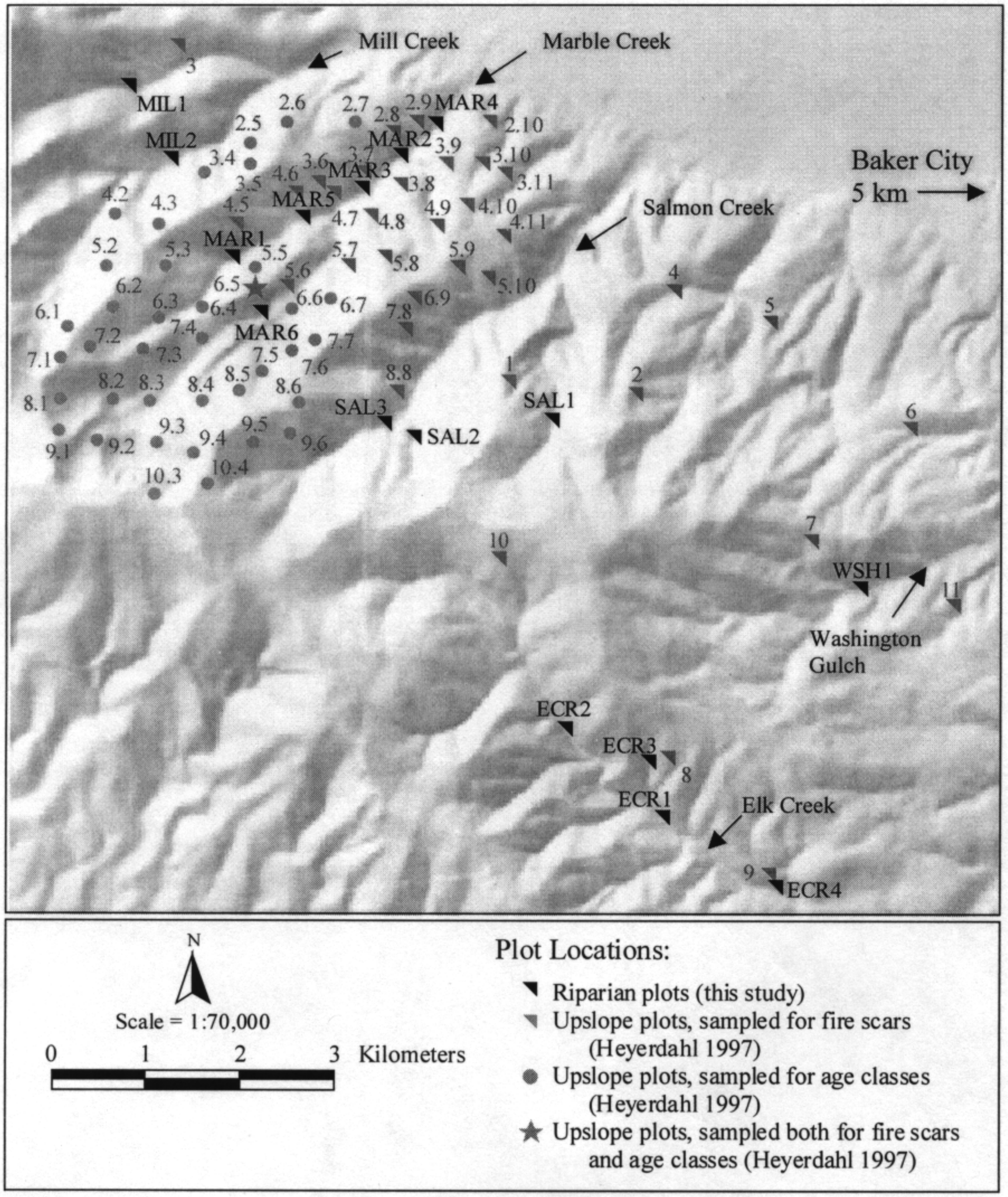


Figure 5. Plot locations for the Baker study area, Wallowa-Whitman National Forest.