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.

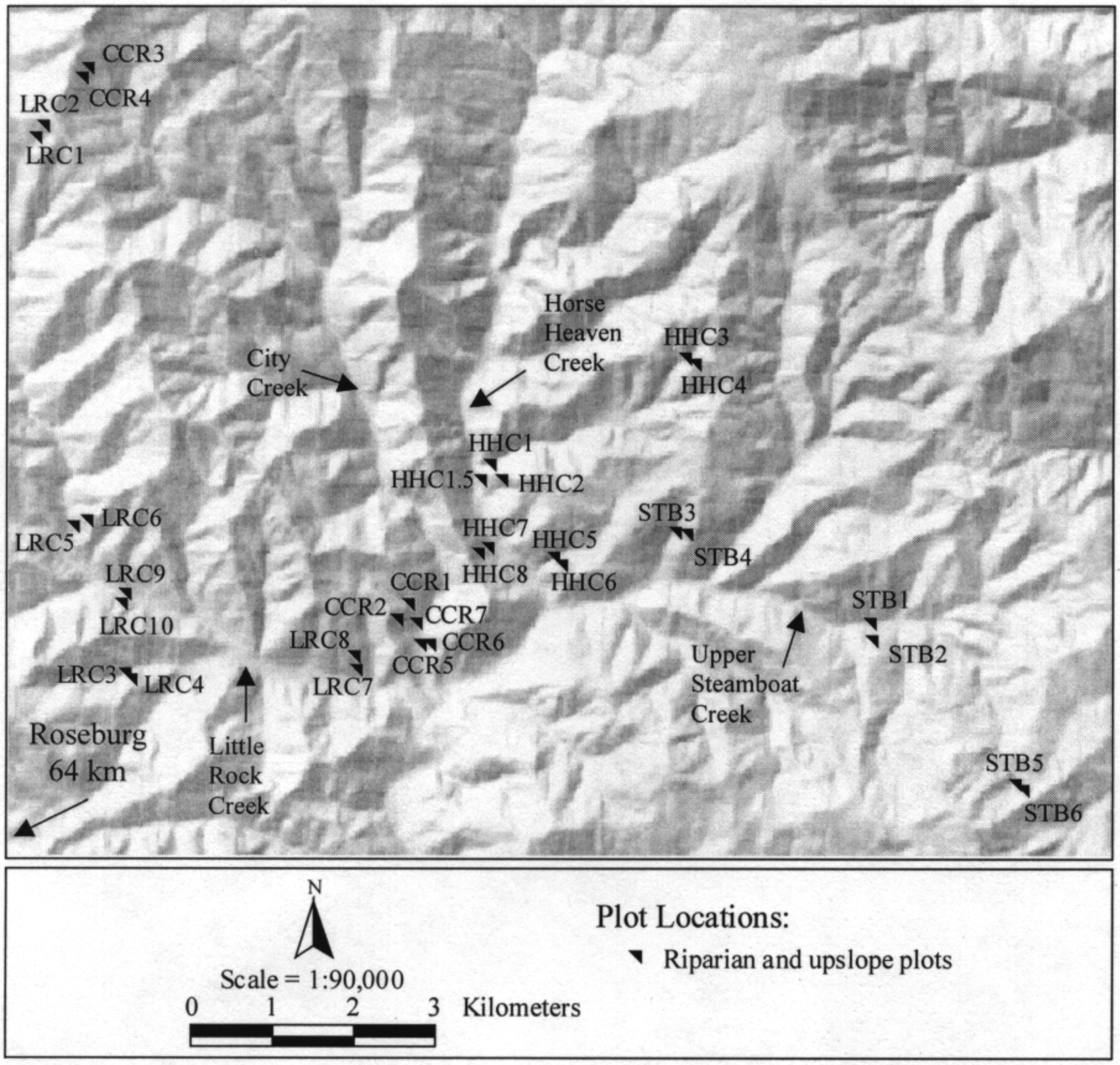

Figure 6. Plot locations for the Steamboat study area, Umpqua National Forest.

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.

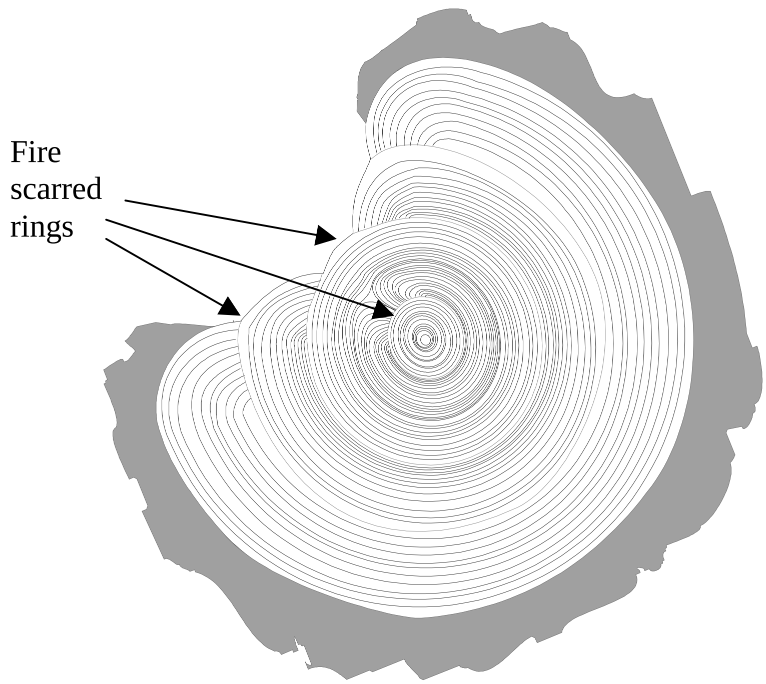

Figure 7. Schematic of the cross-section of a fire scarred tree (graphic originally created by K. Maruoka, University of Washington fire lab).

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).

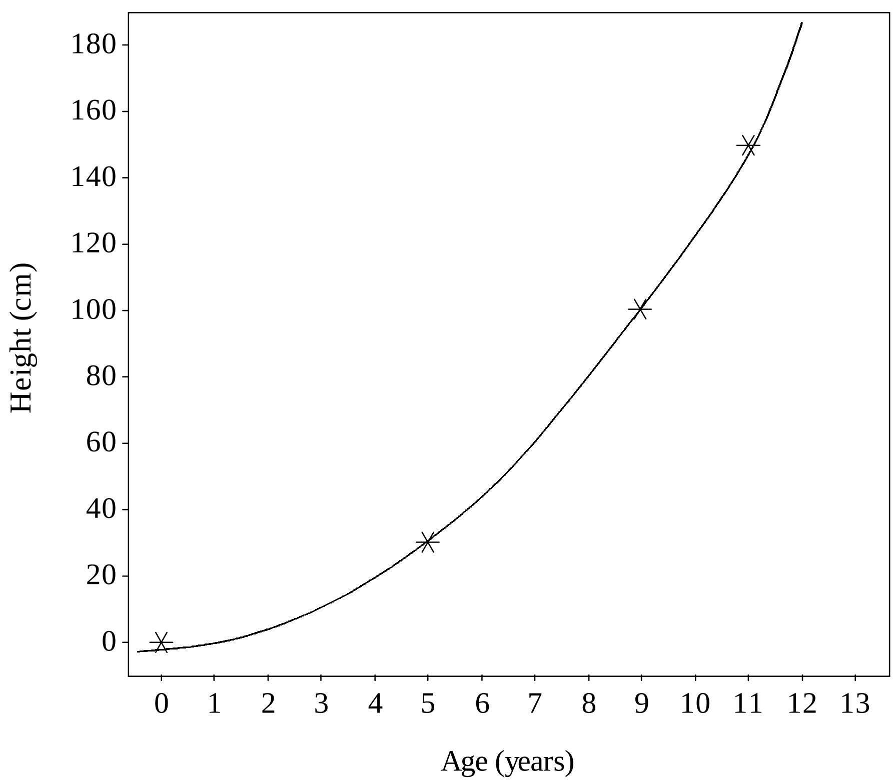

Figure 8. Age versus height curve for Douglas-fir, extrapolated from McArdle and Meyer (1930).

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 43rd and 48th 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).

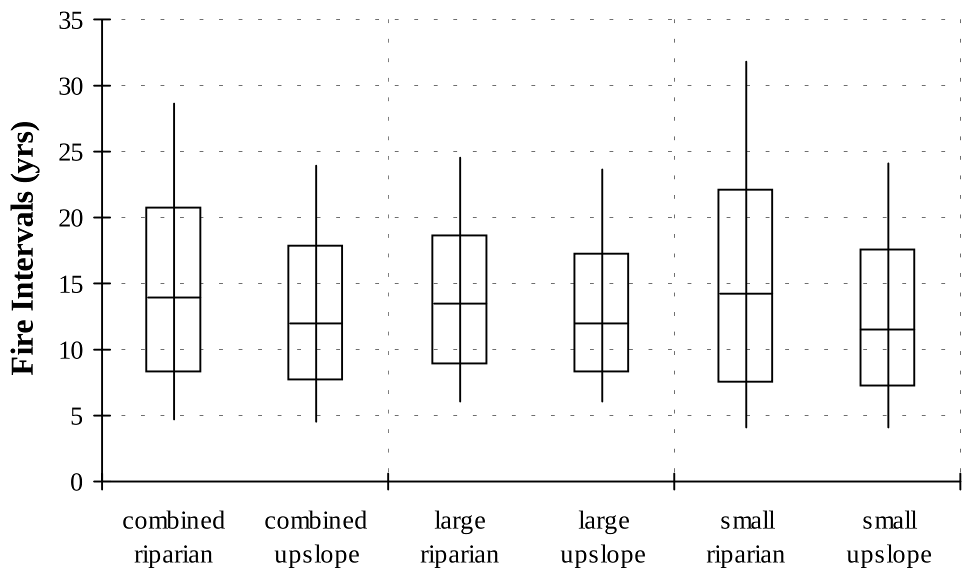

Figure 9. Fire return interval ranges for combined riparian and combined upslope plot categories, large stream riparian and upslope plot categories, and small stream riparian and upslope plot categories, Dugout. Box plots represent, from top to bottom: 90th percentile and 75th percentile exceedance levels, 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.

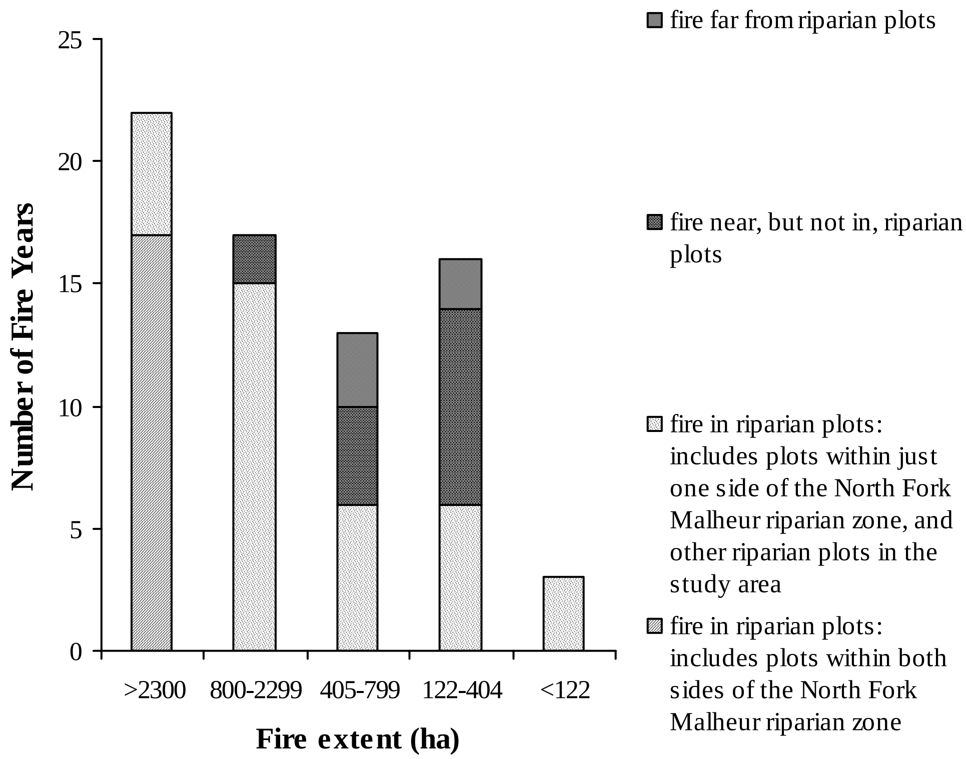

Figure 10. Number of fires that burned in Dugout riparian plots, categorized by fire extent size classes and the location of the riparian plot relative to the North Fork of the Malheur river.

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.

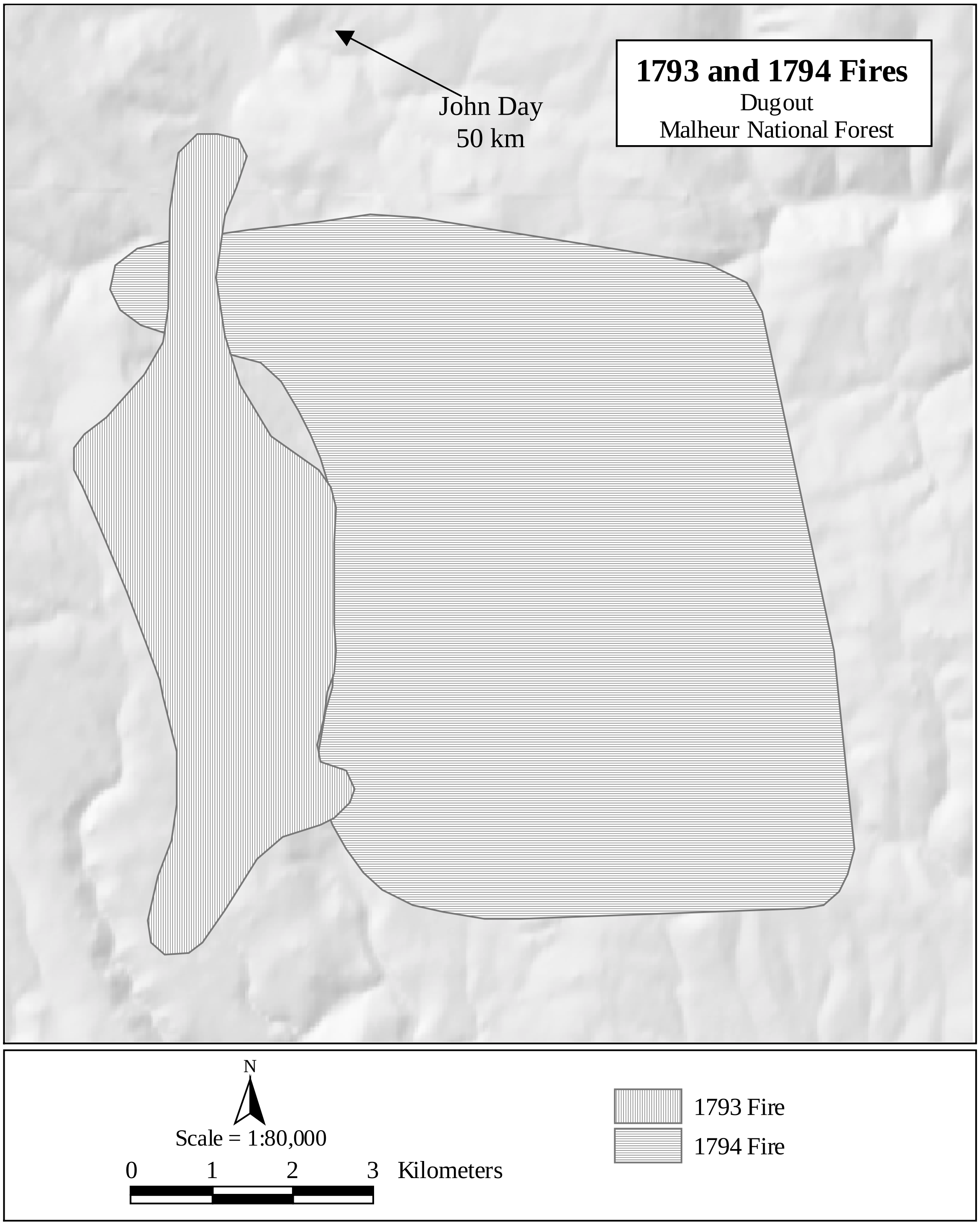

Figure 11. Map of 1793 and 1794 fires, Dugout.

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.