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Continuity in Fire Disturbance Between Riparian and Adjacent Sideslopes in the Douglas-fir Forest Series

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Abstract: Fire scar and stand cohort records were used to estimate the number and timing of fire disturbance events that impacted riparian and adjacent sideslope forests in the Douglas-fir series. Data were gathered from 49 stream segments on 24 separate streams on the east slope of the Washington Cascade Range. Upslope forests had more traceable disturbance events than riparian forests in each of the valley types with a mean difference of 8 to 62 %. Approximately 55 to 73% of the total traceable fire disturbance for a stream segment occurred on either sideslope and 24 to 27 % in the riparian forest. Plant association groups in the riparian forest had 25 to 42% fewer fire disturbance events than the same plant associations upslope. Fewer traceable disturbance events in riparian forest may indicate a reduced disturbance frequency or a more severe disturbance regime or both. Shared fire events between the two sideslopes (65% east/west, 54% north/south) on either side of the riparian and riparian fire events shared with sideslope forests (58 to 79 % among valley types, 64 to 76 %, among aspects) suggests significant continuity in fire disturbance between sideslope and adjacent riparian forests. Fire disturbance regimes of sideslope and riparian forests are quantitatively different, but interconnected through shared fire disturbance events. Disturbance events play a role in maintaining ecosystem integrity and we suggest that disturbance may need to be planned for in administratively defined riparian buffer strips (USDA-USDI [FEMAT] 1993) to protect long-term ecological integrity of riparian and adjacent upslope forests.

INTRODUCTION

Land management and regulatory agencies seek to maintain riparian conditions through the establishment of stream buffers (USDA-USDI [PACFSH] 1994). Stream buffer management needs to consider current scientific theory that views riparian forests as corridors of disturbance. "Management of riparian forests must take into consideration the types of disturbance that typically affect these forests" (Agee 1988:38). "These (riparian) ecosystems are formed and maintained by natural disturbances which serve to contribute resources (woody debris, spawning gravel) to riparian and instream habitat" (Knutson and Nae 1997:38). The need to protect eastern Washington riparian and instream habitat from excessive human disturbance is well documented (McIntosh et al. 1994). However, riparian management strategies should not significantly alter the inherent disturbance regimes and patch dynamics of either the riparian or sideslope forests if ecosystem integrity is to be restored or maintained.Ecosystem response to fire suppression has been described at the landscape scale for forests in eastern Washington (Agee 1993, 1994). The absence of fire has increased fuel loadings and continuity of fuels such that episodic fire events are extensive and severe (Everett et al. 1996). Water flow and sediment transport significantly increase following severe fire events (Wissmar et al. 1994). "The increased dynamics of stream channels that result from these more frequent, intense fires increase riparian habitat dynamics beyond natural levels" (Knutson and Nae 1997:51).

Historical riparian disturbances on the east slope of the Cascades were of such extent and frequency that only small patches of old growth refugia occur at the confluence of streams or in headwall topography; with the majority of riparian forests in the grand-fir series in earlier successional stages (Camp et al. 1996). We do not know how much of this riparian patch dynamics is due to internal riparian disturbance or as a result of disturbance flow from adjacent sideslopes. Riparian areas are subject to water related disturbances not associated with sideslope forests as well as other shared disturbance events such as wind, insect, disease, and fire (Agee 1988). Hall (1988:9) states "We must learn to understand the magnitude of past natural fires, the extent of areas burned, the frequency of burning, and the impact these events may have had on the riverine riparian system."

Riparian forests exist within a matrix of sideslope forests and we do not yet understand the role riparian forests play in the propagation or suppression of fire disturbance on the landscape. Riparian areas with heavy fuel loading and fuel continuity may serve as conduits (disturbance corridors) for the rapid spread of fire (Agee 1993). Conversely, the more mesic riparian areas may serve as fire breaks in ground fires (Minnich 1977). The disturbance relationship between riparian and sideslope forests can be anticipated to change in different landforms and plant associations. Different landforms are associated with contrasting plant associations, and fire frequency and severity (Swanson 1978, Turner and Romme 1994).

Terrestrial and aquatic systems are intricately interconnected physically, chemically, and biologically (Bilby 1988). We know there are many feedback loops between riparian and sideslope forest systems but we do not understand how closely the fire disturbance regimes of riparian and sideslope forests are intertwined. If either sideslope or riparian forests are significantly altered through divergent land management practices, there may be a loss of continuity in disturbance across the landscape (Everett and Lehmkuhl 1999).

Information is needed on inherent fire disturbance regimes and patch dynamics of riparian and sideslope forests if ecosystem integrity is to be conserved. Information is needed on the shared disturbance regimes of riparian and sideslope forests to improve management guidelines for riparian area protection and the conservation of the matrix forest in which riparian forests reside. Until this information is available, we do not know the effects of the establishment and separate management of administrative riparian buffer zones.

We used the "disturbance corridor" view of riparian forests to generate our null hypotheses for the disturbance regimes of riparian and associated sideslope forests. Our null hypotheses included 1) the number of recorded fire disturbance events and stand cohorts is greater in riparian than adjacent sideslope forests, 2) there is no continuity in fire disturbance between riparian and sideslope forests, and 3) different disturbance regimes between riparian and sideslope forests provided different historical stand densities and amounts of current old trees (> 100 years). Rejecting these null hypotheses would support the case for the conservation of disturbance in riparian forests and for maintaining continuity in disturbance across riparian reserve boundaries. The need for integration of riparian buffer zones with the larger forest ecosystem in which they reside would become apparent.

METHODS

Description of Study Areas

All field data for this study were collected within the Douglas-fir (*Pseudotsuga menziesii*, PSME) or ponderosa pine (*Pinus ponderosa*, PIPO) forest series on the east slope of the Washington Cascades. Vegetation at each sample point was within one of five Douglas-fir plant association groups (Lillybridge et al. 1995). The plant association groups reflect climatic variants within the Douglas-fir series and are characterized by specific understory species: cool dry grass [CDG] (pinegrass, *Calamagrostis rubescens* or elk sedge, *Carex gereri*); hot dry shrub/grass [HDSG] (bluebuch wheatgrass, *Agropyron spicatum* or bitterbrush, *Purshia tridentata*); warm dry shrub herb [WDSH] (bearberry, *Arctostaphylos uva-ursi* or pachistima, *Pachistima myrsinities*, or shrubby penstemon, *Penstemon fruiticosus*, or shiny leaf spirea, *Spirea betulifolia lucida,* or mountain snowbery, *Symphoricarpos oreophilus*); or warm mesic shrub/herb [WMESH] (common snowberry, *Symphoricarpos albus*). All the above sideslope plant association groups occurred in the riparian in addition to the cool mesic shrub/herb [CMSH] plant association (dwarf huckleberry, *Vaccinium caespitosum* or low huckleberry, *Vaccinium myrtillus*) that occurred only in the riparian. The HDSG plant association group occurred on 67% of the sideslope forest sites sampled in the Entiat drainage. Sampled sites, both riparian and sideslope forests, had been entered previously for timber harvest. Cut stumps were numerous on sideslope (67.9 stumps/ha, 27.5stumps/acre) and riparian (53.5 stumps/ha, 21.7 stumps/acre) forests over all sites.

Sample sites occurred on the lower portion of the Entiat River drainage in an elevation range between 450 and 1200 meters (1,500 and 4,000 ft.) on the Wenatchee National Forest. Streams associated with the sampled riparian forests were generally small (average stream class = 3.8) where class 3 streams are small perennial streams and class 4 streams are intermittent (Department of Natural Resources, Forest Practices Division, Olympia WA, Forest Practices Rules WAC-222-16-030 [2000]; R-6 Supplement 2500-90-1, [1990]). Sample sites on the Okanogan National Forest were within the Methow River drainage along stream segments with somewhat larger streams (average stream class of 2.4), where class 2 streams are perennial or intermittent of sufficient size to provide fish habitat. Elevations ranged between 670 and 1200 meters (2,200 and 4,000 ft.).

Sampled riparian and sideslope forests occurred in six valley types described by Cupp (1989) (Table 1 and Figure 1). Valley types are intermingled within a common landscape. Prior to Eurosettlement, much of the landscape on the study areas would have been characterized as open forests with widely scattered pines (Plummer 1902). The landscape level fire regime for this open forest type, from at least 1750 until fire suppression around 1910, was low intensity, high frequency with ground fires occurring on a 5.9 to 8.7 year fire-free interval (Everett et al., 2000). Fire maps based on fire-scarred trees show that prior to fire suppression, low-severity fires burned frequently over large areas of the lower Entiat drainage.

Table 1. Description of Cupp (1989) valley types sampled in this study.

Valley Type	N	Shape	Channel gradient %	Valley bottom Width[a]	Sideslope Steepness %
E1	14	v-shaped[b]	2-6	1-2x	> 30 often > 50
E2	12	v-shaped	6-11	1x	> 30 often > 50
E3	3	v-shaped	< 3	2-4x	5-30
F1	4	u-shaped[c]	< 2	> 4x	0-30
G2	12	Ravine[d]	8-20	1x	> 30
G3	4	Headwall[e]	> 20	1x	> 30

[a] valley bottom width is a multiple of the active channel width.

[b] v-shaped alluvial valley

[c] u-shaped glacial trough

[d] mountain sideslope ravine

[e] headwall is the headwater of a stream

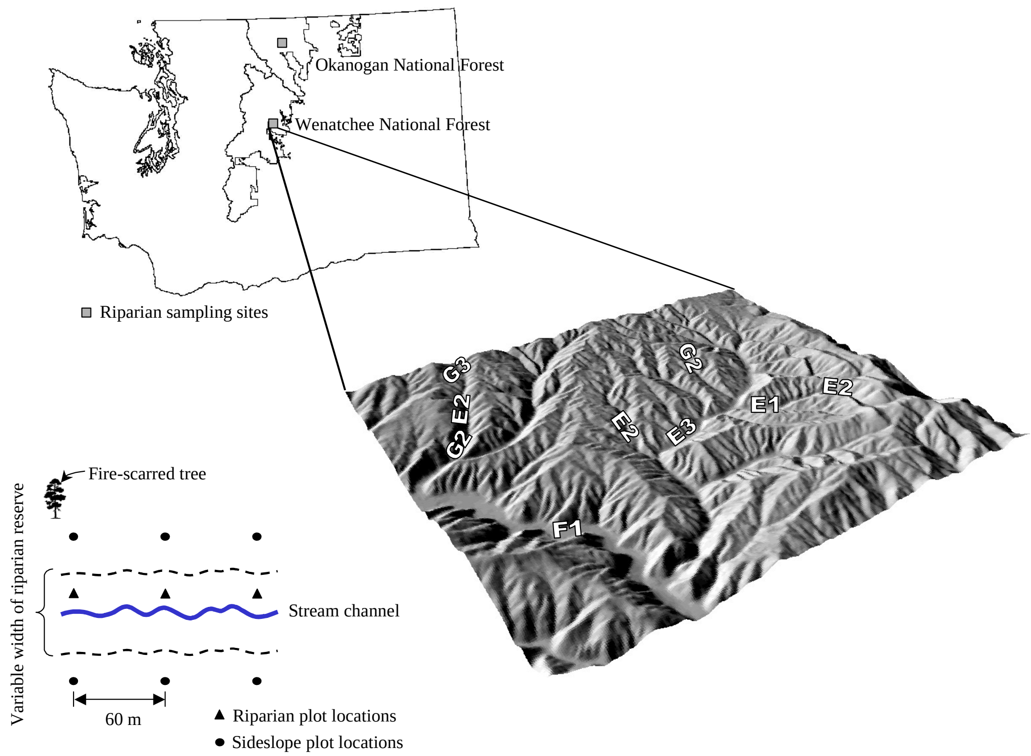

Figure 1. Location of study sites on the Okanogan and Wenatchee National Forests, Washington; the six valley types studied as described by Cupp (1989); and sampling design.

Field Sampling Procedures

Riparian and sideslope sample points were installed along 49 stream segments on 24 separate streams (33 stream segments on the Wenatchee National Forest and 16 on the Okanogan National Forest, Figure 1). Sampled streams were chosen at random from a population of those portions of the Entiat and Methow River drainages that are within the Douglas-fir forest series. Streams were divided into lower, middle and upper portions and each stream segment sampled when continuous forest cover allowed. This process resulted in sampling 27 stream segments with north and south aspect sideslopes and 22 stream segments with east and west aspect sideslopes. A minimum of 6 sideslope/riparian pairs were sampled for each valley type. Plant association groups (25) CDG, (52) HDSG, (18) WDSH, and (3) WMESH occurred on the sideslopes, and (4) CDG, (7) HDSG, (10) WDSH, (25) WMESH and (3) CMSH plant association groups occurred in the riparian.

At each sampled stream segment, nine plots (.02 ha [1/20th acre] fixed radius) were established (three on each of the opposing sideslopes and three in the riparian). All plots were within forested stands. Riparian plots were established adjacent to the active channel and sideslope plots were located beyond apparent riparian vegetation or stream-induced moist soils (Reeves et al. 1991). Also, sideslope plots were outside the riparian reserve widths for sampled stream classes (30 to 90 meters, 100 to 300 feet) as defined in the Northwest Forest Plan (, USDA-USDI [FEMAT] 1993).

Both sideslope and riparian sites were searched for fire-scarred trees. Previous work had shown fire scars to be well distributed across sideslope forests (Everett, et al., 2000). At each site, the first of three sideslope plots was established 20 m distance from a fire-scarred tree along a random azimuth. The additional two sideslope plots were established at 60-m intervals from one another and equidistant to the stream channel. The riparian plots were paired with the sideslope plots (also 60 m apart) along the stream channel.

Fire scar samples were collected (when available) within the riparian and adjacent sideslope forests that contained the 0.02 ha sample plots. Sample sections were cut from live trees, snags, logs, and cut stumps (Arno and Sneck 1977) and taken to the lab for analysis. Because every fire does not leave a scar and stand replacement fire events can cause the loss of existing fire scared trees the fire scar record is not complete. We used the presence of stand cohorts (groups of trees of similar establishment times) to estimate mortality fire events when no fire scar record was found. Trees regenerate for decades following disturbances (Oliver and Larson 1990). We used 20-year age classes to separate out cohorts and validated cohort initiation against recorded fire year dates from scars in the adjacent forest. Other disturbance agents, such as insect and disease, can create forest openings and allow for new cohorts but in this forest type and environmental setting, fire is the major recycling factor impacting stand structure (Arno 1988). Frequent fires (prior to Eurosettlement) would have maintained low stocking levels and reduced probability of damaging populations of insects (Hessburg and Everett 1994).

Valley type, valley bottom width, and sideslope and stream gradients were recorded at each site. At each plot, the slope percent, aspect, elevation, and type of plant association group present were recorded. All live trees, snags, logs, and cut stumps were tallied and grouped by diameter class. The diameter classes used were 3 to 13, 13 to 23, 23 to 41, 41 to 64, and > 64 cm (1 to 5, 5 to 9, 9 to 16, 16 to 25 and > 25 in.). Increment cores from a minimum of two trees of each species and in each diameter class were taken at ground level. Increment cores also were used to estimate mean annual growth increment for each species and diameter class at each sample site. Tree ages were used to determine the number of tree cohorts present at each site.

Analysis

All data sets for sideslope and riparian forests (number of all fire [scar] events, number of cohorts, cohort age, total disturbances, percentage of historical [1896] stand density, and percentage of current old [> 100 yrs.] trees) were analyzed for their approximation of a normal curve and appropriateness for analysis by either paired "t" tests of difference or analysis of variance tests. Skewness and kurtosis values were generally between –1 and +1. As kurtosis values exceeded 2 for number of sideslope cohorts and percentage of current old trees on sideslope sites these data sets were subjected to a logarithmic transformation (log(x+1)) and kurtosis values reduced prior to statistical analysis.

A composite skeleton plot was developed for cross-dating of scars and the numbers and dates of fire events were determined (Stokes and Smiley 1968). A total of 90 fire scar samples were collected from which 1,048 fire years were cross-dated. Numbers of recorded fires (fire scar dates) and numbers of stand cohorts (total found in the 3 plots for each sideslope or riparian forest per stream segment) were compared in paired "t" tests of difference (Little and Hills 1978). The sum of the number of fire scar events and stand cohorts (from separate disturbance events) was combined to determine the total number of fire disturbance events that had occurred at each site (two sideslopes plus riparian). Point fire frequencies were compared between riparian and upslope forests by valley type, plant association group and aspect. The proportion of the total fire disturbance events that occurred at each stream segment was determined for each of the opposing sideslopes and the riparian forest. We compared the number of disturbances that occurred on a sideslope among the array of valley types, aspects, and plant association groups sampled. Also, we evaluated if the number of shared disturbance events between riparian and adjacent sideslope varied by sideslope plant association. We analyzed for disturbance differences associated with different stream sizes, but could not show significant differences and these results were not included in this paper.

Additionally, we were interested in comparing the proportion of common events between sideslopes and between sideslopes and riparian areas. The Jaccard similarity index (Cjk = a/(a+b+c) [Cjk = resemblance coefficient between plots j and k, a = events occurring on both plots, b = events only occurring at a specific plot j, c = events occurring only at the other plot k] Romesburg , page 143, 1984) was used to determine the similarity in fire scar and cohort initiation dates. We specifically queried that of the total number of riparian fire disturbances at a site, what proportion of those events (same date of occurrence) was also found on sideslope forests? The similarity values and the proportion of riparian disturbance events found on sideslopes were used to evaluate the continuity in disturbance among sideslope forests and between sideslope and riparian forests. We evaluated changes in similarity values among valley types, aspects, and plant association groups.

Tree density 100 years before the present (BP) was estimated for sideslope and riparian forests in Crum Canyon in the Entiat drainage, and the Okanogan sites. The 100 BP date was chosen to sample forest conditions prior to organized fire suppression that began about 1910. Live trees ages (from increment cores) and diameters were used to develop species, and diameter class specific mean annual growth increments (MAI) for each sample site. The MAIs were used to predict the age (diameter/MAI) of all live trees that were not increment cored, and also the age at mortality for snags, logs, and stumps. We considered current snags, logs, and stumps to be living trees in the historical stand if the sum of the estimated age at mortality and time since mortality (based on estimated time to reach the current decay class**,** [Everett et al., 1999], or known harvest date) exceeded 100 years. The number of current live trees > 100 years of age was added to the number of snags, logs and cut stumps which were estimated to represent living trees 100 years BP.

The authors realize that because all trees, snags, and logs were not aged directly, estimates on numbers of current live trees (>100 yrs. old) and historical tree density estimates must be viewed as approximations and not absolute numbers. However, MAI estimates were site specific for each species and diameter class and there was close agreement between observed and predicted values for measured trees ($r^2 > 0.9$). Results should provide a reasonable comparative evaluation of tree densities (current and historical) among sideslope and riparian sample locations at a given site.

RESULTS

Fire Disturbance Events

The fire scar record from 1556 to 1910 was consistently greater in the sideslope (mean of 11.7 recorded fires per site) than riparian (mean of 5.7 recorded fires per site) forests (Figure 2). Fire scars were absent in the riparian forests of the E3 valley type and riparian forests had only 20% of the fire scars found on the sideslopes of the G3 headwall valley type.

Fire scar dates were fewer in riparian than sideslope forest regardless of the sideslope aspect (Figure 2). The difference in fire scar records between riparian and sideslope forests was greatest for west aspects and least for north aspects. Riparian areas running north-south had more fires scar events (a mean of 6.3 events) than riparian areas running east-west (5.2 events).

Fire scars and numbers of scarred trees were consistently fewer in riparian than sideslope forest regardless of the sideslope plant association group. Number of fire scars recorded in the riparian was more similar to sideslope forests in the CDG plant association group and most different from the sideslope forest in the WMESH group.

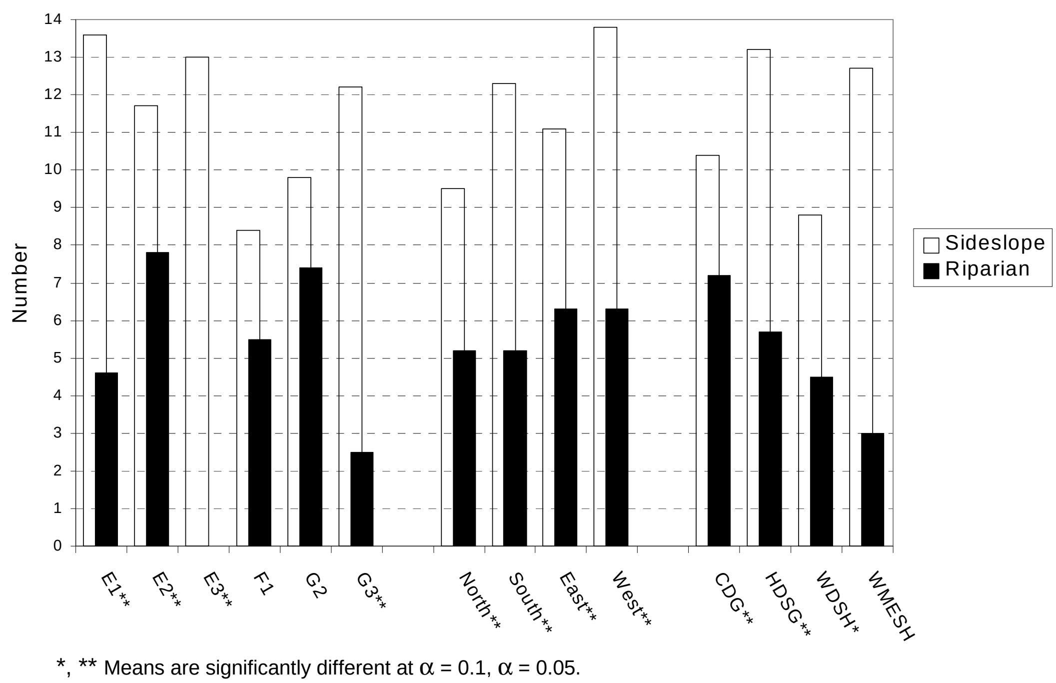

Figure 2. Number of fire scar recorded events in riparian and sideslope forests by valley type, aspect, and plant association group.

A reduced fire scar record in the riparian does not necessarily mean that riparian areas experienced fewer fire disturbances; fire-scarred trees were less abundant and remaining fire-scarred trees had fewer fire scar dates than those in the adjacent sideslope forest. However, the reduced number of fire scars in the riparian forest may be the result of fewer ground fire encroachments into the more mesic riparian forest (Minnich 1977), or the loss of previous fire scars because of increased fire severity when fires did occur in the riparian forest.

Stand Cohorts

The fire scar record was only partially complete, a fire scar date was not found for every stand cohort and a stand cohort was not created with each fire event. Forest landscapes with a high-frequency, low-severity fire regime can have fire events that do not create fire scars or new cohorts. We did not assign any stand cohorts if we did not have a fire scar from either that site or an adjacent one that matched the date. The correlation between a fire event and the creation of a new sideslope forest cohort varied by aspect, plant association, and valley type. A fire in the topography and associated plant cover of the F1 valley type is twice as likely (P = .011) to create and maintain a new sideslope cohort (64% of fires created a cohort) as conditions associated with E1, E2 and E3 valley types (34, 36, and 28%, respectively). The probability of a fire creating a new stand cohort was not statistically different (P = .280) among aspects with a minimum 33 % chance of fire creating a new stand cohort on east aspects and a maximum chance of 46% on south aspects. Fire in the WDSH and WMESH plant association groups had 51 and 53 % chance, respectively, of creating a new stand cohort and this differed significantly (P = .093) from the probability of creating cohorts (36 and 37 %, respectively) for CDG and HDSG PAG's.

Cohort number

The mean number of cohorts was greater in sideslope than riparian forests when all sites were combined (mean difference 1.3 cohorts), and in four of six valley types (Table 2). Number of cohorts was greatest for riparian forests in the broader u-shaped F1 valley types and least in the riparian forest in steep sideslope ravine topography of G2 valley types. Relatively steep side slopes and narrow valley widths may predispose riparian areas to burn often or with greater severity and thereby reduce the number of cohorts present. However, (G3) headwall topography has narrow valley widths and steep stream gradients, but is associated with the creation of fire refugia (Camp et al. 1996) that safeguard existing cohorts from subsequent fire events. Obviously, complex fire history cannot be explained solely by topographic influences. Number of cohorts was greater in sideslope than riparian forests on all aspects and significantly so ($\alpha = 0.05$) on north, south, and west aspects (Table 2). Number of cohorts in sideslope forests was either greater or equal to that in riparian areas regardless of the plant association group present and significantly ($\alpha = 0.05$) so for CDG and HDSG groups.

Table 2. Mean number and age of cohorts by riparian and sideslope forest.

	Mean number of cohorts[a]			Mean cohort age		
	Riparian	Sideslope	Mean difference[b]	Riparian	Sideslope	Mean difference
By valley type						
E1	4.1	5.4	1.3**	145.4	142.9	-2.5
E2	4.3	6.4	2.1**	130.8	150.5	19.7**
E3	4.3	3.5	-0.8	140.4	130.1	-10.3
F1	8.0	6.8	-1.2	156.9	164.3	7.4
G2	3.8	5.1	1.3**	134.9	153.4	18.5**
G3	6.0	8.5	2.5**	130.3	164.9	34.6**
By Sideslope Aspect						
North	4.9	6.3	1.4**	146.2	146.7	0.5
South	4.9	6.3	1.4**	146.2	158.2	12.0*
East	4.2	5.1	0.9	129.4	146.6	17.2**
West	4.2	5.5	1.3**	129.4	147.9	18.5**
By sideslope plant association group						
CDG	4.5	5.8	1.3**	143.8	152.8	9.0
HDSG	3.8	5.3	1.5**	128.9	143.8	14.9**
WDSH	6.7	7.3	0.6	153.4	166.4	13.0*
WMESH	5.7	5.7	0.0	176.2	150.9	-25.3
Mean difference across all possible combinations			1.3**			11.4**

[a] Number of cohorts found at each stream segment.

[b] Mean difference in paired "t" test of differences; **, * denotes significance at $\alpha = 0.05$, $\alpha = 0.1$.

Valley type effect on riparian or sideslope forest cohort number was more variable than aspects or plant associations. The variance in the mean number of riparian forest cohorts among aspects was one quarter (24 %) of the variance among valley types. Variance in mean number of sideslope forest cohorts among plant association groups was one half (51%) of the variance found among valley types. The similarity in number of cohorts among aspects and among plant associations suggest that other unmeasured variables, such as ignition sources or fuel loadings, are having significant impacts on the creation and maintenance of cohorts by valley type.

Cohort age

Mean cohort age (average age of the cohorts found on the site) for sideslope forests was greater (11.4 yrs.) than in riparian forests and this was consistent across all aspects (Table 2). Cohort age was significantly greater in sideslope than riparian forests in three of the six valley types. Mean cohort age was greater in sideslope plant associations CDG, HDSG, and WDSH, but not for the WMESH group. The relatively greater mean age of cohorts in the F1 and G3 valley types (see Table 2) suggests cohorts were maintained through subsequent fire events. Headwall (G3) valley types have previously been suggested as potential old growth refugia in the grand-fir series (Camp et al. 1996).

The trend toward younger and fewer cohorts in riparian forests supports the hypothesis of greater severity of fire disturbance in the riparian. Agee (1994, page 26) gave an example of a younger even aged lodgepole pine riparian forest adjacent an older multiple-cohort Douglas-fir/ponderosa pine forest as an example of a riparian area that burns less frequently, but more severely than the upslope.

These quantitative differences in fire occurrence and cohort creation between riparian and upslope forests still fall within a broad qualitatively similar shared fire disturbance regime at the landscape level. Both riparian and sideslope forests have repeated partial stand replacement events that create cohorts which are maintained through subsequent disturbance events.

Historical cohort numbers

The greatest number of stand cohorts present today were initiated in the 1860s to 1880s with fewer cohorts of either lesser and greater age in both riparian and sideslope forests on the Okanogan and Entiat sites (Figure 3). The peak of cohorts in the 1920's on the Entiat are the result of numerous small fires (Everett et al., 2000). Numbers of cohorts for each 20-year increment were consistently greater in sideslope than riparian forests prior to fire suppression (1910), but numbers of cohorts per 20-year period have been very similar since. There has been a dramatic decline in numbers of cohorts created in both riparian and sideslope forests since 1910. The anticipated inverse exponential curve in age class distribution for cohorts (VanWagner 1979, Agee 1988, Arno et al. 1995) was no longer valid after 1910. The change in the cohort frequency distribution pattern suggests altered disturbance regimes in both riparian and sideslope forests. Reduced fire effects with subsequent increases in stocking level and reduced patchiness caused increased continuity in fuels and host trees across the landscape, which is a precursor for larger and more severe disturbance events (Covington et al. 1994).

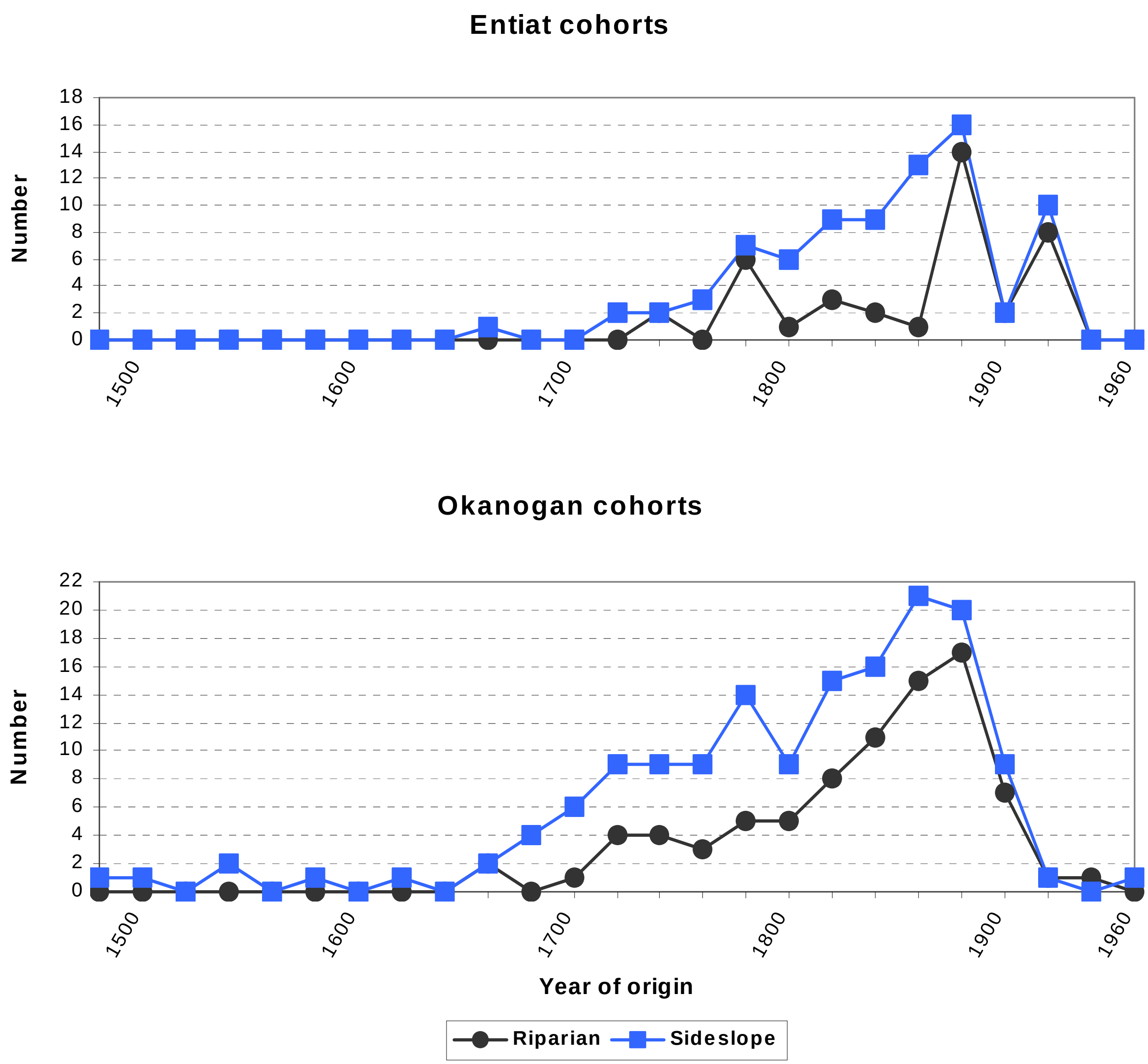

Figure 3. Numbers of stand cohorts initiated in 20-year increments in riparian and sideslope forests on Entiat and Okanogan study sites.

The reader is cautioned again that the cohort numbers reported might not be a complete assessment of all cohorts created by fires at these sites, but reflects those cohorts initiated and sustained through subsequent fire events. Fewer riparian cohorts reported here could be the product of fewer disturbances or the loss of previous cohorts by subsequent severe fire events.

Total Disturbance Record

Fires were more numerous (shorter fire-free intervals) for sideslope than riparian forests for 5 of 6 valley types, for all upslope plant association groups and all aspects (Table 3). The broad F1 valley type had similar point fire frequencies in riparian and upslope forests and we speculate that this may be the result of native American activities. "Indian ignitions substantially increase fire occurrences in lower elevation forests in and near major valleys" (Barrett and Arno, 650:1982).

Three different fire-free intervals were present on site for the riparian and the two opposing sideslope forests. Results indicate composite fire-free intervals for large landscapes are a generalization across a mosaic of habitats with different point fire-frequencies as previously reported (Everett et al. 2000). The reader is cautioned that the point fire frequencies given here for small scale sample plots are used only for plot comparisons and do not reflect the shorter fire free intervals characteristic of the larger landscapes that contain the plots.

Our data indicate the total "traceable" disturbance events from fire (fire scars and cohorts) are not equally distributed between sideslopes and the riparian forest**.** Riparian forests, in most instances, have a much-reduced traceable fire disturbance history than associated sideslopes (Figure 4). Total disturbances (sum of fire scars and cohorts) were greater in sideslope than riparian forests for valley types with a mean difference of 8 to 62%. The proportion of total site disturbance was significantly greater on sideslopes than in riparian (mean difference 31 to 40%) for all aspects. Riparian forests had 25 to 42% less total fire disturbance events than sideslope forests among the plant association groups.

In a comparison of total fire disturbances by north-south and east-west oriented stream segments we found the proportion of events was greater for west (avg. 73% of total) than east

Table 3. Fire-free intervals (FFI)[a] for riparian and upslope forests by valley type, upslope plant association group (PAG) and aspect.

	Riparian		Upslope		
	Mean	Range	Mean	Range	p value [b]
Valley type					
E1	20	11-46	14	7-34	0.001
E2	21	11-63	14	8-39	0.002
E3	26	26	14	10-22	0.309
F1	18	12-31	19	10-31	0.721
G2	15	11-23	12	8-22	0.031
G3	19	13-29	12	6-16	0.007
Upslope PAG					
CDG	20	11-31	14	8-31	0.001
HDSG	16	11-46	11	6-27	0.001
WDSH	26	12-63	19	10-39	0.024
WMESH	24	17-31	17	10-30	0.373
Upslope Aspect (E/W and N/S stream segments)					
East	18	11-63	13	8-31	0.074
West	18	11-63	12	6-39	0.005
North	20	11-46	16	8-34	0.021
South	20	11-46	14	7-31	0.003

[a] FFI rounded to the nearest whole year and based on the total fire events indicated by fire scars and cohorts.

[b] "p" values based on paired "t" test of difference between riparian and upslope FFI.

facing (avg. 55% of total) sideslopes and greater for south (avg. 69% of total) than north (avg. 60% of total) sideslopes. Traceable riparian fire disturbance events averaged 27% of that for sites with north-south opposing sideslopes and 24% of that for sites with east-west opposing sideslopes. The similarity in proportion of traceable fire disturbance among plant association groups (82-90%) in Figure 4 masks differences in fire history when different plant associations groups are found on opposing sideslopes. We found increased fire records among plant association groups in the following order: CDG>WMESH>HDSG>WDSH (also, see similarity section below). We had sufficient replicates to evaluate HDSG plant association groups occurring on opposing east-west slopes, and found a greater number of site disturbances recorded on the west (74%) than east (52%) slopes.

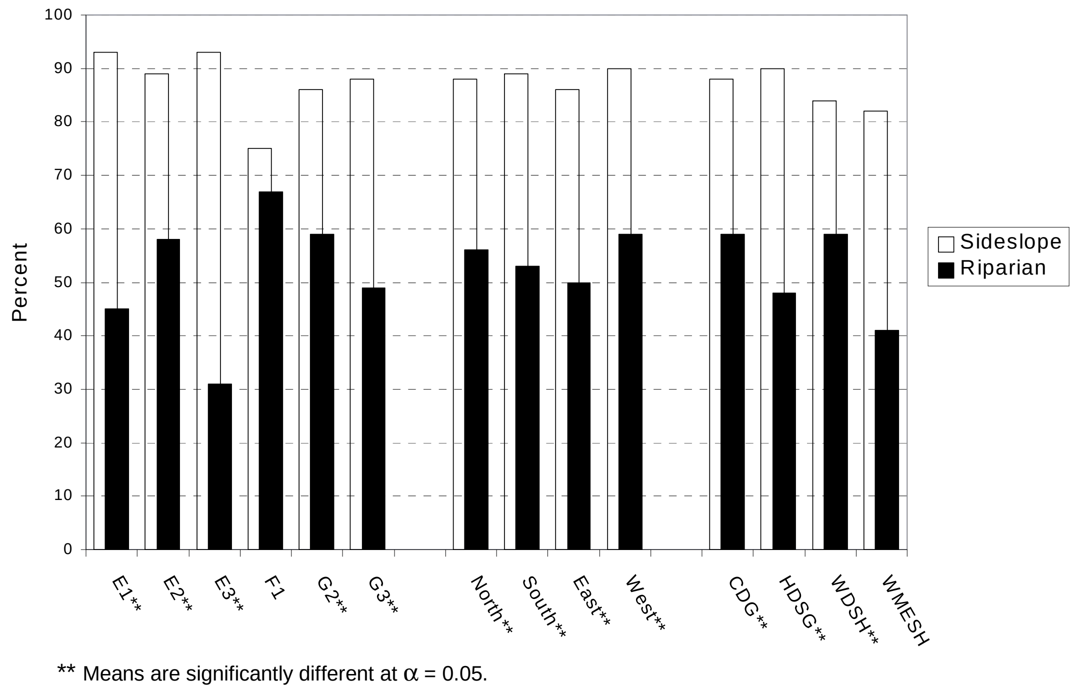

Figure 4. Percentage of total traceable fire disturbance in riparian and sideslope forests by valley type, aspect, and plant association group.

Riparian

The total number of traceable disturbance events found in riparian forests varied among the valley types. Riparian forests in the E2, F1, and G2 valley types had a significantly (α = 0.05, 0.1, 0.1) greater disturbance record (9.8, 9.5, 8.8 events) than in the E3 valley type (4.3 events). Riparian forests with similar valley form (E2 and E3), but with steeper sideslopes (E2) had increased number of disturbances.

The percentage of site disturbance recorded in riparian forests increased from drier (HDSG) to more mesic (CMSH) plant associations (Table 4). The more mesic riparian plant associations appear to have both increased capability to burn and to maintain cohorts through subsequent fire events. When the WDSH plant association group was present on at least one sideslope, the percentage of total fire disturbance found in the riparian doubled (43%) that found with other sideslope plant association groups (Table 4). This value increased to 50% of the total fire disturbance when both sideslopes had WDSH plant association groups. Results indicate the percentage of shared fire disturbance between the riparian and the sideslopes is, in part, the combined result of the riparian forest plant association group, the sideslope plant association groups, and the topography of the site.

Similarity Values

Opposing sideslopes

Although the two opposing sideslopes may have a similar proportion of the total site disturbance, the dates of the disturbances may not be the same; that is, the disturbance events are not shared events. Jaccard similarity coefficients varied from 17 to 70% among valley types for shared disturbance events between opposing sideslopes (Table 5). The low similarity value for the F1 valley type may be related to the presence of a large class 1 stream that reduced the probability of fire propagation from opposing sideslopes. Opposing sideslopes in narrow steep ravines (G2) had 70% similarity in disturbance events. Riparian areas may have propagated fire disturbance by the "chimney effect, (Agee 1988)" to both sideslopes.

Table 4. Percentage of total traceable fire disturbance recorded in the riparian plant association groups and for riparian forest in association with sideslope plant association groups.

	Riparian % of total fire disturbances				
	CDG	HDSG	WDSH	WMESH	CMSH
By riparian plant association group (over all sites)					
P = **.000**	15.4b	12.8b	38.7a	22.4b	48.0a
By sideslope plant association group (over all sites)					
P = **.002**	22b[a]	21b	43a	21ab	Na[b]

[a]Different subscripts denote significant differences (*P* values shown) among means in the same row (Tukeys HSD Multiple Comparisons Test).

[b] Plant association group was not present.

Similarity in disturbance events between opposing sideslopes varied from 9 to 74% among plant association pairs. Low similarity values (9%) for fire disturbances on opposing sideslope plant associations (WDSH-WMESH) may be the result of the riparian area acting as a

Table 5. Percent similarity in disturbance events between opposing sideslopes.

	Similarity					
	- - - - - - - - - - - - - - - - - - - % -					
By valley type						
	E1	E2	E3	F1	G2	G3
P = **.001**	62a[a]	66a	40ab	17b	70a	52ab
By aspect						
		north/south		east/west		
P = .143		54a		65 a		
By opposing sideslope plant association pairs[b]						
	CDG-CDG		CDG-HDSG		CDG-WMESH	
P = **.001**	49ab		69a		21ab	
	HDSG-HDSG		HDSG-WDSH		HDSG-WMESH	
	70a		43ab		74ab	
	WDSH-WDSH				WDSH-WMESH	
	37b				9b	

[a] Different subscripts denote significant differences (*P* values shown) among means (Tukeys HSD Multiple Comparisons Test) within the three comparison groups (valley type , aspect and plant association pairs).

[b] Only those plant association group combinations that were sampled are shown.

green-strip firebreak that prevented fire spread from one sideslope to the other. Conversely, the riparian may have served as a fire conduit to only one sideslope because of different flammability of the sideslope vegetation or fire climatic conditions. High similarity values (74%, HDSG-WMESH) for opposing sideslope forests indicate a shared disturbance regime that either over ran, jumped, or was propagated from the riparian forest. Having similar plant associations on the opposing sideslopes gave a high percentage of shared events for HDSG-HDSG (70%), but not WDSH-WDSH (37%). In the former, the riparian may have been a conduit for fire between sideslopes and in the latter case, the mesic CMSH riparian PAG may have acted as a fire barrier.

Riparian vs. sideslope

Riparian and sideslope forests shared a significantly greater number of disturbance events in G2 (49%) than for either E3 (20%) or E1 (38%) valley types (Table 6). Percent similarities for shared disturbance events for E2 (48%), F1 (38%), and G3 (36%) were not statistically different from G2 valley type. Narrow ravines in the steep topography of G2 and E2 valley types increase the opportunity for the riparian to act as a fire source to both sideslopes or for fire to roll over the riparian from one sideslope to the other.

Shared disturbance events (% similarity values) for riparian and sideslope forests were very consistent among aspects (41 to 43%). Similarity values ranged from a high of 46% (CDG) to 23% (WMESH) among plant association groups, but these differences were not statistically significant ($\alpha = 0.1$).

Table 6. Percent similarity (Jaccard coefficient) in disturbance events between riparian and sideslope forests by valley type, aspect and plant association group.

	-------------------		%		--------------------	
by valley type	E1	E2	E3	F1	G2	G3
p = .001	38b	48a	20b	38ab	49a	36ab
by aspect	north	south	east	west		
p = .976	43	42	41	43		
by plant association group	CDG	HDSG	WDSH	WMESH		
p = .163	46	42	40	23		

Significant differences within rows indicated by p values and different subscripts among means (Tukeys HSD Multiple Comparisons Test).

Riparian disturbances events

The reduced number of recorded disturbances in the riparian forests limited the maximum similarity value for disturbance events between sideslope and riparian forests. If we limit our examination to only those disturbances recorded in the riparian, we found a majority of those

same disturbances occurred on adjacent sideslopes. The percentage of riparian disturbances also found on sideslopes varied significantly among valley types. Sideslopes had many of the riparian disturbances in valley types E1, G3 and E2 (79 to 72%), but less so for E3, G2 , or F1 (62 to 58%) valley types (Table 7). The percentage of riparian disturbance events found on adjacent sideslopes did not vary significantly (64% to 76%) among aspects. Also, we were unable to show significant differences in the proportion of riparian fire disturbance events found among sideslope plant association groups (65% to 73%) or among riparian (58% to 80% plant association groups. These results demonstrate a substantial degree of continuity in disturbance events (58 to 80% shared events) between riparian and sideslope forests regardless of aspect, valley type, or plant association group. Landscape burn maps have shown repeated burns across intermingled sideslope and riparian forests in the Mud Creek area of the Entiat drainage (Everett et al., 2000).

Table 7. Percent of riparian disturbance dates that match sideslope disturbance dates.

	%					
by valley type	E1	E2	E3	F1	G2	G3
p = *.089*	79	72	62	58	63	73
by sideslope aspect	north	south	east	west		
p = .241	67	74	64	76		
by sideslope plant association group	CDG	HDSG	WDSH	WMESH		
p = .529	65	73	70	67		
by riparian plant association group	CDG	HDSG	WDSH	WMESH	CMSH	
p = .281	58	80	72	69	67	

Significant differences within rows indicated by p values, but there were no signficance differences ($p < 0.1$) among means indicated by the conservative Tukeys HSD Multiple Comparisons Test.

Historical Stands and Current Old Trees

One hundred years BP, the proportion of trees at a sample site was apparently greater on sideslopes than riparian areas for all valley types (mean difference 8 to 42%), aspects (mean difference 14 to 38%), and sideslope plant association groups (mean difference 22 to 26%, Figure 5). However, significant differences ($P < 0.1, 0.05$) were limited to the E1 valley type (31% riparian, 69% sideslope), the north aspect (37% riparian, 63% sideslope), and the HDSG, WDSH, and WMESH plant association groups (37 to 38% riparian, 62 to 63% sideslope).

Historical stand density varied among sideslope plant association groups from a high of 186.8 trees/ha (75.6 trees/acre) for WDSH to a low of 109.7 trees/ha (44.4 trees/acre) for WMESH. Both HDSG and CDG had intermediate stand densities of 118.6 and 149 trees/ha, (48 and 60.3 trees/acre) respectively.

We could not show significant differences in the current proportion of old trees (> 100 yrs) between riparian and sideslope forests for any aspect or plant association group. On east-west oriented stream segments 38, 30, and 32% of the sites total of old trees were found on north and south sideslopes, and riparian forests, respectively. For north-south oriented stream segments, the west sideslopes had greater numbers of old trees (48%) than either the opposing east aspect sideslope (28%) or the riparian (24%) forest. The oldest trees at each site were found on sideslopes 84% of the time.

Given fewer and younger cohorts in riparian than sideslope forests and fewer historical tree numbers in riparian than sideslope forests the current equal dispersion of old trees between sideslopes and riparian areas may be a spurious result of fire suppression since 1910. Our attempts to protect old trees in the riparian buffers at the expense of adjacent sideslopes may be misdirected if old trees have been historically more numerous on the adjacent sideslopes.

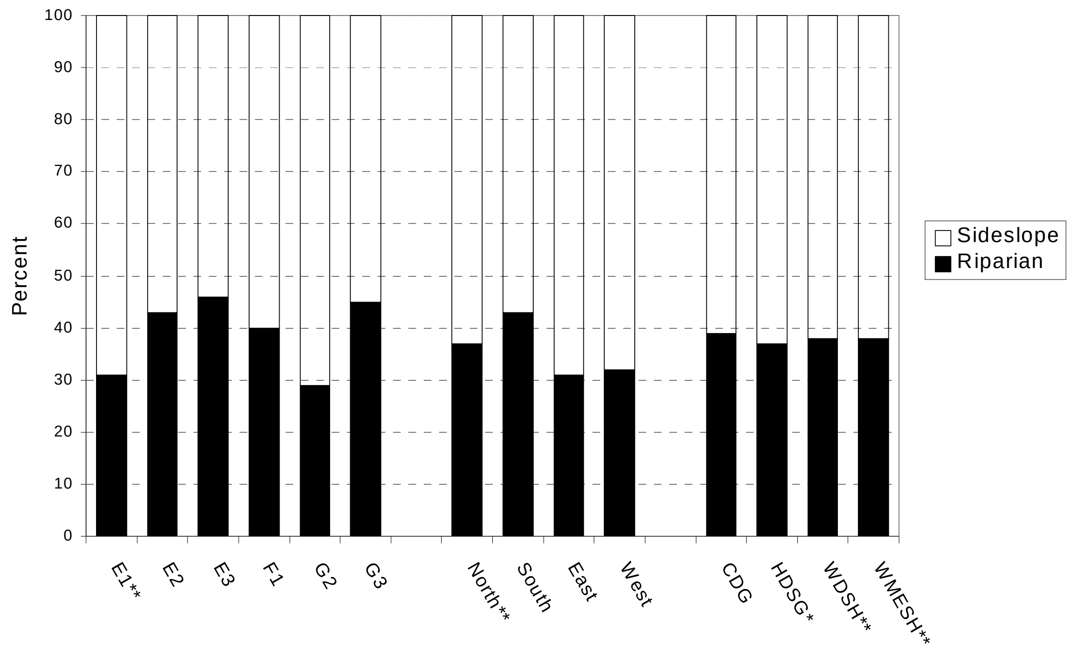

Figure 5. Percentage of historical stand density (100 BP) in riparian and an adjacent sideslope forests.

CONCLUSIONS

We provided evidence to reject our first null hypothesis that disturbance events were more numerous in riparian than sideslope forests. The number of total disturbance events (fire scars plus cohorts) was greater on sideslope than riparian forests in almost all instances, regardless of aspect, valley type, or plant association group. Except for the broad F1 valley type we found fire-free intervals to be 3 to 12 years longer in the riparian than adjacent upslope forest. Reduced numbers of fire scars and cohorts in riparian forests, but younger cohort ages suggests that riparian fires are fewer and more severe. Our logic is that the greater numbers of fire scars and cohorts on sideslope indicates a less severe fire regime that allows both to survive subsequent fire events. Agee (1999) suggested that wetter riparian areas have increased growth and biomass potential that would cause fuels to accumulate more rapidly and burn more severely than upslope forests.

Although fire regimes of riparian and sideslope forests are quantitatively different in numbers of fires and derived cohorts, they are qualitatively similar in partial stand replacement effects and have numerous disturbance events in common. We rejected our second null hypothesis of no continuity in fire disturbance between riparian and sideslope forests. We found disturbance events recorded in the riparian forests were also found on the adjacent sideslopes: 58 to 79% by valley type, 64 to 76% by aspect, and 65 to 73% by sideslope plant association groups. Also, 54 to 65% of fire events found on one sideslope were found on the opposing sideslope for north/south and east/west stream segments, respectively. This substantial, albeit not complete, degree of continuity in disturbance between riparian and sideslope forests and between opposing sideslope forests suggests that the development of management options include consideration of landscape units in their entirety rather than as riparian and sideslope isolates when implementing ecosystem and disturbance management. Reeves et al. (1995) recommended planned disturbance (and its absence) of entire sub-watersheds to maintain the ecological integrity of aquatic/riparian systems.

We could not disprove our third null hypothesis that different disturbance regimes between riparian and sideslope forests provide different historical stand densities and amounts of current old trees (> 100 years). Our results indicate that historical stand density was 22 to 26% greater in sideslope than riparian forest plant association groups, and this relationship held among valley types (8 to 35%) and by aspect (14 to 38%). Although we found no difference in the current number of old trees between riparian and sideslope forests, the results may reflect fire suppression activities since 1910. Current "common" conditions may not reflect the forest structure supported by the different inherent disturbance regimes of riparian and sideslope forests. Our historical cohort information indicate reduced fire effects since the early 1900's have altered the number and age structure of cohorts in both sideslope and riparian forests making them more similar. Increased homogeneity (reduced patchiness) has negative attributes of increased continuity in fuels and insect hosts that create significant problems in the management of sustainable forests.

Historical fires have not discriminated between riparian and upland, they have been stopped by riparian fire breaks and riparian forests have acted as crown-fire corridors to sideslopes that would not burn otherwise (Agee 1998). All of these disturbance roles add to the ecological integrity of the riparian, the uplsope and the larger landscape. If riparian and adjacent sideslope ecosystem integrity is to be restored and maintained, the continuity of disturbance and the subsequent patch (cohort) dynamics need to be reestablished. The loss of this large-scale ecosystem integrity comes home to roost in sideslope, riparian, and stream habitats following severe and extensive wildfire events (Wissmar 1994). Reduced fire effects in the riparian could alter nutrient cycling processes and impact stream chemistry and aquatic system function (Hauer and Spencer 1998). Disturbance within riparian areas may be a required ecological process to provide coarse woody debris and multiple riparian successional states for the proper functioning of the aquatic-land interface (Reeves et al. 1995).

This study has shown varying but nonetheless significant continuity in disturbance regimes between riparian and sideslope forests and we suggest the need to integrate riparian and sideslope forests through shared disturbance events to maintain ecosystem function. Historical stand structure results suggest that conservation of old trees is as important on sideslopes as in riparian forests, and there is connectivity both in disturbance and structure across the riparian-sideslope ecotone. Improved riparian forest integrity may be achieved by reestablishing inherent disturbance effects and establishing areas of old growth riparian refugia where it has a high probability of occurrence under the inherent fire regime for the area. The successful management of riparian buffer zones to protect fisheries and water quality requires the incorporation of knowledge of the dynamics of the riparian ecosystem and the forest matrix in which it exists.

LITERATURE CITED

Agee, J.K., 1988. Successional dynamics in forest riparian zones. In: Raedeke, K. (Ed.) Streamside Management: Riparian, Wildlife and Forestry Interactions. University of Washington, Institute of Forest Resources, Contribution 59, Seattle, WA, pp. 31-44.

Agee, J.K., 1993. Fire Ecology of Pacific Northwest Forests. Island Press, Washington, DC.

Agee, J.K., 1994. Fire and weather disturbances in terrestrial ecosystems of the eastern Cascades. GTR-PNW-320. USDA For. Serv., Pacific Northwest Res. Station, Portland, OR.

Agee, J.K. 1998. The landscape ecology of western forest fire regimes. *Northwest Science* 72 : 24-34.

Agee, J. K. 1999. Fire effects on landscape fragmentation in interior west forests. pp 43-60. IN Forest Fragmentation Wildlife and Management Implications, Ed J, Rochelle, L. Lehmann and J. Wisniewski.. Koninklijke Brill NV, Leiden, The Netherlands. 322p.

Arno, S.F., Sneck, K.M., 1977. A method for determining fire history in coniferous forest of the mountain west. INT-GTR-42. USDA Forest Service, Intermountain Research Station, Ogden, UT.

Arno, S.F., 1988. Fire ecology and its management implication in ponderosa pine forests. In: Baumgartner, D., Lotan, J. (Eds.), Ponderosa Pine—The Species and its Management. Washington State University, Pullman.

Arno, S.F., Scott, J.H., Hartwell, M.G., 1995. Age-class structure of old growth ponderosa pine/Douglas-fir stands and its relationship to fire history. INT-RP-481. USDA Forest Service, Intermountain Research Station, Ogden, UT.

Barrett, S.W., Arno, S.F. 1982. Indian fires as an ecological influence in the Northern Rockies. Journal of Forestry. 80:650.

Bilby, R.E., 1988. Interactions between aquatic and terrestrial systems. In: Raedeke, K. (Ed.), Streamside Management: Riparian, Wildlife and Forestry Interactions. University of Washington, Institute of Forest Resources, Contribution 59, Seattle, WA, pp. 13-30.

Camp, A.E., Hessburg, P.F., Everett, R.L., 1996. Dynamically incorporating late-successional forest in sustainable landscapes. In: Hardy, C., Arno, S. (Eds.), The Use of Fire in Forest Restoration. INT-GTR-341. USDA, Forest Service, Intermountain Research Station, Ogden, UT, pp. 20-24.

Covington, W.W., Everett, R.L., Steele R., Irwin, L.L., Daer, T.A., Auclair A.N. 1994. Historical and anticipated changes in forest ecosystems of the inland west of the United States. Journal of Sustainable Forestry. 2:13-64.

Cupp, C. Edward, 1989. Valley segment type classification for forested lands of Washington. Timber, Fish, and Wildlife TFW-AM-89-001. Washington State Department of Natural Resources. Olympia, WA.

Everett, Richard L; Schellhaas, Richard; Spurbeck, Don, Ohlson, Pete; Keenum, David; Anderson, T. 1977. Structure of northern spotted owl nest stands and their historical conditions on the eastern slope of the Pacific Northwest Cascades, USA. For. Ecol. Manage. 94:1-14.

Everett, Richard L.; Lehmkuhl, John F., 1999. Restoring biodiversity on public forest lands through disturbance and patch management irrespective of land-use allocation. In: Baydack, R.L., Campa, III, H., Haufler, J.B. (Eds.), Practical Approaches to the Conservation of Biological Diversity. Island Press, Washington, DC, pp. 87-105.

Everett, Richard L; Lehmkuhl, John; Schellhaas, Richard; Ohlson, Pete; Keenum, David; Riesterer, Heidi; Spurbeck, Don. 1999. Snag dynamics in a chronosequence of 26 wildfires on the east slope of the Washington Cascades. Int. J. Wildland Fire. 9:223-234.

Everett, R.L.; Schellhaas, Richard; Anderson, Tom; Lehmkuhl, John; Camp, Ann., 1996. Restoration of ecosystem integrity and land use allocation objectives in altered watersheds. In: McDonnel, J.J., Stribling, J.B., Neville, L.R., Leopold, D.J. (Eds.), Watershed Restoration Management. Proceedings, American Water Resources Association, Herndon, VA, pp. 271-280.

Everett, Richard L; Schellhaas, Richard; Keenum, David; Spurbeck, Don; Ohlson, Pete . 2000. Fire history in the ponderosa pine/Douglas-fir foresst on the east slope of the Washington Cascades. Forest Ecology and Management 129:207-225.

Hall, F.C., 1988. Characterization of riparian systems. In: Raedeke, K. (Ed.), Streamside Management: Riparian, Wildlife and Forestry Interactions. University of Washington, Institute of Forest Resources, Contribution 59, Seattle, WA, pp. 7-12.

Hauer, F.R., Spencer, C.N., 1998. Phosphorous and nitrogen dynamics in streams associated with wildfire: a study of immediate and long-term effects. Int. J. Wildland Fire. 8:183-198.

Hessburg, P.F., Everett, R.L., 1994. Managing landscape patterns and insect and disease disturbances on National Forests of the interior Northwest. In: Proceedings, 1993 National Convention, Society of American Foresters, Bethesda, MD, pp. 123-128.

Knutson, K.L., Nae, V.L., 1997. Management recommendations for Washington priority habitats: riparian. Washington Department of Fish and Wildlife, Olympia, WA.

Lillybridge, T.R., Kovalchik, B.L., Williams, C.K., Smith, B.G., 1995. Field guide for forested plant associations of the Wenatchee National Forest. PNW-GTR-359. USDA Forest Service, Pacific Northwest Research Station, Portland, OR.

Little, T.M., Hills, F.J., 1978. Agriculture experimentation: design and analysis. John Wiley and Sons, New York.

McIntosh, B.A., Sedell, J.R., Smith, J.E., Wissmar, R.C., Clarke, S.E., Reeves, G.H., Brown, L.A., 1994. Management history of eastside ecosystems; changes in fish habitat over 50 yrs., 1935-1992. PNW-GTR-321. USDA Forest Service, Pacific Northwest Research Station, Portland OR.

Minnich, R.A., 1977. The geography of fire and big-cone Douglas-fir, Coulter pine and western conifer forest in the east Transverse Ranges, southern California. In: Mooney, H.A., Conrad, C.E. (Eds.), Proceedings, Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems. GTR-WO-3. USDA Forest Service, Washington, DC, pp. 443-450.

Oliver, C. D., Larson, B.C. 1990. Forest stand dynamics. McGraw-Hill, New York, New York, USA.

Plummer, F.G., 1902. Forest conditions of the Cascade Range, Washington. Professional Paper No. 6. Series H, Forestry. USDI, U.S. Geological Survey, Government Printing Office, Washington, DC.

Reeves, G.H., Hall, J.D., Roelofs, T.D., Hickman, T.L., Baker, C.O., 1991. Rehabilitating and modifying stream habitats. In: Meehan, W.R. (Ed.), Influences of Forest and Range Management on Salmonid Fishes and Their Habitats. Publication No 19, American Fisheries Society, Bethesda, MD, pp. 519-557.

Reeves, G.H., Benda,, L.E., Burnet, K.M., Bisson, P.A., Sedell, J.R. 1995. A Disturbance-Based Ecosystem Approach to Maintaining and Restoring Freshwater Habitats of Evolutionarily Significant Units of Anadromous Salmonids in the Pacific Northwest. In American Fisheries Society Symposium. 1995. pp. 334-349.

Romesburg, H.C., 1984. Cluster Analysis for Researchers. Wadsworth, Inc., Belmont, CA.

Stokes, M.A., Smiley, T.L., 1968. An Introduction to Tree-ring Dating. University of Chicago Press, Chicago, IL.

Swanson, F.J., 1978. Fire and geomorphic processes. In: Proceedings, Fire Regimes and Ecosystem Properties. GTR-WO-26. USDA Forest Service, Washington DC, pp. 401-421.

Turner, M.G., Romme, W.H., 1994. Landscape dynamics in crown fire ecosystems. Landscape Ecol. 9, 59-77.

VanWagner, C.E., 1979. Age class distribution and forest fire cycle. Can. J. For. Res. 8, 220-227.

USDA-USDI (FEMAT), 1993. Forest Ecosystem Management Assessment Team. Forest ecosystem management: an ecological, economic, and social assessment. USDA, US Department of the Interior (and others), Portland, OR.

USDA-USDI (PACFISH), 1994. Environmental assessment. Implementation of interim strategies for managing anadromous fish-producing watersheds in Eastern Oregon and Washington, Idaho, and portions of California. USDA, US Department of the Interior (and others), Portland, OR.

Washington Department of Natural Resources, Forest Practices Division, Olympia WA, 2000. Forest Practices Rules WAC-222-16-030. pp. 21-25.

Wissmar, Robert C., Smith, Jeanette E., McIntosh, Bruce A., Li, Hiram W., Reeves, Gordon H., Sedell, James R., 1994. Ecological health of river basins in forested regions of eastern Washington and Oregon. PNW-GTR-326. USDA Forest Service, Pacific Northwest Research Station, Portland, OR.