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Channel changes in burned streams of northern Nevada

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ABSTRACT

In the Great Basin, frequency of large-fire is increasing. To better understand fire and riparian system interactions, we studied pre- to post-fire changes in ten riparian attributes of a randomly sampled reach of forty three streams burned within a three-year period. Post-fire data were collected four to six relatively dry years after late-summer wildfires in sagebrush dominated watersheds of the North Central Great Basin. All streams had been surveyed in the one to fifteen years prior to the fire. Five channel attributes improved; bankfull width decreased 21%, riparian width increased 79%, median dominant riparian vegetation increased by two categories (grass/sod to high brush), bank stability increased by one category, and median bank angle decreased. Four attributes did not change; bank cover, organic debris, bank undercuts, and embeddedness. An increase of sand by 19% in the dominant bottom material was considered unfavorable. Riparian vegetation and systems seem to be resilient and whether improvement was due to fire or changed management and time for recovery was not ascertained. Overall, degradation to stream channel attributes was minimal to non-existent suggesting riparian stability and/or resiliency.

1. Introduction

Two fire problems endanger Great Basin ecosystems. Part of the land continues to accumulate woody fuel in the absence of fire. Young and Clements (2009) state "The government's policy of excluding wildfires during the twentieth century led to greater expansion of woody vegetation in the Great Basin than had occurred since the Neoglacial period 5000 years ago". The absence of fires was also due to the lack of flammable understory herbaceous vegetation for many decades in the late nineteenth and early twentieth centuries due to overgrazing (Burkhardt and Tisdale, 1976; Miller and Rose, 1999). As shrub and tree dominated plant communities grow fuel, eventual fire becomes more certain, fires become hotter, larger, and more damaging to soil, watersheds, and plant communities that become less resilient. This first fire problem is especially damaging where juniper or pinyon pine trees become dominant (Gruell, 1999; Tausch and Tueller, 1990) and where livestock grazing management has stressed and altered the herbaceous understory of sagebrush (West, 1983). As agencies effected conservative grazing practices, herbaceous native perennials and invasive alien species, especially cheatgrass, *Bromus tectorum* L., increased and provide the continuity of fuel that often allows fires to spread rapidly between woody plants including sagebrush (Young and Clements, 2009). In the absence of a resilient understory, upland burned areas often re-vegetate to flammable annuals, especially in the arid part of the sagebrush zone (Chambers et al., 2007). This creates a second fire problem because burned areas re-vegetated with annuals often burn again. Fast moving fires can become quite large quickly and this too increases fire frequency (Miller and Narayanan, 2008). Invasive annuals now fuel dramatically increased fire frequency and fire size (Brooks et al., 2004; Young and Clements, 2009). Global increase in carbon dioxide acts to fertilize plant growth. It elevates productivity and reduces digestibility of cheatgrass which could increase fuel load and fire frequency and intensity (Ziska et al., 2005). Because fire is a natural phenomenon, areas that still retain resilience could benefit from fire or some fire surrogate that releases herbaceous perennials from competition before fire response is permanently changed (Tausch et al., 2009). Fire corrects problem one if timely, or results in problems one and two if not.

In 1999, 2000 and 2001, numerous wildfires burned over 1.1 million hectares (2.8 million acres) across northern Nevada, much of it managed by the Bureau of Land Management (BLM) and the US Forest Service (USFS). These fires of mixed severity burned across numerous riparian areas, affecting them in various ways. In 2005, 2006, and 2007, another 1.28 million hectares (3.1 million acres) burned in Nevada. The area burned annually increased by 8.5 times from before to after 1999. As wildfire frequency and size increases, land managers need tools and information about fire effects, especially in critical management areas such as riparian zones.

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Past and recent policy has been to suppress fires that approach riparian zones, even though fire is often used as a management tool in upland areas (Bisson et al., 2003). This is likely due to the notion that the riparian area is a highly valuable (greater biodiversity, high anthropogenic utility, important hydrologic/geomorphic controls (Debano and Neary, 1996)) and a limited resource (one-half to two percent of the landscape) that should be protected from destruction. This paradigm is being questioned (Agee, 1998) with concerns about increased fuel loads and more homogenous landscapes leading to more severe and larger fires, potentially causing greater riparian damage. With accumulation of fuel, riparian zones may change from fuel breaks to corridors for fire movement (Pettit and Naiman, 2007). Furthermore, riparian areas, especially those dominated by woody vegetation, support greater biomass or fuel than uplands.

Riparian ecosystem diversity is maintained by natural regimes of disturbance such as fire (Naiman et al., 1993; Pettit and Naiman, 2007), potentially making suppression detrimental ecologically. Riparian zones are typically cooler and more humid than surrounding uplands (Danehy and Kirpes, 2000). This often leads to higher fuel and soil moisture content, reducing the severity of a riparian burn compared to the uplands. Riparian plants of Great Basin rangelands are generally fire adapted in that they sprout root suckers or sprout from stumps and underground stems following fire (Bartos and Campbell, 1998; Miller, 2000; Rood et al., 1994; Shepperd and Smith, 1993). These plants also produce seeds that can be delivered to downwind burned riparian areas, where burned duff provides nutrients to establishing seedlings. These conditions can lead to high plant densities on post-fire riparian sites (Havlina, 1995). Forbs and grasses often increase reproduction for some years after fire (Kauffman, 1990). Taken together, these findings suggest a strong resiliency within riparian systems (Dwire and Kauffman, 2003). This is not the case with sagebrush stands which are highly susceptible to fire, and may require thirty years or more to recover original canopy cover and height (Lesica et al., 2007; Paysen et al., 2000).

Riparian areas are known for their resiliency (Wyman et al., 2006), yet post-fire floods have at times caused significant impact (Minshall et al., 1997). Pettit and Naiman (2007) describe a great variety of possible fire effects on riparian areas depending on position in the watershed; fire adaptation of dominant riparian plant species; time since previous fire, fuel loads, and fire intensity; post-fire flows; local geomorphology and topography; and pre- and post-fire management. They emphasize the "requirement for improved understanding of the natural recovery processes of riparian areas after fire." Intense fires that burn a high percentage of watersheds around low order streams present the greatest potential for long-term effects on those streams (Minshall et al., 1997). Short-term affects of increased stream flow energy and changed hydrology, geomorphology, and riparian communities (Arno and Allison-Bunnell, 2002) are likely to affect several aspects of the drainage system for longer periods (Gresswell, 1999). Channel changes to geometry due to incision and bank erosion result in changes to aquifer recharge, subsequent base-flow, and peak-flow discharge characteristics. Fire directly affects watershed and riparian vegetation and soils, and indirectly effects stream channels by changing water and sediment supply, and channel form, roughness and integrity (Debano and Neary, 1996). While it has been found in the moister climes of coastal northwest regions that fire severity and frequency are typically lower in riparian zones than uplands (Morrison and Swanson, 1990), drier forest types have generally similar frequencies between the two (Olson and Agee, 2005). Conversely, riparian zones can burn more frequently than uplands in some southwestern riparian habitats (Busch and Smith, 1993).

Many of the effects of fire on upland and riparian systems can significantly affect aquatic ecosystems both directly and indirectly (Minshall et al., 1997). Cold-water fish often listed as threatened or endangered are sensitive to habitat changes. Land management agencies monitor condition and trend of riparian attributes important to fish habitat and consider changes as either improvement or degradation (USFS, 1989). Management goals in many riparian areas focus on improving or at least not degrading fish habitat. Other important resource values will be higher when fish habitat condition is optimized (e.g., riparian physical functionality and various ecosystem services). Therefore, this study considers improvement and degradation of riparian systems with respect to fish habitat specifically and to resource values in general. Some management goals may not define these changes as such.

With evidence of both improving and degrading effects of fire on riparian areas in other regions, questions remain about fire's general effects and the variability of those effects on Great Basin riparian systems. How the resource is affected on mid-term management scales of about five years (after the resource has been given a chance to recover and is back in use) is not widely studied and not in the Great Basin. Knowledge of mid-term management scale responses is critical as they affect long-term management options. In view of the context with shrub dominated uplands, suspected increased woody fuel loads in riparian zones, and increasing fire size, we hypothesized consistent degradation to stream attributes after fire. To test our hypothesis, we compared pre- and post-fire attributes on forty three stream riparian areas burned in late-summer over a three-year period by fires of mixed severity across northern Nevada.

2. Study design

2.1. Area description

The northern Great Basin is a temperate desert with cold snowy winters and hot dry summers. The sagebrush (*Artemisia* sp. L.) dominated landscape features numerous north–south oriented fault block mountain ranges interspersed with wide valleys or basins (horst and graben). Bryce et al. (2003) described two level III ecoregions incorporating some 14 level IV ecoregions defined by physiography, elevation, geology, climate, vegetation and landcover that encompass these streams. It is not the intent of this study to relate this variability to the effects of fire, and it is assumed that the variability among these streams represents natural and management induced variability of the northern Great Basin in Nevada.

In the rain shadow of the Sierra Nevada and Cascade mountain ranges, Nevada has the lowest average precipitation of any state (241 mm/year). Most precipitation is deposited as snow, especially at higher elevations, and snowmelt with discharge from springs is the major water source for the streams of this study. Most streams in this region terminate in a closed basin.

The numerous wildfires of 1999, 2000, and 2001 burned over 1.1 million hectares (2.8 million acres) including creeks as shown in Fig. 1. Evaluated stations range in elevation from approximately 1560 to 2230 m (5100–7300 ft), slopes are from approximately 0.5–8.0%, and stream order from 1 to 3 (Strahler, 1964). About half of the streams are of a Rosgen (1996) "B" classification (moderate entrenchment and gradient; riffle dominated with infrequently spaced pools; stable plan, profile, and banks), 40% are "A" (steep, entrenched, cascading step/pool streams), "E" (low gradient; meandering riffle/pool; low width/depth ratio; high meander width ratio) and "F" (entrenched meandering riffle/pool channel; low gradient; high width/depth ratio) streams (near evenly distributed), 8% are "C" (low gradient; meandering, point-bar, riffle/pool, alluvial channels; broad, well defined floodplains) and 2% are

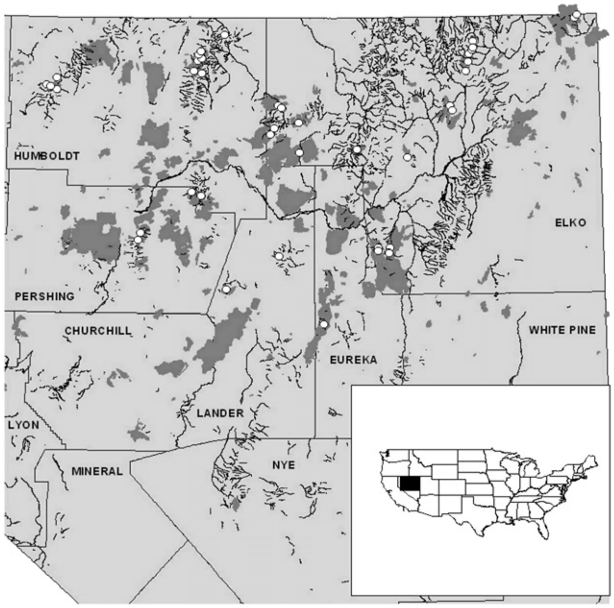

Fig. 1. Stream stations (dots) for this study (northern Nevada counties labeled, perennial steams and fires (dark grey) displayed).

"G" (entrenched gullied step/pool; low width/depth ratio; low to moderate gradient). The thirty year average (1970–2000) precipitation of the watersheds range from 284 to 830 mm (11.2–32.7 in). Typical dominant riparian vegetation includes various species of willow (*Salix* sp. L.), cottonwood (*Populus* sp. L.), aspen (*Populus tremuloides* Michx.), mountain alder (*Alnus incana* L.), river birch (*Betula occidentalis* Hook.), Woods rose (*Rosa woodsii* Lindl.), dogwood (*Cornus sericea* L.), stinging nettle (*Urtica dioica* L.), currants (*Ribes* sp. L.), sagebrush (*Artemisia* sp. L.) and various sedges, grasses, and forbs (Manning and Padgett, 1995).

2.2. Station selection

Forty three study streams (Fig. 1) were selected from the total list of sixty eight burned streams using the following criteria:

- In the Central and Northern Nevada regions of the Great Basin
- Perennial
- Have pre-fire stream survey data available (including photo points)
- Photo points of suitable quality for analysis
- Each station independent of all other stations. That is, no two stations on the same stream. (Streams with multiple potential stations had selected stations chosen at random.)
- Stations on USFS land if otherwise meeting the above criteria for this Forest Service funded study

The burned length of each stream was previously sampled at one to many reaches, one of which was randomly selected and re-sampled after the fire in 2006. Survey intervals (time between closest pre-fire surveys and this study's post-fire surveys) ranged from a minimum of 5 years to a maximum of 19 years. The average survey interval was 11.5 years, the median 10.5 years and the mode 8 years.

2.3. Methods

2.3.1. Channel changes

Changes in the following channel attributes were assessed according to General Aquatic Wildlife System (GAWS) (USFS, 1989) or Modified GAWS (BLM, 2001) protocols.

Bankfull width is observed to the nearest 0.1 m using a meter tape where the flow just fills the channel to the top of its 1.5 year recurrence interval banks, at the point where water begins to overflow onto a floodplain (Dunne and Leopold, 1978).

Riparian vegetation width was recorded to the nearest 0.2 m for the right and left banks at each transect. It was limited to vegetation adjacent to, and that is being maintained by water from, the channel. Riparian vegetation is markedly different from surrounding upland vegetation in this cold desert. (GAWS takes one representative measure of riparian vegetation width that incorporates the stream channel width. For site specific analysis, the bankfull width determined by GAWS was subtracted from the total riparian width and compared to the combined average right and left riparian widths of the Modified GAWS measurements.)

Dominant riparian "vegetation" was classified into: 1) Rock (particle size larger than 0.3 cm); 2) Bare soil, little to no vegetative cover; 3) Annuals, forbs; 4) Grass-perennial bunch grasses; 5) Grass-sod formers; 6) Low brush species; 7) High brush species; 8) Coniferous trees; and 9) Deciduous trees. The second and third most dominant categories were also recorded. The three vegetative classes for each station were summed and the values of the sums were compared for pre- and post-fire.

Bank cover is living riparian vegetation (or none) occurring within the active floodplain. The class: 1) Exposed; 2) Grass; 3) Brush; and 4) Forested; of the streamside vegetation that most commonly influenced each transect was recorded for both the right and left banks 50 feet above and below each transect. (GAWS rates Brush higher than Forested. GAWS data were changed to reflect that of the Modified GAWS for comparison by changing "3"'s to "4"'s and vice versa.)

Bank stability evaluated bank erosion as slow and normal or accelerated on each bank for a distance of 50 feet above and below each transect. Stream banks are part of the active floodplain and form the edge of the bankfull channel. Each bank was assigned a numerical stability class rating: 1) Totally unstable. Heavy erosion and bank sloughing occurring on most of the stream bank length. Erosion constant; 2) Less than 50% stable, but not totally unstable. Moderate to heavy erosion and bank sloughing taking place during high and low flows; 3) 50% or more of bank is stable, but not totally stable. Some erosion present but usually associated with high flows. Banks are recovering naturally; and 4) Bank is totally stable. No evidence of bank erosion at any flow condition. (GAWS evaluates both vegetative and soil stability which was combined for comparison with the integrated modified GAWS assessment.)

Woody organic debris classes and their numerical ratings are: 1) None or infrequent debris, what's present consists of small, floatable organic debris; 2) Moderate frequency, mixture of small (<2 cm diameter) to medium (2–4 cm diameter) debris affects less than 10% of active channel area; 3) Numerous medium to large debris (>4 cm diameter) affects up to 30% of the area of the active channel; and 4) Debris dams of predominantly large material affecting over 30%–50% of the channel area and often occupying the total width of the active channel. One overall rating is given for each survey station.

Bank Angle was determined using a clinometer to measure the angle formed by the stream bank as it meets the more horizontal stream bottom (not necessarily from the horizontal bottom to bankfull). Anomalies such as rocks, hoof prints, etc. were treated by finding a representative angle near the transect. Where the stream bank was undercut, the angle was less than 90 degrees from the protruding edge of the bank to the midpoint of the undercut at the transect line.

Bank Undercut horizontal length was recorded to the nearest 0.01 m directly under the transect line from the furthest point of protrusion of the bank to the farthest undercut of the bank if both measured points were within the bankfull channel.

Dominant Stream Bottom Material size classes are defined as: 1) Other material; 2) Sand/silt (very fine textured soil (<0.3 cm)); 3) Gravel (0.3 cm–7 cm); 4) Cobble (7 cm–30 cm); and 5) Boulders (>30 cm). The bankfull channel under a transect covered by each category was recorded to the nearest 0.1 m. The size class with the average highest percentage from all transects was considered the dominant type for the station.

Embeddedness rates the degree that larger channel particles (i.e. gravel, cobble, and boulder) are surrounded by fine sediment using five classes: 1) Over 75%; 2) Between 50% and 75%; 3) Between 25% and 50%; 4) Between 5% and 25%; and 5) Less than 5%.

Ungulate Damage was evaluated by classifying the right and left stream bank, in intervals of 50 feet above and below each transect. Classes that are combined into one overall rating are: 1) Bank stable and undamaged (Bank damage 0%–10%). Partial or no evidence of bank damage; 90–100% of bank area free from damage. Little or no unnatural bank erosion or sloughing present; 2) Bank damage 11%–20%. Banks are 80%–89% free from damage. Some erosion and sloughing but recovery present after season of rest; 3) Bank damage 21%–40%. Banks are 60%–79% free from ungulate damage. Moderate to heavy bank erosion and sloughing occurring during season of use and continues during rest period. Conditions do not allow for natural recovery of banks to 60% stability; and 4) Bank damage excessive. Banks exhibiting greater than 41% damage from use. Less than 60% of the banks are free from ungulate damage. Severe bank erosion and accelerated erosion and sloughing occur over virtually entire bank surveyed. No evidence of bank recovery, erosion constant. (GAWS ratings are different in that the four classes are divided by bank damages of twenty five percent increments, making comparisons of post-fire collected data to pre-fire data problematic. For example, a GAWS rating of "1" could be interpreted as any Modified GAWS rating from "1" to "3". For this reason, comparison is based on broad, sometimes overlapping categorization.)

2.3.2. About the surveys

Agencies (Nevada Department of Wildlife (NDOW), BLM and USFS) survey stream systems during summer low flow periods by dividing streams into reaches (determined by various criteria) and establishing a representative station at each reach. Stream channel attributes are assessed using either the GAWS or the Modified GAWS protocols. Myers and Swanson (1992, 1993, 1996a,b,c) used such stream survey data and Newman and Swanson (2008) compared such data with three other methods. Established stations are typically comprised of four (26%) or five (74%) transects oriented perpendicular to the channel and spaced at 15.2 or 30.5 m (50 or 100 ft) apart. While the two GAWS methods are similar, some aspects differ and cannot be directly compared. This study examines changes in ten stream attributes and one management attribute (ungulate damage).

Eight of ten stream attributes (Table 1) are measured/assessed at each transect while two (dominant riparian vegetation and woody organic debris) typically have a singular assessment for the entire station. Two of the eight assessed at each transect (riparian width and bankfull width) occasionally had either a singular or no pre-fire measure. For this study, channel changes for attributes with multiple measurements (i.e. measured at each transect) are determined by the difference in the average for continuous variables, or median for ordinal variables, of the transect values from pre- and post-fire survey data. Attributes with singular measures use the difference between the two. Site specific channel changes are those changes in attributes that occur at a particular station, while overall channel changes are the pre- to post-fire difference in attribute values for all combined transect data for all stations across the forty three streams.

2.3.3. Pre-fire survey data

Pre-fire stream survey data including photographs were acquired from agency files for the most recent survey prior to the fire. Documents were photo copied and photographs were scanned. These data were collected for each randomly selected station. Because some data were missing for some stations, a team estimated missing pre-fire attributes by photo assessment. Bankfull width, woody organic debris in channel, and the dominant riparian vegetation were judged to be readily detectable through photography. Each member of the team independently assessed each of these attributes from photos for all study stations.

Bankfull width was modeled by regressing each team member's estimated value by the recorded value for those stations that had data. The model of one team member with the least unexplained variability ($R^2 = 0.42$) was chosen. Each model was then adjusted by the average percentage of difference between the team member's estimated value and the recorded value. Ten bankfull width values were estimated in this way. Similarly, estimates of organic debris

Table 1
Summary of station specific and overall channel changes.

Attribute	n	Percent individual (n) change				Overall change		
		No change %	Increase %	Decrease %	Uncertain[a] %	Median, pre-fire	Median, post-fire	Change[b] (p value)
Bankfull width	43	44	5	28	23	3.4 m	2.7 m	−0.7 m (0.0004)
Riparian width	42	43	14	7	36	6.2 m	11.1 m	4.9 m (0.005)
Riparian vegetation[c] dominant	43	40	48	11	0	5	7	2 (0.0044)
Bank cover[d]	43	60	24	16	0	2	2	no (0.318)
Bank stability[e]	43	53	35	12	0	3	4	1 (<0.0001)
Woody debris[f]	43	56	19	25	0	1	1	no (0.659)
Bank angles	35	77	6	17	0	150 degrees	145 degrees	−5 degrees (0.010)
Bank undercuts	35	94	6	0	0	0.000 m	0.014 m	no (0.934)
Bottom materials[g] dominant	43	53	12	35	0	3	3	yes (0.033)
Embeddedness[h]	32	6	41	53	0	4	3	no (0.150)

[a] *"uncertain"* refers to streams without multiple pre-fire measurements.
[b] Wilcoxon signed-rank test, $\alpha = 0.05$.
[c] Riparian vegetation: Dominant classes are 1 = rock; 2 = bare; 3 = annuals/forbs; 4 = bunch grass; 5 = herbaceous sod; 6 = low brush; 7 = high brush; 8 = conifers; 9 = deciduous trees.
[d] Bank cover classes are: 1 = exposed; 2 = herbaceous; 3 = brush; 4 = forested.
[e] Bank stability classes are: 1 = totally unstable; 2 = <50% stable; 3 = >75% stable; 4 = totally stable.
[f] Woody debris classes are: 1 = none or infrequent to 4 = debris dams of large material affecting >30% of channel.
[g] Bottom material classes are: 1 = other; 2 = sand/silt; 3 = gravel; 4 = cobble; 5 = boulders.
[h] Embeddedness classes are: 1 = >75% embedded; 2 = 50–75%; 3 = 25–50%; 4 = 5–25%; 5 = <5% embedded.

and dominant riparian vegetation from the most accurate team member were used for 18 and 17 stations respectively.

2.3.4. Post-fire survey data

Post-fire stream survey data were collected in the field during the summer of 2005 by a collection team trained by the NDOW stream survey crew while conducting their current surveys. Data were collected according to the modified GAWS (BLM, 2001), which is very similar to the GAWS protocols used by NDOW (USFS, 1989) using the same number and spacing of transects as the pre-fire data. Stations were relocated using GPS and photo verification.

2.3.5. Analysis

All data were entered into Excel spreadsheets for analyses. Descriptive and exploratory analyses (including correlation analyses, *t*-tests and non-parametric tests) were performed using the programs Analyze-it (Analyze it, 2006) and XLSTAT (Addinsoft SARL, 2006). Both use Excel as the primary operating platform but use independent algorithms for statistical analysis. Minitab (2005) was used as a periodic redundant check, although no discrepancies were found among the three programs.

Continuous data (i.e. bankfull width, riparian width, bank angle and bank undercut) were assumed to have station-specific normal distributions, although this was untestable (Shapiro–Wilks test) due to small sample size (D'Agostino and Stephens, 1986). Therefore, the average pre- and post-fire station-specific attributes were compared using Student *t*-tests. The comparison of overall attribute change with categorical response classes could not make assumptions of normality. In fact, exploratory analyses (Shapiro–Wilks test) indicated non-normal distributions that demonstrated high resistance to usual simple transformations. For this reason, station-specific and overall channel change data were analyzed using a non-parametric technique, the Wilcoxon signed-rank test for paired data. Non-parametric tests are only slightly less efficient than parametric ones when underlying populations are normal, but can be much more efficient when they are not (Hollander and Wolfe, 1973). An alpha level of 0.05 was used to define significance.

3. Results

3.1. Channel changes

Bankfull width either from pre-fire field (34 stations) or photo analysis (9 stations) data is comparable at all study sites (Table 1 and Fig. 2). The median overall bankfull width decreased about twenty one percent.

Riparian Width is comparable in all but one study station (Fig. 3). Thirty six percent of these comparisons are based on a sole pre-fire measurement. Among those with multiple width measurements, two thirds exhibited no significant change in riparian width, while one third showed significant change. Of those with significant change, one-third decreased in width, two-thirds increased. Similar proportions occur among all data ($n = 42$): thirty percent decreased, sixty eight percent increased and two percent were identical. The median overall riparian width increased significantly (Table 1).

Dominant Riparian Vegetation either from pre-fire field (26 stations) or photo analysis (17 stations) data is comparable at all study sites (Table 1). The median dominant pre-fire riparian vegetation was grass/sod formers (category 5) while the median dominant post-fire riparian vegetation was high brush (category 7, generally willows). Twenty-six stations were comparable using pre-fire survey data for determining change in the three most

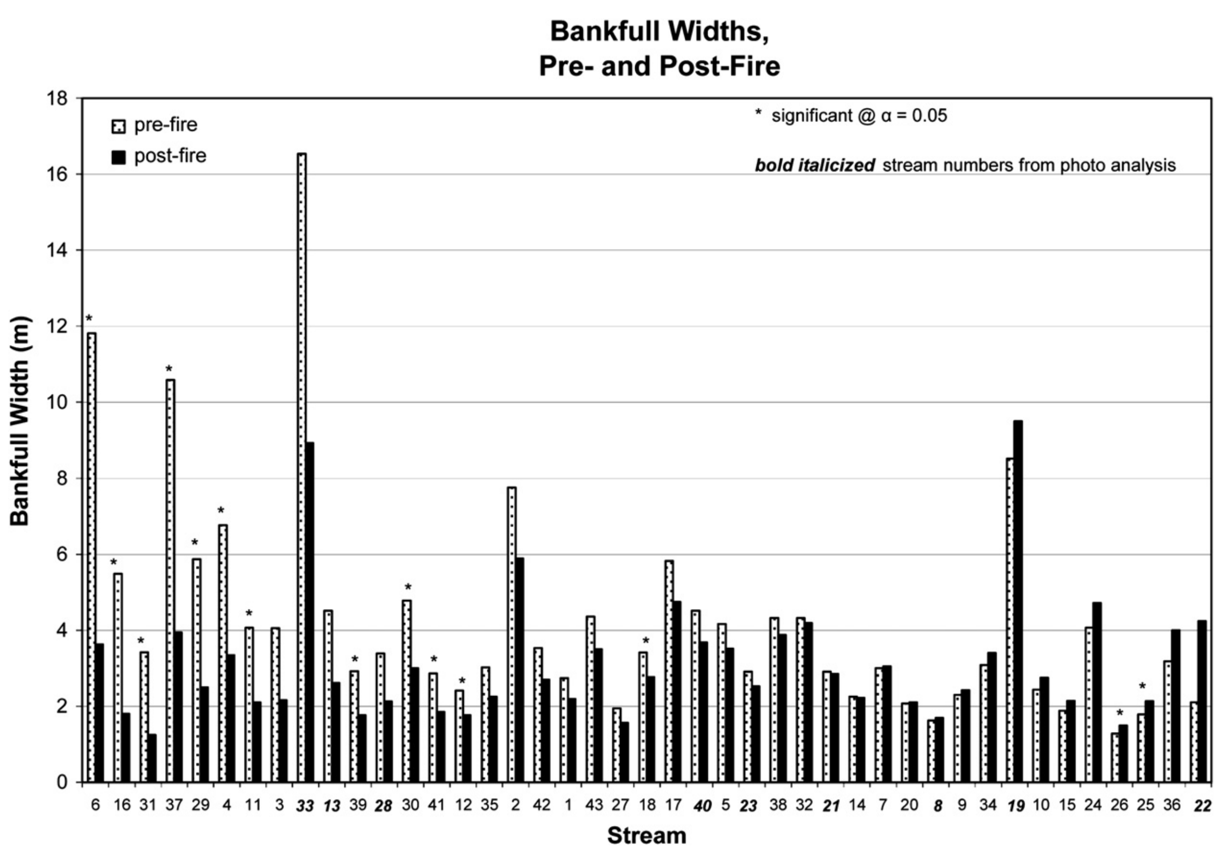

Fig. 2. Bankfull width, pre- and post-fire, by stream. Pre-fire photo estimates are in bold italics.

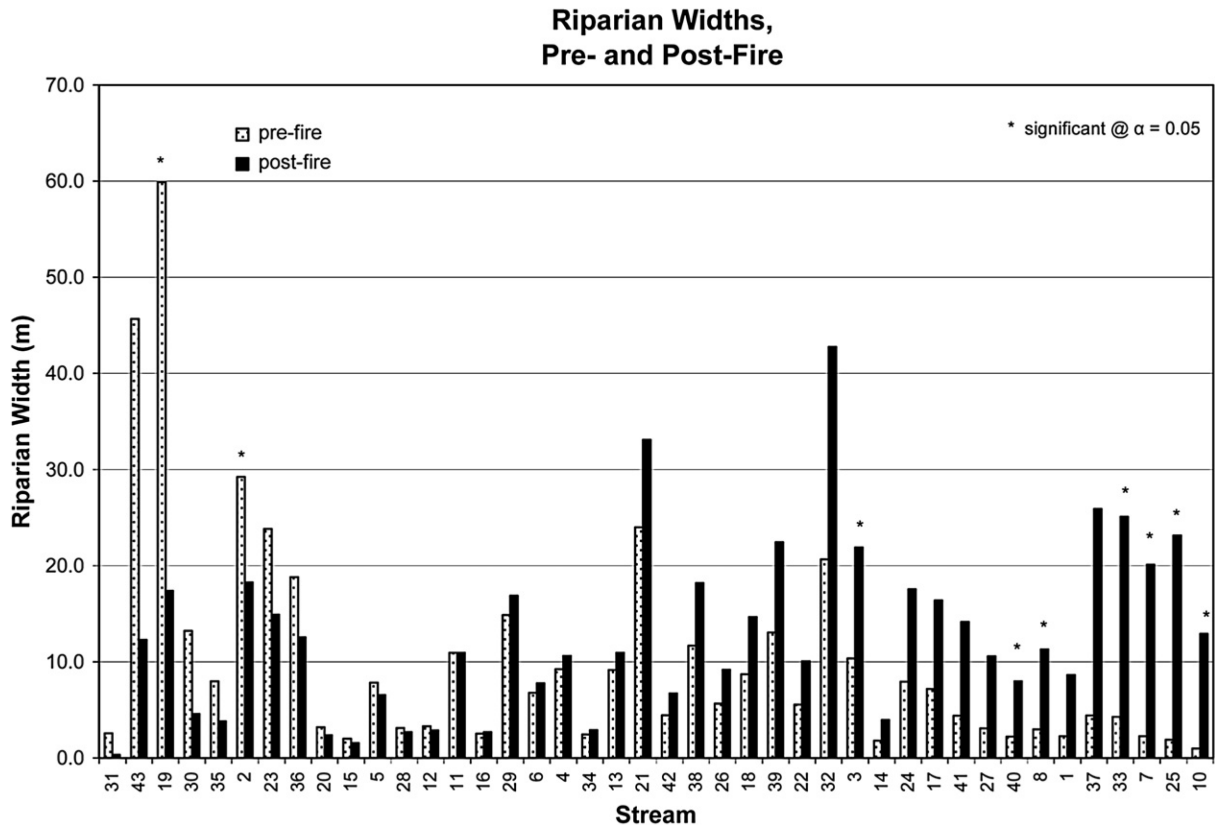

Fig. 3. Riparian width, pre- and post-fire, by stream.

dominant vegetative categories (Fig. 4). Sixty five percent of the study stations had an increase to a higher dominant classification, fifteen percent had no change, and nineteen percent decreased. These results are similar to those using the single dominant class only comparisons (Fig. 5) for all 43 stations, with a substantial reduction of stations that had no change. Comparison of the three most dominant categories also shows a significant increase in class ($p = 0.0074$).

Bank Cover is comparable in all of the study stations (Table 1 and Fig. 6).

Overall, pre-fire cover has equal amounts of grass and brush, post-fire cover has increased grass while brush and forest cover has decreased. Post-fire bank cover is less exposed yet less forested than pre-fire, but this could be an artifact of the mid-categories. The median value for overall pre- and post-fire bank cover is both 2, meaning that the banks are moderately to heavily covered with grasses, forbs, and possibly a low to medium amount of shrubs. There is no significant difference between these median values (Table 1).

Bank Stability was comparable at all study stations (Table 1 and Fig. 7).

Fig. 7 illustrates the over one hundred percent increase in banks that became totally stable and the large decrease in totally and partially unstable banks after the fires. Overall median stability increased significantly by one class.

Woody Organic Debris in channel is comparable at all of the study stations (Table 1 and Fig. 8), 18 of which had pre-fire photo estimates. There was no significant overall change in pre- to post-fire median channel organic debris.

Bank Angles and Undercuts are comparable in 35 study stations (Table 1 and Figs. 9 and 10). Average angles range from 86 to 169 degrees pre-fire, and from 96 to 157 degrees post-fire. Most stations had no significant change in bank angle (Table 1), likely due to the high variation of individual measurements (approximate overall standard deviation is 38.5 degrees). Interestingly, eight did have significant changes in bank angles despite the high variation. Six of the significant changes were due to decreasing angles; two increased. The median overall bank angle decreased significantly but not by much. Average within-station pre-fire undercut values range from 0.00 to 0.21 m, and post-fire from 0.00 to 0.33 m. Only two stations had significantly different, increased, undercut. The overall average pre-fire undercut is 35 mm, 33 mm for post-fire. Data are skewed due to a high number of zero values. The medians are not significantly different (Table 1).

Dominant Channel Bottom Material was comparable in all study stations (Table 1 and Fig. 11). The median dominant material is gravel for both pre- and post-fire data. However, there is a significant difference (Table 1) between the medians. This is noted in the decrease of cobble (by nineteen percent) and the increase of sand (by nineteen percent). The increase in boulder and decrease in other materials is not significant.

Embeddedness was comparable in 32 of the study stations (Table 1 and Fig. 12). Only two stations had a statistically significant change in median embeddedness; however, this lack of significance is likely driven by the small number of replicates ($n = 4$ or 5 transects per station). Median pre-fire embeddedness of streams was 4 while post-fire was 3; however, this is not significant (Table 1).

Ungulate Damage was somewhat comparable on 27 study stations. This must be considered with some caution. Sixty three percent of stations were of the GAWS format which defines the categories differently, having broader ranges that several categories of the modified GAWS format could fit. Ninety two percent of post-fire data placed ungulate damage at twenty percent or less, while only sixty five percent of pre-fire data could possibly fall in this range. Or, eight percent of post-fire data was over twenty percent ungulate damage, while at least thirty eight percent pre-fire data was over twenty percent ungulate damage (Fig. 13).

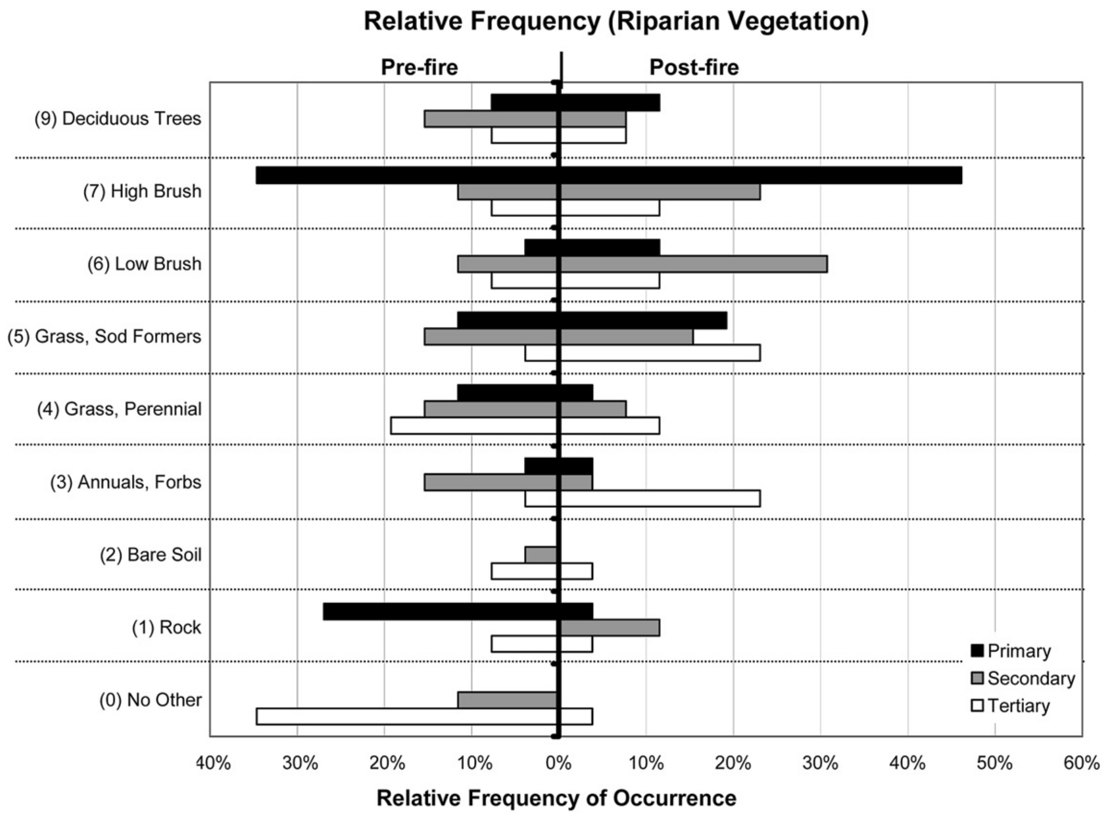

Fig. 4. Relative frequency of the three most dominant plant types, pre- and post-fire, $n = 26$.

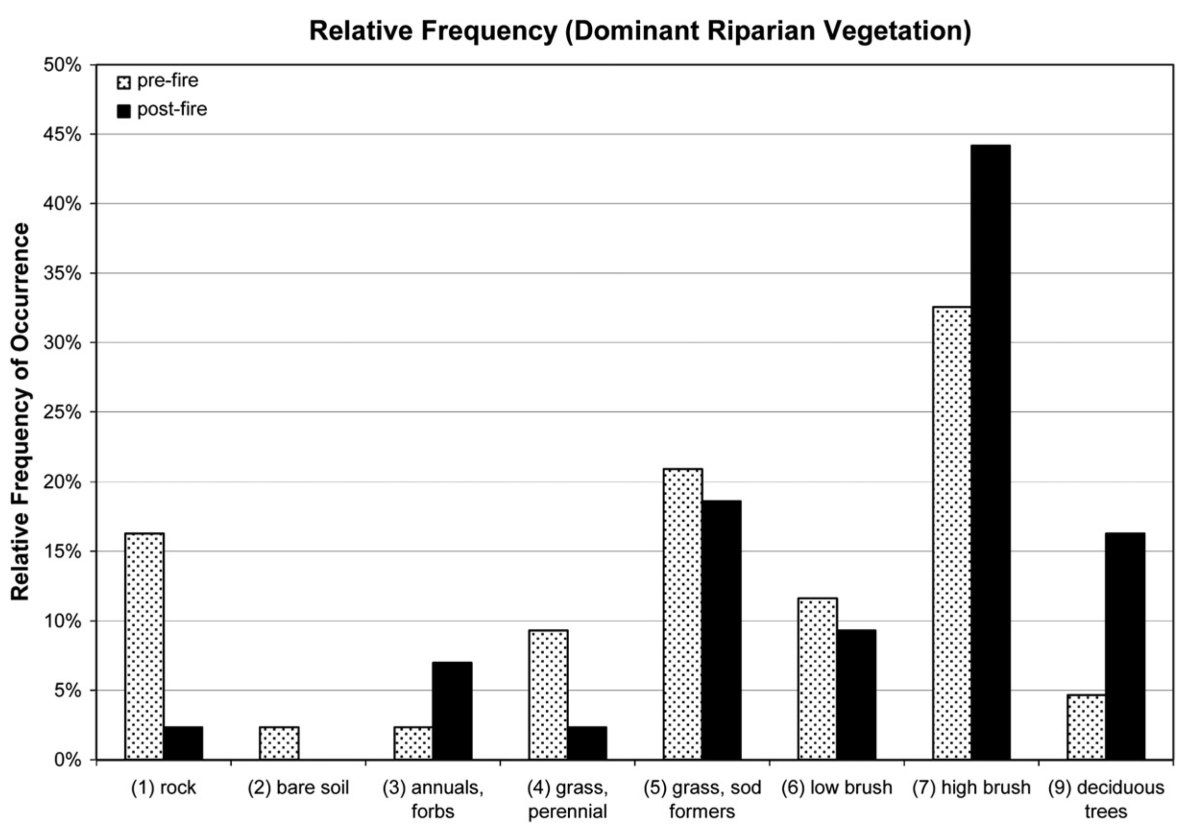

Fig. 5. Relative frequency of dominant plant type, pre- and post-fire.

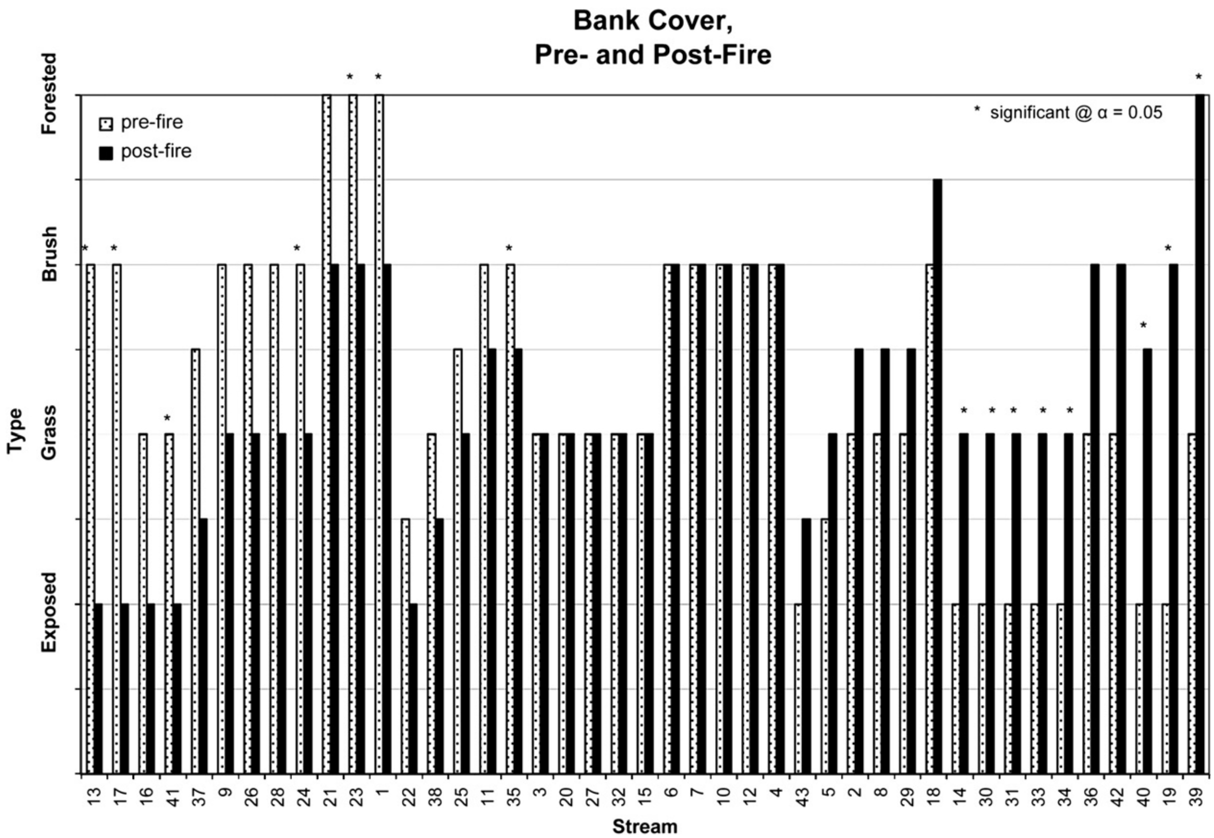

Fig. 6. Bank cover, pre- and post-fire, by stream.

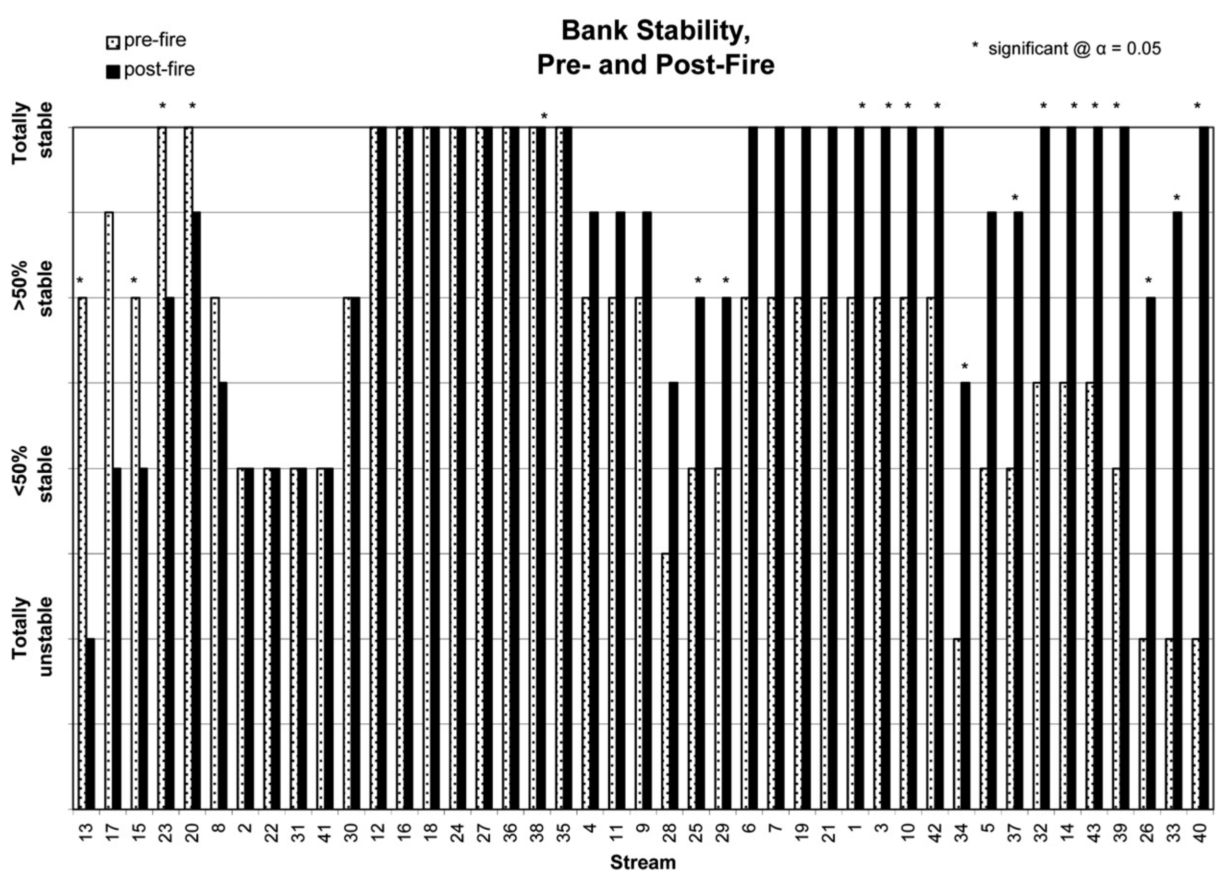

Fig. 7. Bank stability, pre- and post-fire, by stream.

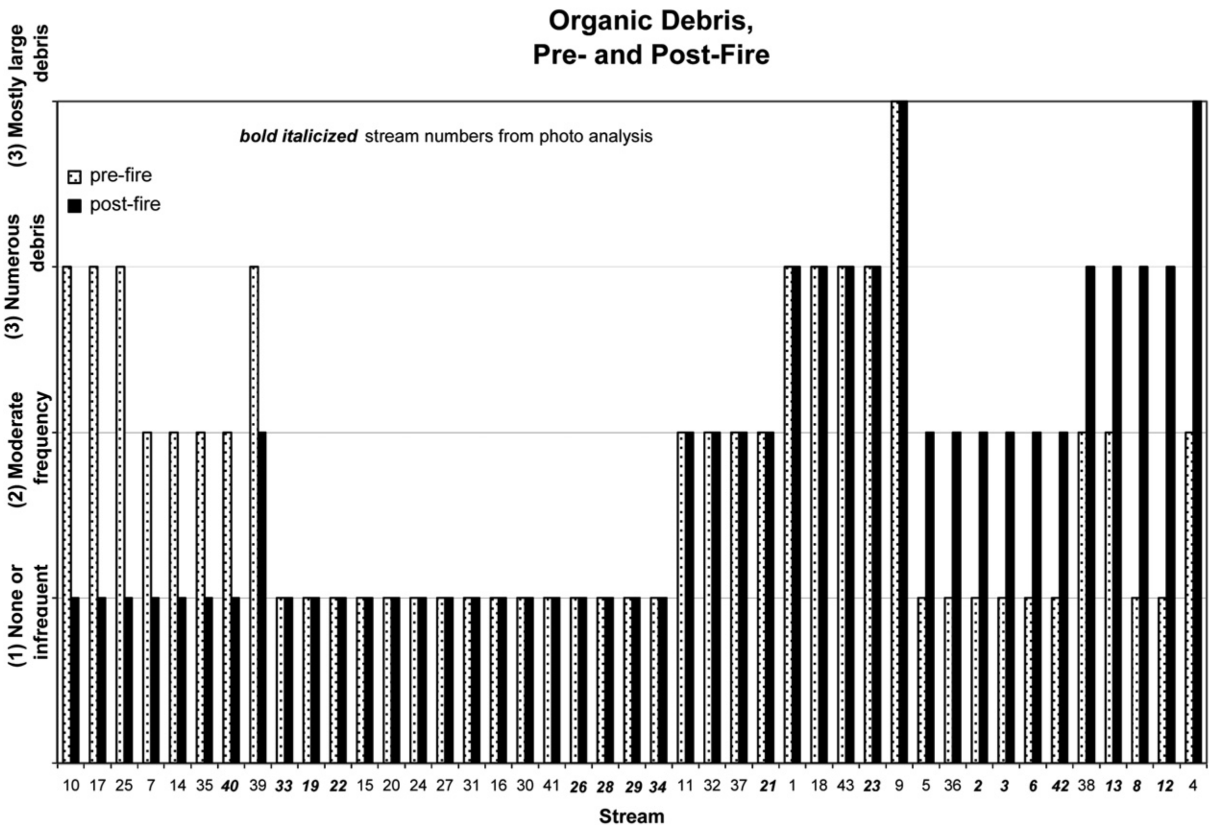

Fig. 8. Organic debris, pre- and post-fire, by stream.

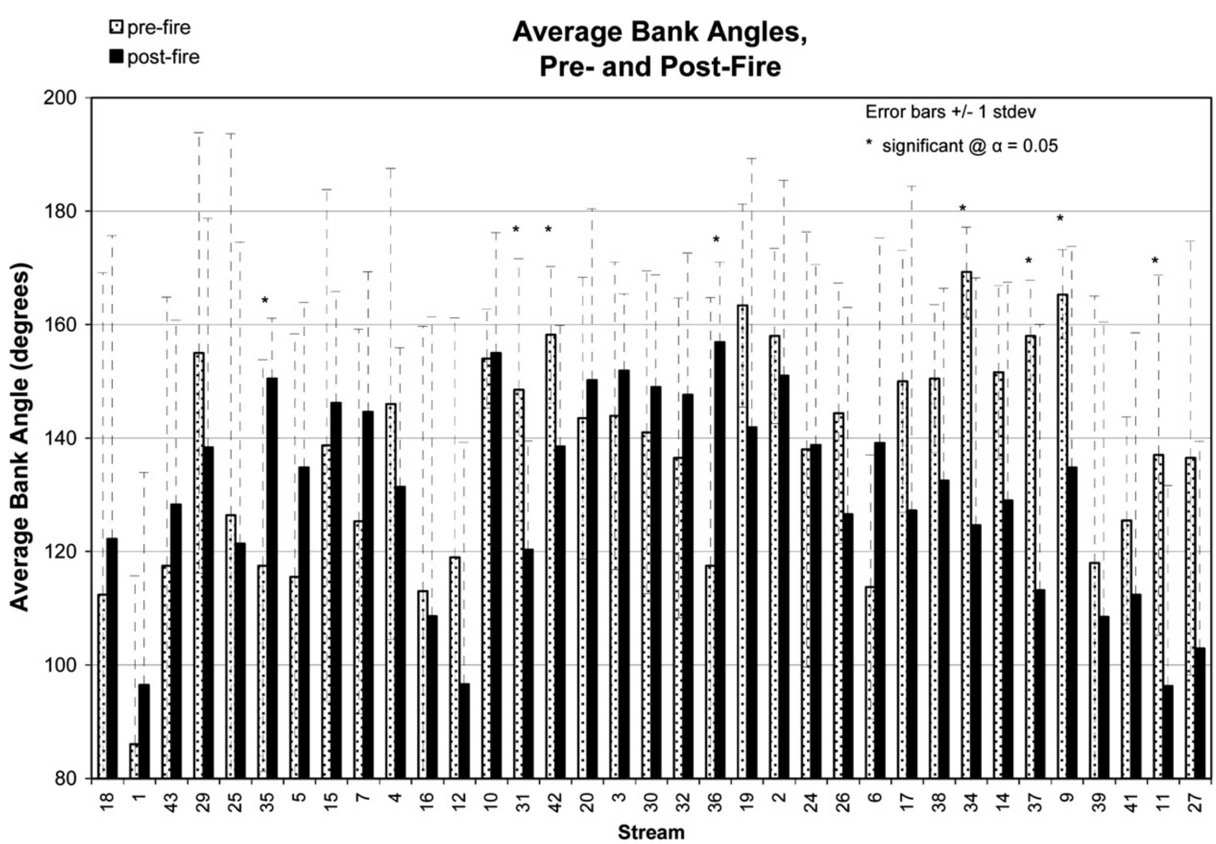

Fig. 9. Average bank angle, pre- and post-fire, by stream.

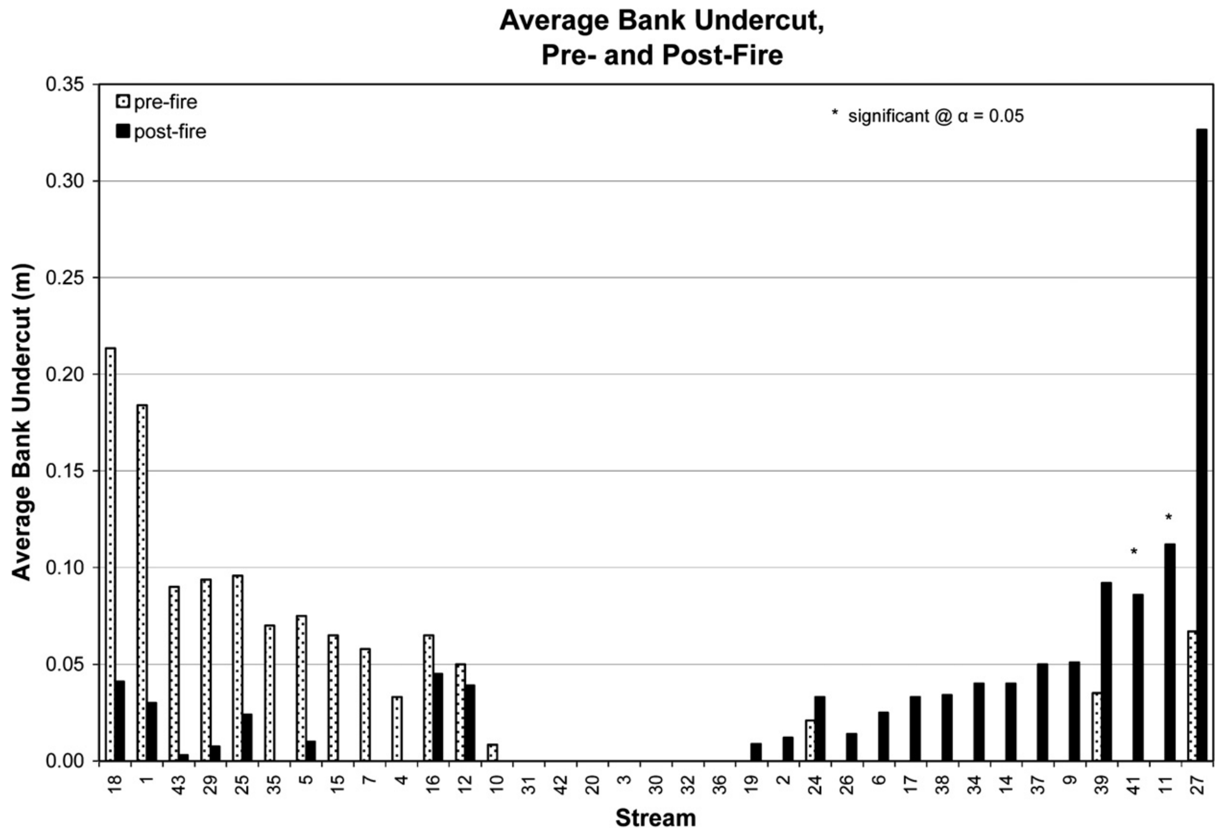

Fig. 10. Average bank undercut, pre- and post-fire, by stream.

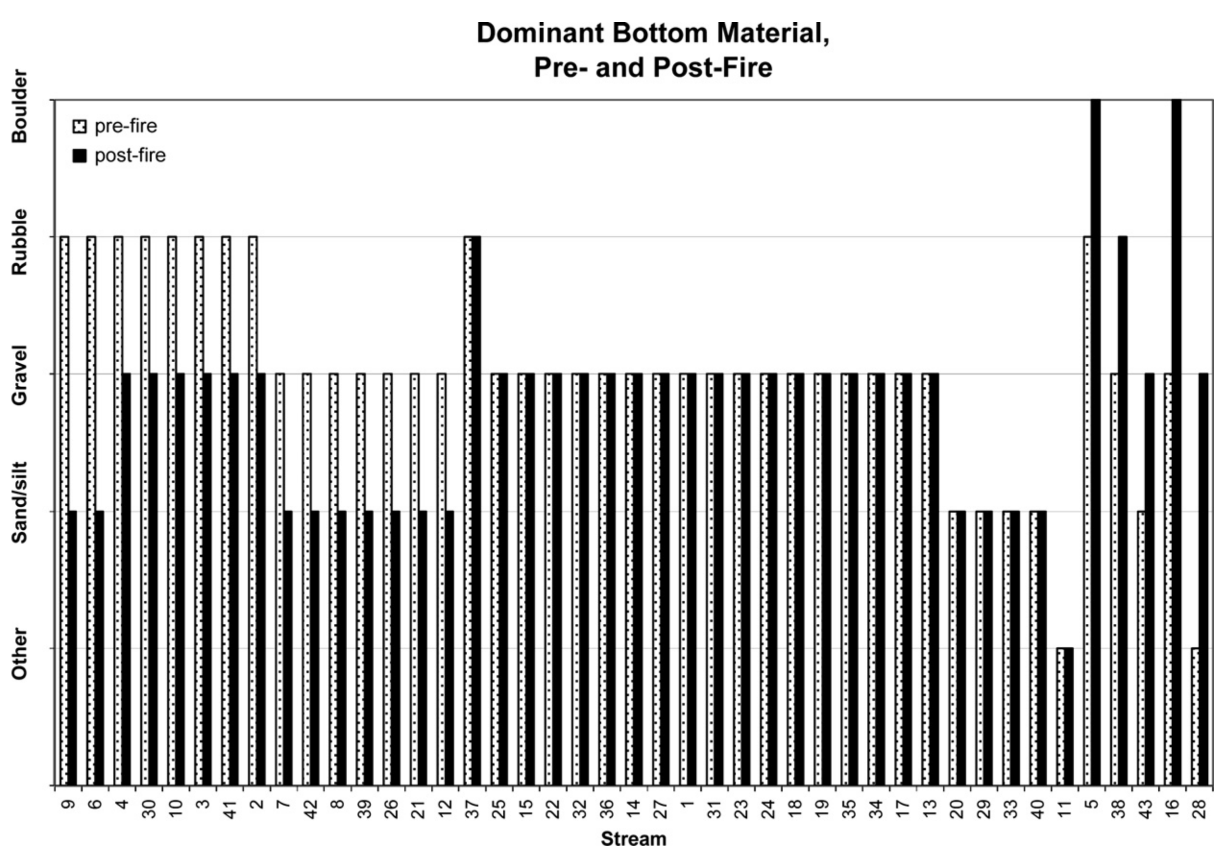

Fig. 11. Dominant bottom material, pre- and post-fire, by stream.

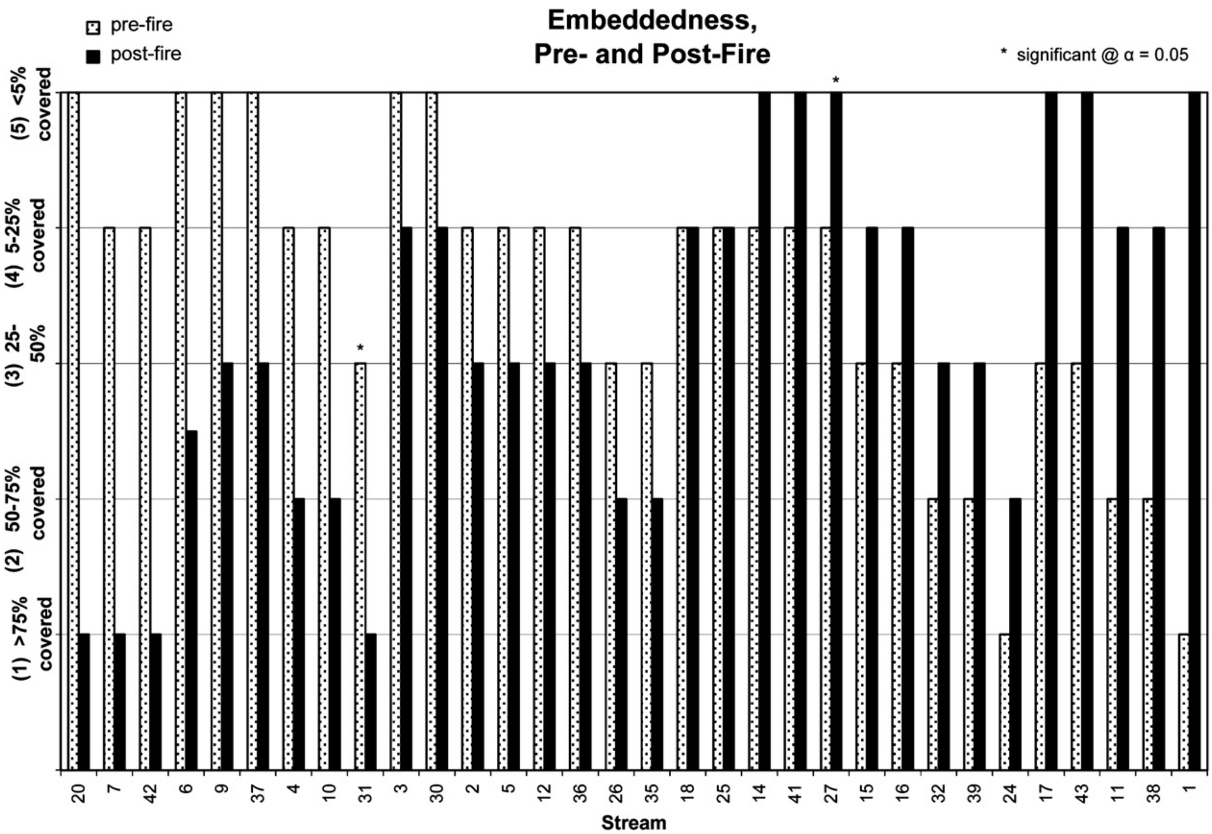

Fig. 12. Embeddedness, pre- and post-fire, by stream.

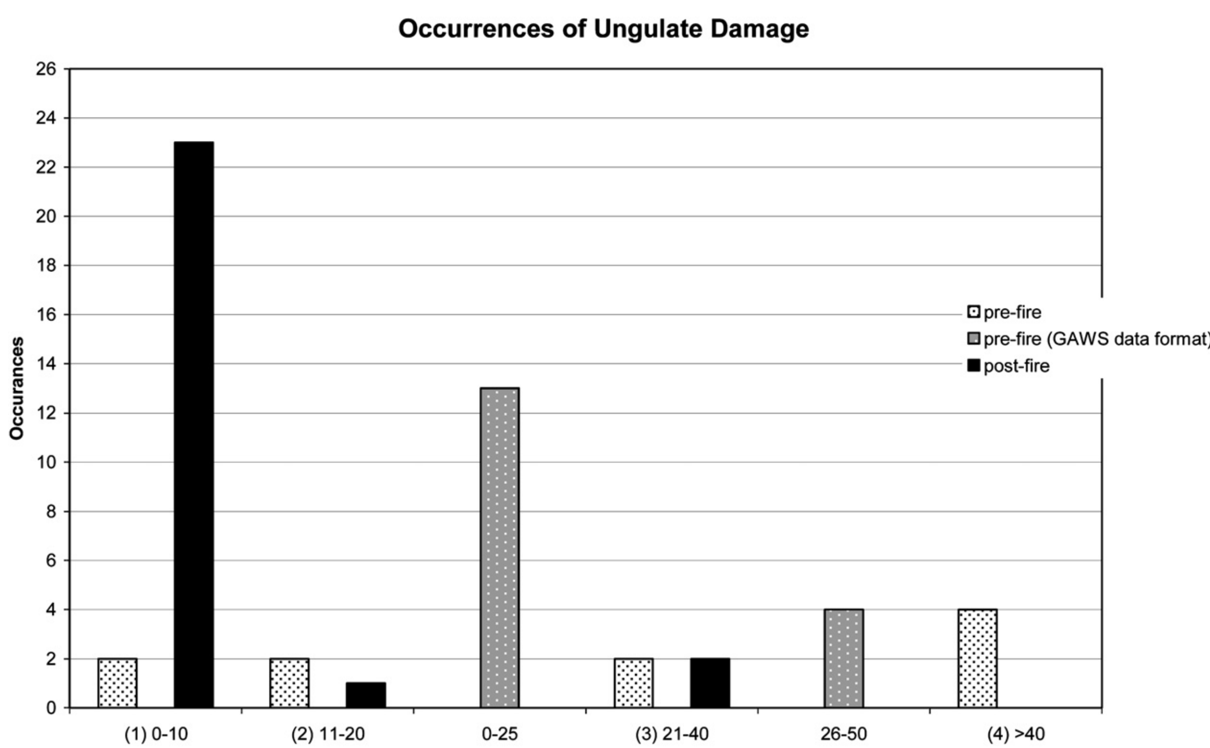

Fig. 13. Occurrence of ungulate damage, pre- and post-fire. Grey pre-fire columns (0–25 and 26–50) represent data in GAWS format.

4. Discussion and conclusions

Overall changes occurred in six of the ten channel attributes examined by this study (Table 1). Of these, NDOW considers five of them improving fish habitat and one (fining of the bottom material) degrading fish habitat. It appears there may have been an influx of sand into the systems, which leads to an insignificant increase in stream bottom embeddedness. This would be expected after a fire, although it would likely be much more evident shortly after the fire (Neary et al., 2005).

A confounding issue is that the fires occurring in northern Nevada for the time of this study were followed by lower than average precipitation. Although some localized storms of heavy precipitation occurred in some study watersheds, most may not have had enough precipitation to cause large enough flows or erosion to manifest morphologic channel changes. Conversely, hydrophobic conditions may have persisted longer making smaller amounts of rainfall and snow runoff more effective at increasing runoff and erosion. After the 1988 Yellowstone fires, relatively moderate change in channel morphology was observed between 1989 and 1990 likely due to the below-normal spring runoff. Most changes were seen in first- through third-order streams with steep gradients. However, runoff events of 1991 and 1992 were larger and produced significant channel alterations (Minshall et al., 1997). Given that many of the streams in this study are lower order streams (1–3) on steeper gradients and possibly prone to some degree of hydrophobicity, it was speculated that morphologic channel changes could have occurred in these streams over the four to six years after fire. Non-morphologic channel changes (e.g., vegetative responses) could also be evident.

Lower than average precipitation and discharge, which is not as effective at transporting added sediment, made it possible to detect sedimentation even 5 years after the fires. Moody and Martin (2001) suggest this effect could be noticeable for long periods. Low amounts of rainfall can lead to increased embeddedness even without fire, as embeddedness tends to increase until a high flow leaves behind clean gravel and cobble. The effects were slight however, and open to other interpretations if not total dismissal. This may also be a result of the differing GAWS protocol for measuring stream bottom composition, which may bias toward larger sediments.

Overall, it appears that the fires did not lead to much if any degradation to the stream channels, and some attributes have improved with respect to fish habitat specifically and resource values in general. Beche et al. (2005) found prescribed fire in riparian zones of streams in the Sierra Nevada had no or short-lasting (one year) impacts, particularly in the areas of riparian vegetation, woody debris, and sediment. While Sierra Nevada riparian environments are quite different in many ways from those of the interior Great Basin, Beche et al. (2005) attributed the limited impacts to conditions similar to many of those found in this study, namely small portions of watershed burned, moderate topography, relatively low post-fire precipitation, and low to moderate fire severity.

Whether a risk that higher fuel loads in riparian areas would lead to hotter fires that could severely compromise or destroy the plant community's ability to rebound is not directly addressed by this study. However, if the assumption is made that many of the study sites had increased fuel loads due to past fire suppression or a lengthy natural fire interval, there is little evidence to suggest it led to riparian degradation.

Whether improvements of attributes examined by this study were due to the effects of fire cannot be concluded. During the time span of survey intervals, managers in many areas have worked to improve riparian zones. The decreased ungulate damage found by this study indicates their efforts are leading to improvements. It is possible that these efforts resulted in conditions that were better at the time of the fire than five years afterward, and that fire could have degraded any or all of the attributes examined. However, if management efforts remain similar to what was experienced by riparian areas during this study, fire did not degrade the resource to below a level of resilience. Sites under good management before a fire were generally not adversely affected by wildfire. This conclusion may or may not hold during a period of wet years (e.g., high spring runoff) after a fire.

Figs. 2–13 and Table 1 show that while there may have been little overall degradation to riparian zones, there is much variation in individual riparian response. This variation could be used to ascertain how individual riparian zones respond given their physical functionality, burn severity, precipitation, or other pertinent variables. This is focus for further studies.

This study concludes that overall degradation to stream channel attributes examined in those riparian areas that had fires in or over them during 1999–2001 was minimal to non-existent, while variability of degradation within each attribute and among individual riparian stations was considerable. Some attributes improved at these sites, though whether improvement was due to fire was not ascertained. This contradicts the initial hypothesis of consistent degradation. There appears to be a lack of evidence that fire is a devastating force that should be controlled to protect Great Basin cold desert riparian areas.

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