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Wildfire burn patterns and riparian vegetation response along two northern Sierra Nevada streams

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Abstract

Riparian vegetation plays an integral role in the ecology of the streams it borders, and in many western US forests, is subjected to frequent wildfire disturbances. Many questions concerning the role of natural fire in the dynamics of riparian zone vegetation remain unanswered. This case study explores the relationships between wildfire burn patterns, stream channel topography, and the short-term response of riparian vegetation to fire along two creeks in the northern Sierra Nevada mixed-conifer forest. Post-fire sampling along 60, 3 m wide transects across riparian zones was used to document the topography, species distribution, sprouting response, and seedling recruitment 1 year after the Lookout fire in the Plumas National Forest, CA. Our results indicate that larger riparian zones acted as natural fire breaks, limiting the progression of the predominantly backing fire downhill toward the stream. On Fourth Water creek's steeper first terraces, where crown fires occurred, the percentage of burned plants that sprouted was higher than in the less-severely burned and more extensive first terraces of Third Water creek (93% versus 33%, $P < 0.05$). Total seedling recruitment was higher along Fourth Water creek (69 versus 35 seedlings, $P < 0.05$), while plant regeneration along Third Water creek was primarily vegetative. Along Fourth Water creek, the percent of burned hardwoods that sprouted increased with proximity to the water's edge from 33% on the slope above the riparian zone to 95% on the gravel bar, suggesting that moisture content plays a role in riparian species response to fire. An influx of white fir (*Abies concolor* Gordon & Glend. (Lindl.)) seedlings on the second terraces of Third Water creek may indicate a shift in species composition if future fires are suppressed and regeneration trends do not change significantly in the next few years. These results contribute to the limited research on natural fire in riparian zones, and can inform management strategies designed to restore and maintain riparian vegetation in the fire-prone forests of the Sierra Nevada.

Keywords: Riparian; Fire; Mixed conifer; *Alnus incana*; *Cornus sericea*; Sprouting; Regeneration; Fire management

1. Introduction

The occurrence of wildfires in riparian zones presents a complex management concern throughout the western US, particularly in ecosystems characterized by high fire frequency. Mixed conifer forests of the Sierra Nevada and elsewhere are characterized by a fire-dominated disturbance regime. Although recent federal policies encourage the acceptance of fire in fire-adapted ecosystems as an inevitable and even integral ecological factor (see USDA, 2000), the practice of fire suppression has dominated federal fire management over the past century, and continues to be administered particularly in streamside ecosystems. More recently, scientists have emphasized the necessity for a better understanding of the role fire plays in riparian zones, suggesting that the intertwined nature of high ecological diversity and frequent disturbance should be taken into account for riparian and stream habitat restoration and sustainability (Naiman et al., 1993, 2000; Dwire and Kauffman, 2003; Everett et al., 2003). A unique study of the influence of prescribed fire on riparian vegetation and aquatic ecosystems found few overall effects, noting changes in understory species composition and a loss of area coverage, but no decrease in plant diversity (Bêche et al., 2005).

By affecting plant community structure and composition, fire has the potential to influence how riparian vegetation affects stream ecosystem functions. Riparian root systems help maintain soil structure and prevent erosion, overstory canopies influence water temperature through shading, and vegetation increases interception and evapotranspiration, affecting flood potential (DeBano et al., 1979; Knight and Bottorf, 1984).

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Streamside vegetation supplies woody debris and other detritus, affecting stream flow, habitat structure, and water quality and in turn influencing aquatic organisms (Mahoney and Erman, 1984; Roby and Azuma, 1995; Erman, 1996; Bragg, 2000). Both short (less than 1 year) and long-term changes in stream ecosystems are associated with fires burning the adjacent riparian zones. Soon after a fire, stream temperatures, flow, and nutrient inputs may increase and changes in channel morphology may occur (Schindler et al., 1980; DeBano and Neary, 1996; Keller et al., 1997). Longer-term effects include increased organic debris and dry ravel deposition and potential changes in leaf litter type and amount of sediment (Davis et al., 1989; Minshall et al., 1989; Roby and Azuma, 1995). The composition and abundance of riparian vegetation likely influences the degree and type of effect fires ultimately have on streams.

Citing a concern for the sensitivity and resilience of stream ecosystems to wildfire, management plans generally exclude wildfire and prescribed burning from Sierra Nevada riparian corridors (DeBano and Neary, 1996), even as dendrochronological evidence indicates significant and consistent historical fire influence on riparian vegetation structure and composition (Olson, 2000; Russell and McBride, 2001; Skinner, 2001; Everett et al., 2003). Determining the fire regime for streamside ecosystems has been limited by the stochastic nature of fire occurrence along with the relatively minor extent of riparian vegetation coverage. Some estimates suggest fire frequencies in the riparian zones of inland US forests are lower and more variable than those in the associated upland forests (Barrett, 1988; Agee, 1993; Skinner and Chang, 1996; Everett et al., 2003), while in drier inland pine-fir forests in Oregon, Olson (2000) showed that fires occurred with similar frequency in upland and riparian vegetation. Evidence for the characterization of fire regimes may be limited in riparian zones, due to the low presence of the gymnosperms necessary for dendrochronological analyses of historical fire patterns. In contrast to upland forests, the geomorphology and hydrologic features of riparian corridors typically result in a greater dominance of shrubs and deciduous trees, with moister and cooler microclimates and higher levels of both live and downed fuel moisture content (Dwire and Kauffman, 2003). Simply extrapolating fire ecology from upslope forests to their riparian components may be inaccurate or even detrimental to sustaining riparian communities that evolved within the context of both flood and fire disturbance regimes.

Although riparian plants are not generally considered fire-dependent, they often possess characteristics of disturbance-adapted species, such as rapid sprouting, suckering, or prolific invasion of disturbed sites (Keeley and Zedler, 1978; Naiman and Decamps, 1997). The influence of fire in riparian zones depends on the synergism of independent species responses and adaptations. An understanding of some key elements of the riparian wildfire regime, including spatial patterns of burn, severity, and vegetation response, would provide useful information for managing riparian areas, and has not been researched in the mixed-conifer or other forests outside the southwestern US. In the present study, we analyze the 1-year post-fire response of riparian vegetation along two Sierra Nevada creeks to the Lookout wildfire of 1999. We also examine how the topography of stream channel environments affects fire spread and severity (Kushla and Ripple, 1997). The importance of physical variables such as slope, proximity to the stream edge, and stream channel topography is two-fold—their influence on fire burn patterns, and how they affect vegetation composition, abundance, and tissue moisture content. In turn, fire spread and severities are likely affected by riparian-related characteristics such as live and dead fuel moisture contents and loads (Dwire and Kauffman, 2003). We therefore seek to link the Lookout wildfire burn patterns to both topography and vegetation. Our objectives are to characterize the short-term response of riparian vegetation to the Lookout wildfire, to interpret any relationships between burn patterns and vegetation response, and to explore the role topography plays in woody plant regeneration and burn patterns.

2. Methods

2.1. Study sites

Located in the Plumas National Forest about 10 miles southwest of the town of Quincy, CA, the study reaches extend 900 m downstream along two similar east-to-west flowing creeks. Third and Fourth Water creeks are small fish-bearing tributaries that lead into Bear creek, which drains a basin of 20 km^2 and feeds the Middle Fork of the Feather River (Fig. 1). The creeks range between 1500 and 1600 m in elevation. The site is characterized by a Mediterranean climate type, with average annual precipitation of 100 cm and average low and high annual temperatures of −3 and 21 °C (Quincy, CA, 2005). Over 95% of the annual precipitation (50% snow) falls between December and April, while summer thunderstorm precipitation averages 3 cm (Quincy, CA). A complex of soils developed from alluvial deposits characterize the riparian zones of either creek. The upslope mixed-conifer forest is composed of incense cedar (*Calocedrus decurrens*, Torrey (Florin)), white fir (*Abies concolor* (Gordon & Glend.) Lindl.), sugar pine (*Pinus lambertiana* Dougl.), and Douglas-fir (*Pseudotsuga menziesii* (Mirbel) Franco *var. menziesii*) in the overstory and serviceberry (*Amelanchier alnifolia* (Nutt.) Nutt.), manzanita (*Arctostaphylos glauca* Lindl.), huckleberry oak (*Quercus vaccinifolia* Kell.), and deer brush (*Ceanothus integerrimus* Hook. & Arn.) in the understory. Nomenclature for all species in this study follows the Jepson Manual (Hickman, 1993). Detailed descriptions of the plant species composition of the mixed conifer forest can be found in Walker (1992).

In late August and early September of 1999, the lightning-ignited Lookout fire burned 1064 ha of national forest and state land. The region had received less than 1 cm precipitation that summer while temperatures were consistently high, leading to a complex of late-summer lightning wildfires burning concurrently in the Plumas National Forest. The Lookout fire ignition occurred along the ridge above the Bear creek drainage, where it burned downhill to Bear creek and continued up the opposite slope. The nearby Bucks and Pigeon fires were larger than the

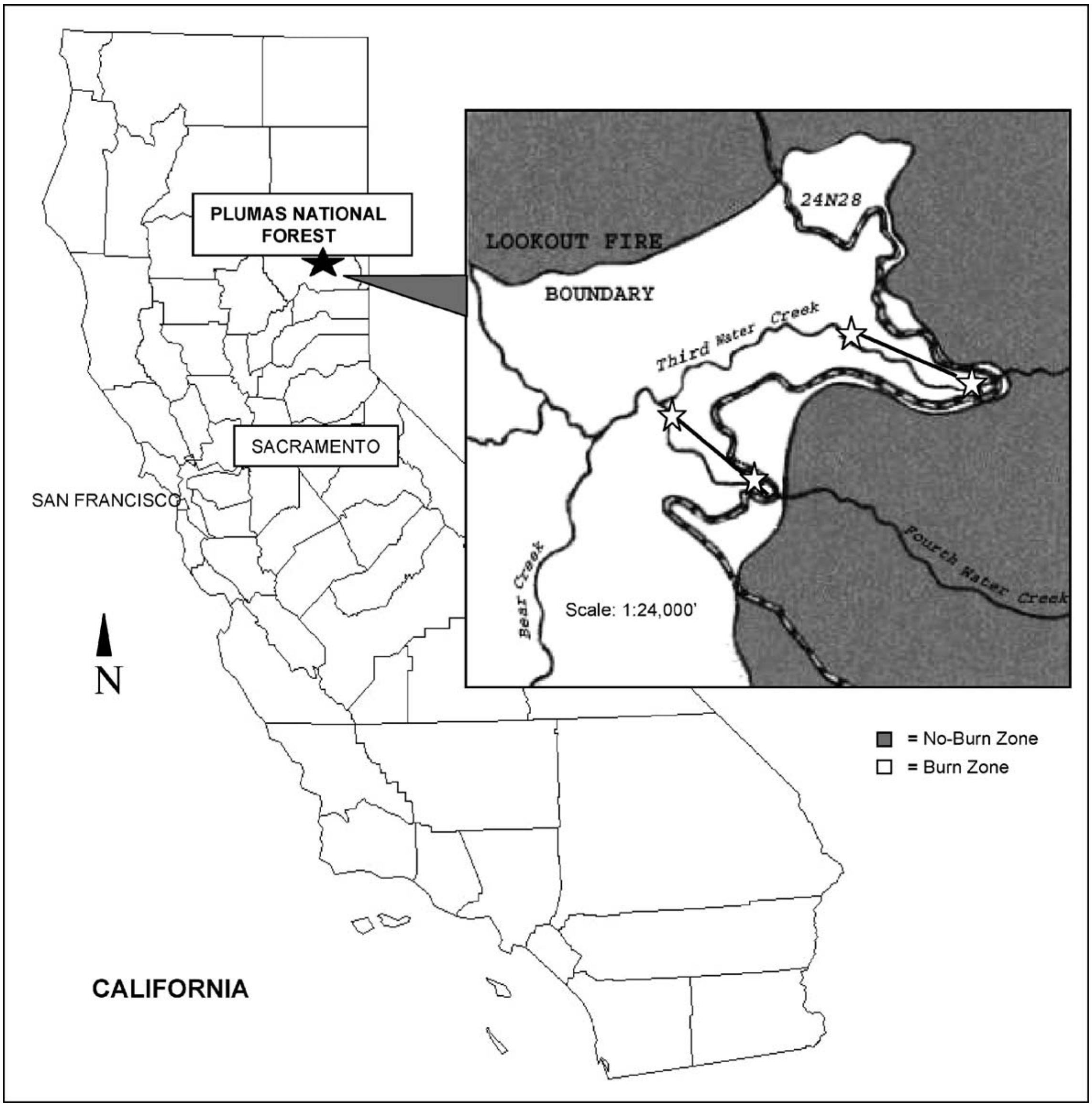

Fig. 1. Map of state of California and location of study sites in the Plumas National Forest. Inset map shows study reaches on Third and Fourth Water creeks between stars. Burn zone is unshaded.

Lookout fire, but did not burn any fish-bearing streams. After 3 weeks, the Mt. Hough Complex comprised of the three fires was controlled, leaving nearly 17,000 ha burned.

The Lookout fire included patches of low, medium, and high burn intensity. The stretches of riparian zones along Third and Fourth Water creeks included sections of all burn zone intensities, as defined on Forest Service (USFS) fire maps from observations fire severity gathered following the fire's burn period. As the fire was known to have burned downslope in the greater watershed encompassing our two creeks, we believe that the fire burned downslope along the two study site creeks as well. There exists the possibility that sections of the riparian zone were influenced by headfire behavior caused by spotting below the fire boundary, especially where stream channels were steepest. We look to evidence of the fire's behavior such as charring and scorch patterns and ground and surface fuels consumption in the context of each transect's topography to help substantiate USFS reports that the fire was a backing fire.

In contrast to other streams within the burn perimeter, Third and Fourth Water creeks were deemed the best sites to evaluate the post-fire riparian vegetation response. They were selected for this study because of the consistent presence of riparian vegetation, their substantial perennial flow, and the degree to which the fire burned a significant length of their respective reaches. The eastern boundary of the fire was partially defined by Forest Service road 24N-28, which intersected both Third and Fourth Water creeks and served as an access point for the study transects (Fig. 1).

2.2. Field methods

All samples were collected 1 year after the Lookout fire ignition, in late August of 2000. The sampling reaches were initiated at a random point within the vicinity of each stream's uppermost burn boundary, and extended downstream along the southern aspects. Northern aspects were largely devoid of riparian vegetation due to the steepness of their slopes, and were therefore not sampled in our study. Therefore, only one side of each stream was sampled. Following each stream downhill, thirty transects were established at 30 m intervals along each stream. Transects were consistently 3 m in width (measured parallel to the direction of stream flow) and extended upslope from the southern edges of the stream to 3 m beyond the upper boundary of the riparian zone. Because the extent of the riparian zone extending up the southern slope from the creeks' edges varied, the lengths of our sampling transects also varied, from 0.3 to 25 m in Third Water and from 4 to 11 m in Fourth Water creek. A permanent marker was established on the slope at the end of each transect for future analysis of longer-term vegetation recovery.

Riparian zone boundaries were determined visually, based on the absence or presence of characteristic riparian vegetation species such as mountain alder (*Alnus incana* (L.) Moench ssp. *tenuifolia* (Nutt.)) and red-osier dogwood (*Cornus sericea* L. ssp. *sericea*), along with indications of floodplain terraces. Distinct fire boundaries within each transect were evidenced by burned and unburned litter and duff layers, exposed mineral soil, and charring on plants. Winter precipitation (snow) effects did not appear to confound the determination of the burn boundaries. We did not sample non-riparian vegetation outside of the transects, but generalized about surrounding live vegetation composition, identifying the predominant overstory tree species, to evaluate potential seed sources for regeneration in the riparian zones. We also observed burned vegetation outside of the transects and across the creeks to help estimate characteristics of the fire in the immediate vicinity of each transect, including fire severity and direction of spread. Because our transect locations were standardized, we encountered a number of entirely unburned riparian areas (nine transects in Third Water, 11 in Fourth Water creek). These non-burned transects were not inventoried for vegetation response, as our study focused on the relationships between burned vegetation response, fire severity, and topography of the burned riparian zones. We did sample topography in these transects, to characterize the features of unburned riparian areas within our study sites.

The lengths of the gravel bars, escarpments, and terraces were measured from the creek edges to the end of each burned transect. Riparian profile features, such as gravel bars, terraces and their escarpments, and slopes, were measured for length and elevation changes between each topographic position and above the level of the water surface. Due to the close proximity of the streams to their riparian zones, we assumed that the elevation of the terraces when compared with the elevation of the creek was a reasonable approximation of the relative depth to the water table between transects. We did not sample depth to the water table explicitly. "Gravel bars" were identified as the expanse of gravel located adjacent to the stream's edge, typically found beneath the primary flood plain. "First terraces" were the primary flood plains, which rose above the gravel bar and provided soil substrate for riparian vegetation. "Second terraces" were found above the first terraces, representing less frequently inundated flood plains and including some non-riparian vegetation. "Slopes" extended upslope from any of the terraces and occasionally directly from the gravel bars. They were differentiated as "riparian slopes" and "slopes outside riparian zone" based on the presence or absence of riparian vegetation. Degrees of slope were measured using a clinometer, and an average value was obtained for both the riparian zone within the transect as well as the slope extending uphill from and outside of the riparian zone. Inclinations of the opposite banks were also recorded. The transects were mapped using tape measures and scaled graphing paper to show the boundary between the riparian and non-riparian vegetation, the location of all burned vegetation and new seedlings, the boundaries of the topographic positions, and the extent of the burn.

Burn characteristics were examined for each transect individually, and one severity value was attributed to the entire transect. We used an evaluation of the degree of damage to vegetation within transects, such as the degree of vegetation consumption due to fire, evidence of bole and/or crown scorch, or the level of surface litter combustion to assess fire severity (Wells, 1979). Severity was defined as the degree to which an entire transect was altered by the fire (McPherson et al., 1990), and was categorized as: (0) no sign of fire in riparian zone, (1) low-severity understory fire, with charring of surface and ground fuels but low mortality for the majority of the understory vegetation, (2) mid-severity ground and surface fuels fire, with large areas of fire-caused mortality in understory vegetation and conspicuous char and soot throughout, with little damage to boles or crowns of overstory, (3) mid-to-high severity fire, with bole scorch and patchy crown consumption (scorching and/or torching) of proximate or in-transect trees and mixed-severity understory burn, and (4) high severity fire, complete crown combustion of the majority of surrounding trees with or without bole scorch (suggesting crown fire behavior), with mixed-severity or patchy understory burn. As transects were generally small in area (less than 30 m^2) we were able to use one fire severity value for each transect. Because of the time lag between the Lookout fire and our study, special care was taken to distinguish fire-caused damage from that of other disturbance factors, such as flooding, pathogens, or insect attacks.

In each burned transect, we measured the distance of each burned shrub species or new seedling from the creek edges. We also measured the location of the vegetation within the 3 m length of the transect, mapping each individual at a 0.3 m spatial resolution. Plant species were identified whenever possible and all burned plants within the riparian zone of each transect were sampled. In order to differentiate seedlings from growth from below ground organs, we gently examined the roots of suspected seedlings. For each sprouting plant, the type and number of sprouting shoots (basal, stem, or both) and the diameter at which they occurred were determined.

Due to the absence of any pre-fire data on the two creeks, the effects of the burn on riparian plant species could only be determined from the residual vegetation. Although our sampling inventoried all burned plants on the transects, completely combusted plants, if present before the fire, would have left little if any trace and could not be inventoried. We have therefore focused on the percent of plants that were burned and sprouted as a measure of resilience of the burned vegetation, rather than assuming that the burned vegetation accurately represents a mortality rate for the pre-fire plant populations.

2.3. Data analysis

Because of the variable and significantly different lengths of the riparian transects, vegetation data were analyzed in relative terms (Bendix, 1994). Percent composition values were calculated using the number of individuals of a particular species divided by the total number of plants or a defined subset of plants (for example, sprouting plants on Third Water creek first terraces). Relativisitic comparisons (using percentage values) of the vegetation data made possible comparisons between different lengths transects, as well as between the two creeks.

For between-creek comparisons, the number of plant individuals of each species was averaged to obtain a mean value for each creek. This approach was repeated for between-creek analysis of fire severity and topography. Differences between topographic features, percent sprouting responses and seedling recruitment for each species, and fire severity between the two creeks were tested using a Student's *t*-test for data that approximated normality. Analysis of variance (ANOVA) was used to compare within-creek to between-creek variance, and to determine whether between-creek comparisons were warranted.

To explore relationships between vegetation response, topographic features, and burn patterns and severity, we used linear regression models, and to test the relative strength of these relationships, step-wise multiple regression analyses and simple linear correlation analyses. To determine whether transects subjected to higher burn severity were associated with topography, we used fire severity as the dependant variable and regressed it against independent variables including the lengths of each topographic position (i.e. gravel bar, first terrace), slope percent inside and upslope from the riparian zone, and the total length of the riparian zone. The same independent variables were regressed against the mean percentage of burned plants that sprouted for each transect. We also used simple linear regression analysis to determine if diameter of burned vegetation was related to post-fire sprouting response, and to determine whether higher burn severity would correlate with lower sprouting and seedling recruitment.

3. Results

3.1. Fire and riparian zone topography

Along with the extent and pattern of burn in the riparian zones, ANOVA results showed differences in the characteristics of the topographic profile between the two creeks, warranting a comparison of the burn patterns in the two creeks. The major difference between the topography of the two creeks was the length of the first terrace, which, when present, measured nearly twice as long for Third Water than Fourth Water creek on average (Student's *t*-test, $P = 0.02$) (Table 1). More than twice as many transects along Third Water creek included second terraces than along Fourth Water creek, while the mean elevation increase from the gravel bar to the terraces was significantly shorter (Student's *t*-test, $P < 0.05$). Only half of the transects along Fourth Water creek included well-established first or second terraces, in contrast to 80% of Third Water creek transects (Table 1). Gravel bars were more common in Fourth Water creek transects (Table 1). The total riparian zone length extending from the gravel bar through the second terrace was greater along Third Water creek (Student's *t*-test, $P = 0.03$).

Steep slopes and rocky escarpments characterized the stream channel of Fourth Water creek, with riparian transect slopes measuring 123% on average (Table 1). In contrast, the topography along Third Water creek typically included long, flat riparian terraces with little exposed rock. Significant differences existed between the steepness of the slopes of the riparian zones of the two creeks (Table 1).

Only three transects along Third Water creek and five along Fourth Water creek were burned throughout the entire transect length, encompassing the area from the water boundary to

Table 1
Mean dimensions (standard deviation given in parentheses) of topographic features and burn patterns for riparian zones of Third and Fourth Water creeks

Topographic feature or burn pattern	Third Water creek	*N*	Fourth Water creek	*N*
All transects, stream width (m)	2.8 (1.5)	30	3.3 (1.5)	30
Gravel bar length (m)	2.1 (1.3)	21	2.4 (2.05)	27
First terrace length (m)	**6.3 (4.9)**	19	**3.3 (1.9)**	14
Second terrace length (m)	5.9 (6.1)	5	4.9 (1.3)	2
Total length of riparian zone (m)	**9.9 (6.5)**	30	**7.4 (2.7)**	30
Slope within transect (%)	**74 (56)**	30	**123 (45)**	30
Number of burned transects	21	21	19	19
Number of transects with level 1 or 2 severity	18	18	10	10
Number of transects with level 3 or 4 severity	3	3	9	9

The number of transects (out of 30 for each site) with the given feature is indicated in the second column (*N*). Significant differences are in bold ($P < 0.05$). Levels of fire severity are described in Section 2 of this paper.

Table 2
Extent of burn along riparian and non-riparian topographic features for Third and Fourth Water creeks

Topographic feature	Transects burned beyond this feature (%)		Transects with burn boundary located on this feature (%)	
	Third Water creek	Fourth Water creek	Third Water creek	Fourth Water creek
Slope outside riparian zone	70	67	30	33
Slope inside riparian zone	63	67	7	0
Base of slope	63	64	0	3
Second terrace	60	64	3	0
Second terrace escarpment	43	64	17	0
First terrace	16	57	27	7
First terrace escarpment	10	27	6	30
Gravel bar	10	17	0	10
Stream edge	0	0	10	17

The standard direction of the burn was downhill from the slope outside the riparian zone, to the slope, the second terrace, first terrace, gravel bar, and finally to the stream edge.

beyond the end of the riparian zone. Around one-third of all transects sampled (20 out of 60 total) had no evidence of fire in the riparian zones (Table 1). Where fire entered the riparian zones, it was likely to burn beyond the second terrace and towards the creek (Table 2). In the Third Water transects, the majority of the burn boundaries were located somewhere along the first terrace or on the escarpment between the first and second terraces, while the first escarpment (typically between the gravel bar and first terrace) served as the burn boundary in most Fourth Water creek transects (Table 2). Only 16% of the longer Third Water creek riparian transects were burned beyond the first terrace, compared with 57% of Fourth Water creek transects (Table 2). A step-wise multiple-regression analysis revealed that, of all the topographic factors, the lengths of Third Water creek gravel bars had the strongest influence on the distance of the fire boundary from the stream edge, accounting for 40% of the variability ($r^2 = 0.396$, $P = 0.005$). In Third Water creek transects, these longer gravel bars were associated with a lower extent of riparian zone burned, while steeper slopes had a small but positive correlation with more extensive burn areas. Again, characteristics of Fourth Water creek's topography were not significantly related to the variability in burn patterns along its transects.

Nearly half of Fourth Water creek transects had evidence of levels 3 and 4 fire severity while Third Water creek was predominantly characterized by levels 1 and 2 severity burns (Table 1). Gravel bar and riparian slope length were inversely proportional to fire severity along Third Water creek ($P = 0.024$ and $P = 0.054$). Including the other measures of topography and riparian zone length (shown in Table 1), these factors yielded a multiple regression model predicting fire severity with an r^2 value of 0.561. A similar analysis could not detect significant correlations between topographic features and fire severity in Fourth Water creek transects.

3.2. Vegetation characteristics and regeneration following fire

Twelve and 14 woody species were identified on Third and Fourth Water creek transects respectively, with nine mutual species (Table 3). Nearly all of Third Water creek transects were populated with mountain alder, in contrast to only 30% of Fourth Water creek transects. Mountain alder and red-osier dogwood comprised the highest percent composition for Third Water and Fourth Water creeks, respectively (Table 3). The slopes above Fourth Water creek's second terraces had greater species richness than the first, second, and third terraces combined, while richness was highest on the first and second transects of Third Water creek. White fir seedlings and red-osier dogwood were the only plants to experience fire-caused mortality on the infrequent second terraces of Fourth Water creek. In contrast, the more numerous second terraces of Third Water creek had a diverse composition of burned plants, including both riparian and non-riparian species such as mountain alder, bitter cherry, white fir, and twinberry. For both creeks, huckleberry oak, chinquapin, deer brush, and incense cedar were only found on slopes outside of the riparian zone (Table 3).

Nearly all of the burned vegetation on the gravel bars of both creeks sprouted. All of the Douglas spirea, thimbleberry, bush chinquapin, and pacific dogwood that burned sprouted (Table 3). Throughout the riparian profile, red-osier dogwood made up nearly 60% of the sprouting vegetation along Fourth Water creek, while red-osier dogwood and mountain alder each contributed between 35 and 40% on Third Water creek. Mountain alder only comprised 21% of the total composition of sprouting plants along Fourth Water creek. Some key differences existed in vegetative response across the topographic positions between the two creeks. The average number of burned plants that sprouted was higher on the first terraces of Fourth Water creek (Student's *t*-test, $P < 0.05$; Table 3). Only 30% of the burned mountain alder on Third Water creek's first terrace sprouted, in contrast to 90% along Fourth Water creek (Table 3). The trend was similar for arroyo willow and red-osier dogwood. Excluding the gravel bar, sprouting along Third Water creek was more abundant further from the stream edge, while the opposite trend was evidenced along Fourth Water creek (Table 3).

The lengths of the riparian slopes and second terraces had the highest positive correlation with the percentage of plants that sprouted along Third Water creek (linear regression, $r^2 = 0.34$ and 0.25, respectively, $P < 0.05$). The percent of

Table 3
Average percent species composition of burned plants and new seedlings at each topographic position, and the percent of each burned plant that sprouted at that topographic position along Third and Fourth Water creeks, CA

Species scientific name	Species common name	Percent composition by topographic position, percent of individuals sprouting											
		Total number of plants		Gravel bar		First terrace		Second terrace		Slope-inside riparian		Slope-outside riparian	
		Third Water	Fourth Water	Third Water	Fourth Water	Third Water	Fourth Water	Third Water	Fourth Water	Third Water	Fourth Water	Third Water	Fourth Water
Salix lasiolepis Benth.	Arroyo willow	5	3	0	0	5.5, 33	4, 100	0	0	0	0	0	0
Prunus emarginata (Hook.) Walp.	Bitter cherry	1	3	0	0	0	8, 100	3.5, 0	0	0	4, 100	0	0
Sambucus mexicana C. Presl	Blue elderberry	0	1	0	0	0	0	0	0	0	4, 100	0	0
Chrysolepis sempervirens (Kellogg) Hjelmq.	Bush/Sierra chinquapin	0	1	0	0	0	0	0	0	0	0	0	5, 100
Ceanothus integerrimus Hook. & Arn.	Deer brush	0	1	0	0	0	0	0	0	0	0	0	5, 0
Pseudotsuga menziesii (Mirbel) Franco var. menziesii	Douglas fir	1	13	0	0	0	0	0	0	10, N/A	0	0	60, N/A
Spiraea douglasii Hook.	Douglas' spirea	4	0	0	0	0	0	0	0	34, 100	0	0	0
Quercus vaccinifolia Kellogg	Huckleberry oak	8	1	0	0	0	0	0	0	0	0	72.5, 75	5, 0
Calocedrus decurrens (Torrey) Florin	Incense cedar	1	1	0	0	0	0	0	0	0	0	9.5, N/A	5, N/A
Acer glabrum Torr.	Mountain maple	0	6	0	0	0	0	0	0	0	4, 100	0	0
Alnus incana (L.) Moench ssp. *tenuifolia* (Nutt.)	Mountain alder	47	25	100, 100	23, 100	48, 30	40, 90	38, 54	0	34, 67	4, 0	0	0
Cornus sericea (L.) ssp. *sericea*	Red-osier dogwood	22	63	0	77, 90	37, 60	36, 78	3.5, 0	67, 100	0	71, 31	0	0
Amelanchier alnifolia (Nutt.) Nutt.	Service-berry	6	0	0	0	2, 100	0	15, 20	0	0	0	0	0
Pinus lambertiana Dougl.	Sugar pine	0	1	0	0	0	0	0	0	0	0	0	5, N/A
Rubus parviflorus Nutt.	Thimbleberry	5	8	0	0	0	4, 100	0	0	22, 100	9, 100	0	0
Lonicera involucrata (Richardson) Banks	Twinberry	4	0	0	0	5.5, 66	0	3, 100	0	0	0	0	0
Abies concolor (Gordon & Glend.) Lindley	White fir	42	9	0	0	2, N/A	8, N/A	38, N/A	33, N/A	0	4, N/A	18, N/A	15, N/A
Species richness (total number of species)		12	14	1	2	6	6	6	2	4	7	3	7

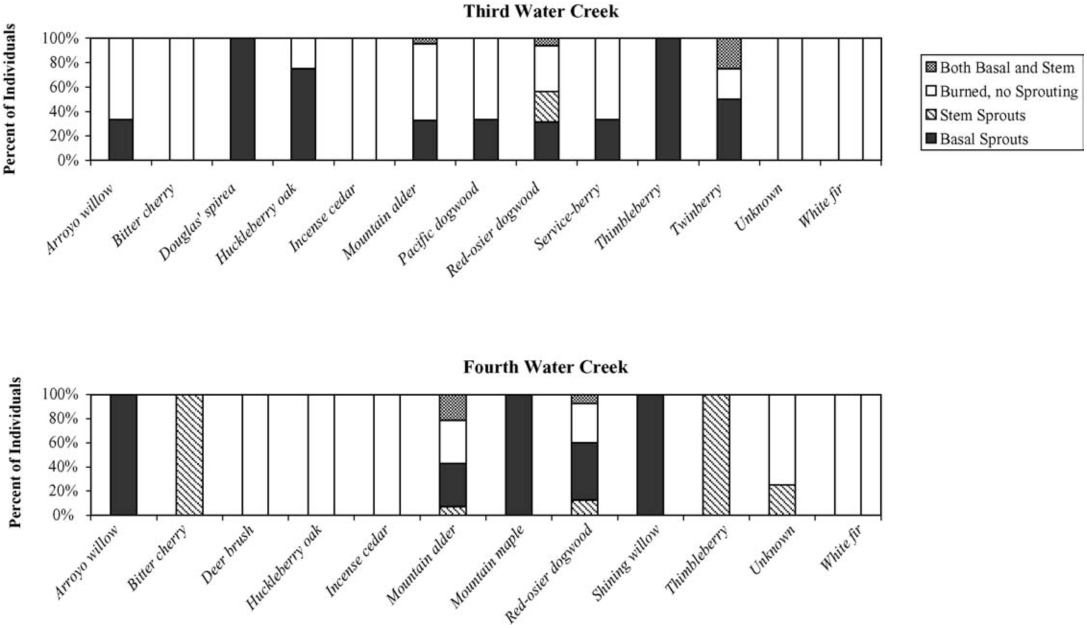

Fig. 2. Percent of individuals for each species sprouting from stem or basal buds, or succumbing to fatality following the fire along Third and Fourth Water creeks. ''Unknown'' species could not be identified using field methods.

burned plants sprouting along Fourth Water creek increased significantly with the length of the riparian slope extending above the second terrace ($r^2 = 0.55$, $P < 0.05$). Linear regression analysis showed a positive relationship between the distance of the burn boundary from the stream edge and the number of burned plants that sprouted for Third but not Fourth Water creek transects ($r^2 = 0.38$, $P < 0.005$). This suggests that the fires burning all the way through Third Water creek's riparian zone to the stream's edge resulted in a higher degree of cambial kill. Fire severity and the percent of burned plants that sprouted were not significantly correlated for either creek. More seedlings were established on the higher severity burned transects along Fourth Water creek, although fire severity and seedling recruitment were not significantly correlated across the riparian zones of either creek.

The occurrence of sprouting following the fire was not significantly related to the diameter of the burned plant stems on any topographic position along the two creeks. The span of diameters observed in sprouting individuals was narrow, ranging from 1 to 6 cm in diameter at the base. This diameter range would correspond to only slight differences in bark thickness. Diameter therefore may not have reflected an actual difference in the insulation capacity of the bark, which affects the ability of the plant to sustain heating and avoid cambial death. Yet patterns of sprouting type differed between the two creeks in some species. Most of Third Water creek mountain alders regenerated exclusively from basal sprouts (88% of sprouting individuals), while Fourth Water creek alders sprouted from both stem and basal buds (Fig. 2). All of the thimbleberry in Third Water creek transects responded to burning through basal sprouting, while Fourth Water creek thimbleberry sprouted only from the stem. Patterns of stem and basal sprouting strategies between the dogwood populations of the two creeks were similar (Fig. 2).

More new seedlings were found on the transects along Fourth than Third Water creek, with 69 seedlings in a total area

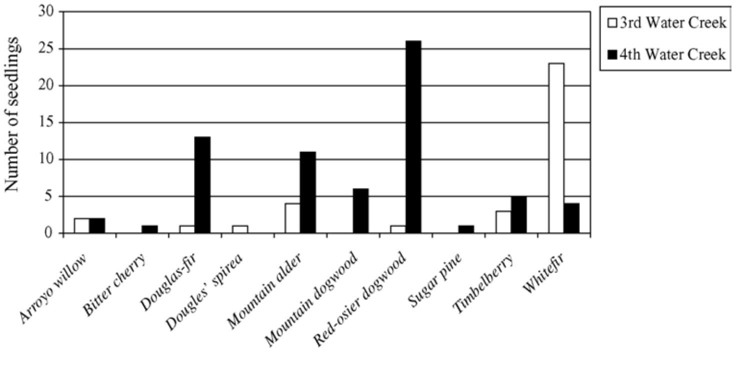

Fig. 3. Number of new seedlings in burned plots of Fourth and Third Water creeks.

of 480 m^2 in comparison to 35 seedlings in 567 m^2 (Student's *t*-test, $P < 0.05$). Seedling species composition was comprised of mostly red-osier dogwood, white fir, Douglas-fir, and mountain alder (Fig. 3). While burned white fir trees outnumbered other burned conifers at both sites, Douglas-fir was the most abundant conifer seedling along Fourth Water creek ($N = 13$). In contrast, regeneration of conifers on Third Water creek transects was predominantly due to white fir establishment on second terraces ($N = 23$), with a single Douglas-fir seedling found in the riparian zone. The dominant overstory conifer species on most Third Water creek transects was white fir, while seedling recruitment in Fourth Water creek reflected its more diverse surrounding mixed-conifer forest comprised of co-dominant incense cedar, Douglas-fir, white fir, and sugar pine (Fig. 3). The abundance of mature red-osier dogwood on Fourth Water creek's gravel bars, first terraces, and riparian slopes was reflected in the proliferation of red-osier dogwood seedlings ($N = 26$). Three-quarters of the seedlings in Third Water creek were coniferous, while about the same amount was attributable to angiosperms in Fourth Water creek transects.

4. Discussion

4.1. Burn patterns and riparian zone topography

Third Water creek riparian zones, with longer first terraces and more gradual slopes, were less frequently burned to the water's edge than Fourth Water creek areas, suggesting that riparian zone length is negatively correlated with the extent of riparian vegetation burned. Kushla and Ripple (1997) found that, in a wildfire-burned forest in western Oregon, local topography features had a substantial influence on vegetation survival and fire behavior. The gravel bars, first, and second terraces of Third Water creek were closer in elevation to the water level of the creek and likely more moist and cool than those of Fourth Water creek. These longer terraces supported more abundant mountain-alder vegetation than those of Fourth Water creek, seemingly slowing the fire's progression towards the stream edge (Agee, 1993). In other areas of the western US, alder populations along riparian corridors have been classified as natural fire breaks or buffers (Davis et al., 1980; Bêche et al., 2005), while riparian understory shrubs and herbs were characterized by higher moisture contents than their counterparts in upland coniferous forests (Agee et al., 2002). A higher tissue moisture content of the vegetation, surface, and ground fuels on the lower terraces of Third Water creek would have contributed to their acting as natural fire breaks, preventing the fire from reaching the stream edge or even the gravel bar (Dwire and Kauffman, 2003). Also in the Sierra Nevada mixed-conifer forest, Kauffman and Martin (1989) linked higher moisture contents of understory vegetation to lower fire intensity and severity, while Bêche et al. (2005) observed greater fire severity where coniferous litter loads were high, and self-extinguishing of the fire where it contacted moist soil and riparian vegetation. High fuel moistures in riparian zones may be in part responsible for the predominantly low severity fire which characterizes the disturbance regime of the mixed-conifer forest, by slowing rates of fire spread and reducing fire intensity across the greater landscape.

Whether fuel moistures have the capacity to affect fire behavior depends on the environmental conditions under which a fire burns. In the case of the Lookout Fire, our results suggest that the vegetation of the larger riparian zones along Third Water creek acted as natural fire breaks. That only Third Water creek transects evidenced an inverse relationship between fire severity and lengths of riparian terraces may have been the result of our limited sample size, or due to the fact that only half of the transects along Fourth Water creek even had first or second terraces.

4.2. Vegetation characteristics and regeneration following fire

Due to the high frequency of fluvial disturbances in Sierra Nevada creeks, riparian vegetation is typically patchy (Naiman et al., 1993), leading authors to speculate that the likelihood of erratic fire behavior therein is high (Dwire and Kauffman, 2003). Bêche et al. (2005) administered a prescribed fire in a Sierra Nevada mixed-conifer forest riparian zone, and documented patchy fire behavior, severity, and consumption of fuels. Local variability in fire behavior may have been responsible for some of the patterns of unburned areas we observed, as well as the response of the vegetation. Within the dense alder thickets of Third Water creek first terraces, slower moving fires with longer residence times would have emitted more radiant heat while consuming more of the surface fuels in proximity to plant stems, explaining the higher rate of cambial death when compared with Fourth Water creek's less continuous vegetation. Such fire behavior would also explain the greater proportion of basal sprouting along Third Water creek, while stem sprouting was more common in Fourth Water creek transects. With rockier and steeper topography, the pre-fire vegetation of Fourth Water creek was most likely less abundant, with less fuel to aid surface-fire spread. Observation of higher occurrences of bole scorch and overstory tree mortality along Fourth Water creek also suggests differences in fire behavior.

When each creek was evaluated independently, longer second terraces and riparian slopes did correlate with higher rates of sprouting for both creeks, suggesting that a greater extent of riparian features is associated with higher post-fire regeneration rates. As the fire burned downhill from the forest into the riparian zones, it first confronted these topographic positions, where the initial change in vegetation type, from manzanita and deer brush to alder and dogwood, may have reduced the fire's intensity or rate of spread. These positions were typically occupied by both riparian and upland species, with lower abundance and density when compared with first terraces. A lessening of fire intensity is only one explanation for the greater sprouting response rate. Pre-fire vegetation data along with a detailed account of wildfire behavior and fuel consumption would provide invaluable information for unraveling the relative importance of topography and fire severity in dictating riparian vegetation response in future studies.

Although species composition differed across the topographic positions, each hardwood species included in the comparative analysis of sprouting in relation to stream proximity had the potential to reproduce vegetatively. The higher rate of survivorship of the burned species closest to the water's edge along Fourth Water creek may reflect species-specific competitive advantages when compared with the riparian species found on the second terraces and riparian slopes. But it is plausible that the potential for vegetation to resume growth following fire increases as one approaches the wetter terraces nearer to the water's edge, where both foliar and soil moisture contents are presumably at their highest levels. We suggest that this pattern may have been a product not only of higher fuel moistures, but also of how fire behavior was influenced by the riparian zone topography and associated vegetation distribution. Fourth Water creek's gravel bars were longer and flatter than the other topographic positions, and generally lacking in continuous surface or ground fuels requisite for continuous fire spread.

The post-fire condition of Fourth Water creek riparian zones suggests that the pre-burn understory vegetation was either initially less abundant, or that complete combustion removed a significant portion of the ground cover. This left the dominant species, red-osier dogwood, unoccupied sites for its establishment by seed regeneration following the burn. Light fires can stimulate the germination of red-osier dogwood seeds, although the species more commonly sprouts from surviving roots or stolons (Haeussler and Coates, 1986). Red-osier dogwood banks its seeds, and is considered semi-tolerant of fire (USDA, 2002), while mountain alder has a higher tolerance due to less-flammable bark and non-resinous leaves (Davis et al., 1980). It is possible that because Third Water creek transects were populated by a greater abundance of the more fire-resistant alder, the vegetation response following the burn was mostly asexual. In contrast, along Fourth Water creek, where the dogwood abundance was higher, seedling recruitment was the predominant regeneration mechanism. Although red-osier dogwood seeds can be ground-stored with germination stimulated by fire, mountain alder seeds lack longer-term viability (Schopmeyer, 1974). The favorable seedbeds created by the burn were most likely colonized by water or wind-dispersed dogwood and alder seeds from locations outside the sampled transect areas. Fall season alder seed dispersal would have coincided with the burning of the Lookout fire, and unburned patches of alder would have been important seed sources for regeneration of burned areas where combustion eliminated banked seeds. The importance of off-site alder stands in colonizing burned sites has been documented in other studies (USDA, 2002).

When all species are included, Fourth Water creek was regenerated by twice as many total seedlings as was Third Water creek, although the abundance of surrounding seed sources appeared similar between the two creeks. We believe that the more abundant population of mature mountain alder along the first terraces of Third Water creek left less unoccupied mineral soil suitable for seedling colonization. The majority of seedling recruitment along Third Water creek was therefore found on or above the second terrace, where the abundance of mature vegetation was lower. Most of these seedlings were white fir, representing a potential shift in species composition along the second terraces. Our best approximation of pre-fire composition, or the burned vegetation, on the second terrace was a riparian community dominated by mountain alder. Most of the alder on the second terrace was killed by the fire and, unlike the alder of the first terrace, did not resprout. The future success of the white fir seedlings in Third Water creek's riparian zone depends on the relative frequencies and potential synergy of the fire and flood disturbance regimes. Although white fir is shallow-rooted and can survive in moister sites, it is intolerant of flooded soils (Burns and Honkala, 1990) and seedlings would not survive an inundation reaching the second terrace. Nor can they withstand understory burns before they reach significant heights and diameters, which would require longer than 8–15 years, or a suggested historical mean fire return interval for northern Sierra Nevada mixed-conifer forests (Stephens and Collins, 2004). Even if the fire return interval is significantly higher in the riparian portions of these forests, the cumulative effects of the fire and the flooding regimes would impact vegetation composition. The fate of these white fir seedlings is, therefore, closely linked to the frequency as well as severity of disturbance in the riparian zone. Other studies have shown that the competitive advantages of hardwoods in riparian zones is linked to disturbance events, and is responsible for limiting conifer growth therein (Nierenberg and Hibbs, 2000). Because vegetation continues to regenerate for a few years after a disturbance, the patterns along Third and Fourth Water creeks may only be short-term artifacts. Longer-term monitoring of vegetation recovery may reveal different implications of the disturbance event for riparian vegetation and the aquatic systems it influences.

4.3. Management concerns

Successful fire suppression, along with human influences on flooding cycles in the northern Sierra Nevada forests may effectively minimize the role disturbance plays in dictating vegetative community composition in the riparian zones of these forests. Whether fire need be excluded from riparian zones is therefore an important question in forest management. Evaluation of fish-bearing stream quality in many of California's National Forests has raised concerns over the implications of disturbance events (Erman, 1996; Kattelmann and Embury, 1996). In the Plumas National Forest, one-third of the fish-bearing streams were found to be in ‘‘poor’’ condition, 78% occurring in small streams such as Third and Fourth Water creeks (USFS, 1988). Such reports have led to a conservative fire exclusion policy in riparian corridors. Yet some authors suggest that the practice of fire prevention itself can evoke more harm than good (Erman, 1996). Suppression-related road building or the creation of fuel breaks often increases sediment erosion, while fuels reduction prescriptions in riparian zones reduces the input of beneficial woody debris and downed snags, evapotranspiration and shading, and moisture levels in the understory habitat (Erman, 1996). On the other hand, mechanical manipulations such as dams or culverts typically reduce the frequency of flooding. This may lead to increased fuels accumulation in riparian corridors, which could alter the historical fire regime (Ellis, 2001). In some cases, such induced fuel build-up associated with the prevention of flooding may require the use of fuels reduction techniques to limit the severity of fires in riparian zones, introducing a cycle of compensatory management practices. In addition, fire suppression-induced species shifts may occur in riparian zones, altering their buffering capacity and the quality of wildfire's influence on streams. Potential for such change was evidenced in our case study by the conifer encroachment into the riparian zone of Third Water creek. Longer-term monitoring of changes in species composition following wildfire would be necessary to understand the implications of altering fire regimes in riparian systems.

Although nearby roads and culverts have likely influenced flooding cycle and fuel loads, the results of this short-term study suggest that the riparian vegetation of Third and Fourth Water creeks remains resilient to even high-severity fires through seedling recruitment and sprouting. Basal resprouting has been described as a primitive angiosperm adaptation to any type of disturbance resulting in defoliation (Bond and van Wilgen, 1996). The capacity of the angiosperms along Third and Fourth Water creeks to sprout following fire may help to buffer any deleterious effects wildfires have on stream quality. In the steeper, less vegetated terrain along Fourth Water creek, the impact of post-fire erosion on stream quality would likely be greater. Still, our results suggest that riparian vegetation regenerates and seedling recruitment begins almost immediately following fire, perpetuating the role riparian vegetation plays in maintaining stream quality.

Allowing fire to burn riparian zones may be effective in decreasing the severity of wildfires across the greater watershed. This study provides one example of how riparian areas may act as natural fire breaks and influence fire behavior. Fire throughout the riparian zone may even prove advantageous in supplying additional woody debris to streams and stimulating seedling regeneration and future shading (Bragg, 2000). Vegetation will likely continue to regenerate over the next 2–3 years, potentially changing the implications we have discussed based on our short-term response study.

Determining whether fire is even a dominant influence in the composition and structure of riparian systems is a question to be further explored before management can address the maintenance or restoration of health and resilience therein (USDA, 2000; Everett et al., 2003). In a study of northern Sierra mixed-conifer riparian vegetation, Russell and McBride (2001) showed that proximity to water exerted a greater influence on vegetation composition than did historical fire occurrence. Additional chronicling of fire's effects on riparian vegetation would benefit our understanding of the role fire plays as a disturbance factor in forested watersheds, and help guide management of fire-prone riparian ecosystems.

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