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Supplementary material for

Influence of wildfire severity on geomorphic features and riparian vegetation of forested streams of the Sierra Nevada, California, USA

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Hypotheses and predictions

We hypothesized that both riparian vegetation and stream geomorphic features would be different between low- and high-severity burned reaches. Specifically, we predicted that (1) riparian shrub and herb cover would be greater in low-severity burned reaches; and (2) shade-tolerant species would dominate and taxa richness would be higher in low-severity burned reaches. Relative to stream geomorphic characteristics, we predicted that (1) following high-severity wildfire, streams would exhibit a decrease in D_{50} (median sediment size) and an increase in embeddedness (degree to which cobbles are surrounded by fine particles); (2) high-severity burned reaches would be characterized by increased entrenchment ratio, incision, and channel-widening (as measured by width-to-depth ratio) compared to low-severity burned stream reaches; and (3) characteristics of channel geometry (i.e., degree of channel widening, channel gradient, sediment size distribution, and embeddedness) would be correlated with community composition of riparian vegetation.

Additional methods

We estimated percentage cover of vegetation in the field using ocular estimates and an octave scale and used the midpoint of each octave for analysis (Muller-Dombois and Ellensburg 1974, Moore and Chapman 1986). Due to species overlap in space, percentage cover can be over 100% (Muller-Dombois and Ellensburg 1974, Goldsmith *et al.* 1986, Jackson and Sullivan 2009). We identified plant species using Hickman (1993) except for willow (*Salix)* and rush (*Juncus*) which we only identified to genus. For riparian trees, shrubs, and herbs, we obtained an importance value from the square of the mean of relative frequency and relative cover and used this value for ordination. Rare taxa with an importance value less than 0.5% were excluded from analysis (McCune *et al.* 2002). We also calculated Pearson's r for importance values and geomorphic characteristics with the resulting NMS axes.

For the drainage area of each study reach, we calculated the proportion of each catchment burned with moderate- to high-severity during the most recent fire > 80 hectares (i.e., fire extent). Our estimate of fire occurrence is defined as the proportion of each catchment burned twice or more. We used this metric since total area burned is largely captured by our severity metric, and previously burned areas in Yosemite that re-burn tend to burn with greater severity and undergo a state change from forest to chaparral (van Wagtendonk 2011). The maximum number of times a catchment burned was 10 times, but only over an extremely small proportion of the landscape (0.0001%).

To estimate fire severity, we used relative differences in normalized burn ratio values (RdNBR) calculated from Landsat 7 Enhanced Thematic Mapper Satellite Imagery following Miller and Thode (2007). Breakpoints in RdNBR were determined for each pixel and assigned as unburned, low-, moderate-, or high-severity. These breakpoints were determined following

Miller and Thode (2007) and acquired directly from YNP (K. Van Wagtendonk *personal communication*).

Extended results

Table S1. Common herbaceous and woody species and their occurrence at each study reach. Site codes are as follows: BV - Buena Vista, FR - Frog, MT - Middle Tuolumne, TA - Tamarack, CR - Crane, ME - Meadow, MO - Mono, CS - Cascade, ST - South Tuolumne, GR - Grouse, CY - Coyote, CA - Camp, CH - Chilnualna. Chilnualna Creek is classified as a reference stream. It was sampled in 2014 following the Rim Fire, but was unaffected by the fire, and had not burned significantly anywhere in the catchment for > 80 years.

Species	Reaches																
	High-severity						Low-severity						Post - Rim Fire				
	BV	FR	MT	TA	CR	ME	MO	CS	ST	GR	CY	CA	FR	MT	CS	ST	CH
Richness	9	12	15	15	15	10	15	9	14	11	23	13	4	10	9	10	11
Trees and shrubs																	
Abies concolor			X		X		X	X	X		X	X			X		X
Alnus incana									X	X						X	
Amelanchier alnifolia											X						
Arctostaphylos patula			X														
Castanopsis sempervirens								X							X		
Ceanothus cuneatus			X														
Cornus nuttallii								X		X					X		
Cornus sericea occidentalis		X	X	X	X			X	X	X		X	X	X	X	X	X
Libocedrus decurrens			X						X	X	X	X				X	
Lonicera involucrata				X			X										
Pinus contorta murrayana	X		X	X	X	X	X		X	X	X				X	X	X
Pinus lambertiana									X		X	X					X
Pinus ponderosa							X			X				X			

Populus trichocarpa														X			
Prunus emarginata		X	X		X		X				X	X					
Pseudotsuga menziesii																	
Quercus lobata										X	X						
Rhododendron occidentale		X	X		X			X			X	X			X		X
Ribes viscosissimum											X						
Ribes montigenum	X	X	X				X				X	X	X	X			
Rosa bridgesii				X	X												
Rubus parviflorus		X									X			X	X		X
Salix spp.	X	X	X	X		X	X	X	X			X	X	X	X	X	X
Spiraea splendens													X				X
Symphoricarpos albus			X														
Forbs																	
Achillea millefolium	X			X		X	X				X						
Anaphalis margaritacea		X		X			X										
Castilleja applegatei				X													
Carex rostrata						X											
Primula jeffreyi																	X
Chamerion angustifolium		X		X	X				X							X	
Equisetum arvense						X	X		X					X			
Erigeron foliosus				X							X	X					
Fragaria virginiana											X	X					
Galium aparine							X				X	X					
Geranium californicum						X					X						
Helenium bigelovii		X			X												
Heuchera micrantha	X		X	X	X			X	X	X	X			X	X	X	X
Heracleum maximum					X				X	X	X	X					
Hieracium albiflorum	X										X						X

Juncus spp.		X	X	X		X	X		X	X				X	
Lilium parvum														X	
Lupinus breweri						X									
Lupinus polyphyllus	X		X		X		X		X		X		X		
Mentha arvensis					X						X				
Mertensia ciliata				X											
Erythranthe bicolor											X				
*Phalaris arundinacea**					X							X	X		
Polemonium occidentale	X														
Pteridium aquilinum		X			X			X	X	X					
Solidago velutina	X			X	X	X	X	X							
Thalictrum fendleri						X					X				
Vicia americana		X	X	X			X							X	X

** Non-native species*

Table S2. Correlations (Pearson's *r*) of physical parameters (elevation, stream gradient, and stream geomorphic measures), time since fire, and individual plant species importance. Axes are from Non-Metric Multidimensional Scaling ordination, representing a 3-dimensional representation of relative riparian woody and riparian herbaceous species importance in community space. Bold-faced values represent *r* > 0.50. Only species correlations greater than 0.50 are shown.

Parameters	Pearson's *r*		
Riparian woody vegetation	Axis 1	Axis 2	Axis 3
Physical parameters			
Width-to-depth ratio	-0.22	0.41	0.15
Entrenchment ratio	-0.29	0.49	0.04
Incision ratio	0.04	-0.17	0.47
Elevation (m)	0.16	-0.24	**0.71**
Gradient	-0.10	0.32	-0.37
Time since last fire (years)	0.28	0.30	-0.12
Species (*r* > 0.5)			
Ribes viscosissimum		**-0.66**	
Prunus emarginata		**-0.73**	
Quercus lobata	**0.67**		
Rosa bridgesii	**0.67**		
Abies concolor			
Pinus contorta murrayana		**0.83**	
Libocedrus decurrens	**0.85**		
Cornus sericea occidentalis			
Ribes montigenum		**-0.69**	
Rhododendron occidentale		**0.59**	**-0.59**

Alnus incana	**0.67**		
Populus tremuloides	**0.63**		
Cornus nuttallii	**-0.66**		
Salix spp.			**0.77**

Riparian herbaceous vegetation	Axis 1	Axis 2	Axis 3
Physical parameters			
Width-to-depth ratio	-0.38	-0.28	0.45
Entrenchment ratio	-0.24	-0.27	**0.56**
Incision ratio	-0.45	0.23	0.12
Elevation (m)	-0.11	0.28	-0.10
Gradient	-0.11	**0.51**	-0.11
Time since last fire (years)	0.15	-0.20	0.11
Species ($r > 0.5$)			
Anaphalis margaritacea			**0.68**
Castilleja applegatei			**0.59**
Erigeron foliosus		**-0.52**	
Fragaria virginiana		**-0.56**	
Galium aparine		**-0.52**	
grasses		**-0.56**	**-0.55**
Helenium bigelovii	**0.64**		
Heracleum maximum			**-0.71**
Heuchera micrantha	**-0.57**		
Hieracium albiflorum		**-0.60**	
Juncus spp.	**0.56**		
Lilium parvum		**0.66**	
Pteridium aquilinum		**0.75**	
Vicia americana	**0.76**		

Table S3. Results of paired before-after control-impact (BACIP) analysis of riparian herb, shrub, and tree cover; taxa richness; D_{50}; embeddedness; and width-to-depth, entrenchment, and incision ratios at two stream reaches burned by the Rim Fire and two control reaches. Middle Tuolumne Creek was previously categorized as high-severity burned by the Ackerson Fire occurring in 1996, and South Tuolumne was previously categorized as low-severity burned by the Wolf Fire in 2002. Middle Tuolumne was again burned with high-severity fire during the Rim Fire and South Tuolumne with low-severity fire, thus creating two separate treatments (i.e., high/high and low/low). We chose Frog Creek and Cascade Creek as control reaches because they were similar in elevation and stream size to Middle Tuolumne and South Tuolumne, respectively. Frog Creek was previously classified as high-severity while Cascade Creek was previously classified as low-severity. Neither was inside the Rim Fire perimeter. At these four reaches, we collected (and calculated) a subset of data (riparian vegetation cover and composition and stream geomorphic features) following the same protocols as in 2011-2012.

	Before	After	Δ
Middle Tuolumne (before, high severity; after, high severity)			
Herbaceous cover (%)	64.6 ± 72.5	43.8 ± 36.5	-20.9
Shrub cover (%)	87.0 ± 48.6	35.3 ± 37.8	-51.7
Tree cover (%)	38.5 ± 54.4	17.5 ± 24.7	-13.8
Taxa richness	15	10	-5
D_{50} (mm)	14.7 ± 2.8	14.0 ± 3.3	-0.7
Embeddedness (%)	7.5 ± 6.6	4.9 ± 5.1	-2.6
Width-to-depth ratio	19.1 ± 6.9	23.3 ±15.3	4.2
Entrenchment ratio	17.4 ± 4.9	16.1 ± 3.8	-64.3
Incision ratio	1.2 ± 0.6	0.9 ± 0.5	-0.3
Frog Creek (before, high severity; after, control)			
Herbaceous cover (%)	81.7 ± 64.0	4.4 ± 8.8	-77.3

Shrub cover (%)	91.4 ± 34.4	73.1 ± 24.5	-18.3
Tree cover (%)	0	0	0
Taxa richness	12	8	-6
D_{50} (mm)	18.4 ± 12.1	8.2 ± 0.1	-10.2
Embeddedness (%)	5.7 ± 4.3	5.9 ± 3.8	0.2
Width-to-depth ratio	21.7 ± 8.8	28.0 ± 18.8	6.2
Entrenchment ratio	18.9 ± 3.8	17.9 ± 7.4	-1.0
Incision ratio	0.7 ± 0.4	0.7 ± 0.4	0.1
South Tuolumne (before, low severity; after, low severity)			
Herbaceous cover (%)	106.4 ± 50.4	44.0 ± 74.7	-62.4
Shrub cover (%)	76.9 ± 19.9	29.6 ± 25.4	-47.3
Tree cover (%)	92.5 ± 130.8	37.5 ± 53.0	-55.0
Taxa richness	14	10	-4
D_{50} (mm)	12.9 ± 9.4	8.1 ± 0.0	-4.8
Embeddedness (%)	4.2 ± 5.0	4.5 ± 2.4	0.2
Width-to-depth ratio	19.6 ± 10.6	18.6 ± 13.3	-1.0
Entrenchment ratio	18.1 ± 2.9	16.5 ± 0.6	-1.6
Incision ratio	1.0 ± 0.4	0.7 ± 0.3	-0.2
Cascade Creek (before, low severity; after, control)			
Herbaceous cover (%)	41.9 ± 49.6	48.8 ± 56.3	6.9
Shrub cover (%)	63.3 ± 32.9	83.8 ± 59.2	20.5
Tree cover (%)	27.5 ± 38.9	17.5 ± 24.7	-10.0
Taxa richness	9	9	0
D_{50} (mm)	30.6 ± 29.2	10.3 ± 2.0	-20.3
Embeddedness (%)	3.3 ± 1.7	5.9 ± 4.2	2.5
Width-to-depth ratio	8.9 ± 3.8	14.1 ± 4.2	5.2
Entrenchment ratio	15.3 ± 2.1	23.1 ± 2.2	7.8
Incision ratio	0.4 ± 0.2	1.0 ± 0.5	0.6

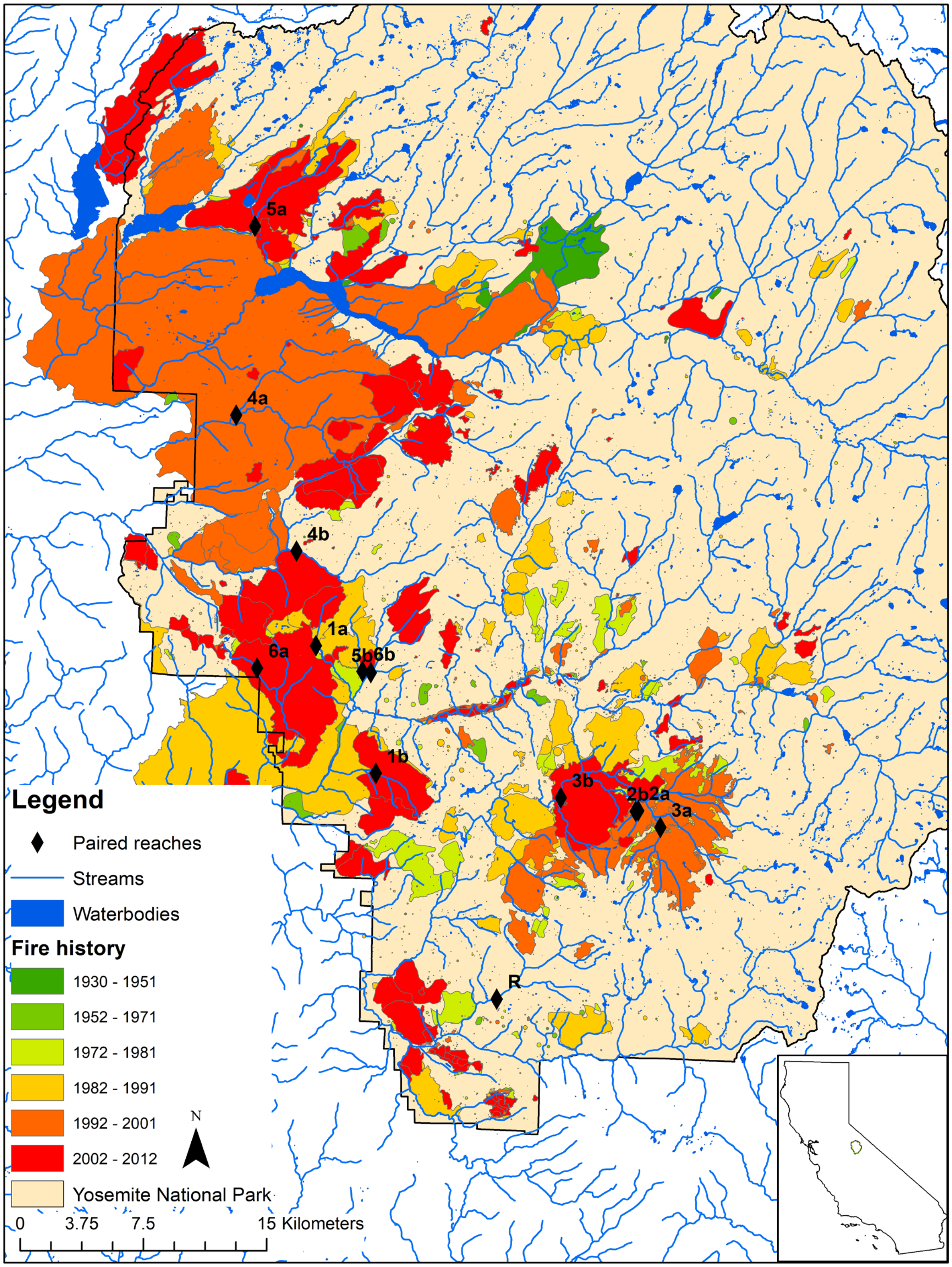
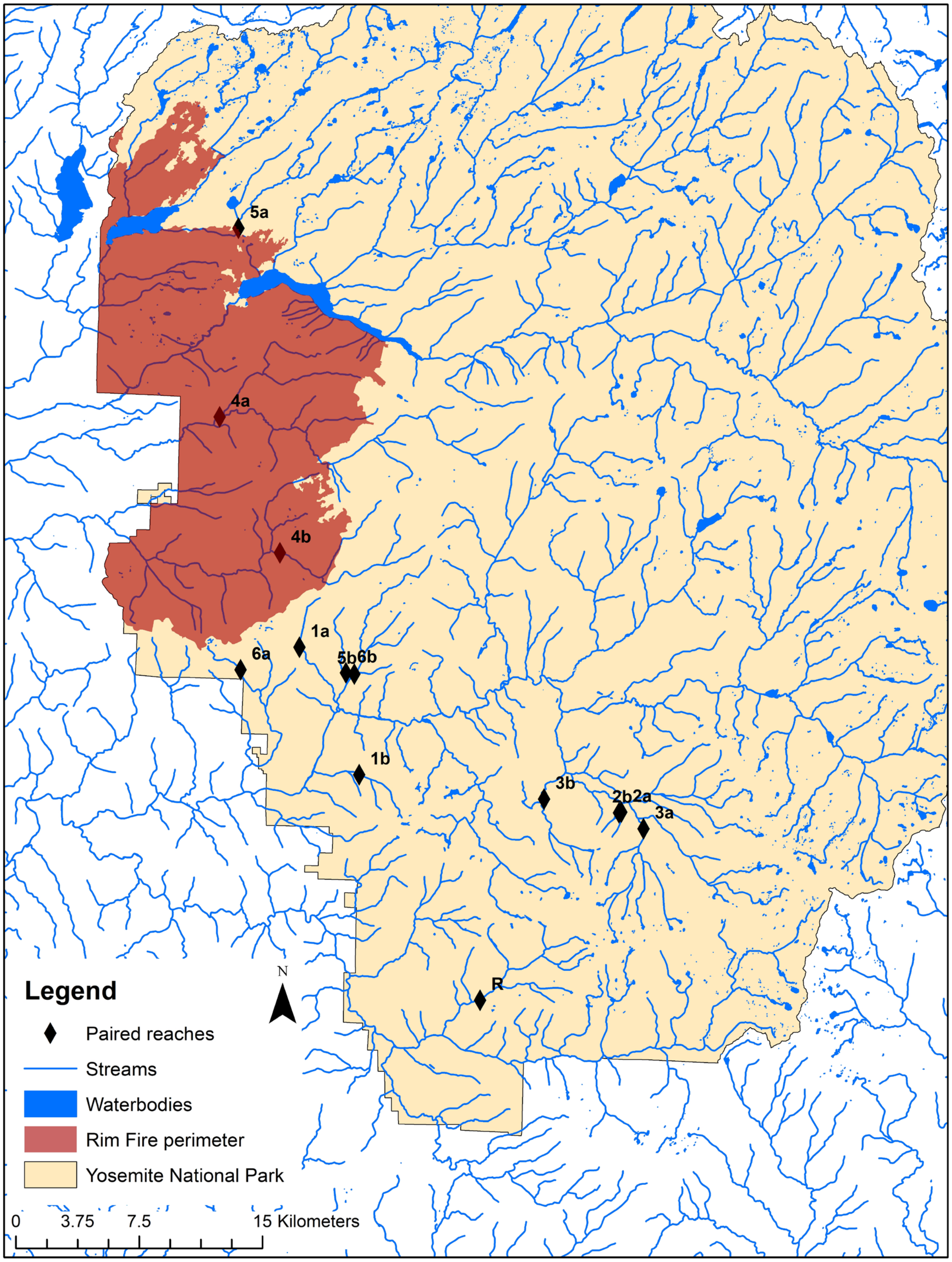

5a
4a
4b
1a
6a
5b6b
1b
3b
2b2a
3a
R
Legend
Paired reaches
Streams
Waterbodies
Fire history
1930 - 1951
1952 - 1971
1972 - 1981
1982 - 1991
1992 - 2001
2002 - 2012
Yosemite National Park
N
0
3.75
7.5
15 Kilometers

Figure S1A.


5a
4a
4b
1a
6a
5b6b
1b
3b
2b2a
3a
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N
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Paired reaches
Streams
Waterbodies
Rim Fire perimeter
Yosemite National Park
0
3.75
7.5
15 Kilometers

Figure S1B.

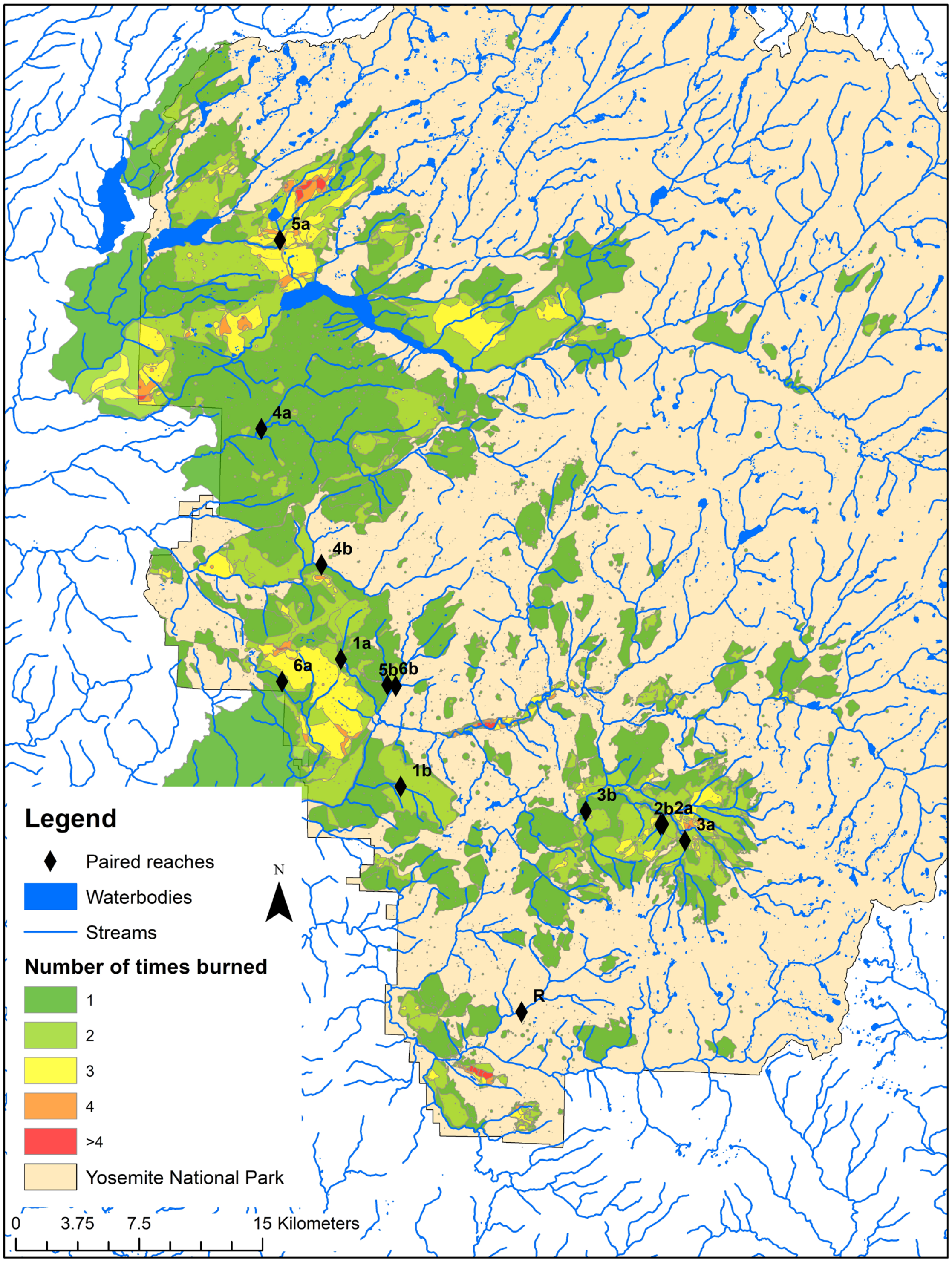
5a
4a
4b
1a
6a
5b6b
1b
3b
2b2a
3a
R
Legend
Paired reaches
Waterbodies
Streams
Number of times burned
1
2
3
4
>4
Yosemite National Park
N
0
3.75
7.5
15 Kilometers

Figure S1C.

Figure S1. (A) Fire history by decade within Yosemite National Park, California, USA (latitude/longitude: 37.85, -119.55). Paired reaches are Tamarack (1a) and Grouse (1b); Meadow (2a) and Camp (2b); Buena Vista (3a) and Mono (3b); Middle Tuolumne (4a) and South Tuolumne (4b); Frog (5a) and Cascade (5b); and Crane (6a) and Coyote (6b). The reference study reach is (R) Chilnualna. The position of Yosemite within California is in the lower right corner. (B) The 2013 Rim Fire perimeter and paired stream reaches sampled in 2011 and 2012. Middle Tuolumne and South Tuolumne were burned by the Rim Fire with high- and low-severity wildfire, respectively, and were used as impact study reaches in 2014. Frog and Cascade were unburned by the Rim Fire and used as high- and low-severity control reaches, respectively. (C) Number of times burned between 1930 and 2012 in Yosemite National Park, California, USA.

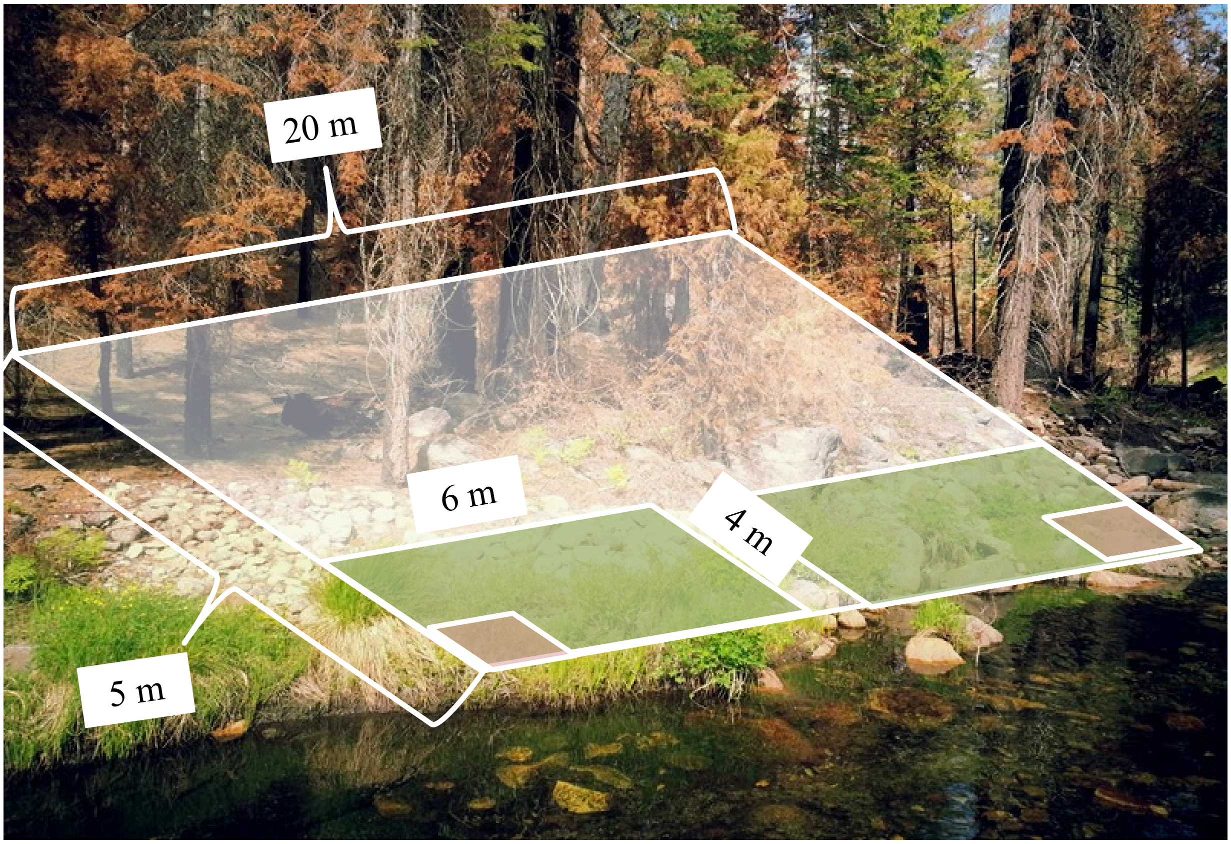

Figure S2. We visually estimated tree cover from the center of the plot in three 5 x 20-m rectangular plots (with long axis parallel to the stream channel) located in the riparian zone along each bank of each study reach. The long axis of the plots was within 0.5 m from the water edge. Nested in each 5 x 20-m tree plot, we established subplots to survey shrubs and herbaceous vegetation. We estimated shrub cover in two 4 x 6-m subplots, and herbaceous species were sampled in two 1 x 1-m subplots. These subplots were completely contained within the riparian zone, and corresponded with channel geometry cross-sections. We chose the location of each plot as representative of riparian vegetation throughout the reach. In addition, we chose each cross-section to survey a different geomorphological feature (i.e., pool, riffle, run). We visually estimated percentage cover for all plant species (grasses, forbs, woody plants, and trees).

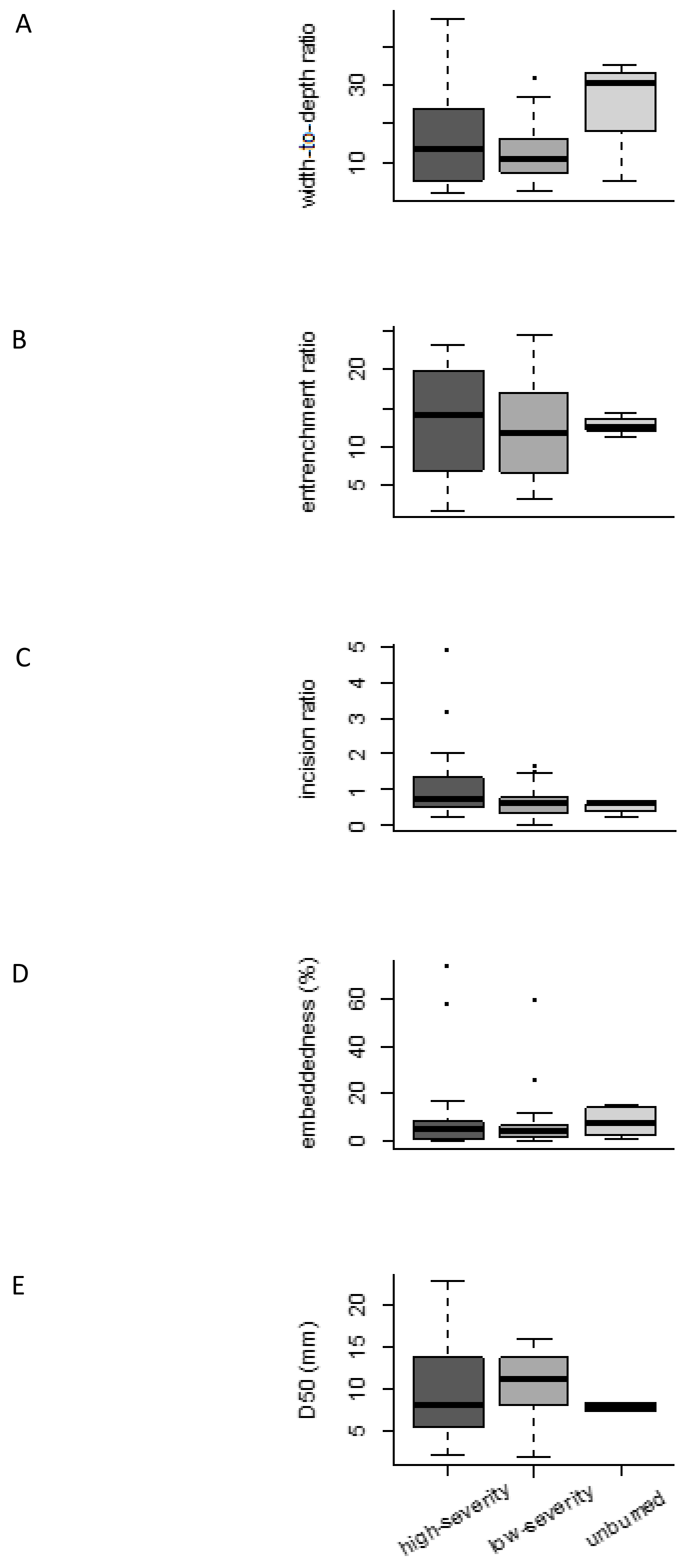

Figure S3. Box-and-whisker plots of (A) width-to-depth ratio, (B) entrenchment ratio, and (C) incision ratio; (D) embeddedness (%); and (E) D_{50} (mm) presented by fire severity classification.

Charcoal columns represent high-severity burned stream reaches, dark-grey columns represent low-severity burned reaches, and light-grey columns represents the reference reach on Chilnualna Creek (i.e., unburned). The black lines represent the median of each variable, boxes represent the 1st and 3rd quartiles, whiskers represent the minimum and maximum values, and open circles represent outliers. None of the responses was different (among fire severity classifications) following sequential Bonferroni corrections.

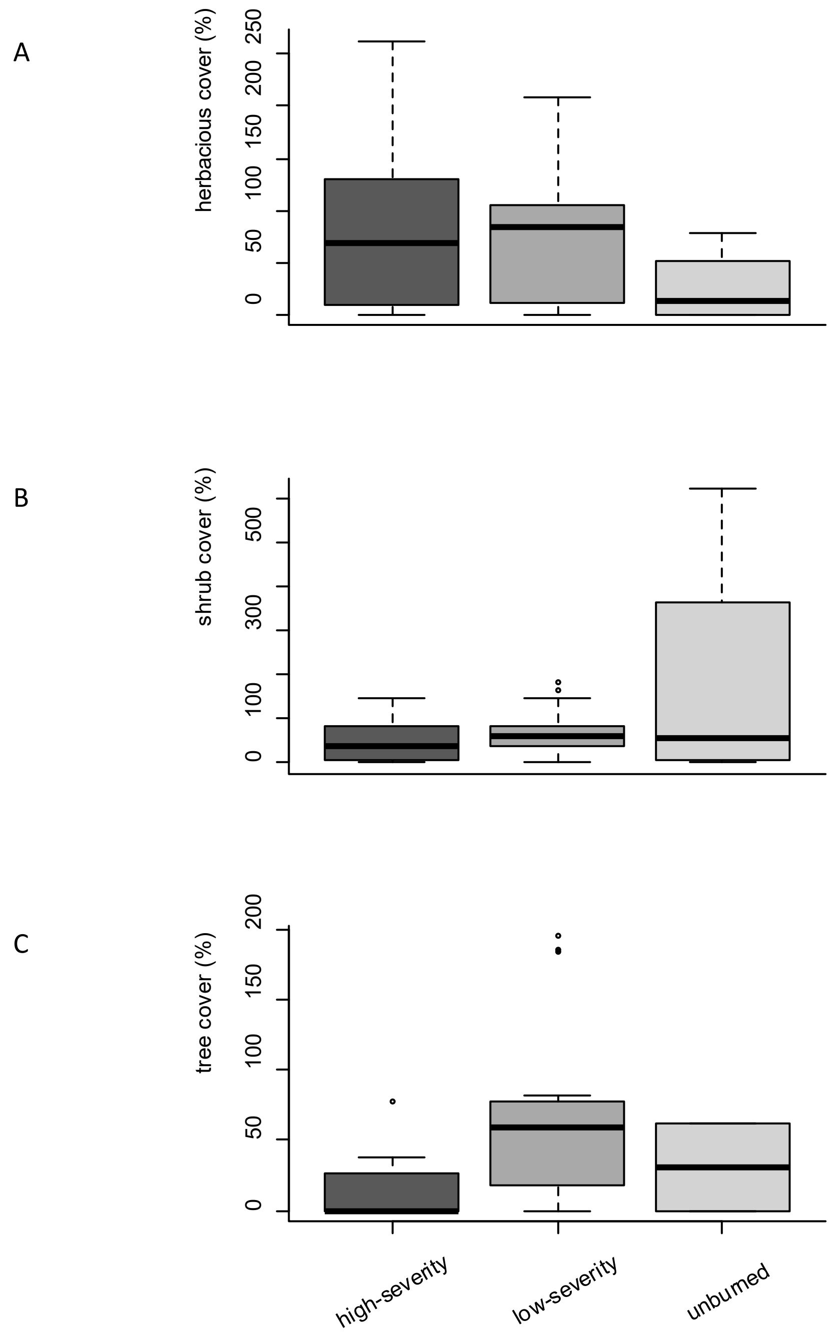

Figure S4. Box-and-whisker plots depicting % cover of (A) herbs, (B) shrubs, and (C) trees within high-severity and low-severity burned study reaches. Charcoal columns represent high-severity burned stream reaches, dark-grey columns represent low-severity burned reaches, and light-grey columns represents the reference reach on Chilnualna Creek (i.e., unburned). Note that overlapping species (in space) can result in cover values that exceed 100%. The black lines represent the median of each variable, boxes represent the 1st and 3rd quartiles, whiskers represent the minimum and maximum values, and open circles represent outliers. None of the responses was different (among fire severity classifications) based on sequential Bonferroni corrections.

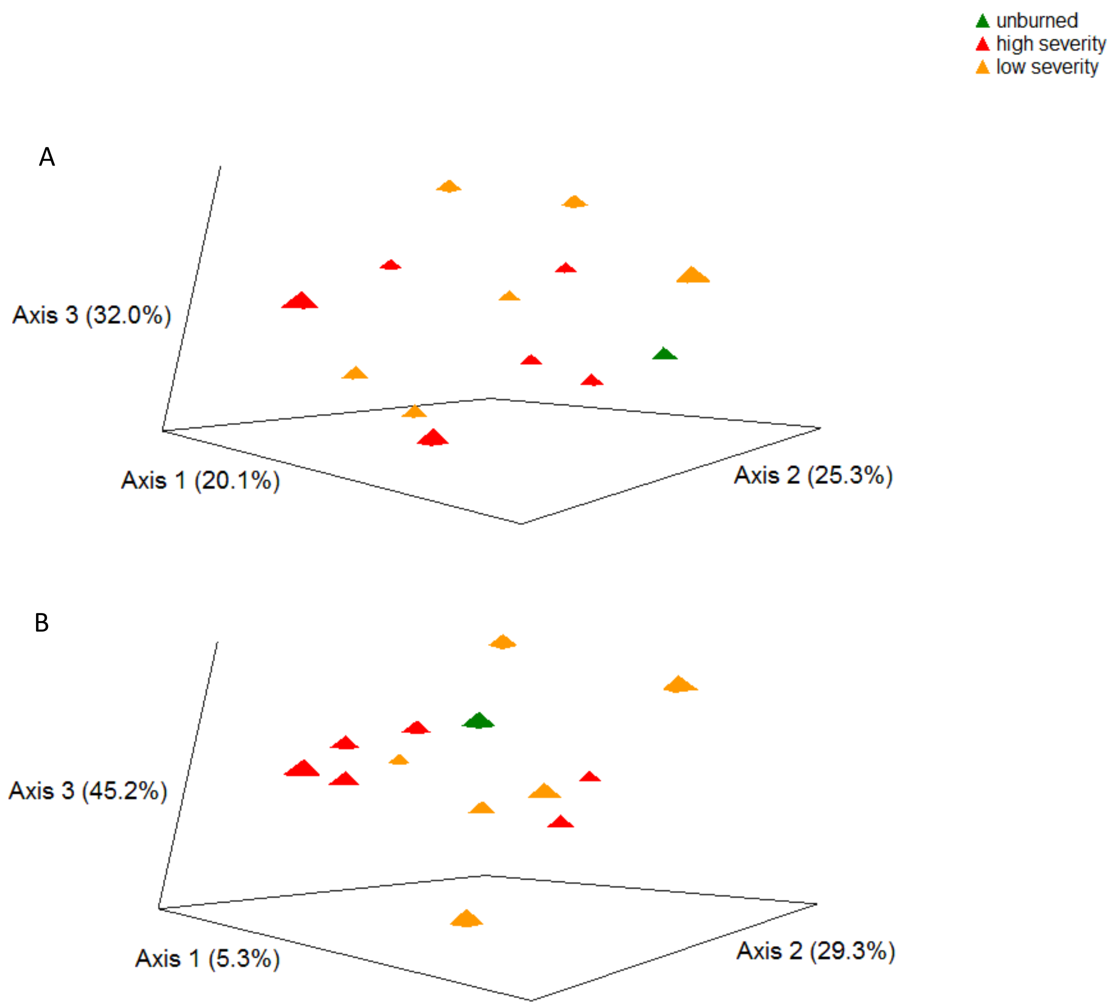

Figure S5. 3D representation of Non-metric Multidimensional Scaling ordination of (A) riparian woody vegetation, and (B) riparian herbaceous vegetation. Reaches classified as high-severity burned are shown in red, low-severity burned in yellow, and the reference reach in green. The three-axis solution shown is a simplification of riparian species importance in community space. Visually there is little partitioning of riparian species importance indicating highly heterogeneous community composition across study locations irrespective of fire severity classification. Axis 1 of the woody vegetation NMS reflected the occurrence of incense cedar (*Libocedrus decurrens)*, quaking aspen (*Populus tremuloides*), valley oak (*Quercus lobata*), and alder (*Alnus incana*) as well as a riparian shrub – rose (*Rosa bridgesii*). Lodgepole pine (*P. contorta murrayana*) was highly correlated with axis 2 along with mountain azalea (*Rhododendron occidentale*), and cover of willow species (*Salix spp.*) was correlated with axis three. Vetch (*Vicia americana*), *Helenium bigelovii*, and rush species (*Juncus spp.*) were all positively correlated with axis 1 of the herbaceous vegetation NMS. On axis 2, lilies (*Lilium parvum*) and ferns (*Pteridium aquilinum*) dominated, and many common species were absent. Pearly everlasting (*Anaphalis margaritacea*) and paintbrush (*Castilleja applegatei*) were positively correlated with axis three, and grasses and cow parsnip (*Heracleum maximum*) were negatively correlated (See Table S2).

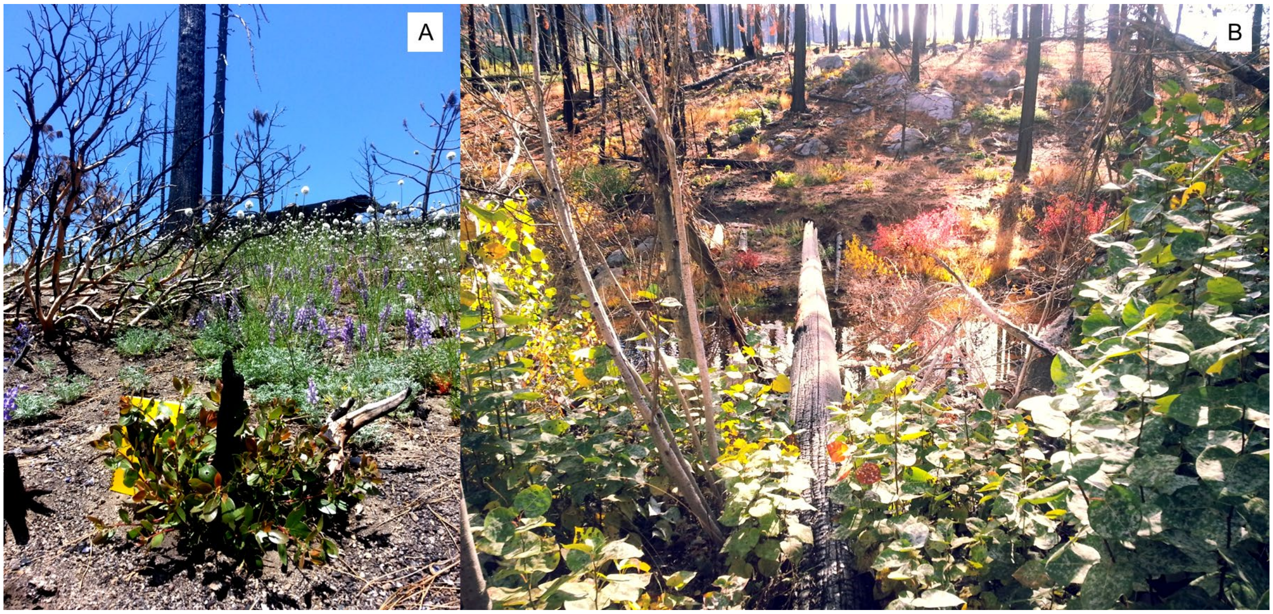

Figure S6. (A) Stump sprouting of the common upland plant *Arctostaphylos patula* in the side slope adjacent to Middle Tuolumne Creek six months following the Rim Fire. 120 x 180-mm yellow notebook (behind the manzanita) is shown for scale. Photo taken in March, 2014. (B) Proliferation of riparian vegetation at Middle Tuolumne Creek 13 months following the Rim Fire. Photo credit B. Jackson.

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