SHORT-TERM EFFECTS OF A LARGE DISTURBANCE EVENT ON STREAMS IN THE STANISLAUS NATIONAL FOREST, CALIFORNIA

A Thesis Presented to the Faculty
of
California State University, Stanislaus

In Partial Fulfillment
of the Requirements for the Degree
of Master of Ecology and Sustainability

By
Sue Ellen Gleaves
August 2017

CERTIFICATION OF APPROVAL

SHORT-TERM EFFECTS OF A LARGE DISTURBANCE

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Sue Ellen Gleaves

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DEDICATION

This work is dedicated to my husband Richard. You have been a constant source of support and encouragement throughout the challenges of graduate school. I am truly thankful for you and for your willingness to assist with my data collection. I cannot thank you enough for climbing up and down those steep slopes with me!

This work is also dedicated to my sister Tracy for her support and encouragement during this endeavor. You are a remarkable sister and educator.

ACKNOWLEDGEMENTS

I would like to acknowledge and express my gratitude to Dr. Matthew Cover. Thank you for sticking with me through numerous changes in thesis topics and my hiatus into the teaching credential program. You were an outstanding advisor and I am grateful for your guidance.

I would also like to acknowledge Dr. Stuart Wooley and Dr. Patrick Kelly for their support and positive guidance during this process. You both were invaluable as committee members.

In addition, I would like to recognize the USDA Forest Service. This research would not have been possible without the support and guidance of personnel from the Stanislaus National Forest in Sonora, California. I thank them for meeting with me, providing a tour of the burn area, and answering my many questions.

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ABSTRACT

I investigated the short-term effects of wildland fire of varying severity on streams. I compared my results to similar studies on western fires to provide a snapshot of post-fire stream recovery. Physical variables, algal growth, and benthic macroinvertebrates were compared across high burn (canopy removed), low burn (intact canopy with understory removed), and no burn streams. The high burn stream had the lowest canopy cover and microalgae presence and the highest temperature, increased sandy substrate, macroalgae, and greater invertebrate abundance compared with the low and no burn streams. Results showed increased primary productivity by macroalgae and increased secondary productivity by invertebrates in the high burn stream. Since wildland fires in the west are predicted to become more frequent and intense, this study provides a foundation for understanding short term wildland fire effects and how to better manage these areas.

INTRODUCTION

Ecological disturbances are important components of ecosystems that can alter physical and chemical environments and dramatically affect community dynamics by favoring disturbance-adapted species (Resh et al. 1988; Lamberti et al. 1991). For example, wildland fire in forests recycles and releases nutrients (Sugihara et al. 2006) to promote the growth of fire-adapted terrestrial plants such as those with fire-activated seeds (Dwire and Kauffman 2003; Miller et al. 2009; Batker et al. 2013) or physical characteristics such as thick bark (Sugihara et al. 2006). In stream ecosystems, floods and drought can alter spatial and temporal heterogeneity (Lake 2000). These aquatic disturbances can alter conditions, resulting in an increase of resistant and resilient aquatic species with adaptable life-history strategies and traits (Lamberti et al. 1991; Lake 2000).

While disturbances of intermediate magnitude and frequency are theorized to result in ecosystems with high species richness, rare and catastrophic disturbances or a high frequency of disturbances can result in ecosystems dominated by a small number of disturbance-adapted species (Connell 1978; Resh et al. 1988; Ward 1998). Wildland fires generally affect stream and riparian zones less frequently than floods or drought due to the generally moist, cool micro-climates found near streams (Dwire and Kauffman 2003; Beche et al. 2005). As a result, fires can have catastrophic impacts on the ecosystem through debris flows (Lamberti et al. 1991; Dwire and Kauffman 2003), increased sedimentation (Dwire and Kauffman 2003; Oliver et al.

2012), or disruption of nutrient cycling and increased water temperatures (Moore and Richardson 2012; Oliver et al. 2012). The level of impact is dependent upon the stream system and fire characteristics such as intensity, severity, and size (Gresswell 1999).

One of the largest disturbance events to be studied in detail by ecologists was the 1988 Yellowstone fire (Christensen et al. 1989; Romme et al. 2011). The Greater Yellowstone Ecosystem (Yellowstone) fire was caused by human activity and lightning. The size and intensity of the fire were the result of an extremely dry summer, a long history of fire suppression, and the resulting accumulation of biofuels (Romme et al. 2011). The fires burned approximately 570,000 hectares of mostly forested landscape (Christensen et al. 1989; Romme et al. 2011) and affected twenty river basins (Minshall et al. 1989). Immediate effects (up to a few days post-fire) on aquatic systems included increased water temperatures, stressed fish, and scorched vegetation (Minshall et al. 1989; Malison and Baxter 2009). Short-term effects (a few days post-fire to the beginning of spring runoff) and midterm effects (from spring runoff to the first few years post-fire) included increased sedimentation, elevated turbidity, erosion of stream banks, and increased productivity in streams (Minshall et al. 1989; Malison and Baxter 2009; Romme et al. 2011). Stream invertebrate communities in burned streams had a greater proportion of generalist species than those in unburned streams (Minshall 2003). Finally, long-term recovery of riparian zones proceeded along the recovery trajectory of the forest ecosystem, resulting in increased shading from the forest canopy, decreased runoff, and normal nutrient cycling (Minshall et al. 1989; Romme et al. 2011). The Yellowstone fire showed that severe fires can be a powerful natural process that result in long-term changes to communities and ecosystem functioning (Romme et al. 2011). The immediate, short-term, midterm, and long-term effects resulting from the Yellowstone fire may serve as a model for the response of other temperate montane ecosystems in the western U.S. to catastrophic wildland fire (Romme et al. 2011).

Other studies of the effects of fire on stream ecosystems have also observed significant short-term effects on stream food webs. A severe fire near Lake Tahoe in 2007 resulted in altered stream flow regimes, increased sedimentation, higher temperatures, and a reduction in the abundance and species richness of macroinvertebrates (Oliver et al. 2012). As with the Yellowstone fire, dominant taxa shifted from specialist feeders such as shredders and scrapers to more generalist feeders such as gatherers (Minshall 2003; Oliver et al. 2012). Although there was an increase in invertebrate scrapers in response to increased periphyton growth in streams affected by the Yellowstone fires, streams affected by the Lake Tahoe fire showed a decline in scrapers two years post-fire (Oliver et al. 2012). Studying the Diamond Peak fire in central Idaho, Malison and Baxter (2010) noted an increase in r-strategist species (species that populate quickly, have a short life expectancy, and high dispersal) in severely burned areas sampled five years post-fire, but saw no change in low-burn areas. They observed higher secondary productivity, greater biomass, and greater emergence of aquatic insects in stream reaches that were severely burned, but did not observe any of these results at unburned and low severity reaches (Malison and Baxter 2010). Unlike the Yellowstone fire, there was no discernible difference in periphyton biomass between high, low, and no burn areas (Malison and Baxter 2010). In summary, ecosystems within a high-severity burn area are more likely to have extended consequences on community dynamics than low and no burn fire areas.

The Stanislaus National Forest (SNF), located on the western slope of the central Sierra Nevada of California, was recently the site of the third-largest wildfire in the state's history (USFS 2013) and the largest in the recorded history of the Sierra Nevada (USFS 2014). The Rim Fire, which began on August 17, 2013, burned over 104,131 hectares before its full containment on October 25, 2013 (USFS and NPS 2013). It began near the confluence of the Clavey and Tuolumne Rivers and quickly spread up the Tuolumne River watershed (USFS 2014). Due to the size and intensity of the fire, many environmental services, such as air quality, carbon sequestration, soil retention, and water regulation were affected (Batker et al. 2013). Batker et al. (2013) estimated environmental losses at $100 million to $736 million for short-term effects (one year post-fire). Short-term terrestrial effects include loss of plant biomass (Gresswell 1999; Parise and Cannon 2012) and increased water repellency by soils (Sugihara et al. 2006; Flores et al. 2013). With 98% of the Rim Fire occurring within the Tuolumne River watershed, these upland effects also impact aquatic ecosystems (Beche et al. 2005)

Shortly after the fire, the USDA Forest Service (USFS) classified the burn area by severity of effects on both vegetation and soil. Severity is defined as the effect of a fire on an ecosystem: low burn indicates surface organic layers are still recognizable; moderate burn indicates some consumption of pre-fire ground litter and fuels; high burn indicates all or nearly all of pre-fire ground cover and surface organic matter was consumed (Flores et al. 2013). High to extreme fire behavior occurred in patches while areas with widely spaced trees and little understory resulted in moderately burned areas (USFS 2014). Areas that were no burn or very low burn included those around natural features such as rock outcrops and riparian areas (USFS 2014). Although riparian areas constituted only 1.3% of the total burn area, 65% of riparian areas that were burned were classified as moderate or high burn for vegetation (USFS 2014). For soil burn conditions, 17% of the fire area was classified as no burn or very low burn, 39% low burn, 37% moderate burn, and 7% high burn (Flores et al. 2013). Due to its size and severity, the Rim Fire is expected to influence succession and aquatic recovery processes in the Stanislaus National Forest for decades (Dwire and Kaufman 2003). The Rim Fire may be a harbinger for future catastrophic fires, as wildland fires in the western U.S. are predicted to grow in intensity, size, and frequency as a consequence of global climate change (Miller et al. 2009). Consequently, more research on short-term recovery processes of western streams is needed to guide future management decisions following catastrophic fires.

For this study, I sampled three streams in different fire intensity areas (high burn, low burn, no burn) of the Tuolumne River watershed to evaluate short-term disturbance effects and recovery processes following a catastrophic wildland fire. Based on the results of other studies of fire impacts on streams, I predicted that:

1. The high burn stream will have increased primary productivity, higher temperatures, and greater nutrient levels due to reduced riparian canopy and greater solar radiation (Minshall et al. 1998; Malison and Baxter 2009; Moore and Richardson 2012).
2. The high burn stream will have benthic invertebrate communities with lower species richness and abundance and a higher proportion of short-lived, generalist species compared to the low and no burn streams (Minshall et al.1998; Gresswell 1999; Malison and Baxter 2009; Moore and Richardson 2012).
3. The low burn stream will exhibit minor differences in water quality and invertebrate abundance and richness when compared to the no burn stream because riparian vegetation was not as severely affected (Malison and Baxter 2009).

METHODS

Study Area

The SNF is 363,478 hectares and contains over 1,287 km of rivers and streams that support aquatic species such as the threatened California red-legged frog (*Rana draytonii*) and the Sierra Nevada yellow-legged frog (*Rana sierra*) (USFS 2014). The Clavey River, one of the longest undammed rivers in the Sierra Nevada, also contains one of the most intact native fish assemblages, including rainbow trout (*Oncorhynchus mykiss*), California roach (*Lavinia symmetricus*), and Sacramento sucker (*Catostomus occidentalis*) in the upper watershed and Sacramento pikeminnow (*Ptychocheilus grandis*), hardhead (*Mylopharodon conocephalus*), and riffle sculpin (*Cottus gulosus*) in the lower reaches (USFS 1997). Additionally, the many rivers and streams of the SNF play an important role in water supply and water quality for the Central Valley and San Francisco Bay. Average annual run-off for the Tuolumne River watershed is 1.8 million acre-feet of water (Epke et al. 2010). Comprising most of the Tuolumne River watershed, the Clavey River, the North, Middle, and South Forks of the Tuolumne River, and Cherry Creek transport and filter runoff from snowmelt for drinking water and irrigation (Batker et al. 2013; USFS 2014).

Study Sites

Research was conducted on three streams within the Stanislaus National Forest, California (Figure 1): a high-burn site, Corral Creek (HB); a low-burn site, Cottonwood Creek (LB); and a no-burn site, Basin Creek (NB). The streams were selected to have similar watershed characteristics such as drainage area, slope, elevation, and access from public roads (Table 1). Corral Creek (latitude 37.890314N, longitude -120.017934W) is a second-order stream. During a visit to Corral Creek on March 13, 2014, approximately five months post-fire, I observed a mostly sandy substrate with very little gravel and cobble. Further, this high burn site had no canopy, but large amounts of woody debris from burned trees within and around the channel (Figure 2a). Cottonwood Creek (latitude 37.992591N, longitude -120.086337W), a second-order stream, has an intact canopy, but a burned understory and the stream has a rockier substrate than Corral Creek (Figure 2b). Basin Creek (latitude 38.003548N, longitude -120.091604W), a third-order stream, did not burn during the Rim Fire and serves as my reference stream (Figure 2c). Access to the study sites was gained through permits from the SNF and the USFS Pacific Southwest Region.

Figure 1: Map (Google Maps) showing the locations of the three study sites: Corral, Cottonwood, and Basin creeks within Stanislaus National Forest. Corral Creek is high burn; Cottonwood Creek is low burn; and Basin Creek is no burn.

Figure 2: Photos of the three study sites classified by burn severity. Corral Creek (a) is classified as high burn severity; Cottonwood Creek (b) is classified as low burn severity; Basin Creek (c) is classified as no burn and is the reference stream.

Table 1: Watershed characteristics (USGS 2014) of Corral Creek (high burn), Cottonwood Creek (low burn) and Basin Creek (no burn) within Stanislaus National Forest.

	Corral Creek	**Cottonwood Creek**	**Basin Creek**
Burn Severity	High (HB)	Low (LB)	No (NB)
Basin Elevation	1,188-1,554	1,324-1,737	1,021-1,737
Drainage Area (km^2)	6.2	7.5	9.3
Mean Basin Slope (%)	18.2	19.2	27.9

Sampling to determine the short-term disturbance effects and recovery processes was completed in July and August 2014. Each stream was visited twice during this time. I selected one sampling reach of 150 m for each stream, avoiding areas with additional water inputs, outfalls, bridges, and nearby roads (Harrelson et al. 1994; Merritt and Cummins 2005; Steinman et al. 2005; Fetscher and McLaughlin 2008). Each sampling reach was divided into 30 m cross-stream transects for a total of six subsampling areas per stream. Measurements of physical variables, algal biomass, and invertebrate sampling were taken at each transect of each stream.

Physical Properties

Physical measurements were taken to ensure that streams were comparable and to investigate the effects of the fire on stream conditions. Stream bankfull width, wetted width, and water depth were measured at each transect. In order to assess the effects of fire severity on water quality, I measured levels of nitrate, phosphate, pH, conductivity, dissolved oxygen, and turbidity during each sampling visit using standard water quality kits and probes. Temperature at each stream was monitored at 15-minute intervals during the one-month study period using a Hobo Water Temp Pro data logger. Canopy cover was evaluated by taking an overhead photo at each transect. The photo was later placed behind graph paper to determine percent canopy cover. Following Harrelson et al. (1994), 100 particles were randomly selected from each reach and then measured for size to classify the streambed substrate: sand (less than 2 mm), gravel (2-64 mm), cobble (64-256 mm) or boulder (larger than 256 mm). This involved randomly selecting a starting point by tossing a pebble into the stream from one of the bankfull elevations within each transect; particles were then selected at each step walking perpendicular to the flow (Harrelson et al. 1994). Sixteen to seventeen particles were chosen per transect for a total of 100 particles within each reach.

Algae

I wanted to sample the abundance of algae as a proxy indicator of primary productivity (Fetscher and McLaughlin 2008) and determine if algae are correlated with physical factors and invertebrate assemblages (Steinman et al. 2005). At each transect, I did a visual assessment of percent cover of each morphospecies of macroalgae. I collected qualitative samples of each morphospecies in order to allow later identification of taxa and estimation of species richness. Since most transects did not have a substantial abundance of macroalgae (i.e., <10% cover), I sampled abundance of microalgae during the pebble count by estimating the thickness of microalgae on each pebble more than 2 mm in size (Fetscher and McLaughlin 2008).

Invertebrate Sampling

Invertebrate communities are used to understand trophic dynamics and ecosystem function and to investigate the richness and abundance of aquatic animals. I sampled benthic invertebrates at each transect (six subsamples per steam). All subsample areas had sufficient stream flow so I collected samples from a one square-foot area of streambed using a 500 μm D-framed kick net, alternating net placement at each transect between the right, center (thalweg), and left sides of the main channel (Merritt and Cummins 2005). Contents of each subsample were placed into a 15 L white plastic tub, and large (e.g., > 1 cm diameter) pieces of leaves, wood, and rocks were rinsed to remove invertebrates before they were discarded (Merritt and Cummins 2005). Invertebrates and organic detritus were then separated from inorganic sediment through elutriation, and the remaining sample material was rinsed through a 500 μm sieve. I placed the contents of each one square-foot subsample in a whirl-pak bag filled with 100% ethanol to preserve the sample until lab analysis (Merritt and Cummins 2005). In lab, I emptied the contents of each bag into a sorting tray and initially sorted invertebrates to order level. Once I went through all samples, I did a secondary sort and classified invertebrates to the family level. Additionally, invertebrates were categorized by functional group (grazer, shredder, filtering collector, gathering collector, predator) (Merritt and Cummins 2005). The richness and abundance of each taxon and the composition of each functional group was determined for each subsample and for the sample as a whole (Merritt and Cummins 2005). Finally, the richness and abundance of the orders Ephemeroptera, Plecoptera, and Trichoptera (EPT) was determined as an indicator of water quality (Carter et al. 2006).

Statistical Analysis

As a result of restrictions on access to the study area, as well as the limited availability of suitable streams that are comparable with regards to important watershed characteristics (drainage area, slope, elevation, etc.), only one stream per burn intensity class could be studied for this project. Despite the quantitative limitations of the project and lack of replicates (Hurlbert 1984), the goal of this study is to characterize the ecosystems of three streams with different levels of burn intensity to develop an initial understanding of the effects of the Rim Fire on stream ecosystems. I used multivariate ordination to explore patterns among the three streams and scatterplots to examine relationships among various components of the ecosystems. Since the datasets had a high degree of heterogeneity and relationships were non-linear, I used nonmetric multidimensional scaling (NMS) (Peck 2010) on data taken at the transect level. After graphing the data through NMS, I standardized the data using relativization, looking at the total abundance of families across transects (Peck 2010). Ecological distance among transects was measured using the Jaccard distance measure (Peck 2010). Jaccard measures similarity between site samples to compare diversity (Peck 2010).

Environmental variables at the stream level were measured twice during the sampling period; those at the transect level were measured once. Environmental variables that were recorded at the stream level were temperature, pH, nitrates, phosphates, turbidity, conductivity, and dissolved oxygen. Temperature was averaged into daily temperature, maximum and minimum temperatures, and temperature range by stream. Environmental variables that were recorded at the transect level were bankfull width, wetted width, and substrate. Substrate measures were determined by totaling the sum of each transect then figuring its percent of the total to use for NMS. In addition to NMS, I compared abundance and richness for all family classifications and specifically for Ephemeroptera, Plecoptera, and Trichoptera (EPT).

RESULTS

Physical Properties

Measures of pH were at or near neutral for all sampling dates except for the measurement at Cottonwood Creek (low burn, LB) in August (Table 2). Nitrate values were greater than 3.0 mg/L except for the LB July reading. Phosphate measures were low in all streams. The highest levels of turbidity were in Corral (high burn, HB) and Basin (no burn, NB) creeks. Conductivity was consistently higher in the NB stream when compared to the other two streams. Dissolved oxygen was at healthy levels in all three streams.

Daily average temperatures were similar for the high burn and no burn streams (Figure 3). The HB stream had a higher average maximum temperature (22.3^{o}C) and a greater temperature range (6.9^{o}C) over the time of study. The LB stream showed the most consistency with temperature, having a narrow range of 2^{o}C. The average canopy cover for HB stream was 46.9% while the other streams had 57% canopy cover. For substrate, the HB and LB streams had a higher percentage of sand substrate than the NB (Table 3). The HB and LB streams contained higher amounts of sand, gravel, and cobble while the NB stream contained higher amounts of gravel, cobble, and boulders.

Table 2: Summary of physical variables for Corral Creek (high burn), Cottonwood Creek (low burn) and Basin Creek (no burn) within Stanislaus National Forest. Each variable was measured once in July and once in August at transect one in each stream.

	Corral Creek (HB)		**Cottonwood Creek (LB)**		**Basin Creek (NB)**	
Measure	July 2014	August 2014	July 2014	August 2014	July 2014	August 2014
pH	7.45	7.27	7.15	9.00	7.47	7.80
Nitrates (mg/L)	6.4	6.6	0.44	6.16	4.4	3.08
Phosphates (ppm)	0.1	0.07	0	0.11	0	0.07
Turbidity (NTU)	2.13	2.82	1.28	0.99	0.78	2.83
Conductivity (µS/cm)	40	70	40	50	130	130
Dissolved Oxygen (mg/L)	7	7	6	9	7	7

Table 3: Summary of substrate composition for Corral Creek (high burn), Cottonwood Creek (low burn) and Basin Creek (no burn) within Stanislaus National Forest. Substrate was measured at six transects per stream then averaged together for stream total.

Percent Substrate Composition for Streams

Substrate Type	**Corral Creek (HB)**	**Cottonwood Creek (LB)**	**Basin Creek (NB)**
Sand	42.7	33.1	11.3
Gravel	29.7	20.6	33.4
Cobble	18.8	20.6	36.5
Boulder	8.8	9.0	18.8

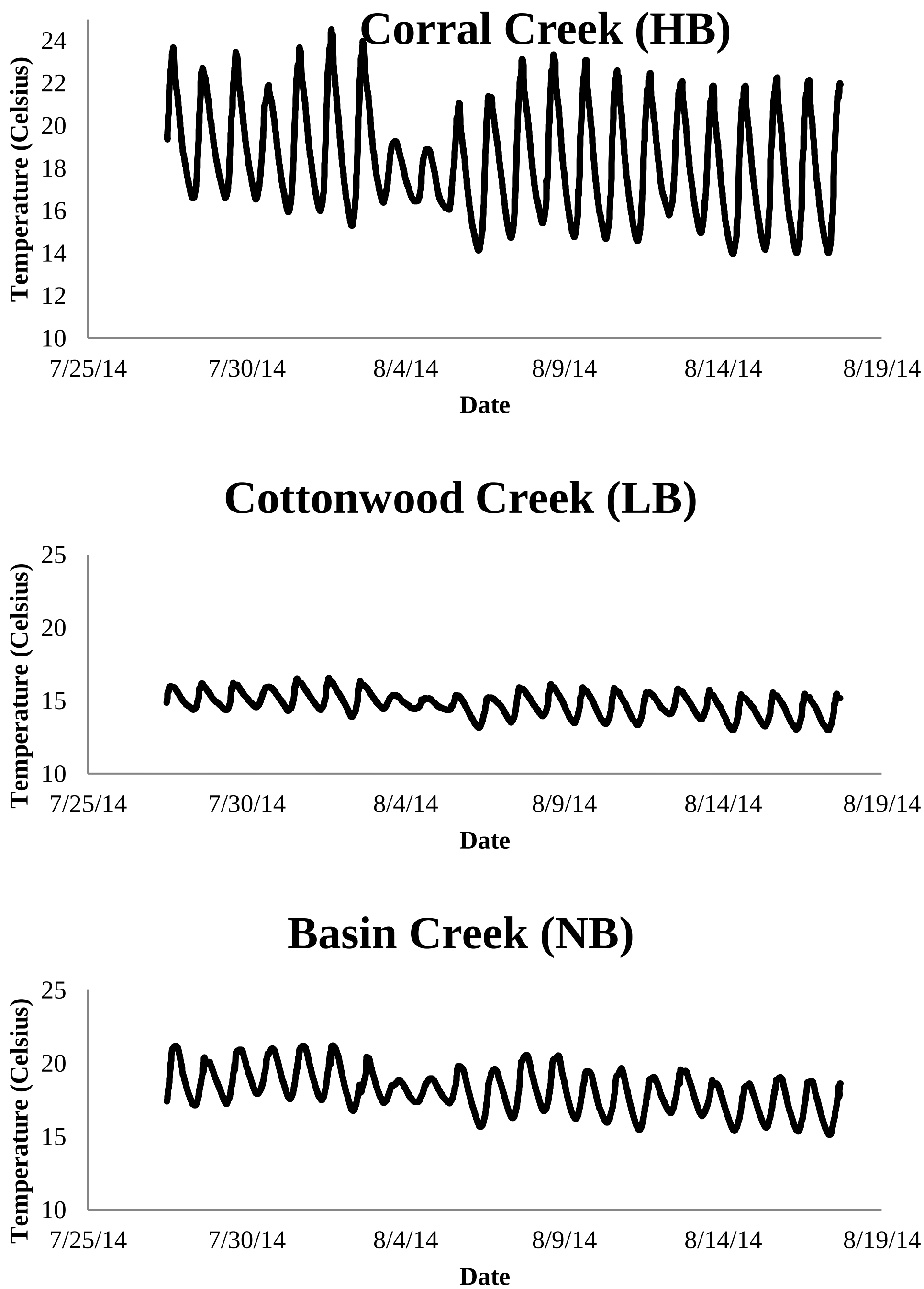

Figure 3: Summary of daily temperature fluctuations for Corral Creek (HB), Cottonwood Creek (LB), and Basin Creek (NB) from July 27, 2014 until August 17, 2014. Temperature was recorded in 15-minute intervals using a data logger placed in transect one of each stream.

Algae

The only stream to contain visible macroalgae was the high burn stream. *Melosira varians* was present at transect 1 at approximately 3% cover, and *Mougeotia* spp. and a floating algal mat (*Volvox, Tribonema, Chlorella,* diatoms, and an unidentified epiphyte) were present in transect 5 at approximately 15% cover. In all streams, streambed cobble was covered with moss to varying degrees. Microalgae was present within all streams, but microalgal cover was low overall (Table 4). The no burn stream had measureable algal thickness in 22% of its areas. The high and low burn streams did not have detectable algal thickness in over 70% of areas sampled.

Table 4: Summary of microalgae presence (Fetscher and McLaughlin 2008) within Corral Creek (high burn), Cottonwood Creek (low burn), and Basin Creek (no burn). Percent presence, as an indicator of primary productivity, was calculated after sampling six transects within each stream.

Percent Presence of Microalgae			
Thickness	**Corral Creek (HB)**	**Cottonwood Creek (LB)**	**Basin Creek (NB)**
No microalgae	74	71	32
Present, not visible	12	12	39
<1 mm	0	3	14
1-5 mm	0	0	8
5-20 mm	0	0	0
Dry point	14	14	7

Invertebrate Sampling

For all eighteen transects sampled, I collected 1,079 individuals: Corral Creek (HB) contained 498 invertebrates, Cottonwood Creek (LB) contained 291 invertebrates, and Basin Creek (NB) contained 290 invertebrates. The high burn stream had higher averages for both total and EPT abundance and richness than the other streams (Table 5). Overall, HB transect 5 had nearly three times the total abundance when compared to values from all 18 transects. In addition, transect 5 had over two times the species richness of all transects in this study. For all individuals collected from the three streams, EPT comprised 38% of total individuals and 47% of taxa richness. The high burn stream had more than twice the EPT abundance of the other streams; however, EPT richness was similar among all streams.

Table 5: Average abundance and richness for all invertebrate families and EPT (Ephemeroptera, Plecoptera, Trichoptera) within Corral Creek (high burn), Cottonwood Creek (low burn), and Basin Creek (no burn). As an indicator of secondary productivity, sampling occurred at six transects within each steam.

	Corral Creek (HB)	**Cottonwood Creek (LB)**	**Basin Creek (NB)**
Average Abundance	93.2	53.5	59.0
Average Richness	13.7	10.5	8.5
Average EPT Abundance	13.4	6.2	6.4
Average EPT Richness	2.0	1.8	1.3

In the low and no burn streams, gathering collectors were present in over 70% of the transects sampled (Table 6). This functional group also comprised the largest group in the HB stream. Chironomidae was the dominant taxon in all three streams (Table 7). Grazers, mostly belonging to the Elmidae family, were present in 24.8% of the samples in the HB stream, but showed low presence in the other streams.

Table 6: Summary of invertebrates classified by functional feeding groups (Cummins 1973) for Corral Creek (high burn), Cottonwood Creek (LB), and Basin Creek (NB). Sampling occurred at six transects within each stream to determine trophic dynamics.

Percent Presence of Invertebrates by Functional Feeding Group			
Functional Group	**Corral Creek (HB)**	**Cottonwood Creek (LB)**	**Basin Creek (NB)**
Collector, filtering	12.5	16.4	17.0
Collector, gathering	54.0	71.2	72.8
Predator	7.0	7.3	7.4
Grazer	24.8	4.0	1.1
Shredder	1.6	1.1	1.8

Table 7: Summary of dominant invertebrate families within Corral Creek (high burn), Cottonwood Creek (low burn), and Basin Creek (no burn). Generalist species had high presence within burned streams.

Corral Creek (HB)	**Cottonwood Creek (LB)**	**Basin Creek (NB)**
1. Chironomidae (23%)	1. Chironomidae (51%)	1. Chironomidae (50%)
2. Elmidae (19%)	2. Nemouridae (8%)	2. Leptophlebiidae (14%)
3. Leptophlebiidae (14%)	3. Psychomiidae (8%)	3. Brachycentridae (14%)
4. Ceratopogonidae (5%)	4. Ceratopogonidae (6%)	4. Ceratopogonidae (9%)
5. Heptageniidae (5%)	5. Brachycentridae (5%)	5. Gomphidae (9%)

Statistical Analysis

Nonmetric multidimensional scaling ordinations using a Jaccard distance measure produced a three-dimensional solution (stress = 11.68, final stability = 0.000). The three axes accounted for nearly 69% of the variability between sample sites (axis 1: r^2 = .169; axis 2: r^2 = .092; axis 3: r^2 = .425). Axes 1 and 3 had the strongest association. Most transects within Cottonwood (LB) and Basin (NB) creeks were ecologically similar (Figure 4). Corral Creek (HB) showed less similarity with the other two streams. Ordination indicates the greatest differences in ecological composition were between the HB stream and LB stream. Canopy cover was the only environmental factor to be strongly associated with both axes (Table 8). Lower canopy cover is correlated with higher species diversity. The invertebrate Chironomidae was an influential variable and had the highest correlation with axes 1 and 3 (Table 9). Chironomidae had the largest presence in the NB stream (HB contained 109 individuals, LB contained 120 individuals, NB contained 142 individuals). This suggests Chironomidae favored the streams with the higher canopy cover.

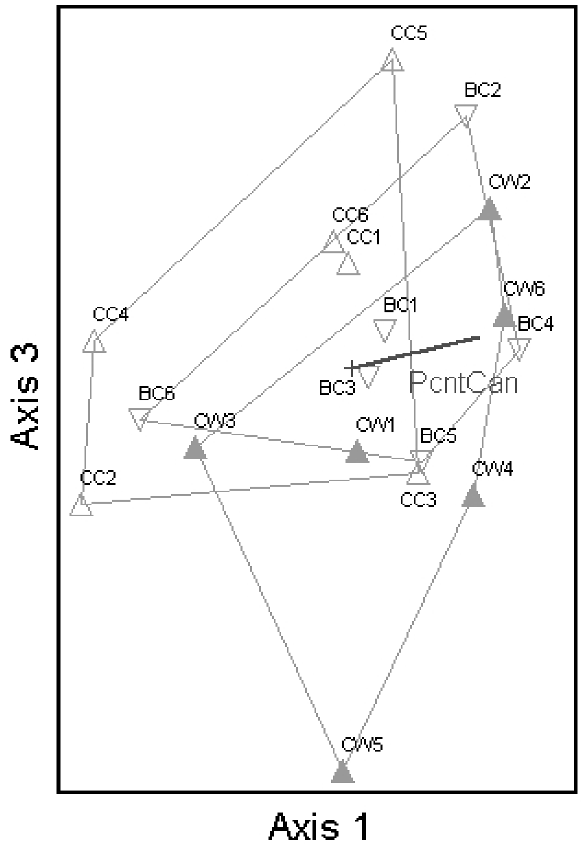

Figure 4: Nonmetric multidimensional scaling ordination plot of invertebrate taxa (axis 2) and environmental factors (axis 1) from samples collected from streams (high burn = CC, low burn = CW, no burn = BC). The number proceeding each stream is the transect number. Lines enclose the area representing each stream (burn category). Percent canopy (PcntCan) was positively associated with both axes.

Table 8: Summary of coefficient of determination (r^2) from nonmetric multidimensional scaling among environmental factors. Environmental factors were compared across six transects within the streams (high burn, low burn, no burn). Percent canopy was most influential among environmental variables in axes 1 and 3. This variable showed a negative association with species diversity.

Environmental Factor	**Axis 1**	**Axis 2**	**Axis 3**
Percent Canopy Cover	**.356**	.001	**.088**
Bankfull Width	.003	.218	.001
Wetted Width	.002	.347	.010
Percent Sand Substrate	.002	.081	.000
Percent Gravel Substrate	.067	.068	.005
Percent Cobble Substrate	.000	.014	.000
Percent Boulder Substrate	.119	.051	.062
Microalgae	.038	.281	.021

Table 9: Summary of coefficient of determination (r^2) from nonmetric multidimensional scaling among invertebrate families. Invertebrate families were compared across six transects within the streams (high burn, low burn, no burn). Chironomidae contributed to species diversity within axes 1 and 3 and Nemouridae was the greatest contributor to axis 2. Both families are gathering collectors and generalist species.

Family	**Axis 1**	**Axis 2**	**Axis 3**
Chironomidae	**.290**	.012	**.582**
Nymphomyiidae	.242	.000	.044
Psychomiidae	.141	.261	.024
Polycentropodidae	.107	.180	.203
Nemouridae	.103	**.389**	.202
Sialidae	.092	.004	.392
Odontoceridae	.072	.014	.005
Ceratopogonidae	.068	.083	.427
Hydrophilidae	.065	.129	.034
Arrenuridae	.048	.181	.000

DISCUSSION

The purpose of this research was to investigate ecological conditions in streams that experienced differing burn severity and compare my results to other studies on the impacts of fire on stream ecosystems. Overall, I found that Corral Creek (HB) had the lowest canopy cover and microalgae level; it also had the highest temperature, a primarily sandy substrate, macroalgae, and the greatest invertebrate abundance. These results suggest that the fire caused high tree mortality, which increased erosion, reduced canopy cover, increased temperatures, increased primary production of macroalgae, and increased secondary production of invertebrates.

A lower amount of canopy cover correlates with higher water temperatures. The temperature of the water in the high burn stream varied on a daily basis by almost 7^{o}C and had a higher maximum temperature compared to the other streams. Similarly, after the Yellowstone fire, reduced canopy increased solar radiation and raised water temperatures by 8-10^{o}C (Minshall et al. 1989). Also, Oliver et al. (2012) found temperature increases of 7-8^{o}C one year after the fire near Lake Tahoe. However, another factor that helped increase water temperature after the Lake Tahoe fire was drought (Oliver et al. 2012). My study was also conducted during a drought; lower stream flows may have contributed to increased water temperatures.

I observed macroalgae only in the high burn stream and microalgae levels were low at all sites. Minshall et al. (1989) reported diatoms and moss were present immediately after the Yellowstone fire while macroalgal growth increased 2-5 years post-fire due to increased nutrient retention by plants and increased light compared to pre-fire levels. Since this study took place one year post-fire and I found moss present in the burned streams, it may be too soon to document significant algal growth. Increased solar radiation, resulting in increased daily average temperatures and temperature fluctuations, may explain the low presence of macroalgae in this study. After the Diamond Peak fire, algal growth did not differ between burn categories five years post-fire (Malison and Baxter 2010). Researchers for the Diamond Peak fire acknowledged algal differences may have not been detected due to rapid turnover of the algal community (Malison and Baxter 2010); that may also be the case in this study. The substrate of the high burn stream was mostly comprised of sand, while the substrates of the other streams were mostly gravel and cobble. The primarily sandy substrate may explain the low presence of microalgae, since there was not much stable substrate to support growth. Although microalgae was low overall, there was one mat of macroalgae found in transect 5 of the high burn stream. This correlates with the high presence of invertebrate grazers in transect 5 (Merritt and Cummins 2005).

Average abundance of invertebrates, including EPT, was greater in the high burn stream; the average EPT abundance was over two times that of the low and no burn streams. Increased abundance may reflect greater primary productivity in the high burn stream. However, EPT richness was not different among the three streams. My results are similar to those found in the Yellowstone study, where there was no change in EPT richness between burned and unburned areas in the Yellowstone fires (Romme et al. 2011).

As expected, most invertebrates were generalists with regards to diet and habitat requirements. Generalists are adapted for changing environments such as those in post-fire streams (Mihuc and Minshall 1995). As observed following the Yellowstone (Romme et al 2012) and the Diamond Peak (Malison and Baxter 2010) fires, Chironomidae were the dominant taxon in all three streams. These detritivores are *r*-strategists (Malison and Baxter 2010), are pollution tolerant, and prefer slower-moving water (Mihuc and Minshall 1995). Streams with a primarily sandy substrate have reduced food resources (e.g., microalgae), which can contribute to generalist species. In addition, an increase in fine sediments can cause a major disturbance to the community and may favor *r*-strategists over endemic species (Minshall et al. 1989).

Water quality variables were generally good in all three streams. Overlap is shown on my ordination, indicating ecological similarity among all streams. Variables such as conductivity, dissolved oxygen, phosphate, and nitrates were within the range of supporting pollution-sensitive EPT taxa (Chadde [Date Unknown]). Levels of pH were within a normal range for most readings; the August readings for the lesser-burned streams were above the 6.5-7.5 healthy range for EPT (Chadde [Date Unknown]). Turbidity was elevated in the high-intensity burn stream, which is to be expected due to the increased sedimentation and burned organic debris present within the stream.

Overall, my prediction of the high intensity burn stream having increased primary productivity was not supported by measurements of microalgae, but was supported by the greater abundance of macroalgae and the higher proportion of grazing invertebrates. The increased turbidity and primarily sandy substrate found in the high burn stream may have contributed to the low presence of microalgae. Additionally, the high burn stream had increased average daily temperature fluctuations and a higher average temperature than the other streams, primarily due to lower average canopy cover. However, the prediction of the high burn stream having lower species abundance and richness was not supported; species richness was similar to the low burn stream. Generalist species were predominant in all three streams. The prediction of the lesser burned streams being similar in water quality and invertebrate abundance and richness was supported.

The Rim Fire was a severe fire that altered the Tuolumne River watershed. By understanding the short-term effects, predictions can be made for future fires and for long-term recovery of the fire area. This study provides a needed snapshot of post-fire ecological relationships, but more study is needed. To achieve more than a snapshot, I would construct a collaborative, multi-year project that has adequate replication of study site conditions (minimally three field sites per burn condition). Further research and monitoring would provide a clearer picture of ecosystem recovery, e.g., observed changes over time in the dominance of *r*-strategists when comparing high and low severity fires (Malison and Baxter 2010). Additional research is important for a number of reasons. Some aspects of the ecosystem I measured are known to be highly variable over time, such as the rapid turnover of microalgae that occurs in streams (Malison and Baxter 2010). Finally, I sampled these streams in the 3rd year of a major drought, prior to any large winter storms or flood flows. The drought may have strongly influenced the short-term impact of the fire (e.g., no large winter storms) as well as the recovery of the ecosystem (e.g., low flows, high temperatures). Since wildland fires in the west are predicted to become more frequent and intense, it is important to develop a stronger understanding of the effects of wildland fire with the overall goal of refining protocols for pre- and post-fire watershed management.

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APPENDIX

APPENDIX A

INVERTEBRATE ABUNDANCE TOTALS FOR CORRAL, COTTONWOOD, AND BASIN CREEKS

Invertebrate Order	**Invertebrate Family**	**Corral Creek (HB)**	**Cottonwood Creek (LB)**	**Basin Creek (NB)**
Acarina	Arrenuridae	1	2	5
Coleoptera	Elmidae	92	8	0
Coleoptera	Hydrophilidae	1	4	0
Coleoptera	Psephenidae	24	0	2
Coleoptera	Ptilodactylidae	1	0	0
Diptera	Ceratopogonidae	25	16	9
Diptera	Chironomidae	109	140	142
Diptera	Culicidae	1	3	1
Diptera	Dixidae	4	0	0
Diptera	Nymphomyiidae	1	0	0
Diptera	Psychodidae	2	2	2
Diptera	Simulidae	7	0	0
Diptera	Tanyderidae	2	0	0
Diptera	Tipulidae	3	3	0
Ephemeroptera	Baetidae	18	2	2
Ephemeroptera	Caenidae	0	0	1
Ephemeroptera	Ephemerellidae	1	3	3
Ephemeroptera	Heptageniidae	25	1	2
Ephemeroptera	Leptohyphidae	0	0	4

Ephemeroptera	Leptophlebiidae	68	8	41
Ephemeroptera	Siphlonuridae	20	5	7
Hemiptera	Mesovellidae	1	1	0
Hemiptera	Naucoridae	0	1	0
Megaloptera	Corydalidae	1	2	0
Megaloptera	Sialidae	5	1	7
Odonata	Cordulegastridae	6	1	3
Odonata	Cordulidae	1	0	1
Odonata	Gomphidae	3	0	9
Odonata	Libellulidae	1	0	1
Odonata	Petaluridae	3	0	0
Plecoptera	Nemouridae	14	21	0
Plecoptera	Peltoperlidae	2	0	1
Plecoptera	Perlidae	0	6	0
Plecoptera	Perlodidae	2	0	0
Trichoptera	Brachycentridae	6	14	39
Trichoptera	Goeridae	2	0	0
Trichoptera	Hydropsychidae	16	2	0
Trichoptera	Hydroptilidae	3	1	0
Trichoptera	Lepidostomatidae	0	0	1
Trichoptera	Limnephilidae	0	0	3
Trichoptera	Odontoceridae	0	2	1
Trichoptera	Polycentropodidae	4	5	0
Trichoptera	Psychomiidae	7	21	1
Trichoptera	Rhyacophilidae	1	0	0
Mollusca		15	16	2