Project Title: Fire and food webs in Yosemite National Park: implications of fire regimes on linked stream-riparian ecosystems

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I. Abstract

Wildfire is an important source of disturbance for mountain streams of the American West. However, linked aquatic-terrestrial ecological responses to wildfire have received limited attention despite their importance for both aquatic and riparian ecosystem sustainability and resilience. In particular, a growing body of literature highlights the role of disturbance in determining fluvial ecosystem properties such as food-chain length (FCL) and cross-boundary flows of energy and nutrients. We investigated the immediate influence of the abnormally large and severe Rim Fire (2013) in Yosemite National Park (YNP) on linked short-term responses of stream geomorphology, riparian habitat, and stream-to-riparian fluxes of carbon and energy (i.e., nutritional subsidies) to riparian spiders. To do this, stream-riparian food webs were analyzed in tributaries of the Tuolumne and Merced Rivers in YNP recently consumed by the unprecedented Rim Fire utilizing a Before-After-Control-Impact (BACI) design. This study built on three years of pre-fire data, and our approach relied on coordinated geomorphic and riparian habitat surveys as well as collections of aquatic and terrestrial primary producers, aquatic-to-terrestrial prey subsidies (i.e., emergent aquatic insects), and riparian spiders. Naturally-abundant stable isotopes (^{13}C and ^{15}N) were used to determine trophic position of spiders and reliance on aquatically-derived energy. We employed a multivariate statistical approach to quantify the relative influence of reach-scale variability (i.e., riparian vegetation, stream geomorphology, benthic invertebrate density and community composition) versus catchment-level variability (i.e.. proportion high-severity fire, high-severity fire patch size, fire extent, and ecosystem size) on FCL and reliance of riparian spiders on aquatically-derived energy. This study further illuminates the mechanisms and scale by and at which wildfire severity within YNP affects linked stream-riparian food webs with implications for ecosystem function.

II. Background and Purpose

Although wildfire is a widespread agent of disturbance in forests and grasslands across the Western U.S. (Agee, 1993), its role in shaping stream-riparian linkages has only begun to receive attention in recent years (Spencer et al., 2003; Malison and Baxter, 2010; Jackson et al., 2012). The ecological connections between streams and their adjacent terrestrial landscapes represent a dynamic area of research (Power, 2001; Baxter et al., 2005), and may provide a better indication of ecosystem resilience and sustainability than more common measurements of ecosystem structure and composition. Meanwhile managers are cautiously proceeding with fuel-reduction treatments in riparian zones, including fires managed for resource benefits (Stone et al., 2010). However, a scientifically-defensible basis for wildfire management in riparian zones is incomplete (Bisson et al., 2003), and resolving the problem of sustainable management of multiple natural resource objectives (e.g., prevention of destructive fires and stream-riparian habitat conservation) remains elusive (Ludwig et al., 1993). Within this context, we proposed to investigate the short-term (6-12 months) influence of wildfire on linked stream-riparian food-web dynamics in fire-prone streams of Yosemite National Park (YNP). To do this, we used riparian spiders of the family Tetragnathidae, a widely distributed riparian consumer highly dependent on aquatic insects that emerge from the stream as adults, as a model consumer via which to measure stream-riparian connectivity and FCL.

1. Project Justification and Expected Benefits: The proposed research builds on three years of research (2011-2013) in YNP, where we relied on a chronosequence approach to compare the effects of fire on stream-riparian ecosystems. The 2013 Rim Fire presents a rare opportunity to experimentally test hypotheses related to fire effects on stream-riparian food-web linkages and the mechanisms that drive these shifts in YNP. The fire perimeter eventually contained two of our study reaches. The proposed research addressed how post-fire shifts in riparian habitat, stream geomorphology, and benthic invertebrates independently and in concert influence: (1) changes in FCL, a key measure of food-web structure; and (2) reliance of riparian spiders on aquatically-derived energy. Finally, we explored landscape-level variability in fire extent, ecosystem size (i.e. drainage area), and high-severity patch size as additional predictors of FCL.

Yosemite National Park has a long history of managing lightning ignitions to restore vegetation structure and composition and protect resources and infrastructure from fires outside the historic range of variability. Federal land managers received new policy guidance in 2009 that allowed use of a "full range of fire management activities", thereby allowing them to use wildfire as restoration technique (NWCG, 2009). Concurrently, funding for fuels treatments in the Department of Interior fire bureaus has become so limited that the only way parks can treat fuels for restoration and protection is through wildfires managed for resource benefit.

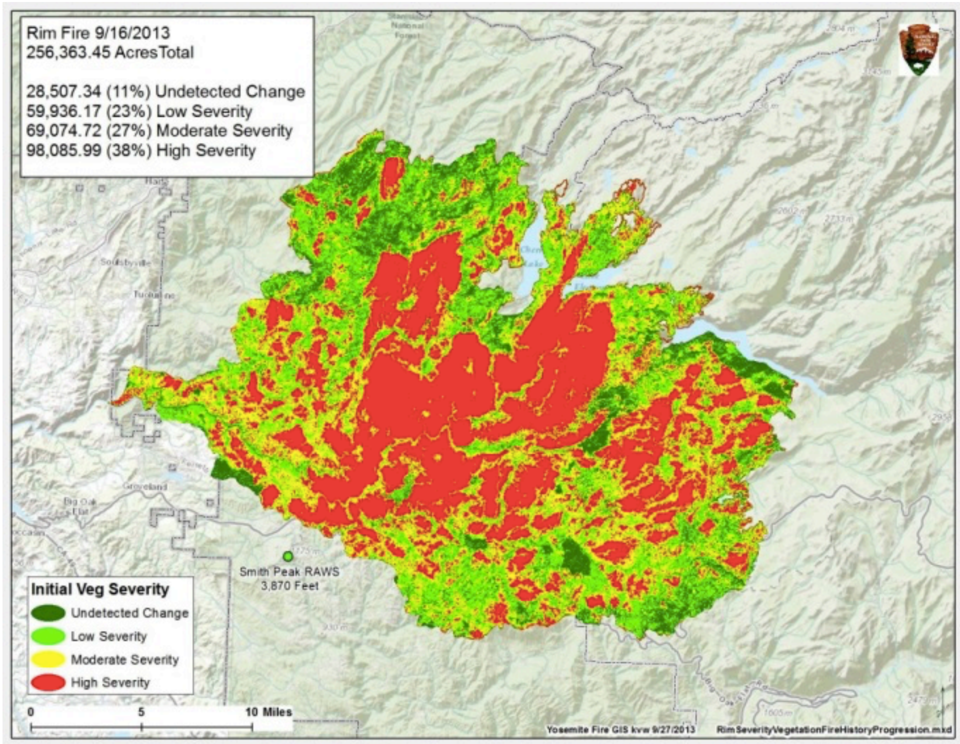
Early analysis suggests that the Rim Fire is exceptional in both scale (3rd largest fire in the history of CA) and intensity (Flores et al., 2013), making it a realization of the mega-fires predicted to increase in the western U.S. (Pyne, 2004). Although the Rim Fire was unprecedented in extent, high-severity patch size, and proportion of high severity until it reached the Park boundary, once inside the park (and outside of patches of chaparral created by antecedent fires) the fire burned at moderate and low severity with relatively smaller patches of high severity (Fig. 1). We anticipated that results from this study further current understanding of the degree to which fire extent, high-severity fire patch size, and proportion of high-severity fire affect stream-riparian ecosystem function in the immediate aftermath of fire. The expected benefit of the proposed work therefore lies in establishing how and at what spatial scale wildfire managed for resource benefit drives stream-riparian ecosystem function as measured by fluxes of energy and organisms (in this study, emergent aquatic insects that provide food subsidies to riparian spiders of the family Tetragnathidae).

2. Objective, Question, or Hypothesis: Riparian spiders of the family Tetragnathidae occupying stream reaches consumed by the Rim fire will exhibit reduced density, less reliance on aquatic nutritional subsidies, and lower trophic position. Collectively, these responses will demonstrate reduced stream-riparian connectivity and FCL.

III. Study Description and Location

1. Study Sites: This research focused on the "after" component of the design; we returned to the two established study reaches consumed in the Rim Fire (Fig. 1) (4a and 4b) as well as two additional control (i.e., not burned by Rim Fire) reaches (5a and 5b) from June to September, 2014.

a



b

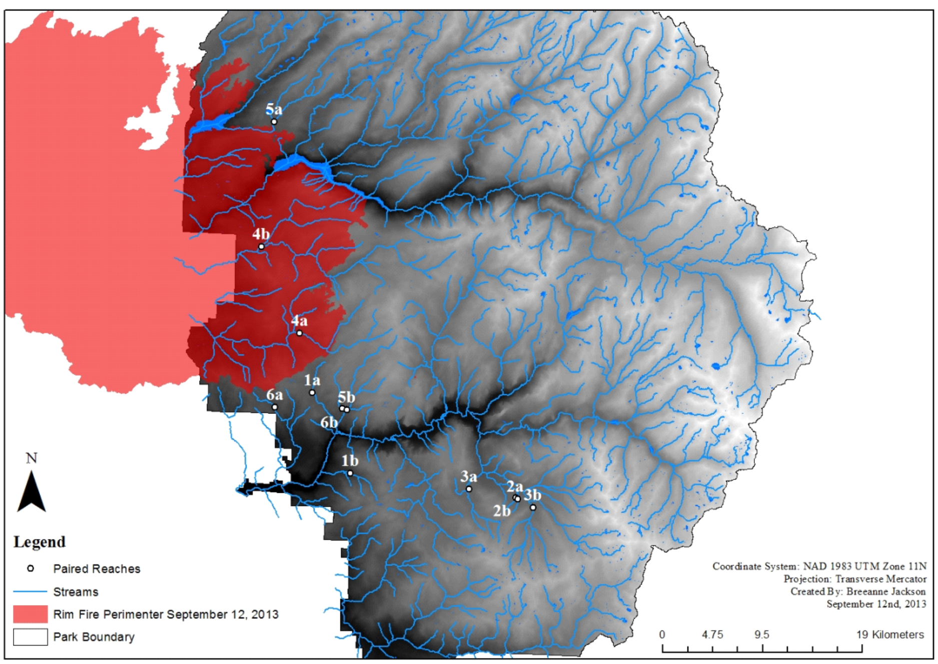


Figure 1. (a) Rim Fire severity (dNBR) illustrating that high severity patches were smaller inside YNP (right portion of map). (b) Rim Fire perimeter from September 12th, 2013 with pre-fire data-complete stream reaches.

2. Sampling Design: The study followed the general framework of a BACI (before-after, control-

impact) design (Stewart-Oaten et al., 1986) (Figure 2a,b). The sampling design for each component is unique and is described in the Field Measurements section.

a

b

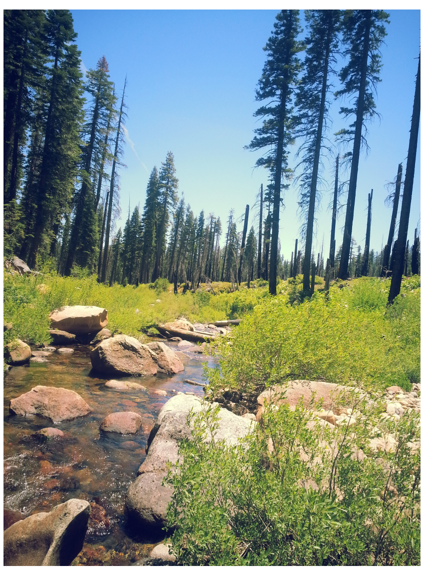


Figure 2. (a) Study stream (Middle Tuolumne) that was burned with high-severity before the Rim Fire, and again by the Rim Fire. (b) Study stream (Frog Creek) that was burned with high-severity before the Rim Fire, but not by the Rim Fire (control in the BACI design).

3. Field Measurements: Tetragnathidae spiders were surveyed along a 30-m transect on each bank centered in each study reach (10x bankfull width) in July and August of 2014 when spiders are at peak abundance. During these surveys 4-8 individual spiders, epilithic algae, and stream conditioned leaf litter were collected for subsequent stable isotope analysis.

Benthic invertebrates: Aquatic macroinvertebrates were collected in the summer using a Surber sampler with a 500μ-mesh net at two locations within each reach and sent to Rhithron Associates, Inc. (Missoula, MT) for species-level identification.

Geomorphology: We returned to 2-3 representative cross-channel transects of each stream reach. At each transect, we measured bankfull width, bankfull depth, and floodprone width. Substrate size was characterized using a gravelometer and a Wolman Pebble Count on 100 pebbles per transect. Embeddedness of each pebble was categorized as: 0-5, 6-25, 26-50, 51-75, or 75-100% embedded in fine sediment. Percent of each reach occupied by large wood (LW >10 cm diameter x 1.0m) and organic debris (LW <10 cm diameter) was measured and counted. In addition, we recorded percent of each reach covered by understory vegetation (<1 m from water surface) and undercut banks. Elevation, aspect, and slope were also recorded for each stream reach based on GIS.

Riparian vegetation: We utilized vegetation plots (rectangular plots 5x20 m with long axis parallel to the stream channel) that were established in study year one within the riparian zone adjacent to each in-stream transect (one per bank). Nested within each 5x20-m tree plot, we established nested shrub and herb subplots (2x4 m and 1x1 m, respectively). We obtained ocular estimates of plant cover for all plant species (grasses, forbs and woody plants), and counted stems and measured diameter at 0.25 m for dominant overstory species including standing dead trees.

4. Additional Data Collection and Analysis

Stable isotopes: Isotopic data relating to aquatic and terrestrial primary producers and riparian spiders were used to quantify the effects of fire on stream-riparian energy flows. Nitrogen ($\delta^{15}N$) signatures were used to estimate riparian spider trophic position. Carbon ($\delta^{13}C$) signatures were used to quantify the contribution of aquatic carbon (via emergent aquatic insects) to riparian spiders. After processing, we estimated spider trophic position using the two-source food web model from Post (2002); $TP = \lambda + \{\delta c - [\delta b1 / \alpha + \delta b2 / (1\text{-}\alpha)]\} / \Delta n$, where λ is the TP of the basal food sources (i.e., 1 for primary producers); δc is the $\delta^{15}N$ signature of the consumer; $\delta b1$ and $\delta b2$ are the signatures of the two basal food sources; α is the proportion of N from basal food source 1; and Δn is the enrichment in $\delta^{15}N$ per trophic level (i.e., 3.4 ‰; Post 2002). The proportion of N derived from basal source 1 (i.e., α) was estimated using a two-end member Bayesian isotopic mixing model solved with the R software package SIAR [Stable Isotope Analysis in R; (Parnell and Jackson 2013)]. The SIAR package is equipped to handle variability in sources, consumers, and trophic fractionation factors (Parnell et al. 2010). We also proposed to incorporate hydrogen (deuterium:hydrogen; δD) as a complementary food web tracer to C and N, however we have not analyzed the deuterium:hydrogen results as of this report.

Ecosystem size and disturbance: We used drainage area (km^2) as a surrogate for ecosystem size (which has been shown to be an important environmental determinant of FCL; Sabo et al., 2010) and delineated the area above each study reach by using the watershed tool in spatial analyst (ArcGIS). Burn severity was estimated at the catchment level using normalized burn ratio values (NBR) calculated from Landsat 7 Enhanced Thematic Mapper Satellite Imagery following Key and Benson (2006). Relative differenced normalized burn ratios RdNBR were calculated for each burned catchment. Breakpoints in RdNBR were determined for each pixel and assigned as either unburned, low-severity, moderate-severity or high-severity fire. From these estimates, percent catchment burned at each level of severity, and total percent catchment burned was determined.

5. Data analysis: We used general linear models (GLM) and multivariate regression to relate continuous variable descriptors of (1) geomorphic and habitat change (in-stream and riparian) to measures of spider density and trophic position and (2) local-scale geomorphic and habitat variables along with ecosystem size and an index of fire severity to FCL. We used non-metric multidimensional scaling (NMDS) to quantify changes in community composition of riparian vegetation among treatments. Following our BACI design, we used *t*-tests to test for spatial and temporal differences in our response variables (Stewart-Oaten et al., 1986).

5. Knowledge Transfer

An additional component of this research project was knowledge transfer to various audiences. Results were shared with the University of California at Merced Yosemite Environmental Science Research Training undergraduate summer semester participants at the Sierra Nevada Research Institute in July 2015 through an oral presentation. Results also continue to be incorporated as part of The Ohio State University's undergraduate and graduate courses in aquatic sciences.

The Co-PI of this study also served as a Resource Advisor for Yosemite National Park. The Resource Advisor (READ) program is a recent development in wildland fire management. READs are red-carded firefighters from multiple agencies (EPA, NPS, USDA, BLM, etc.) who also have knowledge of cultural or natural resources. Their role is to assist both incident command staff and on-the-ground firefighters make tactical decisions to prevent or mitigate damage to resources of concern during fire suppression operations. The results of this study were shared in informal meetings with the head READ for Yosemite National Park and will be incorporated into future READ trainings.

IV. Key Findings

We found little evidence to suggest that the Rim Fire had a significant effect on channel geomorphology, structure and composition of riparian vegetation, community composition of aquatic benthic invertebrates, tetragnathid spider density, or riparian habitat for streamside spiders in the first growing season following the fire (June to September 2014). We have yet to analyze data relating to reliance on aquatically-derived energy (i.e., nutritional subsidies) or trophic position of tetragnathid spiders (a proxy for FCL in this study) following the Rim Fire. However, results from the entire study suggest that fire-severity and time since fire has little effect on food-web attributes. Instead regional precipitation patterns, catchment-level fire frequency, and benthic macroinvertebrate density and composition at the reach level appear to be stronger predictors of reliance on aquatically-derived energy, trophic position, and density of tetragnathid spiders – a common riparian consumer – in this study system.

V. Management Implications

Although wildfire is a widespread disturbance in the American West, we are far from understanding its impact on stream-riparian ecosystems especially over longer periods of time and broader spatial scales. In addition, the majority of information available is concentrated on abiotic effects and effects on populations of individual species, predominantly benthic macroinvertebrates and fish. Therefore, fire managers are uncertain how to conduct prevention, suppression, and restoration activities to promote sustainability of stream-riparian ecosystems, which disproportionately contribute to natural resources across the landscape and are often already impaired due to a legacy of land use. This research, therefore, has the potential to inform fire managers of the ecosystem effects of large, severe wildfires on stream-riparian ecosystem function, at least within the constraints of this study area. Although results from this study are not sufficiently broad-reaching to effectively change fire management policy, our work challenges the often held ideal that wildfires are "bad" for stream-riparian ecosystems.

VI. Relationship to Other Recent Findings and Ongoing Work on this Topic

Research relating wildfire severity to stream-riparian ecosystems has previously focused primarily on abiotic responses (e.g., water quality and channel geomorphology) and biotic responses of specific species at the population level. Whether changes observed in these characteristics of stream-riparian ecosystems translate to functional characteristics (e.g., aquatic-terrestrial food-web connectivity and FCL) is largely unknown, but speaks more directly to the ultimate resistance and resilience of the ecosystems to disturbance. While previous studies have demonstrated significant shifts in populations of individual species over the months to years following wildfire, we found little evidence that aquatic-terrestrial food-web connectivity and FCL are particularly sensitive to fire-severity in the first growing season following a large, severe wildfire. This result may shift the way fire ecologists view the influence of terrestrial disturbances like wildfire on stream-riparian ecosystems and shape further inquiry.

From a theoretical perspective, disturbance is thought to among the most important factors that determine FCL, a key attribute of food webs. Traditionally, in stream ecology, the disturbance of interest has been flow variability. We sought to determine to what extent a recent, severe wildfire also influenced FCL (in this case trophic position of tetragnathid spiders). We found evidence that recent, severe wildfire was not a significant factor determining FCL in small mountain streams in the short term. Instead, we found evidence that ecosystem size and fire-frequency at the catchment level was more strongly associated with food-web attributes in our Yosemite National Park study system.

VII. Future Work Needed

This research is representative of a theoretical shift in the influence of wildfire on stream-riparian ecosystems from focusing primarily on abiotic responses and responses at the population level of select species to a more holistic ecosystem functioning perspective. In addition, this research expands from the traditional reach-scale approaches (i.e., at the local stream reach) by also examining how wildfire (as well as other sources of environmental variation) may influence stream-riparian ecosystems over larger spatial scales (i.e., catchment and region) and longer time frames (i.e., first growing-season following fire to decades following fire). We expect these topics to continue to be of interest to researchers and managers in the future. Specific to this research, the following questions would better elucidate wildfire effects on stream-riparian ecosystems:

1. How do food-web dynamics of stream-riparian ecosystems respond to fire in the years to decades following wildfire?
2. In what ways do complex spatial patterns of wildfire in catchments influence ecological

processes, including food-web architecture across the aquatic-terrestrial boundary?
3. How does fire history within a catchment influence current patterns in stream ecosystem structure and function?

VIII. Deliverables Cross-Walk

Project Milestone	**Description**	**Delivery Date**
Field season	Field surveys and sample collection in YNP	Completed
Laboratory work	Sample preparation and analysis	Completed
Data analysis	Statistical analysis of data and synthesis of results	Completed except for deuterium and trophic-position results
Publication of results	1) Jackson, B.K. and S.M.P. Sullivan. (oral presentation) *Taking a broader persepctive: catchment-level wildfire variability and climate drive riparian spider responses in Yosemite National Park, CA.* 2) Jackson, B.K. and S.M.P. Sullivan. (manuscript) *Responses of riparian tetragnathid spiders to wildfire in a Mediterranean forested ecosystem of California, USA.* 3) Jackson, B.K. and S.M.P. Sullivan (manuscript) *Antecedent and recent wildfire severity in forested ecosystems of the Sierra Nevada, California, USA do not result in heterogeneous patterns in riparian vegetation and stream geomorphology.* 4) Jackson, B.K. et al. (book chapter) *Stream-*	Completed In print Submitted Published

	Riparian Ecosystems and Mixed- and High-Severity Fire.	
PhD Completion	1) Jackson, B.K.. (dissertation) *The role of wildfire in shaping the structure and function of California 'Mediterranean' stream-riparian ecosystems in Yosemite National Park.* 2) Graduation	Defended and approved Completed

I. **Literature Cited**

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I. **Additional Reporting**

Peer-reviewed publications:

Jackson, B.K., S.M.P. Sullivan, C. Baxter, and R. Malison (2015) Stream-Riparian Ecosystems and Mixed- and High-Severity Fire in DeLaSalla, D. and C. Hanson, editors. The Ecological Importance of Mixed-Severity Fire: Nature’s Phoenix. Elsevier

Jackson, B.K. and S.M.P. Sullivan (2015) Responses of riparian tetragnathid spiders to wildfire in a Mediterranean forested ecosystem of California, USA. Freshwater Science. 34:1542-1557.

Jackson, B.K. and S.M.P. Sullivan (Reviewed and in preparation for re-submission) Antecedent and recent wildfire severity in forested ecosystems of the Sierra Nevada, California, USA do not result in heterogeneous patterns in riparian vegetation and stream geomorphology. International Journal of Wildland Fire.

Scholarly Presentations:

Jackson, B.K. and S.M.P. Sullivan. Taking a broader perspective: catchment-level wildfire variability and climate drive riparian spider responses in Yosemite National Park, CA. Oral Presentation In: Society for Freshwater Science Meeting; 2015 May 17-22; Milwaukee, WI.

Invited and Outreach Presentations:

Jackson, B.K. “Wildfire and freshwater ecosystems.” Yosemite Environmental Science Research Training, Sierra Nevada Research Institute, University of California at Merced; August 2014; Wawona, CA.

Sullivan, S.M.P. "Chains, webs, and networks – What does trophic ecology contribute to river science and conservation in a changing world?". Department of Biology, Kenyon College; November 2014; Gambier, OH.