CONCEPTUAL FRAMEWORK TO ASSESS THE EFFECTS OF WILDFIRE ON AQUATIC SYSTEMS IN SEMI-ARID AND ARID REGIONS OF THE WESTERN GULF SLOPE DRAINAGES

by

Virginia L. E. Dautreuil, B.S.

A thesis submitted to the Graduate Council of
Texas State University in partial fulfillment
of the requirements for the degree of
Master of Science
with a Major in Aquatic Resources
December 2013

Committee Members:

Timothy H. Bonner, Chair

Alan W. Groeger

Joseph A. Veech

FAIR USE AND AUTHOR’S PERMISSION STATEMENT

Fair Use

Duplication Permission

ACKNOWLEDGEMENTS

First and foremost I would like to thank Dr. Timothy Bonner, my graduate advisor for encouraging my pursuit of this project both by helping me cultivate such an complex topic into a feasible project as well as encouraging my pursuit of a topic I am passionate about. His knowledge, insight, and professional guidance have been pivotal in the continuation of my development as a biologist. Also a big thank you to my committee members: Dr. Alan Groeger, and Dr. Joseph Veech for their support and insight, which were key to my success.

I would like to thank members of the Bonner Lab, especially Stephen Curtis and Kenny Behen who guided me through my first two semesters (and then some) answering my many questions, and providing support. In addition to Kenny and Stephen, I would like to thank Sarah McMillian, Dave Ruppel, Cody Craig, and Chris Vaughn as well as Tom Heard, Kristy Kollaus, James Tennant, and Ichthyology classes of Fall 2011, Summer 2012, and Fall 2012, for assisting with my fieldwork.

I would also like to thank Kate Crosthwaite for sparking my interest in and providing my foundation in the field of fire ecology, also former and current firefighters of the Bastrop office of the Texas Forest Service, who taught me all I know of wildland fire behavior. And to Rich Gray and Karen Ridenour of the Texas Forest Service for project ideas, locations and data which was invaluable to my research.

Special thanks to my parents, David and Constance Eaton for the support in making the decision to return to graduate school as well as continued support throughout, without which returning to school would not be possible. In addition, they had nurtured my love of the outdoors as a child, whether by taking my siblings and I canoeing in the saltmarshes of Massachusetts, driving me to endless volunteer opportunities, or putting up with the occasional wildlife orphan/ visitor. I would also like to thank my husband, Marc, for being supportive, encouraging and calming when times became hectic. Lastly, thanks to my friends that have been supportive of my academic pursuit and understanding of my absenteeism while finishing my degree. Without this network of colleagues, family and friends this achievement would not have been feasible.

TABLE OF CONTENTS

Page

LIST OF FIGURES

Figure **Page**

ABSTRACT

In 2011, wildfires burned 1.6 million acres in Texas, an unprecedented wildfire frequency, extent, and intensity attributed to several years of below average annual precipitation. High profile fires, such as the Oasis Ranch Fire (Kimble County, Texas), underscore the lack of knowledge in the effect and mitigation of large-scale wildfires on stream communities in arid and semi-arid regions, which typically support a diverse and endemic fauna limited to one or a few streams and highly susceptible to local perturbations. Purposes of this study were to conduct a literature review of wildfire effects on stream communities from regions where wildfires are common (i.e., Northwest USA, Australia), quantify abiotic and biotic responses within stream communities, and develop a framework to predict community responses relevant to arid and semi-arid regions of western gulf slope drainages of New Mexico and Texas. The framework also provides testable hypotheses, which can be validated with independent replications when wildfires occur within the western gulf slope drainages. Among 63 published and non-published articles, abiotic and biotic responses of aquatic communities following a fire ranged from relatively minor habitat and community changes initially, short term, and long term to relatively major habitat and community changes initially and up to 20 years post-fire. Magnitude of change was associated with precipitation timing and amount that transported sediment, woody debris, and nutrients into the stream, which affected stream morphology, macroinvertebrate communities, and fish communities. Among systems with major habitat changes, biotic effects generally included an increase in tolerant macroinvertebrates and decreases in fish abundances and densities. However, abiotic environments and biological communities were resilient through time and returned to pre-fire conditions. The framework was applied to two fires, one (Canon Ranch Fire, Pecos River drainage) located 5 km from the stream in which no detectable abiotic and biotic responses were detected and another (Oasis Ranch Fire, Colorado River drainage) located adjacent to the stream in which sediments and charred woody debris entered the stream but no biotic responses were detected. Literature review and framework provide natural resource managers with proactive and reactive management options. Management options can be used, when feasible, to mitigate large-scale fire effects on stream communities, especially those that support endemic, threatened, or endangered fauna.

CHAPTER I

CONCEPTUAL FRAMEWORK TO ASSESS THE EFFECTS OF WILDFIRE ON AQUATIC SYSTEMS IN SEMI-ARID AND ARID REGIONS OF THE WESTERN GULF SLOPE DRAINAGES

Introduction

Understanding the effects of fire on aquatic communities lags behind that of terrestrial communities. Published literature is generally limited to quantifying adverse effects of fire on aquatic habitats and biota with only a few studies attempting (Bisson *et al.* 2003; Rieman *et al.* 2010) to understand fire and fire effects as a natural, and perhaps necessary, component of the aquatic ecosystems. Following an upland or riparian fire, aquatic habitats are inundated with sedimentation (Ryan *et al.* 2011) and large woody debris (Minshall *et al.* 1989), leading to changes in nutrient inputs (Earl and Blinn 2003), riparian vegetation (Dwire and Kauffman 2003), stream morphology (Eaton *et al.* 2010; Kozlowski *et al.* 2010), warmer water temperatures attributed to reduction in canopy cover (Rosenberger *et al.* 2011), and other physio-chemical parameters (Mahlum *et al.* 2011). Aquatic biota responses include shifts in macroinvertebrates (Hall and Lombardozzi 2007; Malison and Baxter 2010), fish occurrences and abundances, and trophic interactions (Dunham *et al.* 2007; Sestrich *et al.* 2011). Habitat effects and biotic responses are not consistent among fires. Effects and responses are immediate or delayed, depending upon fire severity and size, time until the next precipitation event, and fire proximity to the stream. Disturbances, such as fire and post- fire runoff, create spatially patchy habitats (Townsend 1989), but short-term habitat changes and biotic shifts might be necessary in maintaining biotic integrity, similar to terrestrial habitats and biota. Terrestrial animals associated with early, mid and late serial stages (i.e., habitat heterogeneity; Pianka and Goodyear 2012) will recolonize burned areas as vegetation recovers over a serial sequence. Species became fire-specialists from their ability to use those habitats created by repeated fires (Fox 1982; Smith 2000).

Among published studies, abiotic and biotic responses to fire effects are reported in aquatic systems in the Rocky Mountain region or Pacific Northwest (60%) and montane region of Southwest (17%) USA, Australia (10%), Canada (5%), Mediterranean climates of California (3%), the Appalachian region (3%) and Spain (2%). Studies typically are conducted within coldwater communities and with salmonids (Burton 2005), though a few are conducted with non-salmonids (Rinne and Carter 2008) and in more xeric ecoregions. Applicability of the reported abiotic and biotic responses to other physiographical areas, such as arid and semi-arid regions of western gulf slope (WGS) drainages of New Mexico and Texas, is unknown, but I predict that the effects of wildfires are likely similar. Specifically, I predict that aquatic organisms will shift according to habitat responses to the fire, both temporally and spatially. However, aquatic systems responses within arid and semi-arid regions might noticeably differ from other regions, in that vegetation biomass is much lower in grasslands and desert shrub regions, slope is generally much less, precipitation and therefore runoff are less, streams and rivers receive greater influences from groundwater and many support endemic fauna in isolated populations with low probabilities of recolonization if extirpated. In addition, increasing aridity associated with climate change during interglacial periods is progressing northeastward along the western gulf slope drainages, decreasing fire potential in western regions and increasing fire potential in the eastern regions of the

WGS (Krawchuk *et al.* 2009). Recent high profile fires within the WGS, such as the Oasis Ranch Fire (near Junction, Texas), and Canon Ranch Fires (near Fort Stockton, Texas), underscore the need to understand and quantify the positive and negative influences of fires on aquatic systems.

In order to identify similarities and differences between published accounts and the WGS, I compiled and reviewed relevant literature on the effects of wildfire on aquatic community response. From this I identified co-variables that influence the effects of fires on aquatic systems and developed a conceptual framework with testable hypotheses to assess effects in arid and semi-arid regions of Texas. Unpredictable disturbance events such as fire can be difficult to study due to logistical restraints and costly to develop manipulative studies; however, hypotheses generated from existing body of knowledge can be developed *a priori* and tested opportunistically and repeatedly. I demonstrated how the conceptual framework can be used by applying stated hypothesis towards two stream communities that had fires within their watersheds in 2011 and tracked community responses for up to one year. Additional testing, when available, will enable adequate replication and refinement of the complex interactions between wildfire and aquatic systems within the WGS.

Methods

The literature review consisted of database and internet searches for peer-reviewed and gray literature. A total of 115 manuscripts were selected and grouped into primary literature (reported results of novel studies), secondary literature (new synthesis with results of others), and tertiary literature (compilation of previously reported data).

Primary literature was retained and identified by fire type, wildfire or prescribed fire. I retained only primary literature that reported effects of wildfire and not prescribed fire. A total of 63 manuscripts (Appendix A) were retained for further assessment. Available information was quantified by abiotic and biotic responses among three time periods: initial ($\leq$ 3 months post- fire), short (4-11 months post- fire) and long term effects ($\geq$ 1 year post- fire). Co-variables, such as fire severity and proximity, were noted when necessary, with fire effects either measured against reference sites or data collected prior to the fire. Assessment methodologies (i.e., sampling design) for the two case studies are contained within each case study.

Results

The most common habitat response reported among 51 studies was sediment (26 of 58, 45%), followed by large woody debris (40%), channel morphology (31%), water quality (29%), water temperature (26%), and stream discharge (19%). Periods of observations ranged from immediately to 20 years following a wildfire. Among 24 studies, 22 published accounts documented effects on macroinvertebrate communities and 17 documented effects on fish communities. Periods of observations ranged from immediately to 14 years following a wildfire.

Habitat responses

Among the 26 studies reporting sediment responses, 24 (96%) reported sediments increased in streams, one reported no difference in sediments, observed only during the short term, and one reported less stream sediments during the long term, attributed to high discharge and scouring between the period of observation and the fire. Among studies with sediment increases, all reported sedimentation initially (*N* = 14) and short term (14), and 10 studies (77%) reported sedimentation long term (13). Sedimentation was associated with heavy precipitation events following fires in 53% of the initial period of observation. Among long-term studies, five studies provided repeat assessments across periods of observations; two of the five (40%) reported no evidence of sedimentation in the long term after reporting sedimentation initially and in the short term. Evidence of sedimentation lasted up to 11 years following a fire.

Among 23 studies reporting woody debris responses, 10 (43%) reported woody debris increased in streams, nine reported no change in woody debris up 2 to 6 years after the fire, and five reported decreases in woody debris more than a year after the fire, attributed to channel scouring flood events. Increases in woody debris were reported initially (*N* = 2), short term (3), and 5 reported increases in woody debris over the long term. Long term increases in woody debris were attributed to the decay of fire killed trees that later fell and enter the stream.

Among 19 studies reporting channel morphology response, 89% noted changes in channel morphology after a fire. These changes included increases in riffles and gravel bars, changes in stream gradient, increases and decreases in bankfull width, bank incision, and bank stability. These responses were observed initially (*N* = 10), short term (7), and long term (7). Evidence of bank stability was reported for up to a year after the fire (*N* = 2). Channel morphology responses were attributed to precipitation events in 8 (44%) of the studies and occurred up to 2 years following the fire.

Among 17 studies reporting water quality responses, 10 studies (59%) reported increases in phosphorus and nitrogen levels. Elevated phosphorus and nitrogen levels persisted up to 5 years. Four studies reported decreases in dissolved oxygen concentrations and three studies reported increases in ammonium up to one year after a fire. Three studies did not detect changes in water quality short or long term. Water quality responses were attributed to ash and smoke deposition, fire-fighting retardant, and runoff from burn areas. Two studies reported increases in cyanide in the aquatic system and mercury in the tissues of fishes.

Among 15 studies reporting changes in water temperature, 12 studies reported increases in water temperature initially (5), short term (4), and long term (9). Water temperatures returned to pre-fire conditions one year to 20 years after a fire. Increases in water temperatures ranged from slight (<1°C) to 5°C and were related to fire severity, stream order, riparian vegetation consumption, and extent of scouring and channel morphology response.

Among 11 studies reporting stream discharge responses, seven (64%) studies reported increases in discharge and four (36%) reported no detectable change. Increases in discharge were reported initially ($N = 4$), short term (5), and long term (4), and were attributed to increases in overland flow rate related to reduction in upland and riparian vegetative cover following a fire.

Community responses

Twenty two studies reported macroinvertebrate responses relating to taxa richness (13 of 22 studies; 59%), density (13; 59%), trophic shifts (7; 32%), abundances (5; 23%), and biomass (7; 32%). A common theme among 15 studies was an increase in dipterans (Chironomidae, Simulidae, and Tipulidae), oligochaetes, and ephemeropterans (*Baetis*) and associated decreases in taxa richness (N = 9), changes in relative abundances (5), and increases in densities (5) and biomass (4) within the macroinvertebrate community. These collective changes reported occurred initially (2), short term (7), and long term (12), persisting up to 10 years after the fire. In addition, decreases in macroinvertebrate density (7) and biomass (3) were observed in areas subject to ashing and post- fire scouring, initially (2), short term (6) and long term (4). Two studies reported decreased macroinvertebrate densities in the short term, followed by increased densities during the long-term period. Likewise, one study reported decreases in macroinvertebrate biomass in the short term, followed by increases during the long term. One study reported no change in density or biomass of macroinvertebrates with observations occurring during the short and long term. Another study reported a decline in taxa richness during short term, but taxa richness increased to pre-fire levels within 22 months post- fire. Three studies reported no change in taxa richness. Among all studies, trophic shifts generally favored collector-gathers, scrapers, and shredders. One study reported no changes in the trophic levels of macroinvertebrates, likely linked to frequent disturbances in the study stream.

Seventeen studies reported fish community responses. All studies reported responses by salmonids initially (N = 9), short term (6), and long term (14) with four studies including responses of cyprinids, catostomids, and cottids. Among initial period of observation, 66% (6 of 9) reported fish mortalities, extirpations, and decreases in fish densities, biomass, and abundances, associated primarily with debris flows following a precipitation event. Among short term period of observation, four of six studies reported depressed fish densities with one associating moralities with additional debris flows, whereas two studies reported redistribution of fishes within the affected stream reach and increases in fish densities and biomass.   Among 14 studies reporting long term period of observation, seven studies documented the return of or surpassing pre-fire levels in fish densities and abundances, six studies reported depressed densities and abundances of fishes, and one study documented persistent fish mortalities attributed to continual debris flow up to two years post- fire. Three studies documented changes in food sources with one noting a shift in rainbow trout diets from zooplankton to phytoplankton and two reporting a shift from allochthonous to autochthonous.

Predicted habitat and community responses in arid and semi-arid regions

From the literature review habitat and biota responses among initial, short term, and long term periods are conceptualized and summarized in Figure 1. Magnitudes of positive and negative responses were greatest during the initial period following a fire, followed by a trajectory toward pre-fire conditions within months, years, and even decades, depending on the response variable. Magnitude of responses and time period of recovery are dependent upon additional factors as well, such as such as fire severity, proximity to the aquatic system, hydrological condition (i.e., timing and duration of precipitation events and flow pulses), upland vegetation, watershed and stream slope, and departure from historical fire regime. Nevertheless, the conceptual model provides testable hypotheses to validate the likely relationship between wildfires and arid and semi-arid aquatic habitats and biota through time, while allowing the addition of new response variables. As future opportunities arise, the conceptual model is the theoretical framework to quantify abiotic and biotic responses, thereby providing independent and replicated observations. To illustrate the applicability of the model, I applied the framework to two recent wildfires within watersheds of the Edwards Plateau. Both watersheds contain streams with perennial flows from springs of the Edwards Aquifer and each contain spring-associated fishes that generally occur in the clear and stenothermal waters of spring outflows.

Case Study 1: Oasis Fire, Kimble County, Texas

The Oasis Fire started on 26 April 2011 and was contained 10 May 2011, burning about 10,000 acres of dormant brush, hardwood slash brush, and tall grass (http://inciweb.org/incident/2196/; accessed 24 October 2013). Less than 1 km of riparian corridor along the South Llano River was burned (Appendix B). Sedimentation and charred woody debris was noticeable in the ravines upland from the river and within the river, evidence of precipitation events washing sediment into the river. Pre-fire fish community structure was documented by Curtis (2012), which provided three seasons of fish occurrence and abundances from two sites within the South Llano River. Post- fire, the two sites were sampled initially (within one month on June 2011), short term (six months), and long term (one year), using the same protocols as Curtis (2012).   Specific to Llano River, I predicted that densities of the fish community would be less immediately following the fire as a response to predicted changes in the abiotic aquatic environment and that densities and relative abundances of the spring associated fishes (i.e., *Dionda nigrotaeniata*, *Notropis amabilis*, *Etheostoma lepidum*, and *Percina* *carbonaria*) would be less at least initially and during the short term but recovering to pre-fire levels during the long term.

Abiotic and biotic variables and confounding effects (i.e., precipitation events) were quantified through time. A total of 460 mm of precipitation was recorded between the fire event and the long term sampling event (Figure 2a). Total precipitation was 20 mm before the initial sample, 170 mm before the short term sample, including a 63 mm event two months before the sample, and 270 mm before the long term sample. Abiotic environment (i.e., dissolved oxygen, water temperature, conductivity, percent of large woody debris, and pH) and geomorphic units (availability of riffle, run, and pool habitats) were within seasonal levels. Percentage of silt substrates increased from 13% (pre-fire) to 22% initially, 10% short term, and 46% long term, percentage of algae increased from 5% (pre-fire) to 10% initially, 0% short term, and 40% long term, and percentage of aquatic macrophytes increased from 8% (pre-fire), 15% initially, 14% short term, and 20% long term. Density of the fish community was within mean and 2 standard error (SE) of pre-fire density initially, higher than pre-fire mean and 2 SE in the short term, and lower but within pre-fire mean and 2 SE in the long term (Figure 2b). Density of spring-associated fish community was higher than mean and 2 SE of pre-fire density initially and within pre-fire density and 2 SE during short and long term (Figure 2c). Relative abundance of spring fishes was greater than mean and 2 SE pre-fire abundances, less than pre-fire abundances during the short term, and within pre-fire abundances during the long term (Figure 2d).

Abiotic and biotic responses were related to model predictions (Figure 3). Overlaying precipitation events with timing of fire and sampling, it is unlikely that the initial sample was influenced by direct fire effects or precipitation-induced sedimentation effects. As such, abiotic and biotic responses during the initial period were dropped from further consideration. Increases in silt substrates, percent algae, and percent aquatic macrophytes and observed changes in the density and relative abundances of sensitive fishes (spring-associated) and tolerant fishes (inversely related to sensitive fishes) corresponded in part to predictions. As predicted, greater amounts of percent silt substrate were observed in the South Llano River post- fire but the timing did not correspond as predicted. Highest amount of silt substrates were observed in the long term and not in the short term. Percent algae and percent macrophytes were greater than pre-fire levels in the long term. This could be attributed to fire effects (i.e., higher amounts of sedimentation and increases in nutrients), although seasonality (i.e., greater solar radiation and length during June in both initial and long term) is also an explanatory factor in observed increases. Densities and abundances of tolerant and sensitive fishes conformed to predictions short term and long term, though the exact mechanism of short term changes is not clear. Sedimentation is expected to regulate ratios of tolerant and sensitive taxa, but sedimentation (i.e., inferred from percent silt substrates) was lower in the short term than in pre-fire and long term.

Case Study 2: Cannon Ranch Fire, Terrell County, Texas

The Cannon Ranch Fire ignited by lightning on 11 April 2011 burning approximately 63,500 acres through tall grass and mixed tall grass and scrub before it was contained on 20 April 2011 (http://www.inciweb.org/incident/2167/; accessed 30 October 2013). The fire occurred upland to Independence Creek, at a distance >5 km from the creeks margin (Appendix C). At the time of sampling (18 November 2011; 7 months after the fire occurred), no evidence of sedimentation or charred materials was observed in the creek. In fires located a distance from a stream, I predict that deposition of nutrients from smoke and ash initially and runoff eventually would be detectable. However, 2011-2012 precipitation was <20 mm, reducing the likelihood of precipitation-induced runoff, and riparian vegetation along stream margin is abundant, thus reducing overland flow from transporting nutrients into the stream. As such, I predicted that fire effects in Independence Creek would be minimal and likely undetectable. Pre-fire fish structure community was quantified by Watson (2006). I used the same sampling protocols to assess community structure of the Independence Creek within reaches likely affected by fire sedimentation.

Changes in Independence Creek fish communities between pre-fire and post- fire were assessed with Renkonen's Similarity Index (RSI), $S_R = \sum_{1}^{i} \text{minimum } (p_{1i}, p_{2i})$ (Balmer 2002). Sensitive species were spring-associated *Cyprinella proserpina, Dionda argentosa, Etheostoma grahami, Notropis amabilis*, and tolerant species were *Cyprinella venusta* and *Gambusia*; (Bonner *et al* 2005, Kollaus and Bonner 2012). Sensitive fishes were 81% similar within riffle habitats and 52% similar within run habitats between pre- and post- fire. Tolerant fishes were 98% similar within riffle habitats and 94% similar within run habitats. As predicted, occurrence and abundance of sensitive fishes as measured by RSI differed between pre- and post- fire conditions; however, observed differences were likely not attributed to a fire effect based on the lack of evidence to suggest sediments from the burned region reached the stream and natural variability with the Independence Creek fish community (Watson 2006).

Discussion

Abiotic and biotic responses of aquatic communities following a fire ranged from relatively minor habitat and community changes initially, short term, and long term to relatively major habitat and community changes initially and up to 20 years post-fire. Magnitude of change was associated with precipitation and runoff timing and amount that transported sediment, woody debris, and nutrients into the stream, which affected stream morphology, macroinvertebrate communities, and fish communities. Among systems with major habitat changes, biotic effects generally included an increase in tolerant macroinvertebrates and decreases in fish abundance and densities. However, abiotic environments and biological communities were resilient through time and returned to, and in some instances surpassed, pre-fire conditions often among studies reporting sufficient length of records.

Abiotic and biotic responses in aquatic systems were similar to those in terrestrial systems. Fire directly alters terrestrial vegetation structure and composition and animal communities via mortality or movement (Quinn 1979) and indirectly affects animal communities by extended but temporary changes in vegetative structure (Briani *et al.* 2004; Santos and Poquet 2010). Fires burn with varying severities creating habitat heterogeneity, both spatially and temporally. After a fire, as the vegetation grows and goes through early, mid, and late serial stages, animal communities associated with those serial vegetative communities also change (Letnic *et al.* 2004). Amidst those species associated with the progressing serial communities, are tolerant taxa, able to use a variety of habitat parameters often spanning multiple serial stages, and sensitive taxa associated with particular habitat requirements often within one serial stage.

Aquatic abiotic and biotic responses to fire reported herein is likely similar for arid and semi-arid aquatic systems within western gulf slope drainages. The unpredictable nature of wildfire occurrence and location often precludes manipulative testing of the effects of wildfire on aquatics. Assessing effects of prescribed fires is more feasible, but the value of prescribed fires as a surrogate for wildfires is debatable (Arkle and Pilliod 2010). As such, the conceptual model with *a priori* hypotheses will provide focused objectives for repetitive opportunistic testing when a wildfire occurs. Due to the complexity of both wildfires and aquatic systems, repeated measurements of the covariates and aquatic community response are necessary to adequately validate the conceptual framework. Continued temporal assessment of fire effects in unique semi-arid and arid environments including differing covariates will allow for quantitatively assessing the parameters influencing fire effects in aquatic systems and reevaluating the applicability of the conceptual model. Conceptual models, such as the one proposed herein, are used effectively to assess risk and benefit assessments among various wildfire and logging effects on salmonids in the Rocky Mountain region (O'Laughlin 2005), as well as studies incorporating climatic and herbivore influences on the effects fire timing and interval have on woody recruitment and grassland recovery (Fuhlendorf *et al.* 1996).

Initial testing of the conceptual model with two case studies produced mixed results. Covariates, such as fire severity and size, proximity to the aquatic system, hydrology, fire regime, upland vegetation, and current land use, can influence realized effects. The Cannon Ranch Fire had little, if any, affect upon sedimentation and channel morphology within Independence Creek or upon the riparian corridor of Independence Creek, which acts as a buffer to further minimize fire effects. The fire's distant proximity to the creek (>5 km), regional aridity (i.e., low number of precipitation events), and baseflows provided primarily by spring discharge collectively minimized biotic effects upon the fish community up to 7 months post- fire. These findings are consist with knowledge of intact riparian zones acting as buffers to streams (Naiman and Decamp 1997) as well as fire effects becoming most pronounced in arid environments with high amounts of precipitation (Lyon and O'Connor 2008). The Oasis Fire burned a portion of the South Llano River riparian corridor, and precipitation events and subsequent overland flow (> 60 mm precipitation) carried sediments and debris into the river. Abundances of tolerant and sensitive fishes partly conformed to our predictions, but overall none to minor biotic effects were observed. Tentatively and with recognition to various covariates associated with each fire, I attributed resiliency of both systems to baseflows supported by voluminous groundwater discharge that likely minimize fire effects. Minimizing effects of groundwater discharge also were noted in the Yellowstone Fire of the 1980s in which streams with baseflows supported by groundwater discharge diluted factors associated with the fire (Minshall *et al.* 1997).

Applicability of my proposed conceptual model is intended to span current and future climates within the arid and semi-arid regions of the western gulf slope drainages. However, the conceptual model will likely need to be adjusted according to climate heterogeneity across the western gulf slope drainages. With aridity increasing along a northeast to southwest to gradient and expanding towards the northeast into the future (Cook *et al.* 2004), western gulf slope drainages of Texas and New Mexico have increasingly less water (Cook *et al.* 2004; Seager *et al.* 2007; Woodhouse *et al.* 2010) thereby decreasing fuel loads ultimately leading to decreases in occurrence of wildfires (Marlon *et al.* 2012) along the western edge of the drainages, whereas increasing flammability of fuels and therefore greater frequency of fires along the eastern edge with increases in cycles of drying (Krawchuk *et al.* 2009; Moritz *et al.* 2012). Increase of fire frequency along a northeast trajectory is not a new phenomenon. Among past climates, changes in vegetation composition in northeast Texas were observed within declining forests of *Quercus* and *Betula* species around 3,500 years before present (BP) associated with low fire frequency and promotion of the *Pinus spp.* over the last 3,000 years BP (Albert 2007). Projected decreases in fire frequency might be positive for reducing initial negative effects; however, longer term effects might be detrimental to inputs of nutrients inputs and stream channel heterogeneity. Collectively, quantifying fire influence along the western edge of the gulf slope drainages will further our understandings of how changes in climate, fire frequency, and fuel loads (i.e., vegetation type and biomass) will influence the future fire regime along the eastern border along with changes in how fire effects influence the abiotic and biotic environments of aquatic communities.

Within the WGS, over 40% fish species are imperiled due to several perceived threats but ultimately selected because of the zoogeographical processes restricting them to isolated areas (Hubbs *et al.* 2008). Combine limited range distribution along with wildfire and subsequent abiotic effects lasting longer than an initial effect, some fish populations can be highly susceptible to localized extirpation, and in some cases extinction among a few fishes that are restricted to only one water body. Habitat connectivity can be fragmented, which would inhibit rates of recolonization of areas with localized extirpations (Brown *et al.* 2001; Propst *et al.* 2008; Rinne and Carter 2008; Rieman *et al.* 2010). Collective effects could be greater in systems already stressed by a suite of existing anthropogenic modifications (Rieman *et al.* 2003). Consequently, resource managers have options to mitigate and minimize fire effects on sensitive aquatic communities within the western gulf slope drainages.

Available options include proactive management and reactive management. Proactive management includes prescribe burns and brush management (Agee and Skinner 2005; Beche *et al.* 2005) within the watershed of the stream or water body. While fire is a natural component of the WGS, changes in the historical fire regime may increase potential for negative or unnatural responses of an aquatic system to fire. Restoration of historical fire regimes and fuel loads through management of brush and implementation of prescribed fires alleviate potential negative unnatural effects (Knapp *et al.* 2005). In Texas, combination of brush management and prescribed fires restore areas converted to mesquite or juniper scrubland back to historical grasslands (Ainsley and Jacoby 1986; Fuhlendorf *et al.* 1996). Reactive management includes erosion and sediment control (Wagenbrenner *et al.* 2006; Prats *et al.* 2013) following a fire. In post-fire rehabilitation of burned areas, erosion and sediment controls have been used to minimize runoff and increase soil and stream bank stability using techniques such as: reseeding of native vegetation, mulching, hydromulching, and check dams (Robichaud *et al.* 2000; Robichaud *et al.* 2009). However, it should be noted that little research has been conducted assessing the results of rehabilitation efforts in the semi-arid and arid regions of the Western United States (Eiswerth and Shonkwiler 2006). Both proactive and reactive options are viable to minimize fire effects under special circumstances but with at least one caveat. Despite potential negative effects on aquatic communities, long term benefits of infrequent nutrient pulses are not fully known. Infrequent nutrient pulses have been thought to contribute to complex interactions in biotic communities (Yang *et al.* 2008; Malison and Baxter 2010). Long term nutrient pulses associated with wildfires should be eventually quantified as part of the assessment to determine need to manage and mitigate wildfire effects on imperiled aquatic taxa.

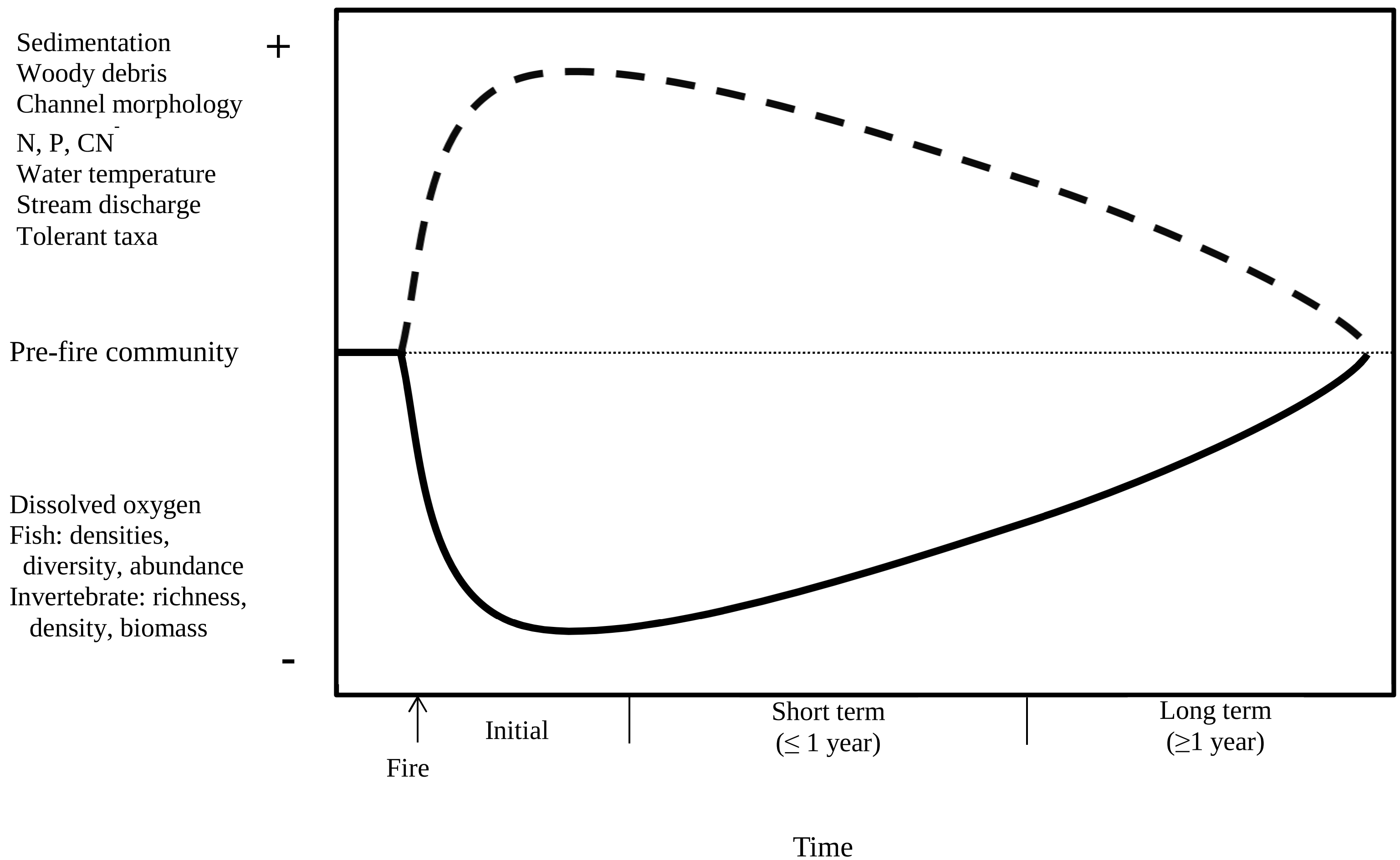


Figure 1. Conceptual framework of abiotic and biotic wildfire effects in the semi-arid and arid regions of the western gulf slope drainages.

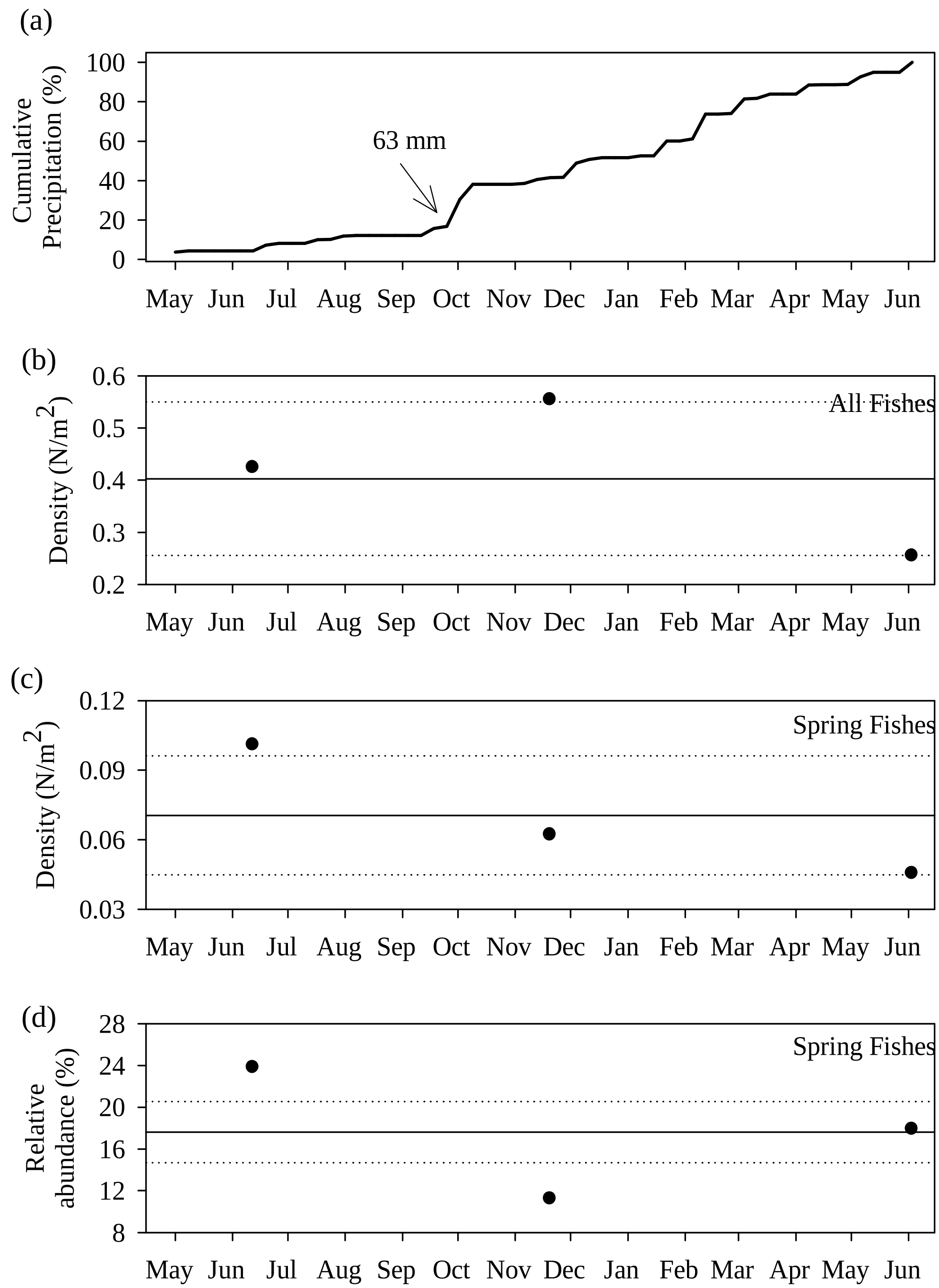


Figure 2. Precipitation in Junction, Texas for May 2011- June 2012 and responses of fishes in the South Llano River to the Oasis Fire. (a) Cumulative precipitation in Junction, Texas for May 2011- June 2012, the year after the Oasis Fire (contained in May 2011). Arrow indicates cumulative precipitation (mm) at time of sampling (b) Density (N/m^2) of all fishes at sampling times in the South Llano River post- fire. (c) Density (N/m^2) of spring fishes at sampling times in the South Llano River post- fire. (d) Relative abundances of spring associated fishes at sampling times in the South Llano River.

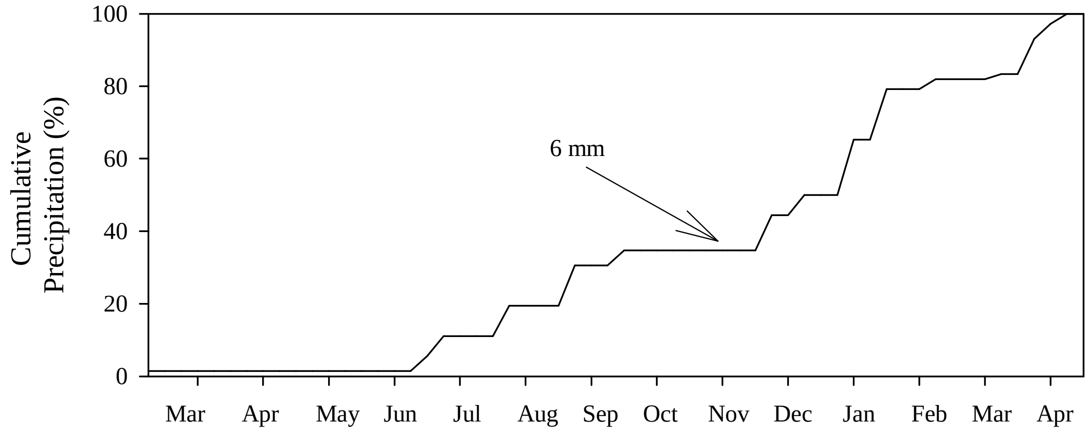


Figure 3. Cumulative precipitation in Fort Stockton, Texas for the March 2011- April 2012, the year after the Cannon Ranch Fire (contained in April 2011). Arrow indicates cumulative precipitation (mm) at time of sampling.

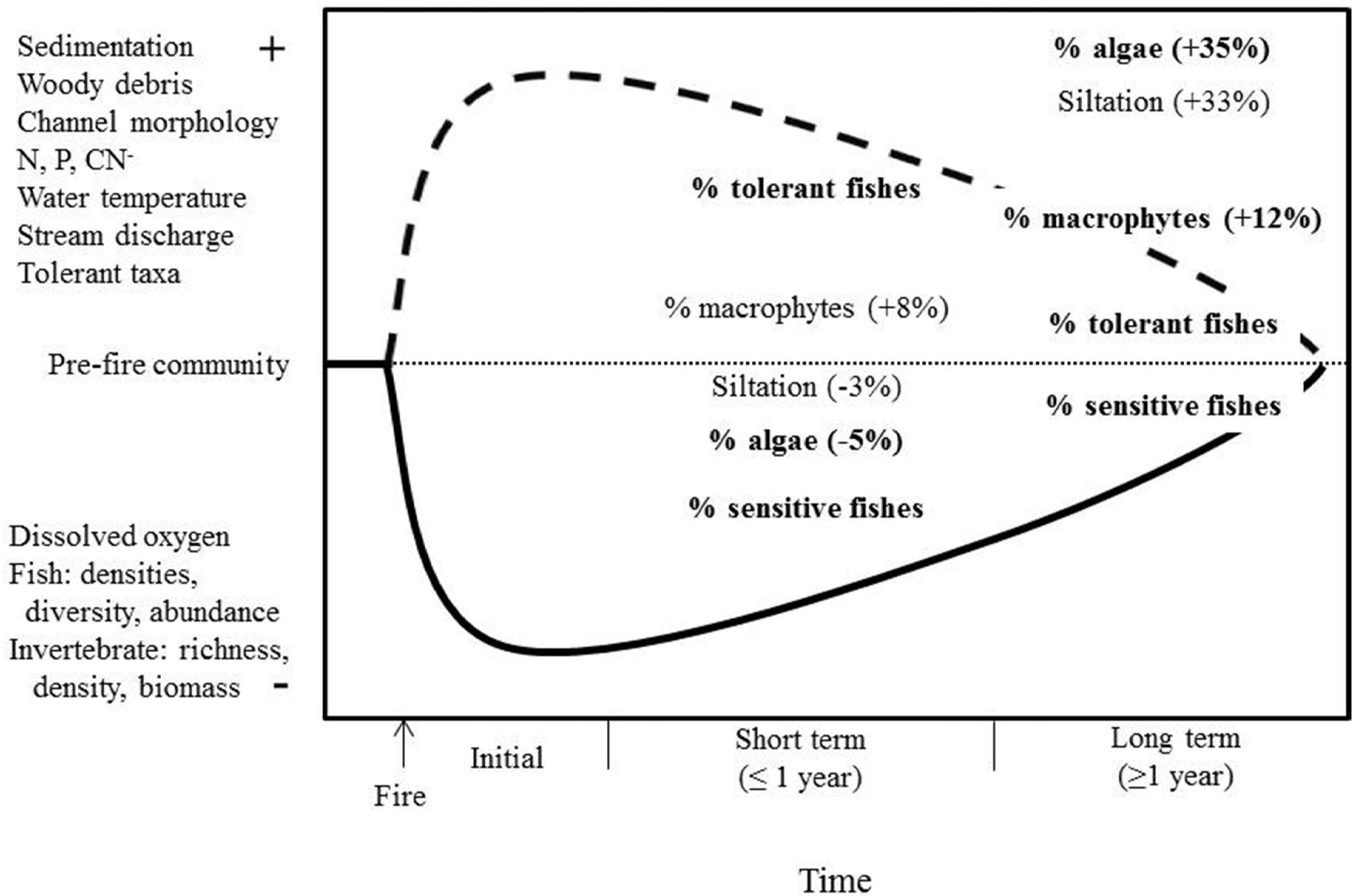


Figure 4. Conceptual framework with responses from case studies related to literature synthesis predictions.

APPENDIX SECTION

Appendix A

Table of articles used in literature synthesis with correlating wildfire abiotic and biotic effects ("x" indicates study includes effect).

					Biotic				Abiotic		
Authors	Year	Title	Journal	Fish	Macro-invertebrates	Water Quality	Sediment-ation	Woody Debris	Channel Morpho -logy	Temper -ature	Stream Discharge
Arkle, R.S., D.S. Pilliod, and K. Strickler	2010	Fire, flow and dynamic equilibrium in stream macroinvertebrate communities	Freshwater Biology 55(2): 299-314	0	x	0	x	x	x	0	0
Barber, T.R., C.C. Lutes, M. R.J. Doorn, P.C. Fuchs-man, H.J. Timme-nga, and R.L. Crouch	2003	Aquatic ecological risks due to cyanide releases from biomass burning	Chemo-sphere 50(3): 343-348	x	0	x	0	0	0	0	0
L. Benda, D. Miller, P. Bigelow, and K. Andras	2003	Effects of post-wildfire erosion on channel environments, Boise River, Idaho	Forest Ecology and Manage-ment 178: 105-119	0	0	0	x	x	x	0	0

Boulton, A. J., G.L. Moss, and D. Smithy-man	2003	Short-term effects of aerially-applied fire-suppressant foams on water chemistry and macroinvertebrates in streams after natural wild-fire on Kangaroo Island, South Australia	Hydrobio-logia. 498: 177-189	0	x	x	0	0	0	x	0
Bozek, M.A., and M.K. Young	1994	Fish mortality resulting from delayed effects of fire in Greater Yellowstone ecosystem	Great Basin Naturalist. 54(1): 91-95	x	0	0	x	x	0	x	x

Brass, J. A., V.G. Ambrosia, P.J. Riggan, and P.D. Sebesta	1996	Consequences of fire on aquatic nitrate and phosphate dynamics in Yellowstone National Park	Proceedings of the second biennial conference on the Greater Yellowstone Ecosystem: the ecological implications of fire in Greater Yellowstone International Association of Wildland Fire, Fairfield, Washington. Pages 53–57 in J. Greenlee, editor.	0	0	x	0	0	0	0	0
Brown, D.K., A.A. Echelle, D.L. Propst, J.E. Brooks, and W.L. Fisher	2001	Catastrophic wildfire and number of populations as factors influencing risk of extinction for the gila trout (*Oncorhynchus giliae*)	Western North American Naturalist. 61(2): 139-148	x	0	0	0	0	0	0	0

Burton, T.A.	2005	Fish and stream habitat risks from uncharacteristic wildfire: observations from 17 years of fire-related disturbances on the Boise National Forest, Idaho	Forest Ecology and Manage-ment. 211(1-2): 140-149	x	0	0	x	x	x	x	0
Carroll, M.D.	2011	Movement of channel-borne sediments in the 2010 Schultz fire burn area	M.S. Thesis, Northern Arizona University-Flagstaff, Arizona.	0	0	0	x	x	x	0	0
Charron, I., and E.A. Johnson	2006	The importance of fires and floods on tree ages along mountainous gravel-bed streams	Ecological applications. 16(5): 1757-1770	0	0	0	0	0	0	0	x

Clinton, B.D., J.M. Vose, J.D. Knoepp, and K.J. Elliott.	2003	Stream nitrate response to different burning treatments in Southern Appalachian forests.	Pages 174-181 in K.E.M. Galley, R.C. Klinger, and KG Sugihara (eds.). Proceedings of Fire Conference 2000: The First National Congress on Fire Ecology, Prevention, and Manage-ment. Miscella-neous Publication No. 13, Tall Timbers Research Station, Tallahassee, FL.	0	0	x	0	0	0	0	0

Dunham, J.B., A.E. Rosenber-ger, C.H. Luce, B.E. Rieman	2007	Influences of wildfire and channel reorganization on spatial and temporal variation in stream temperature and the distribution of fish and amphibians	Ecosystems. 10(2): 335-346	x	0	0	0	x	x	x	0
Earl, S.R., and D.W. Blinn	2003	Effects of wildfire ash on water chemistry and biota in south-western U.S.A. streams	Freshwater Biology. 48(6): 1015-1030	0	x	x	0	0	0	0	0
Eaton, B.C., C.A.E. Andrews, T.R. Giles, and J.C. Phillips	2010	Wildfire, morphologic change and bed material transport at Fishtrap Creek, British Columbia	Geomorp-hology. 118(3-4): 409-424	0	0	0	0	x	x	0	0
Goodwin, A.B.	2012	Biotic response to riparian disturbance in head-water streams in British Columbia	M.S. Thesis, University of British Columbia-Vancouver, British Columbia.	0	x	0	0	0	0	0	0

Hall, S.J., and D. Lombard-dozzi	2008	Short-term effects of wildfire on montane stream ecosystems in the Southern Rocky Mountains: one and two years post-burn	Western North American Naturalist. 68(4): 453-462	0	x	x	0	0	0	x	0
Hitt, N.P.	2003	Immediate effects of wildfire on stream temperature	Journal of Freshwater Ecology. 18(1): 171-173	0	0	0	0	0	0	x	0
Holden, Z.A., C.H. Luce, M.A. Crimmins, and P. Morgan.	2011	Wildfire extent and severity correlated with annual streamflow distribution and timing the Pacific Northwest, USA (1984-2005)	Ecohydro-logy. [doi: 10.1002/eco. 257]	0	0	0	0	0	0	0	x
Howell, P.J.	2006	Effects of Wildfire and subsequent hydrologic events on fish distribution and abundance in the tributaries of the North Fork John Day River.	North American Journal of Fisheries Manage-ment. 26(4): 983-994	x	0	0	0	x	0	0	x

Kelly, E.N., D.W. Schindler, V.L. St. Louis, D.B. Donald, and K.E. Vladick	2006	Forest fire increases mercury accumulation by fishes via food web restructuring and increased mercury inputs	Proceedings of the National Academy of Sciences of the United States of America. 103(51): 19380-19385	x	0	x	0	0	0	0	0
Koestier, P., Q. Tuckett, and J. White	2007	Present effects of past wildfires on the diets of stream fish	Western North American Naturalist. 67(3): 429-438	x	0	0	0	0	0	0	0
Koestier, P., T.R.B. Krause, and Q.M. Tuckett	2010	Present effects of past wildfires on leaf litter breakdown in stream ecosystems	Western North American Naturalist. 70(2): 164-174	0	x	0	0	x	0	x	0
Korb, J.E., J. White, and M. Japhet	2008	Wildland fire: an opportunistic event for reintroducing a native salmonid	Fire Ecology. 4(2): 3-14	x	0	0	x	0	0	0	0
Kozlow-ski, D., S. Swanson, and K. Schmidt	2010	Channel changes in burned streams of northern Nevada	Journal of Arid Environ-ments. 74(11): 1494-1506	0	0	0	x	x	x	0	0

Lyon, J.P., and J.P. O'Connor	2008	Smoke on the water: Can riverine fish populations recover following a catastrophic fire-related sediment slug?	Austral Ecology. 33(6): 794-806	x	0	x	x	0	0	0	x
Mahlum, S.K., L.A. Eby, M.K. Young, C.G. Clancy, and M. Jakober	2011	Effects of wildfire on stream temperatures in the Bitterroot River Basin, Montana	International Journal of Wildland Fire. 20(2): 240-247	0	0	0	0	0	0	x	0
Malison, R.L., and C.V. Baxter	2010	Effects of wildfire of varying severity on benthic stream insect assemblages and emergence	Journal of the North American Benthological Society. 29(4): 1324-1338	0	x	0	0	0	0	x	0
Malison, R.L., and C.V. Baxter	2010	The fire pulse: wildfire stimulates flux of aquatic prey to terrestrial habitats driving increases in riparian consumers	Canadian Journal of Fisheries and Aquatic Sciences. 67(3): 570-579	0	0	0	0	0	0	0	x

Mellon, C.D., M.S. Wipfli and J.L. Li	2008	Effects of forest fire on headwater stream macroinvertebrate communities in eastern Washington, U.S.A.	Freshwater Biology. 53: 2331-2343	0	x	0	0	0	x	x	0
Meyer G.L., and J.L. Pierce	2003	Climatic controls on fire-induced sediment pulses in Yellowstone National Park and central Idaho: a long-term perspective	Forest Ecology and Manage-ment. 178: 89-104	0	0	0	x	x	0	0	0
Mihuc, T.B., and G.W. Minshall	1995	Trophic generalists vs. trophic specialists: implications for food web dynamics in post-fire streams.	Ecology. 76(8): 2361-2372	0	x	0	0	0	0	0	0
Minshall, G.W., D.A. Andrews, J.T. Brock, C.T. Robinson, and D.E. Lawrence	1989	Changes in trout habitat following a forest fire	Proceedings of the Wild Trout IV Symposium. Yellowstone National Park, September 18-19, 1989. Pgs 111-119.	x	0	0	0	x	x	0	x

Minshall, G.W., C.T. Robinson, and D. E. Lawrence	1997	Postfire responses of lotic ecosystems in Yellowstone National Park, U.S.A.	Canadian Journal of Fisheries and Aquatic Sciences. 54(11): 2509-2525	0	x	x	x	x	x	x	0
Minshall, G.W., C.T. Robinson, and T.V. Royer	2001	Response of the Cache Creek macroinvertebrates during the first x0 years following the disturbance by the x988 Yellowstone wildfires	Canadian Journal of Fisheries and Aquatic Sciences. 58(6): 1077-1088	0	x	0	0	0	0	0	0
Minshall, G.W., C.T. Robinson, and T.V. Royer	1995	Benthic community structure in two adjacent streams in Yellowstone National Park five years after the 1988 wildfires	The Great Basin Naturalist. 55(3): 193-200	0	x	0	x	0	x	0	0
Moody J.A., and D.A. Martin	2001	Initial hydrologic and geomorphic response following a wildfire in the Colorado front range	Earth Surface Processes and Landforms. 26: 1049-1070	0	0	0	x	0	0	0	0

Murphy S.F., and J.H. Writer	2011	Evaluating the effects of wildfire on stream processes in a Colorado front range watershed, USA	Applied Geochem-istry. 26: S363-S364	0	0	x	0	0	0	0	0
Neville, H., J. Dunham, A. Rosenb-erger, J. Umek, and B. Nelson	2009	Influences of wildfire, habitat size, and connectivity on trout in headwater streams, revealed by patterns of genetic diversity	Transactions of the American Fisheries Society. 138(6): 1314-1327	x	0	0	0	0	x	0	0
Novak, M.A., and R.G. White	1989	Impact of a fire and flood on the trout population of Beaver Creek, Upper Missouri Basin, Montana	Proceedings of the Wild Trout IV Symposium	x	0	0	0	x	0	0	0
Nyman, P., G.J. Sheridan, H.G. Smith, and P.N.J. Lane	2011	Evidence of debris flow occurrence after wildfire in upland catchments of south-east Australia	Geomorp-hology. 125(3): 383-401	0	0	0	x	x	x	0	0

Peat, P., H. Chester, and R. Norris	2005	River ecosystem response to brushfire disturbance: interaction with flow regulation	Australian Forestry. 68(3): 153-161	0	x	x	x	0	0	x	0
Pilliod D.S., R.S. Arkle, M.A. Yoshim-ura	2008	Post-fire recovery of stream amphibians, benthic macroinvertebrates, and riparian vegetation in a federally designated wilderness	Federal Contract between Cal Poly Corporation of the California Polytechnic State University and USDA Forest Service, Rocky Mountain Research Station. Pgs. 1-19.	x	x	0	0	x	0	0	0
Reneau, S.L., D. Katzman, G.A. Kuyumjian, A. Lavine and D.V. Malmon	2007	Sediment delivery after a wildfire	Geology. 35(2): 151-154	0	0	0	x	0	0	0	0

Rieman, B., D. Lee, G. Chandler, and D. Myers.	1997	Does wildfire threaten extinction for salmonids? Responses of redband trout on the Boise National Forest	Proceedings - Fire Effects on Rare and Endangered Species and Habitats Conference, Nov. 13-16, 1995. Coeur d' Alene, Idaho. Pgs. 47-57.	x	0	0	x	x	0	0	0
Rinne, J. N.	1996	Short-term effects of wildfire on fishes and aquatic macroinvertebrates in the Southwestern United States	North American Journal of Fisheries Management. 16: 653-658	0	x	x	x	0	0	0	
Rinne, J.N.	2003	Wildfire in the southwestern USA: effects on fishes	Proc.5th international wildland fire symposium. Orlando Florida, Nov 16-19, 2003. Pgs. 1-5.	x	0	0	x	0	x	0	0

Rinne, J.N., and C.D. Carter.	2008	Short-term effects of wildfires on fishes in the Southwestern United States, 2002: management implications	USDA Forest Service Gen. Tech. Rep PSW-GTR-189. 2008. Pgs. 653-658	0	0	x	x	0	0	0	0
Robinson, C.T., U. Uehlinger, and G.W. Minshall	2005	Functional characteristics of wilderness streams twenty years following wildfire	Western North American Naturalist. 65(1): 1-10	0	0	0	x	x	x	x	0
Roby K.B., and D.L. Azuma	1995	Changes in a reach of a Northern California stream following wildfire	Environ-mental Manage-ment. 19(4): 591-600	0	x	0	x	0	0	0	0
Rosenberger, A. E., J.B. Dunham, J.M. Buffington, and M.S. Wipfli	2011	Persistent effects of wildlife and debris flows on the invertebrate prey base of rainbow trout in Idaho streams.	Northwest Science. 85(1): 55-63	x	x	0	0	x	x	x	0

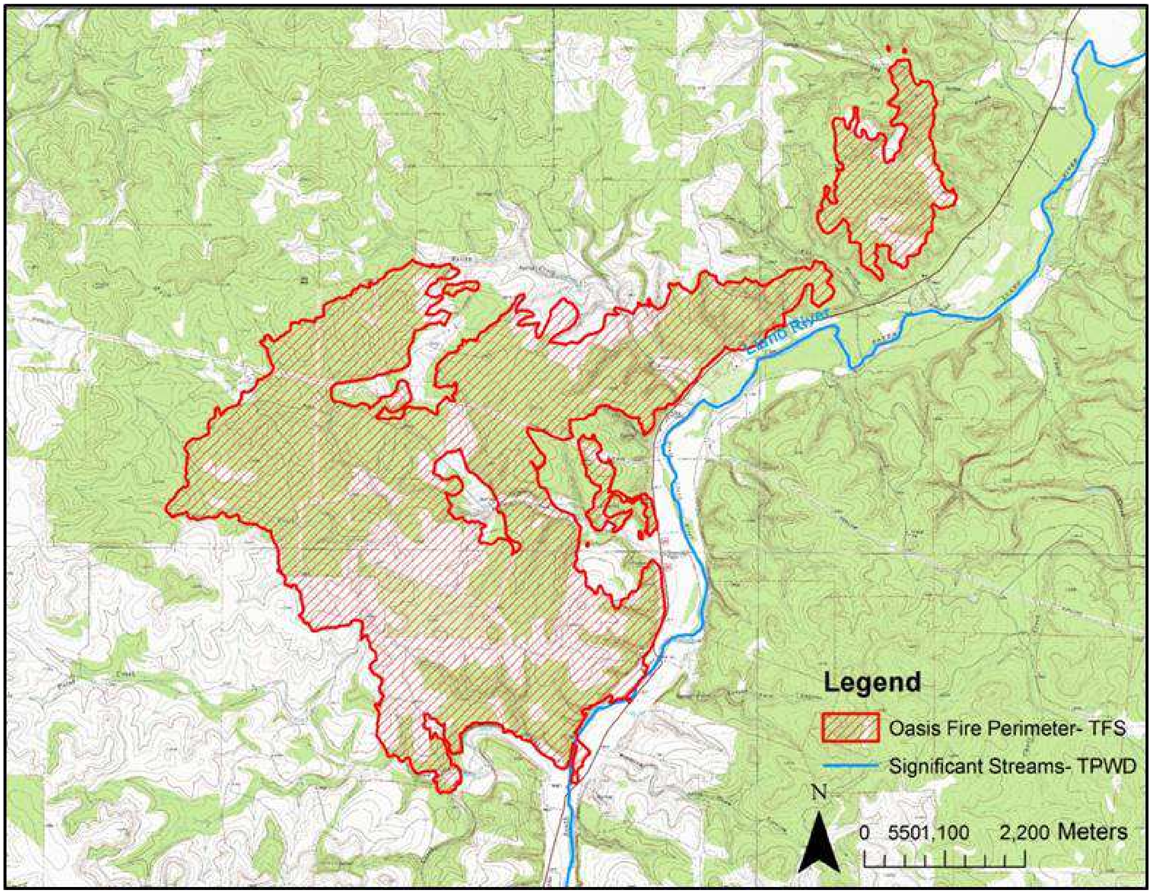
Ryan, S.E., K.A. Dwire, and M.K. Dixon	2011	Impacts of wildfire on runoff and sediment loads at Little Granite Creek, western Wyoming	Geomorph-ology. 129(1-2): 113-130	0	0	0	x	0	0	0	0
Sestrich, C.M.	2005	Changes in native and nonnative fish assemblages and habitat following the wildfire in the Bitterroot River Basin, Montana	M.S. Thesis, Montana State University-Bozeman, Montana.	0	0	x	0	x	x	x	0
Sestrich C.M., and T.E. McMahon .	2011	Influence of fire on native and nonnative salmonid populations and habitat in a western Montana basin	Transactions of the American Fisheries Society. 140: 136-146	x	0	0	x	x	0	0	0
Shakesby, R.A., and S.H. Doerr	2003	Fire severity, water repellency characteristics and hydrogeomorpho -logical changes following the Christmas 2001 Sydney forest fires	Australian Geographer. 34(2): 147-175	0	0	0	x	0	x	0	0

Spencer, C.N., and F.R. Hauer	1991	Phosphorus and nitrogen dynamics in streams during a wildfire	Journal of the North American Bentho-logical Society. 10(1): 24-30	0	0	x	0	x	0	0	0
Townsend, S.A., and M.M. Douglas	2000	The effect of three fire regimes on stream water quality, water yield and export coefficients in a tropical savanna (northern Australia)	Journal of Hydrology. 8(1): 36-50	0	0	x	x	0	0	0	x
Tronstand, L.M., J.C. Bish, R.O. Hall, and T. M. Koel	2011	Comparing stream invertebrate assemblages before and after wildfires in Yellowstone National Park	Report prepared by the Wyoming Natural Diversity Database for the Yellowstone National Park. Pgs. 1-12	0	x	0	0	0	0	0	x

Turner, M.G., E.A.H. Smith-wick, K.L. Metzger, D.B. Tinker, and W.H. Romme	2007	Inorganic nitrogen availability after sever stand-replacing fire in the Greater Yellowstone ecosystem	Proceedings of the National Academy of Sciences of the United States of America. 104(12): 4782-4789	0	0	x	0	0	0	0	0
Verkaik, I.	2010	Wildfire effects on macroinvertebrate communities in Mediterrean streams	Ph.D. Dissertation, University of Barcelona-Barcelona, Spain.	0	x	0	0	0	0	0	0
Vieira, N.K.M., W.H. Clements, L.S. Guevara, and B.F. Jacobs	2004	Resistance and resilience of stream insect communities to repeated hydrologic disturbances after a wildfire	Freshwater Biology. 49(10): 1243-1259	0	x	0	0	0	0	0	0
Vieira, N.K.M., T.R. Barnes, and K.A. Mitchell.	2011	Effects of wildfire and postfire floods on stonefly detritivores of the Pajarito Plateau, New Mexico	Western North American Naturalist. 71(2): 257-270	0	x	0	0	0	0	0	0

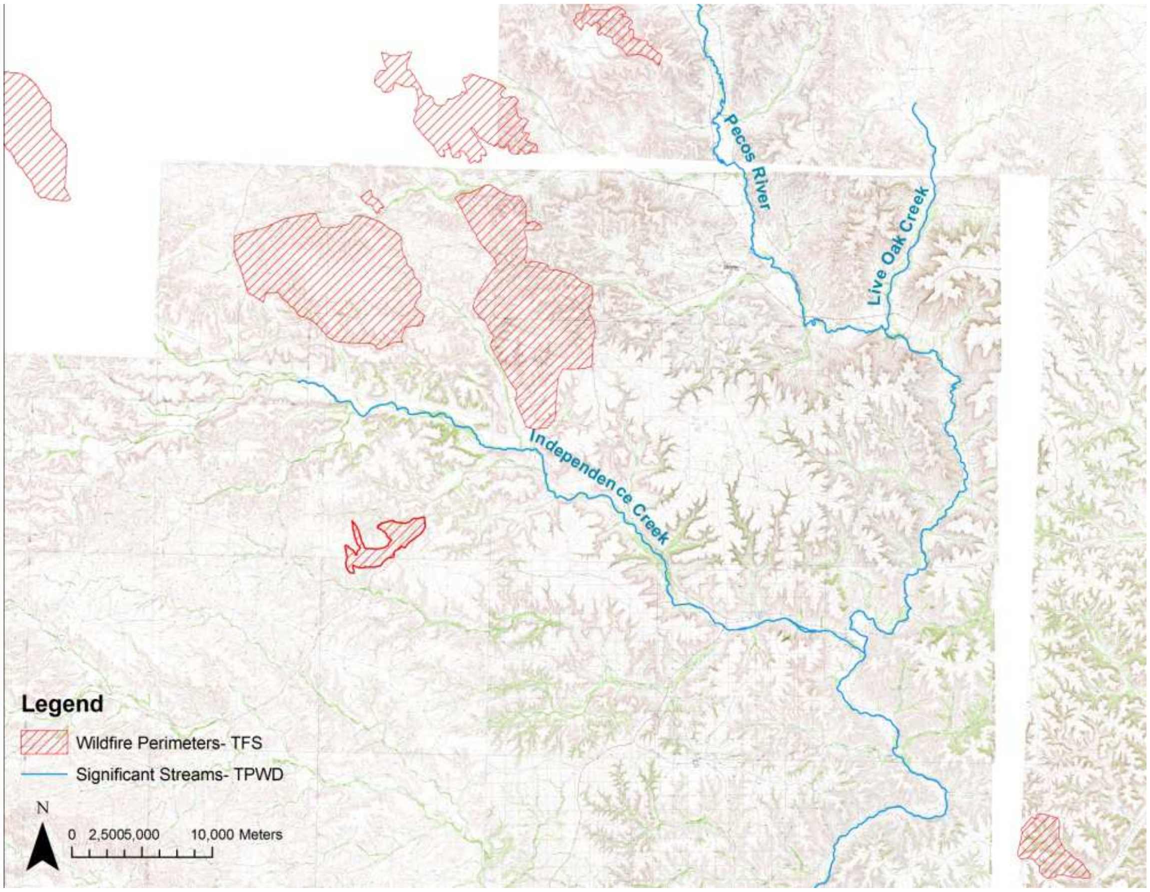
Wohlgem-uth, P.M., J.L. Beyers, and S.G. Conrad	1999	Postfire hillslope erosion in Southern California Chaparral: a case study as a sediment management tool	USDA Forest Service Gen. Tech. Rep. PSW-GTR-173. 1999. 268-276	0	0	0	x	0	0	0	x
Zelt, R.B., and E.E. Wohl	2004	Channel and woody debris characteristics in adjacent burned and unburned watersheds a decade after wildfire, Park County, Wyoming	Geomorph-ology. 57(3-4): 217-233	0	0	0	0	x	x	0	0

Appendix B



Map of Oasis Fire in proximity to the South Llano River in Kimble County, Texas.

Appendix C



Map of Cannon Ranch Fire in proximity to Independence Creek in Terrell County, Texas.

LITERATURE CITED

Agee, J., and C. Skinner. 2005. Basic principles of forest fuel reduction treatments. Forest Ecology and Management. 211:83–96.

Albert, B. M. 2007. Climate, fire, and land-use history in the oak-pine-hickory forests of Northeast Texas during the past 3500 Years. Castanea. 72:82–91.

Ansley, R.J., and P.W. Jacoby. 1998. Manipulation of fire intensity to achieve mesquite management goals in north Texas. In: Pruden, T.L., Brennan, L.A. (Eds.), Fire in Ecosystem Management: Shifting the Paradigm from Suppression to Prescription. Tall Timbers Research Station, Tallahassee, FL, 195–204 p.

Arkle, R. S., D.S. Pilliod, and K. Strickler. 2010. Fire, flow and dynamic equilibrium in stream macroinvertebrate communities.Freshwater Biology. 55:299–314.

Balmer, O. 2002. Species lists in ecology and conservation: abundances matter. Conservation Biology. 16:1160-1161.

Beche, L., S. Stephens, and V. Resh. 2005. Effects of prescribed fire on a Sierra Nevada (California, USA) stream and its riparian zone. Forest Ecology and Management. 218:37–59.

Bisson, P.A., B. E. Rieman, C. Luce, P.F. Hessburg, D.C. Lee, J.L. Kershner, G.H. Reeves, and R.E. Gresswell. 2003. Fire and aquatic systems of the Western USA: current knowledge and key questions. Forest Ecology and Management. 178:213-229.

Bonner, T. H., C. Thomas, C. S. Williams, and J. P. Karges. 2005. Temporal assessment of a west Texas stream fish assemblage. Southwestern Naturalist 50:74-78.

Briani, D.C., A.R.T. Palma, E.M. Vieira, and R.P.B. Henriques. 2004. Post-fire succession of small mammals in the Cerrado of central Brazil. Biodiversity and Conservation. 13:1023–1037.

Brown, D.K., A.A. Echelle, D.L. Propst, J.E. Brooks, and W.L Fisher. 2001. Catastrophic wildfire and number of populations as factors influencing risk of the extinction for Gila Trout (*Oncorhynchus gilae*). Western North American Naturalist. 61:139–148.

Burton, T.A. 2005. Observations from 17 years of fire-related disturbances on the Boise National Forest, Idaho. Forest Ecology and Management. 211: 140-149.

Cook, E.R., C.A. Woodhouse, C.M. Eakin, D.M. Meko, and D.W. Stahle. 2004. Long-term aridity changes in the western United States. Science. 306:1015–1018.

Curtis, S.G. 2012. Effects of a declining hydrograph on instream habitats and fish communities in a semi-arid karstic stream. M.S. Thesis, Texas State University-San Marcos, Texas.

Dunham, J. B., A.E. Rosenberger, C.H. Luce, and B.E. Rieman. 2007. Influences of wildfire and channel reorganization on spatial and temporal variation in stream temperature and the distribution of fish and amphibians. Ecosystems. 10:335-346.

Dunham, J.B., M.K. Young, R.E. Greswell. B.E. Rieman. 2003. Effects of fire on fish populations: landscape perspectives on persistence of native fishes and nonnative fish invasions. Forest Ecology and Management. 178:183-196.

Dwire, K.A., and J.B. Kauffman. 2003. Fire and riparian ecosystems in landscapes of the western USA. Forest Ecology and Management. 178:61-74.

Earl, S. R., and D.W. Blinn. 2003. Effects of wildfire ash on water chemistry and biota in South-western U.S.A. streams. Freshwater Biology. 48:1015-1030.

Eaton, B.C., C.A.E. Andrews, T.R. Giles, and J.C. Phillips. 2010. Wildfire, morphologic change and bed material transport at Fishtrap Creek, British Columbia. Geomorphology. 118:409-424.

Eiswerth, M. E. and S. Shonkwiler, J. 2006. Examining post-wildfire reseeding on arid rangeland: A multivariate tobit modelling approach. Ecological Modelling.192: 286–298.

Fox, B.J. 1982. Fire and mammalian secondary succession in an Australian coastal heath. Ecology. 63:1332-1341.

Fuhlendorf, S., F.E. Smeins, and W.E. Grant. 1996. Simulation of a fire-sensitive ecological threshold: a case study of Ashe juniper on the Edwards Plateau of Texas, USA. Ecological Modelling. 90:245–255.

Hall, S.J., and D. Lombardozzi. 2008. Short-term effects of wildfire on montane stream ecosystems in the Southern Rocky Mountains: one and two years post-burn. 68:453-462.

Hubbs, C., R. J. Edwards and G. P. Garrett. 2008. An annotated checklist of the freshwater fishes of Texas, with keys to identification of species. Texas Academy of Science. 87 p.

InciWeb: Incident Information System. Cannon Ranch Fire Complex, Terrell County, Texas. http://www.inciweb.org/incident/2167/; accessed 30 October 2013.

InciWeb: Incident Information System. Oasis Ranch Fire Complex, Kimble County, Texas. http://inciweb.org/incident/2196/; accessed 24 October 2013.

Knapp, E. E., J. E. Keeley, E.A. Ballenger, and T. J. Brennan. 2005. Fuel reduction and coarse woody debris dynamics with early season and late season prescribed fire in a Sierra Nevada mixed conifer forest. Forest Ecology and Management. 208:383–397.

Kollaus, K.A., and T.H. Bonner. 2012. Habitat associations of a semi-arid fish community in a karst spring-fed stream. Journal of Arid Environments. 76:72-79.

Kozlowski, D., S. Swanson, and K. Schmidt. 2010. Channel changes in burned streams of northern Nevada. Journal of Arid Environments. 74 :1494-1506.

Krawchuk, M. a, Moritz, M.A., Parisien, M.A., J. Van Dorn and K. Hayhoe. 2009. Global pyrogeography: the current and future distribution of wildfire. *PLoS One* 4, e5102.

Letnic, M., C., Dickman, M. Tischler, B. Tamayo, and C.L. Beh. 2004. The responses of small mammals and lizards to post-fire succession and rainfall in arid Australia. Journal of Arid Environments. 59:85–114.

Lyon, J. P. and J. P. O'Connor. 2008. Smoke on the water: Can riverine fish populations recover following a catastrophic fire-related sediment slug? Austral Ecology. 33: 794–806.

Mahlum, S.K., L.A. Eby, M.K. Young, C.G. Clancy, and M. Jakober. 2011. Effects of wildfire on stream temperatures in the Bitterroot River Basin, Montana. International Journal of Wildland Fire. 20:240-247.

Malison, R. L., and C. V. Baxter. 2010. The fire pulse: wildfire stimulates flux of aquatic prey to terrestrial habitats driving increases in riparian consumers. Canadian Journal of Fisheries and Aquatic Sciences. 67:570–579.

Marlon, J.R., P.J. Bartlein, M.K. Walsh, S.P. Harrison, K.J. Brownc, M.E. Edwards, P. E. Higuera, M.J. Power, R. S. Anderson, C. Briles, A. Brunelle, C. Carcaillet, M. Daniels, F.S.Hu, M. Lavoie, C. Long, T. Minckley, P. J. H. Richard, A. C. Scott, D. S. Shafer, W. Tinner, C. E. Umbanhowar, Jr., and C. Whitlock. 2009. Wildfire responses to abrupt climate change in North America. Proceedings of the National Academy of Sciences of the United States of America. 106:2519–24

Minshall, G. W., C. T. Robinson, and D.E. Lawrence. 1997. Post- fire responses of lotic ecosystems in Yellowstone National Park, U.S.A. Canadian Journal of Fisheries and Aquatic Sciences.54:2509–2525.

Minshall, G.W., J.T. Brock, and J.D. Varley. 1989. Wildfires and Yellowstone's stream ecoystems. Bioscience. 39:707-715.

Moritz, M. A., M.A. Parisien, E. Batllori, M.A. Krawchuk, J. Van Dorn, D. J. Ganz, and K. Hayhoe. 2012. Climate change and disruptions to global fire activity. Ecosphere. 3: 1–22.

Naiman, J., and H. Decamps, H. 2013. The ecology of interfaces: Riparian Zones. Annual Review of Ecology and Systematics. 28:621–658.

O'Laughlin, J. 2005. Conceptual model for comparative ecological risk assessment of wildfire effects on fish, with and without hazardous fuel treatment. Forest Ecology and Management. 211:59–72.

Pianka, E.R., and S.E. Goodyear. 2012. Lizard responses to wildfire in arid interior Australia: long-term experimental data and commonalities with other studies. Austral Ecology. 37:1-11.

Prats, S.A., M.C. Malvar, D. C. S. Vieira, L. MacDonald, and J. J. Keizer. 2013. Effectiveness of Hydromulching to Reduce Runoff and Erosion in a Recently Burnt Pine Plantation in Central Portugal. Land Degradation & Development. doi:10.1002/ldr.2236

Propst, D. L., K. B. Gido, and J.A. Stefferud. 2008. Natural flow regimes, nonnative fishes, and native fish persistence in arid-land river systems. Ecological Applications.18:1236–1252.

Quinn, R.D. 1979. Effects on small mammals in the chaparral. Cal-Neva Wildlife Transactions. 1979:125–33.

Rieman, B.E., P.F. Hessburg, C. Luce, M.R. Dare. 2010. Wildfire and management of forests and native fishes: conflict or opportunity for convergent solutions? Bioscience. 60:460-468.

Rieman, B. E., Gresswell, R. E., Young, M. K. & Luce, C. H. 2003. Introduction to the effects of wildland fire on aquatic ecosystems in the Western USA. Forest Ecology and Management. 178:1–3.

Rinne, J.N. 2003. Wildfire in the Southwestern USA: Effects on rare, native fishes and their habitats. Proc. 5th International wildland fire symposium. Orlando Florida, Nov 16-19, 2003.

Rinne, J. N., and C.D. Carter. 2008. Short-term effects of wildfires on fishes in the southwestern United States, 2002: management implications. In: Narog, Marcia G., tech.coord. 2008. Proceedings of the 2002 Fire Conference: Managing fire and fuels in the remaining wildlands and open spaces of the Southwestern United States. Gen. Tech.Rep.PSW-GTR-189. Albany, CA:U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station.167-174 p.

Robichaud, P. R., J. L. Beyers, and D.G. Neary. 2000. Evaluating the effectiveness of postfire rehabilitation treatments. Gen. Tech. Rep. RMRS-GTR-63. Fort Collins: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 85 p.

Robichaud, P.R., S.A. Lewis, R.E. Brown, and L.E. Ashmun. 2009. Emergency post-fire rehabilitation treatment effects on burned area ecology and long-term restoration. Fire Ecology. 5:115-128.

Rosenberger, A.E., J.B. Dunham, J.M. Buffington, and M.S. Wipfli. 2011. Persistent effects of wildfire and debris flows on the invertebrate prey base of rainbow trout in Idaho streams. Northwest Science. 85:55-63.

Ryan, S.E., K.A. Dwire, and M.K. Dixon. 2011. Impacts of wildfire on runoff and sediment loads at Little Granite Creek, western Wyoming. Geomorphology. 129:113-130.

Santos, X. and J.M. Poquet. 2010. Ecological succession and habitat attributes affect the postfire response of a Mediterranean reptile community. Eureopean Jounral of Wildland Resources. 56:895–905.

Seager, R. M. Ting, I. Held, Y. Kushnir, J. Lu, G. Vecchi, H.P. Huang, N. Harnik, A. Leetmaa, N.C. Lau, C. Li, J. Velez, N. Naik. 2007. Model Projections of an imminent transition to a more arid climate in Southwestern North America. Science. 316:1181–1184.

Sestrich, C.M., and T.E. McMahon. 2011. Influence of fire on native and nonnative salmonid populations and habitat in a Western Montana Basin. Transactions of the American Fisheries Society. 140:136-146.

Smith, Jane Kapler, ed. 2000. Wildland fire in ecosystems: effects of fire on fauna. Gen. Tech. Rep. RMRS-GTR-42-vol. 1. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 83 p.

Townsend, C.R. 1989. The patch dynamics concept of stream community ecology. Journal of North American Benthological Society. 8:36-50.

Wagenbrenner, J.W., L.H. MacDonald, and D. Rough. 2006. Effectiveness of three post-fire rehabilitation treatments in the Colorado Front Range. Hydrological Processes. 20: 2989–3006.

Watson, J.M. 2006. Patterns and habitat associations of a desert spring fish assemblage and response to a large-scale flood. M.S. Thesis, Texas State University- San Marcos, Texas.

Woodhouse, C.A., D.M. Meko, G.M. MacDonald, D. W. Stahle, and E.R.A. Cook. 2010. 1,200-year perspective of 21st century drought in southwestern North America. Proceedings of the National Academy of Sciences of the United States of America. 107: 21283–21288.

Yang, L. H., J. L. Bastow, K.O. Spence, & A.N. Wright. 2008. What can we learn from resource pulses? Ecology. 89:621–34.