**Project Title:** Cumulative Effects of Fire and Fuels Management on Stream Water Quality and Ecosystem Dynamics

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This final progress report is being submitted to the Joint Fire Science Program to provide a summary of findings, accomplished deliverables to date, and proposed products. This information is preliminary and is subject to revision. It is being provided to meet the need for timely 'best science' information. The assessment is provided on the condition that neither the U.S. Geological Survey nor the United States Government may be held liable for any damages resulting from the authorized or unauthorized use of the preliminary information. Interpretive results will be published in refereed publications (see list of deliverables enclosed). This project was supported by funding from the Joint Fire Science Program, USDA Forest Service R1/R4 National Fire Plan, US Geological Survey Amphibian Research and Monitoring Initiative, US Geological Survey Fire Science Program, US Geological Survey Forest and Rangeland Ecosystem Science Center, and Aldo Leopold Wilderness Research Institute. Any use of trade names is for descriptive purposes only and does not imply endorsement by the U.S. government.

**Abstract:**

Prescribed fires and wildland fire-use are increasingly important management tools used to reduce fuel loads and restore the ecological integrity of western forests. Although a basic understanding of the effects of fire on aquatic ecosystems exists, the cumulative and possibly synergistic effects of wildfire following prescribed fire are unknown. Wildfires following prescribed fire may produce different burn severities and effects on riparian and stream ecosystems than wildfires in fire suppressed forests (e.g., fires absent >70 yrs) or prescribed fires alone. The goal of this study was to quantify and compare the effects of wildfire on stream and riparian ecosystems under three fire management practices: (1) wildfire following prescribed fire, (2) wildfire in fire suppressed forests, and (3) wildfire occurring at historic fire return intervals. We compared 6-7 years (2001-2006/07) of stream and riparian data collected prior to two large wildfire events to 3 years (2008-2010) of similar data collected after wildfire in catchments along the South Fork Salmon River and Big Creek in central Idaho. Here we report our preliminary findings on riparian- and catchment-level burn severity patterns, riparian forest structure, hydrology, amphibians, aquatic macroinvertebrates, periphyton, and instream habitat, including temperature, chemistry, substrate, sedimentation, and large woody debris. We found that the management practice of prescribed fire treatment prior to wildfire significantly reduced wildfire burn severity patterns in treated catchments relative to untreated catchments. This reduction in burn severity appeared to reduce wildfire effects on stream and riparian ecosystems rather than cause cumulative effects of prescribed fire plus wildfire. Instead, we found that the effects of natural inter-annual variability in stream flow and stochastic disturbances, such as debris flows and channel scouring events, are the dominant drivers of change in stream and riparian habitats in this region, with fire management practices playing a much smaller role.

**Background and Purpose:**

Suppression of wildfires in dry, coniferous forests has resulted in changes in forest ecosystems, including productivity, nutrient cycling, vegetation, and wildlife habitat (Agee 1998). In the last few decades, fire management has shifted from suppression to using fire to create and maintain healthy forests through prescribed fire and wildland fire-use programs. The ecological effects of altered of fire regimes, including promoting low-severity, prescribed fires or what happens when wildfires burn through areas already burned by prescribed fire, are largely unknown.

Stream and riparian ecosystem responses to fire can be variable depending on landscape context, vegetation, climate, weather, historical land management, and burn severity. For the most part, prescribed fires burn at low severity reducing surface fuels, some ladder fuels, and small tree densities (Agee and Skinner 2005, Stephens et al. 2009). The ecological effects of these prescribed fires in streams tend to be negligible or short-term (Beche et al. 2008, Arkle and Pilliod 2010). Wildfires, however, tend to result in significant ecological changes in stream ecosystems that can last for decades, affecting water quality and habitat conditions for sensitive species (Gresswell 1999, Minshall 2003, Arkle et al. 2010). Prior to the study reported here, little was known about how stream and riparian ecosystems respond to wildfires that burn through areas previously burned by prescribed fire; that is, whether the cumulative effects of both fires would magnify ecological changes or whether the moderating effects of the prescribed fire would reduce the effects of the subsequent wildfire.

The goal of this study was to examine and quantify how stream and riparian ecosystems respond to wildfires under different management scenarios: wildfires following prescribed fire, wildfires in fire-suppressed forests, and wildfires occurring at historic fire return intervals.

This project built upon seven years (2001-2007) of existing data by "re-measuring" (RFA Task 5) amphibian, invertebrate, periphyton, water chemistry, riparian forest, and in-stream habitat variables that were previously measured as part of a recently completed prescribed fire study funded by JFSP (#01-1-3-12). In August 2006 and again in August and September 2007, three large wildfires (South Fork Fire Complex, Cascade Fire Complex, and East-Zone Fire Complex) burned across 10 of our study streams. This created a rare opportunity to examine post-fire water quality, stream community, and riparian forest responses to wildfire in streams flowing through catchments that had been previously burned in a prescribed fire (3 streams), streams flowing through fire suppressed forests (10 streams), and streams flowing through an adjacent wilderness area that burned one or more times in the last 20 years under a fairly natural fire regime (7 streams). Because stream and riparian communities are inherently dynamic, availability of pre-fire data allowed for robust analyses capable of differentiating fire effects from natural variability. Together, this allowed us to examine the effects of fire and fuels management on stream water quality and ecosystem dynamics.

**Objectives:**

Using extensive pre-fire data, we quantified and compared the effects of wildland fire on stream and riparian ecosystems under three fire management practices: (1) wildfire after prescribed fire, (2) wildfire in untreated, fire-suppressed forests, and (3) wildfire in wilderness forests with a history of minimal fire suppression allowing for a fairly natural fire regime.

We addressed three main questions:

**1.** What are the effects of fire management practices on burn extent and severity patterns within catchments and within riparian forests?
**2.** How do stream biotic communities (amphibians, aquatic macroinvertebrates, periphyton) respond to fire management practices?
**3.** How are cumulative effects of wildfire after prescribed fire influenced by other disturbances, such as post-fire hydrology and sediment transport?

To address each of these questions, we compared the following metrics to existing pre-fire data:

a. Existing satellite-derived (Landsat) burn severity and extent in upland and riparian communities
b. Density and biomass of 2 species of endemic stream amphibians
c. Composition and abundance of the aquatic macroinvertebrate community (~150 genera)
d. Composition (heterotrophic vs autotrophic) and productivity of the benthic periphyton community
e. Stream habitat conditions including light availability, temperature, chemistry, substrate and large woody debris, stream flow, sediment transport and deposition
f. Riparian forest structure and composition

We expected the three fire management practices analyzed here (i.e. prescribed fire prior to wildfire, historic-fire suppression prior to wildfire, and wildfire under a natural fire regime) to influence wildfire effects on stream and riparian ecosystems primarily through differences in catchment-level wildfire burn severity patterns. Given the consistent relationship between fire management practices and resulting burn severities observed in our study system, we expected to observe (1) moderate effects of wildfire in catchments previously treated with prescribed fire because even low severity wildfire has greater effects on stream and riparian ecosystems than prescribed fire alone (Arkle and Pilliod 2010), and (2) greater effects of fire in fire-suppressed catchments than in catchments that burned under a natural fire regime because burn severity has a strong influence on stream and riparian ecosystem responses (Arkle et al. 2010).

**Study Design and Location:**

*Study Site*

We studied 20 catchments (Table 1) located in the Big Creek and South Fork Salmon River (SF Salmon) drainages of the Salmon River in central Idaho (Figure 1; 44°57'N, 115°41'W). Elevations of sampled catchments range from 1211 to 2711 m in the Big Creek drainage and from 1202 to 2703 m in the SF Salmon drainage. Study streams are low-order (1-3) and high-gradient. Geological parent materials are derived from the granitic Idaho Batholith and stream flows are driven by snowmelt in late spring and early summer (May and June), with base flows occurring from July through September. Plant communities in all catchments are similar, with upland vegetation dominated by firs at higher elevations and on north-facing slopes, and by mixed ponderosa pine and fir communities on south-facing slopes. Riparian forests are characterized by gray alder, red osier dogwood, and Rocky Mountain maple.

In the SF Salmon drainage, no large stand-replacing fires had occurred within the study area in 60-75 years (Barrett 2000), until the summers of 2006 and 2007. Early season (May) prescribed fires were conducted in one catchment in 2004 (Parks) and in two others in 2006 (Fitsum North Fork, Williams). All three of the treated catchments burned in the 2007 wildfires. Eight other focal catchments, representing fire suppressed sites, burned in the 2007 wildfires.

Big Creek is largely confined to the Frank Church-River of No Return Wilderness, and wildfires are not currently suppressed under a "wildland fire use" policy. Consequently, many catchments within the Big Creek drainage burned in 1988, 2000, 2006, and 2007 wildfires. In August and September 2000, the Diamond Peak wildfire complex burned 606.1 $km^2$ of the Big Creek drainage. This mixed severity fire burned portions of both upland and riparian forests in many of the catchments that we had previously studied. These catchments served as reference sites, representing areas under a natural fire regime.

Table 1.  List of streams examined in this study. Streams are grouped by fire management practices.

| Stream | Drainage | Fire management practice | Wildfire | (% catchment burned) | Catchment size (ha) | Stream order |
|---|---|---|---|---|---|---|
| Blackmare | SF Salmon | Historic suppression | 2006 & 2007 | 21.7 | 566 | 2 |
| Buckhorn NF | SF Salmon | Historic suppression | 2007 | 29.5 | 2757 | 2 |
| Buckhorn WF | SF Salmon | Historic suppression | 2006 & 2007 | 50.3 | 5875 | 3 |
| Camp | SF Salmon | Historic suppression | 2006 & 2007 | 62.3 | 2869 | 2 |
| Deadman | SF Salmon | Historic suppression | 2007 | 100 | 604 | 1 |
| Fitsum Main | SF Salmon | Historic suppression | 2007 | 28.6 | 2675 | 2 |
| Fourmile | SF Salmon | Historic suppression | 2006 & 2007 | 82.2 | 3896 | 3 |
| Goat | SF Salmon | Historic suppression | 2007 | 80.3 | 1744 | 2 |
| Nasty | SF Salmon | Historic suppression | 2006 & 2007 | 64.9 | 780 | 1 |
| Reegan | SF Salmon | Historic suppression | 2007 | 72.6 | 2102 | 2 |
| Parks | SF Salmon | Prescribed fire 2004 | 2007 | 35 | 1866 | 2 |
| Fitsum NF | SF Salmon | Prescribed fire 2006 | 2007 | 46.6 | 4253 | 3 |
| Williams | SF Salmon | Prescribed fire 2006 | 2007 | 100 | 245 | 1 |
| Beaver | Big Creek | Minimal suppression | 2000 & 2005 | 16.6 | 11329 | 3 |
| Big Ramey | Big Creek | Minimal suppression | 2000 & 2005 | 40.7 | 8649 | 3 |
| Cabin | Big Creek | Minimal suppression | 2000 & 2008 | 96.6 | 6471 | 3 |
| Canyon | Big Creek | Minimal suppression | 2000 | 99 | 1317 | 1 |
| Cow | Big Creek | Minimal suppression | 2000 | 97 | 1617 | 1 |
| Crooked EF | Big Creek | Minimal suppression | 2000 | 52.3 | 3014 | 2 |
| Crooked WF | Big Creek | Minimal suppression | 2000 | 8.6 | 3879 | 2 |

Notes: Deadman, Williams, and Reegan Creeks experienced post-w ildfire debris flow s in 2008, Parks Creek experienced a channel scouring event in 2008, and all streams experienced very high peak streamflow s in 2008 and 2010.

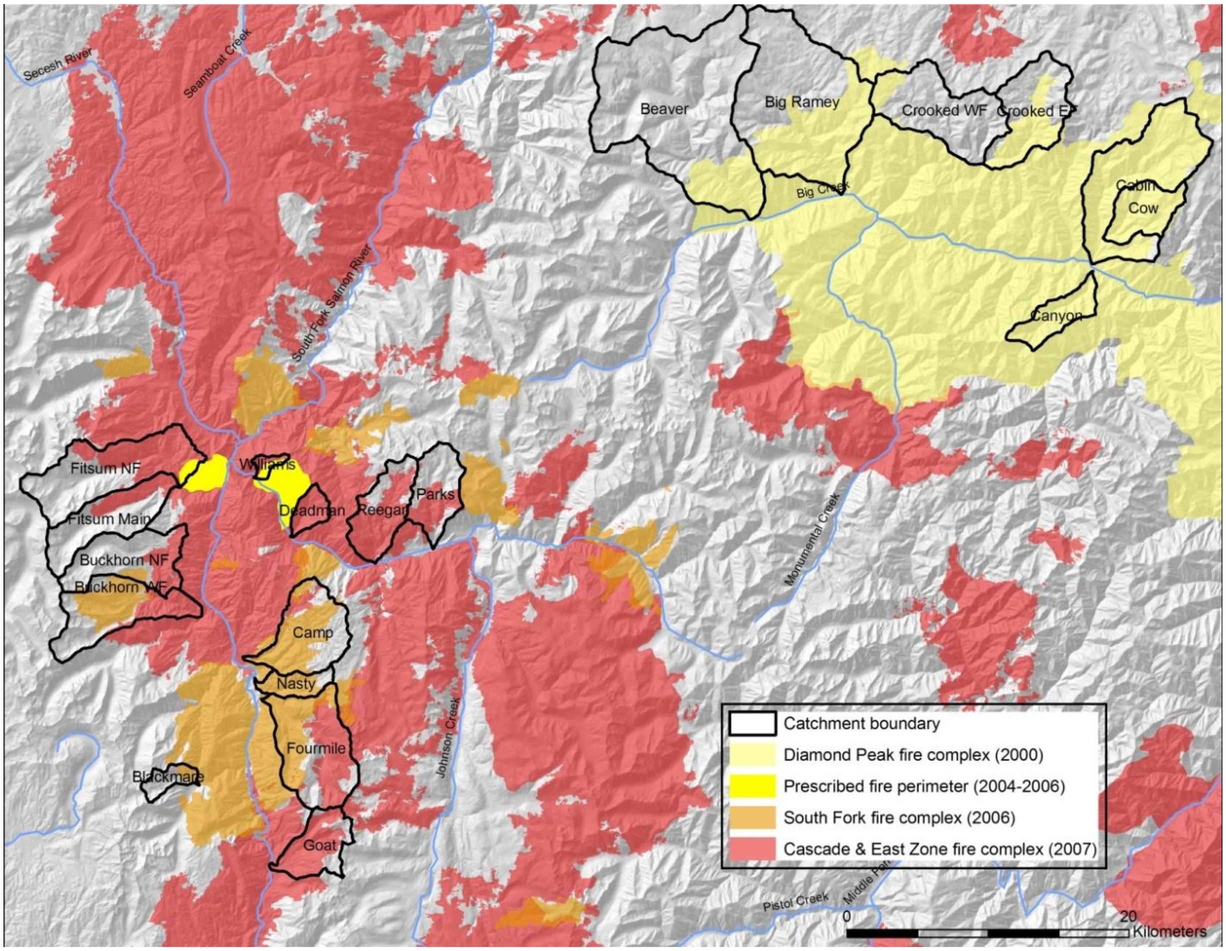


*Figure 1. Map of study area showing catchment boundaries relative to fires. The prescribed fires of 2004 (Parks) and 2006 (Fitsum and Williams) re-burned in the wildfires of 2007. We were interested in how streams in these catchments responded to the cumulative effects of prescribed fire followed by wildfire relative to surrounding untreated catchments where fire had been suppressed for decades. The Northeast catchments along Big Creek are located within the Frank Church – River of No Return Wilderness and are managed under a natural fire regime, last burning in 2000.*

## *Sampling Design*

We quantified the following biotic and abiotic variables in each catchment using sampling designs and protocols established prior to the 2007 wildfires:

*a. Satellite Derived Burn Severity*: We used Landsat multispectral satellite imagery and a GIS to calculate normalized burn ratio (NBR) within the study area for the fires that burned in 2000, 2006, and 2007. In each catchment we derived the percent of the upland and riparian forests burned at high and low severity using published NBR cutoff values (see Arkle et al. 2010). Satellite-derived burn severity was validated with field plots using a composite burn index (see Arkle et al. 2012).

*b. Amphibian Density and Biomass*: We quantified the occupancy and density of two stream-breeding amphibian species (Rocky Mountain Tailed Frog, Idaho Giant Salamander) in 14 streams. Each stream was sampled annually using 30, 1-m belts in a 1-km reach (see Arkle and Pilliod 2010).

*c. Aquatic Invertebrate Communities*: We sampled benthic macroinvertebrate communities in 14 streams. In each stream, we captured invertebrates using a Surber sampler (sample area of $0.10m^2$ with a 250μm mesh) at 5 transects placed at 50-m intervals over a 200-m reach during summer base flow conditions each year (see Arkle et al. 2010). Each sample was preserved in 95% ethanol. In the laboratory, we separated invertebrates from detritus using a 5-diopter lense and identified individuals to genus. We then calculated the density, taxa richness and diversity, and functional feeding groups of each sample and compared among years and fire treatments.

*d. Periphyton*: We characterized autochthonous primary production responses to different fire treatments and subsequent changes in light availability based on benthic periphyton sampling. In each stream, we sampled periphyton at 5 transects placed at 50-m intervals over a 200-m reach during summer base flow conditions each year. At each transect we scraped 3 rocks and collected the sample as described in Arkle and Pilliod (2010). We then calculated chlorophyll-a and ash-free dry mass (AFDM) for each sample providing an index of primary production. Light availability was measured using Solar Pathfinder equipment and software, which provided monthly average kW*hr-1*m2 values.

*e. Stream Habitats*: At amphibian and invertebrate sampling transects (n=35 per stream), we measured physical and chemical metrics (see Arkle and Pilliod 2010). Substrate size and embeddedness were recorded for 900 rocks per stream annually. Current velocity was measured from hand-held flow meters and related to stream gages in SF Salmon and Johnson Creek. We measured suspended sediment annually just after peak flow and estimated sediment deposition (V*) annually in 10 pools per stream. We estimated in-stream wood as percent cover in transects (30 per stream) and as the number of pieces of large woody debris within a 250-m reach. Water temperature was measured continuously at two locations within each reach using data loggers. We collected two water samples per stream per year for spectrophotometric and chemical analysis of concentrations of major ions and DOC at the USGS Water Resources Discipline laboratory in Denver, CO.

*f. Riparian Forest Structure and Composition*: We measured the riparian forest structure and composition in 6 paired, 20 by 50 m plots running parallel to 6 streams. These plots were first measured by Sherry Wollrab (USFS Rocky Mountain Research Station) in 2002-2003 as part of a National Fire Plan study and by us in 2007. Plot pairs were located on opposite sides of the stream channel. At each plot we measured diameter-at-breast-height (DBH) of live and dead trees larger than 10 cm DBH for each species, the distance of each tree from the stream channel, and the distance from the stream channel to the nearest burned vegetation, as well as canopy cover, light availability, dominant understory vegetation, and ground temperature and humidity.

*Data Analysis*

We analyzed the data in four ways: (1) Beyond-BACI (Underwood 1993, 1994), (2) mean difference approach (*sensu* Arkle et al. 2010), (3) general linear models with burn severity as a predictor variable, and (4) multivariate analyses of community and ecosystem responses to treatment, post-fire habitat conditions, and burn severity. We used a Before-After-Control-Impact (BACI) design to compare biotic and abiotic responses across our three treatments from before to after the fires of 2007. Under this robust analytical design, data are analyzed with an asymmetrical analysis of variance proposed by Underwood (1993, 1994). For each response variable, many control streams (catchments in the Big Creek drainage under natural fire regime) are compared to several impacted (treatment) streams to account for the spatial and temporal variability present in ecological systems. Although our control catchments burned in 2000, the strength of the BACI design is that it considers the inter-annual variability within streams and within treatments to provide a conservative estimate of "impacts" to the stream from fire. In this approach, we ran a separate BACI model for each response variable. In addition to BACI, we used the mean difference approach, which compares among our treatments the difference from before (2001-2006) to after (2008-2010) the fires for each of our response variables. An average response value for the wildland-fire-after-prescribed-fire treatment that falls outside the 95% confidence interval for the average before to after change in the wildland fire only streams or the reference streams were considered significant. We examined the specific influence of burn severity among our streams within each treatment using general linear models such as multiple regression. To examine which habitat and burn severity variables were influential in community and ecosystem-level responses, we used several multivariate analyses, including Multi-response Permutation Procedure and Non-metric Multidimensional Scaling (McCune and Grace 2002).

**Key Preliminary Findings:**

**Question 1: Effects of fire management practices on wildfire burn extent and severity**

*Satellite-derived Burn Severity:*

We found that the three management practices had different effects on wildfire severity throughout catchments (i.e. upland and riparian areas combined). Areas that experienced wildfire after prescribed fire treatment had significantly lower wildfire severities and significantly less high severity fire in particular, than surrounding areas where wildfire burned in untreated, fire-suppressed forests (Arkle et al. 2012). Wildfire in wilderness forests with a history of minimal fire suppression (i.e. areas under a fairly natural fire regime) tended to burn at slightly lower severity than in forests that had a history of fire suppression. However, this was only the case when summer fire weather was relatively extreme (i.e. 2000 and 2007). Under more moderate fire weather conditions (i.e. 2006), the historically-fire-suppressed catchments burned at relatively low severity.

Riparian or streamside forests (i.e. areas within 20 m of a stream) tended to burn in direct proportion to the extent of fire in the rest of the catchment, regardless of whether the catchment was in a fire suppressed area or in an area under a natural fire regime. This finding is consistent with earlier studies in the region (Arkle et al. 2010). We also found that the extent of fire in riparian forests was unrelated to fire weather, but milder fire weather conditions did result in less high severity fire in riparian forests. Riparian forests that were treated with prescribed fire prior to wildfire had substantially lower wildfire severities than nearby untreated areas (Arkle et al. 2012).

**Question 2: Effects of fire management practices on stream communities and habitats**

*Amphibian Density:*

Rocky Mountain tailed frog tadpole density fluctuated through time before wildfires and after wildfires, even in catchments with the least disturbance. Tailed frog tadpole populations in these streams appeared to exhibit a cyclic pattern that is unrelated to fire disturbance. Catchments that burned in 2000 under a natural fire regime had lower tadpole densities, but followed the same population cycles as described above for populations in fire-suppressed catchments. We detected post-fire changes in tailed frog tadpole populations in some, but not all, of the historically fire-suppressed catchments. We were more likely to detect population responses in catchments that burned at high severity and extent, and in populations that were small or had high densities of first-year tadpoles prior to the fire. Populations in catchments that were treated with prescribed fire prior to experiencing wildfire exhibited the same post-wildfire trends as were observed in historically fire suppressed sites and in sites under a natural fire regime. However, Parks Creek, a treated catchment, experienced a channel reorganizing debris flow in 2008, which reduced tadpole densities thereafter.

Idaho giant salamander larval occupancy rates (i.e. proportion of transects occupied each year) fluctuated prior to wildfires in historically fire suppressed forests. Some populations appeared to be declining rapidly during this time period. After the wildfires of 2006 and 2007, occupancy rate continued to decline in more heavily disturbed catchments (i.e. those with high wildfire burn severity or those that experienced debris flows). In more moderately disturbed catchments, salamander occupancy increased beyond the levels observed in the two years preceding the wildfire. There was no detectable effect of wildfire in catchments previously treated by prescribed fire. No salamanders were observed in the streams under a more natural fire regime, but these streams appeared to be outside the species range.

*Aquatic Invertebrate Communities:*

The benthic macroinvertebrate communities of streams were highly dynamic from year-to-year. However, communities in less disturbed streams (i.e. those in catchments under a natural fire regime or in catchments that burned at low severity) showed less annual variability than communities in historically suppressed catchments that burned at high severity. Streams that experienced post-fire debris flows or scouring events had the greatest annual variability in community composition. Macroinvertebrates in the sampled reaches of two of these streams were reduced to nearly zero.

In catchments that were historically suppressed, macroinvertebrate diversity (either Shannon or Simpson diversity) decreased significantly after the wildfire. We also observed a pulse increase in total density that was delayed for two years following the fire (in 2009). The decrease in diversity may be the result of habitat specialists, feeding specialists, or disturbance-adapted taxa becoming more dominant in the post-fire stream environment. The delayed increase in total density of macroinvertebrates observed in several streams in 2009 may be due to increased light and nutrient availability combined with increased stability in the physical habitat (i.e. less sediment flux). Macroinvertebrate diversity and density did not change significantly in two of the three streams in catchments that were treated with prescribed fire prior to wildfire. A channel-scouring debris flow in the third treated catchment reduced the total density of macroinvertebrates to zero, except for several chironomid larvae that re-colonized the stream following the debris flow event. Total density of macroinvertebrates in this stream recovered over a two-year period, but taxonomic richness and diversity were markedly lower in this stream compared to other streams. It is unlikely that the debris flow event was related to the prescribed fire treatment since the debris flow began well upstream of the prescribed fire treatment boundary.

*Periphyton:*

We found no clear relationship between fire management practices and periphyton communities in these sites. Instead, periphyton levels more associated with the physical characteristic of streams, annual variations in peak streamflow, and with wildfire burn severity.

Autotrophic periphyton is important to the aquatic food web as the sole source of in-stream primary production. Autotrophic periphyton abundance, as measured by chlorophyll-a concentrations per square meter of benthic substrate, varied considerably through time. We observed a large decrease (up to 33% reduction) in chlorophyll-a in 2008, one year post-wildfire. However, this decrease was confounded by a high spring run-off, the second highest peak flow recorded since 1967. In the following year, 2009, chlorophyll-a concentrations increased to exceed pre-wildfire concentrations in the majority of sampled streams. This may be a result of increased light availability and nutrient content in the stream water. In 2010 (3 years post-wildfire), chlorophyll-a concentrations declined slightly from 2009 levels. Overall, the three largest streams with the least canopy cover had the most abundant autotrophic periphyton. Medium sized (i.e. $2^{nd}$ order), shadier streams had intermediate levels of autotrophic periphyton, whereas small streams, or those that experienced post-wildfire debris flows had the lowest autotrophic periphyton abundances.

Ash-free dry mass (AFDM), an indication of both autotrophic and heterotrophic periphyton abundance, followed a similar pattern as chlorophyll-a. In 2008, the year following the wildfires, levels declined well below pre-fire AFDM levels. In 2009, AFDM values increased to, or nearly to, pre-fire levels in the majority of the streams sampled. In 2010, AFDM continued to increase in the less disturbed streams, but declined slightly from 2009 levels in the more disturbed catchments. The 2010 decline in AFDM (and in Chlorophyll-a discussed above) in disturbed streams could be due to the scouring action of the 2010 peak streamflow (the highest recorded since 1967).

We calculated a modified version of the traditional Autotrophic Index (AI*) using chlorophyll-a and AFDM values, where AI* = [Chlorphyll-a (mg/m2) / AFDM (mg/m2)] * 100. Thus, AI* is positively related to autotrophy (as opposed to the original index which was positively related to heterotrophy) and is expressed as a percentage, with values of 0.1% considered typical of stream habitats. We found that for 8 of 9 streams in historically fire suppressed areas, pre-fire AI* levels were well below the typical stream value of 0.1%. AI* did not decrease in 2008 to the same extent as chlorophyll-a or AFDM in most streams. We observed the largest decreases in AI* in 2008 only in the most disturbed sites (i.e. severely burned by wildfire, or those affected by post-wildfire debris flows). In 2009, most streams exhibited a substantial increase in AI*, which elevated this metric to values approximating the 0.1% reference level. The AI* values of most streams decreased or did not change significantly between 2009 and 2010.

*Stream Habitats:*

Stream flows ($m^3 * s^{-1}$) were higher after the wildfire in most catchments that were historically fire suppressed. This was particularly evident in more severely burned catchments. Catchments under a more natural fire regime did not exhibit a corresponding increase in stream flow during that same time period (2008-2010). Similarly, catchments that had prescribed fire treatments prior to the wildfire also did not have increased stream flows following the wildfires. This interesting trend needs further investigation.

Substrate size of the stream bed either decreased or did not change following the wildfires in the majority of streams that were in historically fire suppressed catchments. Streams where the average substrate size decreased tended to be smaller than unaffected streams. Substrate sizes did not change significantly in streams flowing through catchments that were burned by prescribed fire treatment prior to wildfire, except where post-fire debris flows greatly altered stream beds. In contrast to these findings, we found that substrate sizes increased in streams flowing through catchments managed under a natural fire regime over the same time period (2008-2010).

We found no evidence that fire management practices influenced sediment levels. Substrate embeddedness decreased or did not change following the wildfires in streams flowing through catchments that were historically fire suppressed, except for a small catchment that was severely burned by wildfire. Substrate embeddedness did not change in catchments treated with prescribed fire treatment prior to wildfire or in catchments managed under a natural fire regime. V*, a unitless metric representing the deposition of mobile sediment in pools (see Arkle et al. 2010), did not increase significantly in any of our catchments providing further evidence that wildfires did not cause sedimentation in these systems. By 2010, most streams tended to have lower V* values than they did before the wildfires, probably because of high stream flows in spring 2010.

Summer water temperature patterns changed throughout the course of the study depending on disturbance severity and fire management practices. For example, the number of hours per summer with water temperatures exceeding 16 C (considered lethal or problematic for many stenothermic cold-water species) more than tripled following the 2007 wildfires in some streams that were in historically fire suppressed prior to burning. In contrast, catchments that had been treated with prescribed fire prior to wildfire either did not change or cooled down in the three years following the wildfire. Further investigation is needed to determine how vegetation growth patterns influenced this relationship.

Water chemistry changed substantially following the wildfires in both historically suppressed catchments and in catchments that were treated with prescribed fire prior to wildfire. Small streams that burned severely had the highest suspended organic and inorganic matter, total nitrogen, phosphate, pH, calcium, magnesium, silicon, sodium, and strontium concentrations. Suspended matter in all streams tended to fluctuate depending on the magnitude of peak streamflows in the spring. There was no apparent effect of prescribed fire prior to wildfire on concentrations of suspended organic and inorganic matter.

*Riparian Forest Structure and Composition:*

Riparian or streamside forest structure was strongly influenced by wildfire. This is contrary to a widely held assumption that riparian forests do not burn in wildfires because of higher fuel moisture than the surrounding upland forests. Before the wildfires, riparian forests in historically suppressed catchments had higher densities of trees (DBH > 10 cm), a larger proportion of small trees, and greater dominance of shade tolerant species (i.e. Douglas fir) than sites under a more natural fire regime. Two years after the wildfires, Douglas fir tree (DBH > 10 cm) densities in historically suppressed sites decreased by 3-4 individuals per 1000 $m^2$ and the mean DBH of

Douglas fir trees increased by 5 cm, indicating that fire resulted in decreased densities of young, shade tolerant Douglas firs in particular. The density of fire-adapted ponderosa pine trees in these catchments was less affected by wildfire. Catchments that were treated with prescribed fire prior to wildfire had lower riparian tree mortality compared to nearby untreated catchments; about 5 fewer trees per 1000 $m^2$ died in treated than in untreated riparian forests.

The quantity of large woody debris (LWD) in streams was influenced by wildfire and by hydraulic processes (i.e. high peak flow events, or debris flows). In historically suppressed streams, the number of LWD pieces per meter of stream was positively correlated with burn severity. In streams under a natural fire regime, LWD decreased from 2003 to 2009, probably because fluvial transport exceeded recruitment of new pieces into the streams in the time period since the last wildfire (2000). We also observed a significant loss of LWD following debris flows in two streams with different management practices (one historically suppressed and one that had been treated with prescribed fire prior to wildfire).

**Question 3: Cumulative effects of fire management practices and other disturbances**

Overall, we did not detect a cumulative effect of prescribed fire plus wildfire. Despite having reduced wildfire burn severities in catchments treated previously by prescribed fire, stream and riparian communities and habitats in these catchments did not behave differently in most respects from those in untreated catchments following wildfire. Instead, communities and habitats in treated catchments, historically fire-suppressed catchments, and in catchments under a natural fire regime fluctuated through time in the post-fire environment based on a common set of interacting factors: (1) wildfire burn severity patterns within the catchment (e.g. extent, severity, and distribution of wildfire in the riparian forest and throughout the entire catchment), (2) physical characteristics of the stream and catchment (e.g. stream size, gradient, and catchment slope), and (3) post-wildfire disturbances (e.g. inter-annual variation in peak streamflow, debris flow and channel scouring events, delayed tree mortality or blow-down events).

**Management Implications:**

The results from this study suggest that, in these dry, mixed-conifer forests on the Payette National Forest in central Idaho, prescribed fire management practices effectively reduce subsequent wildfire burn severity (Arkle et al. 2012). This reduction in wildfire burn severity may have reduced the ecological effects of the wildfire in streams and riparian forests located within these catchments, but the strength of this effect is largely masked by the dominant effect of variations in peak flow and stochastic events, such as debris flows and channel scouring.

**Relationship to Other Recent Findings:**

Our findings on the effectiveness of prescribed fire at reducing subsequent wildfire severity (Arkle et al. 2012) are consistent with recent studies in other forests (Finney et al. 2005, Wimberly et al. 2009). The results from this study are also consistent with previous research showing that the interaction of catchment-level burn severity with stream hydrology (particularly peak flow) increases the environmental variability found in streams (Arkle et al. 2010).

**Future Work Needed:**

The difficulty of coupling long-term data sets with relevant fire management practices has limited research in this area and thus future work may want to focus on building evidence to improve interpretation of our findings relative to general patterns. We have no way to assess whether the findings reported here are typical and thus we recommend future research conduct similar studies in other forest types and other locations, where practical.

**Deliverables Cross-Walk:**

We have disseminated the research findings through publication of 2 peer-reviewed articles and presentations at scientific meetings. Several publications are still in progress and will be submitted to scientific journals in 2012 and 2013. We also have shared preliminary results with specialists and managers via annual meetings at local management offices and webinars.

Table 2. Description and dates of project deliverables. Note proposed deliverables and proposed deliverable dates in italics.

| Deliverable | Description | Delivery Dates |
|---|---|---|
| Conference presentations | *(1) Yearly meetings with local resource managers; (2) 2-3 presentations of key findings at BLM and USFS centralized regional workshops; and (3) 2-3 presentations at fire ecology and management conferences* | *Throughout* |
| | (1) We held annual meetings at the Krassel Ranger District Office, Payette National Forest, Idaho. | 3/2010, 3/2011, 2/2012 |
| | (2) We participated and presented in the following federal agency meetings and workshops: | |
| | (a) National Interagency Fire Center Meeting, Boise, Idaho | 3/2009 |
| | (b) Salmon Basin Interagency Meeting, Boise, Idaho | 1/2010 |
| | (c) Fire Lab Seminar Series, Missoula, Montana | 3/2012 |
| | (d) USFS Riparian fuel treatment workshop, McCall, Idaho | 5/2012 |
| | (3) We presented preliminary findings at 3 national and regional scientific meetings: | |
| | (a) Rocky Mountain Tailed Frog responses to disturbance and restoration. Paper presented at Joint Meeting of the Society for Northwestern Vertebrate Biology and Washington Chapter of The Wildlife Society, Gig Harbor, WA, 22-25 March 2011. | 3/2011 |
| | (b) Spring-ignited prescribed fires reduce the severity of subsequent wildfire in central Idaho. Paper presented at | 11/2011 |

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| | Association of Fire Ecology, Interior West. Snowbird, UT, 6-9 November 2011.<br><br>(c) Pattern and process of prescribed fires influence effectiveness at reducing wildfire severity in dry coniferous forests. Paper presented at Northwest Science Association, Boise, ID, 28 March 2012. | 3/2012 |
| Conference posters | *One poster presentations at fire ecology and management conferences*<br><br>We opted to present oral presentation instead a poster at AFE conference. | *2009*<br><br>Not Delivered |
| Peer-reviewed journal articles | *(1) 2-3 refereed scientific journal articles; and (2) expanded factsheet for managers highlighting the important findings of the research*<br><br>Hossack, B.R., and D.S. Pilliod. 2011. Amphibian responses to wildfire in the western United States- Emerging patterns from short-term studies. Fire Ecology 7: 129-144.<br><br>Arkle, R.S., D.S. Pilliod, and J.L. Welty. 2012. Pattern and process of prescribed fires influence effectiveness at reducing wildfire severity in dry coniferous forests. Forest Ecology and Management 276:174-184.<br><br>Pilliod, D.S., R.S. Arkle. In progress. Stream amphibian responses to fire and fuel treatments. To be submitted to peer-review journal.<br><br>Arkle, R.S., D.S. Pilliod. Invertebrates respond to upland and riparian disturbances in managed and unmanaged landscapes. To be submitted to peer-reviewed journal.<br><br>Pilliod, D.S., R.S. Arkle. In progress. Fact sheet: Effectiveness of fuel treatments in mixed-conifer forests. | *2011*<br><br>2011<br><br>2012<br><br>In progress (expected 2012)<br><br>In progress (expected 2012)<br><br>In progress (expected 2012) |

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