Effects of Prescribed Riparian Fire in Small Headwater Streams in the Rogue River Basin, Southwest Oregon.

Christopher J. Volpe
Fish Biologist, Medford District Bureau of Land Management, 3040 Biddle Rd, Medford OR 97504.
Email @ chris_volpe@or.blm.gov

Abstract
Riparian areas are important ecological transition zones between aquatic and terrestrial habitats. Many riparian zones have been altered by past management practices, resulting in unnaturally dense even-aged stands that are potentially vulnerable to wildfire and would benefit from fuel reduction treatments. Federal land managers, required to protect these sensitive environments, have been reluctant to treat these areas in the face of uncertain ecological effects. This study measured riparian and hydrologic parameters including summer streamflow, water quality, channel shade, summer water temperature, and substrate in eight small headwater catchments. Riparian vegetation was treated for fuels reduction in four of the basins, while four paired and adjacent buffered basins were treated only in upland areas. Two control basins did not receive any vegetation treatments. All basins were in the Klamath Mountain Province of interior southwest Oregon, Rogue River Basin. Treatments consisted of cutting prescribed vegetation, handpile burning, and underburning. Precipitation varied substantially between calibration and post treatment seasons, complicating interpretation of some results, but overall the study indicated that treatments did not measurably affect summer flow or water quality. Channel shade was reduced in one of the unbuffered basins, but was maintained or increased in all other study basins. Stream temperature appears to have been affected by the treatments, including in the buffered upland treatment basins, as both warming rates and 7-day average maximum temperatures were increased in most of the study basins, while these same metrics decreased in the control basins. Substrate composition remained unchanged in most basins following treatments, though fine substrate frequency was found to have increased in one of the unbuffered basins. We speculate sampling error and/or bank disturbance resulting from sample efforts may have influenced this result, but suggest that buffering may be appropriate in areas composed of erodible soils.

Introduction

Riparian areas are important ecological transition zones between aquatic and terrestrial habitats (Reeves *et al*. 2006). Riparian vegetation adjacent to stream channels provides many proven benefits to the aquatic ecosystem (Meehan 1991). Riparian vegetation, among other things, stabilizes banks, provides streamside shade, a source of nutrient input, and may act as a filter, blocking the transport of eroded particulates from upland areas.

Past management practices have altered the structure and function of forested areas across the landscape, including riparian zones. Riparian areas were historically among the first areas to be cleared of timber, as they were more accessible and in closer proximity to early settlements (USDI 1998, USDI 2001). Harvest of riparian vegetation continued to be common practice on federal lands until policy shifts in the mid 1990s. In southwest Oregon, past riparian harvest and replanting in plantation-like stands, coupled with decades of fire suppression has resulted in many acres of overly dense, even aged forest stands. Thinning these stands may release existing dominant trees allowing riparian vegetation to obtain desirable mature characteristics sooner (e.g. to provide increased shade and sources of large wood input to the aquatic environment), and to decrease the vulnerability of riparian areas to unnaturally intense wildfire (Dwire 2003). Everett *et al* (2002) suggest that disturbance may need to be incorporated into riparian areas to protect the integrity of riparian and adjacent upslope forests. Prescribed fire is one method of approximating a natural disturbance in riparian areas.

Fire can greatly influence aquatic ecosystems (Dunham *et al.* 2003, Meehan 1991) and aquatic organisms (Rinne 1996, Gresswell 1999). Effects may be positive or negative, with potential to impact many parameters of the aquatic environment, and are dependent upon many variables (Rieman 1997). Fire was historically an important, natural component of western riparian environments (Dwire 2003, Skinner 2003), and there is evidence that some riparian corridors in southwest Oregon burned with comparable frequencies to their associated upland areas (Olsen 2000, Taylor and Skinner, 1998, Olsen and Agee, 2005). In spite of this evidence, riparian areas on federal lands generally have not been treated for fuels reduction in southwest Oregon.

Conventional fuels treatments near natural water ways typically leave vegetative buffers (typically minimum 15.3 meters, or 50', either side of perennial streams) to reduce potential impacts to water quality and aquatic organisms. Fuels have accumulated in some riparian areas to unnaturally high levels. These corridors may act as "wicks" when a wildfire burns through the area (Agee 1993, Taylor and Skinner 1998, Petit and Naiman 2007), reducing effectiveness of fuel treatment projects at the landscape scale. Land managers have been reluctant to treat riparian areas, owing to concerns of how treatments may impact these important ecological areas (Beche *et al.* 2005). Bisson *et al*. (2003) identify key questions for research to address to assist management decisions with regards to both wildfire and fuels management, including the need to quantify and differentiate aquatic effects stemming from wild and prescribed fire.

In partnership with the Klamath Bird Observatory (KBO) and Utah State University, the Medford District Bureau of Land Management (BLM), working under a grant provided by the Joint Fire Science Program (JFSP proposal # 05-2-1-19), conducted a broad research project designed to quantify both the effectiveness and the effects of prescribed burning in riparian areas. A multi-disciplinary approach was employed to address this question, and the final study design included wildlife, macroinvertebrate, botany, fuels, and hydrology components. The study utilized a paired watershed approach, whereby four small catchments (hereafter referred to as the unbuffered basins) incorporated fuels treatments in upland and riparian areas, and four adjacent paired catchments (hereafter the buffered basins) received only standard upland vegetation treatment. Two control basins were also selected for the hydrology component. Note that the term basin, as used to describe the study basins is not the same as the USGS definition based upon their Hydrologic Unit Code (HUC) organization system; the term as applied to the study basins simply mean a catchment that outlets at one distinct point, or mouth.

Fuels treatments across all landscapes directly treated (cut, handpile, and underburn) brushy species and small diameter (< 20 cm, or 8" diameter) conifers and hardwoods, in areas identified by BLM fuels specialists. Overstory, shade producing vegetation and riparian species (e.g. maple, alder, dogwood, etc.) were not directly targeted for removal. Treatments were applied adjacent to stream channels in the unbuffered basins, while in the buffered basins vegetative buffers of 15.3 m and 7.6 m were left adjacent to either side of all perennial and long duration (flow > 30 days) intermittent channels, respectively. Short duration and dry draw channels were not buffered in any of the basins. Fire was not applied on the ground within the buffered areas, but was allowed to back down into the buffers from upland areas.

The hydrology component, the focus of this paper, measured the short term response of several hydrologic and riparian parameters pre and post treatment including: summer streamflow, water quality (pH, electrical conductivity, and dissolved oxygen), stream side shade, summer water temperature, and substrate composition. Long term monitoring was also established, including cross sectional profiles and Proper Functioning Condition (PFC) reach surveys. These long term monitoring efforts are not included in this analysis.

Study basins were selected based upon many filters and screens. The original intent of the study was to utilize three sets of triplet basins, all of which would be located in the Applegate River subbasin. Due to one filter or another, this proved not feasible, and in the end, the selected paired study basins represented the only suitable or practical sites available to the Ashland Resource area of the Medford BLM to conduct the JFS study.

Study Basin Locations and Descriptions

This study took place in the interior Rogue River basin, located in extreme southwest Oregon. The Rogue River is a large coastal river system with its headwaters in the Cascade Mountains, some 190 kilometers east of the Pacific Ocean. It flows through the Klamath Mountains (Siskiyou Range) for much of its length before entering the ocean at Gold Beach. The study drainage basins lie roughly in the middle of the Rogue basin, east of and in the rain shadow of the Klamath Mountains, and west of the Cascades. Climate in the study area is typified by mild, wet winters, and very dry and hot summers (USDI 1998).

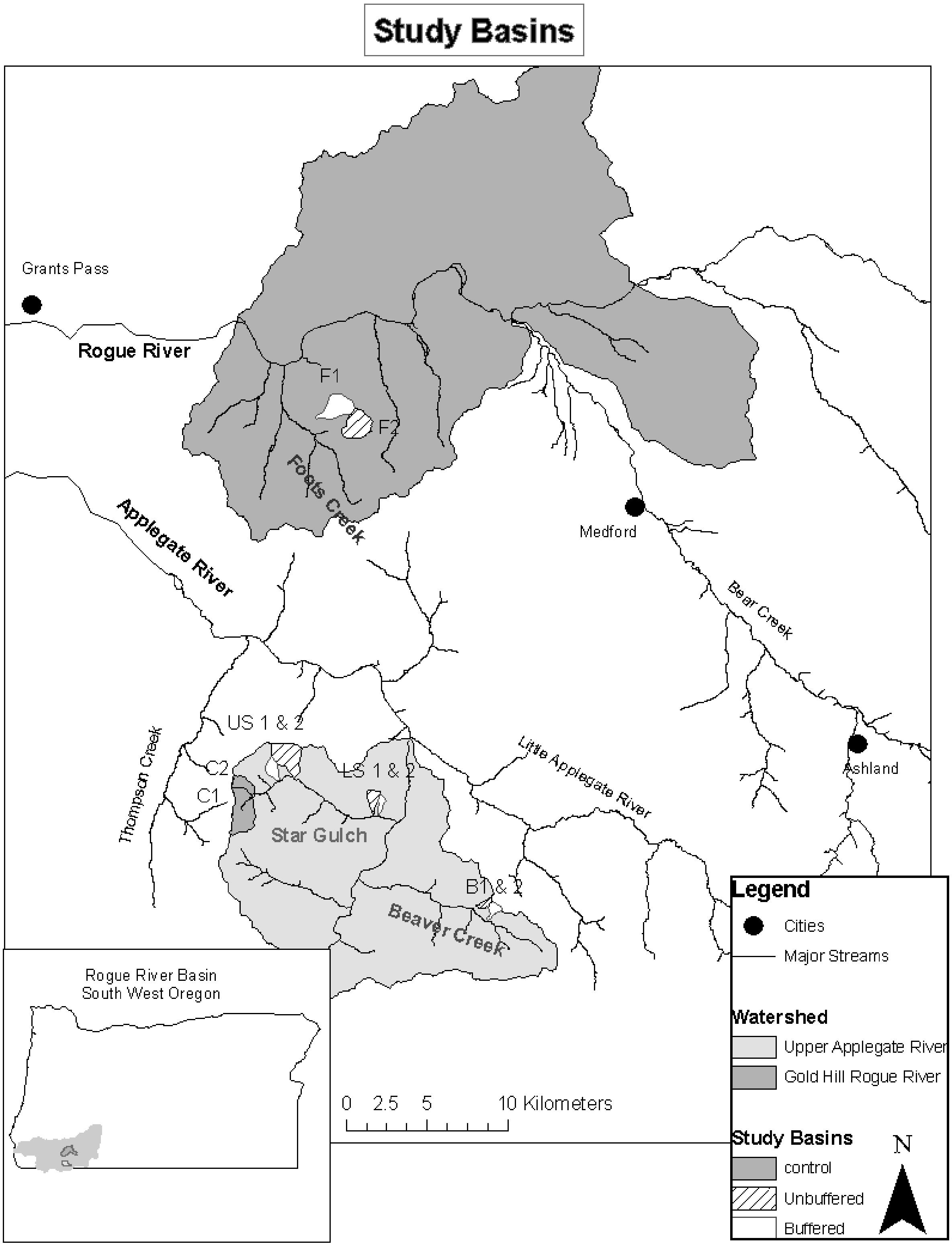
The ten study basins are spread amongst four distinct geographical areas with two study basins in each area (map 1). Two of the basins, Foots 1 (F1) and Foots 2 (F2) are within the Gold Hill Rogue River Watershed, in the Middle Rogue Subbasin. The remaining 8 basins, Controls 1 and 2 (C1, C2), Upper Star 1 and 2 (US1, US2) Lower Star 1 and 2 (LS1, LS2) and Beaver 1 and 2 (B1, B2) are within the Upper Applegate River Watershed, Applegate Subbasin. Each is a headwater basin, whose primary drainage channel is generally a 2^{nd} or 3^{rd} order channel at the basin outlet. In every case, the basins lie adjacent to another paired study basin. One of the two basins (excepting the controls) in each geographical area received the riparian treatment, while its neighboring basin was buffered in riparian areas. Basins were randomly chosen by coin toss to receive one or the other treatments, and then subject to further filtering that would preclude riparian treatments in certain areas (for example, water withdrawals for domestic use).

In general the basins are south to south west orientated, except for C1, which has a north aspect. Vegetation in the basins range from conifer to hardwood/brush dominated, with the riparian corridors and north and east aspects of the basins typified by conifers, while the uplands and south and west aspects generally contain extensive hardwood and brush components. The basins range in size from roughly 80 to 800 acres, and median elevations range from 712 m to 1,167 m. Precipitation rates vary between the basins, from 71 cm a year in the Foots basins, to 117 cm in the upper Star and control basins. Precipitation is predominantly in the form of rain, which occurs primarily between October and April. Occasional shallow snow packs accumulate for short periods at elevations above 1067 m. Table one below includes some of the basin characteristics. Data derived from watershed analysis and BLM resource databases using Geographic Information Systems (GIS) software.

Basin	**Size** (acres)	**Aspect**	**Fuel Unit** (acres)	**Elevation range** (m)	**Precip** (cm)	**Stream kilometers**	
						Perennial	intermittent
Control 1	825	N	-	817-1463	117	4.2	1.7
Control 2	230	S/SE	-	817-1463	117	1.2	.5
Upper Star1	210	S	110	769-1268	117	1	.4
Upper Star2	661	S	433	762-1451	117	1.6	.5
Lower Star1	184	S	100	524-879	74	.6	1.3
Lower Star2	97	S	96	518-884	74	.2	.5
Beaver 1	82	W/SW	38	799-1024	109	.5	.6
Beaver 2	131	S	54	805-1036	109	.3	2.7
Foots 1	559	W/SW	280	436-988	71	1.6	4.2
Foots 2	596	W/SW	393	536-1049	71	1	2.9

Table 1: Study basin physical characteristics.

All of the basins have experienced some past disturbances, including historic placer mining and commercial timber harvest. The lower Star basins (LS 1 & LS 2) were subject to a stand replacing wildfire in 1986 (Star Fire). The fire and subsequent salvage logging operations removed the overstory vegetation in LS1 in particular. Additionally, both Beaver basins (B1 and B2) were subject to recent mechanical (slashbuster) fuel treatments in upland areas.



Map 1: Study Basin Location

Fuels Treatments

Fuels treatments began in the fall of 2006, with cutting and handpiling. Handpile burning began the following spring, and was finished by winter of 2007. As basins came into prescriptions favorable for burning and weather factors allowed, they were underburned during the spring of 2008. Every basin was underburned with the exception of Foots 2, a selected unbuffered basin, which received only a head strip of fire approximately 100 meters in depth at the top of the unit. Unfavorable weather conditions precluded obtaining necessary smoke clearance to complete the burn before the end of the burning season. Fuel reduction objectives were met in this basin through handpile burning alone and fuels specialists have no intent to reenter the basin to complete the burn at this time (Mason 2009). Riparian vegetation in this basin thus was treated by cutting, piling, and handpile burning only.

A mosaic of burned and unburned vegetation remained in each of the basins following underburning, which was especially apparent in riparian areas in the unbuffered basins (photos 1 and 2). Burned areas adjacent to stream channels were generally small and discontinuous with large patches of unburned vegetation common in the unbuffered basins. Many areas did not carry fire. Upland areas generally exhibited larger and more uniform and continuous burned patches than the adjacent riparian areas.

Photo #1: US 2, unbuffered, riparian treatment near the basin outlet looking upstream from left bank. This was one of the more severely burned patches adjacent to the channel in any of the unbuffered basins.

Photo #2: US 2, riparian treatment looking downstream from right bank near the basin outlet. Note the prevalence of unburned vegetation. This photo was taken ~ 40 m downstream from photo #1 above.

Riparian vegetation was not treated in the buffered basins, but in several instances fire from the uplands did back down into the riparian areas, resulting in similar but much less common mosaic patterns of burned and unburned vegetation. LS 2 in particular among the buffered basins experienced some channel adjacent burning resulting in small scorched patches.

The botany and fire monitoring components of the broader Joint Fire Science riparian burn study quantified burn severity and vegetation change within riparian areas of the study basins. Results relevant to this study documented that among the unbuffered basins, LS1 and US2 experienced modest fire severity in understory vegetation in riparian areas. The Foots 2 basin (not underburned) and B1 both displayed traits characteristic of low severity fire (Dejuilio, unpublished data). Among the buffered basins, understory riparian vegetation in LS2 was determined to be subject to low severity fire, while riparian vegetation in the other buffered basins remained largely unburned.

Study Methods

Flow: Check dams constructed of irrigation cloth were placed near the outlets of each of the basins. PVC pipe was used for both the cross pieces to support the dams, and as the outlet pipes from which streamflow measurements were taken. The upstream apron of each dam was covered with rocks, gravel, and fine substrate to achieve the best possible seal. Properly constructed, the dams captured the great majority of flow. However, subsurface flow, upwelling, and seepage under or around the dams occurred to some extent at all sites (estimated less than 5% of surface flow escaped at any one site). The dams were placed one to two weeks prior to survey start date (June 1st) in each of the study seasons. Flow measurements were taken in 2006, the calibration season, before any fuels treatments were initiated to establish short baseline relationships between the basins, and in 2008 after underburning the basins to complete the fuels treatments. Flow was measured once a week from June

1 to September 30 (17 weeks) in the 8 study and 2 control basins. Measurements were made by placing a container of known volume under the outlet pipes and timing the duration it took to fill the container to overflow. Three to five measurements were averaged, and the mean fill time was used to calculate an estimated 24 hour flow rate, expressed as acre feet per day.

Regression analysis performed with Microsoft Excel 2007 software was used to establish the relationship of flow between the study and control basins. Any change in slope of the regression line after treatments was then tested for significance as described by Grabow *et al*. (1998).

Water Quality: Electrical Conductivity (EC) and pH were measured weekly using a hand held Hanna Instruments (HI) 98311 EC/TDS meter and HI 98127 pH meter near the check dams at the basin outlets. Sampling occurred throughout the summer season each year of the study. The hydrogen ion concentration was calculated from measured pH values ($[H^+] = 10^{-pH}$) and used to determine seasonal and study group mean pH values. Dissolved Oxygen (DO) was measured every other week at the basin outlets throughout the summer season in each of the 10 study basins. Samples were taken using the modified Winkler titration method, utilizing a HACH Dissolved Oxygen Test Kit. Measurements were standardized for temperature by transforming the data from mg/l to percent saturation as described by the following on-line publication: http://waterontheweb.org/under/waterquality/oxygen.html. When, during the course of the season a stream began to lose surface flow at its outlet, DO, EC, and pH measurements were taken until it was no longer possible to obtain an accurate measurement. DO measurements were the first to be discontinued as a pool depth equal to the height of the sample bottle (15 cm) was required to obtain a sample unaffected by atmospheric oxygen, while the EC and pH meters required very little water (less than 3 cm) to obtain an accurate reading. Two tailed t-tests were performed with Microsoft Excel software to determine if significant changes in mean values occurred to these parameters post treatment.

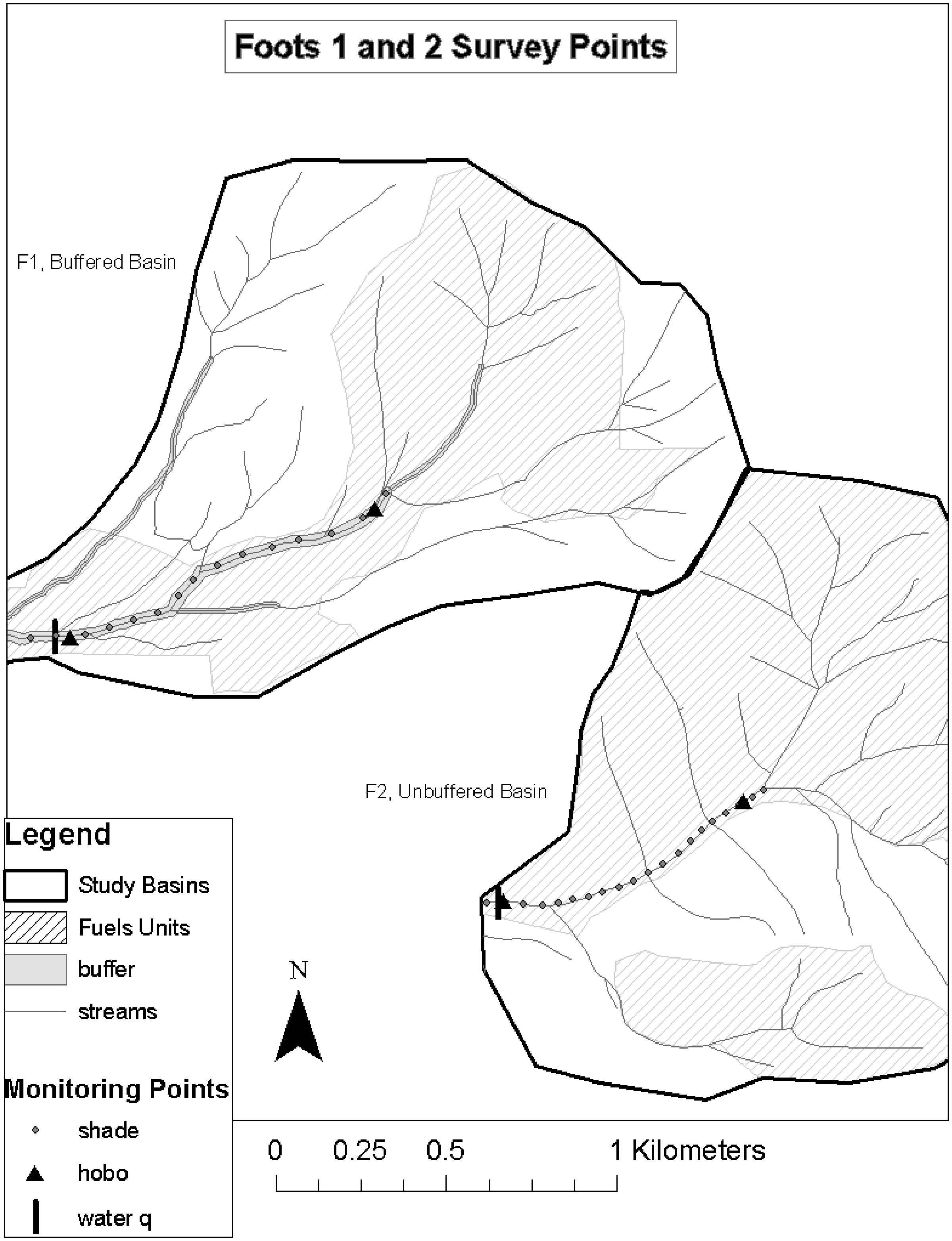
Shade: Percent effective shade, defined as the amount of potential solar energy blocked by vegetation before reaching the stream channel, was measured at 20 points along the perennial reaches of the eight study basins. Shade was not measured in the two control basins. Points were spaced evenly within each reach, depending on reach length as determined from Geographic Information System software (ARCMAP 9.3). Measurement locations were determined in the field with a survey tape measure; the first location was at the basin outlet, and set increments were then measured up the channel. Photos were taken upstream, downstream, left bank, right bank, and directly above each spot a measurement was made. Shade surveys began after full leaf out in 2006. Measurements were made with a Solar Pathfinder, calibrated for 37-43 degrees north latitude and 17^o east of north magnetic declination. Percent effective shade was determined for the months of June, July, and August.

Every attempt was made to take shade measurements at the same location post treatment as they were during the first season, utilizing both the survey tape and the photo record from the first season. To standardize the readings of the sun chart diagrams, the same observer tallied the solar numbers utilizing a set of rules created to minimize variability associated with interpreting the diagrams (for example, how to count a number contained only half way in a polygon) for both seasons. Mean summer shade was then calculated for each point and for the reach in its entirety by averaging the percent effective shade values obtained for June, July, and August. Two tailed t-tests were performed to test for significance of observed differences in mean summer values with Microsoft Excel software.

Water Temperature: Water temperature was recorded in 30 minute intervals throughout the summer low flow period utilizing HOBO Water Temp. Pro (v. 1) data loggers, placed two to a basin. One was placed near each basin outlet, just upstream of the check dam locations, and another placed nearer the top of each of the perennial reaches. Loggers were placed in the same locations in 2006 and 2008, and were launched one week prior to June 1, with the exception of the final year of the study, when they were launched prior to underburning in each of the study basins. Mid season audits of the loggers were made each season to ensure that they were accurately recording stream temperatures. Loggers were retrieved after October 1 both seasons. Daily mean/max temperatures were calculated and utilized for data analysis. Regression analysis examined the relationship of temperature between study basins. Seven day average maximum temperatures were also calculated, and the number of days the 7-day maximum temperature exceeded temperature standards was evaluated. Analysis was conducted with Microsoft Excel software.

Substrate: Pebble counts, as described by Wolman (1954) were used to quantify substrate composition before and after fuels treatments in each of the basins. Three transects were established in each study basin, and in C2. Two lower counts were conducted upstream of the check dam locations, near the lower hobo location. One upper count was done near the top of the perennial reaches, close to the upper hobo locations. Transects began on the upstream right bank, in-line with a pin established on the stream bank outside of the flood prone area. The B-axis size class of each substrate particle encountered every 6 cm was measured, and tallied by size class. Transects continued laterally across the bank-full stream channel to the opposite bank, and a new transect was started 6 cm upstream which proceeded back towards the right bank. This process was repeated until more than 100 counts had been recorded. Initial counts were conducted in the fall of 2006, prior to initiation of fuels treatments. One lower count was reread in early summer 2008 just after treatments occurred as part of the macroinvertebrate study. The other counts were reread in late winter 2009 following winter freshets. All counts within each basin were combined for analysis purposes, and were also lumped by study group (buffered vs unbuffered). Change in percent fines (substrate < 6 mm) was examined using 2X2 contingency tables and the likelihood ratio Chi-square statistic, obtained through SPSS software.

Map 2 below displays an example of how individual study points were distributed throughout the study basins.



Map 2: Example of Study sample points. Pebble counts were conducted near the hobo points. Water Q sites include the check dam locations, and were also the sites of E.C., pH, and D.O. sampling

Sample Seasons

A description of the climatic conditions that proceeded the 2006 and 2008 sample seasons is necessary for interpretation of results, as the two seasons were significantly different hydrologically. The water year (October 1 – September 30) for 2006 recorded 103 cm of rain at the Star Gulch rain gauge, 1.5 times the 10 year average (70 cm) as measured at this site. In contrast, the water year for 2008 documented only 60 cm of rain, 15% less than the 10 year average, and less than 60% of the 2006 total (figure 1). The calibration period of this study was conducted during an unusually wet period, while post treatment data collection was subject to a drier than normal period. One of the strengths of a paired watershed study is that varying environmental conditions are accounted for somewhat, as it is assumed that all watersheds in the study are subject to the same conditions, and respond similarly to varying conditions (Loftis *et al*., 2001). This is especially true of long term studies, spanning many years where differences between years tend to even out. A limitation to this particular study is that only one season of calibration data was collected, owing to the three year nature of the grant. This, coupled with the significant decrease in precipitation between seasons which resulted in reduced post treatment data sets, diminishes the confidence in the responses of several variables in the various basins.

During the 2006 study season, both of the control basins, and both of the Foots, and Beaver study basins retained surface flow at their outlets throughout the 17 week duration of the study period. In the other study basins, all in Star Gulch (US1 and US2 and LS1 and LS2), surface flow disappeared at their outlets between weeks 4 and 11. In 2008, Control two and both of the Foots basins retained surface flow throughout the 17 week summer period. Control one retained pooled water at the check dam location, but ceased flowing for three weeks. Many of the other basins went dry at their outlets before or just after data collection began in 2008 (Table 1). As such, there were less data points collected for flow, E.C., pH, D.O. and temperature during the 2008 season compared with the 2006 calibration period.

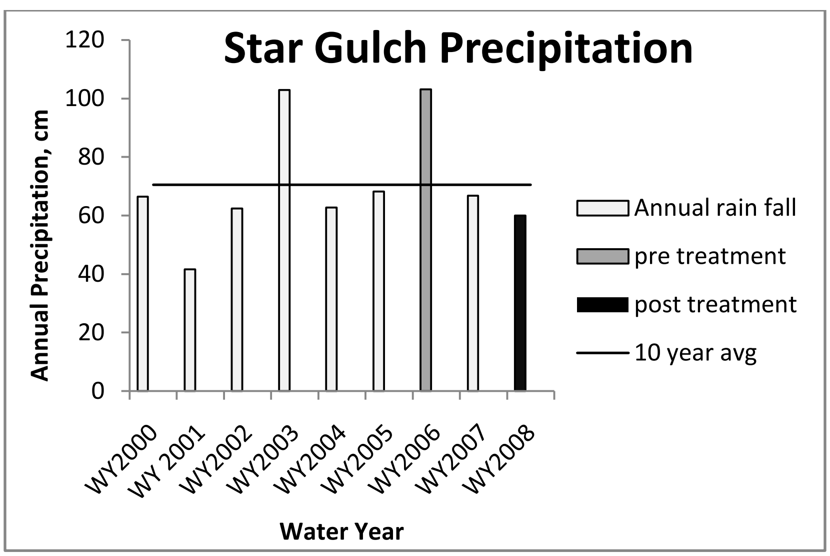


Figure 1: Annual rainfall at Star Gulch Rain Gauge.

# of Weeks of Surface water (E.C./pH observations)	Year	
Basin	2006	2008
Controls	**34**	**34**
C1	17	17
C2	17	17
Unbuffered	**50**	**35**
US2	5	2
LS1	11	6
F2	17	17
B1	17	10
Buffered	**44**	**19**
US1	4	1
LS2	6	1
F1	17	17
B2	17	0

Table 1: Number of weeks of surface flow by study year recorded at each basin outlet.

Air temperature data was collected at a conifer progeny site located several miles from and approximately 300 m of elevation above the control basin outlets. Daily minimum, maximum, and mean air temperature data is available from week six to the end of data collection only; air temperature data is not normally collected at this site during the spring, hence early season data was unavailable. A quick look at average mean and max temperatures suggests air temperature was similar in 2008 compared with 2006 (table 2, figure 2) for the period from July 17 to October 1.

Star Gulch Air Temperature (^{o}C)					
Year	2006	2008	P	T	DF
avg daily mean	17.7	17.9	0.78	-.274	145
avg daily max	24.7	24.3	0.57	.564	140

Table 2: Air temperature average mean, max from July 17 to October 1. P value and test stats from two sample t-test, α= 0.05.

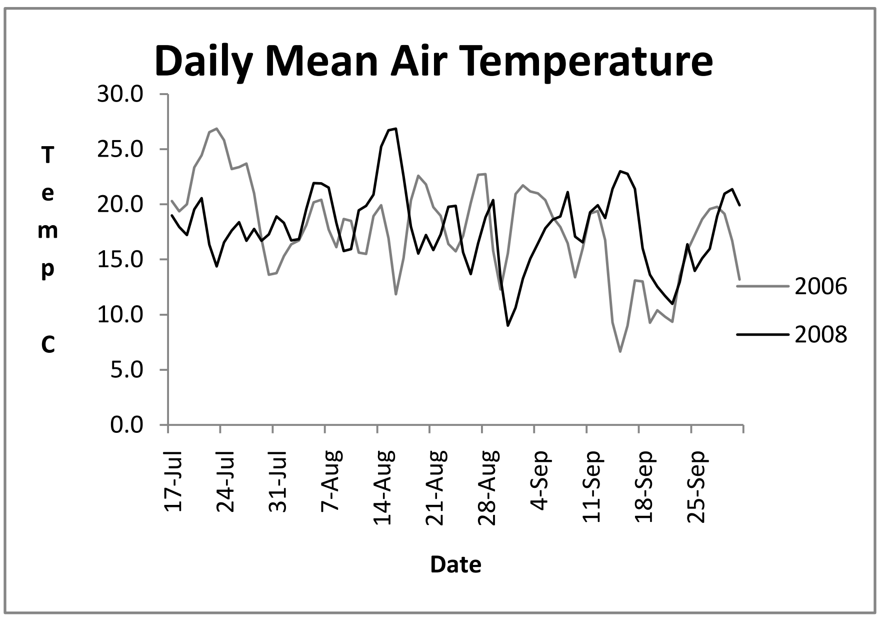


Figure 2: Daily mean air temperature, Star Gulch site ~ 300 m above control basins. Period includes from July 17 (week # 6 of study seasons) to October 1 (study season end).

Results and Discussion

Flow: Past studies suggest a strong correlation between vegetation removal and increased base low streamflows in a variety of stream, habitat, and treatment types (e.g. Rau *et al.* 2005, Harr 1983). There are several described mechanisms by which vegetative treatment may influence streamflow. For example, increased infiltration and percolation of rain water into the ground, coupled with less loss due to evapotranspiration from plants, leads to increased storage and downslope transport of ground water, potentially increasing surface streamflow during the summer months.

Several studies have attempted to quantify the relationship between vegetation removal and increased summer water yield in small drainage basins, and collectively they suggest that increases in removal of vegetation is correlated with increases in summer water yield (Burton 1997, Harr 1976). The majority of these studies occurred in catchments that were subject to timber harvest prescriptions of various intensities (usually clear cutting), often coupled with follow up fuel reduction treatments (generally slash burning). The vegetation treated in most of these studies was the dominant overstory trees and shrubs. No studies, to our knowledge, have attempted to look solely at the relationship between prescribed fire (which generally leaves the dominant overstory tree components) and summer yield, nor the influence that treatments applied in riparian areas may or may not have on yield.

Because of the large differences observed in precipitation and flow between pre and post treatment seasons, the only data sets that are complete and comparable between years are those for basins C2, F1, and F2. As such, the analysis and results are presented here as a case study only between the paired treatment basins F1 and F2 and the control basin C2.

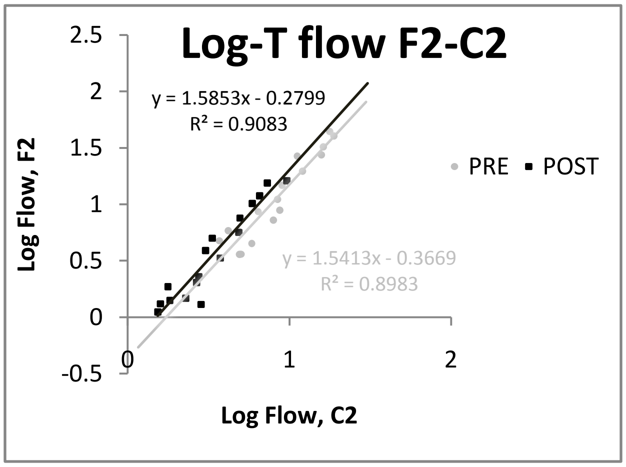
The hydrographs, despite the large differences in volume of flow, are similar in shape for all three basins between study seasons, with a steeper, more apparent drop in flow during the first few weeks each season, followed by a more subtle and gradual decline as the seasons progressed. Total yield per basin in 2008 was roughly 1/3rd of volume observed during the 2006 season, and ranged from 25% (F1), 30% (F2) to 34% (C2).

The relationship of summer flow between basins was not linear, as measured flow volumes declined approximately exponentially as the summer progressed. As such, flow data was log transformed using the following equation: Log-T x = Log (x + d) - c where c = Int (log(Min(x)) and d = Log-1(c), and min(x) is the smallest non zero value in the data set. This transformation tends to preserve the order of magnitude in the data, and is useful for data sets including very small values, such as this one (Mcune and Grace, 2002). Control two proved to be a very good predictor of flow for F1 and F2 ($R^2 \geq 0.9$). Regression runs between summer flow in the predictor basin, C2 (X axis), and the response basins, F1 and F2 (Y axis') showed no significant differences in the slopes of the prediction lines pre and post treatment (table flow 1, figure flow 1 -2).

Regression Output, Log-T Flow, C2 (X-axis) vs Study Basins					
Basin	R2	ΔSlope	P α = 0.05	DF	F
F1	0.94	-0.277	0.109	33	138
F2	0.93	0.044	0.816	33	142

Table Flow 1: Regression output: Change in slope of regression lines, pre/post treatment, and test staticstics.

Analysis suggests that fuels treatments had no significant effect on summer low flow in either F1 (buffered basin) or F2 (unbuffered basin), and that there were no significant differences between treatments. It is unfortunate that data were not available from the other study basins following the 2008 season to support this conclusion. We speculate that given the nature of the fuels treatment (i.e. generally only shallow rooted vegetation removed in patchy and discontinuous areas) that any increased groundwater available as a result of this type of treatment would be utilized by on site remaining vegetation before being discharged to stream channels.



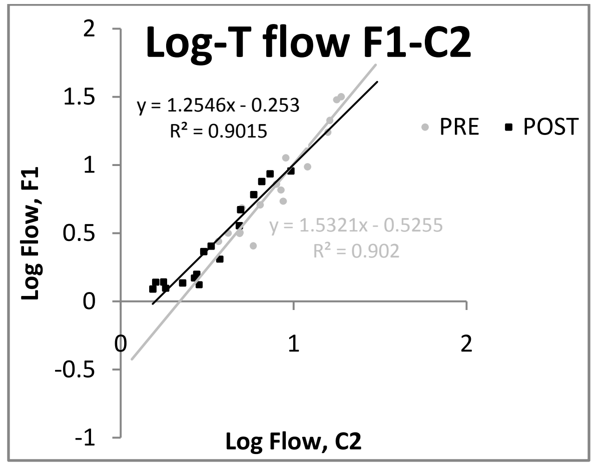


Figure Flow 1: Scatter plot, F2 (unbuffered) vs C2

Figure Flow 2: Scatter Plot, F1 (buffered) vs C2

Water Quality: Electrical Conductivity values varied weekly and seasonally for each of the 10 study basins. A subtle increasing trend was discernable throughout the summer season for each of the study basins during the first study season (2006). This trend was repeated during the 2008 season for the control basins, but was not observed in either the buffered or unbuffered basins, where observed values fluctuated very little throughout the summer season. Seasonal mean values varied between all basins from 1-11% from 2006 to 2008.

Two- Sample t-tests performed for each of the basins (Table WQ 1) found significant differences in seasonal mean EC values in all but two of the study basins (US2 and B1, both unbuffered basins) following fuels treatments, while the decline in mean values in both of the control basins was found not to be significant at $\alpha = 0.05$. P values are not reported for basins B2, US1, and LS2 because lack of water and consequently very few data points during the 2008 season precluded meaningful analysis of means.

The spotty nature of the 2008 data, coupled with the very different climactic conditions makes interpretations of results somewhat problematic. It is interesting to note that conductivity values fell in all of the basins except for US1 and LS2, two buffered basins from which one sample only was obtained from each before surface flow disappeared for the season. Conventional wisdom would suggest that a more likely scenario would have been an observed increase in EC values in 2008 relative to 2006, given there was far less surface water in 2008. Less surface water should have meant that a greater percentage of water sampled was groundwater originated relative to 2006, water that has spent some time below the surface where it would be expected to absorb a higher concentration of minerals, and hence yield a higher EC value (Burkholder et al. 2008).

Also counterintuitive, vegetation management such as prescribed burning has been shown to be correlated with short term 5 to 10 fold increases in concentrations of inorganic nutrients (Meehan 1991), which in turn would be expected to equate to increased EC values. This was not observed in any of the study basins in 2008, most of which trended the opposite direction with measured EC values coming in lower than during the 2006 season.

In light of all this it is unclear what if any effect fuels treatments may have had on EC. The declines in the paired Foots basins, which along with the two controls were the only complete paired data sets in

2008, were very similar. This at least would seem to suggest that the effect to EC from fuels treatments was no different between the buffered and unbuffered basins.

MEAN ELECTRICAL CONDUCTIVITY µS/cm^2						
BASIN	2006	2008	% change	p value	T	DF
Controls	334.9	328.2	-2.0006	0.655	.45	65
C1	286.3	277.1	-3.21341	0.471	.73	25
C2	383.5	379.4	-1.0691	0.717	.37	24
Unbuffered	520.9	489.1	-6.10482	0.009	2.68	76
US 2	452	443	-1.99115	0.576	.61	4
LS 1	621	554	-10.789	0.005	3.37	14
F2	522.3	479.9	-8.11794	0.0007	4.06	18
B1	481.5	475	-1.34995	0.539	.62	22
Buffered	446.9	488	9.196688	0.014	-2.53	54
US 1	418.7	432	3.176499	na	na	na
LS 2	554.8	564	1.658255	na	na	na
F1	526.3	486.8	-7.50523	0.009	2.92	18
B2	350.9	na	na	na	na	na

Table WQ1: Summer mean EC values by group, basin, pre and post treatment. Output from two sample t-tests, α= 0.05.

Throughout the duration of this study, pH was the least variable of all aquatic parameters measured. Measured values ranged from a low of 7.2 to a high of 10.3, with seasonal mean values for all basins ranging only from 7.6 to 8.0. From pre to post treatment there was a very slight (less than 1%) increase in measured mean seasonal pH values across all study groups. This increase was a result of several anomalously high pH measurements recorded during weeks 3, 4, and 5 of the 2008 season, when pH values neared or topped 10 in all of the study basins. This fluctuation was not observed during the calibration period of the study, when pH values held very constant throughout the field seasons in each of the basins. It is unknown why this phenomenon occurred, but as it was observed in both of the control basins as well as in all of the treatment basins it was not a result of fuel treatments. There were no discernable differences in increases observed between the control, unbuffered, and buffered study basin groups.

Measured DO values showed a high degree of variation, both within and between study basins. For example, two observations taken two weeks apart in C2 span a low of 36.2% to a high of 73.9% saturation. There were no trends apparent in the data sets, and the control basins were found not to be good predictors of DO in any of the study basins ($R^2 < 0.2$). This within basin variability and lack of correlation was apparent in each of the basins both pre and post fuels treatments. This, coupled with a scarcity of observations made in 2008 due to low/no flow situations, makes interpretation of results difficult. Only C1, C2, F1, F2, and LS1 had the same number of observations in 2008 as in 2006.

Changes in observed seasonal mean DO between pre and post treatment seasons were also variable, with both controls registering increases in percent saturation, while two of the unbuffered basins showed increases, and one declined (table WQ 2). Only one buffered basin (F1) had meaningful DO data collected in 2008, and its mean DO was very similar to that observed in 2006. Only change in one basin (C2) was found to be significant at $\alpha = 0.05$, likely a result of the wide range of values observed for each of the basins.

No clear relationship presented itself between fuels treatments and dissolved oxygen content in adjacent streams in this study. This, coupled with collecting useable data from only one buffered basin post treatment, makes it impossible to say with any confidence whether or not there were differences between treatments on dissolved oxygen concentration.

Seasonal mean Dissolved Oxygen (% Saturation)						
BASIN	(2006)	(2008)	Δ%	p	T	DF
Controls	64.3	74.7	16.2	0.013	-2.65	28
C1	68.2	74.8	9.7	0.263	-1.16	15
C2	60.4	74.6	23.5	0.024	-2.61	11
Unbuffered	65.1	62.3	-4.3	0.532	.63	23
US 2	61.2	na	na	na	na	na
LS 1	63.2	73	15.5	0.099	-1.82	10
F2	61.6	51.5	-16.4	0.084	1.85	15
B1	71.1	78.3	10.1	0.358	-.97	9
Buffered	60.1	55.2	-8.2	0.187	1.39	29
US 1	44.7	na	na	na	na	na
LS 2	51.6	na	na	na	na	na
F1	54.7	55.2	0.9	0.897	-.13	12
B2	71.6	na	na	na	na	na

Table WQ 2: Seasonal mean dissolved oxygen content by study basin. Reported p-values and test statistics from 2 sample t-tests (α= .05).

Stream Shade: Riparian vegetation adjacent to stream channels provides a source of shade, essential to maintaining cool water temperatures. Cool, well oxygenated water is necessary to support the indigenous fauna native to southwestern Oregon's aquatic lotic habitats. Acknowledging this, target shade levels have been established for many watersheds, and federal land management activities facilitate attainment of those targets. The Oregon Dept. of Environmental Quality (ODEQ) has established target shade levels, which average 91% on stream reaches on all federal lands in the Upper Applegate Watershed (ODEQ 2000, 2004). This includes all study basins except for F1 and F2, which fall in the Gold Hill Rogue River Watershed, for which target shade levels have yet to be established. They will likely be very similar, and this analysis will assume that eventually they will also be set at 91%.

In 2006, pretreatment measured summer shade values ranged from 0% to 100% for any single point, and averaged from 67.2% (LS1) up to 86.2% (US1) for the perennial reaches in their entirety in each of the eight study basins (Figure Shade 1 and Table Shade 1 below). The average percentage of measured shade provided to all eight basins was 76%; by group, the unbuffered basins averaged 75.2% effective shade, while the buffered basins averaged 76.6%. Values were not normally distributed, and skewed towards 100%. As such, data were arc-sin transformed before two sample t-tests were run to test for significant differences in effective shade values between study groups before and after treatments. In 2006, there was no statistical difference in percent effective shade between the buffered and unbuffered basins (two tailed P = 0.6924) at the 95% confidence level. None of the basins were at or above target shade levels set by the ODEQ.

In general, the majority of shade provided to the stream channels came from large overstory trees (> 25 cm DBH) in all of the basins (Photo #3)except for Lower Star 1. Douglas-fir and big leaf maple were observed to provide the majority of channel shade in the upper Star, Beaver, and Foots Creek basins, while oak, Pacific madrone, and brushy species accounted for higher percentages of shade in the two lower Star basins. Lower Star 1 in particular had a large percentage of shade provided to its channel by young resprouted hardwoods and small brush species as a result of the previous wildfire and subsequent salvage logging which removed the previously existing overstory trees (Photo #4).

Photo #3: Foots 2 pre treatment, photo from channel center. Shade provided by large overstory trees, including both conifers and hardwoods. This photo is representative of riparian vegetation in the Foots, Upper Star, and to a lesser extent the Beaver study basins.

Photo #4: Lower Star 1 pre treatment, photo from channel center. A large portion of the channel shade was provided by brushy, resprouted hardwoods and young conifers < 6” DBH. Note the lack of overstory vegetation.

Shade surveys repeated in 2008 following the underburning, documented a somewhat surprising increase in measured shade in all of the study basins except for LS 1 and 2. While there were values that decreased at any one spot in each of the four unbuffered basins, the average of measured values for each reach either was maintained or improved in all other basins. Values ranged from a low of 52.6% (LS1) up to 93.1% (US1). The average for all basins combined also increased to 81.5%, 5% higher than in 2006. A paired t-test on the basins by study group before and after treatments tested for significance of change in shade between 2006 and 2008. Data were not transformed for these tests, as paired t-tests only assume normally distributed differences between pairs, an assumption that was met with this data set. There was a significant increase in average shade in the buffered study basins as a group from 2006 to 2008 (over 8%, P = 0.0004). While the unbuffered basins did show a slight (3%) increase as a group between this same period, it was not significant (P = 0.3537). The disparity in increase of shade percentages between the two study groups was entirely attributed to the loss of over 14% average shade in LS1. This large reduction in LS1 was found not to be statistically significant, a result of the high variance in the data set and corresponding wide confidence intervals. The difference in average shade values between the buffered and unbuffered basin groups after fuels treatments, as in 2006, was not significant (P = 0.0915). Two basins, US1 and F2, exceeded target shade levels set by ODEQ.

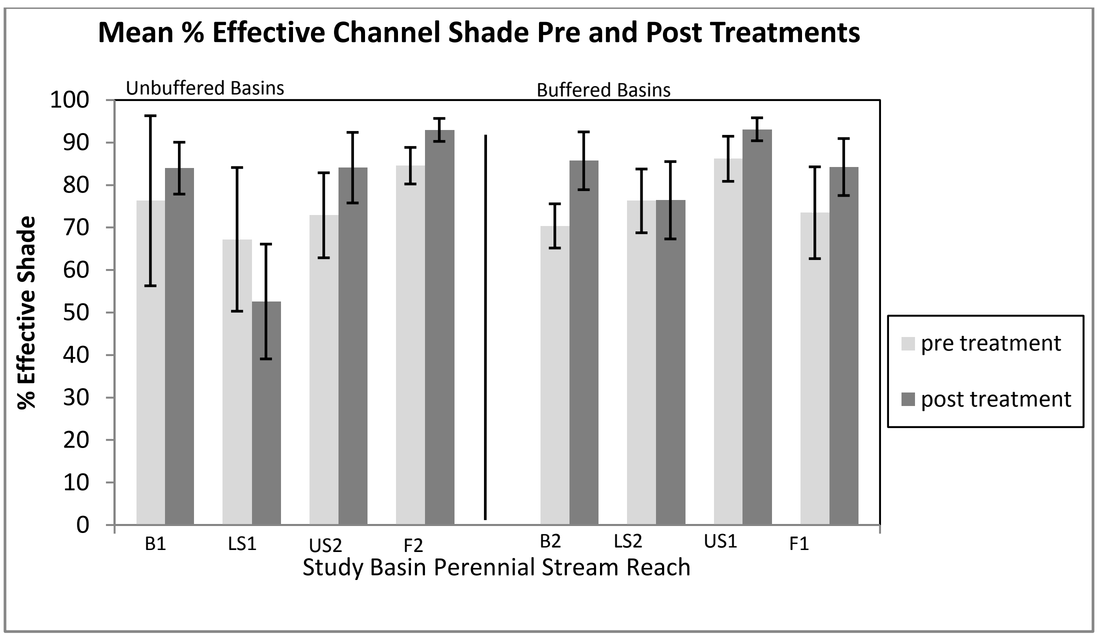


Figure Shade 1: Average Shade provided to stream channels pre and post implementation of fuels treatments. Error bars = 95% C.I.

Mean % Effective Shade						
Basin	**2006**	**2008**	**Δ%**	**p α=.05**	**T**	**DF**
Unbuffered	*75*	*78*	*3*	*0.3537*	*-.93*	*79*
US2	73	84	11	0.0531	-1.99	37
LS1	67	53	-14	0.2702	1.12	32
F2	85	93	8	0.0122	-2.64	37
B1	76	84	8	0.1013	-1.68	38
Buffered	*77*	*85*	*8*	*0.0004*	*-3.68*	*79*
US1	86	93	7	0.0968	-1.71	35
LS2	76	76	0	0.6294	-.49	34
F1	73	84	11	0.2263	-1.23	35
B2	70	86	16	0.0005	-3.96	28

Table Shade 1: Mean reach shade values by study basin, pre and post treatment. Reported p-values and test statistics from 2 sample t-tests (α= .05).

Results suggest that, in basins with a dominant and mature overstory, fuels treatments did not reduce mean % effective shade provided to channel reaches. However, channel adjacent fuels treatments applied in basins lacking this overstory component, such as in LS1, are likely to decrease mean % effective shade at the reach scale for some time before young hardwoods and other brushy species resprout. The buffered basin LS2 also had a component of channel shade primarily provided by younger brushier species, though to a lesser degree than in its paired basin, LS1. Shade remained unchanged in this basin, suggesting buffering is effective in protecting shade provided by brushy species from fuels treatments. Management should consider the nature of channel adjacent vegetation in their decision making processes concerning riparian fuels treatments to avoid reducing shade.

Water Temperature: Wildfire in riparian areas has been shown to increase summer maximum water temperatures for many years post disturbance (Dunham *et al*. 2007). Riparian fuels treatments may reduce the likelihood of high intensity wildfire occurring in these areas. However, removal of stream side vegetation (i.e. by fuels treatments) may potentially increase solar radiation to stream channels, causing increased water temperature (Meehan 1991). Water Quality Restoration Management Plans have been established for both watersheds in the study area, and have defined temperature criteria for streams within them. Management activities on federal lands are mandated to facilitate attainment of these criteria.

Data loggers were launched the last week of May in 2006, and pulled after October first. In 2008, data loggers were launched in each of the study basins in mid spring, prior to underburning of the study basins. All logger sites were wet (flowing water) at the time of underburning in each of the basins. Underburns were conducted from April 7th through May 7th in each basin, as conditions permitted. Underburning did not noticeably affect water temperatures, as no abnormal spikes in temperature were apparent in any of the study basins during the burning windows (Figure Temp. 1) Water temperature loggers were exposed to air temperatures in LS1, US1, and B2 before the end of the summer study season in 2008, resulting in short data sets that included early season temperature data only.

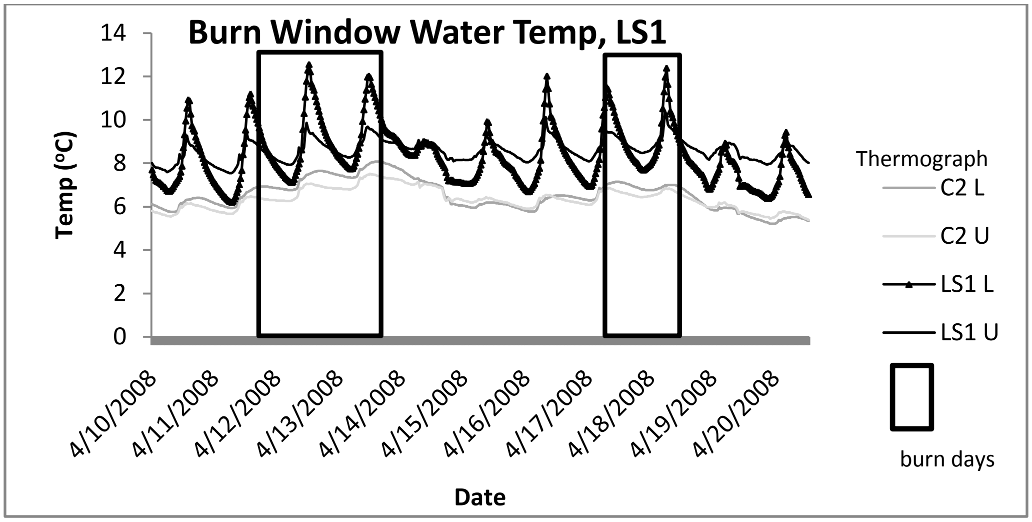


Figure Temp. 1: Example of water temperature during burn period. Depicted are the upper and lower thermograph data from LS1 and C2 during the three days of firing operations. LS1 burned the hottest of all the unbuffered basins, as determined by the fire effects report conducted under the broad study. Diurnal fluctuations are apparent for both basins, but no obvious spike in water temperature during the burn period is discernable from the graph.

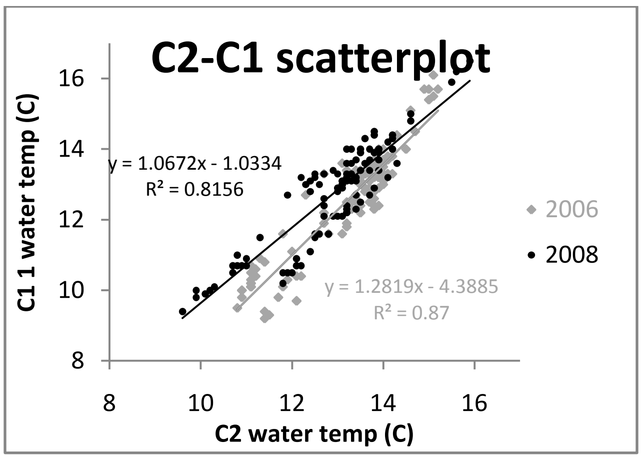
Control two was used as the standard control against which all other basins (including control one) were tested via linear regression, as it was more similar in size and aspect with regard to the study basins than was control one. It proved to be a good predictor of temperature in the study basins (R^2 = .74-.98), except for 2008 in US1, a basin for which prediction lines were generated from only five data points. It also should be noted that the prediction line for B2 was generated from only 10 data points. Confidence in the resulting equations is therefore diminished for both of these basins. Regression analysis showed significant post treatment slope differences in the relationship between water temperature in C2 and all other study basins, except F2 and US1 (Table Temp. 1, left half). By study group, slope changes were also found to be significant. Results indicate that the rate water temperature warmed post treatment relative to predicted by C2, was significantly ($p < 0.05$) increased, as indicated by a positive change in slope, in US2, LS1, LS2, B1, and B2 in 2008 (Figure Temp. 2). The opposite relationship was indicated for C1 and F1; a significant decline in the rate of warming (negative slope change) relative to predicted by C2 during 2008.

Significant increases in slope were detected in 3 of the 4 unbuffered basins, and in 2 of the 4 buffered basins. Slope increases were greatest in B2, a buffered basin, followed by in B1 and LS1, two unbuffered basins, confounding conclusions. In the paired Foots basins, F1 (buffered basin), showed a significant decline, while F2, the unbuffered basin did not significantly change relative to predicted. Why these two basins did not trend as the others may be a result of greater stream flows (and presumably greater contributions of ground water) consistently observed in these basins as compared with the other study basins.

To put the magnitude of the slope change and corresponding warming rate increases in perspective, the change in predicted average temperature was calculated by inserting the mean summer temperature value for C2 into the prediction equations generated for each basin (as described by Grabow *et al.*, 1998). Mean predicted temperatures and their difference pre and post treatment are displayed in the right half of Table Temp. 1 and in Figure Temp 3. Predicted mean temperatures were lower for both of the Foots basins following treatments, and were increased in all other study basins (including C1). This analysis suggests that most of the basins were warmer post treatment than predicted, regardless of treatment. The unbuffered basins as a group showed the largest increase in mean predicted temperature, at over 10%. This was driven by a 2.6^{o} C increase in predicted mean temperature in LS1, the only basin in which shade was found to be reduced post treatment. If LS 1 is omitted from the analysis, the remaining unbuffered basins, as a treatment group, exhibited an increase of .5739^{o} C, or 4.5%, very similar to the changes in both Control 1 and in the buffered group. This would seem to suggest that LS1 notwithstanding, treatments (buffered or not) did not affect predicted mean temperatures. However, looking at the individual paired study basins, it is apparent that 3 out of the 4 unbuffered basins had higher predicted mean temperatures than their buffered neighbors, suggesting that buffering lessened the increase to predicted mean temperatures.

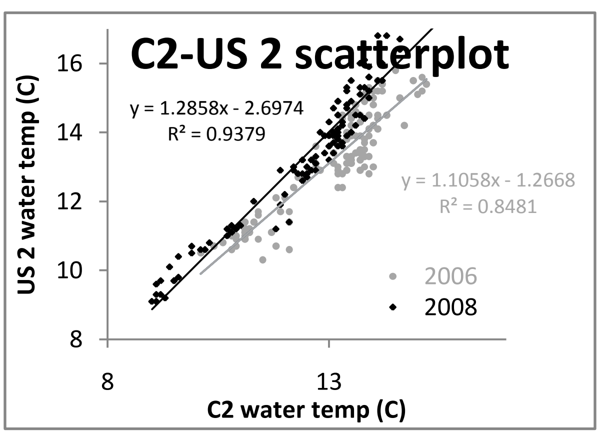
Figure Temp 3: Water temperature trends, pre and post treatment

Control Basins



Note direction of change in C1 is opposite of observed in all the treatment basins except for F1.

UNBUFFERED BASINS



Note: Very few data points for US1 in 2008.

BUFFERED BASINS

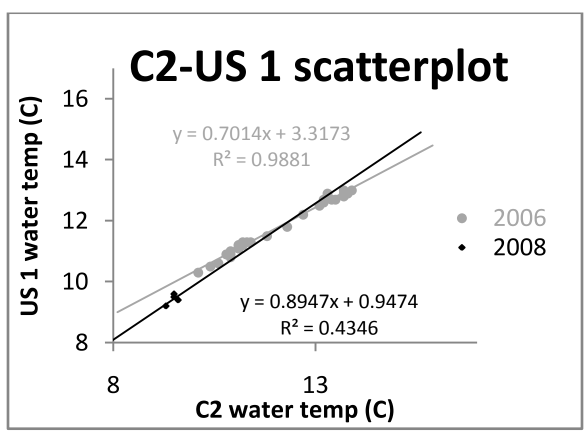
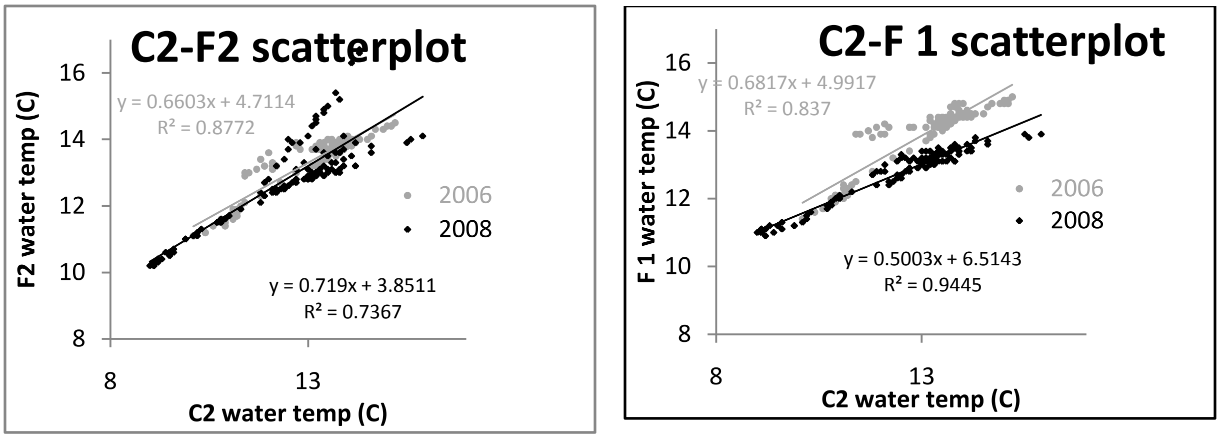
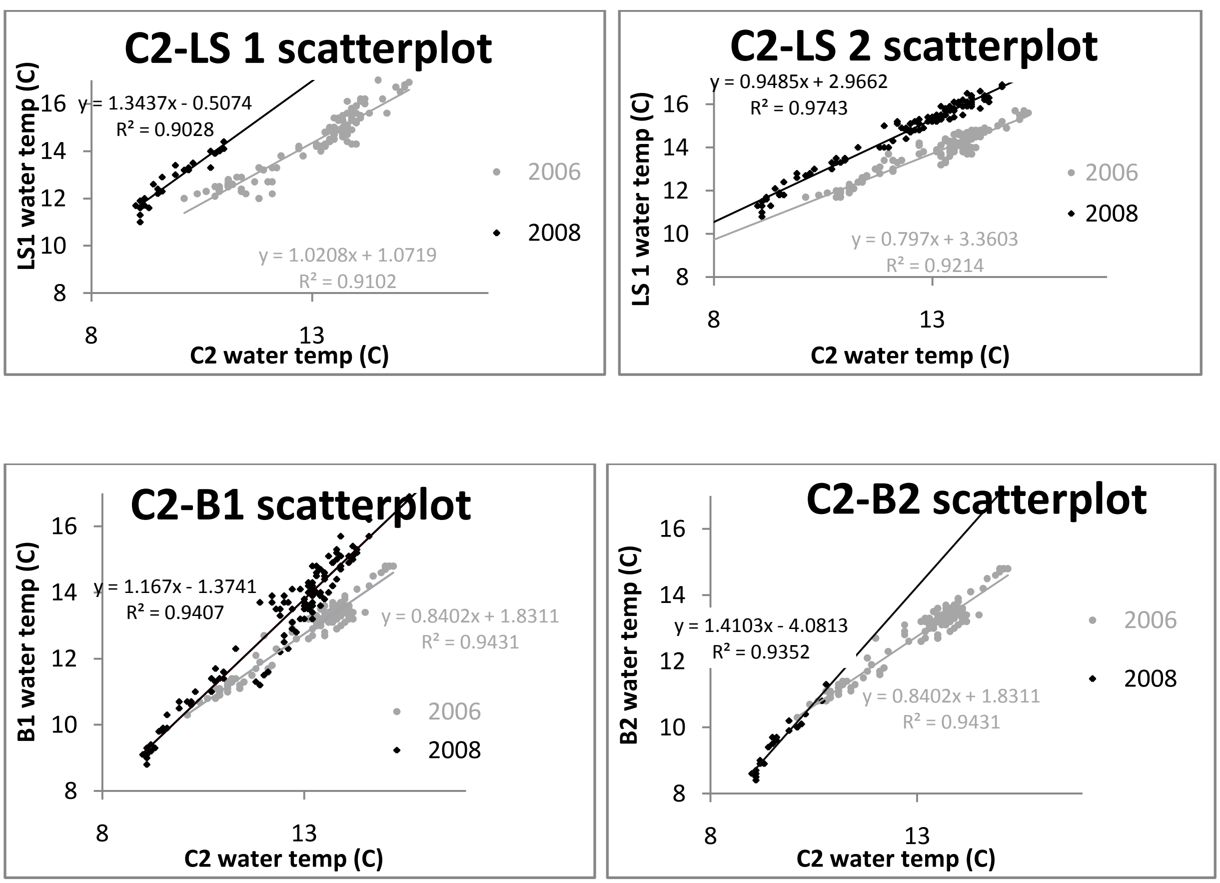


Figure Temp 3 (Cont.): Water temperature trends, pre and post treatment

UNBUFFERED BASINS BUFFERED BASINS



Note: F1 only study basin where 2008 temps trended lower than 2006.



Regression output, study basins (Y Axis) vs C2 (X Axis)						**Mean Predicted temperature (°C)**			
Basin	**R2**	**Δ Slope**	**P**	**F**	**DF**	**Pre**	**Post**	**Change**	**%**
C1	0.85	-0.215	0.002203	388	213	12.1993	12.7736	0.5743	**4.7077**
US2	0.91	0.18	0.000874	739	228	13.0423	13.9409	0.8986	6.8899
LS1*	0.93	0.323	0.006413	575	141	14.2811	16.8801	2.5989	18.1989
F2	0.79	0.059	0.24525	281	228	13.2557	13.1549	-0.110	-0.7604
B1	0.94	0.326	6.04E-17	1228	228	12.703	13.7269	1.0239	8.06
Unbuffered	*0.9*	*0.122*	*0.001082*	696	231	*12.1993*	*12.7736*	*1.1052*	***10.517***
US1*	.99	.193	.66808	1490	40	12.2491	12.5248	0.2757	2.251
LS2	0.96	0.152	1.52E-08	1983	228	13.6735	15.2398	1.5663	11.455
F1	0.92	-0.181	1.29E-09	823	228	13.8129	12.9882	-0.824	-5.9705
B2*	0.97	0.57	3.13E-07	1667	136	12.7033	14.2309	1.5276	12.025
Buffered	*0.89*	*0.195*	*1.59E-07*	624	231	13.1097	13.7459	0.6362	**4.8529**

Table Temp. 1: Regression output and mean temperatures based on prediction equations, pre and post treatment. *= prediction lines were generated from truncated data sets resulting from the dry conditions prevalent during the post treatment season.

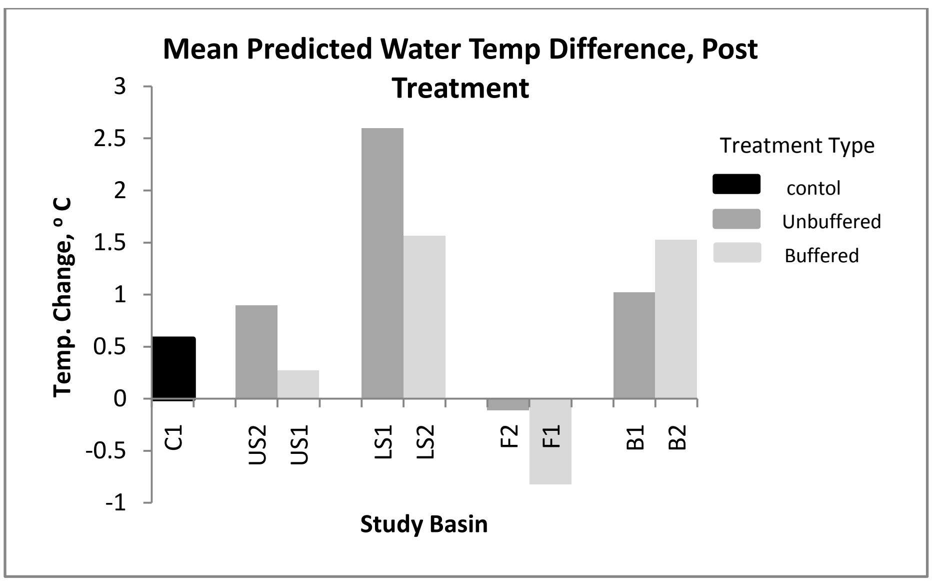


Figure Temp. 3: Chart depicts mean temperature differences, after fuels treatments, as predicted from regression equations between the study basins and C2. Note that of all the unbuffered basins, only the predicted change in B1 was cooler than in its buffered pair.

The reduction in shade that occurred in LS1 and the large predicted mean temperature increase relative to the other basins indicates that treatment of riparian vegetation in this basin led to increased predicted temperatures. It is unfortunate that this basin went dry during week 5 of the post treatment study season, and that temperature data spanning the entire post treatment season is unavailable to corroborate this.

The seven day average maximum temperature is a metric utilized by the Oregon Dept of Environmental Quality (ODEQ) to assess temperature standards in different waterbodies. It calculates the seven day average maximum temperature for the hottest period of record in the summer. Seven day average maximum temperature standards have been set by the ODEQ for the study and control basins, at 16^0 C in the Applegate Subbasin, and 18^0 C in the Middle Rogue Subbasin. In 2006 three study and one control basin exceeded the summer water temperature standard from 3 to 69 days (Table Temp. 2).

Summer 7 day Average Maximum Water Temp (°C)					
	ODEQ	2006		2008	
BASIN	Standard criteria	7 day avg. max	Days over criteria	7 day avg. max	Days over criteria
Controls					
C1	16	16.67	5	16.06	3
C2	16	15.41	0	15.28	0
Unbuffered					
US 2	16	17.24	36	19.19	56
LS 1	16	20.47	69	17.47*	9*
F2	18	14.56	0	18.07	2
B1	16	14.93	0	18.66	49
Buffered					
US 1	16	12.97*	0	10*	*
LS 2	16	16.21	3	18.06	70
F1	18	15.21	0	14.01	0
B2	16	14.93	0	11.8*	*

Table Temp. 2: 7 day average maximum water temperatures, pre and post season. * = incomplete data set as stream went dry sometime during the summer, and values may not include the hottest period.

In 2008 5 study and 1 control basin exceeded these criteria. The most telling point of this data set is that while the seven day average maximum temperature and/or number of days that the temperature standard was exceeded declined in both control basins, these two variables increased in all but one of the study basins (F1) for which a complete data set was collected (those basins not with an asterisk in Table Temp. 1). This suggests that fuels treatments led to increased water temperatures in the study basins during the hottest period relative to the control basins. Analysis of the paired Foots basins showed an increase in 7 day average maximum temperatures and number of exceedance days post treatment in the unbuffered treatment basin F2, while F1 showed a decline during that same period. This suggests that treatment of riparian vegetation may increase 7 day average maximum temperatures as compared with leaving buffer strips.

In whole, there is some evidence to suggest that both the buffered and unbuffered treatments may have increased both the rate at which water warmed, and the 7 day average maximum temperature in most of the study basins. The paired Foots basins appeared to be somewhat more resilient than the other basins with regard to change in warming rates, perhaps a result of more consistent flow contributed by groundwater inputs. Paired data spanning the entire summer study seasons are limited from other basins, but there is some indication that treating riparian vegetation may lead to increased warming rates and increased 7 day average maximum temperatures relative to buffering channel adjacent areas, particularly during the hottest periods of the summer.

Shade values were maintained or improved in all but one study basin and summer mean and maximum air temperatures were very similar between pre and post treatment seasons. The mechanisms by which treatments may have affected water temperature are not known. It is possible opening up of the forest understory changed microclimate conditions, leading to increased air and soil temperatures in the understory adjacent to channels, and perhaps facilitating increased warming rates, as suggested by Moore *et al*. (2005).

Given the somewhat conflicting results, the limited data sets, and the very different hydrological conditions between pre and post treatment years of this study, we are reluctant to conclusively say that post treatment differences to water temperature were attributable to the treatments (buffered vs unbuffered). However, we recommend that there is enough evidence to warrant further investigation and caution in proceeding with implementation of riparian fuels treatments, if water temperature is a management concern.

Substrate: Wildfire has been shown to increase erosion rates and sediment deposition into stream channels (Benda *et al*. 2003). Management activities, including fuel treatments may also lead to changes in aquatic substrate (Meehan 1991). Removal of vegetation and introduction of fire to the landscape may result in patches of bare ground, leaving them temporarily vulnerable to erosion (Wondzell and King 2003). Exposed particulates such as ash or fine sediment may be transported from a disturbed site downslope towards stream channels by rain or gravity. Burned areas adjacent to stream channels would have an increased likelihood of contributing sediments to channels, as a result of both proximity to the channel and lack of vegetation or surface roughness to help capture eroded and transported particulates. Highly erodible soils such as those dominated by decomposed granite would be more susceptible to disturbance than more stable soil series. Megahan *et al*. (1995) documented that prescribed fire significantly increased soil erosion rates in a granitic watershed that was helicopter logged.

Among the study basins, both of the Beaver basins drain pockets of highly erodible decomposed granitic sand, while the other basins primarily drain medi-sedimentary loamy soils (Hass 2009). Within both the Star Gulch and Foots Creek subwatersheds, Vannoy and Voorhies are the most prevalent soil series, both of which are classified as moderately erodible.

Pre and post treatment histograms by treatment group of the combined transect pebble counts are very similar (figure substrate 1 - 3). Substrate in LS1 was comprised almost entirely of tufa, a calcium carbonate deposit formed by chemical and biological precipitation from water bodies possessing a high amount of dissolved calcium. Tufa was counted as bedrock (size class > 4096 mm). Upper Star two also had a large amount of tufa, particularly in the vicinity of the upper pebble count. Beaver 1 was dominated by sand, and B2 had both high amounts of sand and a significant bedrock component. The other basins were dominated primarily by gravel sized material (9 size classes ranging from >2 mm to 64 mm).

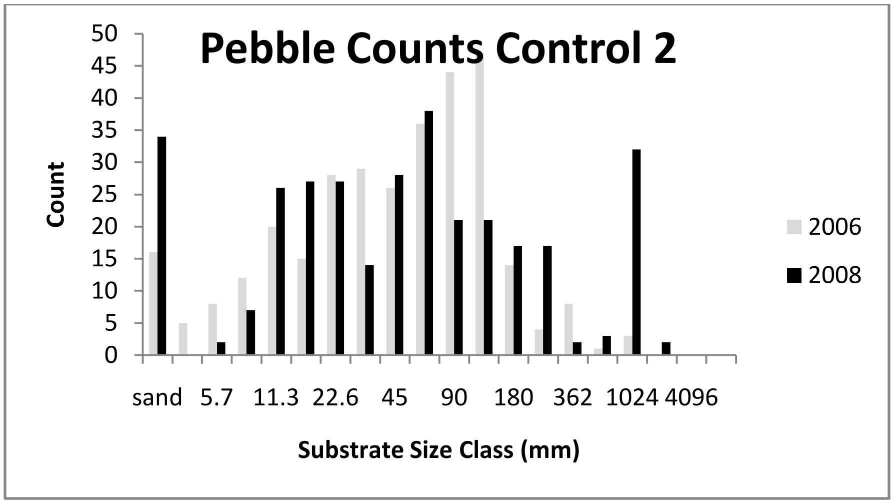


Figure Substrate1: Pebble Counts, Control 2

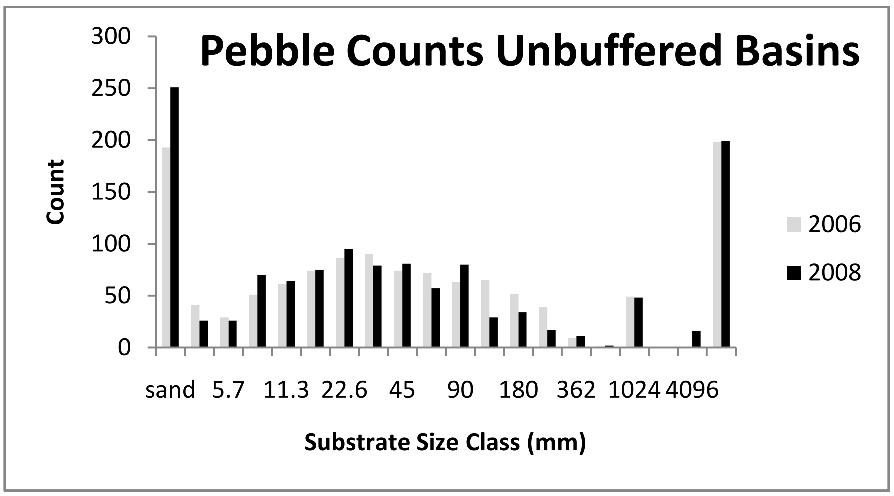


Figure Substrate2: Pebble Counts, Unbuffered Basins

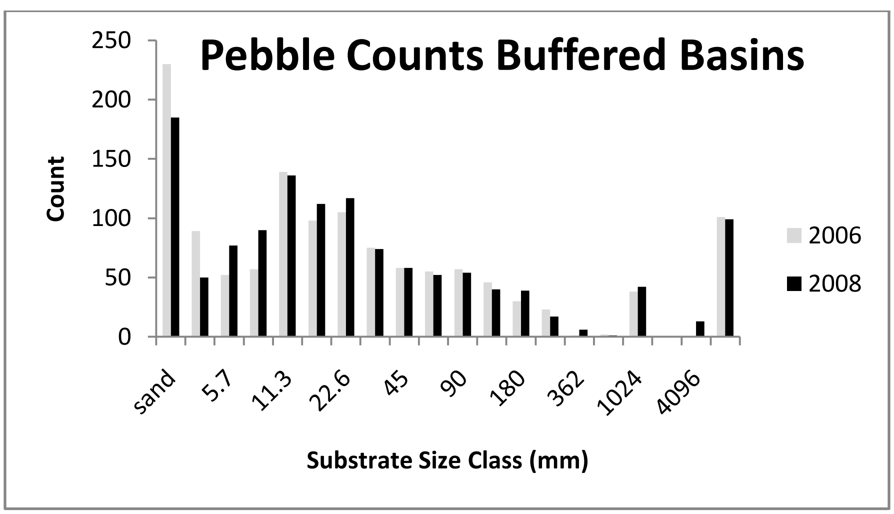


Figure Substrate 3: Pebble Counts, Buffered Basins

To determine if any changes to substrate size class within particular basins were biologically significant, cross tabulation Pearsons' Chi-square analysis was performed on the data by individual basin and study groups, as described by King and Potyandj (1993). 2 X 2 contingency tables of pebble counts were generated of grouped tallies of substrate particles lesser and greater than 6 mm in size. Substrate less than 6 mm in size is generally referred to as fine sediment, and is a widely accepted size class deemed detrimental to aquatic (particularly fish) habitat by aquatic biologists. Output results (Table Substrate 1) suggest that the only significant ($p < 0.05$) biologically detrimental post treatment change occurred in Beaver one, as determined by a reduction in substrate size (increase in fine sediment). All other frequency shifts were determined to be either insignificant or in a positive direction (reduction in frequency of fine sediment). Chi- Square statistic and significance values reported were corrected by the Yates Continuity Correction, as output was generated from a 2 X 2 contingency table, and several cells had expected frequencies less than 10%. Applying the correction did not increase the number of basins which exhibited significant changes.

Results indicate that riparian treatment increased fine sediment in B1, while its paired buffered basin (B2) showed a highly significant decrease in fine sediment frequency post treatment, though by what mechanism this may have occurred is not known. While we do not discount the possibility that treatments resulted in increased sand in B1, it is also possible that post treatment sampling efforts simply encountered more sand particles than they did pretreatment by chance. Although an unbuffered basin, riparian areas in B1 were subject to a low intensity and low severity underburn (Dejuilio, unpublished data). A large amount of vegetation, especially ground cover, remained post treatment adjacent to the stream channel. As much riparian vegetation remained on site adjacent to stream channels, it lessens the likelihood that fuels treatments would have resulted in the measured increase that was observed.

As another possible explanation, the banks adjacent to B1 are very steep, and in many areas are vertical to 3 meters above the stream channel. It was observed that repeated sampling efforts conducted along and adjacent to the stream channel in B1 resulted in trails and bank erosion in several spots as surveyors accessed the steep banks to reach specific plots and study sites. Decomposed granitic sand had been sloughed downslope and towards the stream channel in several areas. These disturbed areas could have been one factor contributing to the apparent increase in sand observed in the post treatment pebble counts. However, the channel of B2 also has steep banks and was subject to the same sampling efforts as B1, and a decrease in sand was observed in B2 post treatment.

Beaver one notwithstanding, there is no evidence suggesting riparian fuels treatments increased short term fine sediment loading to stream channels. The increase in fine sediment observed in B1 may have not resulted directly from the treatments, but given the erodible nature of the soils and steep banks present, it is easy to imagine that a moderate or high severity underburn could accelerate erosion rates in channel adjacent areas. Buffering, as applied in the very similar Beaver 2 basin, appeared to be effective as no increase in sand was observed post treatment. The geology and topography of particular basins should be taken into consideration when deciding where to implement riparian fuels treatments, where fine sediment is a management concern.

Frequency of Fine Substrate

	2006			2008			direction of change	Chi-Square	
Basin	<6mm(fine)	>6mm	Total	<6mm(fine)	>6mm	Total		Statistic	Asymptotic significance
C2	29	287	316	36	282	318	+	0.576	.448
Unbuffered	263	984	1247	303	957	1260	+	2.97	.085
US2	56	249	305	31	285	316	-	9.24	.002
LS1	32	266	298	20	278	298	-	2.67	.102
F2	55	276	331	72	259	331	+	2.49	.114
B1	128	185	313	187	128	315	+	20.69	<.0005
Buffered	371	885	1256	312	950	1262	-	7.14	.008
US1	61	272	333	60	238	298	-	0.228	.663
LS2	81	224	305	63	253	316	-	3.46	.063
F1	116	207	323	125	207	332	+	0.144	.704
B2	122	191	313	70	246	316	-	20.21	<.0005

Table Substrate 1: Frequency of fine and larger sediments and Chi-Square output. A positive direction of change indicates an increase in fine sediment (substrate size < 6mm) frequency.

Summary: Results of the hydrology component of the JFS riparian prescribed fire study suggest that fuels treatments applied in riparian areas did not measurably affect summer stream flows, electrical conductivity, or pH as compared with both conventional treatments which left riparian buffer strips, and with the no treatment control watersheds. Treatment effects, if any, on dissolved oxygen content were unclear and masked by an existing high degree of variability. Channel shade was reduced in one of the unbuffered basins, but was maintained or increased in all other basins, buffered and unbuffered alike. The loss of shade in the one unbuffered basin was a result of the high percentage of young riparian brushy species that were removed by cutting and handpiling. Buffering, as applied in the similar paired basin was effective in maintaining shade provided from brushy species. In spite of this, there was some evidence that summer water temperatures were affected by fuels treatments in most of the study basins, buffered and unbuffered alike. Both the rate at which water temperatures rose and the 7-day maximum temperatures were increased relative to the controls in most of the treatment basins. It appears buffering may reduce the effects on summer temperature to a degree, though at least two of the buffered basins also exhibited increases relative to the control basins. Substrate composition remained essentially unchanged in all but the paired Beaver study basins. The buffered Beaver 2 basin exhibited a significant decrease in fine (<6 mm) sediment post treatment, while the unbuffered Beaver 1 basin was found to have a significant increase in fine sediment. All other detected changes were insignificant or in a positive direction. We speculate that the significant increase in fine sediment in B1 may have been indicative of sample error or other disturbances that occurred in the basin, and not a direct result of the fuels treatments, but that buffers may be an appropriate mitigating measure in highly erodible basins.

Acknowledgements

Thanks to the Joint Fire Science Program for making this study possible through their generous grant funding, and to the Medford BLM managers and supervisors who supported this study and the resource commitments required to make it happen. A special thanks to the BLM Ashland Fuels Program for their cooperation and for contributing three years of their budget and professional time to implementation of the treatments, and to Tim Montfort and David Squyres for assistance with study design, for allowing us to use (abuse) their equipment, and for help in trouble shooting and interpretation of results. Thanks to Daryl Jackson, Brian Wilson, Dakota Otto, Katie Bisbee, Damiana Thompson, and Gwyn Myers for braving the yellow jackets and poison oak to collect much of the data and to Dr. Paul Hosten for advice on many things statistical. To John Alexander and Jennifer Smith for being Project Inspectors, dealing with the administrative and logistical headaches, and for keeping us focused and on track. And thanks to the many folks who offered professional advice along the way, reviewed drafts, and offered encouragement, too numerous to list. Last, but certainly not least, thanks to my co-conspirators, Jaime Stephens with the Klamath Bird Observatory, Jena Dejuilio, fire effects monitor/ecologist with Southern Oregon University /BLM, Charlie Martin, retired (or is he?) fire ecologist, Douglass Degross, formerly with the USGS, and Al Mason, BLM Ashland Fuels Specialist, for contributions of major study design components that together formed the bones of the broad JFS riparian prescribed fire study.

References:

Agee, J.K., 1993. *Fire Ecology of Pacific North-west Forests*. Island Press, Washington D.C.

Beche, L.A., Stephens, S.L., and Resh, V.H. 2005. *Effects of prescribed fire on a Sierra Nevada (California, USA) stream and its riparian zone.* Fire Ecology and Management, 218 (2005) 37-59.

Benda, L., Miller, D., Bigelow, P., and Andras, K. 2003. *Effects of Post-Wildfire Erosion on Channel Environments, Boise River, Idaho*. Forest Ecology and Management 178 (2003) 105-119.

Bisson, P.A., Rieman, B.E., Luce, C., Hessburg, P.F., Lee, D.C., Kershner, J.L., Reeves, G.H., and Gresswell, R.E. 2003. *Fire and Aquatic Ecosystems of the Western USA: Current Knowledge and Key Questions.* Forest Ecology and Management 178 (2003) 213-229.

Burkholder, K.B., Grant, G.E., Haggerty, R., Khangaonkar, T., Wampler, P.J. 2008. *Influence* of *Hyporehic Flow and Geomorphology on Temperature of a Large, Gravel Bed River, Clackamas River, Oregon, USA.* Hydrological Process (2008). 22, 941-953.

Burton, T. A., 1997. *Effects of Basin-Scale Timber Harvest on Water Yield and Peak Streamflow.* Journal of the American Water Resources Association. Vol. 33, NO. 6

Dejuilo, J.B. , in review. *Fuels treatment effectiveness and first order fire effects within small headwater stream corridors within the Rogue River Basin of Southwest Oregon.*

Dejuilo, J.B. ,i n review. *The effects of fuels treatments on headwater stream riparian vegetation within subwatersheds of the Rogue River Basin of Southwest Oregon*

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

Dunham, J.B., Rosenberger, A.E., Luce, C.H. and Reieman, B.E. 2007*. Influences of Wildfire and Channel Reorganization on Spatial and Temporal Variation in Stream Temperature and the Distribution of Fish and Amphibians.* Ecosystems (2007) 10: 335-346.

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

Everett, R., Schellhaas, R., Ohlson, P., Spurbeck, D, and Keenum, D. 2002. *Continuity in fire disturbance between riparian and adjacent sideslope Douglas-fir forests.* Forest Ecology and Management 175 (2003): 31-47.

Grabow, G.L., Spooner, J., Lombardo, L.A., Line, D. E., and Tweedy, K.L. 1998. *Has Water Quality Improved?: Use of a spreadsheet for Statistical Analysis of Paired Watershed, Upstream/Downstream and Before/After Monitoring Designs.* Prepared for the 6th National Nonpoint Source Monitoring Workshop, September 21-24, 1998, Cedar Rapids, Iowa.

Gresswell, R.E. 1999. *Fire and Aquatic Ecosystems in Forested Biomes of North America.* Transactions of the American Fisheries Society 128 (1999): 193-221.

Harr, R.D., 1976. *Forest Practices and Streamflow in Western Oregon.* USDA Forest Service General Technical Report PNW-49.

Harr, R.D., 1983. *Potential for Augmenting Water Yield Though Forest Practices in Western Washington and Western Oregon.* Water Resources Bulletin. American Water Resources Association, VOL 19, No. 3, 383-393.

Hass, T.L., 2009. Personnel communication with T. Hass, soil scientist with the Medford BLM.

King, R., and Potyandj, J. 1993. *Statistically Testing Wolman Pebble Counts: Changes in Percent Fines!* Stream Notes, USDA Forest Service. October 1993. pp.2-5.

Loftis, J.C., MacDonald, L.H., Streett, S., Iyer, H.K., and Bunte, K. 2001. *Detecting Cumulative Watershed Effects: The Statistical Power of Pairing.* Journal of Hydrology, 251 (2001) 49-64.

Mason, A. 2009. Personnel communication with BLM fuels specialist.

Mcune and Grace, 2002. *Analysis of Ecological Communities*. pp. 68-69.

Megahan, W.F., King, J.G., Seyedbagheri, K.A. 1995. *Hydrologic and Erosional responses of a Granitic Watershed to Helicopter Logging and Broadcast Burning.* Forest Science, Vol. 41, No. 4: 777-795.

Meehan, W. R., Editor. 1991. *Influences of Forest and Rangeland Management onSalmonid Fishes and their Habitats.* American Fisheries Society Special Publication 19.

Moore, R.D., Spittlehouse, D.L., and A. Story. 2005. Riparian microclimate and stream temperature response to forest harvesting – a review. J. American Water Resources Association 41:813-834.

Olsen, D. L. 2000. *Fire in Riparian Zones: A Comparison of Historical FireOccurrence in Riparian and Upslope Forests in the Blue Mountains and Southern Cascades of Oregon*. M.S. Thesis, University of Washington, Seattle, WA, USA.

Olsen, D.L. and Agee, J.K. 2005. *Historical fires in Douglas-fir dominated riparian forests of the southern Cascades, Oregon.* Fire Ecology, 1(1), 2005.

Oregon Department of Environmental Quality, 2000. *TMDL Assessment Report: Riparian Shade*.

Oregon Department of Environmental Quality, 2004. *Applegate Subbasin Total Maximum Daily Loads*, Appendix A.

Petit, N.E. and Naiman, R.J. 2007. *Fire in the Riparian Zone: Characteristics and Ecological Consequences.* Ecosystems (2007) 10: 673-687.

Rau, B.M., Chambers, J.C., Blank, R.R., and Miller, W.W., 2005. *Hydrologic Response of a Central Pinyon-Juniper Woodland to Prescribed Fire.* Riparian Ecology and Management 58:614-612.

Reeves, G.H., Bisson, P.A., Rieman, B.E., Benda, L.E. 2006. Post Fire Logging in Riparian Areas. Conservation Biology (2006).

Rieman, B, Clayton, J. 1997. *Wildfire and Native Fish: Issues of Forest Health of Sensitive Species*. Fisheries, V. 22, 11 (1997) 6-15.

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 (1996): 653-658.

Skinner, C. N., 2003. *Fire History in Riparian Reserves of the Klamath Mountains.*

Sroysaard, N., Coon, T., and Jenkins, J. 2000. *Forest Fire Effects on Benthic Invertebrate Populations.* Applied Stream Ecology, Dec. 19, 2000.

Taylor, A.H., Skinner C.N. 1998. *Fire regimes and landscape dynamics in a late-successional reserve in the Klamath Mountains, California, USA*. Forest Ecology and Management 111 (1998) 285-301.

U.S. Department of Agriculture, United States Forest Service. *Wildland Fire in Ecosystems. Effects of Fire on Soil and Water.* General Technical Report RMRS-GTR_42_Volume 4. September, 2005.

U.S. Department of Interior, Bureau of Land Management, Medford District. 1998. *Applegate-Star/Boaz Watershed Analysis*. Version 1.3.

U.S. Department of Interior, Bureau of Land Management, Medford District. 2001. *South Rogue-Gold Hill Watershed Analyses.* Version 1.1.

Wondzell, S.M. and King, J.G. 2003. *Post-Fire Erosional Processes in the Pacific Northwest and Rocky Mountain Regions*. Forest Ecology and Management 178 (2003) 75-87.