Effects of 1988 Fires on Aquatic Systems of Yellowstone National Park

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D-370

EFFECTS OF 1988 FIRES ON AQUATIC SYSTEMS OF YELLOWSTONE NATIONAL PARK

FINAL REPORT

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Date of Submission: May 1990

Covering the Period: October 1, 1989 - April 30, 1990

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ABSTRACT

Collections and measurements were made in September 1988 at 18 burn and 4 reference sites and in March 1989 at 12 of the burn and 1 of the reference sites under support from the National Science Foundation and the US Fish and Wildlife Service. These are being processed and analyzed as part of the present project. In addition, the original 22 burn and reference streams were examined again during August 1989 for comparison with conditions found just after the fire. With a few minor exceptions all of the information specified in our research proposal for September-October 1988 and August 1989 was obtained. Adverse weather conditions or "bear closures" prevented the assessment of all 22 sites in March but the data from the 12 sites that were sampled for invertebrates, periphyton, and organic matter appear to be sufficient to strongly suggest that changes in food quality due to the fire had an adverse effect on the benthic invertebrate community. Although changes in organic and sediment transport and channel and large wood conditions were noted as a result of spring snow-melt and summer rainstorm runoff, they were accompanied by only relatively minor effects on the benthic invertebrates.

INTRODUCTION

We postulate (Minshall et al. 1989, Minshall and Brock 1990) that the effects of the 1988 fires on stream ecosystems in Yellowstone National Park can be partitioned into (1) "immediate" effects arising directly from the fire (e.g., increased temperatures, altered water chemistry, abrupt change in food quality) and (2) delayed impacts resulting from the removal and eventual successional replacement of the vegetative cover. Some of these delayed effects are primarily physical disturbances associated with increased runoff. These are likely to exert their maximum impact within the first few years after the fire. In addition, longer-term alterations associated with the removal and recovery of the riparian and upland terrestrial vegetative cover and consequent alteration of food resources and retention capacity in the stream may be expected (Likens and Bilby 1982, Molles 1982, Minshall et al. 1989).

In order to determine the "immediate" effects and to provide a basis for evaluating subsequent long-term changes, samples of the stream biota and measurements of environmental conditions were obtained before and after the initial, major runoff period. We propose to repeat the measurements made during these two periods at annual intervals (each August) over the next few years in order to document conditions during the anticipated early recovery phases in the streams as the watersheds begin to mend themselves (Bormann and Likens 1979; Arno 1980; Schimpf et al. 1980; Boerner 1982; Arno and Gruell 1983; Lyon 1984; Arno et al. 1985; Stickney 1985, 1986; Waring and Schlesinger 1985; Crane and Fischer 1986). This will provide a quantitative record of the first five years following the Yellowstone megafires and permit an initial test of our hypotheses concerning the temporal responses of major stream ecosystem parameters to wildfire in Yellowstone (Minshall et al. 1989).

Information obtained from this study is critical to understanding the role of wildfires in the flowing water systems of the Park. This information will add to the scientific knowledge of the role of fire in the total ecosystem, will provide educational and interpretive information, and will be helpful in the formulation of future fire policies in the National Park system. By providing documentation of the types and magnitudes of changes in stream habitat and food producing ability, this study would better enable resource managers to: (1) make recommendations for management of fisheries in streams following fire, (2) judge the potential impact on fish habitat of wildfires versus that of prescribed burns, (3) explore the need and possibilities for stream habitat improvement after a watershed has burned, and (4) refine policies concerning fire management in national park wilderness areas.

METHODS

Based on the existing conceptual framework in stream ecology (Vannote et al. 1980, Cummins et al. 1984, Minshall et al. 1985, Minshall 1988, Resh et al. 1988) and our previous studies on the effects of wildfires (Minshall et al. 1981, in prep.), we hypothesize (Minshall et al. 1989) that major differences among streams in terms of intensity of the effect and rates of recovery from the fire will occur as a result of stream size and watershed slope and aspect. Besides affecting the timing and rate of runoff, slope and aspect significantly influence the type and density of riparian and upland vegetation. We have concentrated our efforts on streams of 1st through 4th order (Table 1) because few, if any, streams above 4th order in Yellowstone National Park were directly affected by the fires. The sites proposed for this study were selected in September 1988, through aerial and ground reconnaissance of all of the major 1988 fires in Yellowstone, in collaboration with senior staff members of the U. S. Fish and Wildlife Service (Yellowstone Office). Each burned stream type chosen is replicated at least three times to provide generality to our findings and to avoid problems arising from pseudoreplication. However, the total number of burned-stream sites studied is arbitrarily limited to 18 to meet time and budget constraints.

The thrust of this study is to examine hypotheses relating to stream ecosystem behavior in the early stages of recovery from fire. We have centered on changes in the structure of the biotic community and food resources, in chemical composition of the water (including potentially limiting nutrients), and in physical habitat conditions. Focus is on the measurement of producer (algae) and consumer (mainly invertebrate) standing crops and general chemical properties (alkalinity, hardness, specific conductance, pH) and major nutrient (PO_4, NH_4, NO_3) constituents of the water. These serve as indices of the responses of stream ecosystems to fire. However, general environmental features (temperature, discharge, current velocity, substratum composition) also are being characterized. In addition, five permanent channel cross-section transects and photopoints are resurveyed each year.

Our sampling protocol (Table 2) is dictated by several considerations. First, we have concentrated on factors which provide both a measure of the immediate impact (first 12 months) and a basis for subsequent study of the long-term responses of streams to fire. Second, methods were required which could be put into effect relatively quickly without a great deal of additional preparation or planning. Initial sampling, in autumn 1988, had to be completed in a short period of time (no more than a half day per site) in order to permit sampling of all sites before adverse weather altered conditions or closed off access to the sites. Also, the methods cannot require a great deal of

TABLE 1. STREAM RESEARCH SITES FOR YELLOWSTONE NATIONAL PARK WILDFIRE STUDY (SONYEW = System of Numbering Yellowstone Waters (Mahony and Lentsch 1986); UTM = Universal Mercator Map coordinate system)

STREAM	ORDER	SONYEW	COORDINATES	UTM
		BURNED WATERSHEDS		
BLACKTAIL CREEK-WFK	1B	1017-22	110'35";44'53"	4973.1N, 532.8E
BLACKTAIL CREEK-EFK	1B	101705	110'35";44'53"	4973.5N, 534.3E
CACHE (noname)	1B	1033221001	110'03";44'51"	4966.3N, 575.8E
FAIRY CREEK	1B	20180803	110'52";44'32"	4930.3N, 511.7E
TWIN CREEK	1B	103323	110'10";44'48"	4962.3N, 567.5E
BLACKTAIL CREEK-MAIN	2B	1017-21	110'35";44'53"	4975.9N, 533.5E
CACHE (noname) UPPER	2B	10332210	110'05";44'49"	4966.5N, 573.9E
CACHE (noname) LOWER	2B	10332206	110'05";44'50"	4964.0N, 572.0E
FAIRY CREEK	2B	201808	110'51";44'33"	4930.9N, 511.0E
IRON SPRINGS CREEK	2B	20181604	110'52";44'26"	4921.7N, 511.2E
CACHE CREEK	3B	103322-22	110'04";44'51"	4965.5N, 573.2E
HELLROARING CREEK	3B	1026-22	110'23";45'10"	5001.7N, 548.6E
IRON SPRINGS CREEK	3B	201816	110'51";44'27"	4922.8N, 511.7E
LAVA CREEK	3B	100705	110'38";45'56"	4976.0N, 529.7E
SOUTH CACHE CREEK	3B	10332208	110'04";44'50"	4965.2N, 573.3E
CACHE CREEK	4B	103322-21	110'05";44'50"	4965.0N, 572.7E
HELLROARING CREEK	4B	1026-21	110'23";45'09"	5000.2N, 548.4E
LAMAR RIVER	4B	1033-22	110'08";44'48"	4962.5N, 567.6E
		UNBURNED WATERSHEDS		
AMPHITHEATER CREEK	2	10331714	110'04";44'56"	4974.3N, 571.9E
ROSE CREEK	2	103312	110'13";44'54"	4972.0N, 561.2E
PEBBLE CREEK	3	10331713	110'07";44'56"	4976.0N, 570.0E
SODA BUTTE CREEK	4	103317	110'10";44'52"	4968.5N, 565.7E

Table 2. SUMMARY OF VARIABLES, SAMPLING METHODS, AND ANALYTICAL PROCEDURES FOR EVALUATING THE EFFECTS OF WILDFIRE ON STREAM ECOSYSTEMS

VARIABLE	SAMPLE TYPE	SAMPLING METHOD	ANALYTICAL METHOD	REFERENCE
A. Physical				
1. Temperature (C)	P	Maximum-Minimum recording thermometers.	Direct Observation	
2. Discharge (m^3/s)	T	Velocity-depth profiles.	Calculation: Q=W•D•V; where W=width, D=mean depth, and V=velocity.	Bovee and Milhous 1978
Width (0.1m)	P	Nylon-reinforced meter tape.	Determine width of water and bankful width.	Buchanan and Somers 1969
Depth (0.1m)	T	Meter stick.	Determine water and bankful depths at sufficient intervals to give a good estimate of the mean. No more than 10% of flow should pass between measurements.	
Velocity (0.1m/s)	T	Small Ott C-1 current meter.	Determine velocities at 0.6 x depth (from the surface) at sufficient intervals to give a good estimate of the mean. No more than 10% of the flow should pass between measurements. Estimate bankful velocities from Manning's equation.	Gregory and Walling 1973
3. Channel Gradient (%)	P	Inclinometer.	Measure water surface elevations over extended (150m) lengths upstream and downstream of the discharge transect.	
B. Chemical	P	"Grab" samples from center of stream.		
1. Alkalinity (mg/l)			Gran (in waters <40mg/l alkalinity) or methyl orange titration.	Talling 1973 APHA 1989
2. Hardness (mg/l)			EDTA titration.	APHA 1989
3. Specific Conductance (µmhos)		Determine in the field.	Temperature compensated portable YSI meter. Estimate total dissolved solids using standard conversion factor.	APHA 1989
C. Biological				
1. Periphyton	P/R	Collect samples from five separate cobblestones. Remove material from known area. Brush and rinse three times following prescribed technique. Collect material from each rock on a separate pre-combusted, tared, glass-fiber filter (Whatman GFF).	Acetone extraction of chlorophyll followed by spectrophotometric assay with correction for phaeopigments. Recombine acetone with sample and evaporate to dryness. Determine AFDM as described below.	Stockner and Armstrong 1971 Lorenzen 1966
2. Benthic invertebrates	P/R	Surber sampler fitted with 250 µm mesh net. Collect 5 samples per site in proportion to principal habitat types. Disturb substratum to depth of 10cm, remove all organic matter from larger inorganic particles, preserve in 5% formalin.	Separate invertebrates by species, count, dry at 60C, and weigh. Determine population densities and biomass, species richness, dominance, diversity, and functional feeding group composition.	Platts et al. 1983 Merritt and Cummins 1984
3. Benthic organic matter	P/R	Recover from Surber samples described above.	Estimate percent composition of various plant components (including charcoal) dry at 60C, ash at 550 °C, determine total AFDM.	

P = point sample
R = random throughout a defined lineal reach
T = transect across stream

bulky equipment since most of the sites are in remote backcountry areas reached by helicopter (Fall 1988) or on foot.

Most of our methods (Table 2) are routine in stream ecology and are described in detail in standard reference sources (Weber 1973, Greeson et al. 1977, Lind 1979, Merritt and Cummins 1984, APHA 1989). Further details are provided in the references in Table 2. Methods for sampling invertebrates are described in detail by Platts et al. (1983). Procedures for sample analysis also are outlined in Table 2. In addition to total standing crops, the algal and invertebrate communities were examined in terms of species richness, dominance, and diversity and the invertebrates were evaluated in terms of principal functional feeding groups (Merritt and Cummins 1984, Cummins and Wilzbach 1985)and the top five taxa.

Maps were drawn within specified reaches of study streams to evaluate the importance of woody debris on channel stability and retention. Woody debris was considered to be any piece of wood greater than two cm in diameter and over 30 cm in length. Within the 200 m study section two 50 m reaches (generally between the first and second transects and between the fourth and fifth transects) were mapped. In October 1988 and in August 1989, all wood within the bankfull channel in each reach was mapped according to each pieces' relation to the channel and to other pieces of wood (see Platts et al. 1987 for a more complete description). The diameter and length of each piece of wood was measured and tabulated. Copies of the 1988 maps were taken into the field in 1989 and an attempt was made to relocate all pieces of wood. Many pieces were not found in 1989, we assumed these pieces had moved from 1988 positions. New wood in the stream reaches was measured and added to the 1989 maps.

The information from the maps was analyzed by counting the number of pieces of wood per reach in each year, the number of pieces lost from their original position, and the number of pieces gained in each 50 m study reach. Some wood that was lost or gained may only have moved a short distance, but because this measure is an index of stream stability all moved pieces were considered lost or gained from their original position. The burn and reference streams were grouped by stream order, which separated the effect of watershed condition as well as stream size on the woody debris dynamics.

RESULTS

Channel Morphology

Cross-section Profiles

Five cross-section profiles, 50m equidistant, were completed at each site at permanent transects in October 1988 and August 1989.

Representative profiles from each site by stream order are presented in this report as Figures 1-4. Spring runoff in 1989 was below normal in Yellowstone National Park because of low snow accumulation during the winter. Most changes observed in channel profiles were from sites that are of high gradient. For example, 1st order sites of Twin Creek and West Fork Blacktail Deer Creek showed increases in channel depth between 1988 and 1989, while Fairy Creek, a low gradient system showed no change in channel depth between 1988 and 1989 (Figure 1).

The 2nd order burn streams displayed essentially this same pattern with high gradient systems, e.g. Upper Cache Creek and Lower Cache Creek, showing increases in channel depth from 1988 to 1989. Indeed, Upper Cache Creek apparently scoured until reaching bedrock. Low gradient burn sites, e.g. Fairy Creek, again showed no change in channel form from 1988 to 1989, as with the two reference sites, Amphitheater and Rose Creek (Figure 2).

Little change occurred in channel profiles of 3rd order burn or reference streams, although Cache Creek increased in channel depth from 1988 to 1989 (Figure 3). In addition, 3rd order Hellroaring Creek experienced channel cutting and movement that was not evident in the channel profiles from 1988 to 1989. As with 3rd order sites, most 4th order sites displayed little change in channel form from 1988 to 1989. However, 4th order Hellroaring Creek increased somewhat in channel depth from 1988 to 1989 (Figure 4).

Channel Gradient

In most cases, % slope remained unchanged between October 1988 and August 1989 among both burned and reference study sites, but tended to be lower in 1989 for 1st order burn sites (Table 3). For example, both East Fork Blacktail Creek and Lower Cache Creek study sites showed a 3 % reduction in slope from October 1988 to August 1989. Aerial photos may provide a better measure of temporal slope change by enhancing spatial resolution.

Woody Debris Dynamics

Woody debris is important in structuring stream systems and maintaining channel stability over long periods of time (>200 years)(Keller and Tally 1979), as well as being important in reducing water velocities and acting as sediment traps (Megahan 1982). Large pieces of wood in stream channels are important in retaining much of the food base for macroinvertebrates (Likens and Bilby 1982), and the removal of debris can increase organic matter export by up to 632% (Bilby and Likens 1980). Following wildfire, an increase in total run-off and in peak flow discharge occurs (Bolin and Ward 1987), thus we are studying how this increase affects channel stability and retention by quantifying

Figure 1.

The effects of forest fire on stream morphology in Yellowstone National Park.

Representative cross-sections of 1st order streams.

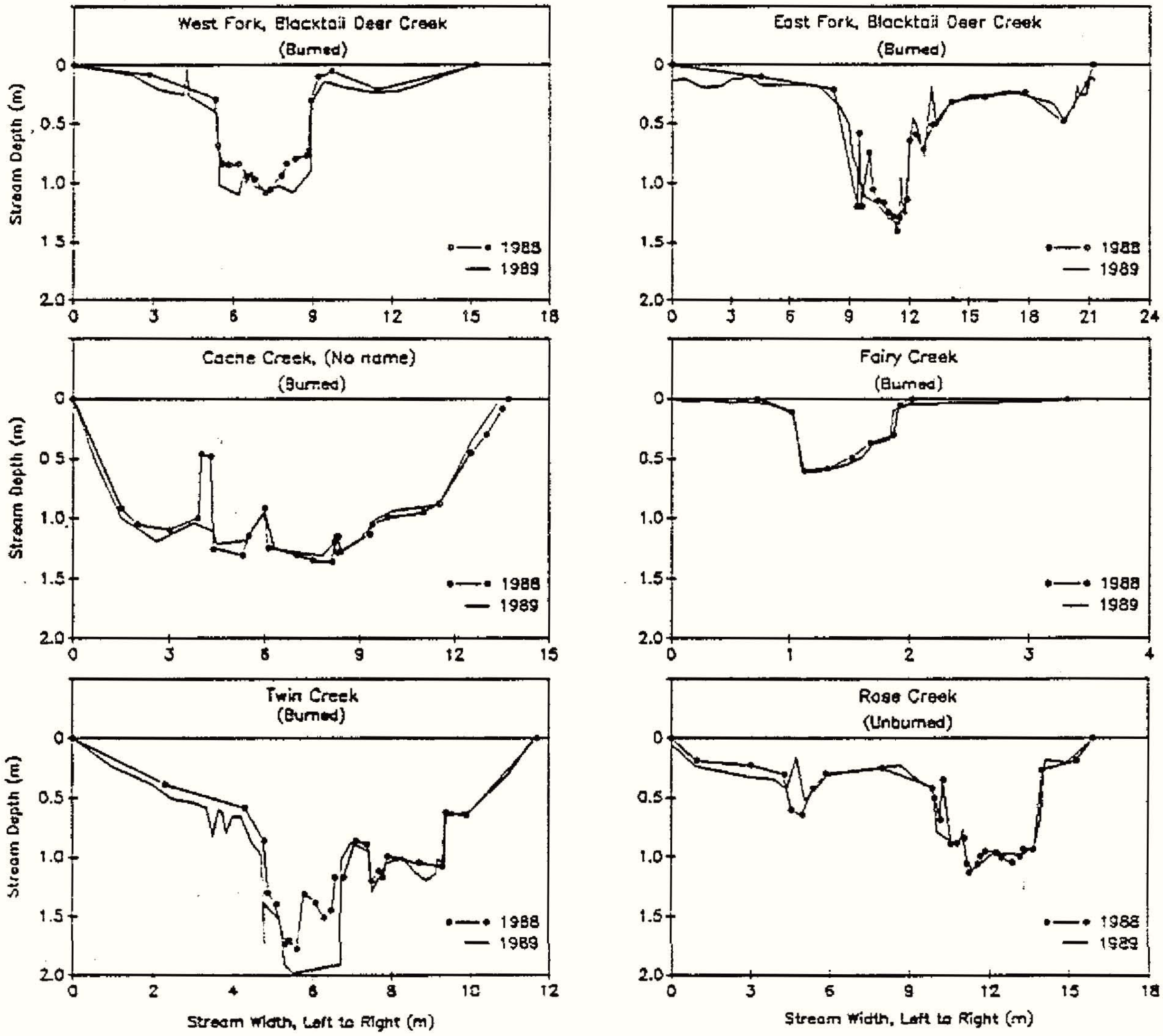

Figure 2.

The effects of forest fire on stream morphology in Yellowstone National Park.

Representative cross-sections of 2nd order streams.

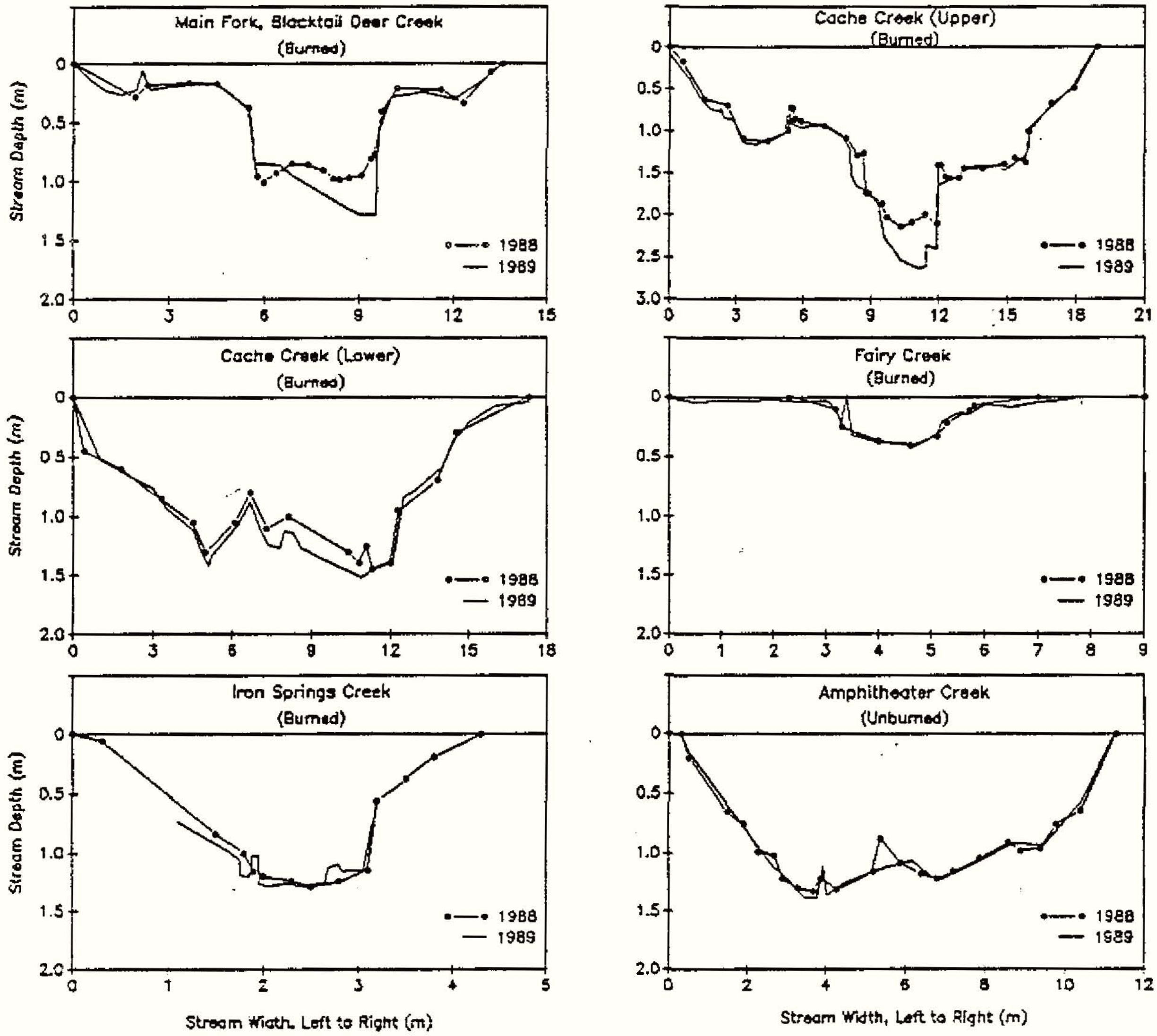

Figure 3.

The effects of forest fire on stream morphology in Yellowstone National Park. Representative cross-sections of 3rd order streams.

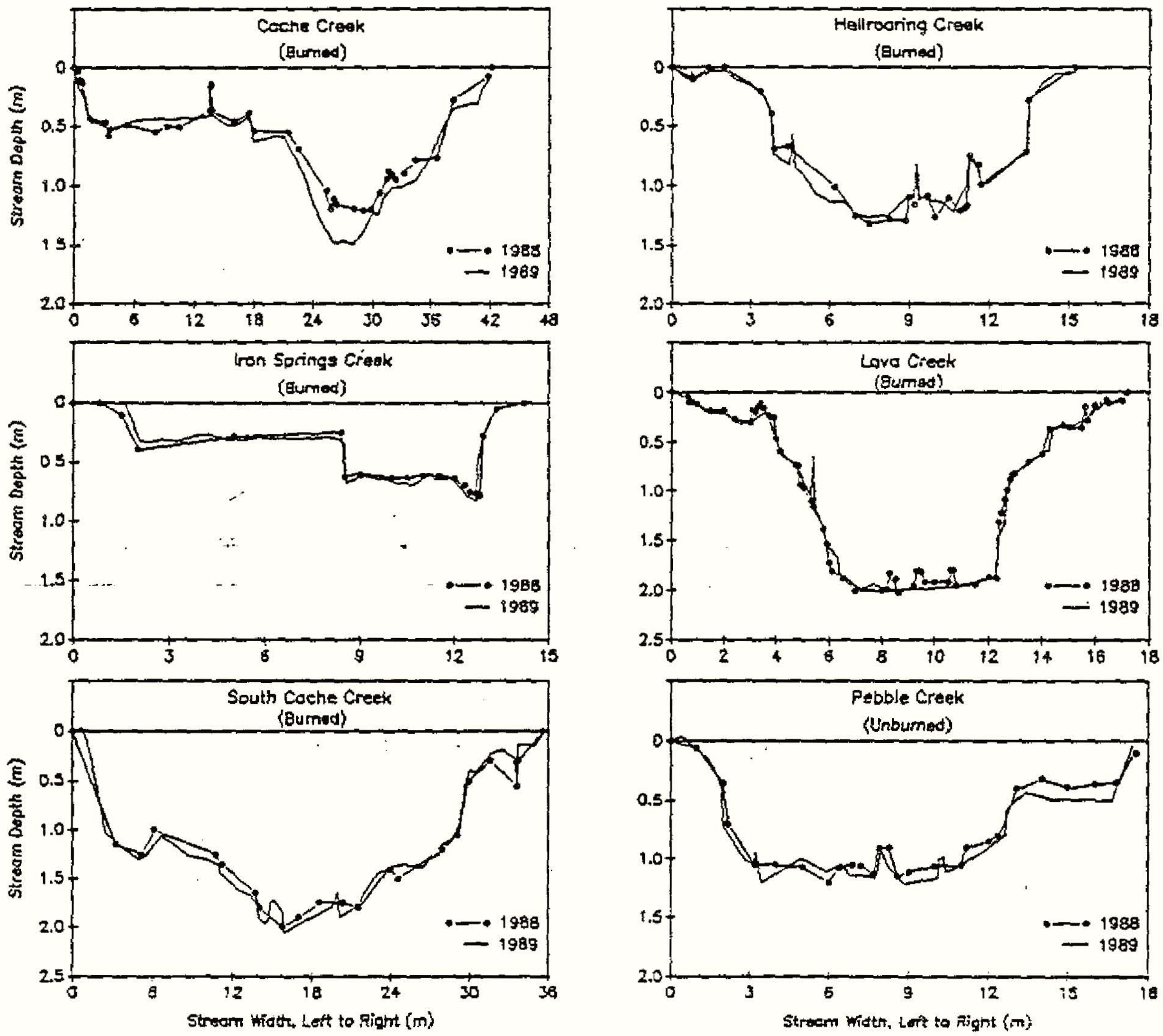

Figure 4.

The effects of forest fire on stream morphology in Yellowstone National Park.
Representative cross-sections of 4th order streams.

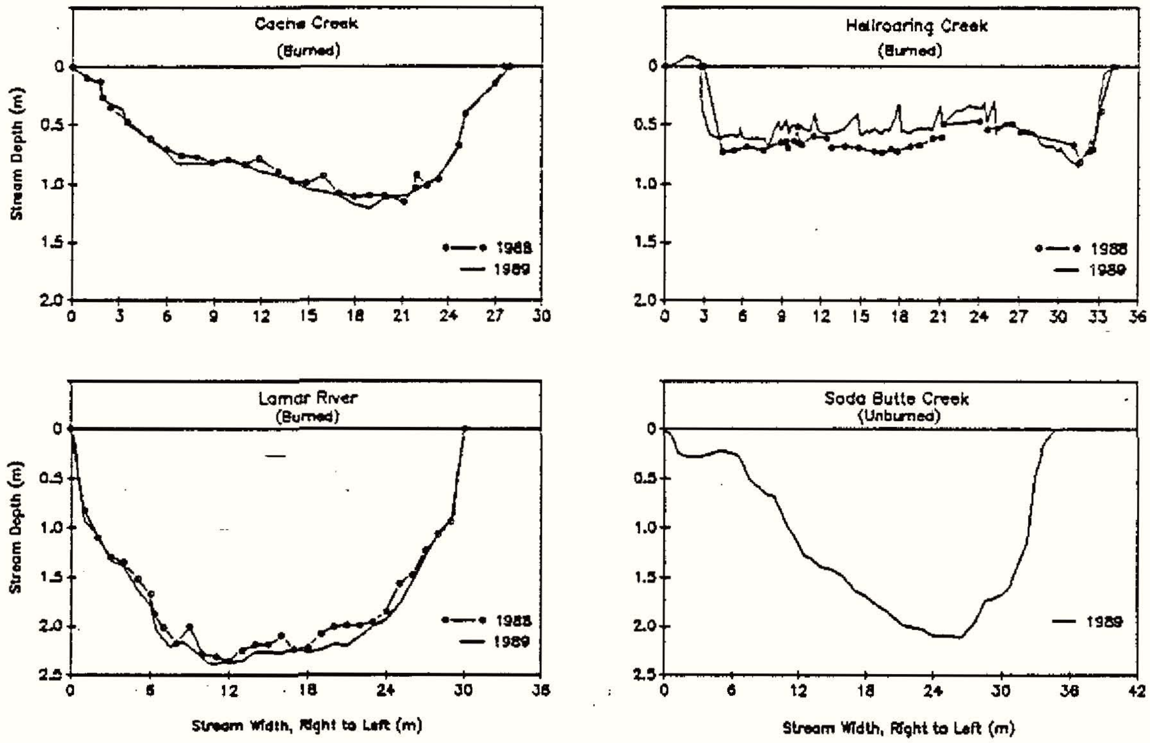

Table 3. Selected channel characteristics, discharge, and slope for the Yellowstone National Park Fire Study sites.

Stream	Order	Date	bankfull channel area (m^2)	SD *	baseflow water width (m)	SD	Q baseflow (m /s)	Q bankfull (m /s)	slope %
Burned Sites									
Blacktail, E. Fork	1	11/88	5.50	1.40	2.20	0.61	0.028	1.116	7
		8/89	5.68	1.32	2.05	0.26	0.050	2.433	4
Blacktail, W. Fork	1	11/88	5.91	1.46	2.70	1.18	0.031	1.090	2
		8/89	6.76	1.86	3.39	0.99	0.020	0.782	3
Upper Cache	1	11/88	15.57	1.92	1.04	0.34	0.001	9.471	13
		8/89	14.87	1.89	1.12	0.45	0.003	7.334	10
Fairy	1	11/88	0.80	0.48	1.58	1.26	0.054	0.465	1
		8/89	1.07	0.52	1.06	0.29	0.050	0.577	1
Twin	1	11/88	11.38	6.56	0.20	2.84	1.230	1.633	11
		8/89	9.97	5.61	3.40	0.97	0.020	1.422	10
Lower Cache	2	11/88	12.78	2.02	1.78	0.47	0.012	16.458	9
		8/89	13.04	2.52	2.23	0.84	0.010	15.937	8
Upper Cache	2	11/88	27.76	5.58	2.00	0.58	0.004	16.280	10
		8/89	30.15	6.27	1.81	0.88	0.010	19.103	10
Fairy	2	11/88	1.52	0.65	2.16	0.49	0.092	0.230	0
		8/89	1.55	1.14	2.36	0.48	0.050	0.188	0
Iron Springs	2	11/88	7.62	4.21	1.52	0.43	0.065	6.706	14
		8/89	7.51	4.35	1.47	0.40	0.030	6.228	13
Blacktail Main	2	11/88	7.08	2.92	2.90	0.43		4.466	
		8/89	7.33	3.49	2.91	0.53	0.32	4.539	3
Cache	3	11/88	50.85	25.22	9.72	3.13	0.184	24.560	1
		8/89	52.00	20.89	13.77	6.87	0.520	26.384	2
Hellroaring	3	11/88	11.81	2.31	5.08	1.74	0.381	11.841	3
		8/89	12.58	2.56	6.05	1.49	0.330	11.095	2
Iron Springs	3	11/88	4.61	1.78	4.20	0.61	0.656	2.066	1
		8/89	4.44	1.46	4.43	0.42	0.230	2.041	1
South Cache	3	11/88	28.28	11.49	7.32	5.73	0.028	10.337	3
		8/89	27.69	12.06	7.64	2.32	0.160	7.776	3
Lava	3	11/88	15.38	5.73	8.88	3.85	0.620	24.129	2
		8/89	15.48	5.78	7.23	1.17	1.180	26.435	2
Cache	4	11/88	22.54	3.08	11.84	1.58	0.336	46.315	2
		8/89	22.20	2.21	14.26	2.05	0.960	38.060	1
Hellroaring	4	11/88	17.91	4.71	7.68	2.87	0.067	8.047	2
		8/89	16.62	4.68	11.55	4.97	0.480	7.312	2
Lamar	4	11/88	62.53	10.57	16.78	2.98	0.581	101.503	1
		8/89	59.96	9.78	21.45	2.17	3.440	66.750	1
Reference Sites									
Amphitheater	2	11/88	12.61	4.05	2.83	0.51	0.077	9.821	6
		8/89	14.39	5.35	5.15	1.90	0.140	14.387	5
Rose	2	11/88	6.39	1.59	2.06	0.96	0.009	1.614	8
		8/89	6.21	1.34	2.31	0.76	0.020	1.544	8
Pebble	3	11/88	10.95	2.36	7.46	2.12	0.225	6.523	3
		8/89	11.18	2.49	8.23	1.72	0.300	5.591	2
Soda Butte	4	11/88	NA	NA	NA	NA	NA	NA	NA
		8/89	34.46	7.28	14.77	1.37	2.370	36.560	1

* n=5 for all measurements except: Twin Creek 1988, E.F. Blacktail Creek 1988, W.F. Blacktail Creek 1988, and Lamar River 1989 (n=4).

woody debris dynamics.

A map from lower second order Cache Creek (Fig. 5) provides an example of the change in woody debris between 1988 and 1989. Some of the wood could be relocated in 1989 downstream of the original position (see asterisk in both reaches). From these maps the total number of pieces per year was found and presented in Figure 6A. All streams in burn and reference watersheds showed no change or an increase from 1988-9, except for the second order burn sites which decreased slightly. Although Figure 6A shows the net change between 1988-9, net change doesn't give any idea of actual stability, which we index by gross change (the sum of pieces gained and pieces lost).

In each stream order more change occurred in the burn streams than in reference streams, which is especially obvious in the third order streams (Figure 6B). No first order reference streams were studied. The same piece of wood was present in both years in the 4th order reference stream which was Soda Butte Ck.

The range of gross change was greater in burn streams compared to reference streams. For example, gross change ranged from 5-35 devices moved in 2nd order burn streams, while in 2nd order reference streams the range was from 5-20 devices moved. In 3rd order burn streams the range in gross change was 21-41 devices moved, while in 3rd order reference streams the range was 8-13 devices moved. In 4th order burn streams gross change ranged from 5-34, while no devices were lost or gained in 4th order reference streams.

Flow

Discharge

Discharge was characterized in respect to baseflow and bankfull water conditions. Baseflow discharge was calculated from water conditions at the time of sampling. Bankfull discharge was calculated using the Manning's equation for estimating bankfull velocities and measurements of bankfull channel width and bankfull water depth (Tables 2,3). Discharge was calculated in October 1988 and again in August 1988 at permanent transects. Baseflow discharge was similar between the two sampling periods in both burn and reference sites. Annual differences in baseflow discharge at a site are likely the result of annual recharge patterns. Changes in bankfull discharge indicate changes in channel form and runoff conditions. Bankfull discharge was substantially greater in over 65% of the burn streams in 1989 than in 1988, whereas bankfull discharge was essentially unchanged in reference streams (Table 3).

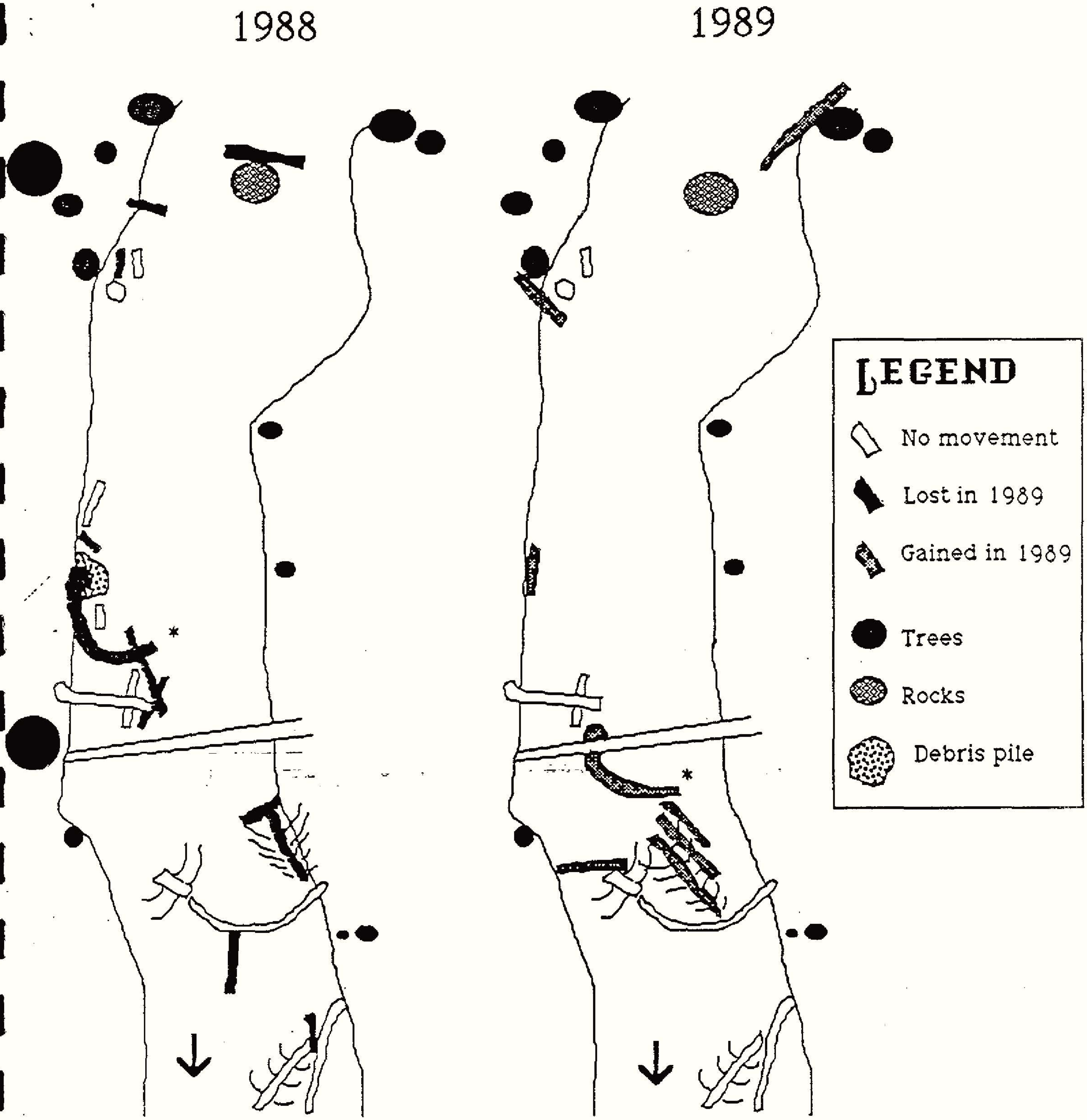

Figure 5. A representative map of a stream reach in 1988 and 1989 for Lower Second Order Cache Ck. This comparison shows changes in total number of pieces of wood, gain of wood to a particular location, and losses of wood from the 1988 location.

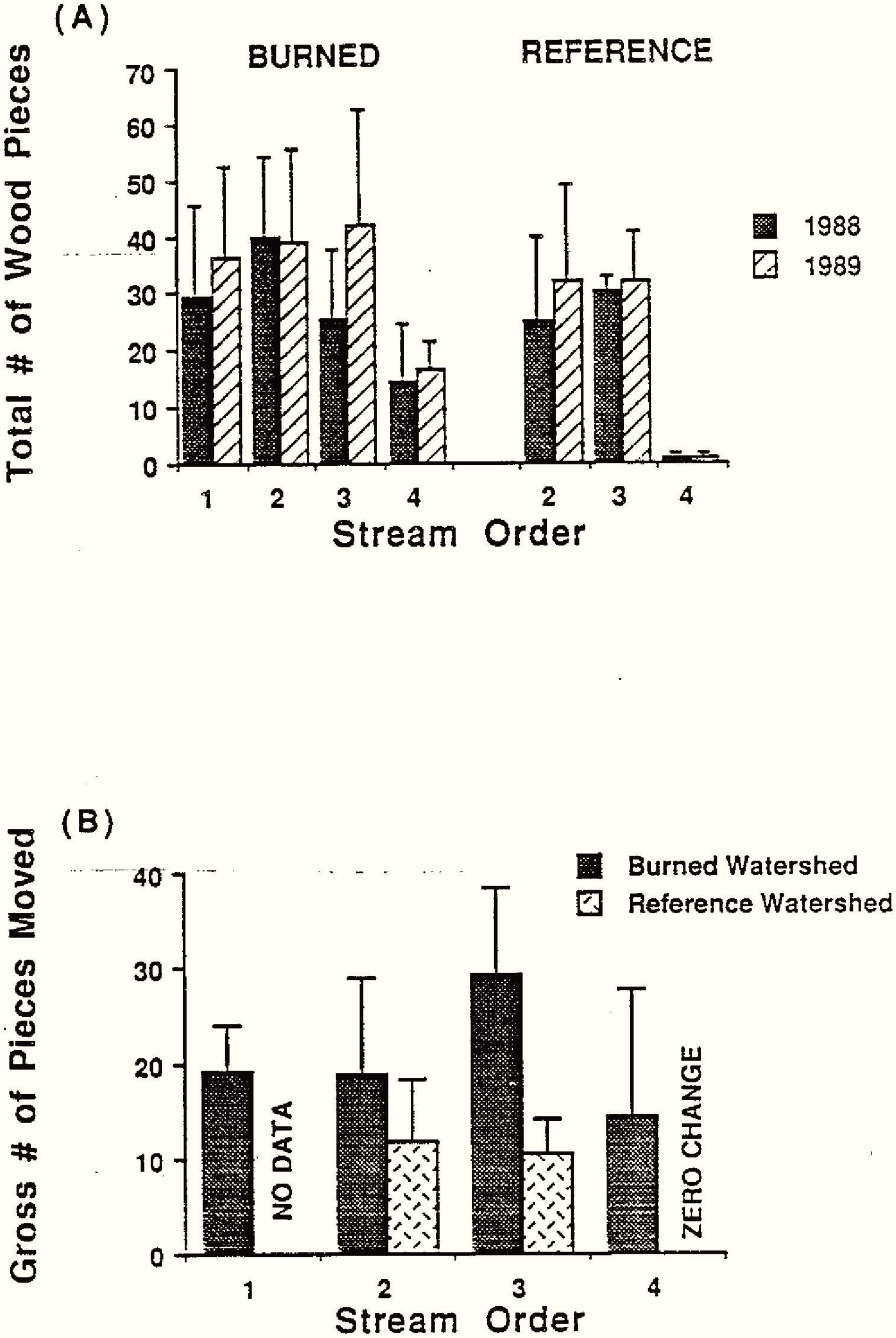

Figure 6. (A) Total number of pieces of wood in 1988 and in 1989 for burned and reference watershed streams of different order. (B) Gross change (total lost added to total gained) in number of pieces of wood in burned and reference watershed streams of stream order 1-4. Error bars are standard deviations in both graphs.

Water Velocity and Depth

Stream bottom velocities and water depth were recorded at 100 random locations at each study site in October 1988 and August 1989. Mean bottom velocities were higher in 1989 than in 1988 in about 90% of the burn streams and 50% of the reference streams (Table 4). Mean water depth also tended to be greater in 1989 than in 1988 in burn and reference streams. The coefficient of variation provides an indication of the amount of variation (heterogeneity) observed among samples. Coefficients of variation for water velocity were lower in 1989 than in 1988 for burn sites, but were similar between years in reference streams indicating a reduction in the heterogeneity of water flow in the burn streams (Table 4). Coefficients of variation for water depth were similar between years in burn and reference streams.

Substratum

Particle Size

Substratum particle size and heterogeneity of particle sizes may play important roles in the distribution and structure of macroinvertebrate communities and populations (Minshall 1984). Three axes of 100 randomly chosen substrate particles were measured at each study site in October 1988 and August 1989. Simple linear regressions were performed against individual axes to determine whether a single axis measurement was sufficient for the analysis. All regressions proved to be highly significant indicating a single axis for each substrate measured is adequate for analysis (Figure 7). Coefficients of variation then were calculated for the x-axis substrate measure to indicate changes in substrate heterogeneity at a site between sampling periods. Mean particle size tended to be smaller in 1989 than in 1988 in the 1st, 2nd, and 3rd order burn streams (Table 4). Similar mean substrate sizes were found in the 4th order burn sites and all reference sites. Coefficients of variation either increased or decreased from 1988 to 1989 in the burn sites, whereas coefficients of variation decreased in all reference sites (Table 4). Changes in substrate size and composition due to fire may be a function of local geology.

Embeddedness

Embeddedness refers to the degree of interstitial filling of the substratum by fine particles. High values of embeddedness indicate a loss of habitat for macroinvertebrate and fish populations due to a reduction in benthic pore space and substrate heterogeneity. Embeddedness was measured at 100 random locations at each site in October 1988 and August 1989. Mean embeddedness values decreased in all 1st order burn sites in

Table 4. Mean velocities, depths, and substrate x-axes with respective coefficients of variation (CV) for the Yellowstone National Park Fire Study Sites.

Stream	Order	Date	n	velocity (m/s)	CV velocity	depth (cm)	CV depth	x axis (cm)	CV x axis
Burned Sites									
Blacktail, E. Fork	1	11/88	100	0.15	1.88	15.2	0.67	18.0	1.19
		8/89	100	0.26	0.89	11.9	0.66	13.7	1.51
Blacktail, W. Fork	1	11/88	100	0.17	1.16	13.0	0.65	12.6	1.45
		8/89	100	0.16	0.83	14.4	0.59	14.2	1.18
Lower Cache	1	11/88	108	0.04	1.02	6.2	0.64	10.7	1.34
		8/89	100	0.15	0.88	3.8	0.68	5.5	1.90
Fairy	1	11/88	100	0.25	0.57	21.4	0.55	0.8	2.04
		8/89	100	0.29	0.46	22.6	0.41	1.2	1.63
Twin	1	11/88	100	0.11	1.83	12.1	0.77	21.5	1.03
		8/89	100	0.21	1.44	15.6	0.66	18.8	0.72
Blacktail, Main	2	11/88	100	0.18	1.11	11.3	0.58	18.1	0.88
		8/89	100	0.33	0.72	18.4	0.72	16.5	0.74
Lower Cache	2	11/88	86	0.11	1.46	9.1	0.57	10.8	1.05
		8/89	100	0.16	0.84	8.9	0.63	8.1	1.26
Upper Cache	2	11/88	100	0.07	1.59	7.2	0.61	8.7	0.89
		8/89	100	0.21	0.77	7.3	0.66	6.5	1.59
Fairy	2	11/88	100	0.22	0.56	16.0	0.67	0.9	2.03
		8/89	50	0.26	0.64	22.6	0.36	0.64	0.64
Iron Springs	2	11/88	100	0.39	0.81	10.4	0.52	11.5	2.03
		8/89	50	0.37	0.78	12.6	0.46	5.0	1.77
Cache	3	11/88	100	0.14	0.88	18.4	0.70	16.4	1.25
		8/89	100	0.29	0.85	21.3	0.66	13.1	0.84
Hellroaring	3	11/88	99	0.12	1.17	14.3	0.59	15.2	0.77
		8/89	100	0.37	0.74	21.2	0.41	12.4	0.92
Iron Springs	3	11/88	100	0.48	0.44	26.3	0.40	11.7	2.92
		8/89	50	0.67	0.45	29.3	0.30	9.78	2.44
South Cache	3	11/88	100	0.13	1.21	14.9	0.46	10.1	0.57
		8/89	100	0.22	0.89	16.8	0.51	13.5	0.81
Lava	3	11/88	100	0.44	0.60	21.0	0.50	57.2	1.24
		8/89	100	0.64	0.62	25.2	0.40	16.7	0.92
Cache	4	11/88	100	0.21	0.80	10.9	0.39	14.0	0.50
		8/89	100	0.23	0.62	19.9	0.41	15.7	0.77
Hellroaring	4	11/88	100	0.10	1.40	17.2	0.83	13.5	0.69
		8/89	100	0.32	0.68	23.8	0.58	12.5	2.36
Lamar	4	11/88	*	0.21	0.92	30.4	0.39	16.0	0.72
		8/89	100	0.23	0.80	34.3	0.49	21.9	0.73
Reference Sites									
Amphitheater	2	11/88	100	0.29	0.78	10.4	0.66	16.4	1.28
		8/89	100	0.27	0.82	15.0	0.78	15.4	1.10
Rose	2	11/88	100	0.14	1.36	9.2	0.51	11.7	0.91
		8/89	100	0.17	0.85	10.6	0.51	11.4	0.78
Pebble	3	11/88	50	0.19	0.87	16.9	0.49	20.0	1.01
		8/89	100	0.38	0.84	18.1	0.54	22.4	0.87
Soda Butte	4	11/88	NA	NA	NA	NA	NA	NA	NA
		8/89	100	0.39	0.63	29.3	0.41	9.0	0.72

* n=34 for velocity, n=99 for other measures

Table 5. Mean percent embeddedness of substrate particles with respective coefficients of variation for the Yellowstone National Park sites.

Stream	Order	Date	n	Mean embedded	Std err embedded	CV embeddedness
Burned Sites						
Blacktail, E. Fork	1	11/88	100	0.68	0.035	0.52
		8/89	100	0.22	0.026	1.21
Blacktail, W. Fork	1	11/88	100	0.46	0.036	0.77
		8/89	100	0.19	0.026	1.41
Lower Cache	1	11/88	108	0.38	0.031	0.85
		8/89	100	0.15	0.024	1.66
Fairy	1	11/88	100	0.85	0.028	0.33
		8/89	100	0.61	0.041	0.68
Twin	1	11/88	100	0.53	0.027	0.51
		8/89	100	0.42	0.034	0.81
Blacktail, Main	2	11/88	100	0.42	0.027	0.64
		8/89	64	0.36	0.039	0.87
Lower Cache	2	11/88	86	0.47	0.036	0.71
		8/89	100	0.33	0.035	1.06
Upper Cache	2	11/88	100	0.21	0.026	1.25
		8/89	100	0.30	0.035	1.15
Fairy	2	11/88	100	0.83	0.028	0.34
		8/89	50	1.00	0.000	0.00
Iron Springs	2	11/88	100	0.50	0.040	0.80
		8/89	50	0.12	0.040	2.31
Cache	3	11/88	100	0.24	0.027	1.08
		8/89	100	0.38	0.036	0.97
Hellroaring	3	11/88	99	0.30	0.031	1.04
		8/89	100	0.30	0.036	1.18
Iron Springs	3	11/88	100	0.32	0.030	0.76
		8/89	50	0.40	0.065	1.15
South Cache	3	11/88	100	0.25	0.027	1.05
		8/89	100	0.32	0.033	1.03
Lava	3	11/88	NA	NA	NA	NA
		8/89	100	0.35	0.030	0.87
Cache	4	11/88	100	0.38	0.025	0.66
		8/89	100	0.41	0.034	0.83
Hellroaring	4	11/88	100	0.21	0.027	1.28
		8/89	100	0.18	0.026	1.44
Lamar	4	11/88	99	0.32	0.029	0.91
		8/89	100	0.48	0.028	0.57
Reference Sites						
Amphitheater	2	11/88	100	0.38	0.031	0.82
		8/89	100	0.37	0.031	0.85
Rose	2	11/88	100	0.37	0.029	0.79
		8/89	100	0.35	0.030	0.85
Pebble	3	11/88	50	0.47	0.054	0.81
		8/89	100	0.40	0.031	0.79
Soda Butte	4	11/88	NA	NA	NA	NA
		8/89	100	0.42	0.034	0.80

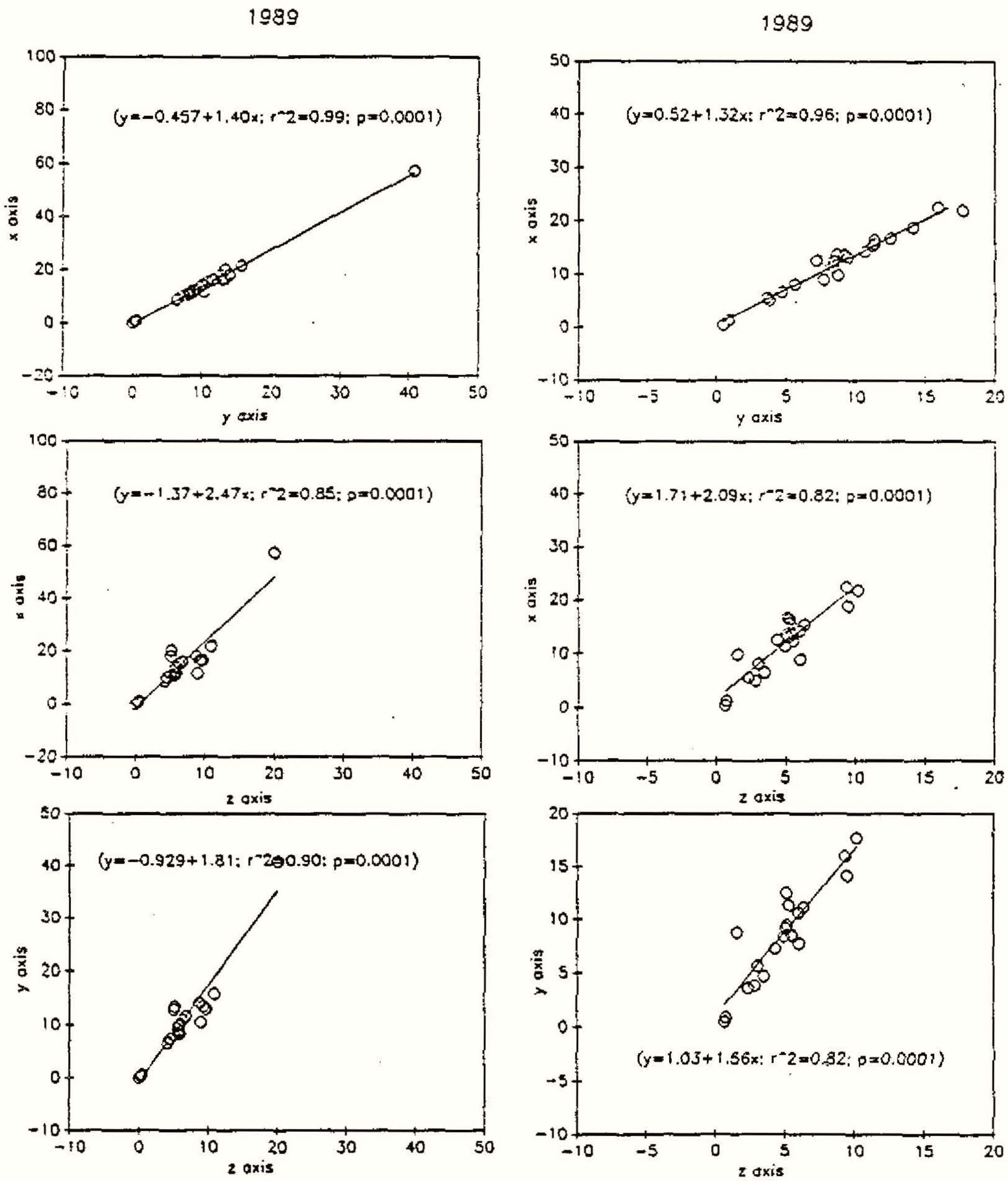

Figure 7. Linear regressions of substrate axes for measurements collected in October 1988 and August 1989 in study streams of the Yellowstone National Park Fire Study. Note all regressions are highly significant indicating a single substrate axis measurement is sufficient. Here the x-axis represents the substrate length dimension, the y-axis represents the substrate width dimension, and the z-axis represents the substrate depth dimension.

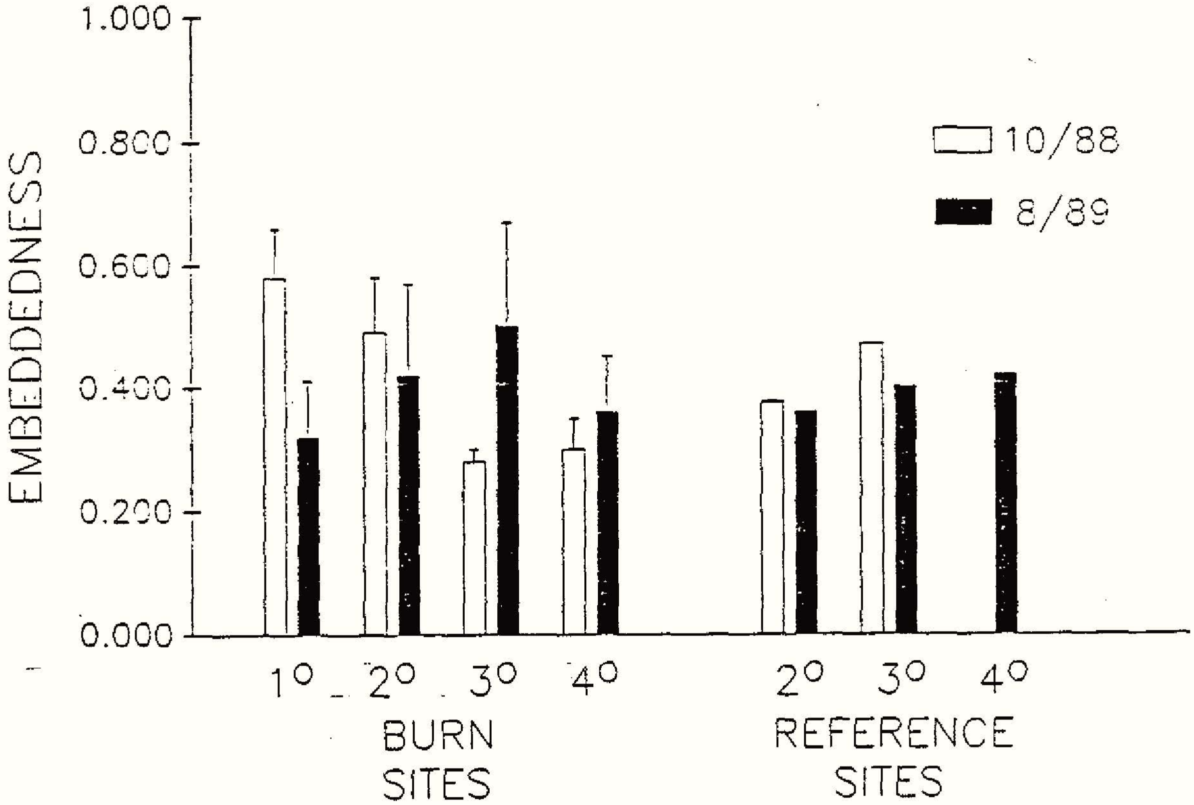

Figure 8. Mean embeddedness (+1 std err) for burn and reference study sites of the Yellowstone National Park fire study in October 1988 and August 1989.

1989, either increased or decreased in 2nd order burn sites, and increased in all 3rd and 4th order burn sites (Table 5). In contrast, mean embeddedness values remained unchanged in the reference streams. Coefficients of variation for embeddedness were higher in 1989 than in 1988 for 1st order burn sites, higher for most 2nd order burn sites, and either higher or lower for 3rd and 4th order burn sites (Table 5). Coefficients of variation were similar between years in the reference streams. These data suggest that many fine particles were transported from the 1st and 2nd order burn sites and deposited in 3rd and 4th order burn sites (Figure 8).

Water Quality

General Properties

The results of the water chemistry analyses are displayed in Tables 6 and 7. As a check of quality against analyses performed by the commercial laboratory engaged by the U.S.F.W.S., the I.S.U. Stream Ecology Center completed separate analyses for the chemical parameters of total hardness, total alkalinity, and specific conductance. These values are indicated as "ISU" in Table 6 under the respective collection date for a particular study site. Fifty-six percent of the commercial laboratory's values were at least 5 units higher (83%) or lower (17%) than the 85 individual "check" values determined by the Stream Ecology Center. Further, field pH always was a half unit or more higher than pH determined in the laboratory. On the basis of these findings, we intend to conduct our own future analyses of hardness, alkalinity, specific conductance, and pH, with the latter two being conducted in the field, and to contract with a different commercial laboratory for analyses of major ions.

Evaluation of the effects of the fires on general chemical properties of the water is hampered by the wide natural variation in conditions among streams (thus precluding comparisons between reference and burned sites) and by the absence of prefire data for the study streams. Some historical information is available from records of stream surveys conducted by the U.S. Fish and Wildlife Service. To date we have examined Technical Reports for 1978 and 1986-1988 but only data for Blacktail Deer, Amphitheater, and Soda Butte Creeks were found. Values for Amphitheater Creek were comparable in 1986 and 1988, while those in Soda Butte Creek were 1.4 to 3.8 times higher in 1986 than in 1988. Blacktail Deer Creek, the only burned stream for which values were found, was assayed in both 1976 and 1985. However, the results varied from being intermediate (total hardness), less (Ca hardness, dissolved solids), and greater (total alkalinity) after the fire than before. In most cases, little change was noted between our October 1989 and August 1989 samples. However,

Table 6. Dissolved chemical constituents in Yellowstone National Park wildfire study streams: General properties.

Stream	Date	Order	Total Hardness	Ca Hardness	Total Alkalinity	Dissolved Solids	Specific Conductance (uMho)	Field pH (units)	Lab pH (units)
BURNED									
[illegible]ktail Deer Cr WF	10/11/88	1	61.8	22.30	61	16	136	8.45	7.8
	ISU	1	44.3		51		112		
	03/17/89	1	77.0	49.90	69	130			7.2
	ISU	1	67.1		65		182		
	08/17/89	1	42.9	25.20	42	130			7.8
	ISU	1	41.8		45		107		
Blacktail Deer Cr EF	10/11/88	1	49.0	17.50	63	<1	126	8.41	7.7
	ISU46	1	43.3		56		117		
	03/17/89	1	76.0	49.40	75	150			7.6
	08/17/89	1	44.9	28.50	62	140			7.9
	ISU	1	50.2		56		123		
Cache Cr UPPER	10/25/88	1							*8.2
	08/20/89	1	50.8	29.00	74	85			8.1
	ISU	1	47.2		48		167		
Fairy Cr	10/08/88	1	20.9	4.12	21	<1	66	8.09	7.0
	ISU	1	17.4		21		68		
	03/15/89	1	24.8	20.70	22				7.1
	ISU	1	20.9		17		68		
	08/10/89	1	18.3	18.30	36	35			7.8
Twin Cr	10/12/88	1	26.9	14.20	96	180	190	8.59	8.0
	ISU	1	34.8		91		194		
	03/18/89	1	40.4	26.50	85	150			7.8
	08/18/89	1	44.4	29.50	74	80			8.0
	ISU	1	92.7		62		151		
Blacktail Deer Cr	10/14/88	2	54.1	20.60	65	56		8.29	7.8
	ISU	2	50.8		59		132		
	03/17/89	2	84.9	54.40	69	120			7.7
	ISU	2	68.1		60		182		
	08/16/89	2	49.1	30.20	53	110			7.9
	ISU	2	48.4		48		123		
Cache Cr UPPER	10/25/88	2							*8.1
	08/20/89	2	51.1	29.20	85	95			8.1
	ISU	2	58.4		72		170		
Cache Cr LOWER	10/25/88	2							*8.3
	ISU88	2	67.3		63		305		
	03/19/89	2	97.5	49.70	100	140			7.7
	ISU	2	87.5		90		286		
	08/22/89	2	79.3	42.20	99	110			8.0
	ISU	2	71.6		80		192		
Fairy Cr	10/08/88	2	17.4	4.12	98	210	318	9.25	8.9
	ISU	2	12.5		100		425		
	03/15/89	2	24.8	20.70	22				7.1
	08/10/89	2	14.9	14.90	100	210			9.2
Iron Springs Cr	10/09/88	2	13.7	4.12	13	90	48	7.76	7.0
	ISU	2	8.5		13		50		
	03/15/89	2	14.4	10.30	18	58			6.9
	08/09/89	2	11.2	11.20	14	25			7.7
Cache Cr	10/25/88	3							*7.9
	03/19/89	3	29.4	15.10	30	90			7.2
	08/21/89	3	31.4	16.60	46	50			7.8
	ISU	3	31.8		35		93		
Hell Roaring Cr	10/13/88	3	30.7	16.10	36	14	85	5.58	7.7
	ISU	3	25.9		33		73		
Iron Springs Cr	10/09/88	3	13.5	4.12	19	14	64	7.86	7.0
	ISU	3	9.9		12		51		
	03/15/89	3	15.0	10.90	18	70			7.1
	ISU	3	8.1		13		68		
	08/09/89	3	11.1	11.10	11	30			8.2

Table 6 (cont.)	Date	Order	Total Hardness	Ca Hardness	Total Alkalinity	Dissolved Solids	Conductance (uMho)	Field pH	Lab pH
[illegible]r	10/27/88	3							*7.9
	ISU88	3	35.8		91		222		
	03/17/89	3	35.6	24.00	39	20			7.4
	ISU	3	29.3		36		91		
	08/16/89	3	25.4	17.00	24	110			7.7
	ISU	3	24.5		32		78		
outh Cache Cr	ISU88	3	21.3		40		105		
	03/19/89	3	27.5	15.10	39	74			7.2
	08/21/89	3	30.8	17.00	51	52			7.9
	ISU	3	27.9		33		107		
ache Cr	10/24/88	4							*7.8
	03/19/89	4	29.1	15.10	35	60			7.1
	08/21/89	4	31.3	17.40	62	50			8.0
	ISU	4	27.8		36		95		
ell Roaring Cr	10/13/88	4	29.6	14.70	34	180	83	8.30	7.5
	ISU	4	16.4		23		52		
	ISU8/89	4	27.8		31		74		
amar River	07/25/88	4	23.3	14.90	38	45	140		8.9
	10/12/88	4	24.7	10.60	65	220	155	8.68	7.8
	ISU	4	20.7		58		124		
	03/18/89	4	32.8	17.90	63	96			7.5
	ISU	4	19.9		29		83		
	08/19/89	4	31.9	67.70	51	60			7.6
	ISU	4	19.1		37		93		
UNBURNED									
mphitheater Cr	10/13/88	2	33.5	16.50	42	2	82	8.13	7.6
	ISU	2	26.4		34		73		
	03/19/89	2	34.9	17.70	35	94			7.3
	08/24/89	2	26.5	13.70	23	35			8.0
	ISU	2	24.9		29		73		
Rose Cr	10/14/88	2	90.3	45.00	94	66	207	8.45	7.9
	ISU	2	67.8		75		152		
	03/19/89	2	105.0	52.20	99	120			7.4
	08/23/89	2	45.3	22.70	67	72			8.5
	ISU	2	66.3		73		148		
ebble Cr	10/27/88	3							*8.2
	03/19/89	3	111.0	68.90	99	130			7.9
	ISU	3	37.6		98		199		
	08/24/89	3	96.9	60.40	120	110			8.4
	ISU	3	79.3		66		153		
oda Butte Cr	08/13/88	4	85.7	58.90	42	40		8.00	8.9
	ISU	4	110.3		111		240		
	08/24/89	4	112.0	71.90	100	130			8.4
	ISU	4	83.6		86		180		

NOTE: Samples with an asterisk processed by Dr. Frank Vertucci.
ISU=Independent analysis of samples by Idaho State University situated under respective stream and date.

Table 7. Dissolved chemical constituents in Yellowstone National Park wildfire study streams: Major ions.

Stream	Date	Order	Na	K	Ca	Mg	Cl-	SO4-	HCO3	NH4	NO3	OPO4
BURNED												
[illegible]tail Deer Cr WF	10/11/88	1	6.24	3.40	15.80	5.42	1.0	6.50	74	0.025	0.006	0.160
	03/17/89	1	8.22	<1.00	20.00	6.59	<1.0	19.00	84	0.086	0.244	0.160
	08/17/89	1	3.37	2.10	10.10	4.29	<1.0	4.50	51	0.021	0.025	0.130
Blacktail Deer Cr EF	10/11/88	1	6.87	3.39	12.60	4.25	1.0	3.90	77	0.023	<0.002	0.130
	03/17/89	1	10.80	<1.00	19.80	6.46	<1.0	18.00	92	0.104	0.175	0.110
	05/23/89	1								0.015	<0.002	0.120
	08/17/89	1	6.46	1.87	11.40	3.99	<1.0	<1.00	76	0.019	0.033	0.140
Cache Cr UPPER	10/02/88	1								0.012	0.230	0.180
VEC	10/25/88	1	21.84	0.66	6.04	3.08	0.56	6.76	84	0.011		0.311
	08/20/89	1	15.00	1.14	11.60	5.30	<1.0	6.40	90	0.025	0.670	0.180
Fairy Cr	10/08/88	1	3.80	3.08	6.72	<1.00	1.0	1.60	26	0.016	0.008	<0.005
	03/15/89	1	6.44	<1.00	8.27	<1.00	<1.0	2.20	27	0.014	0.022	0.008
	06/30/89	1									0.010	0.013
	08/10/89	1	4.91	<1.00	7.31	<1.00	<1.0	1.80	44	0.008	0.006	0.006
Twin Cr	10/12/88	1	31.20	2.56	10.20	3.45	<1.0	4.20	120	0.034	0.026	0.057
	03/18/89	1	32.40	<1.00	10.60	3.38	<1.0	8.80	104	0.010	0.250	0.070
	08/18/89	1	13.90	1.30	11.80	3.63	<1.0	6.10	90	0.017	0.170	0.110
Blacktail Deer Cr	10/14/88	2	6.01	3.61	13.40	5.01	1.0	4.40	79	0.016	0.004	0.078
	03/17/89	2	8.12	<1.00	21.80	7.40	<1.0	22.00	84	0.026	0.270	0.110
	08/16/89	2	4.79	2.08	12.10	4.58	<1.0	4.60	65	0.020	0.017	0.140
ache Cr UPPER	10/02/88	2								0.016	0.008	0.150
VEC	10/25/88	2	13.15	0.79	8.31	4.91	0.56	6.46	77	0.011		0.301
	08/20/89	2	14.90	1.64	11.70	5.32	1.0	5.70	100	0.026	0.450	0.180
ache Cr LOWER	10/03/88	2									0.012	0.078
VEC	10/25/88	2	13.48	1.01	16.91	10.11	0.81	7.63	128	0.021	0.111	0.281
	03/19/89	2	14.40	<1.00	19.90	11.60	<1.0	16.00	120	0.011	0.072	0.074
	07/07/89	2									0.211	0.056
	08/22/89	2	11.90	1.04	16.90	9.00	<1.0	6.10	120	0.018	0.076	0.109
F[illegible] Cr	10/08/88	2	78.80	5.35	5.32	<1.00	50.0	5.90	120	0.015	<0.002	0.014
	03/15/89	2	6.44	<1.00	8.27	<1.00	<1.0	2.20	27			
	08/10/89	2	64.40	1.56	5.96	<1.00	39.0	5.20	30	0.017	0.003	0.015
ron Springs Cr	10/09/88	2	3.51	4.19	3.85	<1.00	2.0	2.20	16	0.021	0.019	0.013
	03/15/89	2	3.52	2.12	4.14	<1.00	<1.0	2.30	22	0.009	0.023	0.007
	08/09/89	2	5.01	1.28	4.47	<1.00	<1.0	4.50	17	0.010	0.016	<0.005
ache Cr	10/02/88	3								0.019	0.004	0.057
VEC	10/24/88	3	6.82	1.04	6.56	3.71	0.64	6.46	46	0.011		0.23
	03/19/89	3	6.31	<1.00	6.04	3.47	<1.0	6.80	37			
	08/21/89	3	6.68	1.04	6.65	3.60	<1.0	3.20	56	0.015	0.380	0.103
ell Roaring Cr	10/13/88	3	2.87	4.28	5.83	3.91	1.0	2.10	44	0.022	0.002	0.041
	08/13/89	3									0.018	0.081
Iron Springs Cr	10/09/88	3	5.87	4.34	3.76	<1.00	1.0	2.40	23	0.024	0.004	0.008
	03/15/89	3	6.12	2.24	4.36	<1.00	<1.0	2.40	22	<0.005	0.010	0.008
	06/30/89	3									0.005	<0.005
	08/09/89	3	6.98	1.14	4.46	<1.00	<1.0	2.20	130	0.016	0.006	0.008
ava Cr	09/30/88	3								0.028	0.023	0.023
	10/04/88	3								0.014	0.041	0.022
VEC	10/27/88	3	4.97	1.34	7.25	2.35	0.5	1.96	43	0.011		0.311
	03/17/89	3	7.80	<1.00	9.61	2.81	<1.0	3.40	48	0.007	0.042	0.019
	08/16/89	3	5.49	1.37	6.80	2.03	<1.0	2.20	29	0.007	0.016	0.013
outh Cache Cr	10/03/88	3								0.022	0.004	0.095
	03/19/89	3	13.00	<1.00	6.05	3.00	<1.0	5.70	48	0.012	0.190	0.090
	08/21/89	3	11.00	<1.00	6.81	3.34	<1.0	4.10	62	0.019	0.043	0.107
ache Cr	10/03/88	4								0.013	0.002	0.063
VEC	10/25/88	4	7.81	0.88	6.11	3.42	0.59	5.76	49	0.011		0.231
	03/19/89	4	7.85	<1.00	6.05	3.39	<1.0	5.50	43	0.010	0.226	0.090
	08/21/89	4	8.01	1.03	6.98	3.37	1.0	4.00	76	0.018	0.290	0.105
[illegible] Roaring Cr	10/13/88	4	3.13	4.10	5.95	3.56	2.0	2.00	41	0.027	0.004	0.039
	08/13/89	4									0.026	0.055

able 7. (cont.)	Date	Order	Na	K	Ca	Mg	Cl-	SO4-	HCO3	NH4	NO3	OPO4
Lamar River	07/25/88	4	7.31	1.44	5.97	2.03	6.5	3.00	46			0.070
	10/12/88	4	21.70	2.46	5.64	2.57	1.0	4.80	79	0.046	<0.002	0.069
	03/18/89	4	20.40	<1.00	7.16	3.61	<1.0	7.00	77	0.024	0.115	0.073
	08/19/89	4	18.50	5.52	27.10	61.20	<1.0	6.00	62	0.099	1.340	0.022
UNBURNED												
mphitheater Cr	10/13/88	2	3.66	2.92	6.80	4.00	1.0	2.60	51	0.015	0.004	0.067
	03/19/89	2	3.58	<1.00	7.08	4.18	<1.0	2.60	43			
	08/24/89	2	4.50	2.07	5.49	3.11	<1.0	1.70	28	0.011	0.014	0.063
Rose Cr	10/14/88	2	3.98	3.86	18.00	11.00	1.0	3.40	110	0.019	0.006	0.026
	03/19/89	2	4.34	<1.00	20.90	12.90	<1.0	3.60	120	0.011	0.120	0.041
	08/23/89	2	2.79	1.73	9.09	5.48	<1.0	1.80	82	0.020	0.016	0.040
Pebble Cr	10/15/88	3								0.020	0.002	0.008
VEC	10/27/88	3	2.27	1.21	26.31	9.84	0.21	3.17	131			0.191
	03/19/89	3	2.23	<1.00	27.60	10.20	<1.0	3.30	120			
	08/24/89	3	3.15	1.43	24.20	8.86	<1.0	2.60	150	0.009	0.005	0.012
Soda Butte Cr	08/13/88	4	2.43	1.79	23.60	6.50	<1.0	3.00	51			<0.030
	10/15/88	4								0.071	0.018	0.011
	08/24/89	4	3.90	1.73	28.80	9.74	<1.0	5.50	120	0.047	0.041	0.016

NOTE: VEC samples by Dr. Frank Vertucci.

in addition to the analytical problems noted above, it is likely that our annual sampling regimen was inadequate to reflect the true dynamics in the water chemistry. Attempts to rectify these two problems through outside funding were unsuccessful. Although the results are disappointing thus far, we will continue to monitor these general properties for at least one more season in case patterns emerge and in order to help characterize the environmental conditions in each stream. We also will continue to search U.S. Fish and Wildlife Service records for additional prefire data for the study streams.

Major Ions

Specific ions were compared from October 1988 and August 1989 from selected 1st through 4th order burn sites of the Cache Creek drainage (Figure 9). In the figure, data from the Lamar River burn site was used to represent likely conditions in a larger 4th order stream downstream from Cache Creek 4th order, even though this site was upstream from the Lamar River/Cache Creek confluence. The specific ions examined were sodium (Na), potassium (K), calcium (Ca), nitrate (NO_3), orthophosphate (OPO_4), ammonia nitrogen (NH_4), bicarbonate (HCO_3), and sulfate (SO_4). Sodium values showed similar trends between years, although they were slightly lower in August 1989 than October 1988 at the 1st order site (Figure 9). Sodium values were much higher at the Lamar River site than the 2nd, 3rd and 4th order Cache Creek sites for both years. The high values in 1989 at the Lamar River site were associated with runoff from a rain storm. Potassium levels also displayed similar trends between years, although being somewhat higher in August 1989 than October 1988 at the Lamar River site. Calcium levels were higher in August 1989 than in October 1988 for the 1st order, 2nd order, and Lamar River sites, but were similar between years at the 3rd and 4th order sites. Nitrate levels increased substantially for all sites from October 1988 to August 1989, especially at the Lamar River site (Figure 9). These data indicate nutrient accrual, derived from the surrounding terrestrial area as a result of fire, from either groundwater or overland flow.

Orthophosphate concentrations followed similar trends as nitrate levels in being higher in August 1989 than in October 1988. In addition, orthophosphate levels decreased as stream order increased for both years (Figure 9). Ammonia levels showed similar trends as orthophosphate, and had relatively low values, for both years. Ammonia values tended to be higher at the Lamar River site than at the 1st through 4th order Cache Creek sites for both years. Ammonia is more volatile than the nitrate form of nitrogen thus the low values are not surprising. Bicarbonate values were higher in August 1989 than in October 1988 at all sites except the Lamar River site (Figure 9). Sulfate concentrations were similar between years, although being

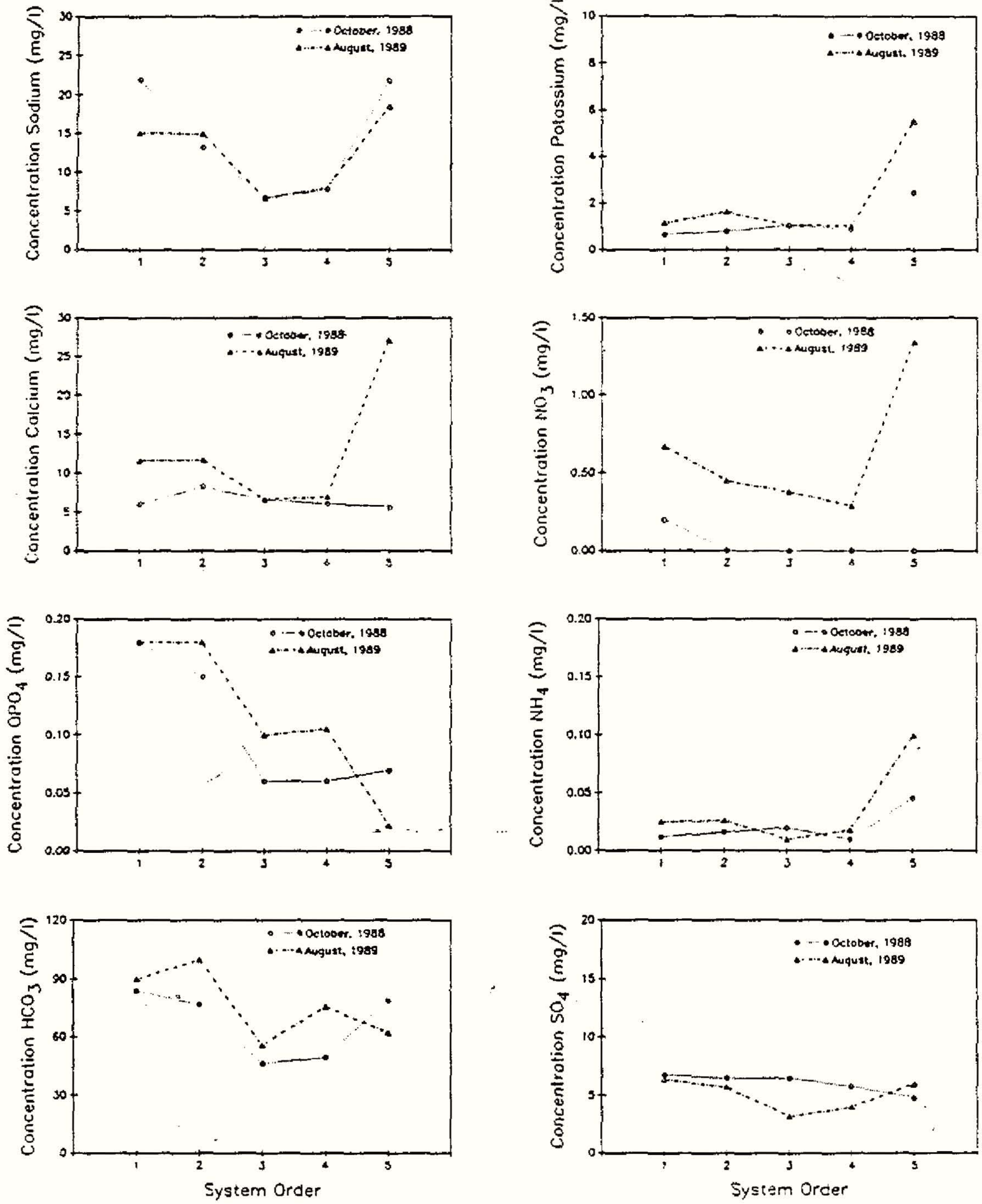

Figure 9. Selected chemical parameters for the Cache Creek drainage collected in October 1988 and August 1989. The 5th order site is represented by the Lamar River 4th order study site.

slightly lower in August 1989 than in October 1988 at the 3rd order burn site. Sulfate levels also showed similar values among sites for both years (Figure 9).

Biological Responses

Transported Organic Matter

Transported organic matter (TOM) was collected in October 1988 and August 1989. TOM was categorized as being either coarse particulate organic matter (CPOM, >1.0 mm) or fine particulate organic matter (FPOM, 0.52-1.0 mm). CPOM showed similar trends between burn sites and reference sites of the same stream order between years, although the material was qualitatively different (see below). Both burn and reference 2nd order sites showed substantial increases in August 1989 over values observed in October 1988 (Figure 10).

FPOM concentrations, however, displayed differences between burn and reference sites and differences between years (Figure 10). FPOM levels were higher in August 1989 than in October 1988 in all burn sites, with 2nd order burn streams experiencing the greatest increase in FPOM levels. The reference sites, on the other hand, displayed no difference in FPOM levels between years (2nd order sites) or FPOM was lower in August 1989 than in October 1988 (3rd and 4th order sites; Figure 10). Apparently CPOM and FPOM dynamics differ temporally following wildfire implying the importance of measuring these parameters over a number of years.

Analysis of the composition for the CPOM and FPOM provides an indication of the source of TOM at a site. The % charcoal was substantially greater in both CPOM and FPOM in burn sites than in reference sites for both years (Figure 11). Indeed, reference sites displayed less than 20% charcoal for CPOM, and less than 5% charcoal for FPOM for both years. The CPOM in burn sites averaged greater than 40% charcoal, with the % charcoal of CPOM being higher in August 1989 than in October 1988 (Figure 11). The % charcoal of FPOM increased from 15-20% in October 1988 to greater than 40% in August 1989 for all burn sites suggesting a substantial input of burned material between October 1988 and August 1989 as a result of runoff (Figure 11).

Benthic Organic Matter

Benthic organic matter (BOM) was collected in conjunction with the sampling of lotic macroinvertebrates in October 1988, March 1989, and August 1989. Composition of the BOM also was analyzed, with % charcoal being addressed in this report. The quantity of BOM was similar between burn and reference sites in October 1988.

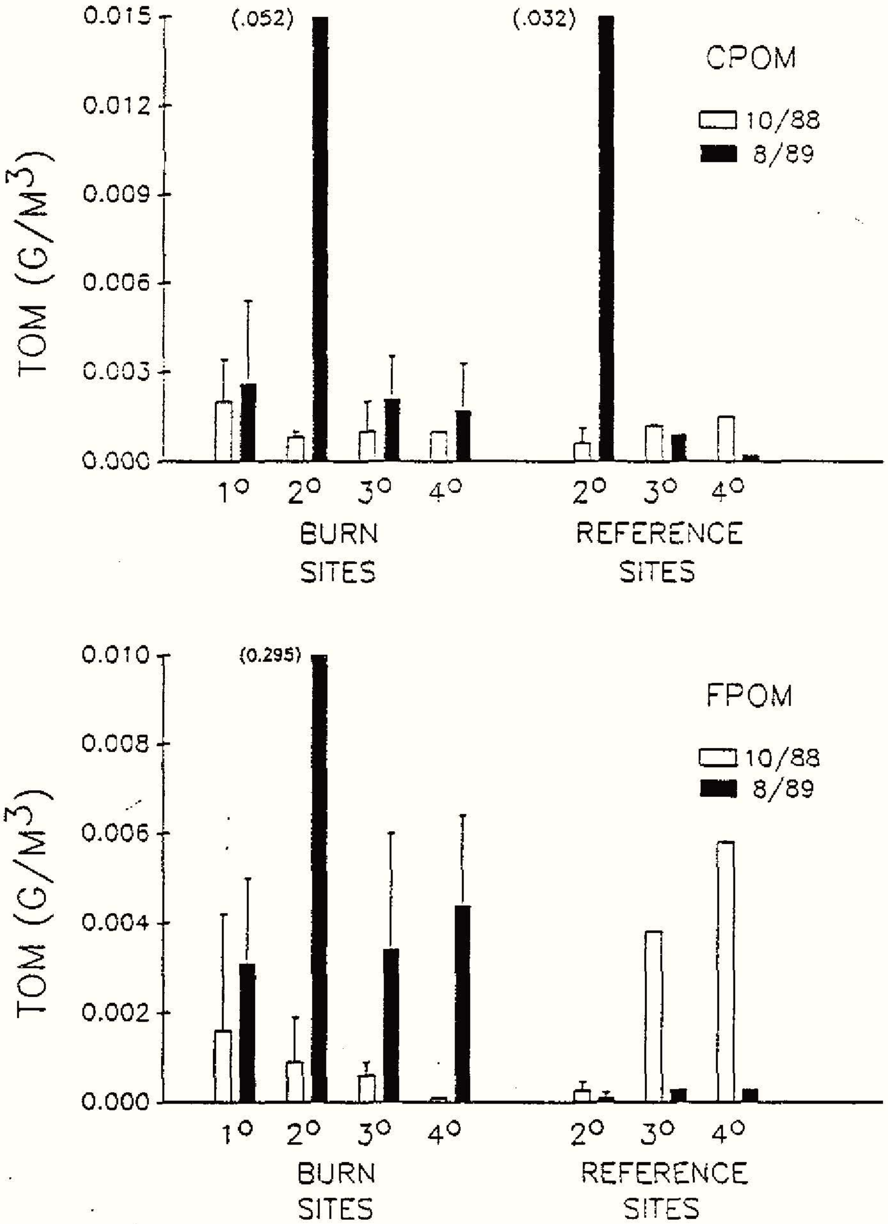

Figure 10. Transported organic matter (g/m^3) as coarse (CPOM) or fine (FPOM) particulate organic matter in burn or unburned stream study sites. Numbers represent respective stream orders. Bars represent one standard error of the mean. Sample size equals five sites (2 samples per site) for burn streams orders 1–3, three sites for burn stream 4th order, two sites for unburn 2nd order, and one site for unburn 3rd and 4th order study streams. Numbers in parenthesis represent values outside range of graph.

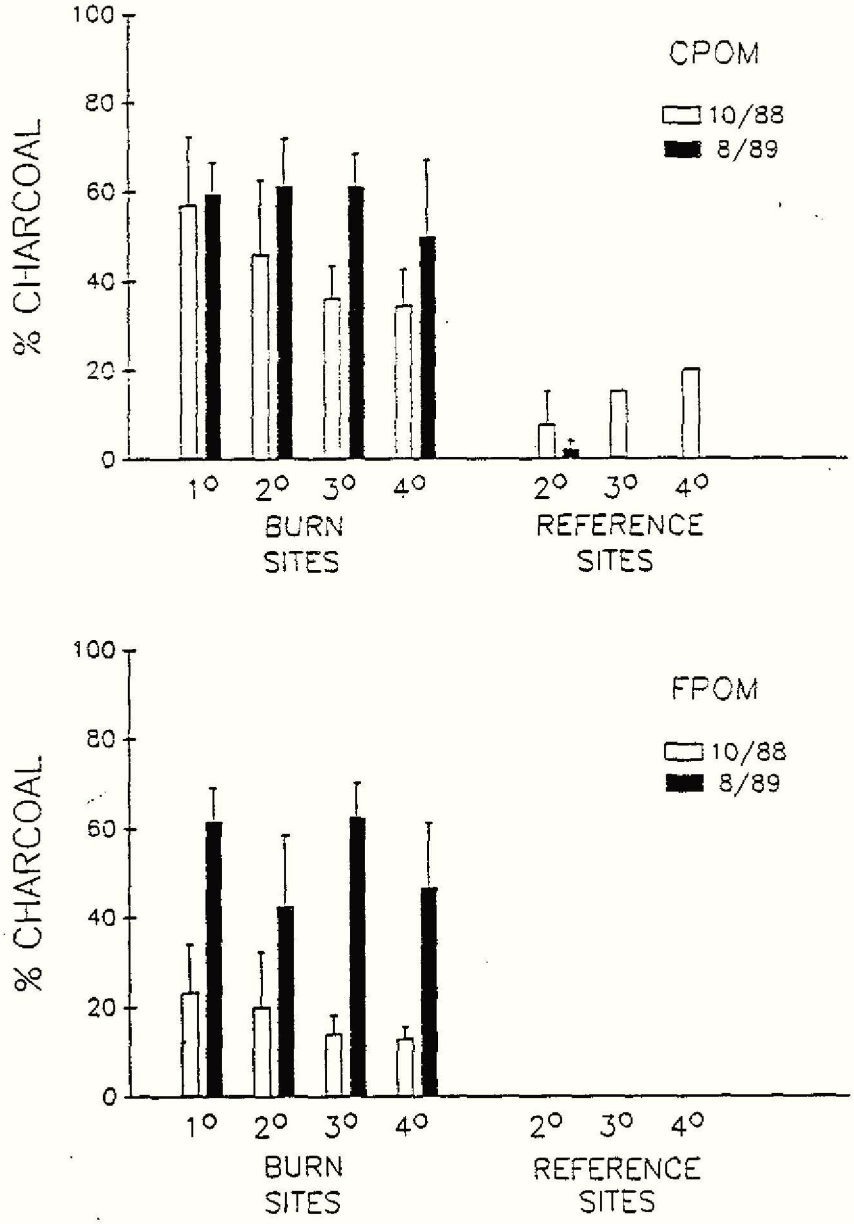

Figure 11. The percent charcoal comprising transported organic matter Bars represent one standard error of the mean. Sample size as in figure 5.

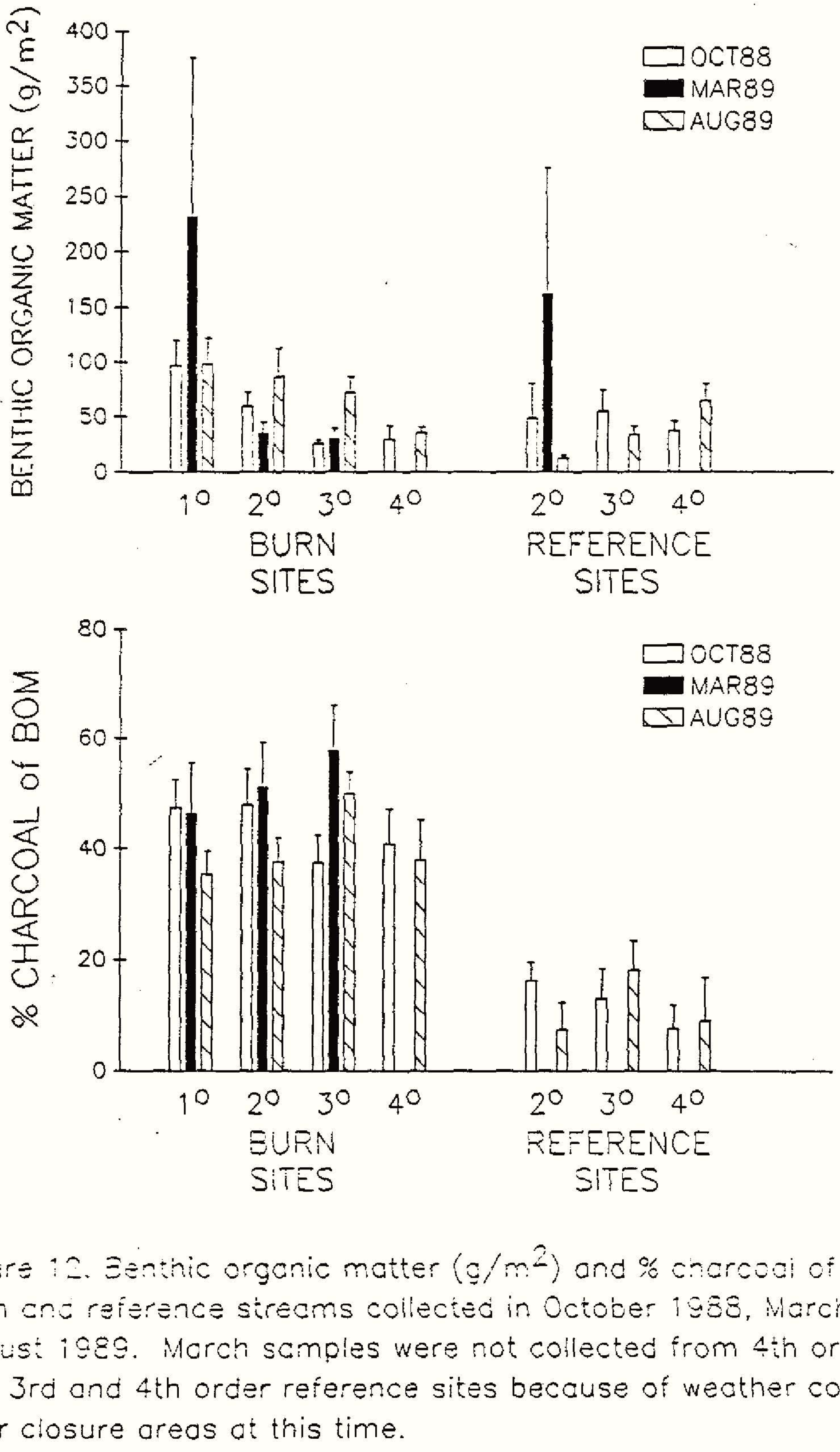

Figure 12. Benthic organic matter (g/m^2) and % charcoal of BOM from burn and reference streams collected in October 1988, March 1989, and August 1989. March samples were not collected from 4th order burn, and 3rd and 4th order reference sites because of weather conditions or bear closure areas at this time.

In March 1989 the 1st order burn sites showed a dramatic increase in BOM (Figure 12). The 2nd order reference sites also displayed an increase in BOM in March 1989. BOM levels dropped in 1st order burn sites in August 1989 to levels found in October 1988, whereas BOM levels increased in 2nd and 3rd order burn sites in August 1989 (Figure 12). BOM levels were similar in October 1988 and August 1989 in reference sites. These data suggest that a wave of organic matter has moved from smaller headwater burn streams to larger streams (2nd and 3rd order) between October 1988 and August 1989. The % charcoal was substantially greater in burn sites than in reference sites at all collection times (Figure 12). Charcoal comprised greater than 35% of the BOM in the burn sites regardless of collection period, whereas charcoal comprised less than 20% of the BOM in the reference sites.

Periphyton

Periphyton was collected in October 1988, March 1989, and August 1989 and analyzed as chlorophyll a, ash-free-dry-mass (AFDM), and biomass/chlorophyll ratio (B/C index). Chlorophyll a levels decreased among collection times for all burn and reference sites except 4th order reference sites (Figure 13). The AFDM of periphyton in August 1989 decreased from that found in October 1988 in the 1st and 2nd order burn sites, while being similar among collection times for the other burn and reference sites. The 4th order reference sites showed an increase in August 1989 from values found in October 1988 (Figure 13). The B/C index, an index of relative autotrophy, was much higher in August 1989 than in March 1989 or October 1988, except for 1st order burn sites which had similar B/C values between years (Figure 13).

Benthic Macroinvertebrates

Community level responses: The abundance of macroinvertebrates decreased from October 1988 to March 1989 in 1st and 2nd order burn sites, then returned to October 1988 levels by August 1989 (Figure 14). Macroinvertebrate abundance remained unchanged among sampling times in the 2nd order reference sites. The 3rd order burn and reference sites each displayed decreases in macroinvertebrate abundance from October 1988 to August 1989. Macroinvertebrate abundance decreased in 4th order burn sites from October 1988 to August 1989, whereas abundance increased in the 4th order burn site for this period (Figure 14).

Macroinvertebrate biomass decreased in 1st, 2nd, and 3rd order burn sites from October 1988 to March 1989. Biomass levels returned to October 1988 values by August 1989 in all burn sites (Figure 14). The biomass of macroinvertebrates was similar among sampling periods in the 2nd and 3rd order reference sites, and biomass increased in the 4th order reference site from October 1988 to August 1989.

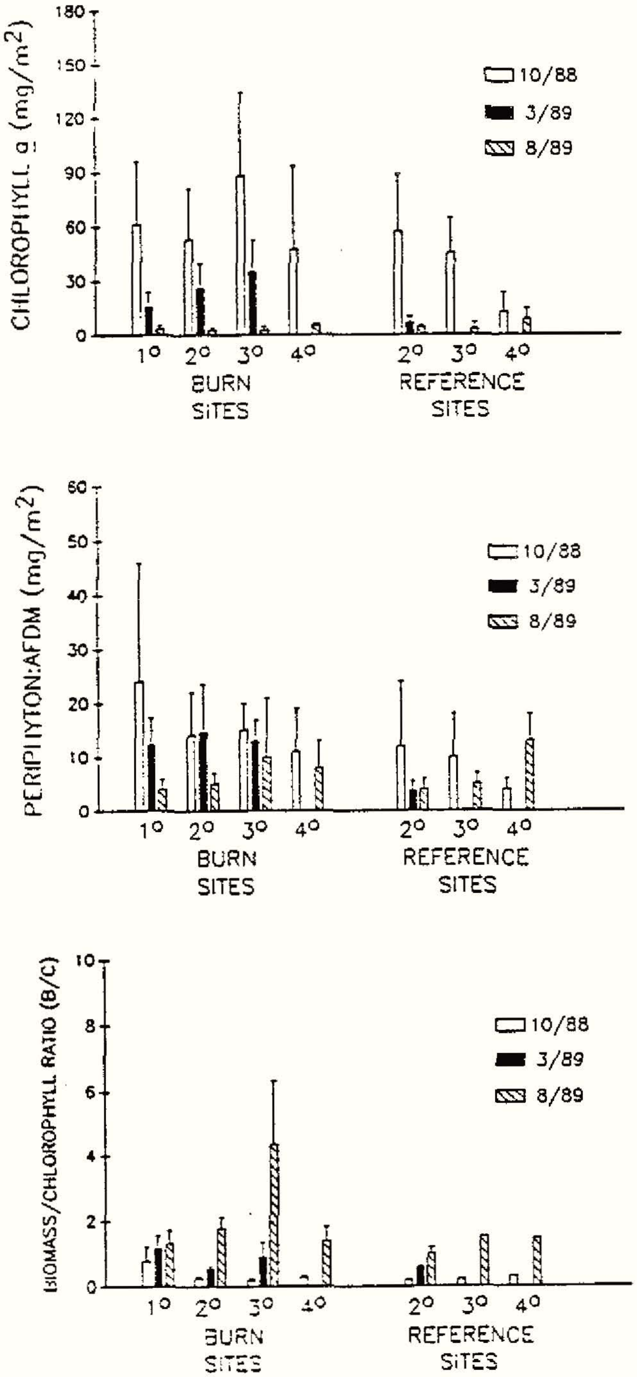

Figure 13. Periphyton characteristics as chlorophyll a (mg/m^2), AFDM (mg/m^2), and biomass/chlorophyll ratio (B/C) for the Yellowstone National Park study streams in October 1988 and August 1989. Bars represent one standard error of the mean. Sample size equals five sites (5 samples/site) for 1st, 2nd, and 3rd order burn streams, three sites for 4th order burn stream, two sites for 2nd order unburn stream, and one site each for 3rd and 4th order unburn streams.

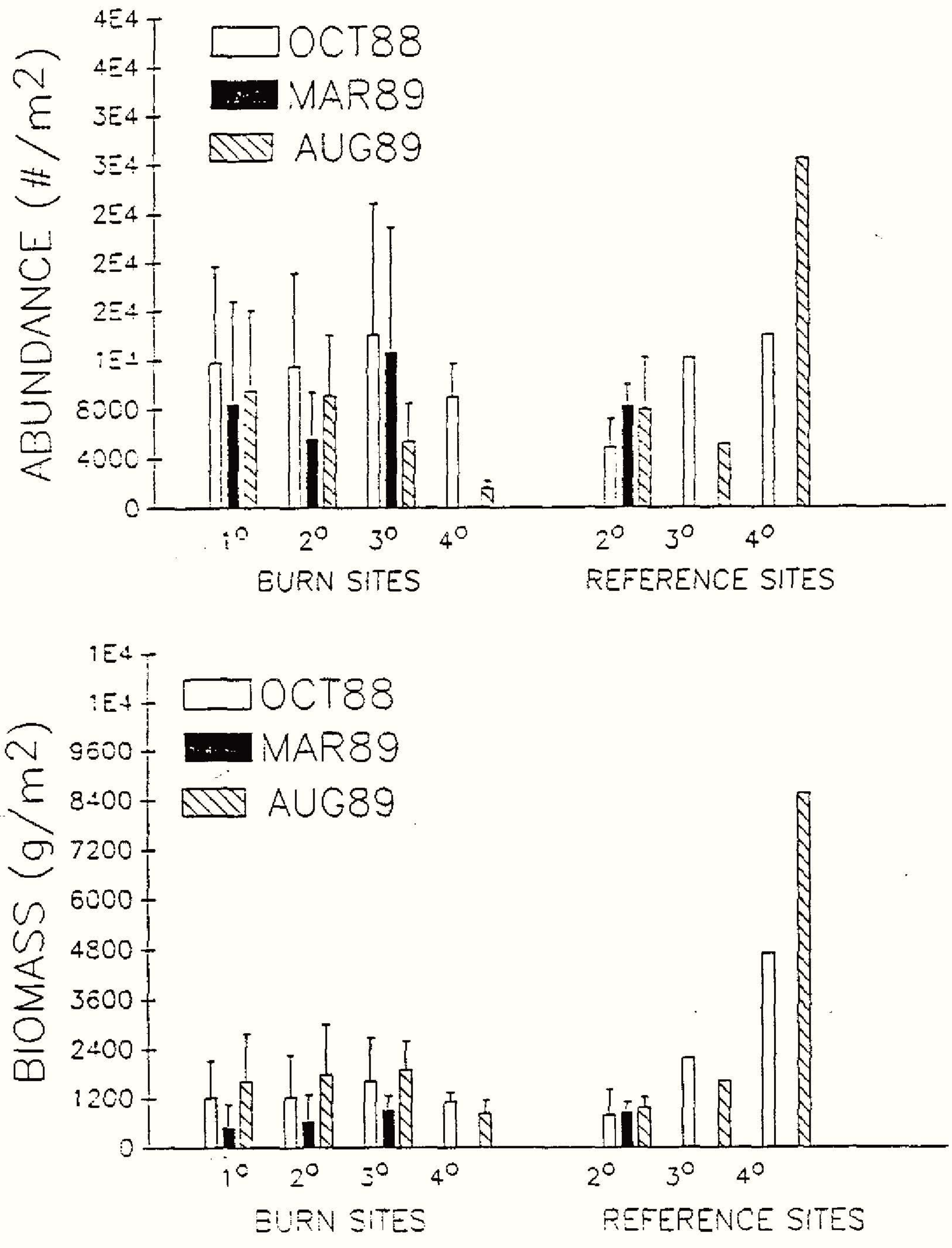

Figure 14. Macroinvertebrate abundance and biomass from burn and reference streams in Yellowstone National Park. Bars represent one standard deviation. Sample size as in figure 12.

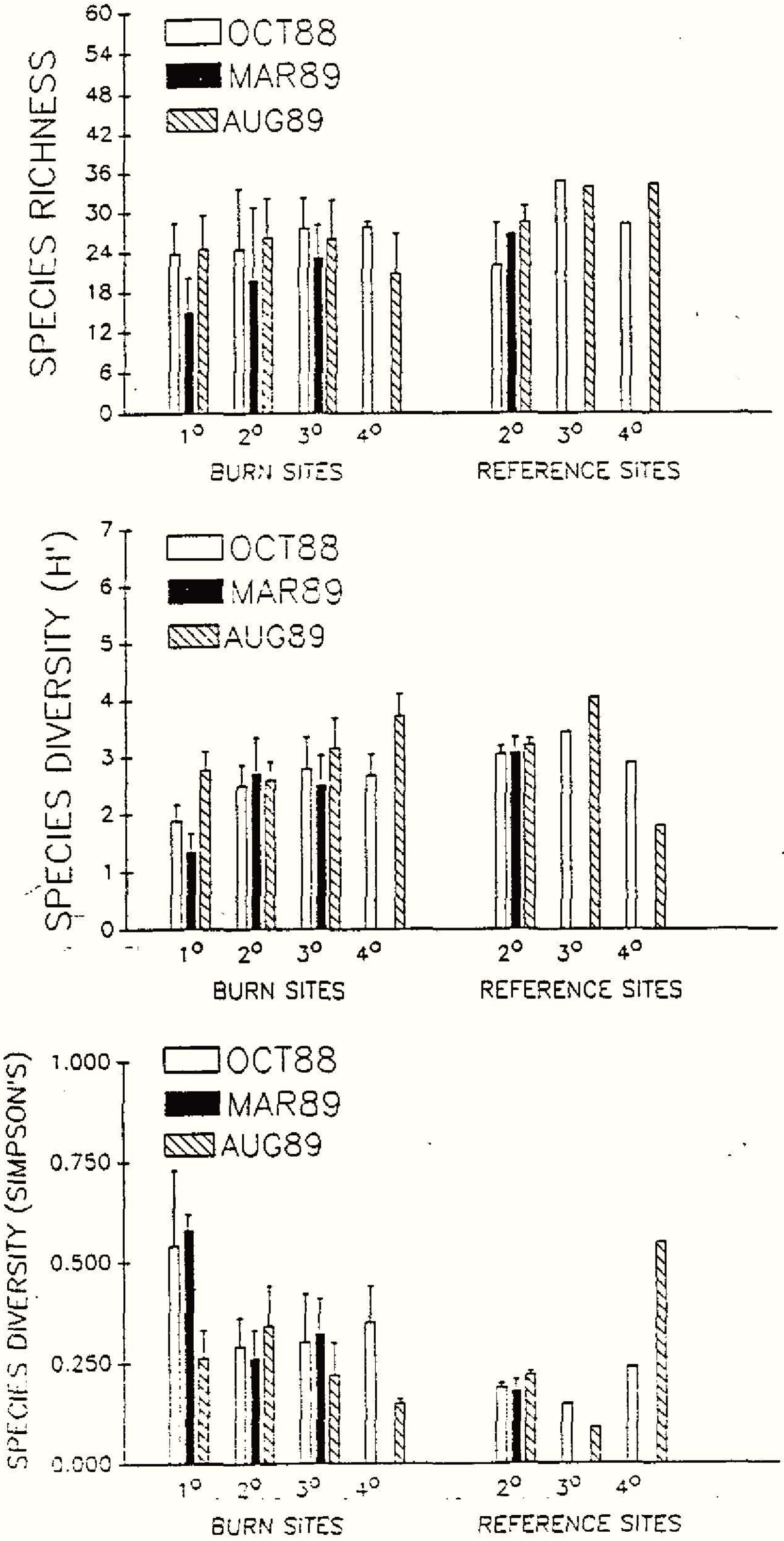

Figure 15. Macroinvertebrate species richness, Shannon—Wiener diversity (H'), and Simpson's diversity (C) for burn and reference streams in Yellowstone National Park. Bars represent one standard deviation. Sample size as in figure 12.

The species richness (# of species present) decreased in 1st, 2nd, and 3rd order burn sites from October 1988 to March 1989, with richness values returning to October 1988 levels by August 1989 in these sites (Figure 15). Species richness tended to decrease in the 4th order burn sites from October 1988 to August 1989. Species richness remained unchanged in the reference sites among sampling periods.

The diversity of macroinvertebrates was determined using Shannon-Wiener's (H') and Simpson's diversity. H' diversity decreased in 1st order burn sites from October 1988 to March 1989 then increased in August 1989 (Figure 15). Shannon's diversity (H') remained essentially unchanged in 2nd, 3rd, and 4th order burn sites, as with 2nd and 3rd order reference sites among sampling periods. H' decreased in the 4th order reference site from October 1988 to August 1989.

Simpson's diversity remained unchanged in 1st, 2nd, and 3rd order burn sites from October 1988 to March 1989. Simpson's diversity decreased in August 1989 compared to October 1988 and March 1989 in 1st, 3rd, and 4th order burn sites, while remaining unchanged in the 2nd order burn sites among dates (Figure 15). Simpson's diversity remained unchanged in 2nd and 3rd order reference sites among dates, whereas it increased in the 4th order reference site from October 1988 to August 1989 (Figure 15).

Macroinvertebrate functional feeding groups. The absolute and relative abundance and biomass of predators displayed little difference between burn and reference sites among sampling periods (Tables 8-11). Predators generally comprised less than 10% of functional feeding group (FFG) abundance, while comprising greater than 25% of FFG biomass at most sites. The relative abundance of predators increased in August 1989 in 3rd and 4th order burn sites, and 2nd and 3rd reference sites (Table 10).

Gatherers comprised less than 10% of FFG abundance and generally less than 20% of the FFG biomass (Tables 10-11). The absolute and relative abundance of gatherers was similar between burn and reference sites among sampling dates, except for the 4th order reference site where gatherer abundance decreased in August 1989 from October 1988. In contrast, the absolute and relative biomass of gatherers decreased in August 1989 from October 1988 in all burn sites, while remaining unchanged in the reference sites (Tables 9,11).

The absolute abundance of scrapers decreased in 2nd, 3rd, and 4th order burn sites in August, while remaining essentially unchanged in the reference sites (Table 8). The biomass, however, of scrapers remained unchanged in all burn sites from October 1988 to August 1989, whereas scraper biomass increased in reference sites for this same period (Table 9). The relative abundance and biomass of scrapers was higher in 2nd and 3rd order reference

Table 8. Average *abundance* (#/m2) and standard deviations of macroinvertebrate functional feeding groups for the Yellowstone National Park burn and reference sites.

Burn Sites Date	Order	Predators X	SD	Gatherers X	SD	Scrapers X	SD	Shredders X	SD	Filterers X	SD	Miners X	SD
11/88	1	812	424	611	398	2374	4084	811	690	483	328	6729	3072
3/89	1	278	287	329	247	1218	1603	208	268	56	38	6326	6000
8/89	1	738	413	669	770	2080	1509	870	889	195	157	4899	4232
11/88	2	926	544	1305	1514	2088	2694	474	491	1642	2470	4669	2462
3/89	2	481	399	624	792	1350	890	256	215	93	75	2633	1755
8/89	2	533	297	957	1453	612	446	717	1004	1544	3089	3345	2906
11/88	3	1079	590	1206	736	2975	1956	1465	1701	524	363	6713	7798
3/89	3	684	452	599	428	5163	5236	573	409	315	340	5330	4027
8/89	3	889	581	530	597	975	723	568	547	562	629	1810	1239
11/88	4	622	257	324	122	1475	358	1110	613	184	145	5260	2796
8/89	4	536	346	36	9	343	119	162	58	97	67	401	235
Reference Sites													
11/88	2	568	493	210	89	2286	1295	725	165	43	28	1029	617
3/89	2	497	288	523	456	3626	1492	1620	1117	337	92	1656	26
8/89	2	1256	445	534	412	2244	1514	359	277	1178	1110	2386	437
11/88	3	958	511	506	252	4170	1353	2422	963	393	156	3707	1108
8/89	3	1268	351	320	185	1882	539	625	307	130	52	877	199
11/88	4	1854	973	2121	1399	1097	649	1012	623	491	304	10749	5449
8/89	4	1630	492	966	238	902	413	966	409	2038	983	21962	5001

Table 9. Average biomass (#/m2) and standard deviations of macroinvertebrate functional feeding groups for the Yellowstone National Park burn and reference sites.

Burn Sites		Predators		Gatherers		Scrapers		Shredders		Filterers		Miners	
Date	Order	X	SD	X	SD	X	SD	X	SD	X	SD	X	SD
11/88	1	274	184	230	216	166	216	209	239	48	49	278	160
3/89	1	167	201	106	125	53	67	67	88	3	0	97	90
8/89	1	420	245	182	181	222	143	82	110	139	217	558	427
11/88	2	508	417	214	254	152	226	74	52	148	145	191	152
3/89	2	212	197	106	141	107	82	35	30	88	93	62	46
8/89	2	581	484	153	179	134	119	28	30	465	511	267	198
11/88	3	483	251	323	212	263	161	71	27	263	265	202	224
3/89	3	229	54	111	77	242	138	49	26	136	130	147	189
8/89	3	449	192	173	216	233	115	101	104	719	555	191	166
11/88	4	293	88	108	60	264	10	100	33	214	126	129	68
8/89	4	390	294	12	5	142	122	54	58	177	128	34	23
Reference Sites													
11/88	2	275	243	38	32	218	114	205	189	26	24	23	14
3/89	2	297	111	67	44	344	233	191	101	12	2	39	26
8/89	2	248	142	35	8	467	280	31	19	130	128	42	29
11/88	3	470	254	127	54	551	238	416	477	486	468	121	61
8/89	3	599	366	49	35	752	175	60	21	168	153	43	20
11/88	4	566	490	372	346	579	432	2082	2291	892	632	196	165
8/89	4	1057	614	646	208	1216	999	589	256	3796	2054	1243	294

Table 10. Relative abundance (#/m2) of macroinvertebrate functional feeding groups for the Yellowstone National Park burn and reference sites.

Date	Order	Predators	Gatherers	Scrapers	Shredders	Filterers	Miners
Burn Sites							
11/88	1	7%	6%	11%	6%	6%	64%
3/89	1	3%	5%	8%	1%	1%	81%
8/89	1	8%	8%	24%	9%	2%	48%
11/88	2	9%	8%	18%	7%	14%	43%
3/89	2	7%	15%	31%	5%	5%	38%
8/89	2	8%	9%	9%	8%	14%	52%
11/88	3	9%	9%	28%	8%	4%	41%
3/89	3	6%	7%	36%	5%	2%	44%
8/89	3	18%	9%	18%	11%	8%	36%
11/88	4	7%	4%	17%	16%	2%	54%
8/89	4	31%	3%	23%	12%	8%	23%
Reference Sites							
11/88	2	9%	5%	45%	22%	1%	20%
3/89	2	7%	8%	42%	18%	5%	21%
8/89	2	18%	6%	25%	4%	10%	37%
11/88	3	8%	4%	34%	20%	3%	31%
8/89	3	25%	6%	37%	12%	3%	17%
11/88	4	13%	15%	8%	7%	4%	53%
8/89	4	6%	3%	3%	3%	7%	77%

Table 11. Relative biomass (#/m2) of macroinvertebrate functional feeding groups for the Yellowstone National Park burn and reference sites.

Burn Sites Date	Order	Predators	Gatherers	Scrapers	Shredders	Filterers	Miners
11/88	1	25%	18%	9%	14%	5%	29%
3/89	1	30%	20%	8%	8%	3%	29%
8/89	1	28%	13%	16%	4%	6%	33%
11/88	2	44%	11%	12%	10%	6%	18%
3/89	2	22%	23%	23%	9%	8%	16%
8/89	2	38%	9%	9%	2%	17%	25%
11/88	3	33%	20%	18%	6%	13%	10%
3/89	3	27%	11%	26%	6%	18%	12%
8/89	3	24%	9%	13%	6%	37%	11%
11/88	4	27%	9%	25%	9%	20%	11%
8/89	4	43%	2%	20%	8%	23%	4%
Reference Sites							
11/88	2	28%	4%	43%	19%	2%	4%
3/89	2	35%	11%	36%	21%	1%	6%
8/89	2	32%	4%	44%	3%	11%	6%
11/88	3	22%	6%	25%	19%	22%	6%
8/89	3	37%	3%	47%	4%	10%	3%
11/88	4	12%	8%	12%	44%	19%	4%
8/89	4	12%	8%	14%	7%	44%	15%

sites than in respective burn sites.

The absolute abundance of shredders decreased in 3rd and 4th order burn sites and 2nd and 3rd order reference sites in August 1989, whereas shredder biomass decreased in all sites except 3rd order burn sites in August 1989 (Table 8,9). The relative abundance of shredders remained unchanged in all burn sites among sampling periods, whereas the relative abundance of shredders decreased in August 1989 in reference sites (Table 10). The relative biomass of shredders decreased in 1st and 2nd order burn sites and all reference sites in August 1989 (Table 11).

The absolute abundance and biomass of filterers decreased in March 1989 from October 1988 in burn sites, but returned to October 1988 levels by August 1989. The absolute abundance of filterers increased in 2nd and 4th order reference sites in August 1989 (Tables 8,9). The relative abundance and biomass of filterers followed the trends found for absolute values (Tables 10,11).

The absolute abundance and biomass of miners were substantially greater in burn sites than in reference sites except for the 4th order sites for all sampling times (Tables 8,9). The relative abundance and biomass of miners also were greater in the burn sites than in the reference sites except for the 4th order sites on all sampling dates (Tables 10,11). Miners comprised the greatest proportion of the functional feeding group composition in the burn sites in abundance, whereas miners and scrapers were predominant in the reference sites. Miners, scrapers, and predators were predominant in burn sites in relative biomass, while predators and scrapers were predominant in the reference sites.

Individual Taxon Response:Chironomidae were the predominant orgamisms in the benthos at 1st order burn sites. The chironomids typically had 8X greater abundance than any other taxon and typically comprised over 70% of the assemblage at these sites in October 1988 and March 1989 (Table 12). However, by August 1989 the abundance of chironomids was only 2x greater (and less than 40% of the assemblage) than most other taxa, and actually were less abundant than <u>Baetis</u> at Fairy Creek. Indeed, <u>Baetis</u> increased in relative abundance at most 1st order sites comprising greater than 18% of the assemblage (Table 12).

The relative abundance of chironomids was lower in 2nd order burn sites among sampling periods, in contrast to 1st order burn sites. Chironomids were generally 1-3x the abundance of other taxa, although at some sites abundance was 7-20x in August 1989 (Table 12). Fairy Creek was a notable exception with chironomids being ranked lower than other taxa, especially <u>Simulium</u>. Fairy Creek is a low gradient system situated in a meadow. Chironomids were low in abundance and ranked lower in 2nd order reference

Table 12. Relative and absolute abundances of the top five invertebrate taxa in Yellowstone National Park study streams.

Stream Burn Sites	Order	Rank	Date 11/88	%	#/m2	Date 3/89	%	#/m2	Date 8/89	%	#/m2
EF Blacktail	1	1	Chironomidae	65.0	3470	Chironomidae	78.9	1641	Chironomidae	59.2	3824
		2	Ostracoda	16.0	856	Alloperla	4.3	90	Ostracoda	7.2	371
		3	Alloperla	10.5	559	Ostracoda	3.6	75	Chiron. pupae	5.3	341
		4	Zapada oregonensis	2.3	124	Cinygmula	1.2	26	Elmidae	5.2	271
		5	Elmidae	2.1	105	Limnophila	0.9	19	Baetis bicaudatis	5.1	331
WF Blacktail	1	1	Chironomidae	62.3	8361				Chironomidae	30.8	4213
		2	Micrasema	8.2	1103				Baetis bicaudatis	18.8	2576
		3	Elmidae	6.1	813				Elmidae	9.2	1253
		4	Zapada oregonensis	4.7	634				Micrasema	8.3	1131
		5	Ephemerella inermis	3.9	519				Ephem. infrequens	6.8	928
Upper Cache	1	1	Chironomidae	70.7	6869				Chironomidae	42.4	2108
		2	Alloperla	7.2	702				Baetis bicaudatis	27.8	1383
		3	Ostracoda	4.4	425				Capnia	9.9	491
		4	Oligoplectrum	4.0	388				Alloperla	4.2	207
		5	Visoka cataractae	2.3	224				Glutops	3.3	166
Fairy	1	1	Chironomidae	74.8	3306	Chironomidae	84.1	2407	Baetis sp.	42.7	854
		2	Elmidae	8.3	367	Elmidae	8.9	254	Chironomidae	30.7	615
		3	Hydracarina	2.7	117	Baetis intermedius	4.2	120	Baetis bicaudatis	20.1	322
		4	Zapada oregonensis	2.5	111	Zapada sp.	0.5	15	Elmidae	12.2	243
		5	Chironomidae pupae	1.3	55	Rhyacophila vespula	0.5	13	Baetis intermedius	11.5	184
Twin	1	1	Chironomidae	43.2	11312	Chironomidae	72.8	14782	Chironomidae	61.9	12529
		2	Baetis bicaudatis	33.9	8895	Epeorus sp.	11.1	2260	Baetis sp.	18.7	3775
		3	Zapada oregonensis	3.0	785	Baetis bicaudatis	3.8	777	Zapada oregonensis	3.2	647
		4	Capnia	2.7	715	Alloperla	1.8	359	Ephem. infrequens	1.8	365
		5	Cinygmula	2.6	670	Amaletus sp.	1.3	267	Chiron. pupae	1.6	331
Blacktail	2	1	Chironomidae	36.6	8833	Chironomidae	30.3	2565	Chironomidae	38.7	2478
		2	Baetis bicaudatis	18.2	4385	Ephem. inermis	16.8	1426	Baetis bicaudatis	18.4	1176
		3	Cinygmula	5.9	1434	Elmidae	11.0	933	Zapada oregonensis	8.5	542
		4	Antocha	5.9	1428	Pericoma	5.8	495	Heterlimnius	7.2	459
		5	Elmidae	5.0	1210	Baetis bicaudatis	5.5	467	Oligochaeta	3.4	173
Lower Cache	2	1	Chironomidae	54.5	3771	Epeorus sp.	38.9	37	Chironomidae	53.7	8015
		2	Capnia	19.6	1353	Chironomidae	22.2	21	Capnia	13.3	1991
		3	Cinygmula	5.7	397	Podmosta adult	11.1	11	Chironomidae pupae	8.0	1201
		4	Alloperla	5.2	359	Prosimulium	11.1	11	Elmidae	3.7	548
		5	Heterlimnius	2.6	181				Alloperla	3.3	493
Upper Cache	2	1	Chironomidae	53.9	1291				Chironomidae	70.3	2249
		2	Ostracoda	11.2	269				Chironomidae pupae	5.1	162
		3	Alloperla	10.7	256				Baetis bicaudatis	2.5	81
		4	Cinygmula	6.9	164				Simulium	2.5	79
		5	Capnia	3.3	79				Zapada columbiana	2.2	70
Fairy	2	1	Simulium	42.2	6686				Simulium	33.9	5111
		2	Chironomidae	29.6	4693				Ostracoda	20.7	3120
		3	Elmidae	12.9	2038				Elmidae	11.4	1718
		4	Tricorythodes	3.5	561				Hyallela azteca	11.1	1665
		5	Hydroptila	2.2	348				Chironomidae	6.9	1046
Iron Springs	2	1	Chironomidae	35.8	2883	Chironomidae	61.7	4951	Chironomidae	67.9	3956
		2	Drunella sp.	25.7	2070	Neothremma	5.6	446	Ostracoda	4.5	265
		3	Ostracoda	10.1	815	Zapada oregonensis	5.3	423	Chironomidae pupae	2.4	141
		4	Ephemerella inermis	4.3	348	Hydracarina	5.0	401	Baetis intermedius	2.0	115
		5	Alloperla	3.7	299	Drunella coloradensi	4.3	344	Hydracarina	1.9	113

Table 12 cont.

Stream	Order	Date 11/88	%	#/m2	Date 3/89	%	#/m2	Date 8/89	%	#/m2
Cache	3	1 Chironomidae	62.3	5860	Chironomidae	58.1	2990	Chironomidae	30.7	271
		2 Antocha	7.0	651	Cinygmula	12.4	638	Zapada sp.	13.0	115
		3 Brachycentrus	5.3	495	Epeorus sp.	6.1	312	Hydracarina	6.5	58
		4 Cinygmula	4.5	420	Epeorus deceptivus	4.2	216	Drunella doddsi	6.5	58
		5 Oligoplectrum	3.4	318	Nemoura	3.6	184	Rhyacophila hyalinat	5.1	45
South Cache	3	1 Chironomidae	62.2	21568	Chironomidae	61.9	5235	Chironomidae	45.4	3884
		2 Micrasema	10.2	3545	Epeorus sp.	10.8	913	Zapada sp.	15.8	1351
		3 Cinygmula	5.7	1991	Micrasema	3.9	331	Hydracarina	8.6	738
		4 Antocha	3.4	1180	Oligophlebodes	3.4	284	Arctopsyche grandis	5.7	491
		5 Hydracarina	2.1	726	Cinygmula	3.2	273	Baetis bicaudatis	2.6	218
Hellroaring	3	1 Chironomidae	34.4	1161				Chironomidae	57.5	1577
		2 Cinygmula	28.4	958				Cinygmula	8.2	224
		3 Zapada sp.	5.9	198				Hydracarina	8.1	222
		4 Alloperla	3.3	111				Drunella doddsi	2.2	60
		5 Tubificidae	2.8	94				Zapada oregonensis	2.0	55
Iron Springs	3	1 Baetis intermedius	29.1	3852	Chironomidae	39.1	11857	Baetis intermedius	24.0	2108
		2 Chironomidae	19.9	2633	Baetis intermedius	35.5	10777	Chironomidae	20.8	1829
		3 Micrasema	8.8	1165	Baetis bicaudatis	4.8	1451	Simulium	13.3	1172
		4 Brachycentrus	5.2	691	Ephem. inermis	4.7	1413	Rhyacophila vespula	6.6	583
		5 Elmidae	4.7	623	Micrasema	3.1	935	Hydracarina	5.3	465
Lava	3	1 Cinygmula	45.6	4309	Drunella sp.	24.4	1639	Elmidae	17.4	1001
		2 Oligochaeta	9.1	858	Chironomidae	15.0	1009	Chironomidae	16.0	922
		3 Elmidae	8.6	815	Ephemerella sp.	7.9	529	Ostracoda	9.4	216
		4 Chironomidae	6.9	647	Elmidae	7.7	519	Neothremma	7.5	429
		5 Rhithrogena	3.0	280	Baetis bicaudatis	6.2	416	Micrasema	5.4	309
Cache	4	1 Chironomidae	69.2	8598				Chironomidae	32.4	534
		2 Cinygmula	4.5	563				Zapada sp.	13.2	218
		3 Micrasema	4.4	551				Drunella doddsi	6.4	105
		4 Baetis bicaudatis	3.5	429				Arctopsyche grandis	6.1	100
		5 Rhithrogena	2.7	333				Rhithrogena	3.1	51
Hellroaring	4	1 Chironomidae	54.6	4878				Chironomidae	23.1	516
		2 Cinygmula	10.3	922				Alloperla	15.6	348
		3 Baetis bicaudatis	5.2	465				Cinygmula	12.4	277
		4 Rhithrogena	4.1	367				Oligophlebodes	5.9	132
		5 Oligochaeta	2.0	175				Hydracarina	4.2	94
Lamar	4	1 Chironomidae	28.5	1620				Baetis bicaudatis	15.5	132
		2 Micrasema	26.7	1519				Arctopsyche grandis	14.2	122
		3 Nemoura	6.3	359				Micrasema	14.0	120
		4 Rhithrogena	6.0	339				Chironomidae	7.7	66
		5 Chiron. adult	4.1	230				Anagapetus	7.5	64
Reference Sites										
Amphitheatre	2	1 Capnia	20.1	504	Oligophlebodes	23.8	2382	Baetis intermedius	30.3	3683
		2 Cinygmula	19.2	482	Nemoura	17.3	1731	Chironomidae	22.0	2678
		3 Chironomidae	16.2	408	Chironomidae	16.1	1614	Simulium	14.0	1359
		4 Oligophlebodes	12.6	316	Cinygmula	15.3	1534	Rhyachophila vespula	6.0	583
		5 Prostoia	8.9	224	Prostoia	7.0	696	Ostracoda	5.1	615
Rose	2	1 Baetis bicaudatis	36.2	2618	Chironomidae	25.4	1654	Chironomidae	46.9	1726
		2 Chironomidae	21.4	1543	Baetis bicaudatis	17.3	1127	Baetis intermedius	5.2	190
		3 Cinygmula	6.3	457	Alloperla	7.0	459	Turbellaria	4.9	181
		4 Alloperla	4.8	350	Cinygmula	6.6	427	Alloperla	4.4	160
		5 Capnia	4.4	316	Ostracoda	6.5	425	Chironomidae pupae	4.2	154
Pebble	3	1 Chironomidae	28.8	3498				Baetis sp.	12.7	647
		2 Baetis bicaudatis	19.3	2341				Chironomidae	9.8	501
		3 Zapada sp.	7.7	930				Alloperla	8.6	437
		4 Cinygmula	5.9	711				Zapada oregonensis	6.8	350
		5 Oligophlebodes	4.4	531				Baetis tricaudatis	6.5	333
Soda Butte	4	1 Chironomidae	39.6	5546				Chironomidae	59.0	16805
		2 Oligochaeta	12.9	1810				Brachycentrus	5.4	1532
		3 Podmosta	9.2	1289				Pteronarcella sp.	2.1	602
		4 Pteronarcella sp.	6.8	958				Chirononomidae pupae	1.6	448
		5 Hydracarina	4.7	653				Hydracarina	1.4	395

sites than in burn sites. In the 2nd order reference sites the mayfly's, usually Baetis sp., were ranked higher than chironomids.

Taxon response was variable in the 3rd order burn sites. In Cache Creek and South Fork Cache Creek chironomids were most abundant over other taxa (>60%) in October 1988 and March 1989 and decreased in abundance (about 30%) by August 1989. While in Iron Springs, Hellroaring, and Lava Creeks the chironomids were low in abundance (<40%), and typically ranked below other taxa (Table 12). In these sites the mayfly's again were predominant, in particular Baetis sp. and Cinygmula. Baetis was predominant over chironomids in the 3rd order reference site.

Chironomids were relatively abundant in both burn and reference 4th order sites for both sampling dates. Notable differences in taxa response in the 4th order burn sites was the absence of Oligochaeta and Pteronarcella, and the presence of Micrasema (Table 12). Micrasema also was present in other lower order burn sites, while being absent in the reference sites.

DISCUSSION

Initial Impacts

Our assessment of the immediate effects of the fire are based on comparison of measurements and direct observations in the 18 burned and 4 unburned streams within the first few weeks following fire. Apart from obvious losses in watershed and riparian vegetation and almost instantaneous conversion to charcoal and ash, the most evident immediate changes were the incineration and scorching of emergent mosses and the heat fracturing (splaying) of rocks in and adjacent to 1st and 2nd order streams. In addition, the carcasses of up to 10 cutthroat trout per 250 m were observed in 3rd order Cache and West Fork of Blacktail Deer Creeks. Most dissolved chemical measures showed increased levels associated with fire. Following the 1988 Red Bench Fire in Glacier National Park, ammonium increased from <10 to 260 ug/l and water temperatures increased up to 10_{o} C within a day of the fire (R. Hauer and C. Spencer as quoted by D. Schwennesen in the Missoulian, March 1990); either factor could have resulted in mortality of fish. Little or no immediate deleterious effect of the fires was evident in periphyton and benthic macroinvertebrates in our study.

Effects of Alteration of Food Quality

Between October 1988 and March 1989 there were marked decreases in abundance, richness, and H' diversity in six of eight burn

sites examined, whereas these values increased or remained constant in the reference streams (Figure 14,15). We attribute these changes to high amounts of charcoal on the stream bottoms and in transport as a result of the fires (Figure 11,12), since little physical disturbance from runoff occurred during this period. We believe that the charcoal decreased the palatability and quality (e.g., increased C:N values) of the organic matter pool as food. Although benthic organic matter increased in amounts between October and March in six burn streams, it decreased in five others and similar patterns were seen in the two reference streams (Figure 12). However, the burn streams all had substantially greater proportions of charcoal making up the BOM than did the reference streams and in all but three of the burn streams the amounts of charcoal increased while decreasing in the reference streams. Chlorophyll a and algal standing crops (AFDM) decreased in the burned streams (except Iron Springs 3^{o}) during this period, with comparable changes observed in the reference streams (Figure 13).

Effects of Runoff

Melting of the spring 1989 snow pack was much slower than had been anticipated (P. Farnes, SCS, Bozeman, pers. comm.). Consequently, even though several periods of "blackwater" associated with runoff from heavy rains occurred between runoff and our August sampling period, erosion of the stream bed and alteration of channel morphology generally were much less than we had anticipated (Figures 1-4). However, several 1st through 3rd order streams, particularly in the Cache Creek and Hellroaring Creek drainages, did sustain substantial channel alteration. Should more usual runoff patterns occur this spring with the near normal snowpack, severe scouring of the channels may still develop. But, if the milder conditions experienced in 1989 persist over the next year or so, damage from the fire may be much less severe and recovery much more rapid than we had originally predicted (Minshall et al. 1989). Even with the more "controlled" runoff, changes in woody debris and channel conditions were detected (Figures 5,6; Table 3). Marked reductions were observed in diversity of current velocities in the burn streams, as indicated by differences in coefficients of variation between the two dates. Similar changes in substratum were recorded in half of the burn stream sites (Table 4). No comparable changes in either velocity or substratum occurred in the reference streams.

Many dissolved constituents were higher in August 1989 than in October 1988, apparently in response to rains during or immediately prior to the summer 1989 sample collections. In the burn streams, charcoal increased in amount and relative abundance in transport between 1988 and 1989 and BOM values suggested that charcoal was being removed from the headwater streams and

deposited in the downstream (3rd and 4th order) locations. Periphyton also tended to be scoured from the headwater streams but to be enhanced in the most downstream study sites (4th order) following runoff in 1989.
Woody debris movement is mainly a function of stream width and peak stream discharge, so with increased flows following a fire more pieces of normally stable wood are likely to be moved. Over the first year following the 1988 fires, little net change occurred in either burn or reference streams in terms of total number of pieces of wood in a given stream reach (Figure 6). Before the fires, watersheds and riparian zones were old growth Douglas Fir and Engelmann Spruce, except for the fourth order Soda Butte Ck. which has a grassy riparian zone along the study reaches. A comparison of the reference and burn woody debris load showed each have similar amounts of wood in 1988, so change that occured in the burn streams but not the reference streams can be attributed to the fire. The exception for this is Soda Butte Creek, where because of the lack of woody riparian vegetation the channel is nearly devoid of wood. For this reason, Soda Butte Creek is not representative of a true reference stream, and the values seen in Figure 6 do not reflect the prefire conditions of the 4th order burn streams.

As stream size and peak discharge increase, fewer pieces of wood are large enough to remain stable across a channel. The 4th order streams in Yellowstone are able to move old growth trees from across the channel to along the high flow channel banks (from data not presented here), indicating stable debris dams cannot be maintained across the channel.

Most change took place in 3rd order burn streams, where the largest size of wood could be moved downstream but not necessarily removed from the channel (Figure 6). Smaller streams only can move smaller pieces of wood, so less change takes place and fewer pieces of wood are relocated. Fourth order streams don't have as many pieces of wood in the channel to be moved, so this value also decreases from the 3rd order stream value. The 2nd, 3rd, and 4th order burn streams showed more change than the respective reference streams, indicating greater disturbance and instability. This increase in stream instability will likely have an impact on the pool-riffle-run structure of the streams over the next few years, until the stream wood movement returns to the normal levels of wood rearrangement and the channel morphology changes at a slower rate.

These changes were related also to the invertebrate shifts and the channel cutting that was observed in the burn streams, where the more variable environment eliminates some species which have adapted to a more structured habitat with less disturbance. Some invertebrates have adapted to surviving disturbance events by finding refugia or by being in an adult or egg phase during spring run-off, so these species can recolonize a stream

immediately after other insects have been removed from the stream channel.

In keeping with the moderated physical disturbance from the first postfire runoff, relative little impact on the benthic invertebrate community was detected. The most notable apparent effects were decreases in abundance and richness (but not biomass) in 4th order burned streams and a disproportionate amount (numbers and biomass) of miners (chironomids) in the burned streams. The differences observed at the Fairy Creek sites indicate that stream gradient or substrate size may influence macroinvertebrate response to fire. The changes in chironomid abundance evident in higher gradient systems, e.g. the Cache Creek sites, were not observed at Fairy Creek. Indeed, chironomids were ranked below other taxa at Fairy Creek 2nd order site for both time periods. The substratum at Fairy Creek also is comprised primarily of small pebbles, while cobbles are predominant in the higher gradient streams.

ACKNOWLEDGMENTS

R. E. Gresswell and R. D. Jones of the US Fish and Wildlife Service and J. Fowler and J. D. Varley of the National Park Service in Yellowstone have helped immeasurably with logistical matters related to this study. Numerous individuals have helped to make the field work both successful and enjoyable: D. A. Andrews, M. Arunachalam, S. J. Bailey, C. Biastock, G. Bowles, D. G. Carty, T. Fuhrman, S. Hart, P. Koetsier, J. Lawrence, J. Mann, D. L. Mahony, M. McIntyre, S. McIntyre, J. M. Minshall, J. N. Minshall, S. C. Minshall, G. Mladenka, K. Moholt, C. Nelson, B. Parker, S. Relyea, D. Taylor, R. L. Vannote, J. Wood, and G. Zappetti. Others who have helped with sample collection are: R. Ewing, J. Mohrman, and L. Wallace. In addition, many of the field personnel also helped with the processing of samples and/or data in the laboratory where they were joined by: B. Olenick, J. Check, R. Gill, J. Mihuc, T. Mihuc, and L. Reed. P. Farnes and J. Mohrman generously provided data and information on precipitation and runoff. J. Clark, horsepacker, taught us a whole new level of verbal expression. The "bear brothers", M. Jamison and J. Jonkle, shared their cabin, grub, and tall tales with us on Hellroaring Creek.

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