Figure 5. Chipmunk Creek, Yellowstone National Park, in unburned area. *Photograph by the author, July 1976.*

Figure 6. Yellowstone National Park Stream No. 174 after the 1976 Continental Divide fire. *Photograph by the author, July 1976.*

Aufwuchs accumulation on artificial substrates was used here as a comparative index of productivity between Chipmunk Creek and Passage Creek. The substrates were clear plexiglass plates, 15 cm^2 by 3 mm thick. A 16-mm diameter hole was drilled in each substrate; the hole was centered 14 mm in from the midpoint of one edge of the square substrate. Surface area of each side of the substrates was 223 cm^2. Each substrate was positioned in the stream by slipping it down a 13-mm diameter hardwood dowel driven into the stream bottom. One substrate, resting on the stream bottom, was used per dowel.

On 24 June, three artificial substrates were placed in the streams at each of Stations C-1, C-2, C-3, P-1, P-2, P-3, and P-4 (Figure 2). Station locations were matched with respect to elevation. Elevations of the stations were: C-1 and P-1, 2438 m; C-2 and P-2, 2487 m; C-3 and P-3, 2505 m; P-4, 2566 m. Station P-4, located in Passage Creek above the burned area, was chosen to provide a comparison of burned and unburned Passage Creek stations.

Accumulated aufwuchs were collected from the substrates on 7 and 8 July, 4 and 5 August, 18 and 19 August, and 1 and 2 September. Aufwuchs were collected from both sides of the substrates with a single-edge razor blade and a wash bottle with demineralized water. The collections were preserved in Lugol's solution (Slack, et al. 1973).

Due to decreasing stream water level, some substrates were partially or completely exposed after the first two accumulation periods. Samples from exposed substrates were used only for identification of aufwuchs organisms. Those substrates were later repositioned in deeper water for the following accumulation period. At the time of collection of each aufwuchs sample, percent sky, water depth, distance from nearest streambank, percent silt, percent sand, percent of Yellowstone Lake (Figure 1). A decision was made to allow the fire to burn. By 16 July, the Continental Divide fire had burned over most of its eventual area of 200 ha. The fire continued to smolder in spots until fall when it was extinguished, presumably by rain and snow. The overstory, which was completely killed, was mostly Engelmann spruce and subalpine fir; some lodgepole was also killed. The spruce and fir in the area were about 300 years old; the lodgepole pine dates back to about 1879 (D. G. Despain, Plant Biologist, U.S. National Park Service, pers. commun.).

Two small streams draining the Continental Divide into the South Arm, Yellowstone Park Streams Nos. 173 and 174, run through the burn (Figures 1 and 6). The watersheds of the two streams were almost entirely burned by the fire.

Figure 3. Chipmunk Creek, Yellowstone National Park, at the boundary of the burned area, about 1 km above the confluence with Passage Creek. *Photograph by the author, July 1976.*

MATERIALS AND METHODS

Chipmunk Creek-Passage Creek Study Area

The Chipmunk Creek-Passage Creek Study Area lies about 25 km from the nearest road. Access to the area was by boat from Lake, Wyoming to the end of the South Arm of Yellowstone Lake, and then by trail from there to the study area (Figure 1). All equipment and supplies were backpacked to the study area from the South Arm. Six trips were made to the study area at 2-week intervals between 21 June and 2 September 1976.

Stream temperature data on Chipmunk Creek and Passage Creek were gathered just above the confluence of the two streams. A pocket thermometer was used on 23 June. A dual probe recording thermograph (Belfort Instruments No. 5-1135) placed at the confluence recorded temperatures over 9-day periods in both streams starting 7 July, 21 July, 4 August, and 18 August, respectively. The thermograph was recalibrated before being put into operation each time it was used. Average daily temperatures were estimated from the thermograph charts by reading the charts at every 2-hour interval on the chart, and calculating the arithmetic average.

Figure 4. Passage Creek, Yellowstone National Park, in the area of the 1931 burn. *Photograph by the author, July 1976.*

Streamflow was measured in both streams near their confluence on each of the trips to the study area using the method of Robins and Crawford (1954). The areas of the watersheds of the two streams were determined with USGS topographic maps and a polar planimeter. From flow and drainage area data, daily water yields were estimated by dividing the daily discharge by the drainage area.

Water samples were taken from both creeks near the confluence on 23 June, 22 July, 5 August, and 31 August. The samples were analyzed for total dissolved solids (TDS), total hardness, calcium hardness, magnesium hardness, sodium, potassium, iron, manganese, copper, total alkalinity, phenolphthalein aklalinity, bicarbonate alkalinity, chloride, fluoride, sulfate, nitrate-nitrogen, Kjeldahl nitrogen, phosphate, orthophosphate, carbon dioxide, total organic carbon (TOC), silica, turbidity, and pH. Collection, preservation, and analysis of water samples were conducted according to *Standard Methods for the Examination of Water and Wastewater* (American Public Health Association, et al. 1971). The water analyses were performed by Orlando Laboratories, Orlando, Florida. On 23 June and 22 July, pH was also determined in the field with a Hellige Color Comparator pH kit. From the water quality and water yield data, daily mineral export rates were estimated by multiplying concentration times daily water yield.

Picea engelmannii, in the overstory. Grasses; sedge, *Carex*; and willow, *Salix*, are present along streambanks.

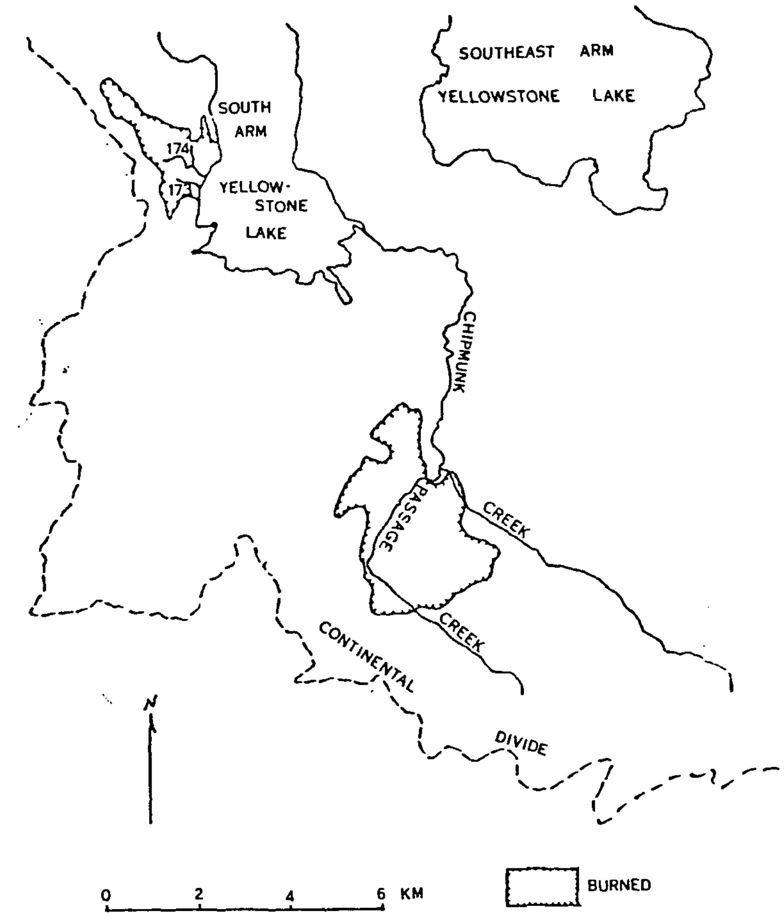

Figure 1. Chipmunk Creek, Passage Creek, and Streams Nos. 173 and 174, Yellowstone National Park, Wyoming. The locations of the 1931 and 1940 Chipmunk Creek burn, and of the 1976 Continental Divide burn, are shown.

In September 1931, a fire burned 506 ha near the confluence of Chipmunk Creek and Passage Creek (Figure 2). In June 1940, a fire burned 481 ha immediately south of the 1931 burn. Both fires were started by lightning and suppressed artificially. In both fires, the forest overstory was completely killed. In August 1953, a fire burned 49 ha in a location about 3 km east of the 1931 and 1940 burns.

The 1931 and 1940 burns, which have a common boundary, form a burned area of 987 ha. The burned area occupies about 20% of the Passage Creek watershed and borders both sides of Passage Creek for the lower 60% of the

length of the creek (Figure 2). The 1931 and 1940 burns also extend partially into the Chipmunk Creek watershed. Burned area, including the 1953 burn, occupies about 3% of the Chipmunk Creek watershed, and borders Chipmunk Creek along the lower 1 km of its length. For the purposes of this study, the burned areas in the Chipmunk Creek watershed are considered to be negligible with respect to possible effects on Chipmunk Creek.

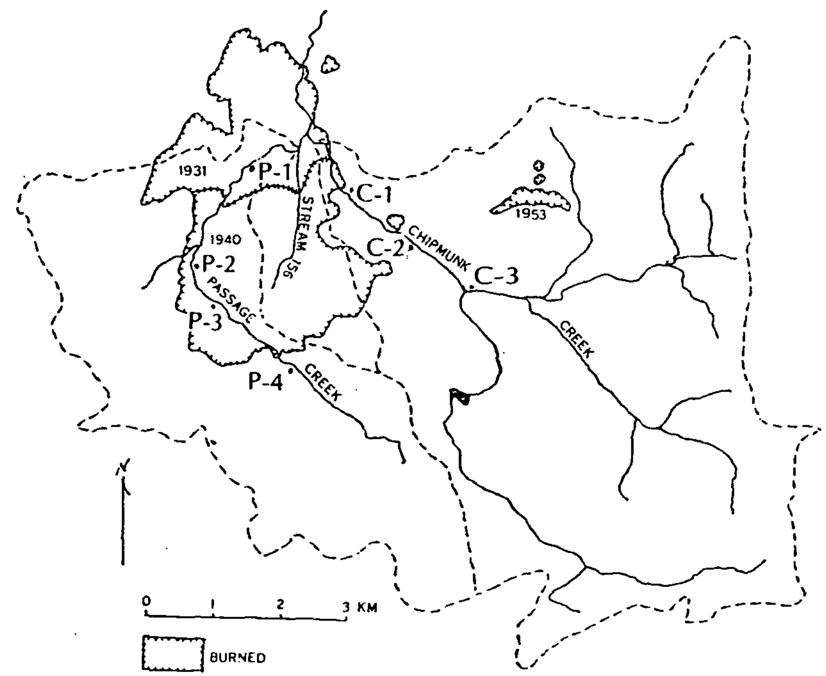

Figure 2. Chipmunk Creek-Passage Creek area, Yellowstone National Park, Wyoming. The 1931, 1940, and 1953 burns are shown. The dashed lines denote watershed boundaries. Locations of sampling stations C-1 through C-3 and P-1 through P-4 are shown.

There is still a distinct contrast between the 1931–1940 burned area and the surrounding forest (Figure 3). The landscape in the burned area is relatively open. Snags, standing and fallen, are present throughout the burn (Figure 4). Below standing snags, patches of lodgepole pine (about 4 m high in the 1940 burn and 6 m high in the 1931 burn) are recolonizing the burn area. The riparian area along Passage Creek is open; there is no overstory. The surrounding forest, which is about 300 years old, is very dense relative to the burned area. Along Chipmunk Creek, the overstory forms a tangle of foliage that shades most of the water surface (Figure 5). There is little low brush overhanging either Chipmunk Creek or Passage Creek.

1976 Continental Divide Fire Study Area

On 11 July 1976, lightning started a fire near the west shore of the South Arm

Calif. Fish and Game 65(4): 1979

FIRE AND STREAM ECOLOGY IN SOME YELLOWSTONE LAKE TRIBUTARIES [1]

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This study attempted to clarify some effects of forest fires on streams in selected tributaries to Yellowstone Lake, Yellowstone National Park, in partial evaluation of the Park's natural burn fire management policy.

In a stream in a watershed burned 45 and 36 years ago (Passage Creek) some changes were found, when compared to a similar stream in an unburned adjacent watershed (Chipmunk Creek). Summer stream temperatures averaged about 1.5 C higher in Passage Creek. Streamflow showed a greater seasonal fluctuation and a higher water yield in Passage Creek. Water quality conditions in both streams were similar, but mineral export was greater in Passage Creek due to greater water yield. Aufwuchs accumulation on artificial substrates showed no significant difference between the two streams. Benthic sampling suggested a general increase in benthic macroinvertebrates in Passage Creek. The fry of Yellowstone cutthroat trout, *Salmo clarki lewisi*, appeared to emerge from the gravel earlier in Passage Creek than in Chipmunk Creek. Based on stream temperature differences, the difference in egg incubation time was calculated to be 4 days.

Two other streams were studied during and immediately after a fire burned their watersheds (Streams 173 and 174). No harmful effects were found. Concentrations of calcium, magnesium, potassium, chloride, sulfate, phosphate, and total organic carbon were raised somewhat during a rainstorm, apparently as a result of ash leached into surface runoff.

INTRODUCTION

According to the Second Law of Thermodynamics, organic material is an inherently unstable arrangement of matter. Organic material must eventually return, through disaggregation and release of energy, to the more stable inorganic state. The return to the inorganic state can be accomplished biologically, by decay and decomposition, or physically, by fire. In some terrestrial communities, the greater the accumulation of plant biomass, the greater is the probability of fire when conditions of wind and moisture are correct. Fire can be a natural, periodic occurrence.

The primary management philosophy in Yellowstone National Park is to maintain the Park in as natural a condition as possible, with human impact held to a minimum (U.S. National Park Service 1975). From about 1890 to 1972, fires were artificially suppressed throughout the Park; fire was prevented from assuming its full ecological role. In 1972, 138,000 ha of the Park were designated "natural fire zones." From 1972 to 1975, 19 lightning-caused fires totaling 340 ha were allowed to burn out, unsuppressed, in the natural fire zones. In February 1976, a natural fire management plan for the entire Park was adopted (U.S. National Park Service 1976). The plan calls for suppression of fires that are man-caused, or that threaten human life and property, cultural and historic resources, outside lands and resources, or endangered species. Other fires are generally allowed to burn. Fire control decisions are made on a fire-by-fire basis.

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The intent of the 1976 plan is to restore the natural influences of fire to the Park's plant and animal communities, in subscription to the Park's primary management philosophy. During the summer of 1976, under the 1976 fire management plan, a lightning-caused fire that burned 200 ha was allowed to burn out, unsuppressed, in the Continental Divide area of the Park.

To fully evaluate the 1976 Yellowstone Park fire management plan, the effects of fire on stream ecology in general, and on Yellowstone's fish populations in particular, should be known, whether the effects are beneficial, benign, or detrimental. This study attempted to identify and evaluate some of the long-term effects of fire on stream ecology by comparing a stream in an unburned watershed (Chipmunk Creek) with an otherwise similar stream (Passage Creek) in a watershed with burns 36 and 45 years old. In Chipmunk Creek and Passage Creek, effects on stream temperature, streamflow, water quality, benthic macroinvertebrates, stream productivity, and Yellowstone cutthroat trout, *Salmo clarki lewisi*, populations were examined. The hypotheses tested were:

1. Fire indirectly increases summertime stream temperatures by reducing stream shading through reduction in riparian vegetation.
2. Fire alters streamflow regimes as a result of changes in terrestrial vegetation and other watershed conditions.
3. Fire alters stream chemical water quality as a result of minerals contributed by ash and alteration of other watershed conditions.
4. Fire increases the biological productivity of streams.

This study also attempted to identify and evaluate some of the short-term effects of fire on streams by examining streams (Yellowstone Park Streams Nos. 173 and 174) during and immediately after the 1976 Continental Divide fire burned their watersheds. In Yellowstone Park Streams Nos. 173 and 174, effects on stream temperature, water quality, benthic macroinvertebrates, and Yellowstone cutthroat trout populations were examined, but in less detail than in Chipmunk Creek and Passage Creek. The hypotheses tested were:

1. During a fire, stream temperatures are increased.
2. During and immediately after a fire, stream chemical water quality is altered as a result of minerals contributed by ash.
3. The immediate temperature and water quality effects of fire may be lethal to aquatic life.

STUDY AREAS

Chipmunk Creek-Passage Creek Study Area

Chipmunk Creek and its main tributary, Passage Creek, are located in southeastern Yellowstone National Park, Wyoming. The creeks drain off the eastern slope of the Continental Divide into the South Arm of Yellowstone Lake (Figure 1). As used herein, "Chipmunk Creek" will refer to that portion of Chipmunk Creek above its confluence with Passage Creek. Above their confluence, Chipmunk Creek and Passage Creek are similar in gradient. Both streams are characterized by long, shallow riffles, and few pools. Chipmunk Creek drains an area of 39.3 km^2; Passage Creek drains an area of 21.2 km^2.

The woody vegetation in the area is composed predominately of lodgepole pine, *Pinus contorta*; subalpine fir, *Abies lasiocarpa*; and Engelmann spruce, gravel (0.5–5.0 cm), percent rubble (5–30 cm), and surface water velocity were estimated, in the immediate vicinity of the substrate. Water depth and distance from the nearest streambank were measured with a meter stick. Percent sky (the portion of the sky not blocked out by vegetation or hills), and percent silt, sand, gravel, and rubble were estimated by eye. Surface velocity was measured with a stopwatch and a float on a measured leader, or with a Gurley pygmy current meter, or, in the case of very slow velocities, with spit, meter stick, and stopwatch. Air and water temperatures were taken with a pocket thermometer at each station.

The ash-free weight of each sample was determined by weight loss on ignition at 500 C (American Public Health Association, et al. 1971). The ignition of blank samples confirmed that Lugol's solution added no ash-free weight to the samples.

Due to logistical problems, the nine Passage Creek aufwuchs samples collected 7 July were in the stream 13 days, the single Chipmunk Creek sample collected 4 August was in the stream 27 days, and the six Passage Creek samples collected 5 August were in the stream 29 days. All other aufwuchs samples were in the stream 14 days. For comparative purposes, the weights of the 16 samples with exposure times other than 14 days were converted to 14-day weights by linear interpolation or extrapolation. Analysis of covariance (Nie, et al. 1965) was used to determine if aufwuchs accumulation at the burned stations was significantly different from aufwuchs accumulation at the unburned stations.

To investigate the relationships between environmental variables and aufwuchs accumulation, a multivariate correlational analysis (Cooley and Lohnes 1971) was performed on the data. The variables were: (1) days past June 1 at time of collection (this variable should account for seasonal trends in aufwuchs accumulation), (2) elevation, (3) years since burn, (4) percent sky, (5) substrate depth, (6) substrate distance from nearest streambank, (7) percent silt, (8) percent sand, (9) percent gravel, (10) percent rubble, (11) surface velocity, and (12) 14-day ash-free weight of accumulated aufwuchs.

To compare the benthic macroinvertebrate communities of Chipmunk Creek and Passage Creek, benthic sampling in the two streams was conducted on 22 July. Samples were taken at Station C-1 in Chipmunk Creek and at Station P-1 in Passage Creek (Figure 2). The Chipmunk Creek sampling site was in a well-shaded riffle, typical of that stream. The Passage Creek sampling site was in an unshaded riffle, typical of that stream.

Due to the variety of physical habitats found even within a single physically uniform riffle, the distribution of benthic organisms in it tends to be very irregular. In reappraising the data of Needham and Usinger (1956), Chutter (1972) calculated that 448 Surber samples (Surber 1936) would have been necessary to be 95% confident of being within 5% of the true mean of the number of benthic macroinvertebrates per ft ^{2} in a single riffle in Prosser Creek, California.

Due to the difficulty of obtaining good estimates of benthic macroinvertebrate populations over an entire riffle, benthic sampling was limited to a narrowly defined physical biotope. Reliable estimates of composition and size of populations within a narrow biotope may be obtained with relatively few samples. Differences in that biotope's benthic populations between streams could be indicative of general benthic population differences between streams. Benthic sampling was therefore arbitrarily limited to the biotope defined by the following physical parameters: distance from streambank, 0.5–1.5 m; depth, 0.15–0.25 m; surface velocity, 0.5–0.7 m/sec; substrate mainly of 5–15 cm rubble. Velocity was measured with a stopwatch and a float attached to a measured leader. A portable invertebrate box sampler (PIBS) (Ellis-Rutter Associates, Douglassville, PA) with a net of 0.35 mm mesh was used to collect eight benthic samples within the biotope at each sampling riffle. Sampling time was 8 minutes per sample.

The organisms in the benthic samples were preserved in 70% EtOH, identified, and counted. For each sample, a diversity index was calculated using the formula:

$$\bar{d} = -\sum_{i=1}^{s}\left(\frac{n_i}{n}\right)\log_2\left(\frac{n_i}{n}\right)$$

where n is the total number of individuals in the sample, n_i is the number of individuals in the i^{th} taxon, s is the total number of taxa, and $\bar{d}$ is diversity (Slack, et al. 1973). The diversity index is a reflection of the number of different taxa in the sample.

To capture downstream migrant cutthroat trout fry, drift nets were set at Station C-1 in Chipmunk Creek and at 0.5 km above the confluence in Passage Creek on 21 and 22 July and again on 18 and 19 August. The nets were 30.5 cm square by 1 m deep. The net material was Nitex® No. 656.

1976 Continental Divide Fire Study Area

Access to the Continental Divide Fire area was by boat from the South Arm of Yellowstone Lake. Streams 173 and 174 (Figure 1) were studied on 19 July, 23 July, 27 July, 3 August, and 9 September. On each trip, stream temperatures were taken with a pocket thermometer, and general observations of the aquatic biota were made. On 19 July, 3 August, and 9 September, water samples for chemical analysis were taken at the mouths of the streams. The chemical tests performed and the methods used were the same as those for Chipmunk Creek and Passage Creek water samples. The July 19 samples were taken when the fire was burning actively. The August 3 samples were taken during a rainstorm which was contributing some surface runoff to the streams. The September 9 samples were taken on a clear day with no surface runoff. The fire was still smoldering in spots on 3 August and 9 September.

RESULTS

Chipmunk Creek-Passage Creek Study Area

On 23 June, the temperature of Chipmunk Creek was 1.1 C warmer than the temperature of Passage Creek. In all subsequent measurements, the daily average temperature of Passage Creek was between 1.3 and 2.2 C warmer than that of Chipmunk Creek (Figure 7). The difference between the weekly average temperatures of the two streams was widest in late July (1.9 C), when the weekly average temperatures were warmest (12.4 C in Chipmunk Creek, 14.3 C in Passage Creek). The diurnal temperature fluctuation patterns of Chipmunk Creek and Passage Creek were nearly identical and parallel; temperatures were lowest at about 0600 hours and highest at about 1500 hours. Diurnal temperature fluctuations in both creeks ranged from 2.2 to 11.7 C. The highest instantaneous temperatures recorded were 19.4 C in Chipmunk Creek on 24 July and 20.9 C in Passage Creek on 25 July. The lowest instantaneous temperatures recorded were 3.9 C in Chipmunk Creek on 27 August and 5.8 C in Passage Creek on 27 August. The air and water temperatures at each aufwuchs collection station were always taken sometime between 0920 and 1620 hours. Air temperature was in all cases warmer than water temperature.

Streamflow in Chipmunk Creek and in Passage Creek decreased to less than one-tenth of the initial values during the study period (Table 1). Chipmunk Creek flow dropped from 4.06 m^3/sec on 23 June to 0.29 m^3/sec on 31 August; Passage Creek flow dropped from 4.24 m^3/sec on 23 June to 0.11 m^3/sec on 31 August. Thus Passage Creek flow was initially slightly greater than Chipmunk Creek flow; in late August, Passage Creek flow was less than half than the flow of Chipmunk Creek.

TABLE 1. Flow and Water Yield for Chipmunk Creek and Passage Creek, Yellowstone National Park, Summer 1976.

	Flow (m^3/sec)		*Water Yield (m^3/ha/day)*	
	Chip.	*Pass.*	*Chip.*	*Pass.*
23 Jun	4.06	4.24	89.3	173
8 Jul	1.55	1.29	34.1	52.6
21 Jul	0.66	0.50	14.5	20
4 Aug	0.45	0.20 (5 Aug)	9.9	8.2 (5 Aug)
18 Aug	0.32	0.16	7.0	6.5
31 Aug	0.29	0.11	6.4	4.3

Daily water yield per ha of watershed also decreased from June to September in both creeks (Table 1). Chipmunk Creek water yield dropped from 89 m^3/ha/day on 23 June to 6.4 m^3/ha/day on 31 August; Passage Creek water yield dropped from 173 m^3/ha/day on 23 June to 4.3 m^3/ha/day on 31 August. In June and early July, water yield was much higher in Passage Creek than in Chipmunk Creek. In August, water yield was slightly higher in Chipmunk Creek than in Passage Creek. Total water yields for the 6 days measured were 161.2 m^3/ha in Chipmunk Creek and 264.9 m^3/ha in Passage Creek.

In general, chemical concentrations in Chipmunk Creek were not markedly different from chemical concentrations in Passage Creek (Table 2). TDS values were slightly higher in Chipmunk Creek than in Passage Creek. TDS in Chipmunk Creek rose from 27 mg/l on 23 June to 82 mg/l on 31 August; TDS in Passage Creek rose from 24 mg/l on 23 June to 75 mg/l on 31 August. There were no consistent differences in calcium, magnesium, or sodium ion concentrations between the two creeks. Potassium concentration was consistently higher in Chipmunk Creek (average, 1.28 mg/l) than in Passage Creek (average, 1.06 mg/l). There were no differences found in iron, manganese, and copper concentrations between the two creeks. There were no consistent differences found in alkalinity, chloride, fluoride, sulfate, or nitrate-nitrogen concentrations. Except in the August 31 samples, more Kjeldahl nitrogen was found in Chipmunk Creek than in Passage Creek. On 22 July and 31 August, phosphate was slightly higher in the Chipmunk Creek samples than in the Passage Creek samples. Carbon dioxide, TOC, silica, turbidity, and pH showed no consistent differences between the two creeks. The August 31 Passage Creek sample had the highest pH and the lowest carbon dioxide concentration of any sample.

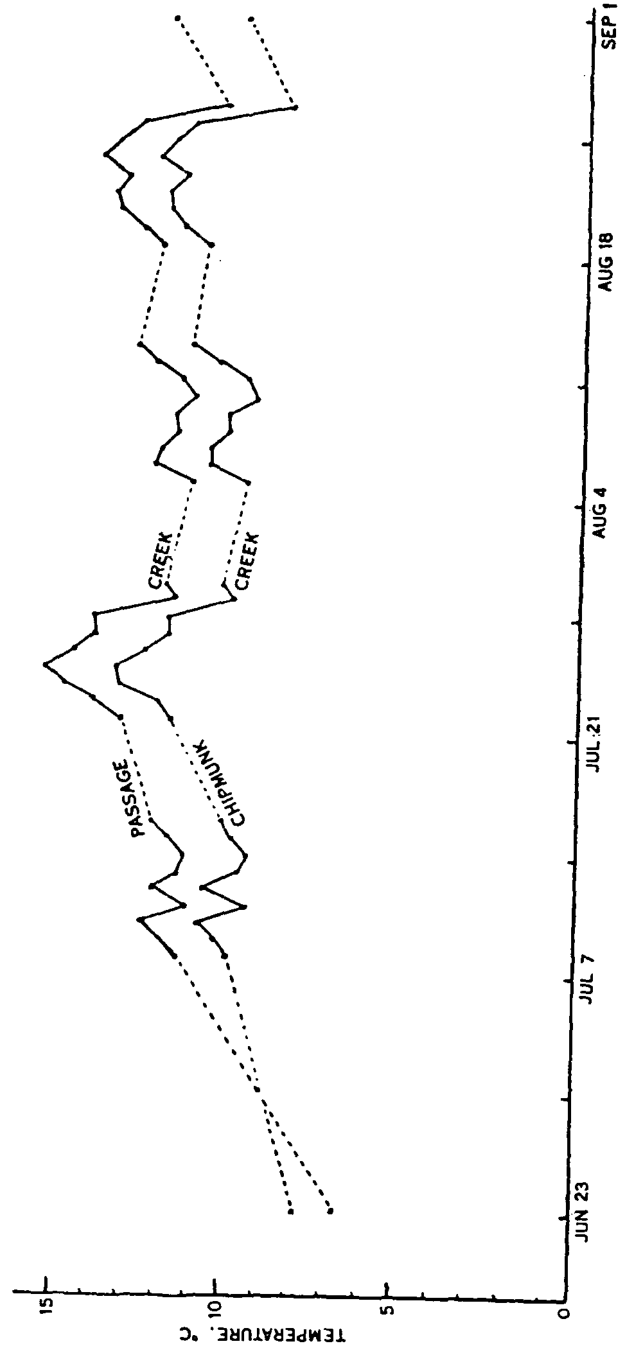

Figure 7. Average daily stream temperatures in Chipmunk Creek and Passage Creek, Yellowstone National Park, Wyoming, at the confluence of the two creeks, summer 1976. The 23 June values are single measurements taken at 1300 hours.

TABLE 2. Water Quality in Chipmunk Creek and Passage Creek, Yellowstone National Park, Wyoming, Summer 1976.

	23 June		22 July		5 Aug.		31 Aug.	
Substance (mg/l)	*Chip.*	*Pass.*	*Chip.*	*Pass.*	*Chip.*	*Pass.*	*Chip.*	*Pass.*
TDS	27	24	62	57	55		82	75
•Total hardness	16	16	26	24	24		28	24
•Calcium hardness	12	12	20	20	20		22	18
•Magnesium hardness	4	4	6	4	4		6	6
Sodium	1.9	1.5	2.1	1.7	2.5		8	9
Potassium	1.0	0.68	1.24	1.08	1.20		1.69	1.42
Iron	0.2	0.2	0.05	0.05	0.05		0.1	<0.1
Manganese	<0.05	<0.05	<0.05	<0.05	<0.05		<0.05	<0.05
Copper	<0.1	<0.1	<0.1	<0.1	<0.1		<0.1	<0.1
•Total alkalinity	14	14	28	26	24		40	40
•Carbonate alkalinity	0	0	0	0	0		0	4
•Bicarbonate alkalinity	14	14	28	26	24		40	36
Chloride	1	1	<1	<1	1		3	3
Fluoride	<0.1	<0.1	0.10	0.10	0.1		0.06	0.13
Sulfate	3	1	4	3	3		3	3
Nitrate-nitrogen	0.06	0.05	0.03	0.02	0.02		0.02	0.02
Kjeldahl nitrogen	0.53	<0.01	0.36	<0.01	0.08		<0.01	<0.01
Phosphate, as PO_4	<0.1	0.1	0.17	0.13	0.16		0.20	0.16
Orthophosphate, as PO_4	<0.1	0.1	0.17	0.13	0.16		0.20	0.16
Carbon dioxide	1.9	2.2	1.6	2.2	1.3		2.1	<1.0
Total organic carbon	9.9	7.5	5.2	8.6	3.2		0.60	1.05
Silica, as SiO_2	5	5	11	10	10		10	8.8
Turbidity, NTU	1.0	0.9	0.56	0.38	0.43		0.27	0.41
pH (Laboratory)	7.2	7.1	7.6	7.4	7.6		7.6	8.4
pH (Field	7.2	7.2	7.6	7.5				

Lost Sample
•as $CaCO_3$

Mineral export was generally higher in the Passage Creek watershed than in the Chipmunk Creek watershed on 23 June and 22 July, and higher in the Chipmunk Creek watershed on 31 August (Table 3). Due to higher overall water yield in Passage Creek, the 3-day totals of estimated export were generally higher in Passage Creek than in Chipmunk Creek. In the 3 days measured, TDS export estimates were 5633 g/ha in Passage Creek and 3726 g/ha in Chipmunk Creek. Sulfate ion was the only substance with higher 3-day export in Chipmunk Creek (341 g/ha) than in Passage Creek (247 g/ha).

A total of 67 aufwuchs samples (36 from unburned stations and 31 from burned stations) was gravimetrically analyzed. Mean aufwuchs accumulation was 32.6 mg per substrate at the burned stations and 22.9 mg per substrate at the unburned stations (Table 4). Analysis of covariance, however, showed the difference to be statistically insignificant ($p = 0.146$).

The main diatoms found on the artificial substrates from both streams were of the genera *Synedra, Ceratoneis, Denticula, Gomphonema,* and *Cocconeis.* The green alga *Ulothrix* was also found. Tendipedid larvae and Ephemeroptera naiads were found grazing on some substrates, in which case they were included in the sample.

Aufwuchs accumulation was positively correlated most strongly with percent silt ($r = 0.50$) and days past 1 June (indicates a seasonal trend) ($r = 0.43$), and

was negatively correlated most strongly with surface water velocity ($r = -0.42$). Other correlations showed that higher surface velocity was associated with larger substrate sizes, and that the older the burn, the less sky was visible through the canopy. Multiply regression analysis showed that 49% of the variation in aufwuchs accumulation could be predicted by all the other variables measured, and that 33% of that variation could be predicted by the variables percent silt, days past 1 June, and surface water velocity.

TABLE 3. Mineral Export, g/ha/day, in Chipmunk Creek and Passage Creek Watersheds, Yellowstone National Park, Wyoming, Summer 1976.

	Export, g/ha/day							
	23 June		22 July		31 Aug.		Totals	
Substance	*Chip.*	*Pass.*	*Chip.*	*Pass.*	*Chip.*	*Pass.*	*Chip.*	*Pass.*
TDS	2410	4147	900	1162	416	324	3726	5633
•Total hardness	1428	2765	377	489	142	103	1947	3357
•Calcium hardness	1071	3629	290	408	112	78	1473	4115
•Magnesium hardness	357	691	87	82	30	26	474	799
Sodium	170	259	30	35	41	39	241	333
Potassium	89	118	18	22	8.6	6.1	116	146
Iron	18	35	0.7	1				
•Total alkalinity	1250	2419	406	530	203	173	1859	3122
Chloride	89	173			15	13		
Fluoride			1.4	2	0.3	0.56		
Sulfate	268	173	58	61	15	13	341	247
Nitrate-nitrogen	5.4	8.6	0.4	0.4	0.1	0.09	5.9	9.1
Phosphate, as PO_4		17.3	2.5	2.6	1.0	0.69		20.6
Silica, as SiO_2	446	864	160	204	51	38	657	1106

•as $CaCO_3$

TABLE 4. Ash-free Weights, in mg, of Aufwuchs Accumulated 14 Days on Artificial Substrates at Burned and Unburned Stations in Chipmunk Creek and Passage Creek, Yellowstone National Park, Summer 1976. Values in Parentheses are Corrected 14-day Weights for Samples Collected After Periods Other than 14 Days. Asterisks Indicate Missing or Exposed Substrates.

	Burned			Unburned			
	P-1	*P-2*	*P-3*	*P-4*	*C-1*	*C-2*	*C-3*
7-8 July	5.0 (5.4)	2.5 (2.7)	3.1 (3.3)	1.5 (1.6)	3.0	2.2	5.1
	5.4 (5.8)	0.6 (0.6)	*	2.7 (2.9)	13.3	4.3	10.0
	51.1 (55.0)	2.3 (2.5)	*	*	5.7	0.3	1.5
4-5 Aug.	*	32.3 (15.7)	36.5 (17.6)	*	39.4 (20.4)	*	*
	*	43.3 (20.9)	19.0 (9.2)	*	*	*	*
	*	47.6 (23.0)	23.4 (11.3)	*	*	*	*
18-19 Aug.	170.6	18.7	61.8	40.7 (38.0)	16.5	41.0	8.1
	54.1	14.9	50.5	33.9 (31.6)	80.8	20.1	13.7
	55.5	22.3	40.8	19.0 (17.7)	90.9	9.9	13.4
1-2 Sept.	38.0	14.7	18.0	20.9	26.3	72.8	14.9
	69.5	20.1	23.7	32.5	23.2	27.5	19.2
	106.7	21.8	35.0	54.3	32.8	11.6	34.7
	$n = 31$			$n = 36$			
	$\bar{x} = 32.6$			$\bar{x} = 22.9$			

More benthic macroinvertebrate individuals were found in the Passage Creek benthic samples than in the Chipmunk Creek benthic samples (Tables 5 and 6).

The Mann-Whitney U-Test (Sokal and Rohlf 1969) was applied to the data and the difference was found to be statistically significant ($p < 0.05$). The difference was most evident in the Acari (1088 in Passage Creek, 138 in Chipmunk Creek), the Coleoptera (104 in Passage Creek, 17 in Chipmunk Creek), the Ephemeroptera (1144 in Passage Creek, 366 in Chipmunk Creek), and the Plecoptera (446 in Passage Creek, 204 in Chipmunk Creek). Fewer Trichoptera were found in Passage Creek (89 individuals) than in Chipmunk Creek (191 individuals).

The diversity indices of the Passage Creek benthic samples (Table 6) were generally higher than the diversity indices of the Chipmunk Creek benthic samples (Table 5). The Mann-Whitney U-Test was applied, and the difference was found to be statistically significant ($p < 0.05$).

TABLE 5. Benthic Macroinvertebrate Samples Taken from Chipmunk Creek, at Altitude 2438 m, Yellowstone National Park, Wyoming.

Sample	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*Total*	
Acari										*138*
sp. 1	15	9	5	8	24	8	17	23	109	
sp. 2	1	2		4	2	1	1	3	14	
sp. 3	2		1		2	1	6	3	15	
Coleoptera										*17*
Gonielmis					7		1		8	
Hydrovatus			5	1		3			9	
Collembola										*2*
Sminthurus								2	2	
Diptera										*1563*
Chironomidae sp. 1	128	43	123	142	267	239	116	287	1345	
Chironomidae sp. 2	19	34	10	26	38	19	20	18	184	
Atherix		1							1	
Simuliidae sp. 1			3			1			4	
Diptera sp. 1	11		1	1	10	4	2		29	
Ephemeroptera										*366*
Baetis	29	19	20	11	18	24	13	13	147	
Cinygmula	21	2	19	23	31	17	13	12	138	
Epeorus	7	3	2	3			3		18	
Ephemerella			7	2	2	1			12	
Heptagenia	4	5	7	3	3	1	3	1	27	
Pseudo cloeon		2		5			7	6	20	
Rhithrogena							2	2	4	
Plecoptera										*204*
Acroneuria		1						1	2	
Alloperla	16	4	13	9	31	16	8	6	103	
Isogenus	4	8	4	4	11	10	8	9	58	
Nemoura	4	7	6	1		1	6	6	31	
Paragentina			7		3				10	
Trichoptera										*191*
Arctopsyche	2	2	8	1			3	2	18	
Dicosmoecus					1	2			3	
Micrasema			1						1	
Neothremma	10	14	19	18	3	5	17	8	94	
Polycentropus	9	3	10	3	7	5	6	1	44	
Rhyacophila		2	4		1		1	4	12	
Sericostoma	4	1	4			6	2	2	19	
Totals	286	162	279	265	461	364	255	409	2481	
Diversity index	2.96	3.32	3.22	2.57	2.40	2.13	3.09	1.98		

TABLE 6. Benthic Macroinvertebrate Samples Taken from Passage Creek, at Altitude 2438 m, Yellowstone National Park, Wyoming.

Sample	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*Total*	
Acari										*1088*
sp. 1	42	97	360	62	110	62	147	100	980	
sp. 2	1	5	9	3	9	9	8	7	51	
sp. 3	5	9	18	3	5	5	9	3	57	
Coleoptera										*104*
Carabidae sp. 1	1			1		1			3	
Cleptelmis	13	13	24	1	11	7	22	10	101	
Collembola										*1*
Sminthurus		1							1	
Diptera										*1250*
Anthomyiidae sp. 1		1							1	
Chironomidae sp. 1	118	54	94	39	105	164	104	74	752	
Chironomidae sp. 2	46	75	105	22	98	23	43	66	478	
Hexatoma	3		2						5	
Limnophila					2				2	
Simuliidae sp. 1	2	1	2	1	1	2		1	10	
Diptera sp. 1			1	1					2	
Ephemeroptera										*1144*
Baetis	58	22	33	22	27	14	60	12	248	
Callibaetis		3	1	1			3	2	10	
Centroptilum	38	28	31	37	103	43	29	14	323	
Cinygmula	43	31	54	21	35	69	69	41	363	
Epeorus	4	8	3	1	2	5	4	4	31	
Ephemerella	4	5				1	1		11	
Heptagenia		1				1	1		3	
Paraleptophlebia	14	10	36	10	25	30	6	17	148	
Pseudocloeon		1							1	
Rithrogena	6								6	
Hemiptera										*5*
Aphididae sp. 1			1						1	
Corixidae sp. 1						1			1	
Mesovelliidae sp. 1	1						1	1	3	
Megaloptera										*2*
Sialidae sp. 1	2								2	
Plecoptera										*446*
Acroneuria	6	1	4		2	4	9	2	28	
Alloperla	25	19	97	15	33	55	57	34	335	
Isogenus	12	8	9	4	7	10	18	11	79	
Nemoura			1			1	2		4	
Trichoptera										*89*
Arctopsyche	2								2	
Brachycentrus	2	1							3	
Dicosmoecus	1		2				1		4	
Neothremma	1	8	5	2	6	6	4	1	33	
Rhyacophila	4	5	12	4	4	5	10	3	47	
Totals	454	407	904	250	583	520	608	403	4129	
Diversity index	3.53	3.49	3.02	3.26	3.18	3.26	3.39	3.19		

There were spawning runs of cutthroat trout in Chipmunk Creek and in Passage Creek. Adult fish exhibiting spawning behavior were seen in many areas of both creeks on June 22–23.

No cutthroat trout fry were captured or seen in the 21 and 22 July drift net sampling. In the 18 and 19 August sampling, 273 fry were captured from Chipmunk Creek and 47 fry were captured from Passage Creek. Fry lengths from

Chipmunk Creek ranged from 22–38 mm (mean, 26.4 mm); fry lengths from Passage Creek ranged from 23–36 mm (mean, 26.6 mm). Thus there was no difference found in fry lengths between the two creeks.

On 4 and 5 August, cutthroat trout fry were observed at three different locations in the burned area of Passage Creek, and in the lower reaches of Yellowstone Park Stream No. 156, which lies entirely within the burned area (Figure 2), but nowhere in Chipmunk Creek. Cutthroat trout fry were observed in abundance in both Chipmunk Creek and Passage Creek on the next trip to the study area, 18 August. Fry apparently emerged from the gravel earlier in Passage Creek than in Chipmunk Creek.

1976 Continental Divide Fire Study Area

Fire burned to the water's edge of Streams 173 and 174 (Figure 6). The watersheds were covered by a layer of ash and charred debris. Charred trees fell across the streams, and bits of charred debris were present on the stream bottoms. No visible turbidity was ever observed in the streams. There was no evidence of ash being washed directly into the streams.

The highest temperature found in either stream during or after the fire was 12 C. Calcium, magnesium, potassium, chloride, sulfate, phosphate, TOC, and turbidity were higher in both streams during the rainstorm of 3 August than on the dry days of 19 July and 9 September (Table 7). Calcium and magnesium concentration were both 2 mg/l (as $CaCO_3$) higher in the 3 August samples than in the 19 July and 9 September samples. Potassium concentrations were about 0.5 mg/l higher in the 3 August samples than in the other samples. Chloride ion was raised to detectable concentrations in the 3 August samples. Phosphate concentrations on 3 August were about four times the concentrations on 19 July and 9 September. The increase in turbidity in the 3 August samples was not great enough to be detectable by eye. Sodium concentrations were lower in the 3 August samples than in the 19 July and 9 September 9 samples.

Benthic insects were observed in both streams during and after the fire; they were abundant and no dead insects were seen. Cutthroat trout eggs in a redd in Stream 174 appeared normal and in good condition on 23 July, during the fire. Fry emerged from the gravel in both streams, and they appeared normal and healthy on 9 September.

DISCUSSION

Chipmunk Creek-Passage Creek Study Area

Passage Creek was cooler than Chipmunk Creek on 23 June (Figure 7). Th lower water temperature found in Passage Creek on that day may have been du to greater exposure to lower air temperatures. Snow fell in the study area on th afternoon of 23 June, so mid-afternoon air temperatures were probably coole than water temperatures (6.7 C in Passage Creek, 7.8 C in Chipmunk Creek possibly resulting in a greater cooling effect on more exposed Passage Cre than less exposed Chipmunk Creek.

In all measurements taken after 23 June, Passage Creek was warmer th Chipmunk Creek (Figure 7). Passage Creek is less shaded than Chipmunk Cre (Figures 4 and 5), so the persisting pattern of warmer temperatures in Passa Creek than in Chipmunk Creek during the summer was probably due at lea

partially to more solar radiation reaching Passage Creek than Chipmunk Creek. After 23 June, all measurements of daytime air and water temperatures at the aufwuchs collection stations showed daytime air temperatures to be warmer than daytime water temperatures. Therefore, the persisting pattern of warmer temperatures in Passage Creek than in Chipmunk Creek during the summer may also have been due to greater exposure to warmer air temperatures in Passage Creek than in Chipmunk Creek.

TABLE 7. Water Analysis of Yellowstone Park Streams 173 and 174, Summer 1976, During and After a Fire Burned Their Drainages. The 3 August Samples were Taken During a Rainstorm. There was No Rain When the 19 July and 9 September Samples were Taken.

Date	*July 19*		*Aug. 3*		*Sept. 9*	
Substance (mg/l) / *Stream*	*173*	*174*	*173*	*174*	*173*	*174*
TDS	78	66	78	68	90	65
*Total hardness	36	28	40	32	36	28
*Calcium hardness	24	18	26	20	24	18
*Magnesium hardness	12	10	14	12	12	10
Sodium	3.7	3.5	2.8	2.6	3.2	2.8
Potassium	2.00	1.52	2.52	1.78	1.94	1.37
Iron	0.06	0.08	0.1	0.1	0.1	0.1
Manganese	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Copper	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
*Total alkalinity	40	32	34	32	44	34
*Phenolpthalein alk.	0	0	0	0	0	0
*Bicarbonate alk.	40	32	34	32	44	34
Chloride	<1	<1	2	1	<1.0	1.0
Fluoride	0.15	0.31	0.2	0.3	0.2	0.3
Sulfate	3	3	6	4	2	2
Nitrate-nitrogen	0.02	0.04	0.03	0.04	0.04	<0.01
Kjeldahl nitrogen	0.07	0.13	0.02	0.36	0.02	0.02
Phosphate, as PO_4	<0.1	<0.1	0.52	0.60	0.23	0.10
Orthophosphate, as PO_4	<0.1	<0.1	0.50	0.55	0.23	0.10
Carbon dioxide	5.2	4.1	4.5	5.4	2.3	1.9
Total organic carbon	4.8	6.4	9.5	7.1	0.72	0.55
Silica, as SiO_2	10	11	13	10	16	12
Turbidity, NTU	0.3	0.6	0.50	1.8	0.24	0.48
pH (Laboratory)	7.2	7.2	7.2	7.1	7.6	7.6
pH (Field)	7.2	7.2	7.2	7.2	7.4	7.3

* as $CaCO_3$

Shading acts as a temperature buffer on streams. Edington (1966) found that, [i]n northern England, shaded reaches of streams were cooler in summer, and [w]armer in winter, than unshaded reaches. Chipmunk Creek and Passage Creek [b]oth probably freeze in winter, but due to greater exposure, Passage Creek may [w]arm faster to warmer air temperatures in spring, and cool faster to cooler air [t]emperatures in fall, than Chipmunk Creek.

The greatest difference in average daily temperatures found between Chip[m]unk Creek and Passage Creek was 2.2 C. Burned areas at lower elevations, at [l]ower altitudes, or with more southerly exposures than the Chipmunk Creek-[P]assage Creek area may have greater increases in summertime stream tempera[tu]res than were found in the Chipmunk Creek-Passage Creek area. Helvey (1972) found that late summer stream temperatures increased up to 5.6 C in a [s]outh-facing burned watershed in Washington.

During the summer, Passage Creek flow decreased more than Chipmunk Creek flow (Table 1). Flow per ha of watershed of Passage Creek was greater than that of Chipmunk Creek in early summer, and was less than that of Chipmunk Creek in late summer. Higher early summer flows in Passage Creek could be caused by faster snowmelt in the less shaded burned area, by decreased moisture retention capacity of the burned soil resulting in faster runoff (Dyrness 1963), by decreased plant transpiration due to less vegetation in the burned area, or by a combination of the three factors. The first two factors could cause the lower late summer flows found in Passage Creek. A greater influence of springs in Chipmunk Creek than in Passage Creek could also cause the late summer difference.

Estimated total water yield for the 6 days measured was higher in Passage Creek than in Chipmunk Creek. The 6 days for which water yield was estimated were evenly distributed at 2-week intervals during the study period, so trends in water yield for the study period are probably accurately represented by the 6-day totals. The water yield results may be indicative of higher annual water yield in Passage Creek than in Chipmunk Creek. The difference in vegetation density and plant transpiration between the burned area of the Passage Creek watershed and the unburned Chipmunk Creek watershed may be still great enough to cause a difference in water yield between the two watersheds, 36 years after the more recent burn. Helvey (1972), Pase and Ingebo (1965), and Wright (1976) all reported increased annual water yields the first few years after fires. In the study of Pase and Ingebo (1965), annual water yield was again approaching control levels by the fourth year after fire.

Chemical concentrations in Chipmunk Creek were not consistently different from chemical concentrations in Passage Creek (Table 2); there was no evidence of enrichment by increased concentrations of chemical nutrients in Passage Creek. Potassium concentration was consistently slightly higher in Chipmunk Creek than in Passage Creek. In the 31 August samples, pH was higher and carbon dioxide concentration was lower in Passage Creek than in Chipmunk Creek. Those samples were taken in late afternoon on a cloudless day, so those chemical conditions may have been a result of a higher rate of instream photosynthesis in Passage Creek than in Chipmunk Creek.

Mineral export per ha of watershed was higher in Passage Creek than in Chipmunk Creek in late June and July, and was higher in Chipmunk Creek than in Passage Creek in late August (Table 3). Chemical concentrations in the two streams were similar (Table 2), so water yield per ha of watershed was the main factor controlling mineral export per ha of watershed. On the 3 days measured, the stream with the higher water yield had the higher mineral export (Tables 1 and 3). In view of the higher summer water yield found in Passage Creek than in Chipmunk Creek, summer mineral export was probably also higher in Passage Creek than in Chipmunk Creek. Higher mineral export in Passage Creek might increase the productivity of attached aquatic flora in that creek, due to increased flux of available nutrients past the attached flora.

Tiedemann and Helvey (1973) found that increased annual water yield was the factor responsible for increased annual cation export after a fire in eastern Washington. In the year after a fire in northeastern Minnesota, Wright (1976) found increased export of potassium and phosphorus, due to increased water yield and to increased concentrations.

Mean aufwuchs accumulation was nearly 50% higher at the burned stations than at the unburned stations (Table 4), but the difference was not statistically significant. The three highest correlations with aufwuchs accumulation were days past 1 June, percent silt, and surface velocity. The main trend that the correlational analysis revealed was that as summer progressed, surface velocities became slower, and aufwuchs accumulation became greater. Water velocity is an important factor in the attachment of algae in streams; the faster the current, the greater is the tendency for the more loosely attached species to be washed downstream (Whitton 1975). Despite greater water yield, there was no evidence of excessive scouring in Passage Creek. In addition to slower current velocities, increasing nutrient concentrations as summer progressed (Table 2) may also have stimulated growth of aufwuchs in the later samples.

The significantly greater number of benthic macroinvertebrates found in the Passage Creek samples than in the Chipmunk Creek samples could be indicative of a general difference in benthic macroinvertebrate populations between the two study streams. Such a general difference could be due to more instream primary production and/or to more allochthonous litter fall in Passage Creek than in Chipmunk Creek. There was no visually obvious difference in allochthonous litter fall between the two streams. Increased instream primary production, due to more sunlight and greater mineral export, could cause greater benthic macroinvertebrate populations in Passage Creek. The algal grazers *Baetis, Cinygmula,* and *Epeorus* (mayflies) were found in much greater numbers in Passage Creek samples (Table 6) than in the Chipmunk Creek samples (Table 5). Higher populations of algal grazers could, in turn, account for the higher numbers of the predators *Acroneuria, Alloperla,* and *Isogenus* (stoneflies) found in the Passage Creek samples than in the Chipmunk Creek samples. Generally higher benthic macroinvertebrate production in Passage Creek could result in higher resident trout production in that creek, due to more available energy to the fish from the preceding (macroinvertebrate) trophic level.

The higher diversity indices of the Passage Creek samples are a reflection of the greater number of taxa found in Passage Creek (36 taxa) than in Chipmunk Creek (30 taxa). If, as the benthic samples indicate, there are more benthic macroinvertebrate taxa in Passage Creek than in Chipmunk Creek, then Passage Creek may have a greater variety of benthic macroinvertebrate food species available to trout.

Based on the field observations, the actual difference in time of trout fry emergence between Chipmunk Creek and Passage Creek could theoretically have been as short as 1 day or as long as 27 days, because the sampling interval was 2 weeks. A more precise estimate of the difference can be made using the stream temperature data. In the 4 weeks preceding August 5, the date when fry were first seen in Passage Creek, the recording thermograph was in operation July 8–16 and July 22–30. Average stream temperatures during those 18 days, when eggs should have been in the gravel, were 10.9 C in Chipmunk Creek and 12.7 C in Passage Creek. Yellowstone cutthroat trout eggs hatch in 24 days at 14.2 C (U.S. Fish and Wildlife Service, unpublished data), for an average of 612 temperature units to hatch. Based on 612 temperature units and average stream temperatures of 10.9 C in Chipmunk Creek and 12.7 C in Passage Creek, Yellowstone cutthroat trout eggs would have hatched in 31 days in Chipmunk Creek and in 27 days in Passage Creek. Thus, on the average, fry in Passage Creek could have emerged and drifted down to Yellowstone Lake about 4 days earlier than fry from Chipmunk Creek.

The changes in stream shading, temperature, flow, and benthic macroinvertebrates found in Passage Creek appear to be long-term effects of fire; they are still manifest decades after the burns. Those long-term effects could have many effects on Yellowstone cutthroat trout that use Passage Creek only as spawning habitat, and also on those trout that are resident throughout the summer.

Potential effects on spawning fish from Yellowstone Lake would be due to temperature and flow differences. Water temperature is an important cue in the migration of fish that live in lakes and breed in streams (Hynes 1970). In Yellowstone Lake tributaries, spawning runs of Yellowstone cutthroat trout commence in early summer when stream temperatures rise to about 8.5 C (J. D. Varley, Fishery Management Biologist, U.S. Fish and Wildlife Service, pers. commun.) If Passage Creek warms faster than Chipmunk Creek, then the Passage Creek run could commence earlier than the Chipmunk Creek run. The cumulative effect of earlier spawning and shorter egg incubation in Passage Creek could result in a difference in time of fry emergence greater than 4 days. By drifting down to Yellowstone Lake sooner, fry from Passage Creek could attain a competitive advantage over fry from Chipmunk Creek, based on zooplankton work in Yellowstone Lake (Varley, pers. commun.) The higher early and midsummer water yield in Passage Creek may result in easier fish access to the upper reaches of the creek, and in more available spawning habitat, than before the fires.

Populations of Yellowstone cutthroat trout that are summer residents of Passage Creek could be affected by other long-term effects of fire, in addition to effects on spawning and egg incubation time. In the subalpine climate of the Yellowstone Lake area, low water temperatures are a limiting factor to trout production. The warmer summertime temperatures of Passage Creek may increase trout growth and production in that creek, as compared to Chipmunk Creek. If benthic macroinvertebrate populations are higher in Passage Creek than in Chipmunk Creek as these results suggest, then there may be a beneficial effect on resident trout production.

1976 Continental Divide Fire Study Area

The observed temperatures in Streams 173 and 174 did not approach levels that would be limiting to trout, either during or after the fire.

No drastic increases of dissolved materials occurred in Streams 173 and 174; with exception of phosphorus, general levels of dissolved materials were comparable to those in Chipmunk Creek and Passage Creek at about the same time (Tables 2 and 7).

McColl and Grigal (1975) and Wright (1976) found that, after fire, phosphorus concentrations were higher in surface runoff waters, but were unchanged in stream and lake waters. They theorized that phosphorus is leached from ash by surface runoff, but that the phosphorus is again immobilized as the runoff percolates through deeper, unburned soil layers. Grier (1975) found a similar phenomenon for calcium, magnesium, and potassium leached from ash into soil after fire. The water quality data of Streams 173 and 174 (Table 7) indicate that this phenomenon may have occurred in the Continental Divide Fire area. Calcium, magnesium, potassium, chloride, sulfate, phosphate, and TOC concentrations were raised somewhat when the rainstorm of August 3 was probably causing some surface runoff to reach the streams directly. On July 19 and September 9, there was no rain, and all water probably reached the streams as subsurface flow.

Higher phosphorus concentrations from stream outflow during the storm may have stimulated primary productivity in the South Arm in the vicinity of the mouths of Streams 173 and 174. Over a number of years, natural fire management may result in greater productivity in Yellowstone Lake due to a greater influx of nutrients from a number of burns. Further research in this area is needed.

Despite the drastic changes that fire made on the terrestrial community in the watersheds of Streams 173 and 174, life in the streams proceeded apparently undisturbed. No evidence was found that the fire had any immediate effect on aquatic life in those streams.

ACKNOWLEDGMENTS

This study was funded by a grant from the U.S. National Park Service (U.S.N.P.S. Grant Contract No. CX-1200-6-B037) through the Northern Rocky Mountain Cooperative Park Studies Program. The field work was accomplished through the support of the Yellowstone Fisheries Investigations Unit of the U.S. Fish and Wildlife Service.

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AN EVALUATION OF REARING FALL-RUN CHINOOK SALMON, *ONCORHYNCHUS TSHAWYTSCHA*, TO YEARLINGS AT FEATHER RIVER HATCHERY, WITH A COMPARISON OF RETURNS FROM HATCHERY AND DOWNSTREAM RELEASES [1]

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Fall-run chinook salmon, *Oncorhynchus tshawytscha*, were reared to yearlings ($\overline{wt}$ = 58 g) at Feather River Salmon and Steelhead Hatchery, and released in equal numbers at the hatchery and 225 km downstream in the lower Sacramento River near Rio Vista. Combined returns to the fisheries and spawning stocks were 7.5%: 6.1% to the fisheries and 1.4% to the spawning stocks. Yearlings released at the hatchery contributed more to the fisheries and spawning stocks (8.3%), with considerably less straying from the natal stream, than those released near Rio Vista (6.6%). When compared with returns from fingerling salmon ($\overline{wt}$ = 5 g), yearlings released at the hatchery contributed 12 times more to the fisheries. Based on minimum contributions to the fisheries and spawning stocks of all marked yearlings of the three brood years released, the benefit/cost ratio was 18.0:1.

INTRODUCTION

Studies with fall-run chinook salmon fingerlings in the Sacramento River system during the past two decades by the California Department of Fish and Game (CDFG) have demonstrated that hatchery releases of advanced fingerlings weighing 5 g contribute more adults to the fisheries and spawning stocks than do releases of fingerlings weighing 0.5 g (CDFG, unpublished data). Studies with advanced fingerlings have also shown that if they are released in the lower Sacramento River rather than at the hatcheries, many of the losses that occur during seaward migration are eliminated, resulting in greater returns to the fisheries and spawning stocks. Rearing as many chinook salmon fingerlings as egg supplies, space, and budgets permit to a minimum size of 5 g prior to release is now a standard procedure at Federal and State salmon and steelhead hatcheries on the Sacramento River System.

The Department of Fish and Game initiated a study in 1957 to find out if even greater returns to the fisheries and spawning stocks could be obtained by releasing chinook salmon as yearlings. In spring 1957 fall-run chinook salmon yearlings ($\overline{wt}$ = 56 g) were marked and released in the American River at Nimbus Salmon and Steelhead Hatchery. Total adult returns to the hatchery from the yearlings were about 34 times greater than average adult returns from advanced fingerlings

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