Ecology of Streams of Crater Lake National Park

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ABSTRACT

Four streams outside the caldera of Crater Lake and six springs within the caldera were investigated in 1985-86 to determine if man's activities in the park were altering the water chemistry or aquatic ecology of these streams. Munson Creek had higher concentrations of dissolved inorganic nitrogen and greater biological activity than other study streams outside the caldera. Abundance of benthic algae and rates of primary production were greater in Munson Creek than Sun Creek, Dutton Creek, or Goodbye Creek, and the lower meadow site on Munson Creek tended to be more productive than the upper forested site. Lower Munson Creek also contained higher densities of invertebrates than the other streams. Substrates and organic matter in both sites in Munson Creek supported higher growth rates of caddisflies than similar material from Dutton and Goodbye Creeks. Previous investigations indicated that the greater biological activity in Munson Creek as compared to Sun Creek may not be a recent phenomenon. The close proximity of the maintenance area and the linkages through storm drains present a potential risk to Munson Creek, and Park management should closely review activities and use of hazardous materials on a routine basis.

Dutton Creek was less productive and had more depauperate invertebrate communities than the other study streams outside the caldera, reflecting its ephemeral hydrologic nature. There was no evidence to indicate that the septic facility in the headwaters had any measurable influence on the chemistry or ecology of Dutton Creek. Dutton Creek frequently flows intergravel, which restricts the distribution of aquatic biota.

Investigation of six caldera springs found that Spring 42, in particular, exhibited high concentrations of nitrate (287 ppb in August 1986); the other springs all contained less than 60 ppb. In Spring 48, there was a rapid uptake of nitrate from the source to the outlet into the lake, decreasing from 58 to 18 ppb. The length of stream and the relative biological activity in different springs may greatly influence the observed water chemistry of the springs where they enter the lake. Biological activity in the study springs corresponded to the observed pattern of nutrient availability. Abundance of benthic algae and rates of gross primary production were highest in Spring 42. At the relative concentrations of nitrogen and phosphorus in these springs, primary production would be limited by inorganic nitrogen; therefore, the elevated primary production in Spring 42 may be a result of the higher nutrient supply.

Primary production was also high in Spring 48. The headwaters of Spring 48 were located in a mature conifer forest, and the channel was geomorphically more stable than the other springs. This greater stability may allow development of a more abundant assemblage of primary producers. Primary production in the other springs was less than half of that observed in Springs 42 and 48, which may be related to either lower nitrate concentrations or more unstable channels.

Aquatic invertebrates, excluding chironomids, were more abundant in Springs 42 and 48, possibly a result of the higher primary production in these two springs. Invertebrates were most abundant in Spring 48, which may be related to the greater channel stability in this stream. The fauna of these streams were less abundant and included far fewer taxa than those in streams outside the caldera.

We suggest that the National Park Service should consider: 1) alternative approaches for treating human wastes on the rim of the caldera of Crater Lake, 2) experimental nutrient uptake studies in the springs of the caldera, integrated with expanded monitoring of water and soil solution chemistry, 3) fluorescent tracer analysis of groundwater dynamics in the caldera rim, and 4) establishment of baseline monitoring of water chemistry in the surface waters of Crater Lake National Park.

INTRODUCTION

National parks are faced with an inherent contradiction in land management. They are established to preserve unique natural ecosystems in their pristine state. National parks must also attract thousands of visitors to view these resources each year. The very public that visits the National Parks potentially threatens these pristine ecosystems with sewage, automobile emissions, damage to vegetation, disturbance of native wildlife, forest fires, and vandalism. Some of these impacts can be minimized by appropriate distribution of visitor facilities within the National Parks, but others cannot be avoided because visitors cannot view the natural attractions without being in close proximity to them. Ultimately, land managers may find themselves in the situation of causing the demise of the very resource they are protecting.

Crater Lake National Park, due to the central location of the lake, is faced with the inherent risks of alteration of the natural ecosystem by the large number of visitors and the support activities necessary to operate the park. Crater Lake National Park contains Crater Lake, the deepest lake in the United States, the seventh deepest in the world, and one of the most oligotrophic in the world. In addition, the park contains alpine meadows, subalpine forests, and numerous pristine streams. Crater Lake lies in the caldera of a quiescent volcano, Mount Mazama, at an elevation of 6,176 feet. Visitor facilities at Rim Village and the park highway lie on the rim of the volcano, which is composed of a complex array of unstable talus slopes and intrusive flows of lava. Even small numbers of visitors pose serious risks for such a fragile ecosystem, and Crater Lake National Park attracts more than 600,000 visitors annually (Mohler 1986). The influence of visitors in Crater Lake National Park is focused largely the the Rim Village vicinity, which receives approximately 75% of the summer use and 54%

of the winter use of the Park, thereby accentuating the potential risk to the lake and biological communities in this area.

Sewage facilities are required for the public and the park staff, but the wastes from these facilities potentially can enter the lake and streams and gradually bring about their eutrophication. In 1975, a sewer line was obstructed and sewage flowed out a manhole and into Munson Springs, the water supply for the visitor facilities and Park Headquarters (Craun 1981). Although the public drinking water was chlorinated, it was not sufficient to purify the contaminated water. An outbreak of more than 1000 cases of diarrhea resulted. In 1986, sewer pipes below the Park Headquarters ruptured because of freezing and delivered raw sewage into Munson Creek; but there was no risk to human health due to the location of the release. The human health hazards from such events are obvious, but they point to the potential for chronic contamination of the natural ecosystem by man's use of the National Park.

There are four major sewage facilities in the vicinity of Crater Lake. On Crater Lake itself, there is a modern composting system at Cleetwood Cove that produces no liquid wastes. The Rim Village concession stand and cabins are served by a septic leach field at the headwaters of Dutton Creek. Sewage facilities for the lodge, Park Headquarters, and the associated residences consist of a septic leach field and sewage lagoons on Munson Creek one kilometer below the Headquarters. The septic leach field that originally served the Lodge is located in the headwaters of Munson Creek and is now deserted. Mazama Campground has a separate sewage treatment facility, but it will not be considered in this report because of its low elevation.

The goal of this research was to determine whether human activities in the Crater Lake vicinity have affected the biological communities of Munson Creek and Dutton Creek. In response to requests from Park staff after the study began, we added a study site on Goodbye Creek to include a stream with minimal human influence. In the second year, we expanded the research on Munson Creek with a comparison of similar study reaches on Sun Creek in the adjacent watershed, and we evaluated the biological communities of springs within the caldera of Crater Lake to determine if human activities in the Rim Village area are altering water chemistry or stream communities. This research was designed to describe water chemistry, aquatic primary production, detrital standing crops, decomposition rates, and invertebrate assemblages in streams within and outside of the caldera at Crater Lake. This information provides a foundation for evaluation of the status of aquatic resources in streams of Crater Lake National Park.

STUDY SITES

Streams Outside the Rim

In 1985, we investigated three streams on the outer rim of Crater Lake - Munson Creek, Dutton Creek, and Goodbye Creek (Fig. 1). These streams are located on the south slope of the mountain and flow away from the lake. Munson and Goodbye Creeks drain into the Klamath River, and Dutton Creek is a tributary of the Rogue River drainage on the west slope of the Cascade Mountain Range. All three streams flow across recent volcanic terrain, originating just below the rim of the crater in subalpine forests. These streams originate in the Hudsonian vegetation zone (Wynd 1941), which is dominated by mountain hemlock (*Tsuga mertensiana*), red fir (*Abies procera*), and white bark pine (*Pinus albicaulis*). Some lodgepole pine is found in the lower areas of this zone as it nears the Canadian vegetation zone at approximately 1,900 m. Snow cover persists for approximately 7 months, with an average depth of 3 m in winter (Sterns 1963). During the winter, snow completely bridges all three streams, occasionally broken by openings that are up to several meters in length.

Two of the study streams, Munson and Dutton Creeks, have a great potential to be influenced by man's activities. Human use of the land along Munson Creek far exceeds that of any other stream in the Park. An abandoned septic leach field is located above Munson Springs. In 1975, a sewer line became blocked, releasing sewage into the headwaters of Munson Creek (Craun 1981). Park Headquarters, maintenance buildings, and staff residence halls and cabins are located on Munson Creek at the head of Munson Meadows (Fig. 2). The septic facility for these buildings is located adjacent to Munson Creek approximately one kilometer downstream from the

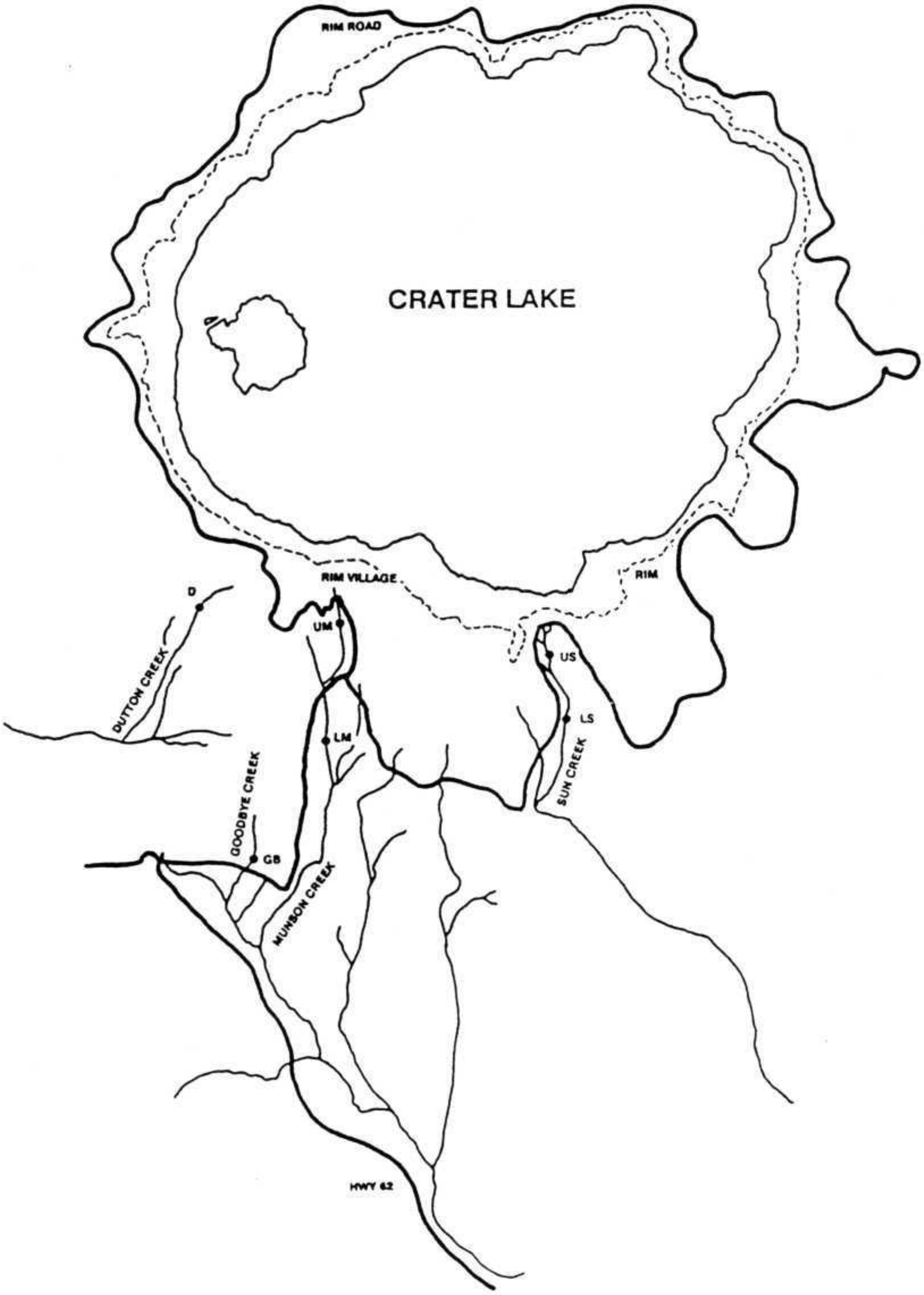


Figure 1. Location of study streams and sampling sites in Crater Lake National Park (UM - upper Munson, LM - lower Munson, US - upper Sun, LS - lower Sun, D - Dutton, GB - Goodbye).

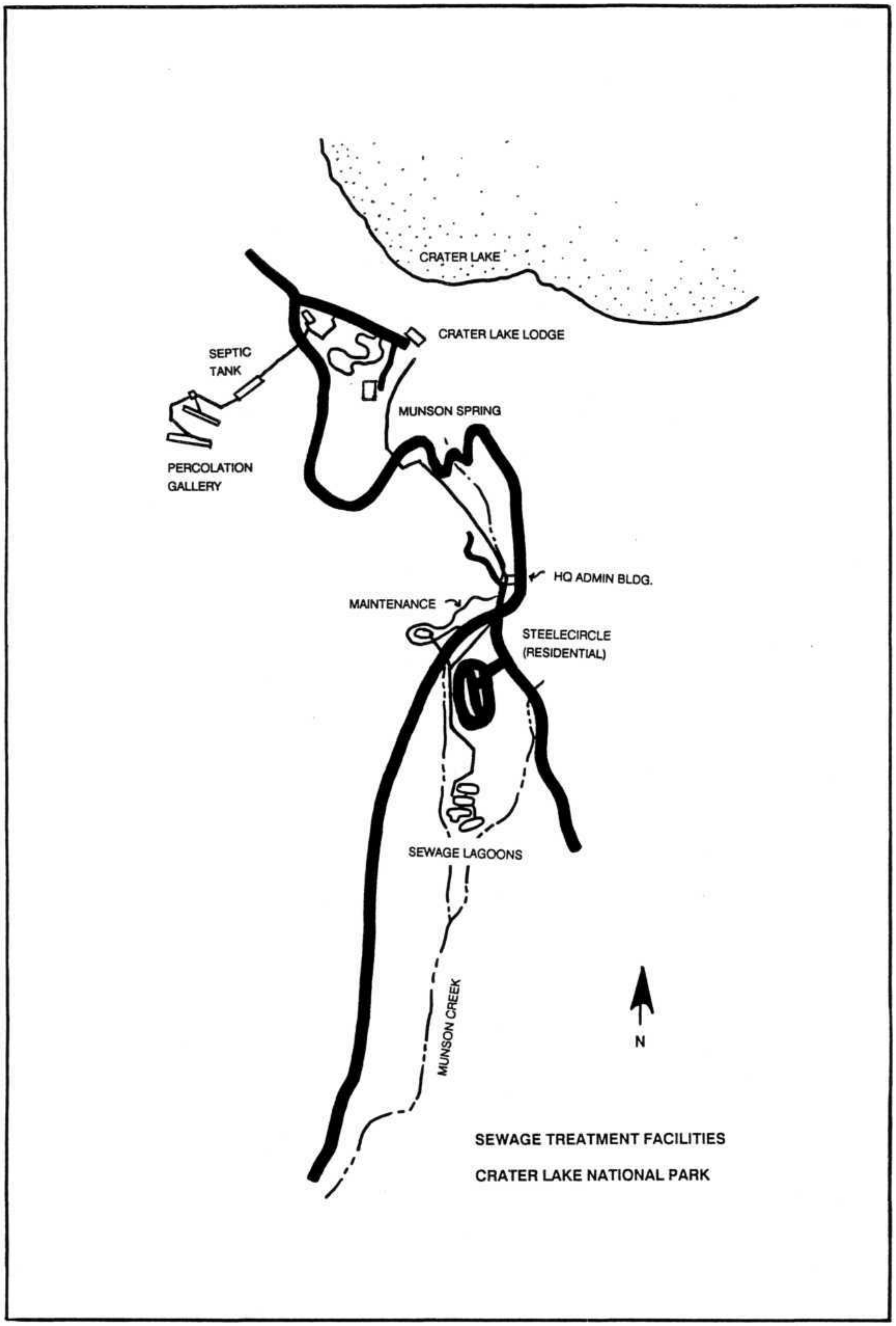


Figure 2. Location of sewage facilities associated with Rim Village and Park Headquarters (adapted from Mohler 1986).

headquarters. As recently as the winter of 1986, a break in the delivery pipes to the septic field released raw sewage into Munson Creek immediately below our study reach.

The Park Headquarters includes a vehicle maintenance area. Chemicals used in equipment operation and repair can potentially enter Munson Creek through storm drains in the maintenance area. A septic leach field that services the Rim Village and Lodge area is located above the headwaters of Dutton Creek; there are no other known influences of man on Dutton Creek. The third study stream, Goodbye Creek, receives little human activity. There is a small picnic area immediately downstream from the study site on Goodbye Creek, but there is no other concentrated use in the basin.

Munson Creek originates from Munson Springs at an elevation of 2,075 m and flows through subalpine forest for several hundred meters before entering Munson Meadows immediately above the Headquarters of Crater Lake National Park. It is a second-order stream with basalt substrates (Table 1). We sampled Munson Creek at two sites, one at its headwaters in subalpine forest (UM) and one immediately below the Headquarters and living facilities in Munson Meadow (LM) (Fig. 1). Both sites are potentially affected by human activity; the upper site (UM) is influenced potentially by the deserted septic facilities in the headwaters, and the lower site (LM) is affected potentially by the use of the Headquarters, vehicle maintenance yard, and residences.

Table 1. Physical characteristics of the study streams and their watersheds (UM - upper Munson, LM - lower Munson, US - upper Sun, LS - lower Sun, D - Dutton, GB - Goodbye; * - no data).

SITE	SLOPE (%)	ELEVATION (m)	DRAINAGE AREA (km^2)	MEAN WIDTH (m)	MEAN DEPTH (cm)	MEAN VELOCITY ($cm \cdot s^{-1}$)
UM	15	2,010	0.52	0.80	9.2	11.4
LM	3	1,920	2.62	1.73	10.2	24.4
US	20	2,070	0.48	0.77	6.8	7.8
LS	7	2,010	1.85	0.90	7.2	21.2
D	15	1,980	0.94	*	*	*
GB	12	1,830	1.29	*	*	*

Dutton Creek is a tributary of Castle Creek to the southwest of Crater Lake, originating at an elevation of approximately 2,090 m. Dutton Creek differs substantially from the other study streams in its hydrology. The stream flows intermittently for much of its length, becoming perennial at an elevation of approximately 1,900 m. During late summer, the study section of Dutton Creek consisted of a series of isolated pools separated by longer reaches of subsurface flow. Surface flow was never observed for several hundred meters downstream from the septic leach field. The drainage area of the watershed at the study site was intermediate between the drainage areas of the UM and LM study sites; but the width and depth of the channel were similar to the UM site, reflecting the differing hydrology of the two watersheds.

Goodbye Creek is a relatively undisturbed watershed that lies immediately to the west of Munson Creek at the base of Munson Ridge. The study site on the creek (GB) was located upstream of a small picnic area where the highway crossed the stream. The stream was slightly larger than the upper sites on Munson and Sun Creek and approximately 100 to 200 m lower in elevation (Table 1). Goodbye Creek was selected to represent an undisturbed watershed of similar aspect, geology, topography, and vegetation to that of the forested reaches of Munson and Dutton Creeks.

In 1986, we compared the physical, chemical, and biological characteristics of upper and lower Munson Creek with similar sites on Sun Creek. Sun Creek is the next major drainage to the east of Munson Creek. Like Munson Creek, it originates in a subalpine forest above 2,000 m in elevation and flows through a long meadow. Both watersheds have been reshaped by glaciation and are almost identical in aspect, geology, elevation, topography, and vegetation (Table 1). The major difference in the two watersheds is the lack of human activity the narrower valley (3,200 m at LM versus 2,200 m at LS) in Sun Creek. The rim road crosses the headwaters of Sun Creek, and a small campground is located below the study sites. Two sites (US and LS) were chosen to match the study sites on Munson Creek.

Streams Inside the Rim

In 1986, we studied six streams inside the caldera rim that drain into Crater Lake. Previous studies of their water chemistry had found elevated concentration of nitrate in several springs in the vicinity of Rim Village and the Lodge (Dr. Cliff Dahm and Dr. Doug Larson, personal communication; Dr. Gary Larson, personal communication).

The Crater Lake National Park staff has numbered the caldera springs within the rim of Crater Lake in a clockwise direction starting at Cleetwood Cove. The study streams were Springs 20, 35, 38, 39, 42, and 48, all located on the southwest wall of the caldera (Fig.3). Spring 20 is in the Chaski Slide area, Spring 35 is in the Eagle Point area, Springs 38, 39, and 42 are in the Rim Village area, and Spring 48 is in the Discovery Point area. Springs 20, 35, and 38 usually exhibit relatively low concentrations of nitrate and have little human

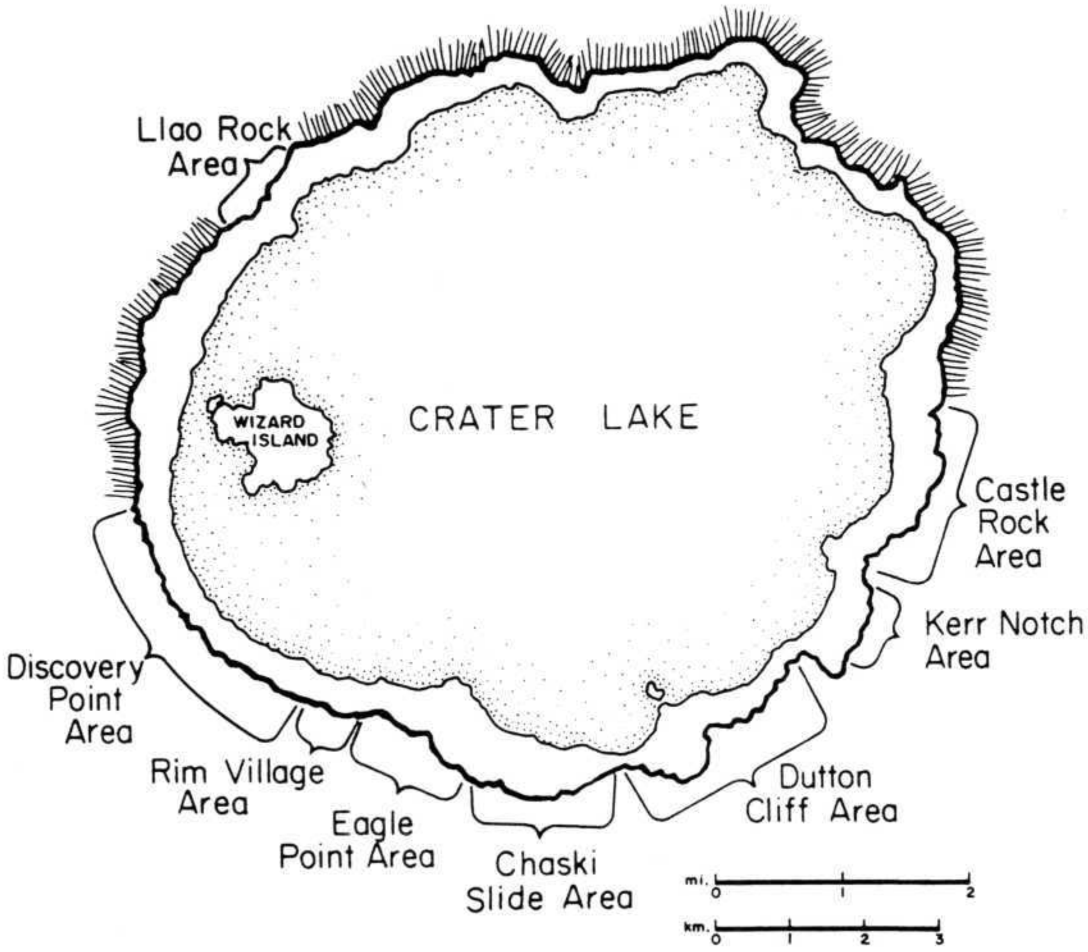


Figure 3. Major study areas within the caldera of Crater Lake (from Larson et al. 1986).

activity in their vicinity. Spring 48 occasionally has nitrate concentrations between 50 to 100 ug NO_3-N/l, but there is no concentrated human activity in its drainage. Spring 39 is immediately below the Lodge and has exhibited nitrate concentrations in the range of 50 to 150 ug NO_3-N/l. Spring 42 consistently contains higher concentrations of nitrate than any other stream in the National Park, and is located immediately below the Rim Village area. Nitrate concentrations in Spring 42 are generally in the range of 250 to 300 ug NO_3-N/l.

All of the springs on the walls of the caldera are extremely high gradient streams, ranging from 50 to 140%, and are geomorphically unstable. Avalanches occur frequently (i.e., several times each decade, as evidenced by age of streamside vegetation), and substrates consist of loose accumulations of gravel, cobbles, and boulders. Although water chemistry may potentially influence biological activity in these streams, it must be recognized that physical instability exerts profound influences on the aquatic organisms. Springs 20, 38, and 39 are relatively open and are lined by small shrubs and herbaceous plants. Sitka alder (*Alnus sinuata*) create a low, narrow thicket along Spring 35. Springs 42 and 48 flow through mature conifer forests with an understory of Sitka alder immediately adjacent to the channels.

METHODS

Water Chemistry

In 1985, water chemistry was sampled from upper and lower Munson Creek and Goodbye Creek in March, early August, and September, representing the winter, summer, and fall seasons. Dutton Creek was sampled at the same times in August and September, but a sample was not obtained in winter because no running water was found when we dug through the snow to the stream channel. Because of the intermittent nature of Dutton Creek, we sampled water chemistry at the point where surface water was first found and at a lower point that was sampled for the full suite of ecological measurements. The spring from which Munson Creek originates at 6,760 ft in elevation was also sampled in September. In 1986, we sampled upper and lower sites on Munson and Sun Creeks, Goodbye Creek, and six springs inside the rim of the crater.

Water samples were collected in two 1-l polypropylene bottles and a 250-ml Pyrex BOD bottle at each site. All water samples were held on ice in darkness immediately after collection and filtered through 0.7 u GFF glass fiber filters as soon as possible (less than 8 hr in all cases). Water samples in polypropylene bottles were analyzed for nitrate, ammonium, orthophosphate, Kjeldahl nitrogen, total phosphorus, pH, and alkalinity. Concentrations of organic nitrogen were calculated by subtracting ammonium concentrations from kjeldahl nitrogen concentrations. In the first sampling in winter of 1985, we also analyzed for calcium, magnesium, potassium, and sodium. Water samples in Pryex BOD bottles were poisoned with $HgCl_2$ after filtration and were analyzed for dissolved organic carbon. The BOD bottles were fired at 500°C prior to sampling to prevent contamination with organic carbon. Water samples were held on ice in darkness and returned to the laboratories at Oregon State University (OSU) within 24 hr. All water samples were refrigerated and analyzed by the Central Chemistry Analytical Laboratory at OSU within one week. A refrigeration malfunction resulted in the loss of more than two-thirds of the preserved DOC samples, therefore only a limited data set is available for DOC.

Benthic Algae

Substrates were collected from all streams on all sampling dates for determination of standing crop of chlorophyll *a*, an index of the abundance of benthic algae. Three substrate samples consisting of three cobbles each were collected from each site on each sampling date. Chlorophyll samples were stored on ice in the dark and were returned to the laboratory at OSU within 48 hr. At OSU, substrate samples for chlorophyll analysis were frozen and analyzed within 4 wks. For the extraction of chlorophyll, substrates were submersed in a known volume of 90% acetone for 24 hr at 4°C in the dark. Chlorophyll concentration in the extract was determined by the trichromatic method (Strickland and Parsons 1968). Substrate surface area was measured by wrapping the rocks with aluminum foil, weighing the foil, and multiplying by the foil area per unit weight.

Benthic primary production was measured for all streams sampled in August and September of 1985 and in August 1986. Substrates were collected from each site, placed in plastic bins, stored on ice in the dark, and returned to laboratories at OSU within 48 hr. In 1985, primary production was measured by placing substrates in recirculating chambers with well water from the Fairplay Laboratory of the Department of Fisheries and Wildlife at OSU. The chambers were held in a water bath at 13°C; artificial metal arc lamps maintained a light intensity of 400 $uE \cdot m^{-2} \cdot s^{-1}$. This light intensity is sufficient to saturate photosynthesis, and the nutrient concentrations in the well water were high (5.0 mg NO_3-N/l, 180 ug PO_4-P, pH 7.20, 16.95 mg/l total alkalinity); therefore, rates of primary production represent maximum potential photosynthesis for a given site. Changes in dissolved oxygen concentrations in the closed chambers were measured for 3-hr incubation periods. Changes in oxygen concentrations in chambers in the dark represent community respiration and changes in the light respresent net community primary production; gross primary production is calculated by adding community respiration and net community primary production for the photoperiod (Bott et al. 1978).

In 1986, primary production was measured as described above, but water from each site was used for measurement of primary production instead of well water. These rates of primary production represent the maximum potential primary production at those sites at their existing water chemistry.

Detritus

In 1986, standing crops of detritus were sampled for the four sites on Munson and Sun Creeks. Three samples were taken at each site by inserting a McNeil corer into the sediment to a depth of approximately 10 cm and removing all detrital material. The larger detritus was removed initially by hand, and then a known volume of water was pumped from the corer. Pumping continued until the water became clear or until 10 l of water had been removed. The water was immediately sieved through a 250-u Tyler sieve, and a 200-ml subsample of the water that passed through the sieve was collected. The material greater than 250 u and the subsample were held on ice and taken to laboratories at OSU within 48 hr. In the laboratory, the material greater than 250 u was sieved again and separated into a fraction greater than 500 u and a fraction between 250 to 500 u. The subsample of material less than 250 u was filtered through a 0.7 u GFF glass fiber filter. The filters and detritus samples were dried at 55°C for 48 hr, weighed, ashed at 550°C for 4 hr, and reweighed.

Benthic Invertebrates

Benthic invertebrates were collected from all study sites at each sampling date. In 1985, qualitative samples were collected by disrupting the substrate upstream of a D-frame net (250-u mesh); surface substrates were brushed off by hand, and then deeper substrates were kicked for 30 seconds over an area extending 1 m upstream of the net to dislodge associated invertebrates. Three samples were collected at each site and preserved in 90% ethanol. Aquatic insects were counted and identified to genus (species if possible), and non-insect invertebrates were identified to class.

Invertebrates were assigned to functional feeding groups according to Cummins and Merritt (1984). Four major feeding functional groups were considered - shredders, scrapers, collectors, and predators. Shredders consume coarse particles of organic matter by tearing and shredding them into smaller particles. Scrapers rasp and scrape across substrates to remove attached organic matter. Collectors consume small particles of organic matter, and predators engulf other animals.

In 1986, quantitative samples of benthic invertebrates were taken with a Hess sampler (250-u mesh) at the four sites on Munson and Sun Creeks and from the springs inside the rim of the crater. Samples were preserved and processed as described above.

In late summer of 1985, growth rates of a dominant caddisfly were measured in growth boxes in Munson, Dutton, and Goodbye Creeks. The caddisfly *Psychoglypha sp.* was collected from Munson Creek, and seven individuals were placed in each of two growth boxes at the four sites. Twenty-five individuals were saved to determine the initial weights of the insects. Substrates and detrital material from the study site were placed in growth box as a food source for the caddisflies. After one month, the animals were removed from the growth boxes, dried at 55°C for 48 hr, and weighed. Growth was expressed as the difference between initial and final weights.

Processing (microbial decomposition plus invertebrate consumption) of allochthonous organic matter was determined by placing leaf packs of known weights in coarse mesh bags at the four study sites in 1985. Alder leaves were used in the packs because they are relatively high quality as a food source for shredders and are found along the streams in the National Park. Twenty leaf packs were placed in each site in late August and were collected after 36 days in the streams. Leaf packs were stored in ice and returned to the laboratory. Packs were rinsed to remove extraneous material, dried at 55°C for 48 hr, and weighed. Decomposition was expressed as both percent weight loss and instantaneous decay rate, assuming an exponential rate of decay (Petersen and Cummins 1974).

RESULTS

Streams Outside the Crater Rim

Water Chemistry

In the comparison of Munson, Dutton, and Goodbye Creeks in 1985, nitrate concentrations were always highest in Munson Creek, and nitrate in lower Munson was higher than upper Munson at all three dates (Fig. 4). Nitrate concentrations in Munson Creek ranged from 15-45 ug NO_3-$N \cdot l^{-1}$, but nitrate concentrations never exceeded 8 ug NO_3-$N \cdot l^{-1}$ at the other sites. In August, nitrate concentration increased by only 2 ug NO_3-$N \cdot l^{-1}$ from the upstream station to the downstream station in Munson Creek; but in September, nitrate concentration increased from 2 ug NO_3-$N \cdot l^{-1}$ at Munson Springs to 15 ug NO_3-$N \cdot l^{-1}$ at upper Munson and 23 ug NO_3-$N \cdot l^{-1}$ at lower Munson.

There were no major differences in ammonium concentrations between sites (Fig. 5), and ammonium concentrations never exceeded 8 ug NH_4-$N \cdot l^{-1}$. The Munson Creek sites were higher in ammonium than Goodbye Creek at all three sampling dates, but this difference was never greater than 4 ug NH_4-$N \cdot l^{-1}$. In Munson Creek, ammonium concentrations were a small fraction of the total dissolved nitrogen (NO_3, NH_4, and organic N) (Fig. 6), generally accounting for less than 20% of the total. Organic nitrogen concentrations were less than 10 ug/l, and there were no consistent differences between sites (Fig. 7).

Dissolved orthophosphate phosphorus and total phosphorus generally declined at all sites from winter through fall, ranging from 5 to 21 ug PO_4-$P \cdot l^{-1}$ and 1 to 56 ug total $P \cdot l^{-1}$ (Fig. 8 & 9). Dissolved phosphorus concentrations increased from upper Munson to lower Munson in all seasons; this downstream increase in phosphorus was not observed in Dutton Creek in August and September. In September, there was no major change in dissolved

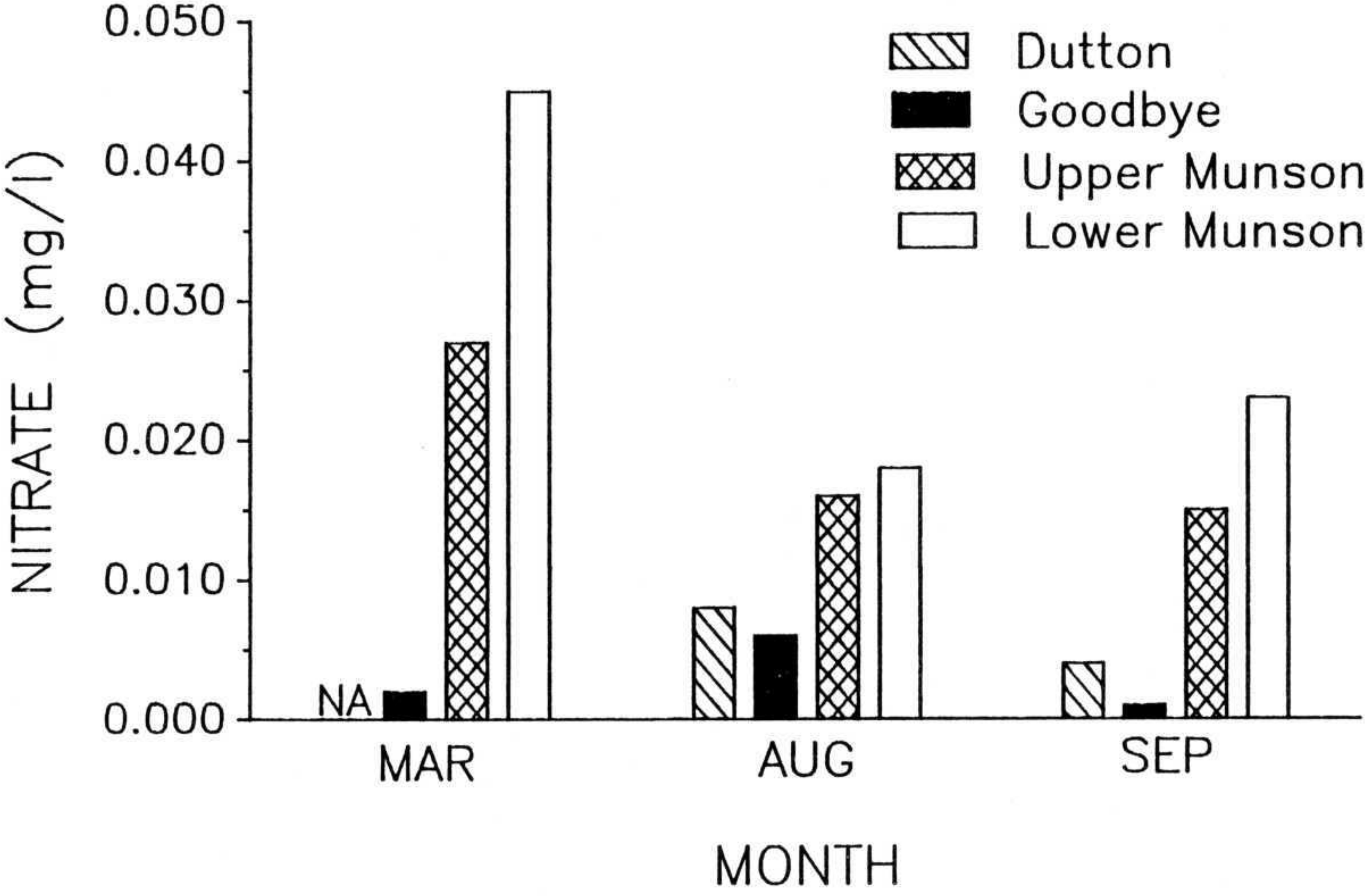


Figure 4. Nitrate concentrations in streams outside the caldera in March, August, and September 1985 (UM - upper Munson, LM - lower Munson, D - Dutton, GB - Goodbye).

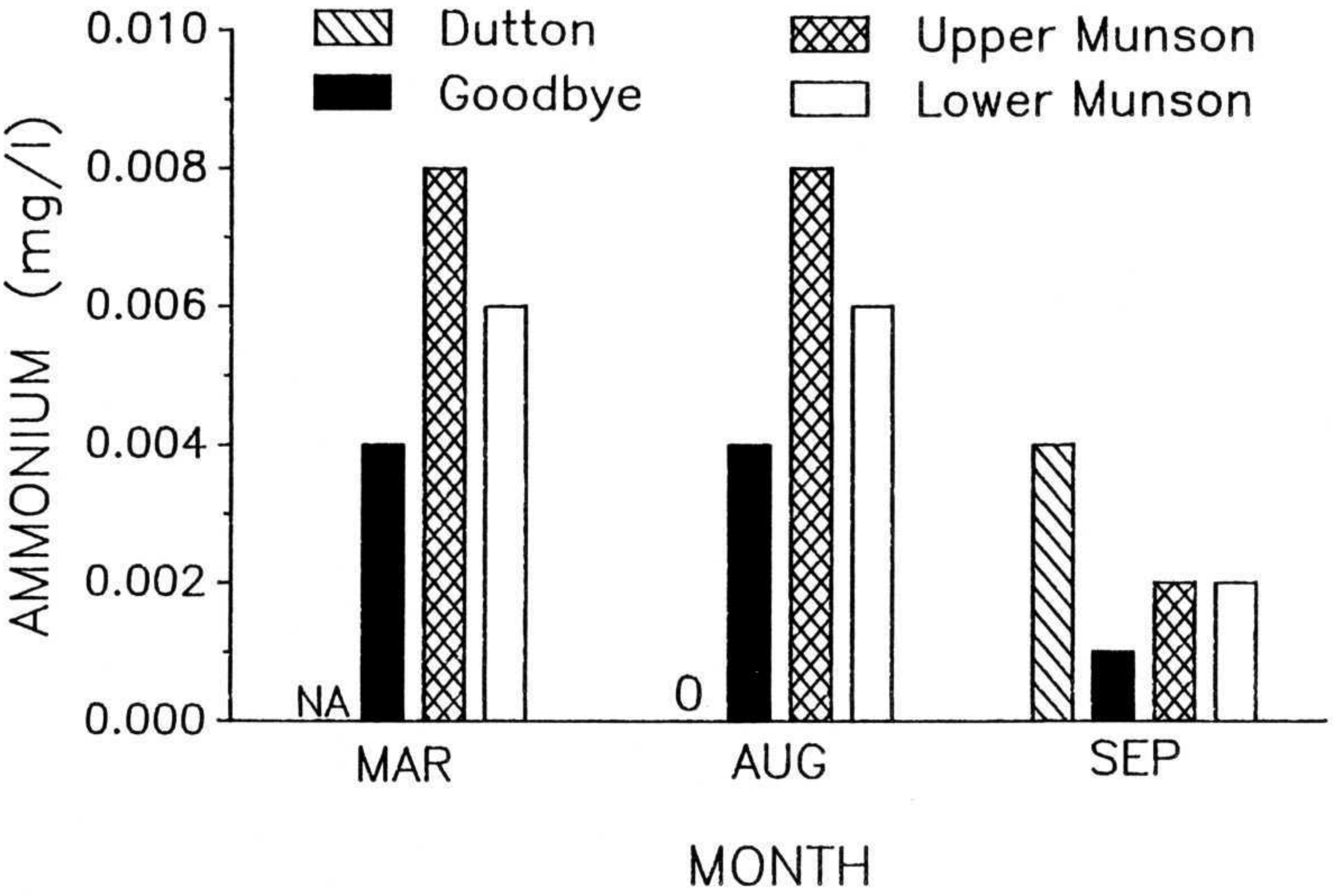


Figure 5. Ammonium concentrations in streams outside the caldera in March, August, and September 1985 (UM - upper Munson, LM -lower Munson, D - Dutton, GB - Goodbye).

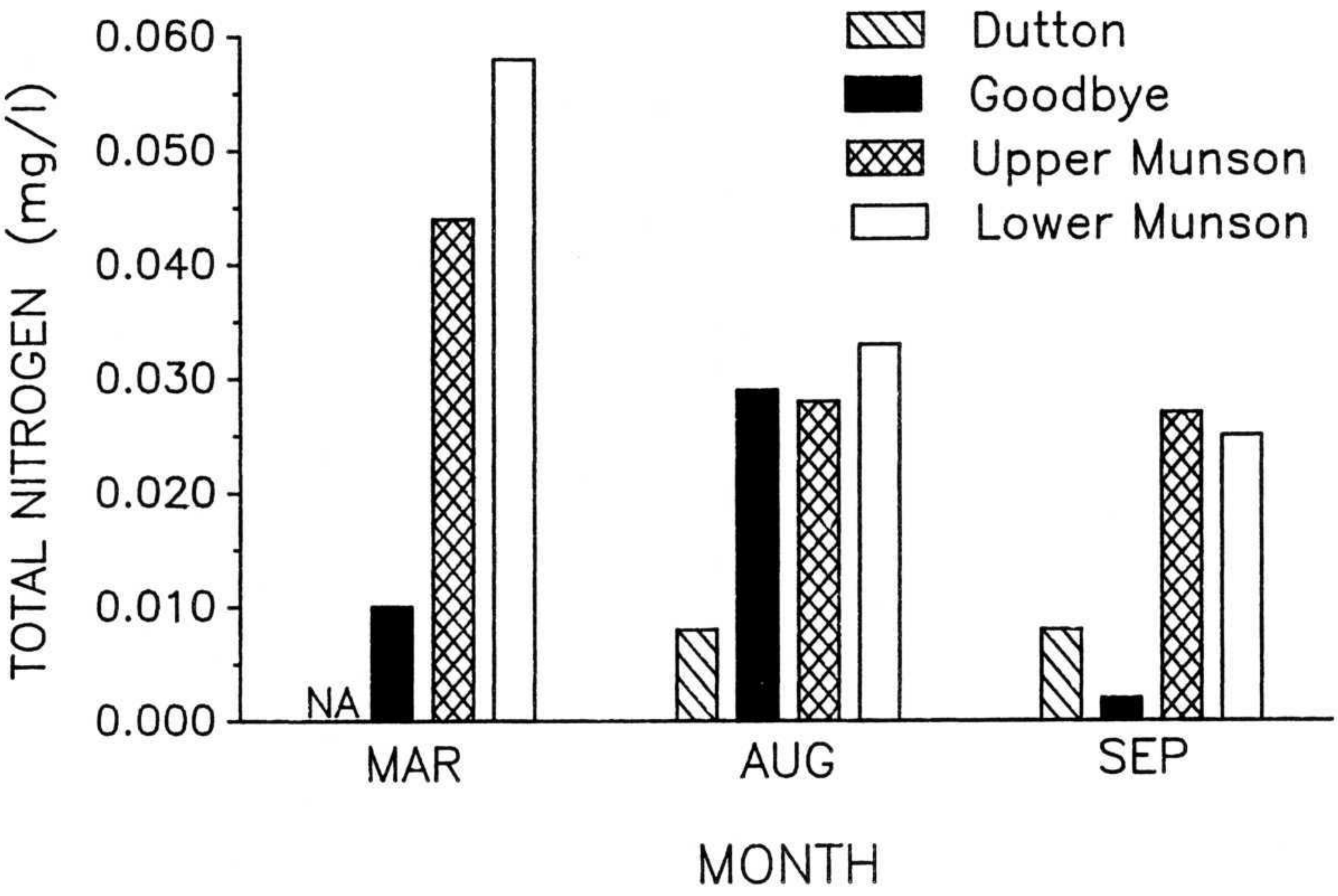


Figure 6. Total dissolved inorganic nitrogen concentrations in streams outside the caldera in March, August, and September 1985 (UM upper Munson, LM lower Munson, D - Dutton, GB - Goodbye).

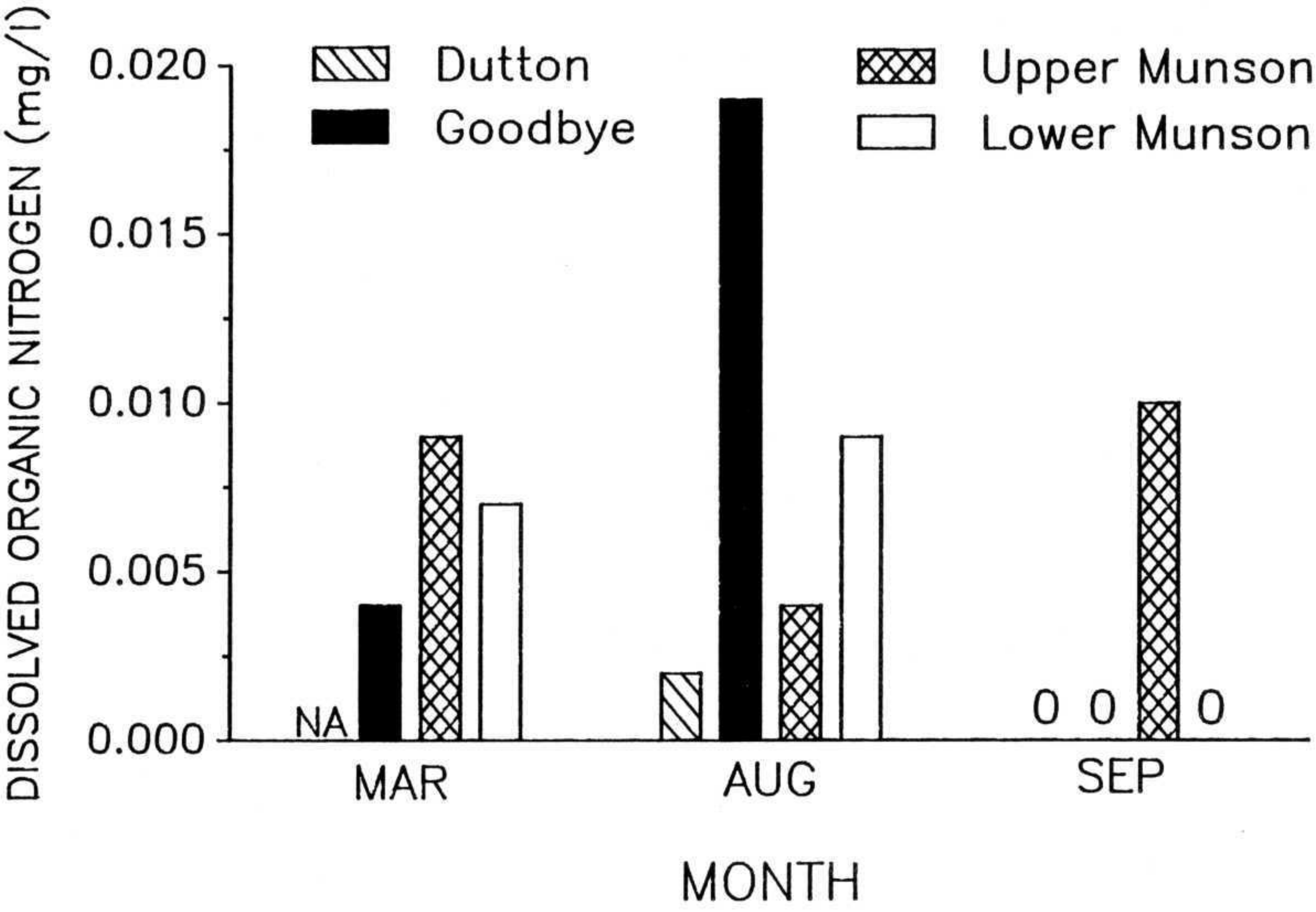


Figure 7. Total organic nitrogen concentrations in streams outside the caldera in March, August, and September 1985 (UM - upper Munson, LM - lower Munson, D - Dutton, GB - Goodbye).

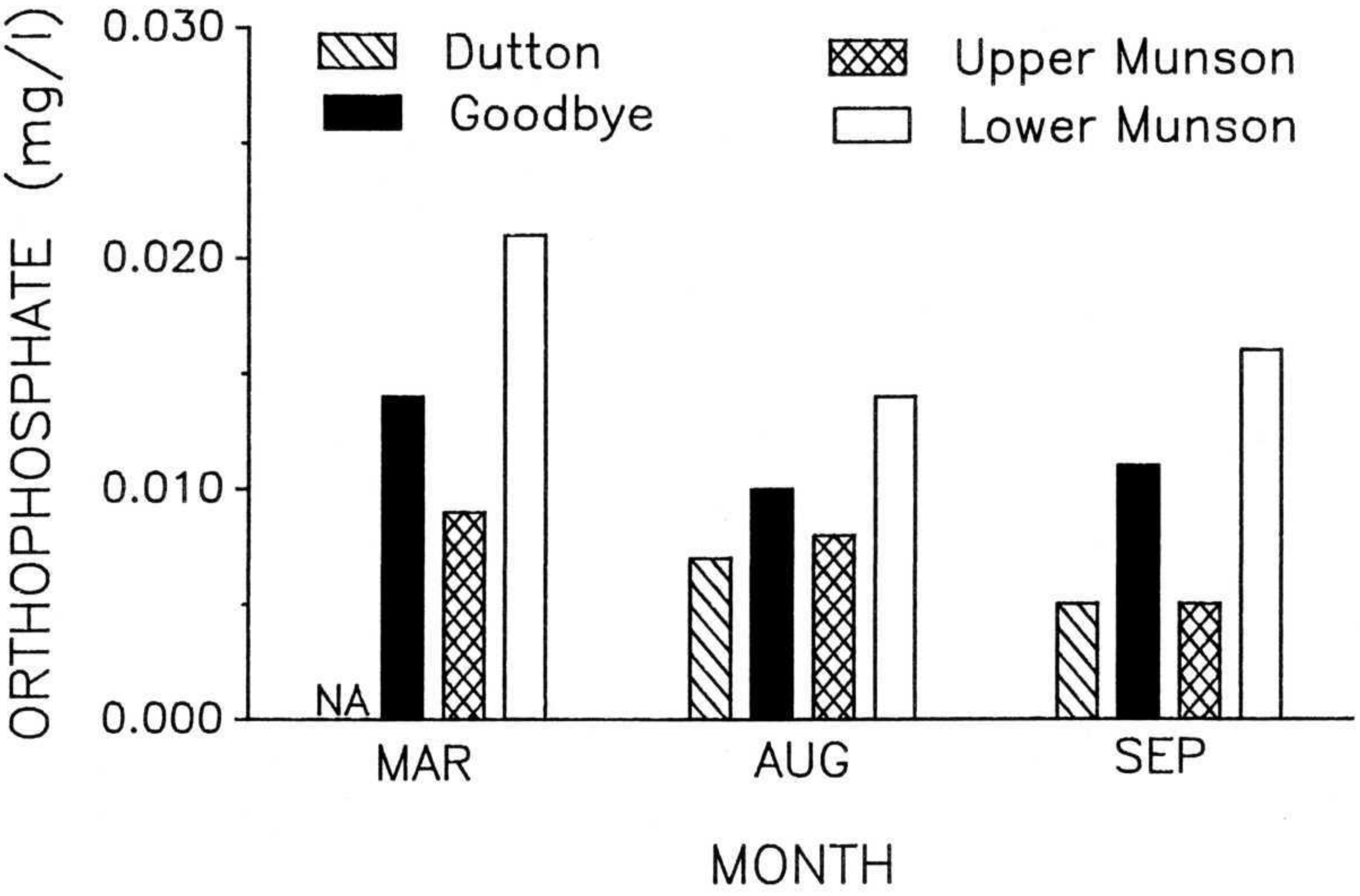


Figure 8. Dissolved orthophosphate concentrations in streams outside the caldera in March, August, and September 1985 (UM - upper Munson, LM - lower Munson, D - Dutton, GB - Goodbye).

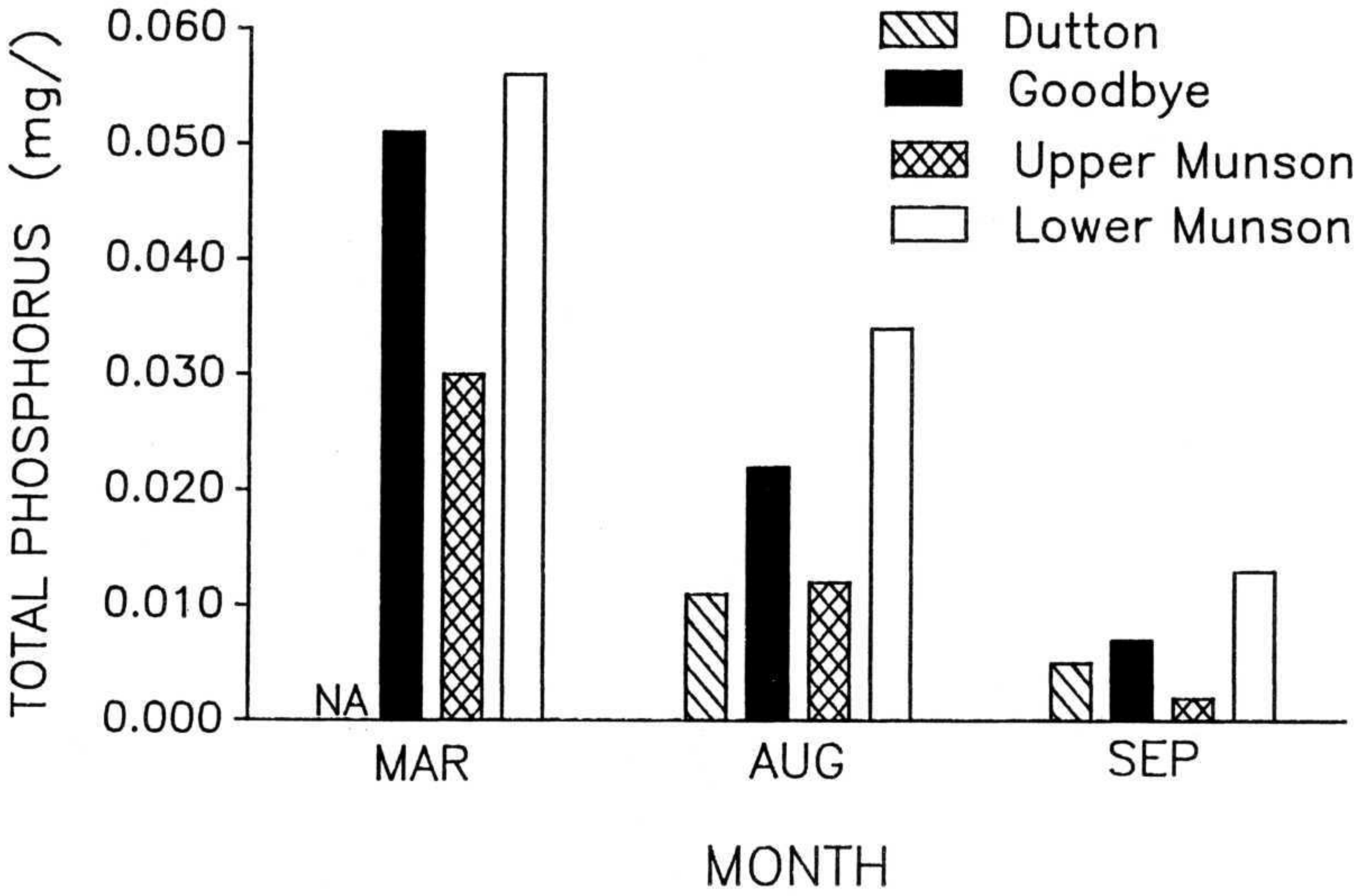


Figure 9. Total dissolved phosphorus concentrations in streams outside the caldera in March, August, and September 1985 (UM - upper Munson, LM - lower Munson, D - Dutton, GB - Goodbye).

phosphorus concentrations between Munson Springs and upper Munson, but there was an increase of 10 $ug \cdot l^{-1}$ of both orthophosphate and total phosphorus between the upper and lower sites.

The pH in all study streams was close to neutrality, and total alkalinity was extremely low (Table 2). There were no seasonal trends in pH and alkalinity, but Goodbye Creek and lower Munson Creek had slightly higher buffering capacities than the other sites.

Table 2. pH and total alkalinity of streams outside of the crater rim in 1985. Total alkalinity is expressed as mg $CaCO_3 \cdot l^{-1}$.

SAMPLE SITE	WINTER		SUMMER		FALL	
	pH	ALK	pH	ALK	pH	ALK
Goodbye	7.4	37.9	7.3	32.1	7.4	35.4
Munson Spring					6.6	21.2
Upper Munson	7.1	25.7	7.2	21.1	7.2	22.5
Lower Munson	7.1	33.3	7.2	31.8	7.1	34.4
Upper Dutton			6.9	18.5	7.0	18.0
Lower Dutton			7.1	19.8	6.3	18.0

Major cation concentrations were analyzed for Goodbye and Munson Creeks for March samples to provide background information. The cations in these streams are dominated by sodium, followed by calcium, potassium, and magnesium in that order (Table 3). These concentrations are typical of streams of the west slope of the Cascade Mountains, though magnesium commonly dominates over potassium in order of concentration.

Table 3. Cations concentrations in Goodbye and Munson Creeks in March 1985 (all concentrations are expressed as mg l^{-1}).

SAMPLE SITE	NA	CA	K	MG
Goodbye	2.032	1.030	0.870	0.733
Upper Munson	1.638	0.950	0.500	0.298
Lower Munson	2.346	0.800	1.060	0.494

In 1986, water chemistry of Goodbye Creek, upper and lower Munson Creek, and two sites in Sun Creek that correspond to the Munson Creek sites in relative position within the watershed were compared. Nitrate concentrations in Goodbye Creek and lower Sun Creek were extremely low, but upper Sun Creek and both sites on Munson Creek had nitrate concentrations in the range of 12-17 ug NO_3-$N \cdot l^{-1}$ (Table 4). Organic nitrogen concentrations also were highest in upper Sun Creek. Ammonium concentrations were low in all five locations. Phosphorus concentrations, both total phosphorus and orthophosphate, were highest in Sun Creek.

Table 4. Dissolved nitrogen and phosphorus concentrations in Goodbye Creek, upper and lower Munson Creek, and upper and lower Sun Creek in August 1986.

SAMPLE SITE	Organic N	NH_4-N	NO_3-N	Organic P	PO_4-P
Goodbye	0.016	0.000	0.002	0.021	0.009
Upper Sun	0.043	0.000	0.017	0.044	0.028
Lower Sun	0.020	0.003	0.002	0.057	0.033
Upper Munson	0.015	0.002	0.012	0.017	0.005
Lower Munson	0.025	0.002	0.016	0.031	0.014

Detritus

The standing crops of detritus in Munson and Sun Creeks were compared in 1986. The upper sites in both creeks contained greater amounts of particulate organic matter in the sediments than the lower sites (Table 5), and the quantities of detritus in the upper and lower locations of both streams were practically identical to each other. Roughly half of the particulate organic matter in these streams consisted of coarse detritus greater than 500 u in diameter.

Table 5. Standing crops of particulate organic matter in upper and lower sites on Munson and Sun Creeks in August 1986 (g ash-free dry mass·m^{-2}).

	SIZE FRACTION			
SITE	>500 u	250-500 u	<250 u	TOTAL
Upper Munson	357.0	24.0	150.6	531.5
Lower Munson	93.0	27.6	106.5	227.1
Upper Sun	301.7	38.3	226.1	566.2
Lower Sun	158.0	29.2	142.5	329.8

Benthic Primary Producers

Algal abundance in Munson Creek differed substantially from that in the other study streams. Standing crop of chlorophyll *a*, an index of the abundance of benthic algae, was greatest at lower Munson at all seasons in 1985 (Fig. 10). Standing crop of chlorophyll *a* at lower Munson was greatest in winter, dropping by approximately 50% in summer and fall. Abundance of chlorophyll *a* at UM increased gradually from winter through fall. Dutton and Goodbye Creeks exhibited much lower standing crops of chlorophyll *a*, generally a third or less of that in Munson Creek.

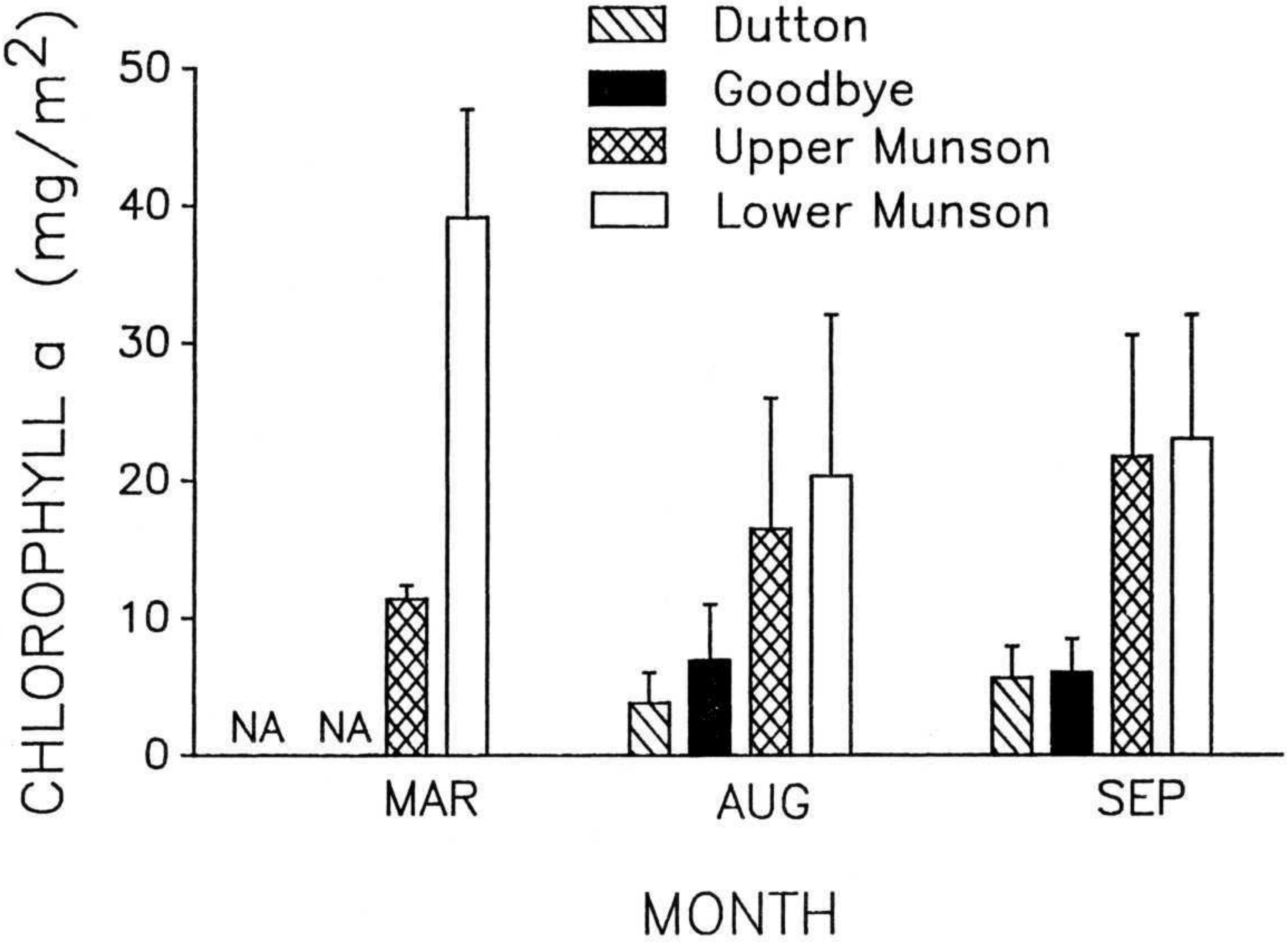


Figure 10. Standing crops of chlorophyll *a* in streams outside caldera in March, August, and September 1985 (UM - upper Munson, LM - lower Munson, D - Dutton, GB - Goodbye).

In 1986, we compared algal abundance in Munson Creek and Sun Creek and used Goodbye Creek as a reference to responses observed the previous year. Lower Munson Creek again contained the highest standing crops of chlorophyll *a* (Fig. 11). Standing crops of chlorophyll *a* at lower Munson Creek was more than twice that observed at the downstream site; however, the lower site in Sun Creek had less than half the abundance of algal pigments observed at the upstream site. The values for LM were similar to those observed in 1985, but those in UM were lower than the previous year. Algal abundance in Goodbye Creek again was much lower than that observed in Munson Creek and was similar to that observed in lower Sun Creek.

Rates of benthic metabolism by algal assemblages were similar to patterns of chlorophyll standing crops in the four study sites in 1985; both sites in Munson Creek had significantly higher rates of gross primary production than Dutton or Goodbye Creek (Fig. 12). Lower Munson was generally more productive than upper Munson, and both of these sites were approximately four times as productive as Goodbye or Dutton Creek. Daily gross primary production was less than the daily respiratory demand of the algal assemblage at all sites (Fig. 13). The P/R ratio was higher in Munson Creek than the other streams.

In 1986, benthic metabolism was compared for the four sites on Munson and Sun Creeks (Fig. 14). Again, Munson Creek exhibited the highest rates of benthic metabolism. Lower Munson was more than twice as productive as upper Munson, based on rates of gross primary production. The pattern of gross primary production in Sun Creek was the opposite; primary production was lower at the downstream station. This shift in primary production is consistent with the standing crops of chlorophyll *a* observed at the two sites. The Munson Creek sites also had higher P/R ratios than the Sun Creek sites

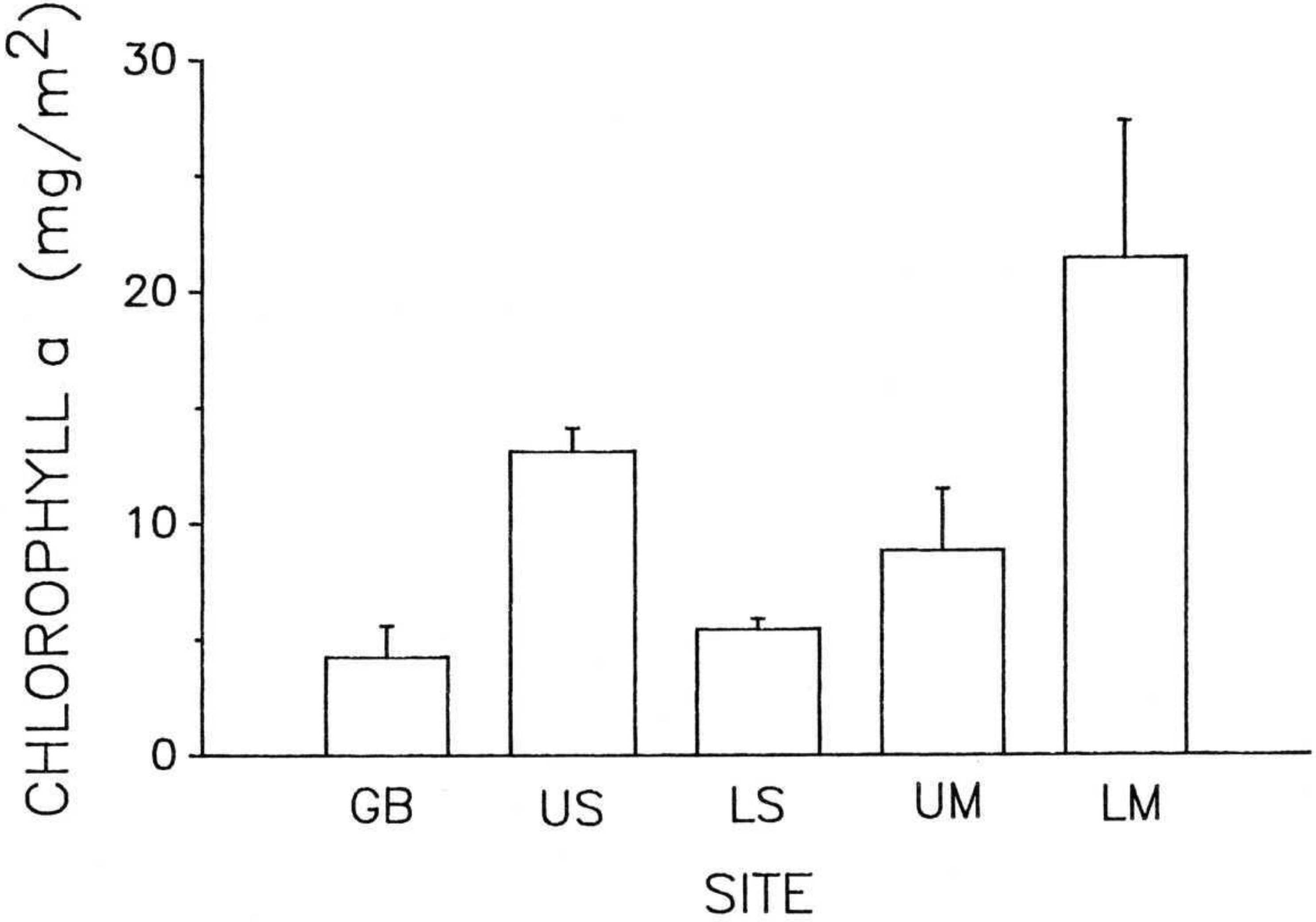


Figure 11. Standing crops of chrorophyll *a* in streams outside the caldera in 1986 (UM - upper Munson, LM - lower Munson, US - upper Sun, LS - lower Sun, GB - Goodbye).

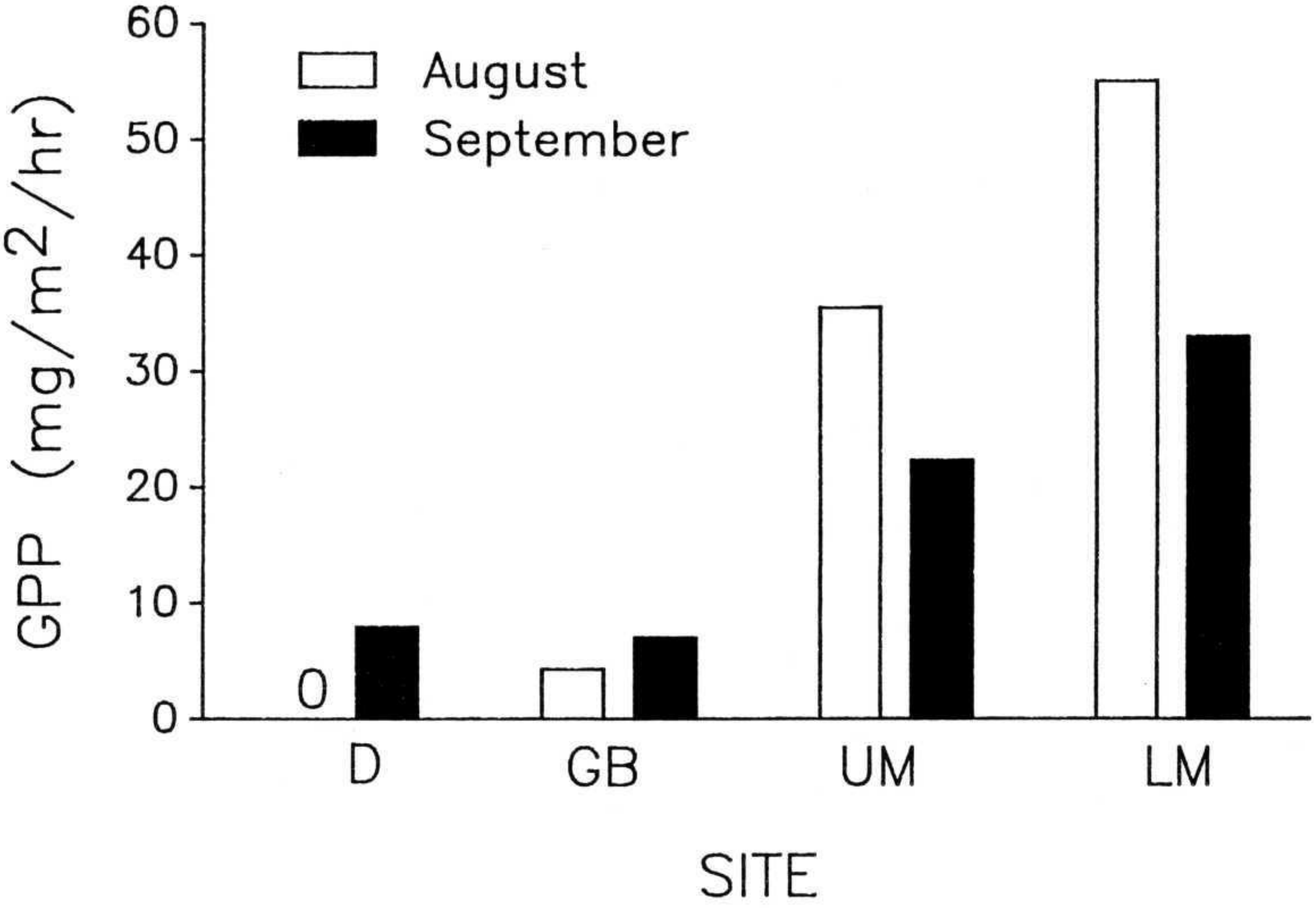


Figure 12. Rates of gross primary production of benthic algae collected from streams outside the caldera in August and September 1985 (UM - upper Munson, LM - lower Munson, D - Dutton, GB - Goodbye).

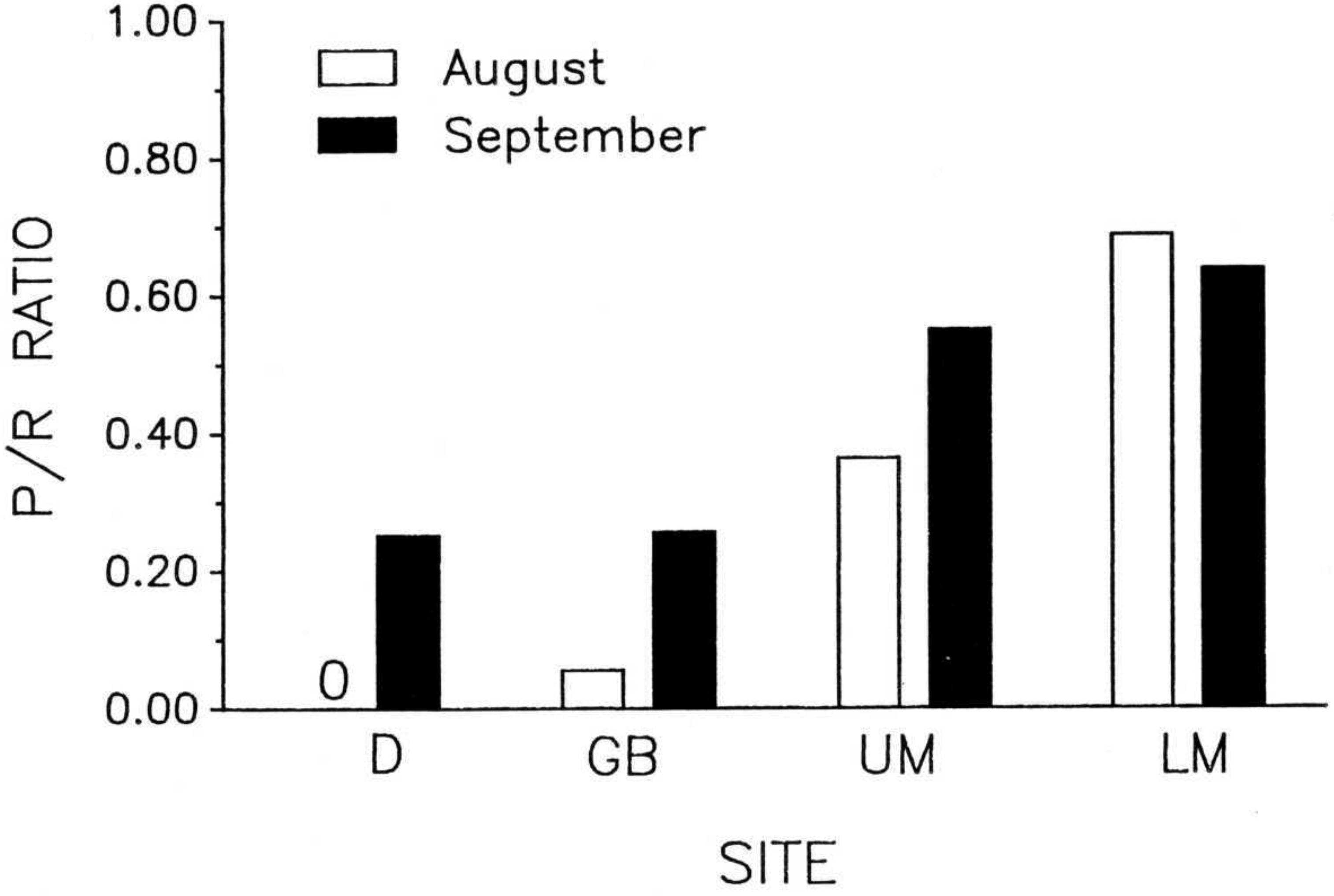


Figure 13. Ratios of gross primary production to community respiration (P/R) on substrates from streams outside the caldera in August, and September 1985 (UM - upper Munson, LM - lower Munson, D - Dutton, GB - Goodbye).

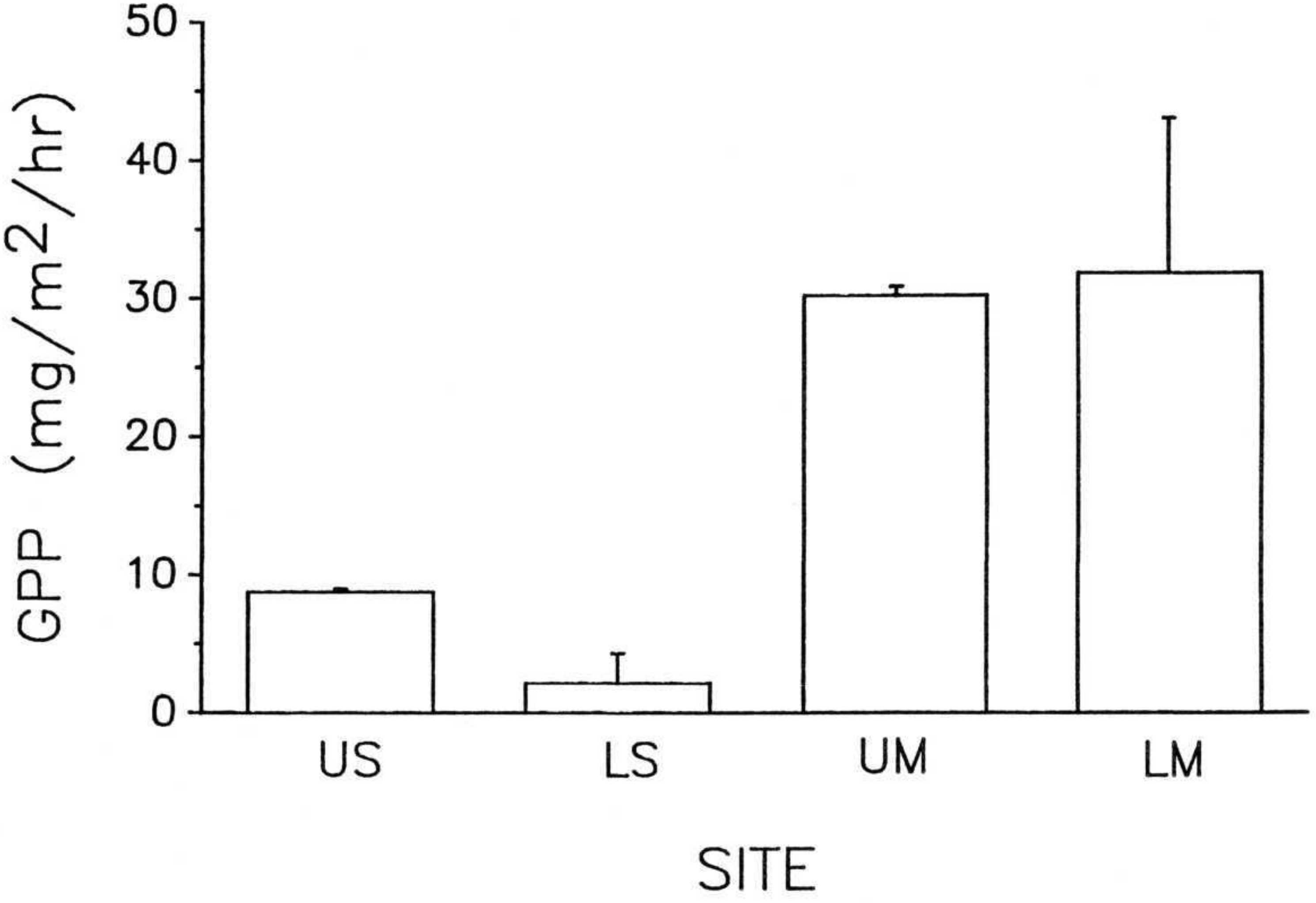


Figure 14. Rates of gross primary production of benthic algae collected from streams outside the caldera in 1986 (UM - upper Munson, LM - lower Munson, US - upper Sun, LS - lower Sun, GB - Goodbye).

(Fig. 15). Rates of gross primary production at the two sites in Munson Creek in 1986 were slightly lower than those observed there the previous year, but P/R ratios were much higher than observed in 1985.

Benthic Invertebrates

In 1985, composition of benthic invertebrate communities at the four study sites was compared. Goodbye Creek and the two sites on Munson Creek were similar in terms of total numbers of taxa found at each site (Table 6), but Dutton Creek contained fewer taxa than the other streams. A total of 56 taxa were found at all the sites in 1985. Lower Munson Creek had the greatest number with 42 taxa, and samples from upper Munson Creek contained 37 taxa. Numbers of taxa were somewhat less in Goodbye Creek (31 taxa), but Dutton Creek contained only 13 taxa. Seasonal patterns in numbers of taxa at the different sites were consistent with the annual trend (data not shown).

The invertebrate community in Dutton Creek is distinct from those of the other study sites when compared on the basis of major orders of insects (Table 7). In Dutton Creek, Dipterans, primarily Chironomidae, comprise most of the invertebrate assemblage, and the stoneflies and mayflies are nearly absent. Dutton Creek also contains fewer genera of caddisflies than any other site. Both of the forested sites, upper Munson and Goodbye Creek, had high numbers of stoneflies, made up largely of the detritivorous nemourid, *Zapada columbiana*. In August and September 1985, 2,204 individuals were collected in lower Munson Creek in kick samples, 2,034 in upper Munson Creek, 1,378 in Dutton Creek, and 2,274 in Goodbye Creek.

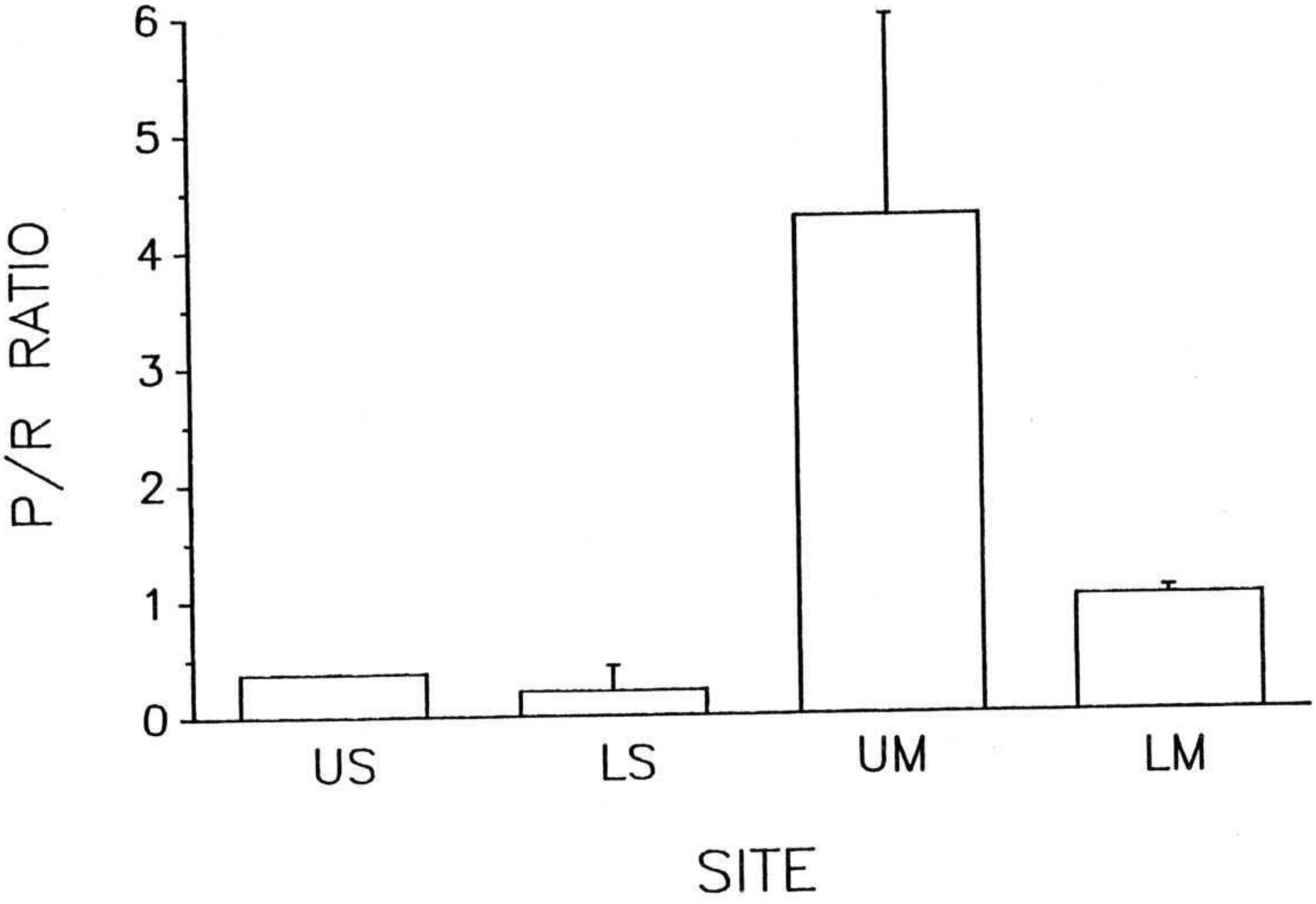


Figure 15. Ratios of gross primary production to community respiration (P/R) on substrates from streams outside the caldera in 1986 (UM - upper Munson, LM - lower Munson, US - upper Sun, LS - lower Sun, GB - Goodbye).

Table 6. List of taxa observed in streams outside the caldera rim in 1985.

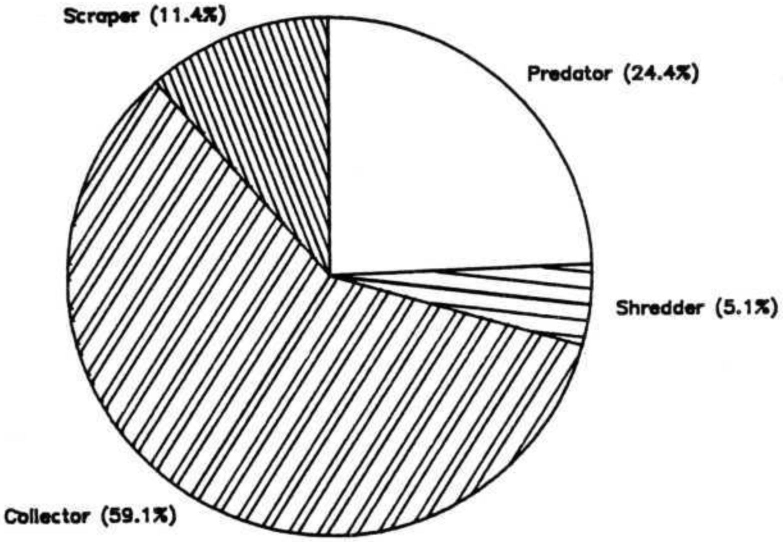
ORDER FAMILY GENUS SP	LOWER MUNSON	UPPER MUNSON	DUTTON	GOODBYE
DIPTERA				
Chironomidae	X	X	X	X
Empididae	X	X		X
Hemerodromia sp.		X		
Oreogeton sp.		X		
Tipulidae				
Dicranota sp.	X	X	X	
Limnophila sp.	X			
Pedicia sp.	X		X	
Simulidae			X	
Prosimulium sp.		X		X
PLECOPTERA				
Peltoperlidae				
Yoraperla mariana	X			X
Taeniopterygidae				
Doddsia occidentalis	X			
Nemouridae				
Visoka cataractae	X			X
Zapada columbiana	X	X	X	X
Zapada oregonensis		X		
Leuctridae				
Megaleuctra sp.	X			
Moselia infuscata		X		X
Capniidae				
Capnia sp.	X	X		X
Perlodidae				
Isoperla sp.	X	X		
Kogotus sp.	X			
Megarcys subtruncata	X	X		X
Chloroperlidae				
Kathroperla perdita				X
Sweltsa sp.	X			X
EPHEMEROPTERA				
Siphlonuridae				
Ameletus sp.	X	X		X
Baetidae				
Baetis sp.	X	X	X	X
Heptageniidae				
Cinygma sp.				X
Cinygmula sp	X	X		X
Iron sp.	X	X		X

Ephemerellidae				
Caudatella sp.	X	X		X
Drunella sp.	X			X
Drunella doddsi	X	X		X
Ephemerella sp.	X	X		X
Leptophlebiidae				
Paraleptophlebia sp.	X			X
TRICHOPTERA				
Hydropsychidae				
Parapsyche sp.	X			X
Glossosomatidae				
Anagapetus sp.	X			
Glossosoma sp.	X			
Limnephilidae				
Apatania sp.	X			
Chyranda sp.	X	X		
Cryptochia sp.		X		X
Desmona sp.		X		
Ecclisocosmoecus sp.	X	X		X
Ecclisomyia sp.	X	X		
Homophylax sp.		X	X	X
Imania sp.	X	X		
Limnephilus sp.		X	X	
Neothremma sp.	X	X		X
Oligophlebodes sp.	X			
Psychoglypha sp.	X	X	X	X
Rhyacophiloidea				
Rhyacophila sp.	X	X	X	X
Rhyacophila verrula	X	X		
COLEOPTERA				
Elmidae	X			
Staphylinidae		X		X
COLLEMBOLA	X	X	X	
GASTROPODA		X		
HIRUDINEA	X	X	X	X
HYDRACARINA	X	X		
OLIGOCHAETA	X	X	X	X
TOTAL TAXA	42	37	13	31

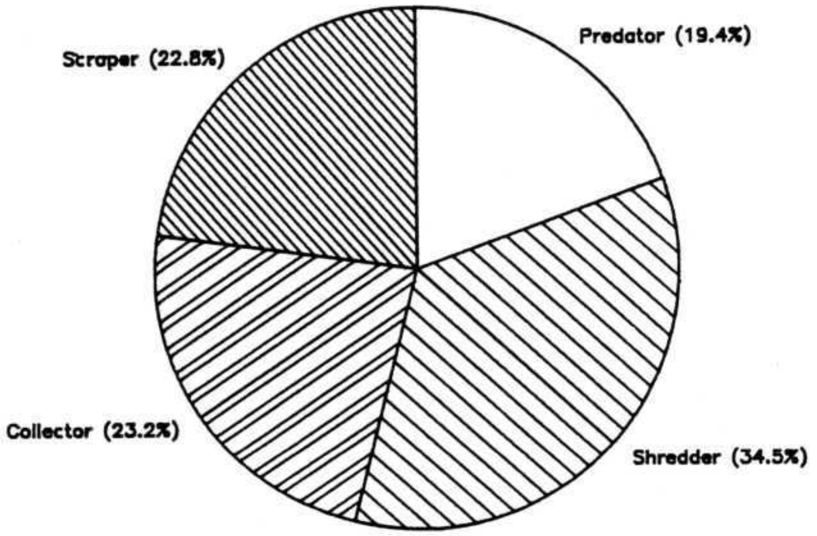
Table 7. Numbers of invertebrates of the major insect orders and other non-insects contained in kick samples from the study streams outside of the crater rim in 1985 (DIPT = Diptera; PLEC = Plecoptera; EPHEM = Ephemeroptera; TRICH = Trichoptera; OTHER = other insect orders; NON-INS = non-insect).

SITE	DATE	DIPT	PLEC	EPHEM	TRICH	OTHER	NON-INS
UM	Mar 85	265	41	19	52	0	158
	Aug 85	115	505	51	42	9	152
	Sep 85	63	849	22	36	0	190
LM	Mar 85	689	958	529	794	0	127
	Aug 85	117	132	74	106	0	124
	Sep 85	431	226	976	142	1	142
D	Aug 85	642	1	1	28	0	116
	Sep 85	366	0	0	42	0	182
GB	Aug 85	82	250	358	161	1	85
	Sep 85	92	622	180	343	4	96

Additional ecological information may be obtained by examining the functional feeding groups of benthic invertebrates at the different sites (Fig. 16). Shredders comprised major portions of the invertebrate communities in the two forested sites, upper Munson and Goodbye Creeks but were a small fraction in the meadow site at lower Munson and the more ephemeral Dutton Creek. Collectors accounted for more than half of the invertebrates in Dutton Creek. Lower Munson Creek was more open to solar radiation, and scrapers made up almost half of the invertebrate community. Predators ranged from 10% to 30% of the invertebrate assemblages in the four sites. The relative composition was more even between functional groups at Goodbye Creek than the other locations. Seasonal trends in functional group composition are illustrated in Figs. 17-20. Shredders increased in relative proportion in the fall in the three forested sites.



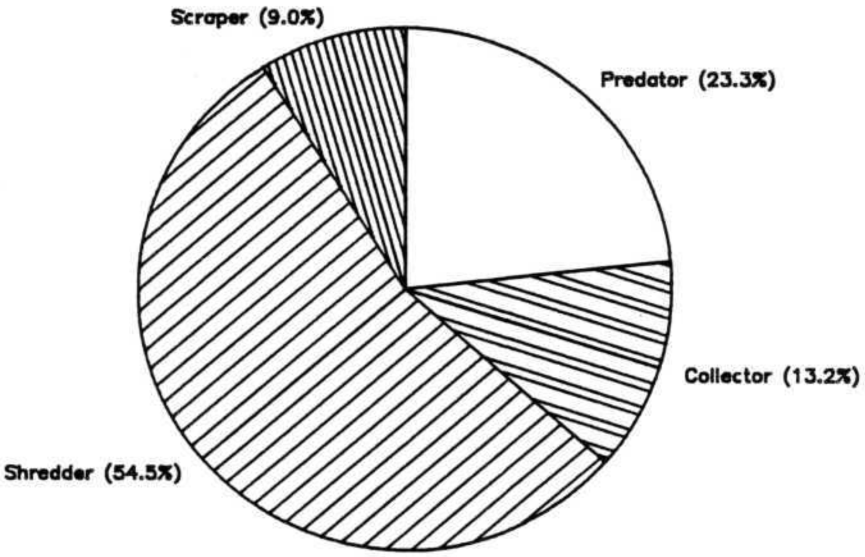
DUTTON



GOODBYE

Figure 16. Average relative proportions of functional feeding groups in streams outside the caldera for 1985 (UM - upper Munson, LM - lower Munson, US upper Sun, LS - lower Sun, D - Dutton, GB - Goodbye).

UPPER MUNSON



LOWER MUNSON

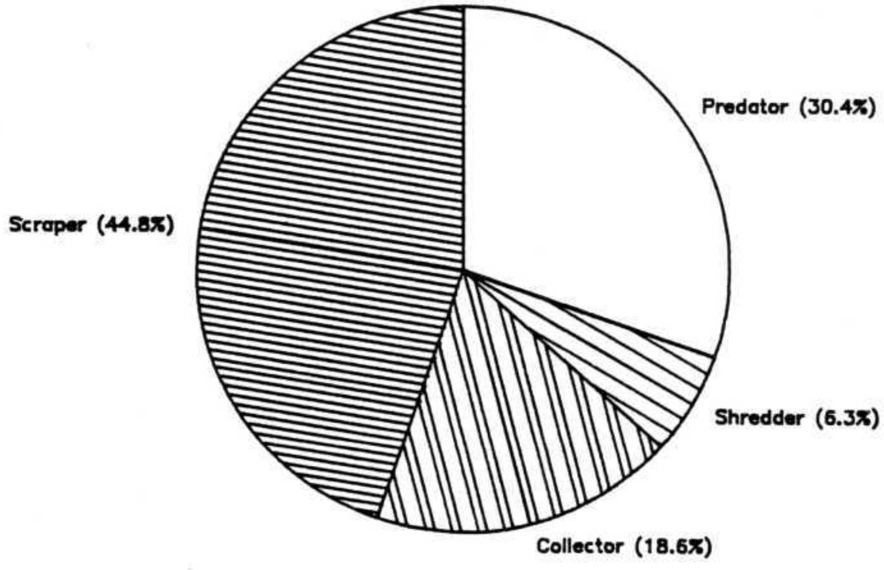
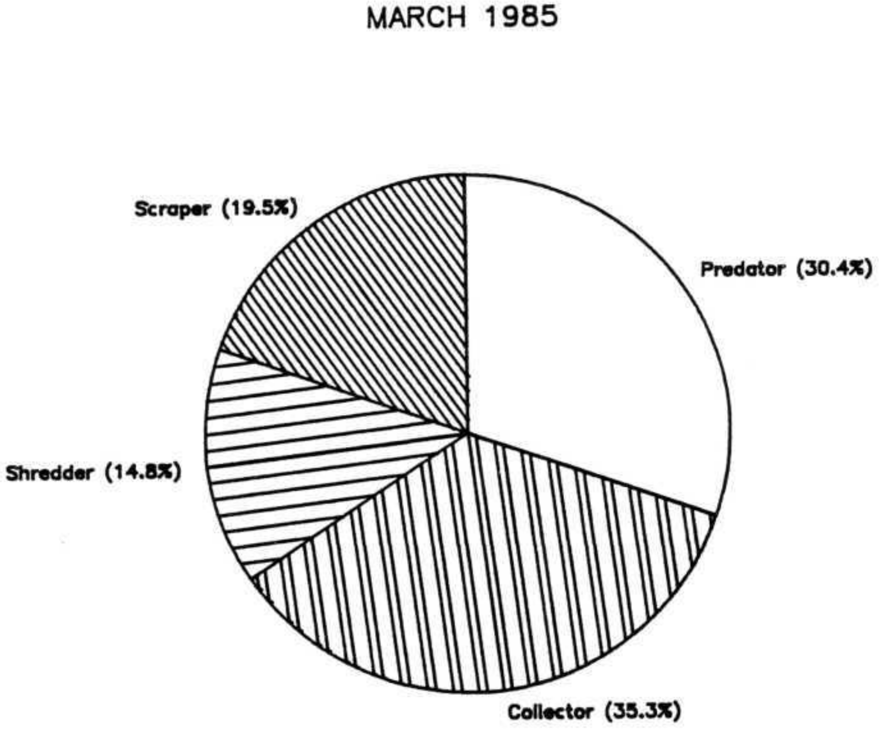


Figure 16. (continued)



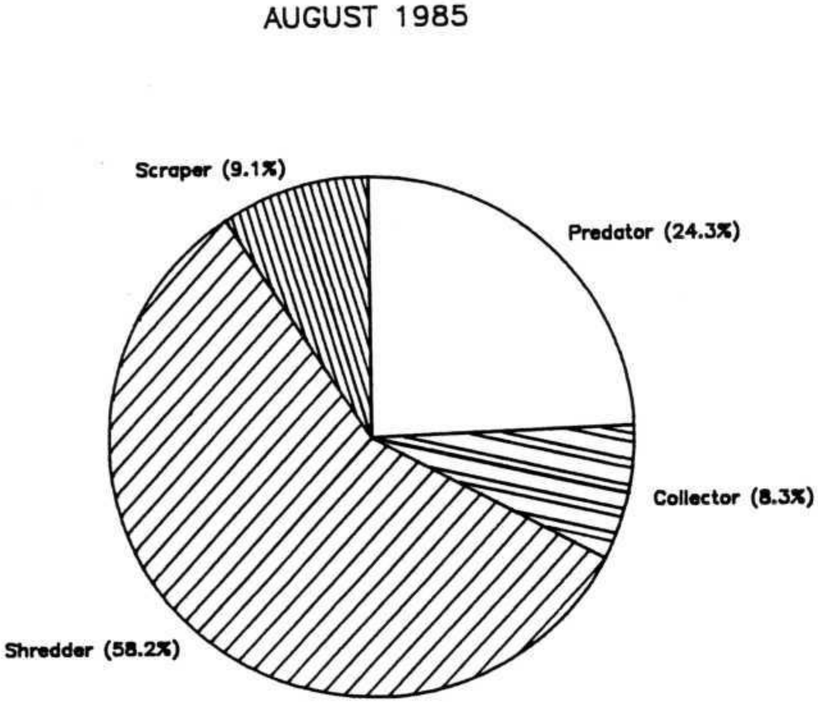


Figure 17. Relative proportions of functional feeding groups in upper Munson Creek in March, August, and September 1985.

SEPTEMBER 1985

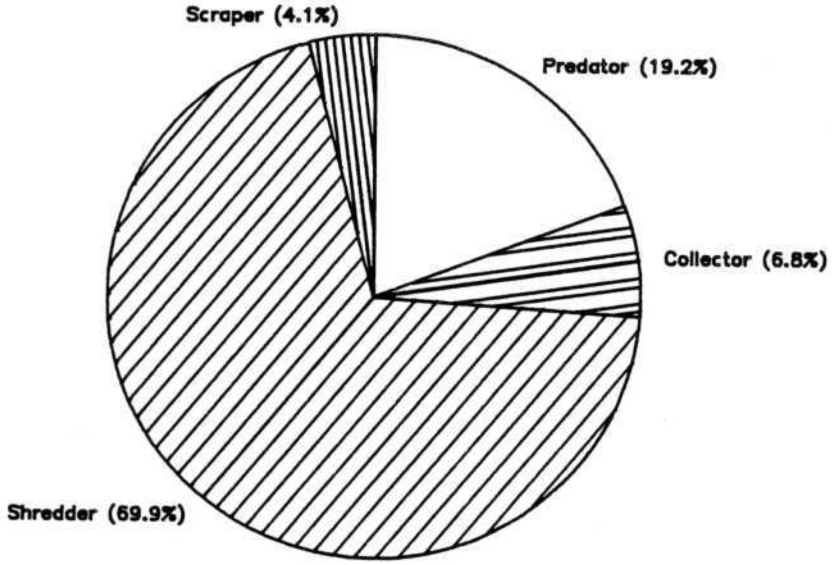
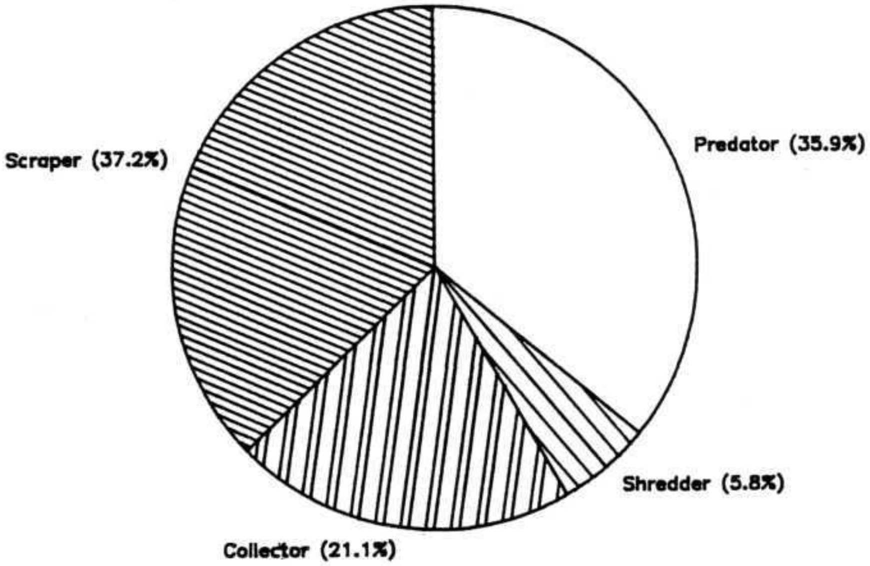


Figure 17. (continued)

MARCH 1985



AUGUST 1985

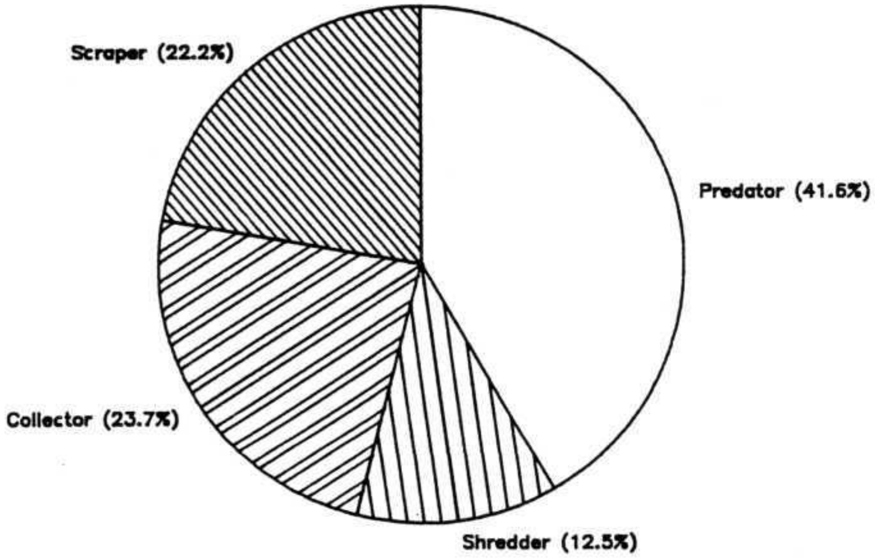


Figure 18. Relative proportions of functional feeding groups in lower Munson Creek in March, August, and September 1985.

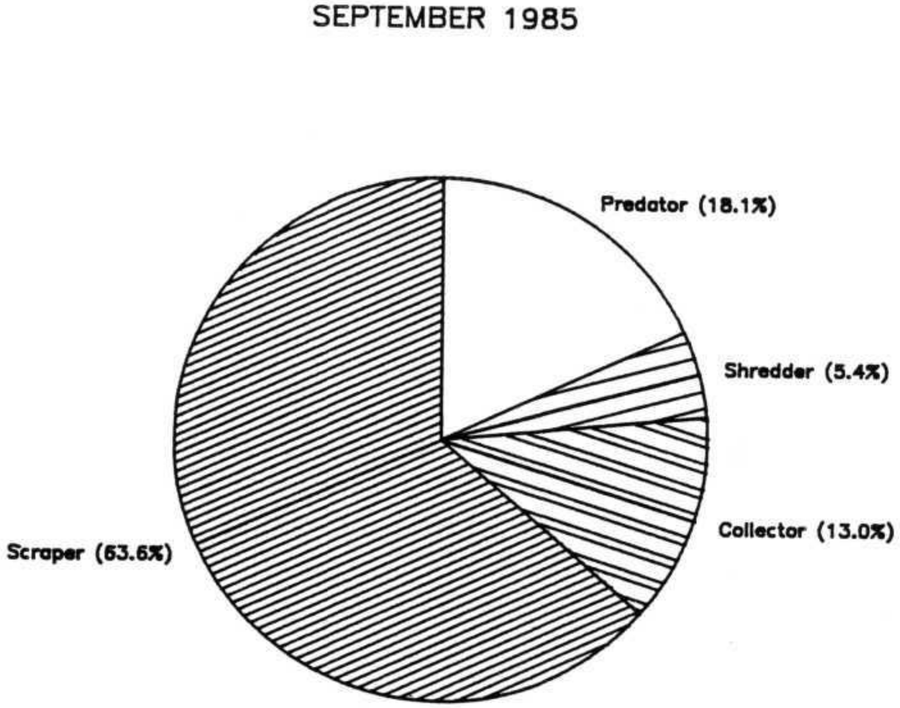
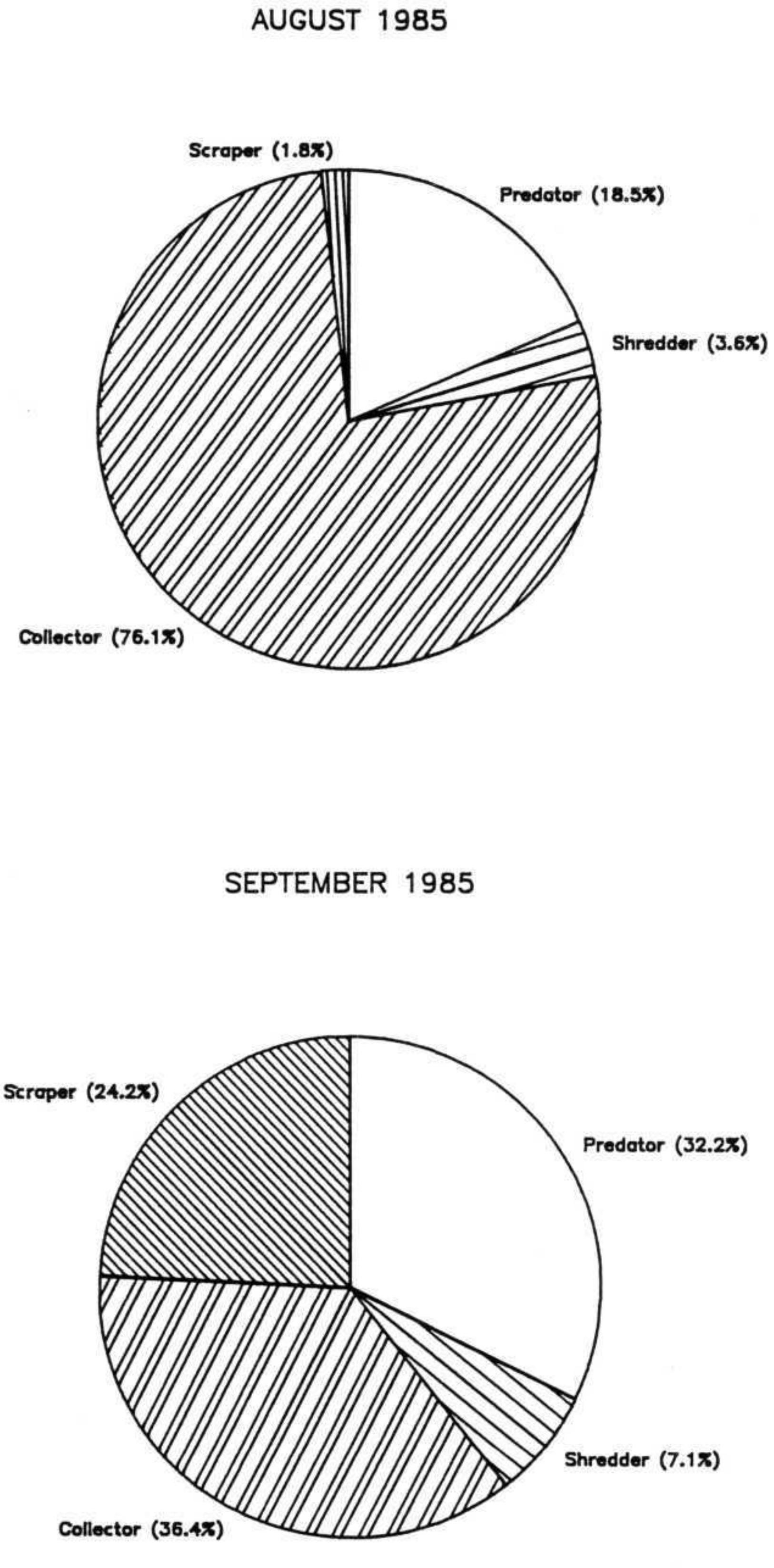


Figure 18. (continued)

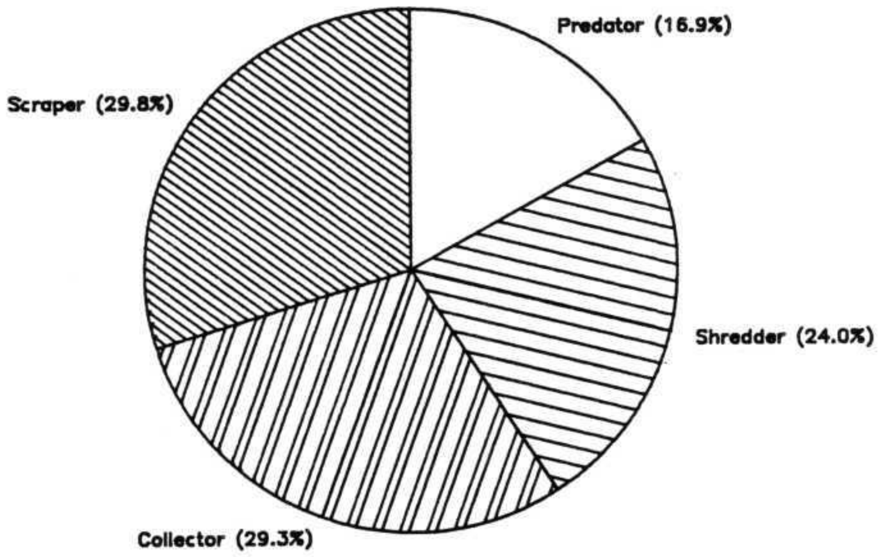


AUGUST 1985

SEPTEMBER 1985

Figure 19. Relative proportions of functional feeding groups in Dutton Creek in August and September 1985.

AUGUST 1985



SEPTEMBER 1985

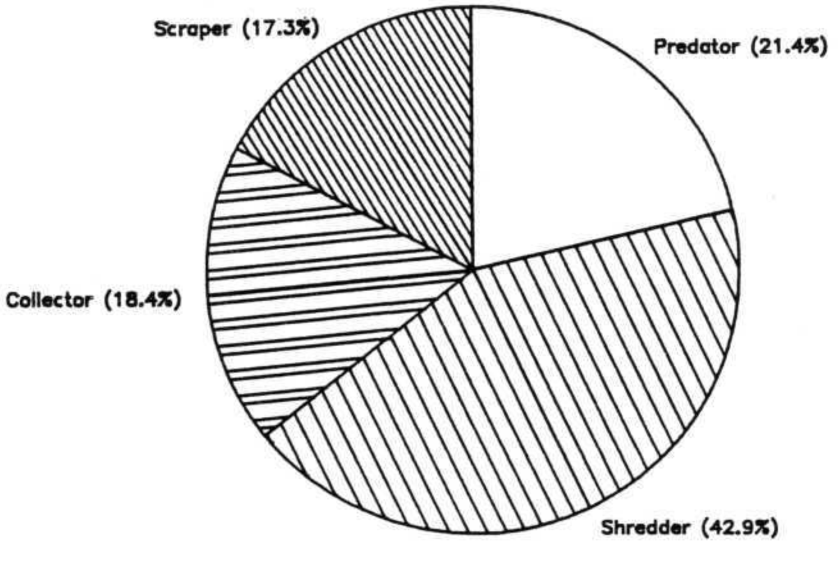


Figure 20. Relative proportions of functional feeding groups in Goodbye Creek in August and September 1985.

Lower Munson contained higher numbers of taxa and higher densities of invertebrates than the other study sites (Fig. 21 and 22). Both the upper and lower sites on Sun Creek were similar in numbers of taxa and densities of invertebrates. The number of taxa and the densities of invertebrates were less at upper Munson Creek than in the two sites on Sun Creek.

Munson and Sun Creeks differed substantially in functional feeding group composition (Fig. 23). The two sites in Munson Creek exhibited similar patterns to those observed at those sites in 1985. Upper Munson Creek was dominated by collectors, and scrapers and collectors made up the majority of the invertebrate assemblage in lower Munson Creek. Sun Creek, on the other hand, showed almost identical composition at both upper and lower sites. Collectors accounted for most of the invertebrates in this stream, followed by predators, scrapers, and shredders, respectively. The invertebrate communities in Sun Creek most closely resembled those in lower Munson Creek.

The growth of the caddisfly *Psychoglypha* on food resources from each of the four study sites was used as an indicator of the potential for each site to support invertebrate growth. Growth of *Psychoglypha* was three times greater in the two sites on Munson Creek than in Goodbye Creek (Fig. 24). In Dutton Creek, growth of the caddisfly was intermediate between that observed in Munson and Goodbye Creeks.

Weight loss of alder leaves also was used as a measure of biological processes, integrating microbial decomposition, invertebrate consumption, and mechanical abrasion. Although weight loss was slightly greater in lower Munson Creek and slightly lower in Dutton Creek, there were no significant differences in leaf decomposition between the four study sites (Fig. 25). The lower rate of decomposition in Dutton Creek reflects the drying of the stream

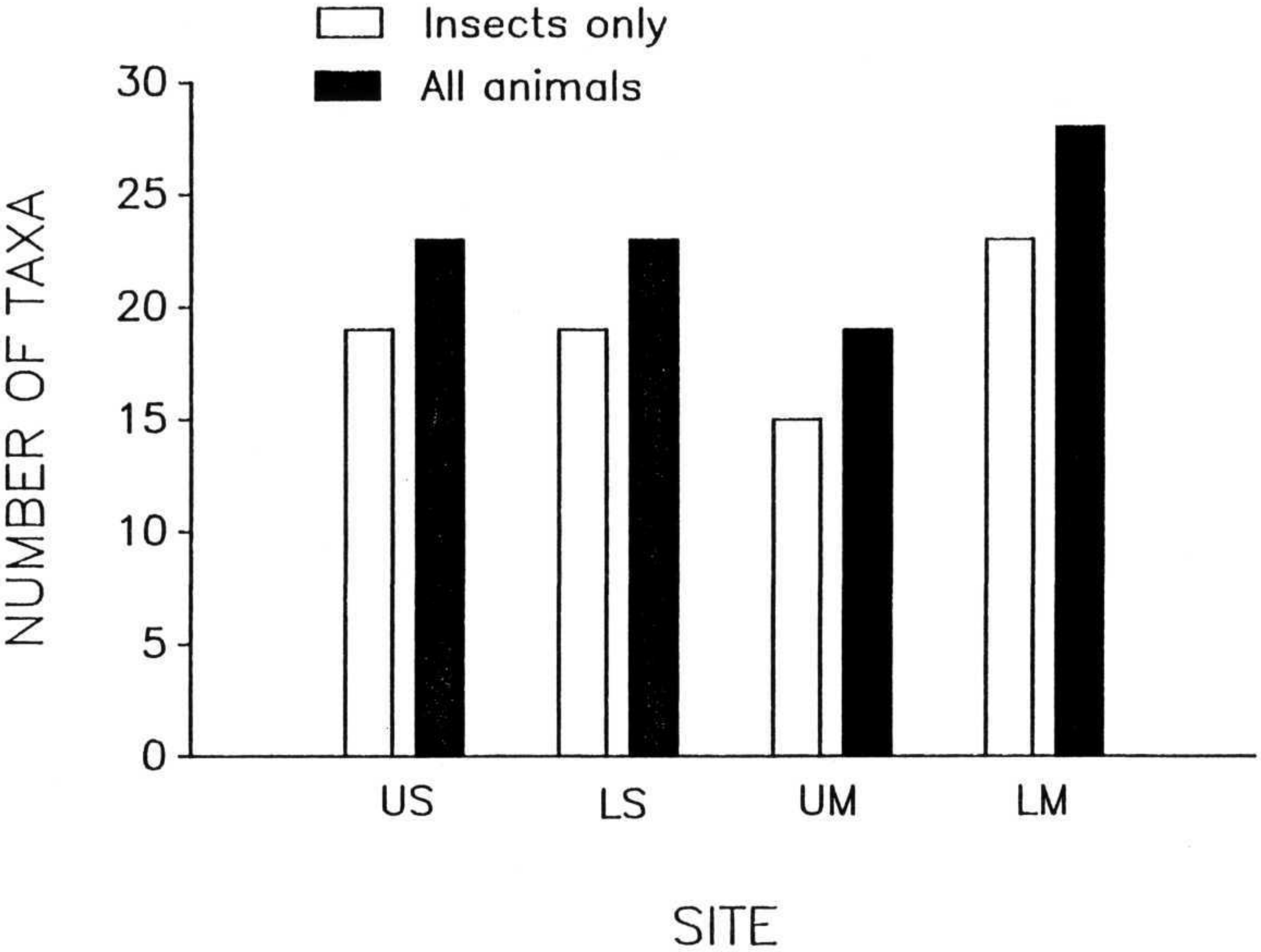


Figure 21. Total numbers of taxa collected in streams outside the caldera in 1986 (UM - upper Munson, LM - lower Munson, US - upper Sun, LS - lower Sun).

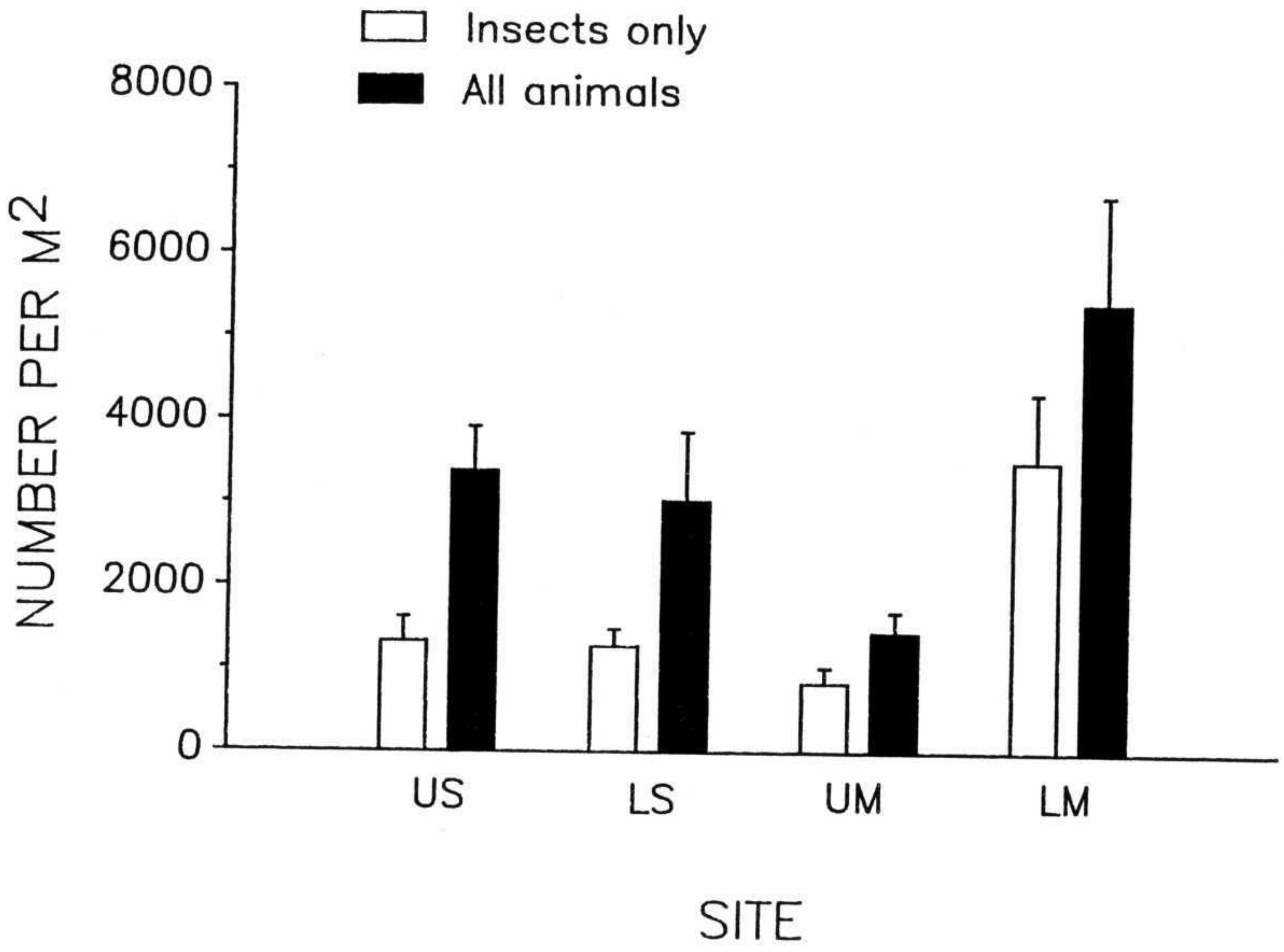
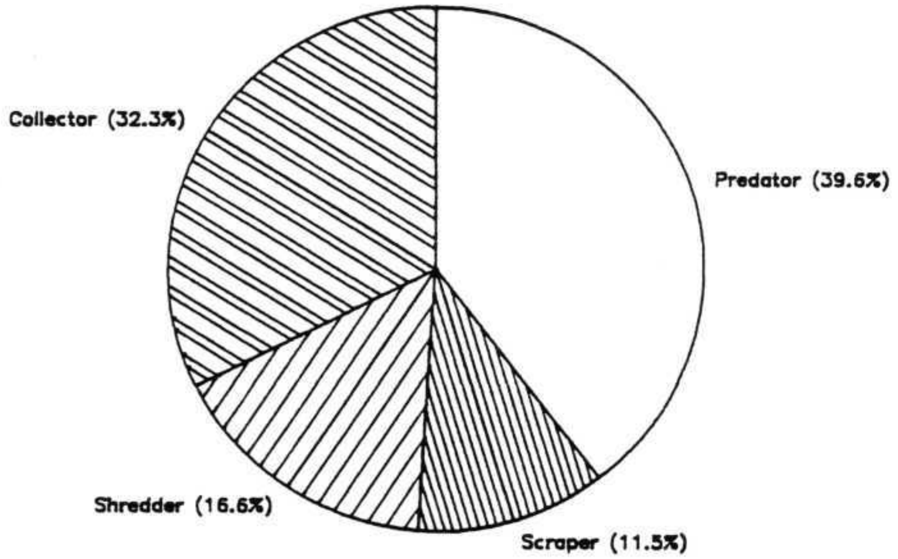


Figure 22. Mean densities of total invertebrates and aquatic insects in streams outside the caldera in 1986 (UM - upper Munson, LM - lower Munson, US - upper Sun, LS - lower Sun).

UPPER MUNSON



LOWER MUNSON

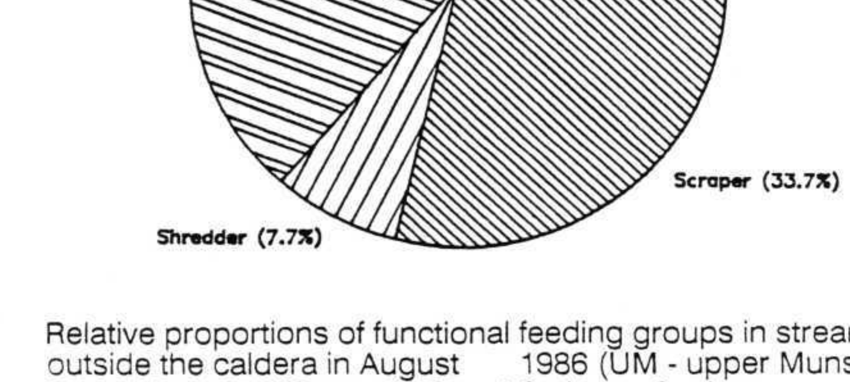
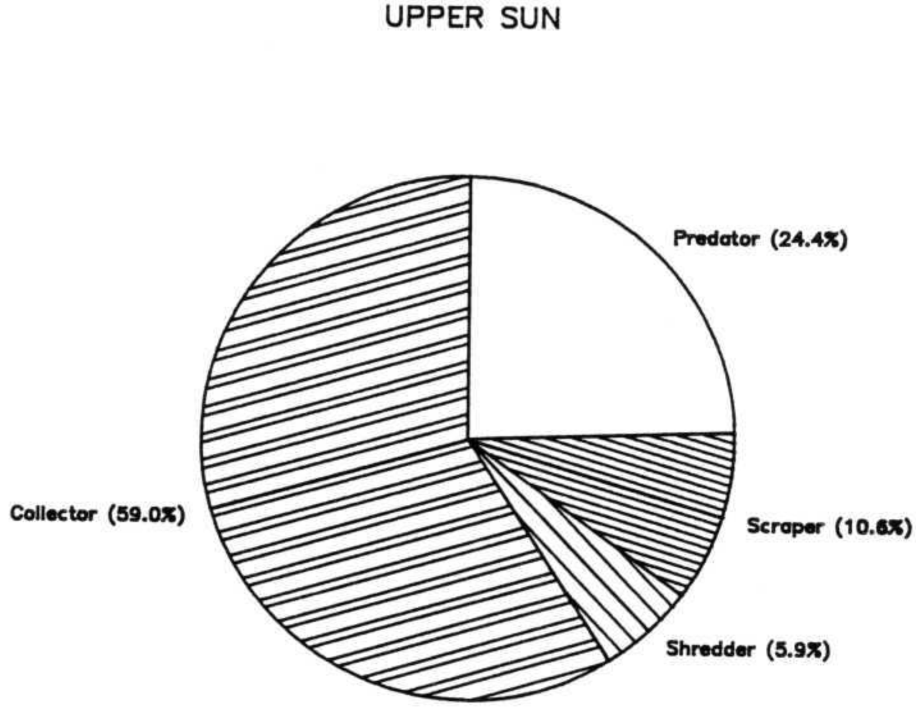


Figure 23. Relative proportions of functional feeding groups in streams outside the caldera in August 1986 (UM - upper Munson, LM - lower Munson, US - upper Sun, LS - lower Sun).



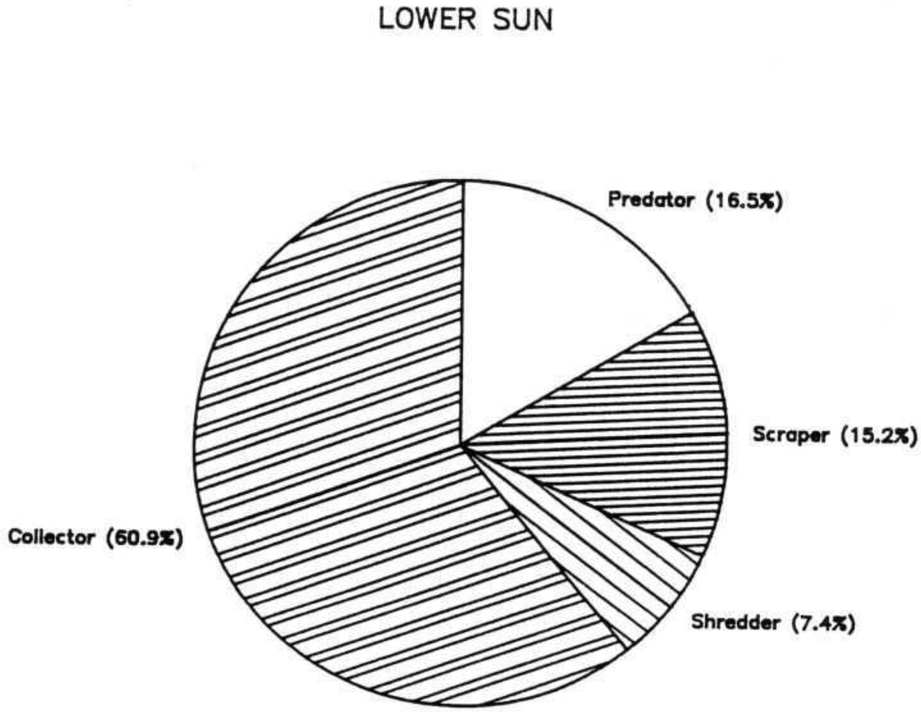


Figure 23. (continued)

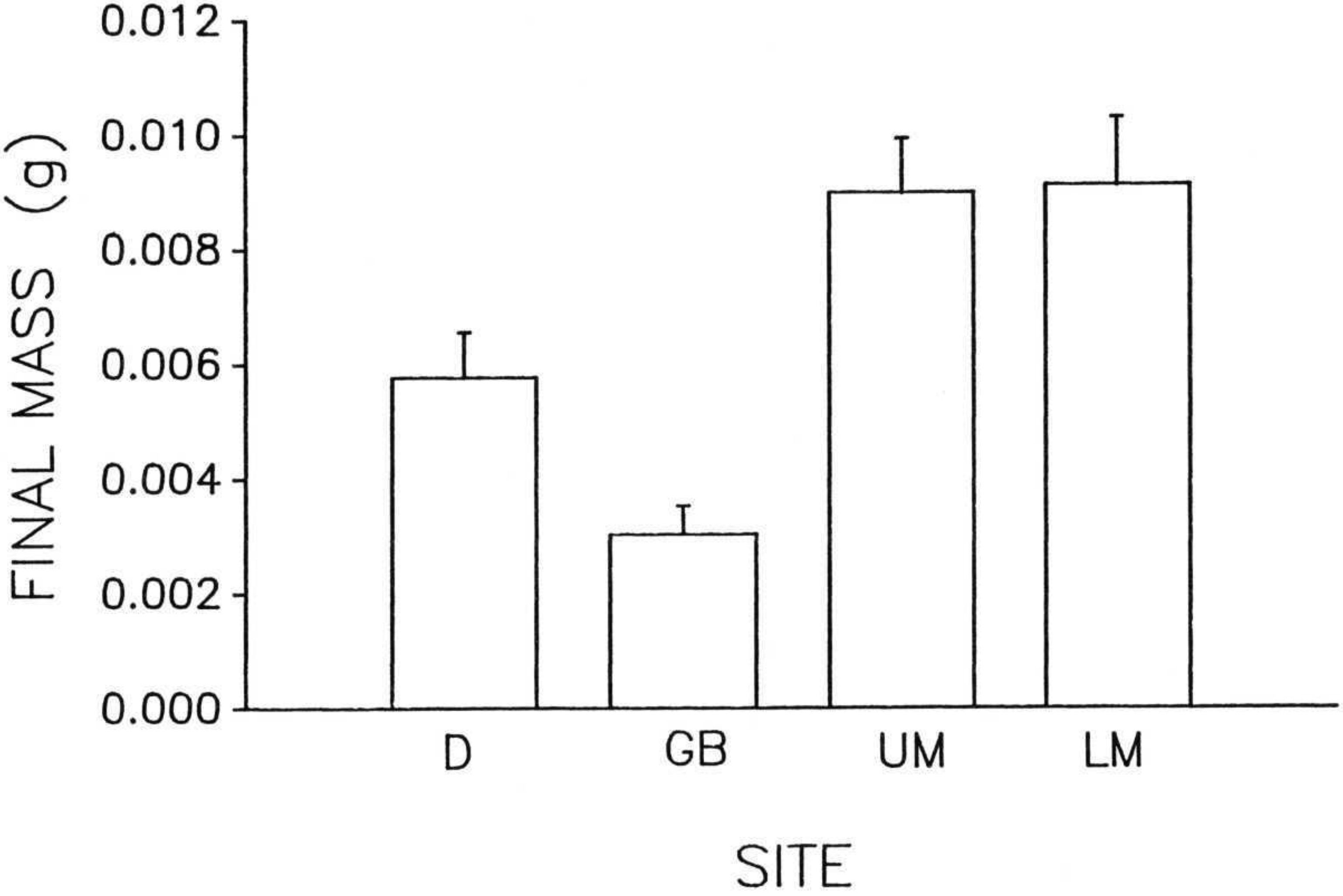


Figure 24. Growth rates of *Psychoglypha* in streams outside the caldera in August and September 1985 (UM - upper Munson, LM - lower Munson, D - Dutton, GB - Goodbye).

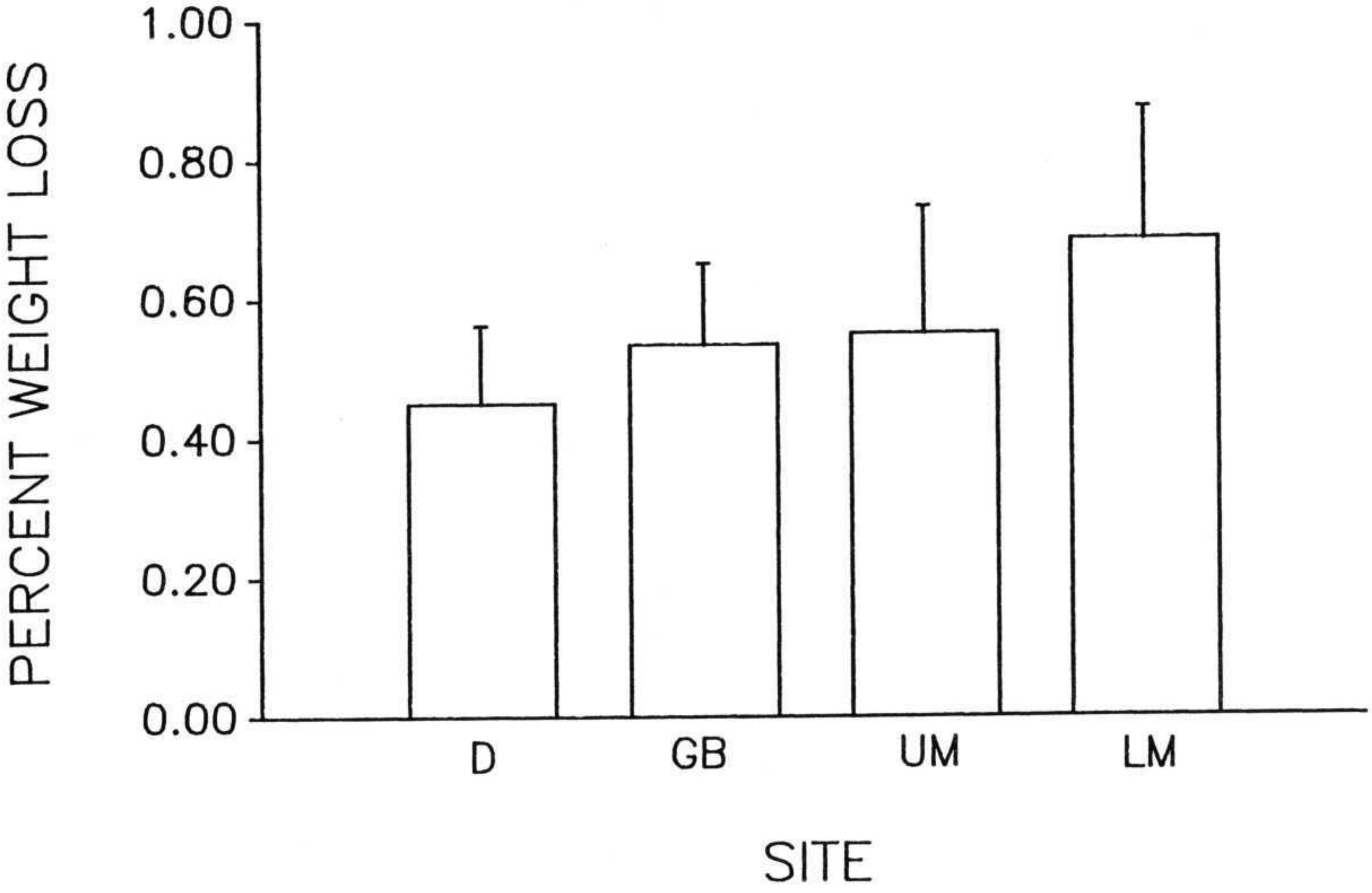


Figure 25. Weight loss of alder leaves in streams outside the caldera in August and September 1985 (UM - upper Munson, LM - lower Munson, D - Dutton, GB - Goodbye).

channel in late summer. If only leaf packs that remained wetted throughout the study period are used in decay calculations, rates of leaf decomposition in Dutton, Goodbye, and upper Munson Creeks are identical.

Caldera Springs

Water Chemistry

In August 1986, the concentration of nitrate in Spring 42 was 287 ug NO_3-$N{\cdot}l^{-1}$ and far exceeded that observed in any other spring within the crater rim (Fig. 26). No other spring exceeded 60 ug NO_3-$N{\cdot}l^{-1}$ on this sampling date. We climbed to the source of Spring 48 to examine the longitudinal change in water chemistry in a rim spring. Nitrate concentration decreased from 58 ug NO_3-$N{\cdot}l^{-1}$ to 18 ug NO_3-$N{\cdot}l^{-1}$ along its course, but there was a slight increase of ammonium from the source to the outlet (Fig. 27). Ammonium concentrations were extremely low or undetectable in all springs. Organic nitrogen concentrations were less than 25 ug $N{\cdot}l^{-1}$ in the rim springs, and were not detectable in Springs 42 and 48 (Fig 28).

Phosphorus concentrations were relatively high in all rim springs, a typical condition in volcanic regions. Most springs contained approximately 40 ug PO_4-$P{\cdot}l^{-1}$ and 80 ug total $P{\cdot}l^{-1}$ (Fig. 29 and 30). Spring 39 was somewhat lower in phosphorus than the other streams, and Spring 35 was slightly higher.

Benthic Primary Producers

The standing crop of benthic algae was similar in all springs except for Spring 42 (Fig. 31). Chlorophyll *a* was more than twice as abundant in Spring 42 than in the other streams, and Spring 35 contained slightly less plant

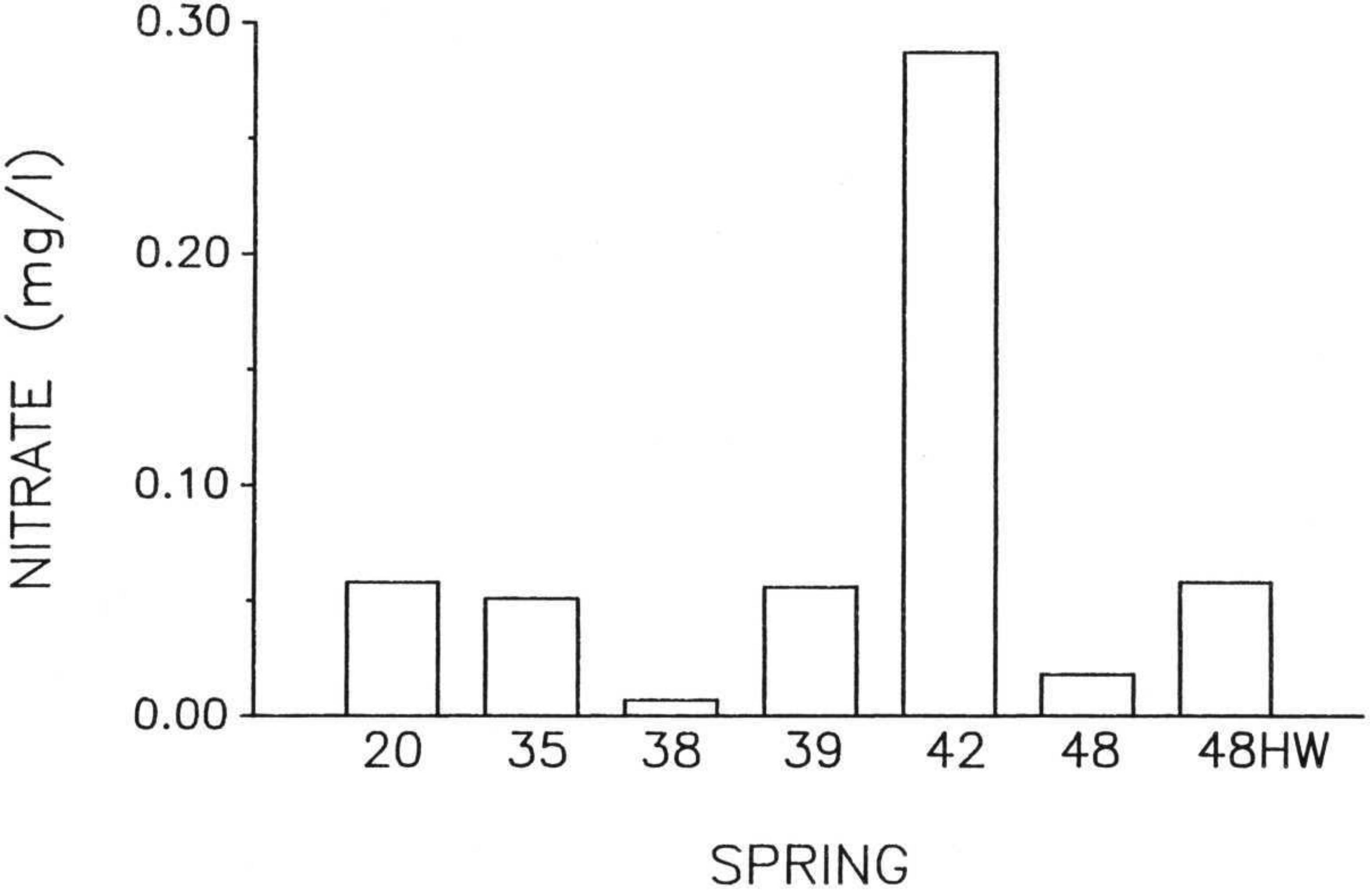


Figure 26. Nitrate concentrations in springs inside the caldera in August 1986.

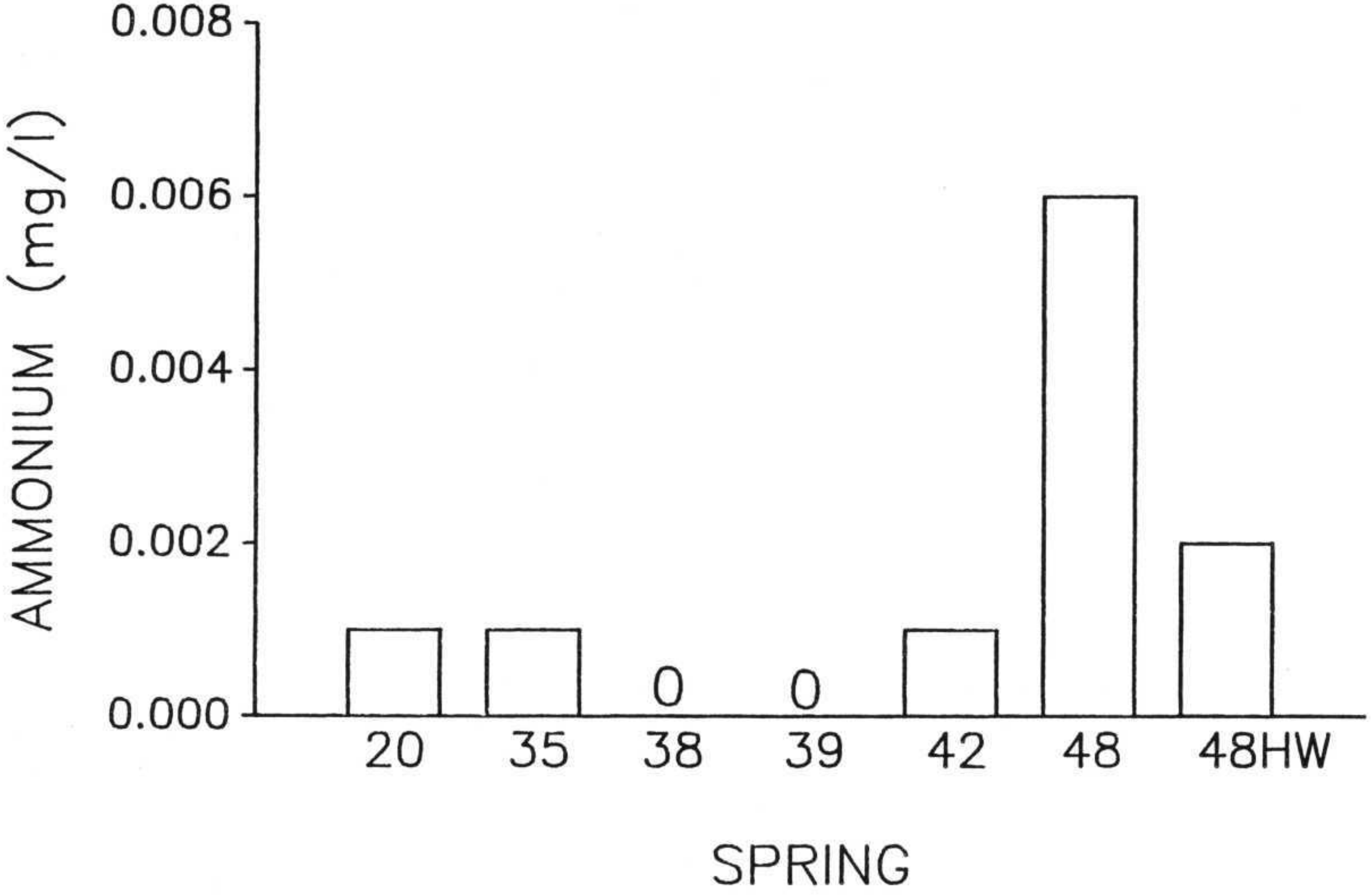


Figure 27. Ammonium concentrations in springs inside the caldera in August 1986.

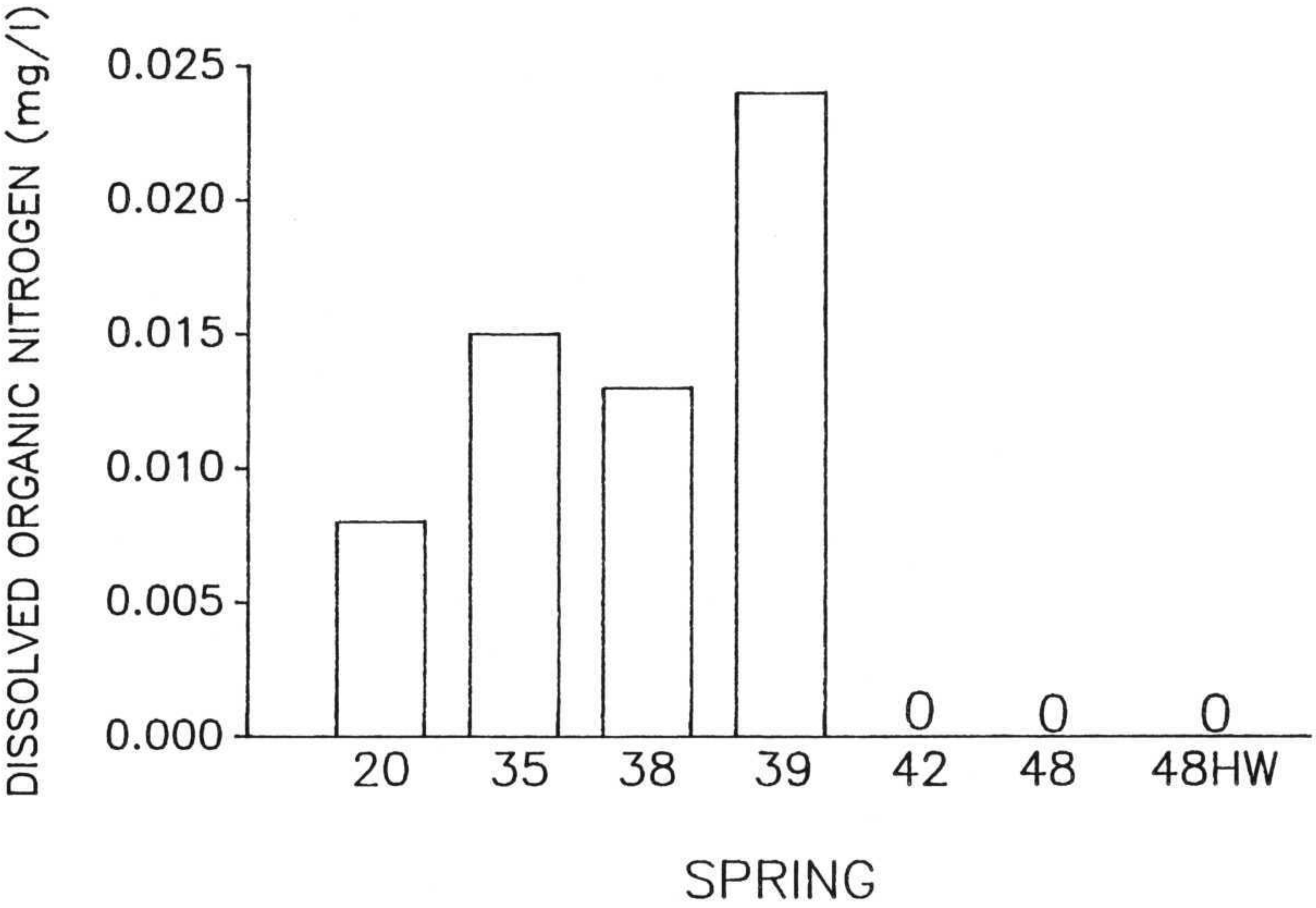


Figure 28. Total organic nitrogen concentrations in springs inside the caldera in August 1986.

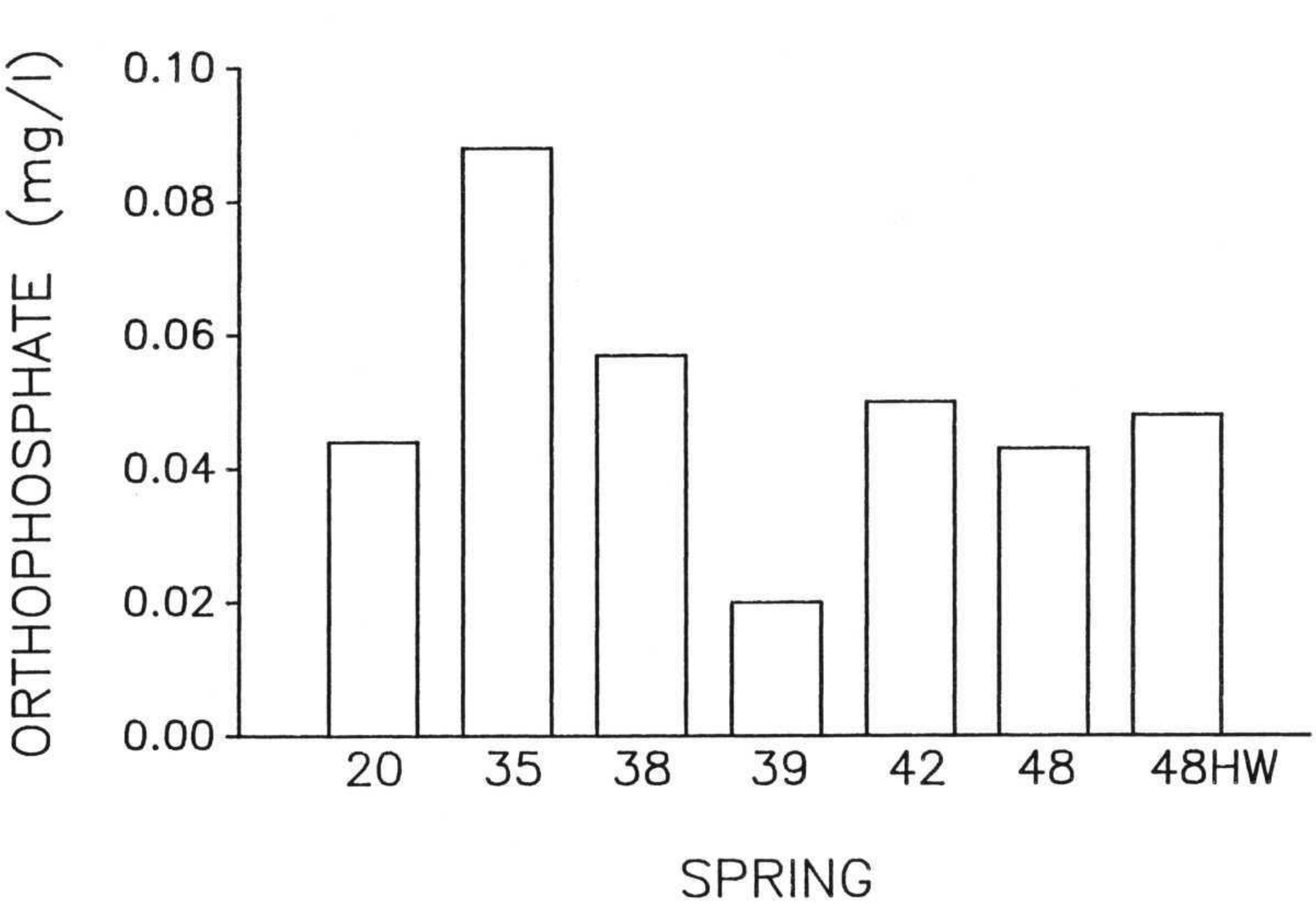


Figure 29. Dissolved orthophosphate concentrations in springs inside the caldera in August 1986.

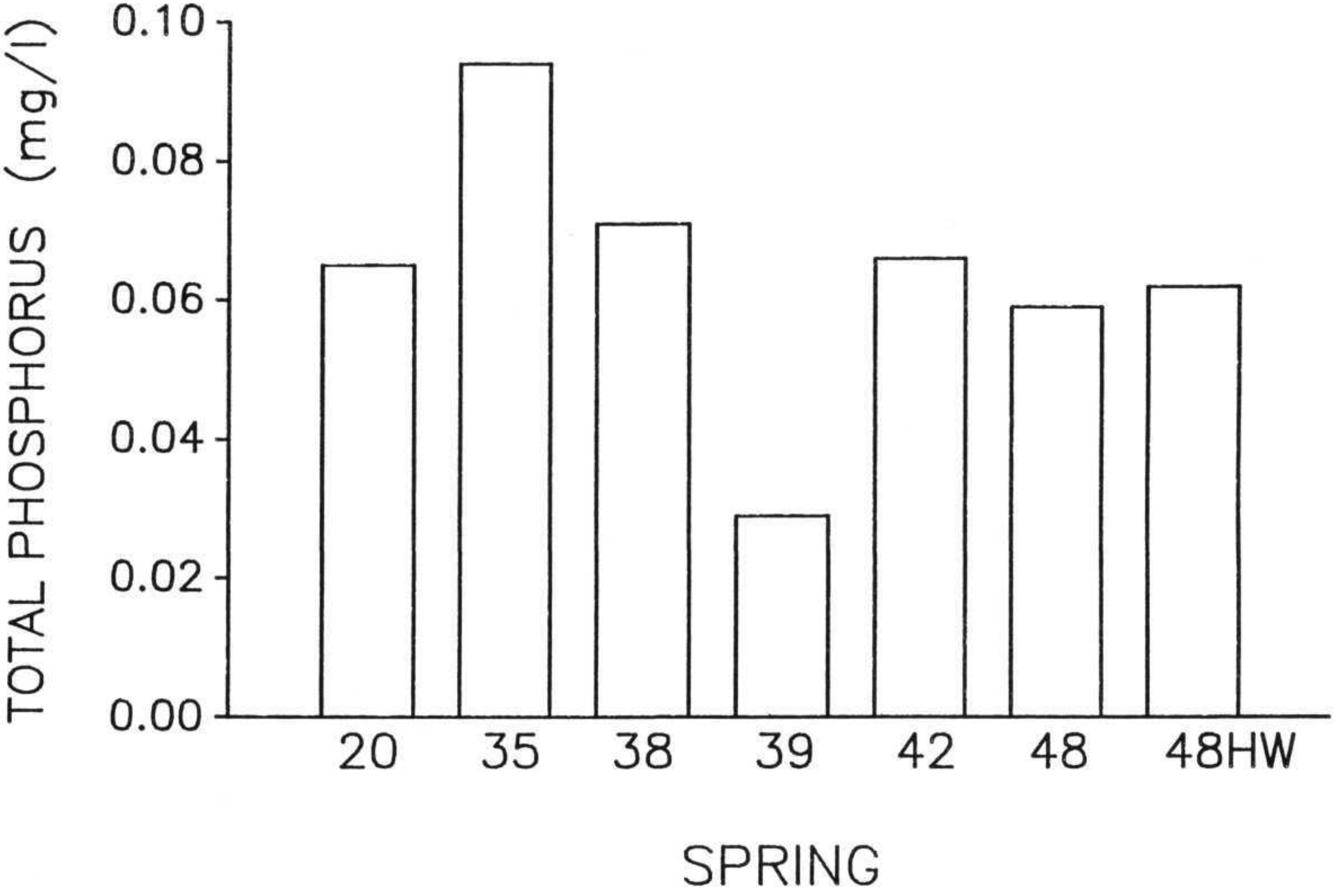


Figure 30. Total dissolved phosphorus concentrations in springs inside the caldera in August 1986.

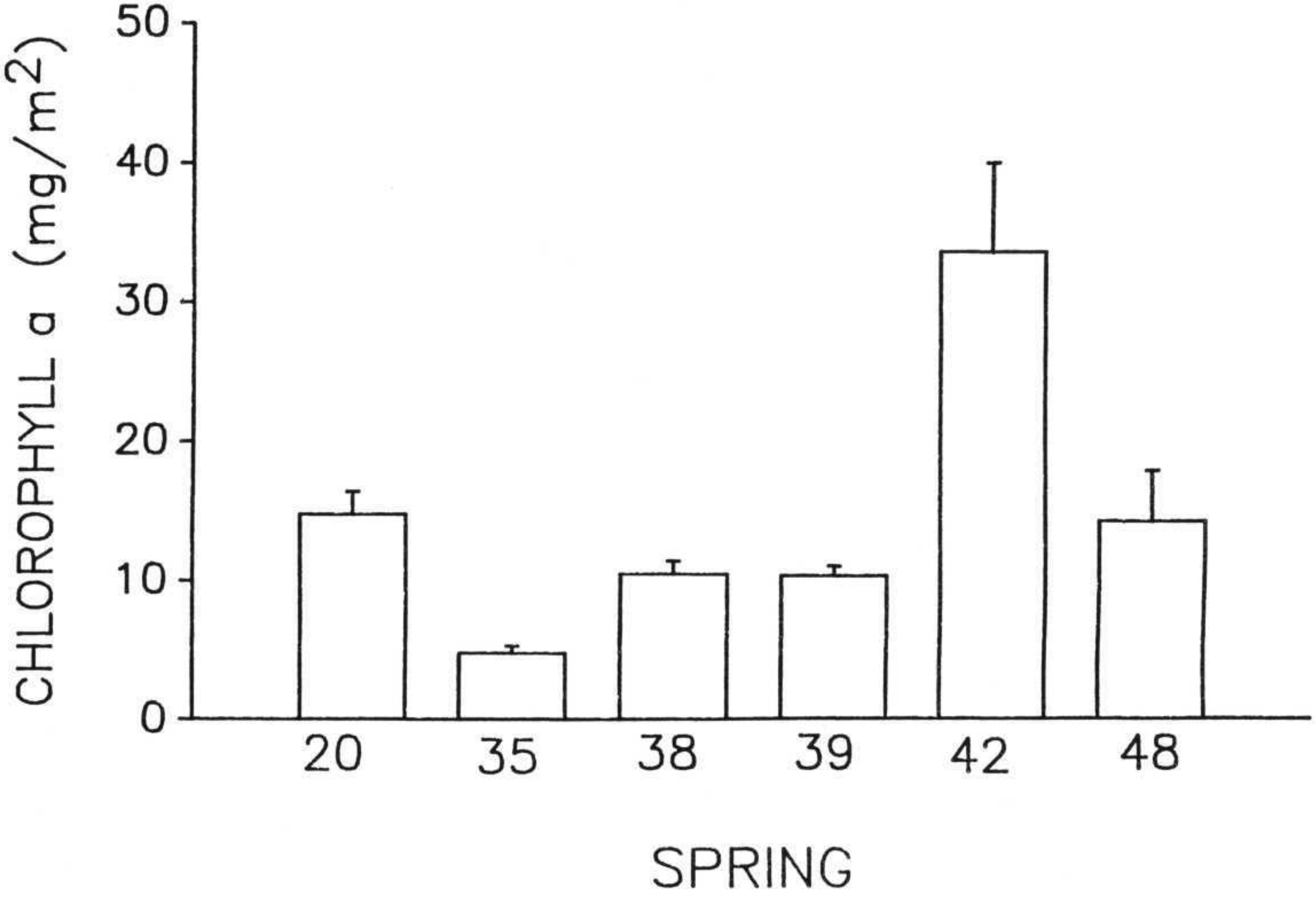


Figure 31. Standing crops of chlorophyll *a* in springs inside the caldera in August 1986.

pigment. The abundance of benthic algae was reflected in the rates of benthic metabolism in these streams (Fig. 32). Gross primary production was greatest in Spring 42, but was also somewhat elevated in Spring 48. Benthic community respiration was also elevated in Spring 42. P/R ratios for most of the streams ranged from 1.0 to 1.75 (Fig. 33), but the P/R ratio in Spring 48 exceeded 3.5.

Benthic Invertebrates

Fewer taxa of benthic invertebrates were observed in the springs within the caldera than in the study streams on the outer slopes of Mount Mazama (Table 8). The invertebrate faunas of the rim springs were quite similar to one another, with the exception of Springs 38 and 39. Samples from both of the latter springs were devoid of mayflies, and Spring 39 lacked caddisflies. Spring 39 contained the fewest taxa, and Spring 48 supported the richest fauna. A caddisfly, *Farula sp.*, and a true fly, *Dixa sp.*, were observed in the rim springs but were not found in the outer streams.

Benthic invertebrate communities in springs within the rim of the crater were composed primarily of aquatic insects. Benthic invertebrates were most abundant in Springs 20 and 48 (Fig.34), but most of the invertebrates in these two springs were small midges. If the chironomids are excluded from consideration, the pattern changes dramatically (Table 9). Excluding chironomids, densities of aquatic insects or total invertebrates were 4 to 10 times higher in Springs 42 and 48 than in the other four springs. Further, invertebrate density in Spring 48 was approximately double that in Spring 42. The densities of aquatic invertebrates in the rim springs were somewhat lower than those observed in the outer streams, and the aquatic insects other than chironomids were much less abundant in the rim springs.

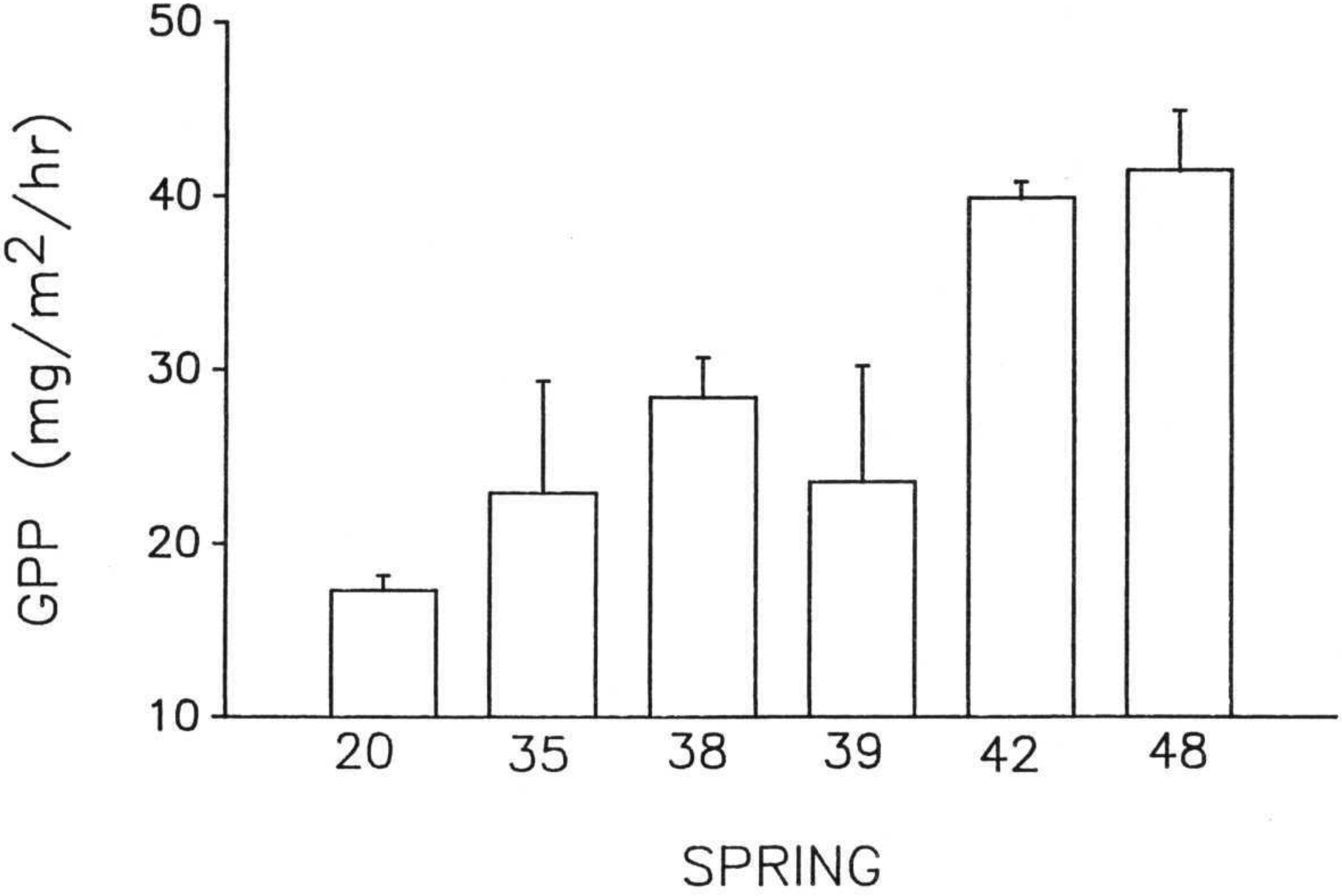


Figure 32. Rates of gross primary production of benthic algae in springs inside the caldera in August 1986.

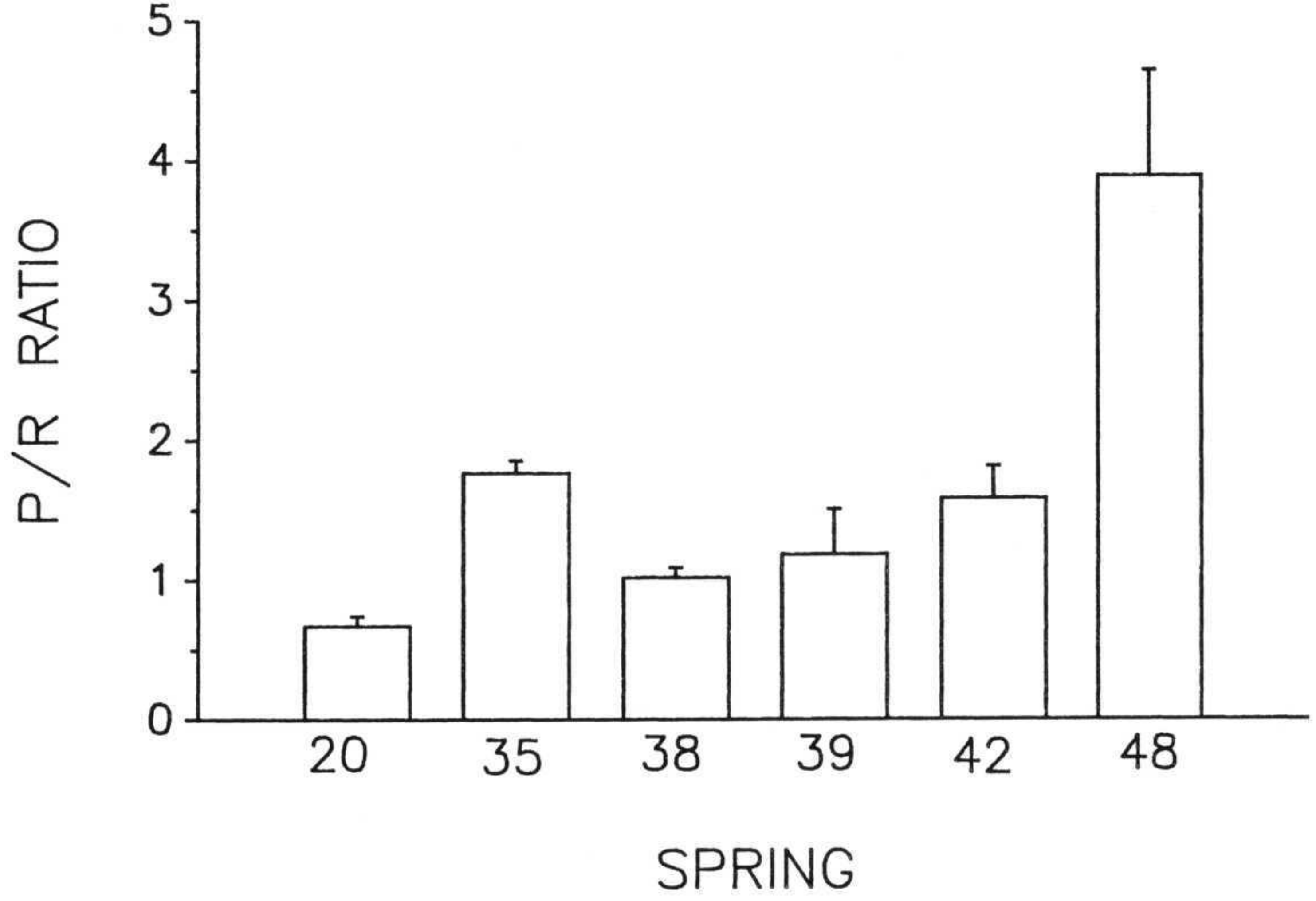


Figure 33. Ratios of gross primary production to community respiration (P/R) on substrates from springs inside the caldera in August 1986.

Table 8. List of taxa observed in caldera springs in 1986.

ORDER FAMILY GENUS SPECIES	SPRING					
	20	35	38	39	42	48
DIPTERA						
Chironomidae	X	X	X	X	X	X
Dixidae						
Dixa sp.		X				
Empididae						
Oreogeton sp.			X			
Tipulidae						
Dicranota sp.	X					
Tipula sp.			X			
Simulidae				X	X	
Prosimulium sp.	X					X
Psychodidae						
Psychoda sp.		X				
PLECOPTERA						
Peltoperlidae						
Yoraperla sp.						X
Nemouridae						
Zapada columbiana	X	X	X	X	X	X
Capniidae						
Capnia sp.						X
EPHEMEROPTERA						
Baetidae						
Baetis sp.	X	X			X	X
Leptophlebiidae						
Paraleptophlebia sp.						X
TRICHOPTERA						
Hydropsychidae						
Parapsyche sp.						X
Limnephilidae						
Farula sp.						X
Imania sp.	X	X	X		X	
Neothremma sp.		X	X			X
Psychoglypha sp.	X		X			
Rhyacophilidae						
Rhyacophila sp	X	X			X	X
TURBELLARIA	X	X			X	X
HYDRACARINA			X		X	X
OLIGOCHAETA	X	X	X	X		X
OSTRACODA			X	X	X	X
TOTAL TAXA	10	10	10	5	9	15

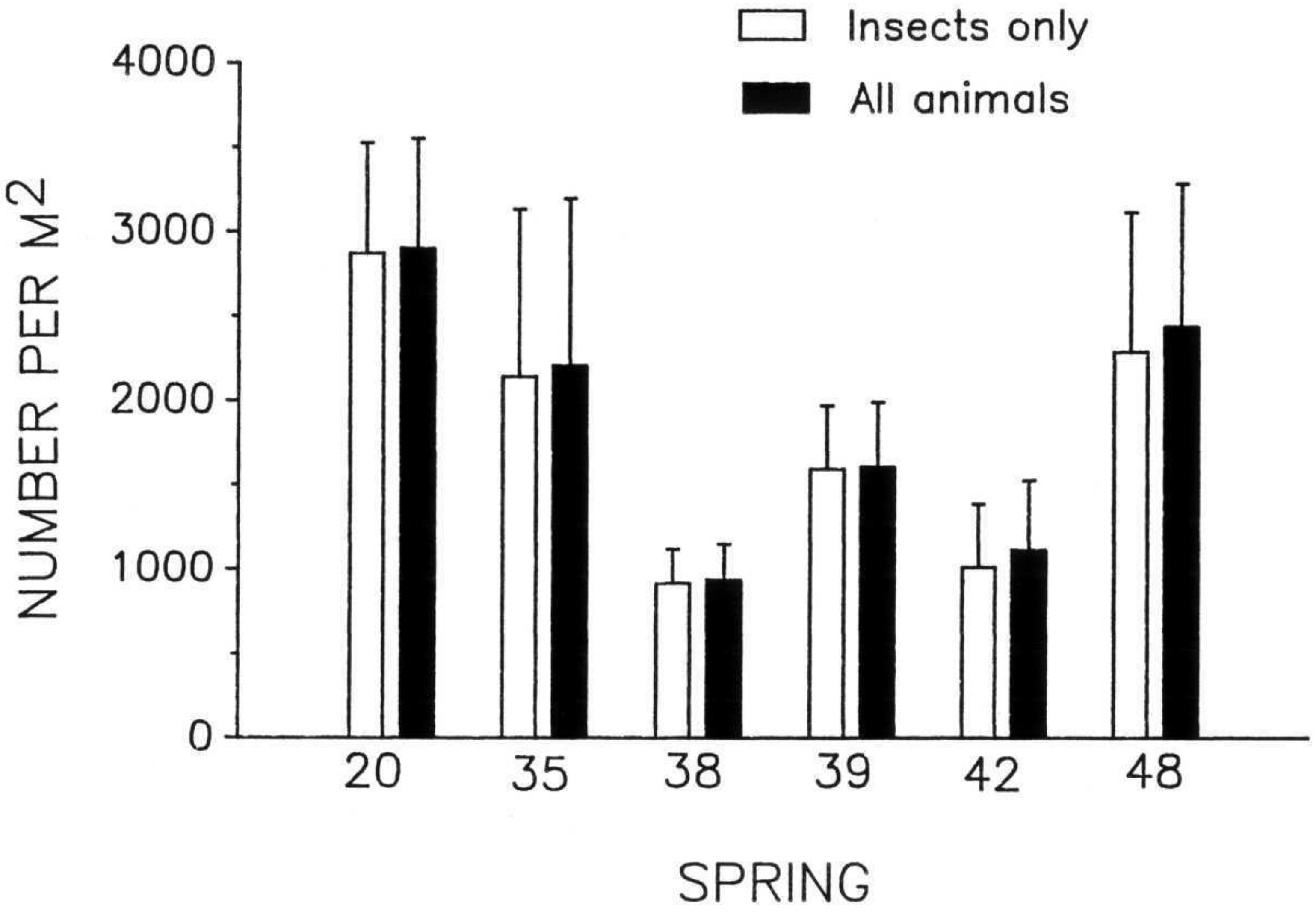


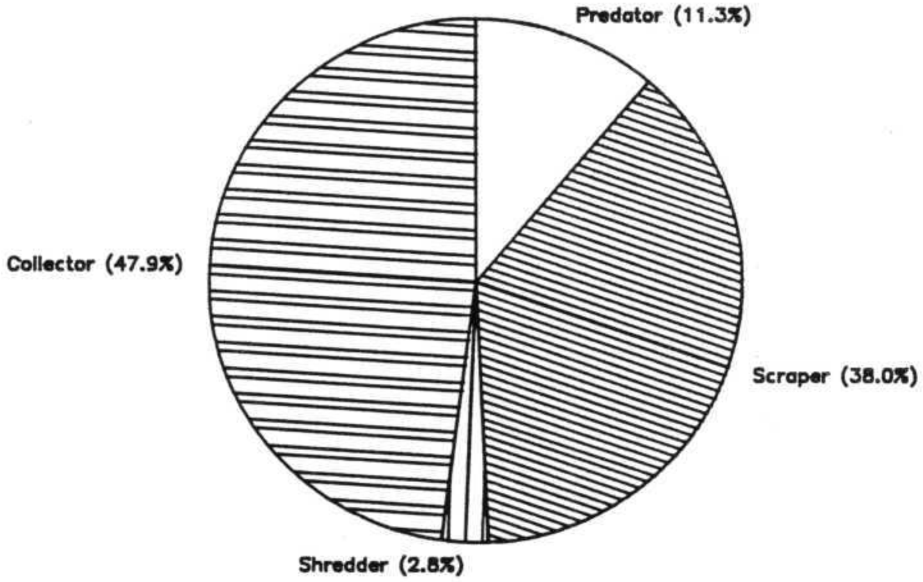
Figure 34. Mean densities of aquatic invertebrates in springs inside the caldera in August 1986.

Table 9. Abundance of benthic invertebrates in springs within the rim of the crater, expressed as number of individuals·m^{-2} (* = without chironomids).

	SPRING					
	20	35	38	39	42	48
Insects*	149	99	177	54	754	1,704
Invertebrates*	177	103	197	68	856	1,901
Total Invertebrates	2,900	2,247	937	1,616	1,113	2,519

Three major patterns in functional feeding group composition were observed in the six rim springs (Fig.35). The most common pattern, an equal dominance of both collectors and scrapers, was observed in Springs 20, 38, and 39. This largely reflects the dominance of chironomids in these streams, because the midges were considered to be 50% collectors, 40% scrapers, and 10% predators. In Springs 35 and 48, scrapers made up more than 75% of the invertebrate assemblage, resulting from the large number of scraping caddisflies (*Neothrema* and *Imania* in Spring 35; *Neothrema* in Spring 48). Shredders, primarily the stonefly *Zapada columbiana*, comprised half of the invertebrate assemblage in Spring 42.

SPRING 20



SPRING 35

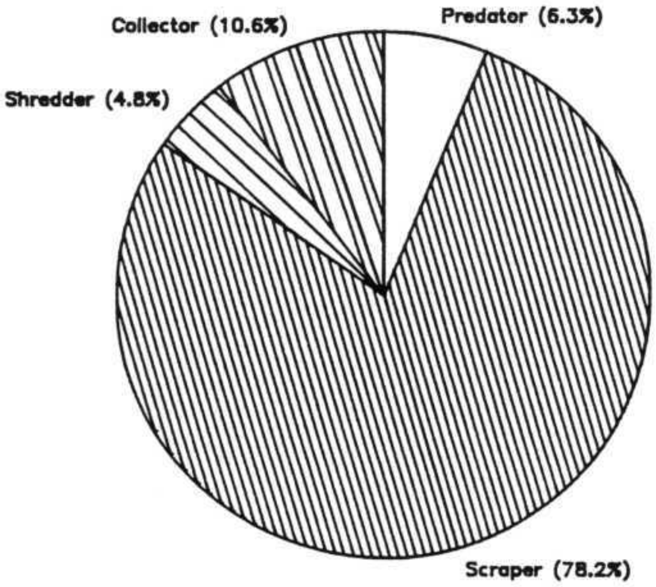


Figure 35. Relative proportions of functional feeding groups in springs inside the caldera in August 1986.

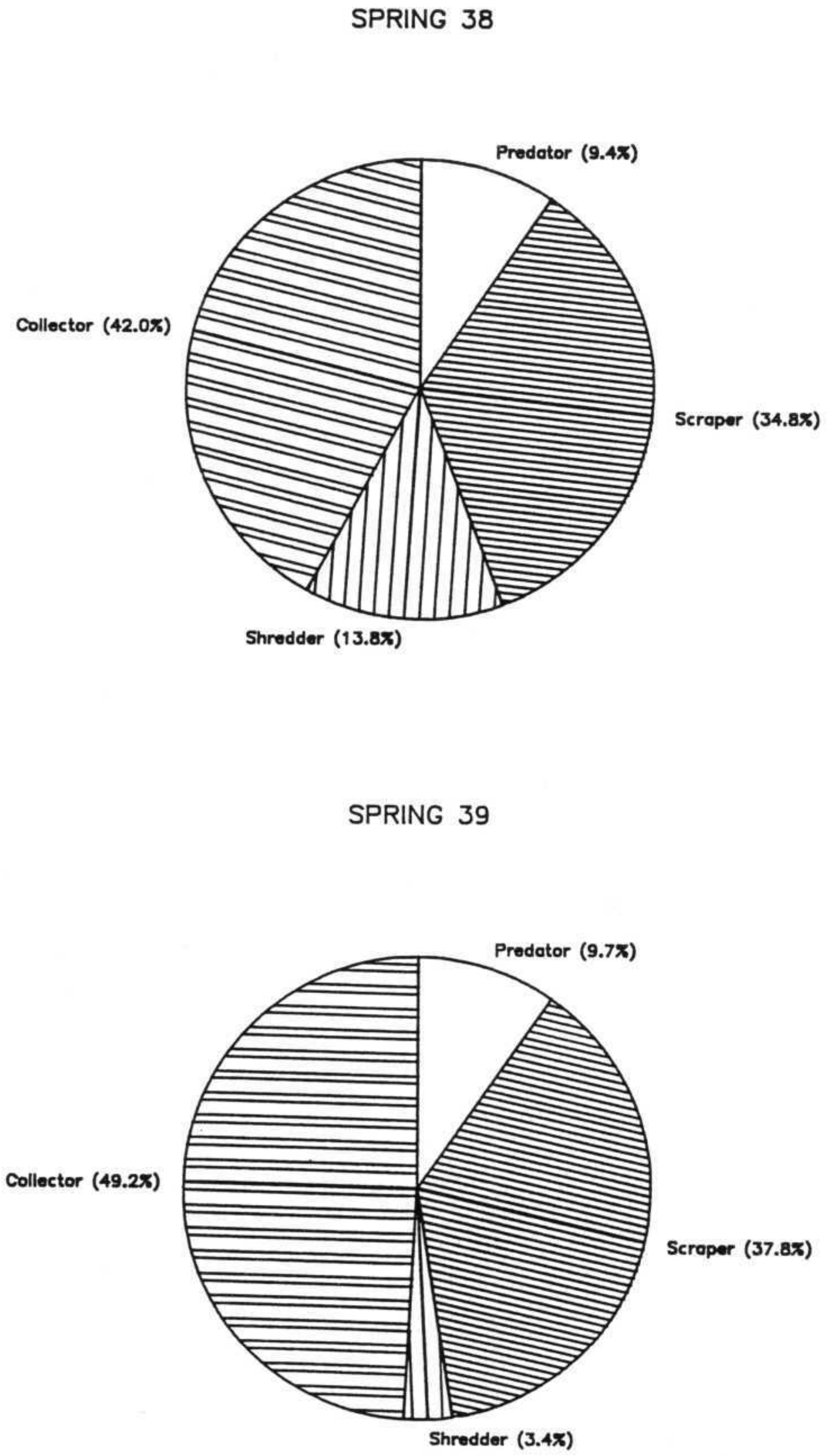
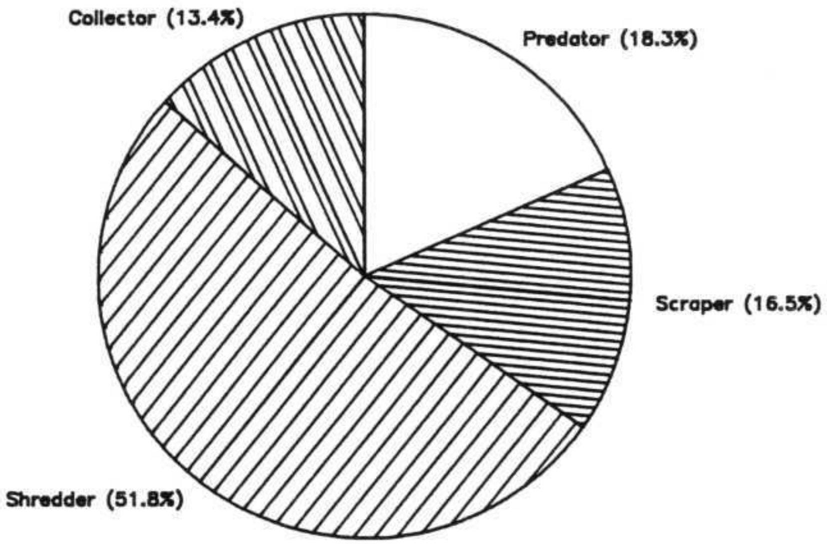


Figure 35. (continued)

SPRING 42



SPRING 48

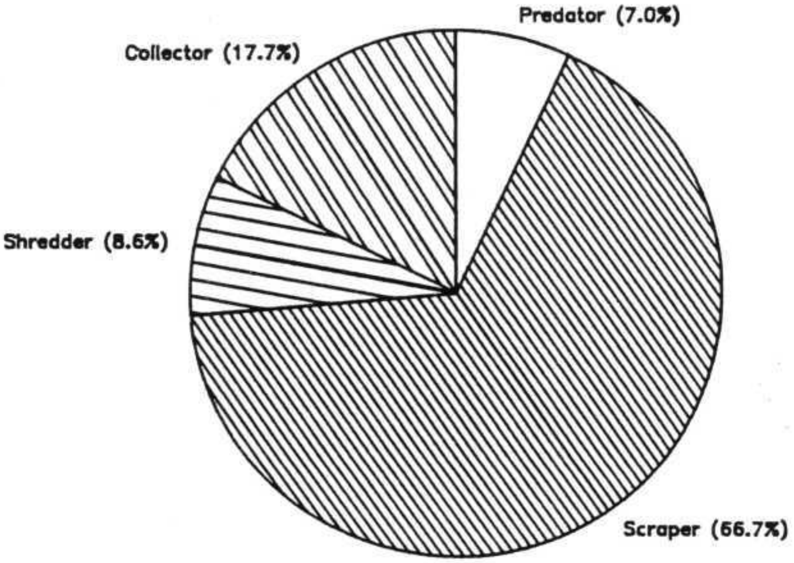


Figure 35. (continued)

DISCUSSION

Streams Outside the Caldera

Crater Lake National Park contains one of the world's most spectacular aquatic resources and includes excellent examples of subalpine forests and streams. Protection of these resources requires the National Park Service to examine the consequences of public use of the Park and their own management activities. This study of the ecology of selected streams in Crater Lake National Park indicates that several streams in the vicinity of Rim Village and Park Headquarters differ from streams away from these centers of activity, and explores possible causes of these differences.

Munson Creek had higher concentrations of dissolved inorganic nitrogen and greater biological activity than other study streams outside the caldera. At the concentrations of inorganic nitrogen and phosphorus observed in these streams, nitrogen would potentially limit primary production; therefore elevated nitrate concentrations could account for greater biological production. Abundance of benthic algae and rates of primary production were greater in Munson Creek than Sun Creek, Dutton Creek, or Goodbye Creek, and the lower meadow site on Munson Creek tended to be more productive than the upper forested site. Lower Munson Creek also contained higher densities of invertebrates than the other streams. The composition of the insect community in lower Munson Creek was consistent with that of an open, algal-dominated ecosystem, a pattern also observed in both sites on Sun Creek. Substrates and organic matter in both sites in Munson Creek supported higher growth rates of caddisflies than similar material from Dutton and Goodbye Creeks.

All of these factors demonstrate that Munson Creek is more productive than other streams in its immediate vicinity, but there is no evidence that the vehicle maintenance facilities have had negative effects on the aquatic biota of Munson Creek. The question remains as to whether the greater production in Munson Creek is natural or a result of man's influence. It might be argued that the Munson Creek basin is greatly different than the Dutton and Goodbye Creek basins, but the Sun Creek basin is almost identical to Munson Creek in geological history, morphology, and vegetation. Both valleys were occupied by glaciers at the time of the eruption of Mount Mazama more than 6,000 years ago, and avalanches of pumice and lava descended down these channels. The extensive meadows in these drainages reflect their similar history. They are adjacent drainages with almost identical aspects and elevations. The vegetation follows similar patterns of open headwalls followed by lower forests that open into meadows.

The primary difference between the Munson Creek and Sun Creek drainages is the human activity associated with each. Crater Lake National Park was established in 1902, and Park Headquarters have been located on Munson Creek since 1931. The original septic facilities for the Lodge on the rim of Crater Lake were located at the head of the Munson Creek watershed. The only human activity in the Sun Creek drainage is rim road and a small campground, but both study sites on Sun Creek were upstream from the campground.

The greater biological activity in Munson Creek as compared to Sun Creek may not be a recent phenomenon. A study of fish food organisms in 14 streams within the National Park in 1947 found that aquatic insects were almost three times more abundant in Munson Creek than in Sun Creek (Wallis 1948). Of the streams that were more than 5000 feet in elevation and less than 10 feet wide, Munson Creek had the highest density of aquatic insects, though Castle Crest Creek, a tributary of Munson Creek, had similar insect densities. Wallis's study was conducted more than 25 years after the Park Headquarters were established on Munson Creek, so there had been sufficient time for man's activity in the basin to alter the productivity of Munson Creek. No residences or other facilities have ever been located on Castle Crest Creek; however, it lies entirely within the glacial valley floor and may be closely associated with the water table of Munson Creek.

The present study clearly demonstrates that Munson Creek is more productive than other streams in its vicinity, but it does not prove that this productivity is due to man's activities. The biotic communities and productivity of Munson Creek are not abnormal for a high elevation stream in the Cascade Mountains; they simply are more productive relative to similar streams in the area. The characteristics of Munson Creek are not a cause for immediate concern about existing management practices in the Munson Creek basin. The close proximity of the maintenance area and the linkages through storm drains present a potential risk to Munson Creek, and Park management should closely review activities and use of hazardous materials on a routine basis.

Dutton Creek was less productive and had more depauperate invertebrate communities than the other study streams outside the caldera, reflecting its ephemeral hydrologic nature. There was no evidence to indicate that the septic facility in the headwaters had any measurable influence on the chemistry or ecology of Dutton Creek. Dutton Creek frequently flows intergravel, which restricts the distribution of aquatic biota. Dutton Creek contained far fewer taxa of invertebrates, and practically no stoneflies or mayflies were found. It was surprising that no mayflies were found in Dutton Creek because mayflies would be expected to be present in emphemeral habitats. It is possible that water temperatures during periods of surface flow were so low that complete development of a generation was not possible. The only long-lived taxa present were caddisflies, and caddisflies can exist in temporary streams by aestivating or diapausing as larvae or diapausing in the egg stage. There was never any indication of elevated nutrient concentrations in Dutton Creek, and the water chemistry did not change longitudinally.

Springs Inside the Caldera

There are more than forty perennial springs that originate on the crater wall above the surface of Crater Lake, and most of these springs are located on the south wall of the crater. Phillips and Van Denburgh (1968) did not consider any of these streams to be perennial; but the Park Service staff has monitored these springs since 1983, and many flow year round. Diller and Patton (1902) examined more than 63 springs in mid-July 1901 and estimated their total discharge to be 10.75 cfs. All of these streams have extremely high gradients (>50%) and exhibit numerous indications of recent avalanches down the channels.

Previous sampling by the Park Service and other investigators at Oregon State University found that several springs in the vicinity of Rim Village often contained higher concentrations of nitrate than other springs around the lake. Three springs in the Rim Village area (Springs 40, 41, and 42) consistently exhibited nitrate concentrations ranging from 100 to 300 ug NO_3-N·l^{-1} in 1983-85; but none of the other springs ever exceeded 100 ug NO_3-N·l^{-1}, and most were less than 50 ug NO_3-N·l^{-1}. This study of Springs 20, 35, 38, 39, 42, and 48 found a similar pattern. Spring 42 contained 287 ug NO_3-N·l^{-1} in August 1986, and the other springs all contained less than 60 ug NO_3-N·l^{-1}. In Spring 48, there was a rapid uptake of nitrate from the source to the outlet into the lake, decreasing from 58 to 18 ug NO_3-N·l^{-1}. The length of stream and the relative biological activity in different springs may greatly influence the observed water chemistry of the springs where they enter the lake.

Biological activity in the study springs corresponded to the observed pattern of nutrient availability. Abundance of benthic algae and rates of gross primary production were highest in Spring 42. Although Spring 42 originates in a section of the rim wall that contains a mature conifer forest, the channel itself was extremely unstable. The substrates in the stream were packed more loosely than those in the other study streams, and walking in the channel created small avalanches of rocks. At the relative concentrations of nitrogen and phosphorus in these springs, primary production would be limited by inorganic nitrogen; therefore, the elevated primary production in Spring 42 may be a result of the higher nutrient supply.

Primary production was also high in Spring 48. The headwaters of Spring 48 were located in a mature conifer forest, and the channel was geomorphically more stable than the other springs. This greater stability may allow development of a more abundant assemblage of primary producers. Primary production in the other springs was less than half of that observed in Springs 42 and 48, which may be related to either lower nitrate concentrations or more unstable channels or possibly to both conditions.

Aquatic invertebrates, excluding chironomids, were more abundant in Springs 42 and 48, possibly a result of the higher primary production in these two springs. Invertebrates were most abundant in Spring 48, which may be related to the greater channel stability in this stream. The fauna of these streams were less abundant and included far fewer taxa than those in streams outside the caldera; but the steep, unstable nature of the rim springs would not be expected to support dense populations and diverse faunas. It is interesting that the dominant insects in the rim springs were also found in the streams outside the caldera, thus it does not appear that these extreme aquatic environments contain unique assemblages of invertebrates. Most aquatic insects were identified only to genus, so the actual species in the rim springs may or may not be different. Chironomids were a major portion of the invertebrate assemblage in most of these springs, and the midges would be well suited to the harsh environments of the rim springs because of their short life histories and wide array of feeding habits.

Management Implications

The studies of the streams of Crater Lake National Park indicate that Munson Creek and springs within the crater in the vicinity of Rim Village are more productive than similar adjacent streams. These streams contained higher concentrations of nitrate, supported greater amounts of benthic algae and higher rates of primary production, and had more abundant and diverse invertebrate faunas than their counterparts. The cause for these patterns of production cannot be proven by the research, but potential causes can be identified.

If it is assumed that these patterns in stream production are natural and not caused by man's activities in the Park, the characteristics of these portions of the Park landscape must be unique in some respect. Munson Valley was glaciated, and the sites on Munson Creek and Goodbye Creek lie within the glacial terrain of that valley. Dutton Creek does not lie within a glacial valley, and its ephemeral hydrologic regime may result from its location on the flanks of the crater. Goodbye Creek lies in a lateral arm of the glacier, and its soils and hydrology may differ substantially from that of Munson Creek. Munson Creek drains a broad glacial valley that is filled to depths of more than 250 feet with pumice and scoria from the avalanches associated with the eruption of Mount Mazama. Sun Creek is very similar to Munson Creek in elevation, geology, history, aspect, and vegetation. Unlike Munson Creek, its glacial valley is not as broad as Munson Valley, and the study sites were located on an upper bench at the head of the valley. It is possible that the geology, soils, and water table of Sun Creek differ enough from those of Munson Creek to account for the differences in productivity.

The rim springs that have exhibited the highest concentrations of nitrate (Springs 39 - 42) are immediately below the Rim Village area and are located on the southwest wall of the crater. Because of the northerly aspect of these slopes on the south wall, they are cooler and more moist than those on the north side of the crater. The slopes on the southwest wall are vegetated by a mature forest of hemlock, fir, and pine, but the slopes on the southeast wall are sparsely vegetated. Although there were trees and shrubs along Springs 20, 35, 38, and 39, their basins were less vegetated than those of Springs 42 and 48. It is possible that the forests have been associated with the southwest wall over the last several thousand years and have built up a nitrogen pool in the soil that is reflected in the spring chemistry. It is also interesting to note that the outer wall to the southwest was not extensively glaciated, but the outer wall to the southeast includes the three major glacial valleys of Mount Mazama - Munson, Sun, and Kerr Valley. What effect this might have on the groundwater of the caldera is unknown.

We have recently conducted nutrient uptake studies in streams in the McKenzie River drainage to the north of Crater Lake, and we observed that nitrate was released in habitats where there was rapid depletion of ammonium (particularly in lateral depositional areas or depositional areas associated with debris dams), indicating a high potential for microbial nitrification. We also measured nitrate concentrations in the range of 100-200 ug NO_3-$N \cdot l^{-1}$ in old-growth, headwater streams in the Bull Run watershed on the north flanks of Mt. Hood (unpublished data, Bruce McCammon, U.S. Forest Service). After clearcutting, nitrate output from watersheds is often elevated starting one to three years after harvest and continuing for approximately five years (Fredriksen 1975, Likens et al. 1977). This response has been attributed to increased nitrification. Other heterotrophs usually out-compete nitrifiers for organic matter and ammonium; but when a watershed is disturbed, the nitrifiers are able to obtain sufficient recources because of the lowered demand by terrestrial plants. Patterns of nitrate concentrations found the the springs of the caldera of Crater Lake might be related to similar phenomena. The frequent disturbance by avalanches creates an unstable environment in which nitrifiers might well be able to compete with other heterotrophs. On drier sites with little terrestrial vegetation (e.g., Spring 20 and other springs to the north wall of the caldera), low moisture and low organic matter availability in streamside soils may minimize rates of nitrification; therefore low concentrations of nitrate nitrate would be observed in the springs. On the more moist, well-vegetated sites on the southwest wall of the caldera, higher soil moisture and greater availability of organic matter would be more conducive to nitrification. The greater potential for heterotrophic activity and the extreme geomorphic instability of these streams may create conditions under which nitrification can produce high concentrations of nitrate in solution. This hypothetical scenario warrants further investigations through experimental nutrient releases in the caldera streams.

If it is assumed that the differences in aquatic productivity are not explained by natural factors, human activity in the Park might account for the observed responses. Park Headquarters and residences have been located in the Munson Valley for more than 55 years, and addition of nutrients to the basin is inevitable. Munson Creek did have higher concentrations of nitrate than other streams in the vicinity. The difference was generally less than 10 ug NO_3-N·l^{-1}, but the uptake associated with the greater productivity might mask even greater differences in water chemistry. Recent examinations of the sewage pipes with remote cameras indicated several breaks and leaks in the pipes, therefore release of sewage to the groundwater is certain though the amount of sewage delivery is unknown. In addition to chronic delivery of low volumes of wastes, large amounts of sewage have been released accidentally into Munson Creek several times in the past. From a biological point of view, the present productivity of Munson Creek is not a cause for concern. The aquatic community is typical of high elevation, Cascade Range streams. The major management concern, however, is that anthropogenic influences on any stream within the Park need to be minimized and mitigated, particularly those streams that enter Crater Lake.

The elevated nitrate and greater productivity of the springs below Rim Village may also reflect a contamination of the groundwater by sewage. Nitrate concentrations in the rim springs are far greater than those in streams outside the crater. This may reflect the shallower soils and sparser vegetation within the crater, which would account for lower demand for nutrients in the terrestrial ecosystem. The three springs that always have nitrate concentrations in excess of 100 ug NO_3-N·l^{-1} are located immediately below Rim Village, and other springs in the forested southwest wall of the crater only occasionally have nitrate concentrations that approach the lower concentrations found in the springs below Rim Village. Nitrogen-fixing alder occur on all the springs studied, and it is unlikely that this natural source of nitrogen would account of the differences between springs.

This study does not prove that human activity in Crater Lake National Park is responsible for differences in water chemistry and productivity in Munson Creek and the springs below Rim Village, but it does identify a critical resources issue for the management of Crater Lake National Park. The water chemistry and aquatic productivity of streams are elevated in the area of greatest human activity, but it is not the productivity of these streams that is of primary concern. If these ecological patterns are linked to human activity in these areas, nutrient loading into Crater Lake and Munson Creek may be elevated and could lead to the gradual eutrophication of this unique ecosystem.

We have identified several opportunities for research and management based on the patterns of water chemistry and biological activity observed. The most immediate need is a better understanding of the dynamics of nitrogen in the springs of the caldera. Experimental releases of dissolved nitrogen species and conservative hydrologic tracers would greatly improve our understanding of the nitrogen transformations occurring within the streams. Integration of this research with measurement of soil solution chemistry with lysimeters would substantially increase our ability to interpret the source of nutrients observed at the mouths of caldera streams. Groundwater dynamics in the caldera rim is a major component of the delivery of anthropogenic inputs to the springs and Crater Lake and warrants detailed analysis. In the longer term, a more thorough baseline study of water chemistry in the surface waters of Crater Lake National Park would contribute to the evaluation of their current status and provide an invaluable reference for future management of the Park.

Although additional information is needed to accurately evaluate the potential for nutrient loading into Crater Lake from sewage facilities, managers of the Park can begin to assess alternative approaches for treating human wastes in remote locations. It is obvious that leach field septic systems are poorly suited for the porous rim of a volcanic crater in an alpine environment. It is also obvious that alternative treatment systems will be expensive to install. Evaluation of the alternatives, both from civil engineering and budgetary standpoints, could be initiated before further research is completed.

RECOMMENDATIONS

Based on our studies of the streams of Crater Lake National Park, we submit the following recommendations for future management and research:

Investigate the feasibility of installing composting sewage facilities at major rim locations or transporting all wastes off the caldera rim to the Munson Creek sewage lagoons. The greater cost of these systems could be spread over 10-20 years, and would almost guarantee that nutrients from human wastes would not enter Crater Lake.

Conduct experimental nutrient releases with nitrate, ammonium, and conservative fluorescent tracers in the caldera springs to determine rates of nitrogen transformation and determine whether nitrification could be responsible for high concentrations of nitrate observed in springs on the southwest wall of the caldera.

Initiate a study of the hydrology of the goundwater in the Rim Village area. Fluorescent dyes or salt tracers could be injected into the sewage system and groundwater to determine: 1) if wastes are entering the groundwater, 2) how the groundwater moves through the rim of the crater, and 3) if nutrients in groundwater are entering Crater Lake.

Develop an extensive survey of the chemistry of streams, springs, and lakes of Crater Lake National Park. These data should be collected monthly in as many systems as possible. Longitudinal transects should be included. This information would provide a baseline for future evaluation of resources of the Park.

In view of the enhanced biological activity in Munson Creek, keep anthropogenic inputs into Munson Creek to an absolute minimum.

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