Aquatic Habitat Assessments in Mined and Unmined Portions of the Birch Creek Watershed

by
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EXECUTIVE SUMMARY

The tri-agency placer mining study team, comprised of representatives from the Alaska Departments of Environmental Conservation (ADEC), Natural Resources (ADNR), and Fish and Game (ADF&G), was formed in Fiscal Year 1985 to assess the effects of placer mining on aquatic resources and to provide management alternatives to protect those resources. This report presents the ADF&G component of the study: to assess affects of mining on aquatic habitats.

Mined and unmined portions of streams in the Birch Creek watershed were inventoried to collect data on fish presence, habitat quality, and the densities and community structure of benthic invertebrates. The Birch Creek watershed includes both the Crooked Creek and Birch Creek drainages and is located in the Circle Mining District.

Placer mining in the Birch Creek watershed resulted in (1) elimination of the riparian vegetation, (2) increased particle embeddedness and a higher proportion of silt and sand deposited on the stream bottom below mining, (3) elimination of fish habitat, (4) depressed aquatic invertebrate populations, and (5) elimination of all fish from mined streams and from streams above active mining.

On the average, 45% of streambanks next to previously mined sites and 2.8% of streambanks next to unmined sites were devoid of vegetation. Stream bottom substrates were generally more embedded in fine silt and sand in sites below active mining than in sites above mining or unmined sites. Substrates in sites below active mining were an average of 41% embedded and substrates in control sites, an average of 20% embedded. Study sites located below active placer mining areas contained one-tenth as many benthic invertebrates as sites either above mining or in unmined sites. An average of 7.5 invertebrates per 0.1 meter square ($0.1/m^2$) were found below active mining and an average of 71.2 invertebrates/0.1 m^2 in sites above mining and in unmined sites. No fish were found in actively mined streams or in sites above mining. In contrast, an average of 27 fish were caught per 100 m reach in the unmined streams. Except for one round whitefish (Coregonus nasus), fish collected in the unmined streams were arctic grayling (Thymallus arcticus) and slimy sculpin (Cottus cognatus).

INTRODUCTION

Placer gold deposits are usually found in ancient stream channels near the alluvial gravel-bedrock interface. Much organic and inorganic material (overburden) usually has to be removed before this gold-bearing area is uncovered. Gold is separated from the lighter material by washing, usually with a sluice box and water from the adjacent stream.

The high content of fine clays and sand prevalent in the soils of many of the mining areas results in high levels of fine sediment being released in the washing process. Settling ponds are usually constructed below the mining operation to remove most of the larger sediment particles. Clays and other fine particles usually do not settle in the ponds but pass into the stream as suspended solids. Toxic metals are often associated with the gold-bearing minerals and may also be released to the stream during placer mining.

A tri-agency team comprised of the Alaska Departments of Fish and Game (ADF&G), Natural Resources (ADNR), and Environmental Conservation (ADEC) was formed in Fiscal Year 1985 to assess the effects of placer mining on aquatic resources and to develop technological alternatives to protect those resources. The placer mining study was a survey-level effort designed to document fish presence, habitat quality, water quality and quantity, and the density of benthic invertebrates in both undisturbed, clearwater streams and mined streams. The study was conducted in the Birch Creek watershed, which includes the Birch Creek and Crooked Creek drainages.

This document presents the biological results of placer mining studies initiated by the ADF&G in 1984 to investigate the relationships among levels of disturbance from placer mining and aquatic resources. Results from the hydrologic- and water-quality investigations are contained in the ADNR, Division of Geological and Geophysical Survey's (DGGS) Technical Report (1985).

The goal of the ADF&G component of the study was to determine the relationships among fish distribution and other aquatic populations and various levels of disturbance from placer mining. The scope of the project was limited by personnel, budget, and field time.

The specific objectives were as follows:

I. The first objective was to compare the following physical and biological habitat characteristics between streams affected by placer mining and unmined streams:

- Composition and percentage of cover of riparian (stream-side) vegetation
- Stream bottom substrate composition and degree of embeddedness
- Benthic (stream bottom) invertebrate densities and community structure and
- Fish species distributions and abundance

II. The second objective was to provide resource inventory information that can be used

- to determine the present and attainable uses of each waterway in the Birch Creek watershed;
- to develop management options for placer mining and other present and future water uses;
- and to determine if fisheries constitute a reasonably attainable use and, if so, what measures can be taken to maintain and restore fish habitat.

Additional stream inventories were conducted in tributaries to the Middle Fork of the Koyukuk River by the ADF&G, the U.S. Environmental Protection Agency (USEPA), and the U.S. Forest Service Institute of Northern Forestry (USFS/INF). These inventories were conducted using the same methods as studies conducted in the Birch Creek watershed; however, they were not as extensive and did not include as many sampling sites. Results of the Middle Fork Koyukuk studies will be presented by the USEPA by late 1985.

STUDY AREAS

The tri-agency placer mining study was conducted in the Birch Creek watershed, located approximately 150 km northeast of Fairbanks in the Circle Mining District. This watershed was chosen as a study area because it is an important mining area with many historical and active claims. The watershed contains many mined streams as well as a sufficient number of unmined streams with physical features similar to the mined streams, thereby allowing comparisons to be made between areas below mining and areas either previously mined or unmined. The Birch Creek watershed is close to Fairbanks, thus maximizing data-collection efforts during a short field season.

Eagle Summit divides the Birch Creek watershed into the Crooked Creek and Birch Creek drainages. Vegetation type is primarily black and white spruce (*Picea mariana* and *P. glauca*), willow (*Salix* sp.) and alder (*Alnus* sp.) forest at lower elevations and tundra at higher elevations.

Study sites were selected in July 1984 on tributaries to Birch and Crooked creeks. Sites were chosen on mined streams both above and below mining and on unmined streams near headwaters and in lower reaches. Sites were selected where the stream formed a single channel, had defined banks, and where the streambed was not undergoing direct physical alteration from a mining operation. Sites below mining were located downstream from a series of operations and thus were not specific to a particular operation. Our study objectives sought to focus on cumulative effects of mining rather than effects from individual operators.

Eleven streams in the Crooked Creek drainage and 5 streams in the upper Birch Creek drainage were selected for study. A total of 26 sites was identified: 9 sites that had been previously mined, 9 sites below mining, and 8 sites that had not been mined.

Streams selected for study in the Crooked Creek drainage were Porcupine, Bonanza, Miller, Mammoth, Mastadon, Independence, Bedrock, Boulder, Ketchem, and Deadwood creeks and Crooked Creek proper. Crooked Creek flows into Birch Creek about 90 river kilometers below the town of Central.

Streams selected on the west side of Eagle Summit were Ptarmigan, Fish, Bear, North Fork, and Twelvemile creeks. All of these creeks flow into Birch Creek, except the North Fork, which flows into Twelvemile Creek about 2 km above the confluence with Birch Creek.

The Birch Creek watershed and specific drainages are described in detail in Appendix 1. The study sites and the level of mining are presented in table 1. A map showing the location of each study site is presented in figure 1. Specific locations of the study sites by legal description are given in Appendix 2.

Table 1. Channel characteristics and mining activity at placer mining study sites, Birch Creek watershed, 1984

Site Map #	Stream	Above or Below Past or Present Mining	Current Mining Activity in Stream	Disturbance, Amount of Tailings
1	Crooked	Below	High	Gravel floodplain prevalent
2	Deadwood, u/s	Above	High	recently bladed, old and revegetated
3	Deadwood, d/s	Below	High	None
4	Ketchem, u/s	Above	Moderate	None
5	Ketchem, d/s	Below	Moderate	None
6	Boulder, u/s	Above	None	Few
7	Boulder, d/s	Below	None	None
8	Bedrock	Above Crooked	None	None
9	Mammoth	Below, above	High	Few old tailings, floodplains
10	Independence, u/s	Above	Low	Revegetated tailings
11	Independence, d/s	Below	Low	Revegetated tailings
12	Mastodon, u/s	Above	High	Prevalent
13	Mastodon, d/s	Below	High	Prevalent
14	Miller, u/s	Above	None	Mining approx. 60 years ago

(Continued)

Table 1 (continued).

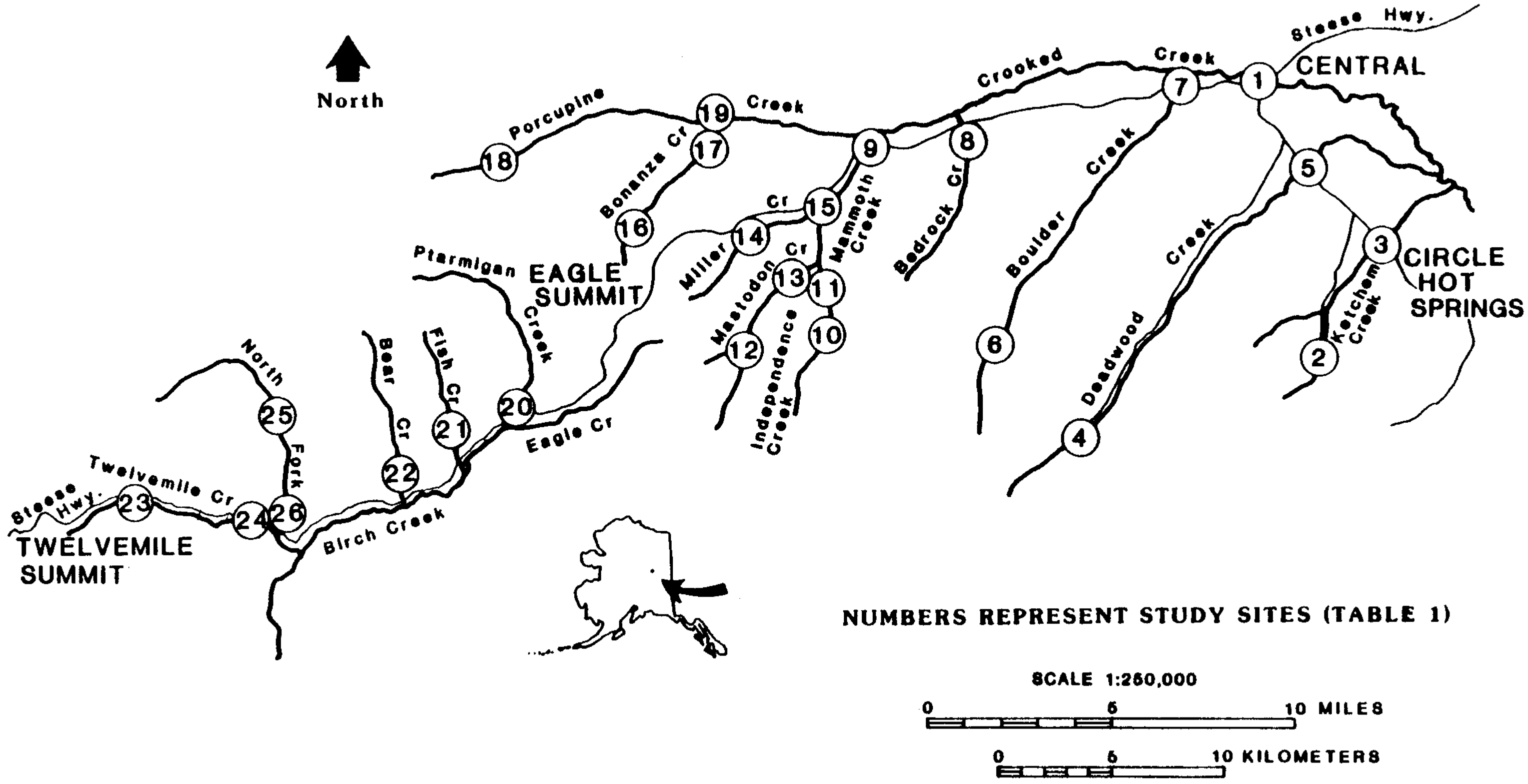
Site Map #	Stream	Above or Below Past or Present Mining	Current Mining Activity in Stream	Disturbance, Amount of Tailings
15	Miller, d/s	Below	None	Previous mining
16	Bonanza, u/s	Above	Moderate	Old, flattened and revegetated
17	Bonanza, d/s	Below	Moderate	Old, flattened, from road
18	Porcupine, u/s*	Above	Moderate	Tailings, exposed bedrock
19	Porcupine, d/s	Below	Moderate	Few old tailings
20	Ptarmigan	Above Birch	None	None
21	Fish	Above Birch	None	None
22	Bear	Above Birch	None	Small exploration, no tailings
23	Twelvemile, u/s	Above Birch	None	None
24	Twelvemile, d/s	Above Birch	None	None
25	North Fork, u/s	Above Birch	None	None
26	North Fork, d/s	Above Birch	None	None

u/s = upstream study reach.
d/s - downstream study reach.
*limited data were collected at upstream Porcupine Creek.
See figure 1 for number locaton of each site.

FIGURE 1

LOCATION OF SITES FOR PLACER STUDIES

Circle Mining District
Birch Creek Watershed
May 1985



NUMBERS REPRESENT STUDY SITES (TABLE 1)

METHODS

Study sites consisted of stream reaches of 100 m length. Reaches were selected to encompass at least one riffle-run sequence where the stream was contained in a single channel. Reaches were marked with survey stakes. Study sites were classified as either below mining or control. Areas classified as "control" included sites above current mining, which may have been mined previously, and sites in streams where no mining had occurred. Unless otherwise specified, comparisons were made between these two treatments.

Descriptive information gathered for each site included a description of the riparian vegetation, channel morphology, and sketch maps of key habitat and physical characteristics. Biological data were collected on fish and invertebrate populations over a six-week period to minimize seasonal differences when making comparisons among different streams. Sites above and below mining were usually sampled within a two-day period to eliminate any short-term temporal variation within specific streams. Dates when each stream was sampled are shown in table 2.

Hydrology and Water Quality

Methods for stream hydrology and water quality are described in the ADNR, Division of Geological and Geophysical Surveys, Technical Report (1985). Stream gradient was measured with an Abney hand level.

Riparian Vegetation

The composition of the streamside vegetation and percentage of cover were estimated along both banks in each 100 m study reach. An adaptation of the streamside cover rating system presented by Platts et al. (1983) was used to compare streamside cover among the study sites. Platts (1974) correlated types of riparian vegetation with fish densities to develop vegetation ratings. This ranking system is based upon the percentage of cover of the stream bank by trees, shrubs, and herbaceous plants. The ratings are valued by the importance of each vegetation type in providing streambank protection from erosion, stream shading, and cover for fish.

We added an additional ranking to derive an overall score weighted for percentage of cover. This ranking considered the percentage of the 100 m study reach that contained vegetative cover. The rating criteria for dominant vegetative type and percentage of cover are presented in table 3.

Table 2. Sampling dates for each study site*

Stream	Upstream Site	Downstream Site
Crooked		8-21-84
Deadwood	7-24-84	7-24-84
Ketchem	8-29-84	8-21-84
Boulder	7-25-84	7-26-84
Bedrock		7-25-84
Mammoth		8-21-84
Independence	8-02-84	8-02-84
Mastodon	8-01-84	8-01-84
Miller	7-30-84	7-31-84
Bonanza		8-09-84
Porcupine	8-08-84	8-08-84
Ptarmigan		8-22-84
Fish		8-22-84
Bear		8-15-84
Twelvemile	8-14-84	8-14-84
North Fork	8-29-84	8-15-84

*Electrofishing was usually not completed until the day following the sample date listed above.

Table 3. Ranks for vegetation type and percentage of cover

Vegetation Type	Rank
The dominant vegetation is shrub	4
The dominant vegetation is trees	3
The dominant vegetation is grass or forbs	2
Over 50 % of the streambank has no vegetation, and the dominant material is soil, rock, bridge materials, road materials, culverts, and mine tailings	1

Percentage of Cover	Rank
75-100	3
50-74	2
Less than 50	1

Source: Adapted from Platts et al. (1983)

We noted the percentage of cover by trees, shrubs, and herbaceous plants of the streambanks along each 100 m study reach.

Vegetation was observed approximately 2 m back from the streambank. Where there was a difference between the right and left banks, the values for the banks were averaged. The product of these ratings for dominant vegetation and percentage of cover were used to determine an overall riparian vegetation score. The scores range from 1: totally bare of vegetation, to 12: 100% covered with vegetation, with the dominant vegetation being shrubs.

Composition of the riparian vegetation and percentage of cover were determined in previously mined sites and in sites where no mining had occurred. General observations of the presence of the vegetation were made at areas presently being mined; however, because none of these areas were within the defined study reaches, detailed observations of riparian vegetation were not made, and these general observations were not included in statistical analyses.

Stream-Bottom Substrates

Substrate characteristics were evaluated at 0.5 m intervals across transects at the upstream, downstream, and midpoint of each 100 m study reach. A visual technique adapted from the substrate score described by Crouse et al. (1981) was used to describe the substrates. The substrate score is a summation of four ranks, three concerning the size of substrate particles, the fourth describing the level of embeddedness. The rating criteria for each substrate type are listed in table 4. Particle sizes - silt, sand, gravel, cobble - are defined by Platts et al. (1983) (Appendix 3). "Embeddedness" is a measure of how much of the dominant substrate (gravel, cobble, etc.) is buried in silt or sand.

The predominant and second most predominant particle sizes are assigned ranks based on size. The third rank corresponds to the size of the embedding material. The fourth rank is the level of embeddedness of the substrate by the material ranked in the third evaluation. The average rank across the transects for each of the four evaluations was summed, and an average of the three transects was determined for a single value corresponding to the substrate score. Lower values indicate poor habitat for benthic invertebrates and fish, and, conversely, higher values indicate high-quality habitat.

Table 4. Ranks for substrate characteristics (substrate size is used to describe the predominant, second most dominant particles and size of the embedding material; embeddedness is used to describe the coverage of the substrate with the embedding material

Particle Type or Size	Rank
50% organic cover	1
1-2 mm	2
2-5 mm	3
2-25 mm	4
25-50 mm	5
50-100 mm	6
100-250 mm	7
over 250 mm	8

Embeddedness	Rank
85-100%	1
60-85%	2
35-60%	3
20-35%	4
0-20%	5

Source: Adapted from Crouse et al. 1981

Benthic Invertebrates

Benthic invertebrates were sampled with an enclosed box sampler, which sampled 0.1 m^2 of streambed. A random sampling design, which included only riffle areas, was used for all invertebrate sampling. Five samples were located in riffle areas by a random number table to determine the distances from the downstream end of the study reach and from the stream bank. Invertebrate sampling was not conducted in pools because these habitats usually have extremely low invertebrate densities (Weber 1981) and differences could not be attributed to the effects of mining.

The substrate was brushed with a medium bristle brush, then stirred with a three-prong garden rake. Invertebrates were washed into a 0.67-m-long nytex (80 micron mesh) net, attached to the box sampler. Samples were placed in whirl-pac polyethylene bags in 90% ethyl alcohol in the field and subsequently transferred to 70% ethyl alcohol with 1% glycerol after returning from the field. Invertebrates were identified to the lowest reasonable taxonomic level (usually genus) with available keys (Baumann et al. 1977, Merritt and Cummins 1984, Usinger 1974, Wiggins 1977) and enumerated.

Invertebrate populations below-mining sites were compared with control sites. Additional comparisons were made between sites above and below mining within the same streams to determine if differences in populations could be attributed to conditions associated with sites above and below mining, to differences between specific streams, and to the interaction of within- and between-stream factors. Invertebrate densities are reported as numbers/0.1 m^2, the size of the invertebrate sampler. Because a stream channel is an extremely heterogeneous environment and invertebrate distributions are generally clumped (Elliott 1971), converting densities to numbers/m^2 would produce misleading results.

Distribution and Density of Fish

Fish were sampled throughout the 100 m study reach with a Smith-Root gasoline-powered electrofisher. The upper and lower limits of the 100 m stream reach were first blocked with nets, and the entire reach was electrofished. All fish caught during each of three successive passes were removed from the blocked area, identified, and measured from the head to the fork in the tail (fork length).

Any method for sampling fish has certain biases for size class and species (Ricker 1975). Therefore, minnow traps were also used to determine whether certain species or size classes were present in the stream and were not being collected by the electrofisher. Six minnow traps were baited with salmon roe, placed in areas of the stream deep enough to be covered by water, and left overnight. Sampling with minnow traps was always completed before electrofishing to avoid sampling bias resulting from removal of the fish from the stream reach or from other disturbances. Fish caught in the minnow traps were first counted and measured to fork length, then placed back in the stream in the same reach where they had been caught before sampling with the electrofisher.

Population densities from the electrofishing data were estimated by the Zippin (1958) method described by Platts et al. (1983). The Zippin method is based upon a maximum-likelihood model. The formulae for the population estimates and the standard error of the estimate, and the probability graphs, are presented in Appendix 4.

Statistical Methods

The nonparametric Mann-Whitney U test was used to compare all ordinal level data or data expressed as ranks, such as vegetative cover scores and stream bottom substrates scores.

The nonparametric median test (Siegel 1956; Zar 1974) was used to determine whether invertebrate densities in control sites (above mining and unmined sites) and below-mining sites were consistently higher or lower than the overall median. Invertebrate populations were compared for density between sites below mining and control sites with the t-test.

T-tests were used to determine significant differences in the occurrences of the most common taxonomic groups between control and below-mining sites. Common taxonomic groups were defined as those that have a mean density of at least 1.0 individual/0.1 m^2 in either the control or below-mining sites.

The two-way analysis of variance (ANOVA) test was used to compare densities and occurrence of the more common genera between and within sites above and below mining.

Zar (1974) stated that both the t-test and the ANOVA are sufficiently robust to withstand departures from normality and equality of variances provided the sample sizes are equal or nearly equal. Because invertebrate populations were randomly sampled with five replicates per sample, the t-test and the ANOVA are appropriate.

Diversity indices were not used because it is not known how meaningful they are when applied to invertebrate populations from Alaska, which have comparatively fewer taxa than found in streams of the lower 48 states, and which are usually not identified to the species level.

Trophic functional groups, as defined by Cummins (1973; 1977) were also not used because it is not known how well functional groups apply to invertebrate taxa in Alaska. Aquatic invertebrates in Alaska can often be identified only to the genus level, and functional groups usually rely upon species distinctions. Additionally, it has been shown (Weber 1981) that many Alaskan species fall into different trophic categories from those defined by Merritt and Cummins (1978) for a given taxon. Detailed analysis of the food habits of aquatic invertebrates, including examination of the gut contents, is beyond the scope of this project.

RESULTS

Channel Characteristics

Study streams in the Crooked Creek and Birch Creek drainages were relatively small second- and third-order tributaries. In 1984, summer low flows ranged from 0.07 m^3/s to 0.8 m^3/s. These streams were typically of moderate gradient (0.5 to 3%), with unaltered streams having relatively straight channels with short meanders. Stream channels that have undergone placer mining were almost entirely straight. The physical characteristics of each study stream are summarized in table 5.

Hydrolgy and Water Quality

Results of the hydrology and water quality sampling are presented by ADNR (1985).

Riparian Vegetation

The most prevalent vegetation growing next to undisturbed streams included black spruce, willow, alder, and herbaceous plants, including blueberry, cinquefoil, grasses, forbs, and mosses.

The percentage of the streambank covered by trees, shrubs, herbaceous plants and devoid of vegetation for sites previously mined, unmined, and where mining was currently occurring is presented in figure 2. The streamside vegetation was rated by the methods previously described, and comparisons were made between previously mined and unmined sites for percentage of cover by trees, shrubs, herbaceous plants, and bare ground and for the overall riparian vegetation rank. Ground covered by trees or shrubs with an understory of herbaceous plants was rated as covery by trees or shrubs. Ground covered exclusively by herbaceous plants was rates as herbaceous cover.

Shrubs were the most important vegetative component in unmined sites, where they comprised 79% of the riparian zones. Percentage of cover of shrubs was significantly less (Mann-Whitney U test, $p = 0.05$) in previously mined sites than in the unmined sites, where they covered an average of 64% of the riparian zones.

Trees occurred in 14 of the 19 unmined sites, where they covered, on the average, 6% of the riparian zones. Trees were found in only one of the previously mined sites.

Table 5. Physical characteristics of study streams, Birch Creek watershed, 1984

Stream	Drainage Area (km^2)	Channel Length (km)	Channel Shape	Elevation of Headwaters (m)	Average Slope (%)	Aspect (DEG.)	Average Discharge* (July-Sept. 1984) (m^3/s)
Crooked	432.5	19.5	Some meander	280	0.8	100	1.1 (40)**
Deadwood	91.2	21.6	Straight	1065	2.0	37	0.3 (9)
Ketchem	31.8	9.7	Straight	625	4.0	30	.09 (3)
Boulder	85.5	22.0	Straight	1050	2.0	40	
Bedrock	25.4	9.7	Slt. meander	1250	6.0	20	.06 (2)
Mammoth	107.5	6.6	Slt. meander	480	2.0	30	.58 (20)
Independence	36.8	8.9	Straight	1220	2.0	355	
Mastodon	27.7	10.3	Straight	1340	3.5	30	
Miller	28.0	9.3	Straight	1115	3.0	50	
Bonanza	37.0	10.6	Slt. meander	1310	5.0	65	
Porcupine	131.1	24.3	Straight	1295	2.0	90	.38 (13)
Ptarmigan	46.4	12.9	Straight	1340	4.0	160	
Fish	19.2	7.7	Straight	1250	5.0	170	
North Fork	63.5	14.5	Straight	1145	3.0	170	
Twelvemile	64.0	13.7	Straight	950	2.0	110	
Birch at Twelvemile Confl.	221.2	13.0	---	695	0.7		

Source: ADNR 1985

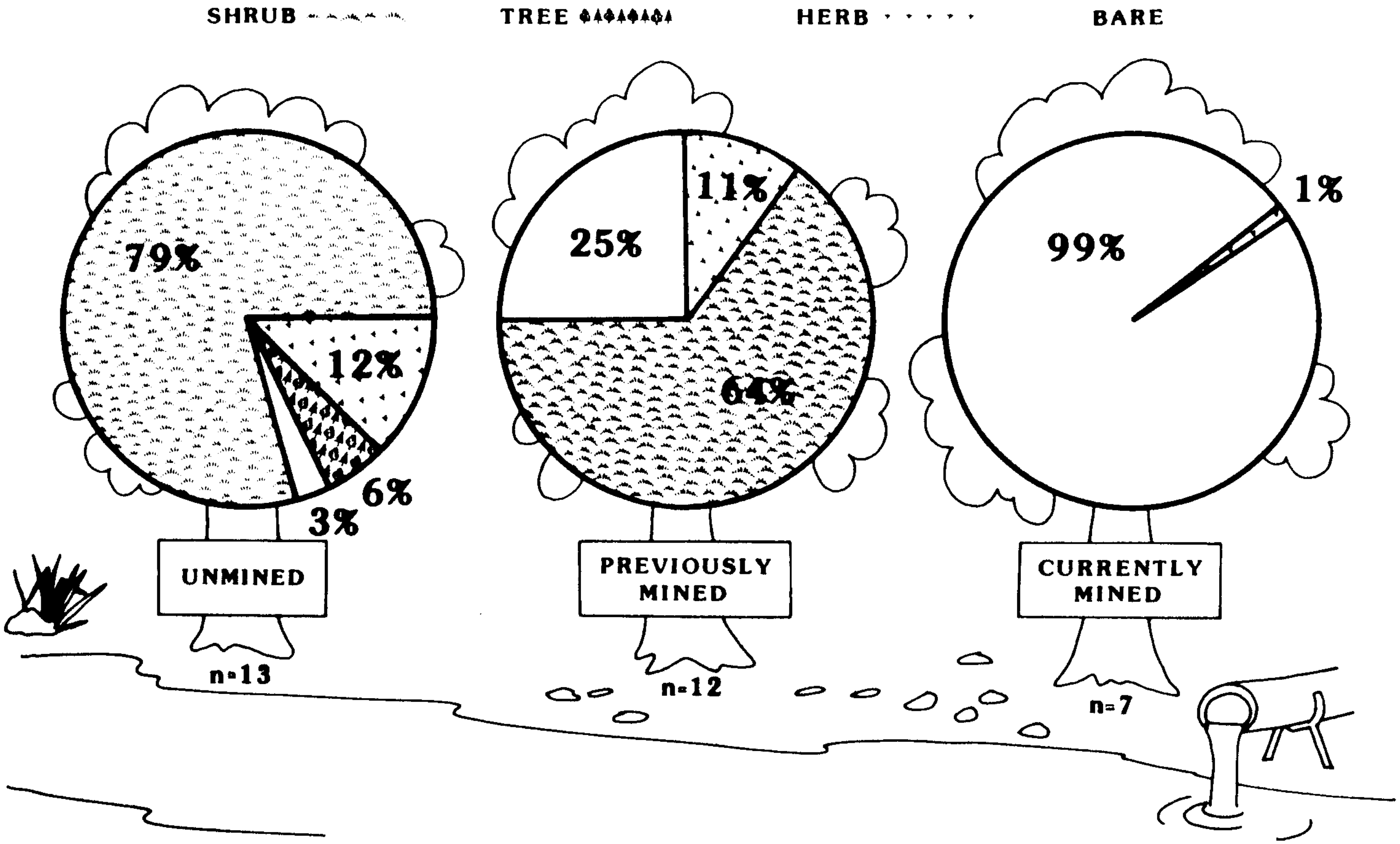
* Average summer discharges were determined for streams with staff gauges only.

** Numbers in parenthesis are discharges in cubic feet per second.

--- means no data were available.

FIGURE 2

COMPOSITION OF RIPARIAN VEGETATION



Herbaceous plants were a relatively minor component of the riparian communities in both unmined and previously mined sites, where they covered 12% and 11%, respectively, of the riparian zones.

There was significantly less total vegetative cover in the previously mined sites than in unmined sites (Mann-Whitney U test, $p = 0.002$). One hundred percent of the riparian zone in upper Porcupine Creek and 75% in upper Miller Creek were devoid of vegetation. Other previously mined sites contained large patches of bare ground (table 6). In contrast, study sites with undisturbed streambanks had 75 to 100% of the banks covered by riparian vegetation, with an overall average of 97% for these sites.

Riparian vegetation ranks, which incorporated percentages of trees, shrubs, herbaceous plants, and base ground, were significantly lower in previously mined sites than in unmined sites (Mann-Whitney U test, $p = 0.002$).

Composition of the riparian vegetation also varied between previously mined and unmined sites. Sites where mining had occurred previously contained primarily barren tailings, with scattered alder, willow, and herbaceous plants. In contrast, sites that had not been previously disturbed by mining generally had overstories of willow and alder, with understories of blueberries, cinquefoil, fireweed, and grasses. Although composition and percentage of cover of streamside vegetation was not determined in stream reaches where mining was actually occurring, observations showed these areas to be almost entirely devoid of vegetation.

Streamside vegetation was evaluated at previously disturbed sites to determine the rates and extent of regeneration. Observations showed that about 25% of the streambanks in the upper reaches of Miller Creek had revegetated in the 60 years since mining. The remainder of the area was covered with barren tailings. Old tailings with patchy growths of willow and alder extended behind the riparian zone. There was no regeneration in the upper reaches of Porcupine Creek, which had been mined in 1982.

Stream Bottom Substrates

The stream bottom substrate ranks were determined for sites below mining, previously mined sites, and unmined sites (table 7). Comparisons of the substrate ranks were first made between sites below mining and control (above mining and unmined) sites. Control sites included both previously mined sites and unmined sites, as defined in the Methods section.

Table 6. Composition of the riparian vegetation and vegetative rank, Birch Creek watershed, Alaska, 1984

	Percent Cover of Dominant Vegetation				Rank
	Tree	Shrub	Herb	Bare	
Previously Mined Sites					
Bonanza, u/s	0	50	20	30	8
Bonanza, d/s	0	95	0	5	12
Boulder, u/s	0	53	7	40	8
Deadwood, u/s	0	80	20	0	12
Independence, u/s	0	92	8	0	12
Independence, d/s	0	90	10	0	12
Mammoth	0	85	5	10	12
Mastodon, u/s	0	70	10	20	12
Mastadon, d/s	0	68	22	10	12
Miller, u/s	0	15	10	75	1
Miller, d/s	3	65	22	10	12
Porcupine, u/s	0	0	0	100	1
Unmined Sites					
Bear	0	87	13	0	12
Bedrock	40	60	0	0	12
Boulder, d/s	0	90	10	0	12
Crooked	0	65	10	25	12
Deadwood, d/s	0	90	10	0	12
Fish	5	77	13	5	12
Ketchem, u/s	10	80	10	0	12
Ketchem, d/s	40	50	10	0	12
North Fork Birch, d/s	0	87	13	0	12
Porcupine, d/s	15	85	0	0	12
Ptarmigan	7	83	10	0	12
Twelvemile, u/s	0	78	22	0	12
Twelvemile, d/s	0	87	13	0	12

Table 7. Ranks and substrate scores for stream bottom substrates, Birch Creek watershed, 1984

Area	Dominant Substrate	Subdominant Substrate	Embedded Material	Percent Embedded	Embedded Rank	Substrate Score
Below Mining						
Bonanza, d/s	6	3	3	52	2	14
Crooked	6	4	4	34	3	17
Deadwood, d/s	4	2	2	77	2	10
Independence, d/s	6	4	4	17	3	17
Ketchem, d/s	4	3	3	57	2	12
Mammoth, d/s	7	2	3	52	2	14
Mastodon, d/s	6	4	3	10	4	17
Miller, d/s	6	3	3	22	3	15
Porcupine, d/s	5	4	3	52	2	14
Control Sites						
Previously Mined						
Bonanza, u/s	7	3	4	16	4	18
Boulder, u/s	6	2	4	29	3	15
Deadwood, u/s	6	5	5	5	6	22
Independence, u/s	6	2	4	29	3	15
Mastodon, u/s	7	4	4	28	3	18
Miller, u/s	6	4	5	10	4	19
Ptarmigan	5	4	4	18	4	17
Unmined						
Bear	6	4	5	28	4	19
Bedrock	6	4	4	22	3	17
Boulder, d/s	5	2	3	33	3	13
Fish	5	5	4	26	4	18
Ketchem, u/s	6	5	4	20	4	19
N. Fork, u/s	7	6	5	17	4	22
N. Fork, d/s	6	5	4	20	4	19
Twelvemile, u/s	7	7	5	9	7	26
Twelvemile, d/s	7	6	4	15	6	23

Source: See table 4 for a definition of ranking system

The most striking differences between sites below mining and control sites were the percentage of embeddedness of the substrate and the size of the embedding material. The substrates in sites below mining were significantly more embedded (Mann-Whitney U test, probability less than 0.002) than in the control (not currently mined or unmined) sites. Embeddedness in the sites below mining ranged from 10 to 77%, with an average of 41%. In contrast, substrates in control sites were only 5 to 33% embedded, with an average of 20%.

Substrates in sites below mining were embedded primarily in fine silt and sand, whereas substrates in the control sites were embedded in coarse sand and small gravel.

The predominant particle sizes were not significantly different between control and mined sites (Mann-Whitney U test, probability greater than 0.05). However, there were significant differences in the sizes of the subdominant substrates between below mining and control sites (Mann-Whitney U test, probability less than 0.02). Substrates in control streams were generally of medium-to-large cobble surrounded by rock and gravel. Substrates in sites below mining were also of medium-to-large cobble; however, they were surrounded by silt and sand.

Stream bottom substrate scores, which combined ranks for dominant and subdominant particle sizes, the degree to which the gravel or cobble was embedded in fine material (clay, silt, or sand), and the size of the embedding material, were compared to determine if there were significant differences between the sites below mining and control sites. Substrate scores were significantly lower in the sites below-mining than in the control sites (Mann-Whitney U test, probability less than 0.002). Substrate scores in the below-mining sites ranged from 10 to 17, with an average of 14, and in the clearwater sites the scores ranged from 13 to 26, with an average of 19.

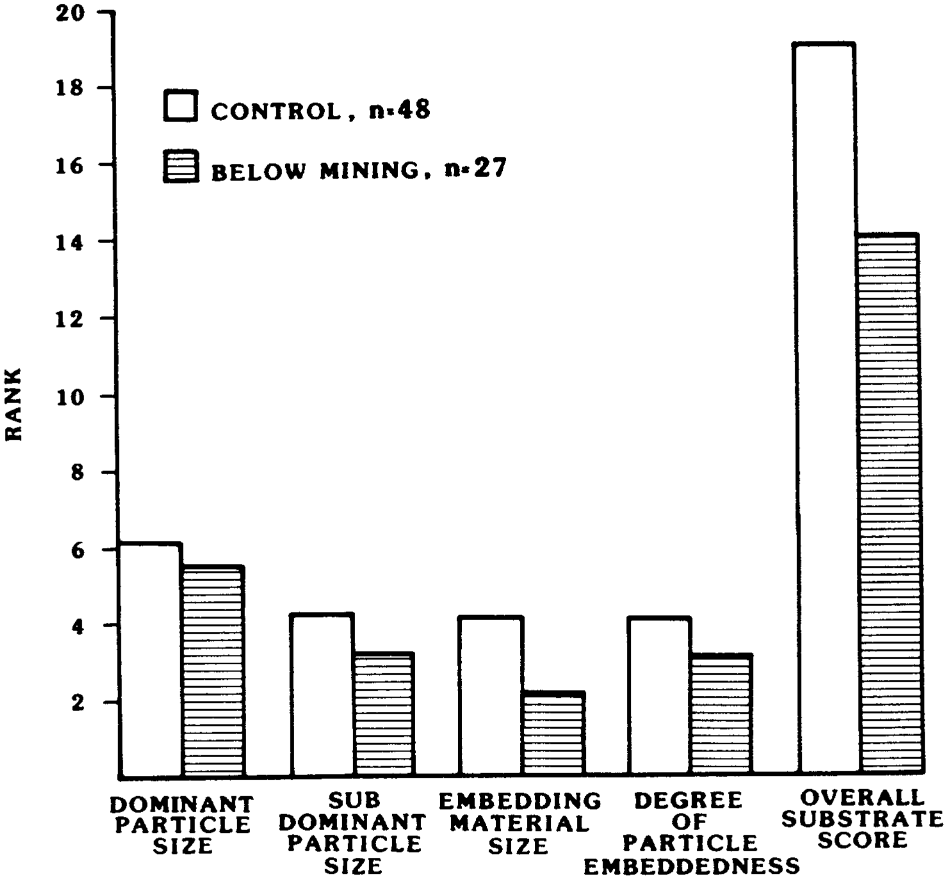
The ranks for dominant and subdominant particle size, embeddedness, and the overall substrate score are shown in figure 3 for control and below-mining sites.

Individual substrate scores were then compared between sites above mining that had been previously mined and sites below mining. The sizes of the predominant substrates and of the subdominant substrates were not significantly different between sites above and below mining (Mann-Whitney U test, probability = 0.134 and 0.265 for predominant and subdominant substrates, respectively.) However, there were significant differences between the percentage of

FIGURE 3

AVERAGE STREAM BOTTOM SUBSTRATE RANKS

AND OVERALL SUBSTRATE SCORE FOR CONTROL AND BELOW MINING SITES



embeddedness (Mann-Whitney U test, probability = 0.031) and the size of the embedding material (Mann-Whitney U test, probability = 0.009).

Total substrate scores were also compared between previously mined sites and sites below mining. As mentioned in the Methods section, low substrate scores indicate poor habitat for benthic invertebrates and fish, and higher values indicate higher-quality habitat. Total scores were significantly lower in sites below mining than in previously mined sites (Mann-Whitney U test, probability = 0.003).

Benthic Invertebrates

1. Invertebrate Density

Benthic invertebrate densities were significantly higher in control (above-mining and unmined) sites than in the below-mining sites (Mann-Whitney U test, probability less than 0.001). Samples from control sites contained an average of 71.2 invertebrates/0.1 m^2 (standard error = 6.19), and samples from sites below mining contained an average of 7.5 invertebrates/0.1 m^2 (standard error = 1.28).

Invertebrate densities were also compared between control and below-mining sites using the nonparametric median test (figure 4). Seventy-five percent of the invertebrate samples from control sites had higher invertebrate densities than the median for all sites. In contrast, only 4% of samples from the below-mining sites had densities higher than the median.

Paired comparisons were made of invertebrate populations in each stream that was sampled above and below mining in the Crooked Creek drainage to determine if differences in the populations could be attributed to differences among streams or to differences from the treatment, i.e. above or below mining. Data from streams where no mining has occurred were omitted from this analysis.

Invertebrate densities were significantly higher overall in areas above mining than in areas below mining (two-way ANOVA, one-tailed probability less than 0.001).

There was also a significant difference in invertebrate densities among streams sampled above and below mining (two-way ANOVA, one-tailed probability less than 0.005). The interaction between stream and mined or unmined condition was significant at $p = 0.001$. The mean invertebrate density per 0.1 m^2 for sites in each stream above mining and below mining are shown in table 8.

FIGURE 4

INVERTEBRATE SAMPLES

WITH DENSITIES LESS THAN OR GREATER THAN THE MEDIAN

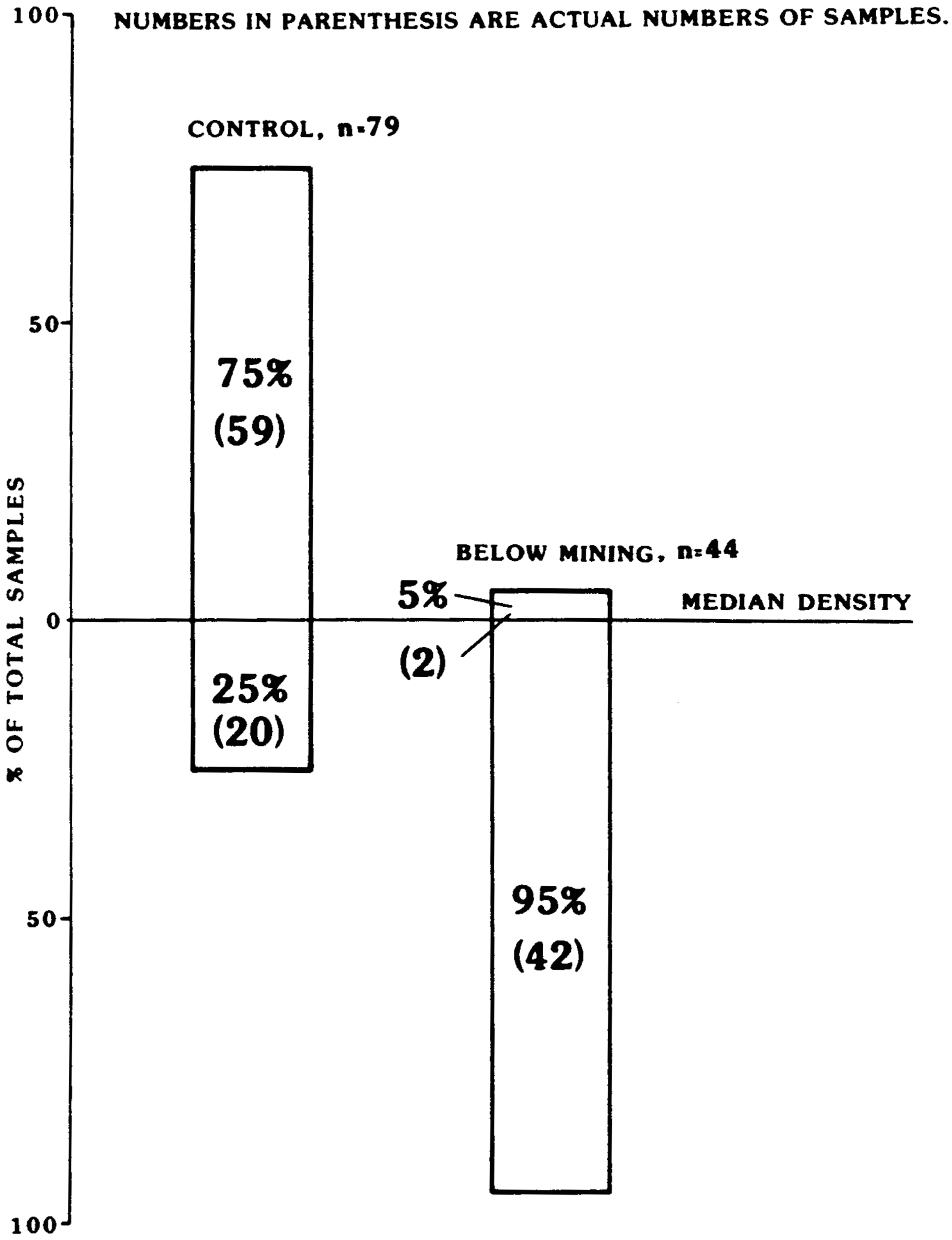

NUMBERS IN PARENTHESIS ARE ACTUAL NUMBERS OF SAMPLES.

Table 8. Invertebrate densities from sites above and below mining Crooked Creek drainage, 1984

Stream	Above Mining Inverts/0.1m²	n	Below Mining Inverts/0.1m²	n
Bonanza	41.4	5	2.6	5
Deadwood	1.3	4	3.4	5
Ketchem	107.4	5	22.0	5
Independence	15.4	5	9.6	5
Mastodon	64.4	5	8.2	5
Miller	115.4	5	12.6	5
Porcupine	24.8	5	4.3	5

n = number of samples.

The upstream areas of Ketchem Creek, Miller Creek, Mastodon Creek, and Bonanza Creek contained the highest invertebrate densities. Downstream sites in Bonanza Creek and Porcupine Creek and both the upstream and downstream sites in Deadwood Creek had the lowest densities of aquatic invertebrates.

If data from the upstream site of Deadwood Creek, which had been recently disturbed by a bulldozer, are excluded, invertebrate densities in sites above mining can be compared to densities in unmined streams to determine if invertebrate populations in previously mined sites have recovered from disturbance. There was an average of 52.7 invertebrates/ $0.1m^2$ in previously mined sites and an average of 83.8 invertebrates/$0.1m^2$ in sites where no mining has occurred.

2. Invertebrate Community Structure

Benthic invertebrates collected in sites below mining and in control sites were identified to the lowest reasonable taxonomic level with available keys applicable to Alaskan taxa. This was usually the genus level; however, Chironomidae were not identified below family. A list of all taxa found in the Birch Creek watershed is presented in Appendix 5.

Invertebrate populations were compared to determine whether certain taxonomic groups occurred more frequently in either the control or below-mining sites. Comparisons among sites were first made at the ordinal level to detect general differences in community structures between these sites and to determine if major groups were absent from either control or below-mining sites or both (figure 5).

The largest group of invertebrates collected from both below-mining and control sites was Diptera, or true flies, with 43% of the invertebrates collected from control sites and 77% collected from below-mining sites. Forty three percent Diptera from control sites represents a mean density of 30.4 Diptera per $0.1\ m^2$; 77% of the Diptera from below-mining sites represents a mean density of 6.4 Diptera per $0.1\ m^2$.

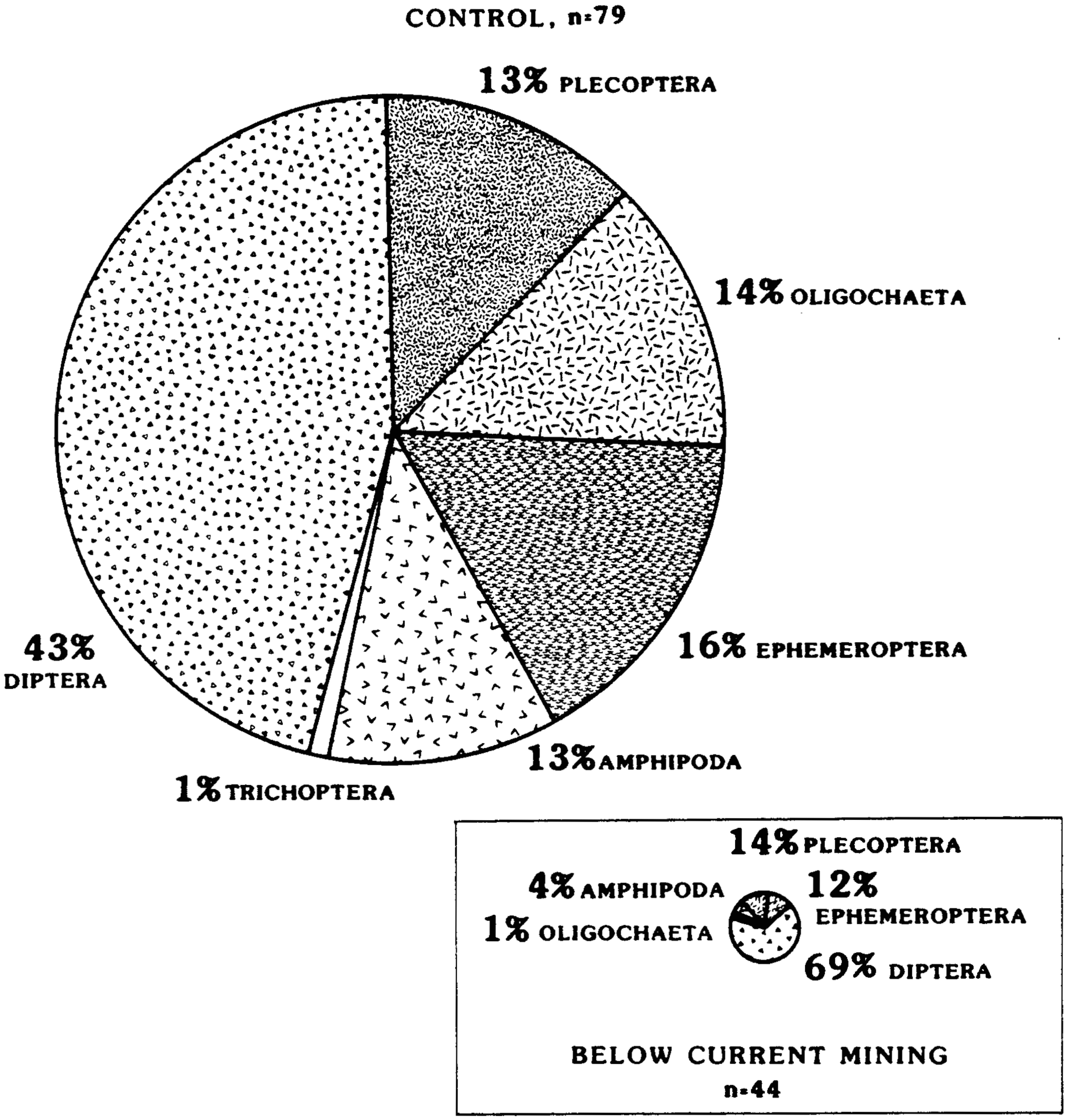
Trichoptera, or caddisflies, were the rarest, with only 0.6% of the invertebrates in control sites and none from the below-mining sites. Limnephilid caddisflies were collected from minnow traps in Ketchem and Crooked creeks below mining; their presence was noted but not added to the invertebrate data because the minnow traps were not part of the quantitative invertebrate sampling program.

FIGURE 5

INVERTEBRATE COMMUNITIES

AVERAGE PROPORTION OF INVERTEBRATES IN EACH ORDER.

SIZE OF THE GRAPHS ARE PROPORTIONATE TO THE DENSITIES



Densities of each genus were compared to determine differences in invertebrate community structures between control and below-mining sites. The mean density of each taxa (usually genus) for below-mining and control sites is presented in table 9. Alloperla (Plecoptera), Dicosmoecus, Rhyacophila and Glossosoma (Trichoptera), and Ephemerella (Ephemeroptera) were rare in the control sites and were not found in below mining-sites. Ameletus (Ephemeroptera), Tipula, and Dicronota (Diptera: Tipulidae) were rare in all sites.

The most common taxonomic groups (as defined in the Methods section) were compared with t-tests to determine differences in the occurrences of these groups between control and below-mining sites. The family Chironomidae was the most common taxonomic group in the below-mining sites, where it comprised an average of 98% of the total Diptera. Other taxonomic groups were extremely rare in the below-mining sites, with average densities of less than one individual/0.1 m^2 (table 9). All taxonomic groups had lower densities in the below-mining sites than in the control sites (t-test, $p = 0.001$).

Fish Distribution and Density

Results of fish population surveys performed by the electrofisher are shown in table 10. No fish were found either above or below mining in the eight actively mined tributaries to Crooked Creek or in the upper reaches of Crooked Creek proper, which is also mined.

Two grayling (Thymallus arcticus) and no sculpin (Cottus cognatus) were captured in Boulder Creek in July during a period of record high discharge (approximately 0.8 m^3/s). Boulder Creek was sampled again during August, at relatively low discharge (approximately 0.14 m3/s); no fish were caught during the second effort. No fish were found in Bedrock Creek, an unmined tributary to Crooked Creek about 13 km upstream from the town of Central.

More fish were captured in the clearwater tributaries on the west side of Eagle Summit than in tributaries to Crooked Creek. Eight sculpin and four grayling were caught in the upstream site of the North Fork, and 71 sculpin were caught in the lower site. Four passes were made with the electrofisher in the lower site because the numbers of sculpin caught during the first three passes did not decrease. Twelve sculpin, 5 grayling and 1 round whitefish (Coregonus nasus) were caught in the upstream site of Twelvemile Creek, and 20 sculpin and no grayling were

Table 9. Average densities of invertebrate taxa from control and below mining sites, Birch Creek watershed, 1984

	Control			Below Mining		
	x	SE	n	x	SE	n
Ephemeroptera						
** *Cinygmula*	5.6	0.9	79	0.3	0.1	44
** *Epeorus*	3.2	0.6	79	0.1	0.1	44
Ephemerella	0.2	0.05	79	0	0	44
** *Baetis*	2.3	0.6	79	0.3	0.1	44
Ameletus	0.4	0.1	79	0.2	0.1	44
Plecoptera						
** Nemouridae	7.7	1.5	79	0.6	0.2	44
** Capniidae	1.7	0.4	79	0	0	44
Alloperla	0.4	0.1	79	0	0	44
Trichoptera						
Dicosmoecus	0.2	0.1	79	0	0	44
Rhyacophila	0.3	0.1	79	0	0	44
Glossosoma	0.2	0.1	79	0	0	44
Diptera						
** Chironomidae	24.4	3.8	79	5.0	1.1	44
Tipula	0.3	0.1	79	0	0	44
Dicronota	0.4	0.1	79	0	0	44
** *Prosumulium*	2.5	0.6	79	0	0	44
** *Empididae*	2.1	0.5	79	0	0	44
Anphipoda						
** *Hyalella azteca*	8.7	1.9	79	0.1	0.1	44
** Oligichaeta	9.6	1.6	79	0.2	0.1	44

** Significantly different at p less than 0.001 (t-Test). Other taxa were not subjected to statistical tests because of very low densities. Rare taxa (less than 0.1/0.1 m^2) are not included.

Table 10. Total fish caught with three passes of the electrofisher in 100 m block-net sections (four passes in North Fork, DS) (US = upstream site, DS = downstream site)

Area	Slimy Sculpin	Arctic Grayling	Round Whitefish	Estimated Density per m²	Standard Error of Estimate
Boulder, DS	0	2	0	NC	--
Bear	0	12	0	0.01 GR	0.96
North Fork, US	8*	4*	0	NC	--
North Fork, DS	71**	2	0	∞ SS	--
Twelvemile, US	12	5	1	0.02 T	1.41
Twelvemile, DS	20	0	0	0.03 T	3.92
Remaining sites	0	0	0	0	--

* Area not blocknetted. Total fish from one pass recorded.
** No decrease in the number of slimy sculpin caught after four passes.
T = total fish.
SS = slimy sculpin only.
GR = arctic grayling only.
NC = not calculated.
-- means no data were available.

caught in the downstream site. Twelve grayling were caught in Bear Creek.

Density estimates of fish caught in Twelvemile, upstream North Fork, and Bear creeks were generally within 5 to 20% of the total number of fish caught within the 100 m study reach (table 10). Density estimates were not made for the lower site in Twelvemile Creek because the numbers of sculpin caught did not decrease during the four passes.

Minnow traps were not as successful in catching fish as the electrofisher. Only one grayling was caught in Bear Creek, five sculpin were caught in the downstream section of the North Fork, and one grayling in the downstream section of Twelvemile Creek. In no instance were fish caught with the minnow traps and not with the electrofisher. Size classes of fish caught in the minnow traps were similar to sizes caught with the electrofisher.

Grayling collected with the electrofisher from all sites were primarily in the 100 mm to 200 mm size classes (fig. 6). Figure 6 also shows the approximate age classes for these fish. The size of each fish collected with the electrofisher is presented in Appendix 6. No young-of-the-year grayling were collected from any of the streams with either minnow traps or the electrofisher.

Albert Creek, an unmined tributary to Crooked Creek below Central, was not sampled for fish; however, observations showed 200 to 300 young-of-the-year grayling (fork length less than 75 mm) in each of the large pools and backwater areas near the Steese Highway. The creek could not be waded beyond 100 m above the Steese Highway, and observations were not made beyond that point. Albert Creek is the only tributary where young-of-the-year grayling were observed.

Sculpin collected with the electrofisher from all sites fell into three fairly distinct sizes: 30-50 mm, 50-80 mm, and 80-110 mm (fig. 7). The three predominant size classes of sculpin collected are approximately ages 1, 3, and 5 fish. See Appendix 6 for the size of sculpin collected from each site with both electrofisher and minnow traps.

FIGURE 6

ARCTIC GRAYLING CAUGHT

WITH ELECTROFISHER IN CONTROL STREAMS

(NO GRAYLING WERE CAUGHT IN PLACER MINED STREAMS)
BIRCH CREEK WATERSHED, 1984
SIZE CLASSES FROM SCOTT AND CROSSMAN, 1973

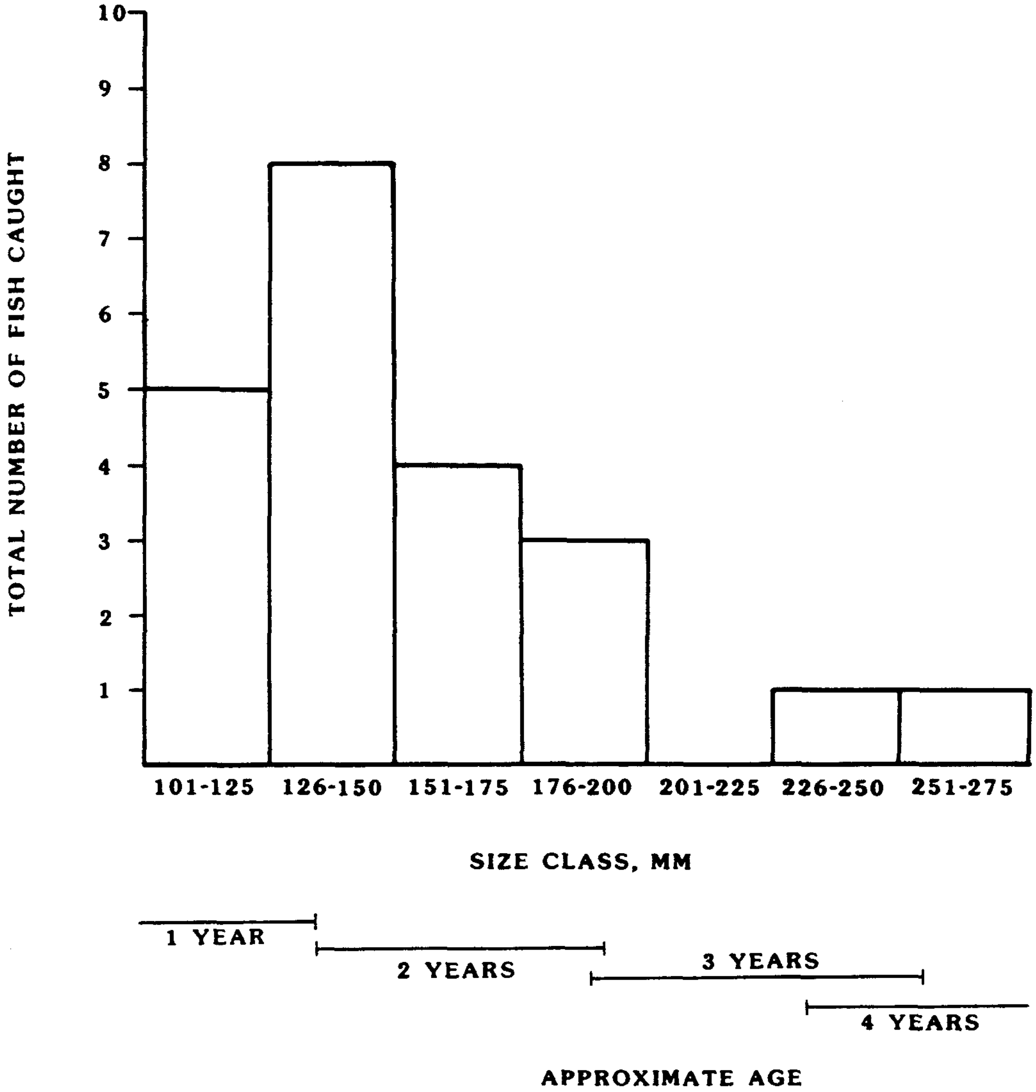
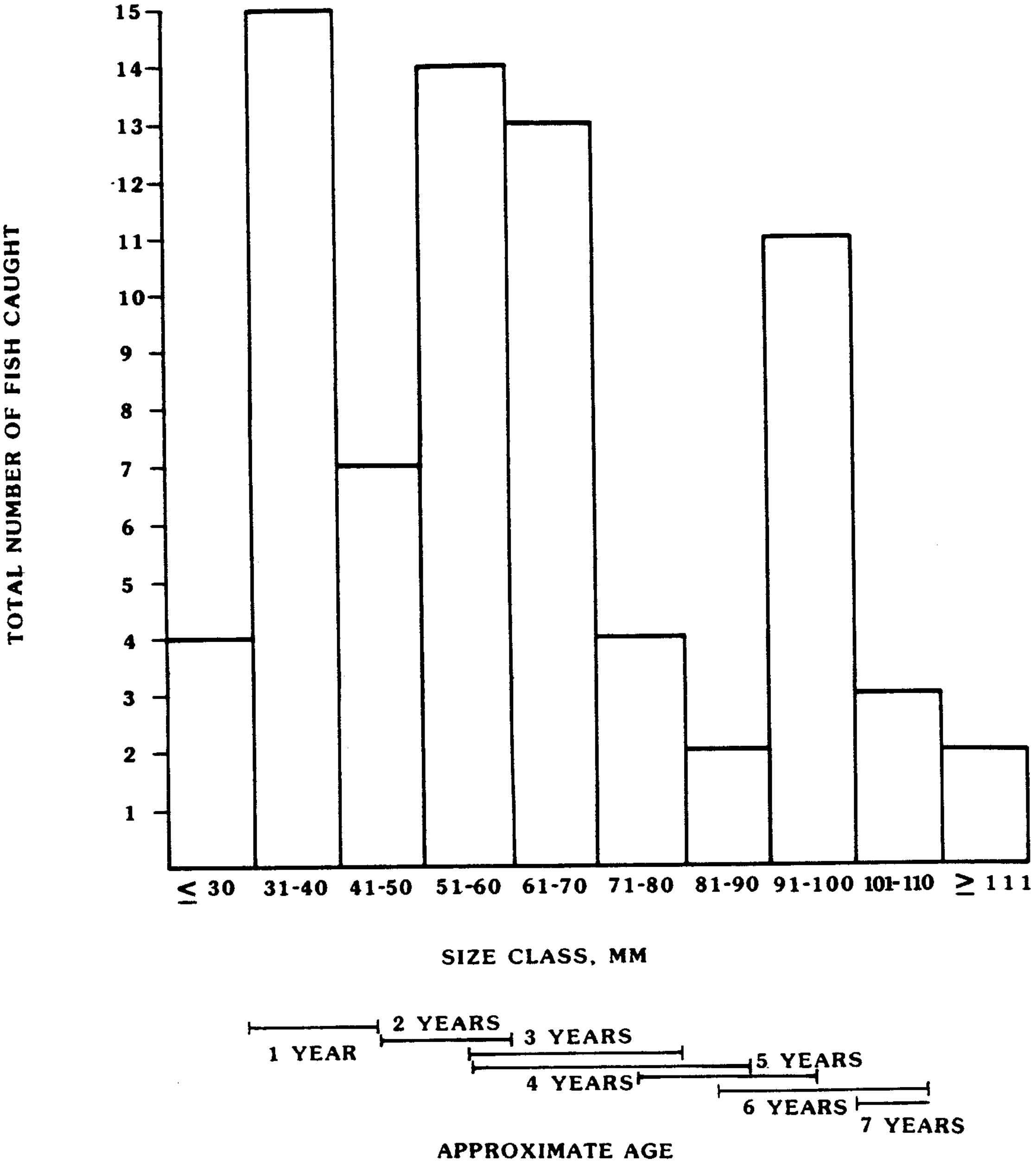


FIGURE 7

SLIMY SCULPIN CAUGHT

WITH ELECTROFISHER IN CONTROL STREAMS

(NO SCULPIN WERE CAUGHT IN PLACER MINED STREAMS)
BIRCH CREEK WATERSHED, 1984
SIZE CLASSES FROM CRAIG AND WELLS, 1976



DISCUSSION

Placer mining has caused the following physical alterations to the stream channels in the Birch Creek watershed: (1) stripping of the riparian vegetation and removal of soils associated with the riparian zone, (2) elimination of stream banks as the overburden was removed, (3) diversion of the stream channels and subsequent elimination of pools, meanders, and other habitat features, (4) changes to substrate conditions, and (5) adverse changes to water quality. The consequences of both channel alteration and decreased water quality observed during the placer mining study are discussed below.

Riparian Vegetation

Relationships among riparian, upland, and stream ecosystems have been defined into three categories (Lowrance et al. 1985): (1) biologic fluxes - movement of plants (including organic detritus) and animals; (2) hydrologic fluxes - movement of water and sediment; and (3) energy fluxes - primarily the kinetic energy of wind and water.

The importance of the riparian zone to subarctic Alaskan streams as a biologic flux is not known. Recent studies (e.g., Cowan and Oswood 1983, Cowan et al. 1983) have indicated that although the riparian zone does contribute organic detritus to the stream ecosystem, its importance may be considerably less than in temperate latitude streams. Cowan et al. (1983) stated that a considerable portion of the benthic detritus in an Alaskan subarctic stream was immobilized for most of the year by winter ice. They found no evidence of invertebrate use of the detritus after spring thaw; however, invertebrates were using the detritus as an energy source in the fall. Detrital resources in subarctic streams of the Birch Creek watershed are extremely meager. Samples from temperate latitudes usually contain a large proportion of organic detritus. However, we found very little detritus in invertebrate samples or on the streambed in these streams. LaPerriere (pers. comm. 1985) reported a similar absence of organic material from benthic samples taken in the Birch Creek watershed.

Riparian vegetation is very important in regulating hydrologic fluxes, especially in controlling nonpoint sources of pollution. This vegetation is essential for stabilizing streambanks and regulating water temperatures (Karr and Schlosser 1978). Much of a stream's sediment load, particularly during high flows, results from bank erosion and from surface runoff. Levels of suspended solids increase quickly during storm events when riparian vegetation is absent (Schlosser and Karr 1981).

Placer mining along a stream channel eliminates the hydrologic and energy control mechanisms in those portions of the channel, leaving extensive streamside areas subject to erosion and continual nonpoint sources of sediment pollution (Lowrance et al. 1985).

The removal of the overburden for placer mining in the Birch Creek watershed resulted in the elimination of virtually all riparian vegetation within the zone of active mining (fig. 2). Such removal has a long-term effect: areas mined two years earlier contained no vegetation along either streambank, and areas mined 60 years earlier were only sparsely vegetated. Regeneration was particularly poor on old mine tailings and most successful along stream reaches where soils were left intact or replaced.

Stream Bottom Substrates

Sediment that settles to the stream bottom results in a reduction in the average particle size of the substrate from predominately cobble and gravel to predominately sand and silt. The amount and size of interstitial space available in the substrate for aquatic habitat is reduced or eliminated in streams where fine particles are the predominant substrate or in substrates highly embedded with fine particles.

Direct effects to the biological communities also occur. Increased sediment deposited on the substrate inhibits growth of algae and macrophyte production by smothering the plants and eliminating suitable substrate (Van Nieuwenhuyse 1983).

Studies on the effects of increased suspended solids and sedimentation of the substrate to the benthic communities have shown reduced aquatic invertebrate densities and taxonomic richness (Cordone and Kelley 1961, Gammon 1970, Luedtke and Brusaven 1976, Sorensen et al. 1977, Rosenberg and Weins 1978, Griffiths and Walton 1978, Pickral 1981, Wagener and LaPerriere 1985). Increased sediment inputs have also been shown to limit food resources of aquatic invertebrates by reducing algal production (Cordone and Kelley 1961, Griffiths and Walton 1978) and by decreasing the ratio of organic to inorganic material (Naiman and Sedell 1979). Van Nieuwenhuyse (1983) found that the mined fork of Birch Creek, Alaska, contained lower levels of algal productivity and lower invertebrate densities and fewer taxa than the unmined, clearwater tributary.

The most significant effects of increased sedimentation to invertebrates probably result from covering the coarse gravel and cobble that are the preferred habitats of most invertebrates (Cordone and Kelly 1961, Hynes 1970, Sorenson et al. 1977). Other effects may occur from clogging the feeding apparatus of filter-feeding invertebrates (Gammon 1970) and abrading and damaging invertebrate gills and spiracles (Griffiths and Walton 1978).

Fish populations may be reduced by the deposition of fine sediments over spawning gravels. As spaces within the gravel become filled with sediment, intergravel flow of water is disrupted. This subsurface flow supplies oxygen to eggs for respiration, removes metabolic wastes, and helps maintain even temperatures and pH. Studies by Cooper (1965), Shelton and Pollock (1966), Koski (1972), and Phillips et al. (1975) have shown that increased settleable solids in spawning gravels greatly reduce survival of eggs. Cordone and Kelly (1961) stated that eggs and preemergent fry suffered the highest mortality rates of any salmonid life stage when levels of settleable solids were increased.

Stream sites in the Birch Creek watershed that had been previously mined or were located below mining contained benthic substrates that were of poorer quality for fish habitat than areas unaffected by mining (fig. 3). Previously mined areas like upper Porcupine Creek and lower Miller Creek contained extensive areas of exposed bedrock with small amounts of gravel or cobble. Substrates in areas of Ketchem and Deadwood creeks located below mining were heavily embedded in clay, silt, and sand. The heavily embedded, predominately silt and clay substrates of the lower sites of these two creeks probably resulted from many years of mining-sediment input. It is doubtful that annual flood events are of sufficient magnitude to resuspend deposits in small, low-flow streams such as Ketchem and Deadwood creeks.

In contrast, benthic substrates in control sites are armored with gravel and cobble rather than embedded in fine particles. The differences in armoring and embedding have important consequences to aquatic communities. For example, substrates covered by silt and sand have few interstitial spaces for invertebrates and small fish such as sculpin to find shelter. Additionally, there is no suitable substrate for periphyton, a primary nutrient source in high-latitude stream communities, to colonize and grow (LaPerriere pers. comm. 1985, Cowan et al. 1983). An armored substrate provides a hard, stable surface for periphyton colonization and growth and ample interstitial spaces for invertebrate and sculpin habitation.

Aquatic Invertebrates

The occurrence and distribution of aquatic invertebrates in stream channels are regulated by many factors, including (1) current velocity (Hynes 1970), (2) water temperature, (3) water chemistry (Madsen 1972), (4) stream-bottom conditions (Hynes 1970, Tolkamp and Both 1977), and (5) amounts and types of food (Cummins 1974, Cummins and Lauff 1968). Placer mining in a stream channel can result in the alteration of each of these factors. Current velocities increase when the stream is shortened by channelization and meanders are eliminated. Water temperatures may increase when extensive amounts of riparian vegetation, which provides shade, are removed or when the water is impounded in shallow settling ponds. Water quality is degraded when sediments are released into the stream from hydraulic stripping, sluicing, bank erosion, or erosion from settling ponds. Stream-bottom substrates have a higher proportion of fine material and greater cobble embeddedness when sediments are deposited below mining operations. Food sources are altered through the elimination of riparian vegetaion and resultant detrital inputs (cf. Results: Riparian Vegetation) and by covering the periphyton on the stream bottom (cf. Results: Bottom Substrate). Disruption of the physical habitat through the action of heavy equipment may also directly affect aquatic invertebrates.

Placer mining significantly decreased the density of aquatic invertebrates below the zone of active mining and created habitat conditions that excluded many taxonomic groups. Invertebrate populations in areas below placer mining had, on the average, densities that were an order of magnitude smaller than populations in control streams (fig. 5). Most of the mayfly and stonefly genera occurred rarely in areas below mining (an average of fewer than 0.5 invertebrates per sample), if at all (table 9).

The taxonomic composition of invertebrate communities was quite different between control and below-mining sites (table 9). These differences can be attributed to alterations in many of the physical factors discussed previously.

Most of the mayfly and stonefly genera found in control sites are associated with cold, clear-flowing water (Merritt and Cummins 1978). Most _Cinygmula_, _Epeorus_, _Ephemerella_, and _Baetis_ (Ephemeroptera) species are herbivores that scrape rock surfaces for periphyton and detritus. Silt deposited on the rocky substrates below mining covers the periphyton, thus limiting the food sources. The stonefly families Nemouridae and Capniidae are also found in clear, flowing water where they consume decomposing organic material and periphyton on the bottom substrate.

Filter-feeding invertebrates, such as the blackfly larvae (Simuliidae), are probably excluded from areas affected by mining because the fine particles in the water clog their filtering mechanisms. Simuliidae are strongly associated with clear, fast-flowing water, as are most filter-feeding invertebrates. These genera occurred rarely in sites below mining (an average of fewer than 0.05 invertebrates per 0.1 m^2), if at all (table 9).

Invertebrate communities compared with the two-way ANOVA tests (table 9) between sites above and below mining within the same streams showed two important trends: first, that there is a very significant negative effect of placer mining on the invertebrate communities and second, that areas such as upper Miller Creek, upper Mastodon Creek, and upper Bonanza Creek have been successfully recolonized after placer mining has ceased. Excluding Deadwood Creek, invertebrate densities in sites below mining were on the average only 19% of the densities above mining (table 8). Invertebrate densities in upper Deadwood Creek were the lowest of any of the sites (an average of 1.25 invertebrates/0.1 m^2). The gravels in this stream reach had been recently moved by a bulldozer, which probably accounted for the extremely low population levels. Because this disturbance occurred within the same season in which we sampled, there was not time for recolonization by adult forms of aquatic invertebrates to occur. Additionally, because this site was located near the headwaters of Deadwood Creek, there was little invertebrate habitat available to colonize downstream reaches.

Although invertebrate populations in previously mined sites are lower than populations in unmined sites, populations in previously mined sites appear to be successfully recovering from disturbance. The lowest densities occurred where disturbances had been most recent. For example, upper Porcupine Creek, mined two years previously, had densities of 24.8 invertebrates/0.1 m^2. In contrast, Miller Creek, mined about 60 years ago, had densities of 115.4 invertebrates/0.1 m^2. Recovery of the invertebrate populations appears to be related to the time since mining and to the conditions of the stream-bottom substrates. Stream-bottom substrates in upstream sites were less embedded in fine sediment and of higher quality for aquatic organisms than in sites below mining. The upstream sites are generally of higher gradient and, consequently, have higher water velocities than sites below mining. Higher current velocities in the upstream sites may be sufficient to remove many of the fine sediments deposited from placer mining.

There was also a significant interaction among streams sampled and between sites above and below mining. The interaction component can probably be attributed to the level of mining in the system and the resultant water quality and physical conditions. Sites in Mastodon, Deadwood and Bonanza creeks below mining had among the lowest invertebrate densities (8.2, 3.4, and 2.6 invertebrates/0.1 m^2, respectively, table 8) and the largest numbers of active placer mines. Turbidities at the time invertebrate samples were taken were 365 NTU, 1,400 NTU, and 2,800 NTU in downstream sites of Mastodon, Deadwood and Bonanza creeks, respectively (cf. ADNR 1985) An exception to the correlation of mining intensity, turbidity, and invertebrate densities occurred in lower Ketchem Creek, where the turbidity level was 3,250 NTU and the invertebrate density averaged 22 individuals/0.1 m^2. Ninety percent of the invertebrates found in Ketchem Creek were Chironomidae, a Diptera family that contains species highly tolerant to low oxygen and high sediment levels (Merritt and Cummins 1978).

Fish Distribution and Density

Each species of fish has specific environmental requirements necessary for it to survive and reproduce. In general, fish require food, cover, oxygen, compatible temperatures, and a place to spawn and incubate their eggs.

Salmon, grayling, whitefish, sculpin, and other species occurring in Alaska's streams and rivers feed primarily on insects and other invertebrates that fall into or live in the stream. Cover, or a hiding area, is needed by fish for protection from predators and from fast currents. Grayling use pools, backwater areas and undercut banks for cover; sculpin often hide under or behind stream-bottom cobble.

Grayling spawn in spring after breakup. The small eggs settle to the bottom, where they collect in the crevices of stream gravel. Rough stream-bottom substrates prevent eggs from being washed downstream. Sculpin eggs are deposited in nests on the underside of rocks or ledges. The adhesive eggs remian on the rock surfaces for about four weeks until they hatch.

Fish may be affected by loss of habitat through stream channelization and subsequent loss of cover, loss of suitable substrates resulting from deposition of fine sediments on the streambed and removal of stream gravels, and reduction in feeding because of diminished food supplies. Simmons (1984) placed grayling from another drainage in cages in both the clearwater North Fork and mined Birch creeks. After six days, he found that there were very few organisms present in the stomachs of grayling held in Birch Creek compared to the stomachs of grayling held in the North Fork. Simmons stated that this was probably due to either a lack of food organisms in Birch Creek or to reduced sight-feeding capabilities resulting from increased turbidities.

Simmons (1984) also found that grayling held in Birch Creek had fewer fat deposits around their internal organs and less parr mark development compared to caged grayling in North Fork. According to Simmons, the development of parr marks is a morphological and physiological process in juvenile salmonids that may be inhibited when nutritional requirements are not met.

Placer mining has greatly reduced the grayling and sculpin populations in the Birch Creek watershed; no fish were found in any of the streams that were actively placer mined. Fish were probably excluded from placer-mined streams for reasons discussed previously: loss of habitat, including cover; degraded substrate; poor water quality; limited opportunities for sight feeding; decreased food sources; and in some cases, obstruction of the channel. It is not known to what extent fish populations have been limited because the fish have avoided streams affected by mining or because increased sediment in the water has caused lethal effects to early life stages.

No fish were found in Bedrock Creek, Fish Creek, or Ptarmigan Creek, which are unmined. Only two grayling were collected from lower Boulder Creek, with a third grayling sighted.

The physical and chemical features of these unmined streams suggest that they contain habitat that is suitable for grayling and sculpin spawning and rearing. These streams contain large pools, undercut banks, and backwater areas. Stream gradient and water velocities were well within the range of suitability for both slimy sculpin and arctic grayling. The substrate contained ample medium-to-large cobble for sculpin to find shelter. Nothing about the water chemistry of any of these creeks suggests the exclusion of grayling or sculpin (cf. ADNR 1985).

Except for Ptarmigan Creek, none of the tributaries sampled on the west side of Eagle Summit had active or past placer mining; however, exploratory mining had occurred near these streams. North Fork, in particular, had been subjected to fairly extensive exploration. A small, primarily exploratory mining operation in Bates Creek contributed some sediment to Ptarmigan Creek. Birch Creek, the receiving water for these tributaries, had regions of extensive mining in the headwaters.

The absence of fish in unmined Bedrock, Boulder, Fish, and Ptarmigan creeks is probably due in part to the many kilometers of highly turbid water between the overwintering areas and the spawning and summer rearing areas (ADF&G pers. comm. 1985). Fish may avoid swimming through 100-150 kilometers of highly turbid water to reach spawning and summer rearing areas. Stream water in the upper reaches of Birch Creek is very turbid; a water sample collected in Birch Creek below the confluence with Ptarmigan Creek on September 6, 1984 had a turbidity level of 2100 NTU. A second sample collected on the same day above the confluence with Ptarmigan Creek had a turbidity level of 7000 NTU (cf. ADNR 1985)

Obstructions from in-channel mining in the receiving waters below Ptarmigan and Fish creeks also limit fish passage. The headwaters of Birch Creek have been extensively altered by placer mining and the construction of settling ponds that partially or totally obstruct fish passage.

Streams in the Birch Creek watershed have historically supported populations of grayling. A local resident in Central reported fishing in Miller and Mastodon creeks three years earlier, and miners operating on Porcupine and Bonanza creeks reported that grayling had inhabited these waters four years earlier "before all the miners moved into upper Bonanza Creek." Employees at the U.S. Bureau of Land Management summer fire camp at Central reported successful sportfishing for grayling in Crooked Creek near the BLM station until 1977. Miners, residents of Central, and other rural residents reported "good sportfishing success" for grayling in Ptarmigan Creek. These reports, combined with the results of our fish-sampling efforts, suggest that fish inhabitated these creeks but began avoiding the turbid, disturbed areas when mining became more prevalent.

Other investigators found that fish avoid turbid, placer-mined streams in preference for clearwater, undisturbed tributaries. Simmons (1984) found juvenile grayling in unmined McManus Creek and no grayling in mined Faith Creek. Morrow (1971) sampled both Faith and McManus creeks 12 years earlier, when only a very small one-person placer mine was operating intermittently in Faith Creek. At that time, there were high numbers of grayling in both Faith and McManus creeks.

CONCLUSIONS

Examination of the 1984 data from the Birch Creek placer studies showed that active placer mining resulted in (1) elimination of the riparian vegetation, (2) increased substrate embeddedness and a higher proportion of silt and sand deposited on the stream bottom below mining, (3) channel alteration that eliminated fish habitat, (4) depressed aquatic invertebrate populations that were an order of magnitude lower than in control streams, (5) elimination of essentially all fish from both mined streams and unmined streams above mining, and (6) degraded water quality.

Elimination of riparian vegetation is a relatively long-term effect. Revegetation of old tailings is sparse, even after 60 years. Rates of revegetation could be enhanced by stockpiling the overburden and replacing it on contoured tailings.

Increased embeddedness of stream-bottom substrates may be either a short-(one season of high flows) or long-term disturbance, depending upon flood regimes and whether or not the substrate is cemented. Previously mined areas upstream from active mining had substrates that were generally not embedded. Channel gradients in these upstream reaches were higher than at the valley bottoms, and high seasonal flows were probably sufficient to clean gravels. Sediment deposition in low gradient reaches below mining is probably a long-term effect. Water velocities in these low-gradient reaches are probably not sufficient to remove the sediments deposited on and alongside the streambed. Sediments deposited on and next to the streambed will constitute a long-term source of nonpoint pollution. Erosion from these areas may contribute sediments to the stream water for many years after mining has ceased. The deposition and subsequent erosion of fine sediments below mining can only be reduced by better control of settleable solids at the mine site.

Channel alteration, resulting from stripping the overburden, diverting the streams and channelizing flows, and removing stream gravels, eliminates fish habitat. The consequences of channel alteration are long-term and can be mitigated only by restoring the channel to its original condition.

Fish were essentially eliminated from all mined streams and from unmined streams located above active mining. The absence of fish was due to downstream physical- and water-quality conditions and to the lack of physical habitat in previously mined reaches. Repopulation rates after cessation of mining are not known.

Resident fish populations in interior Alaska are limited by the amounts of spawning and rearing habitat in the summer and the occurrence of free-flowing water in the winter. Available habitat for resident fish in the Birch Creek watershed will be reduced in direct proportion to the number of streams directly affected by placer mining and the number of streams affected by placer mining sedimentation.

Elimination of fish habitat is likely a long-term effect of mining. In watersheds with extensive mining, as the Birch Creek watershed, fish stocks can be preserved only if sediment discharges are controlled at the mine sites and if fish habitat is maintained or restored.

The placer mining studies in the Birch Creek watershed found that fish habitat was decreased or eliminated by (1) channelization that resulted in fewer channel meanders and decreased stream length, (2) lack of pools, undercut banks, overhanging vegetation, and other features that provide cover for fish, (3) unstable stream banks resulting from bank and channel disturbance and lack of riparian vegetation, (4) decreased suitability of the stream-bottom substrates for fish and invertebrate habitation, and (5) decreased food sources for the fish resulting from decreased invertebrate populations. Population sizes in specific streams may have been reduced because fish have avoided these streams. It is not known what levels of sediment are required to cause lethal effects to sac-fry, juvenile, or adult resident fish.

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APPENDIX 1
Detailed Descriptions of Study Streams

Streams inventoried in the Crooked Creek drainage were Mastodon, Miller, Independence, Mammoth, Porcupine, Bonanza, Boulder, Bedrock, Ketchem, and Deadwood creeks. The study sampled in the Birch Creek-Crooked Creek Drainage are described below and shown in figure 1. General features of each stream are summarized in tables 1 and 5.

The Circle Mining District consists of the area between latitude 65°15'N and 65°51'N and between longitude 143°53' W and 145°47' W. The northern part of the district contains wide, flat valleys extending to the Yukon Flats area. The southern part of the district contains a range of mountains consisting of Porcupine Dome (1,520 m elev.) and Mastodon Dome (1,220 m elev.). The predominant rocks in this region are known as the Birch Creek schists (Matthew 1940), consisting of recrystallized sedimentary rocks, which include quartzite, quartzite schist, quartz-mica schist, mica schist, feldspathic and chloritic schists, and minor amounts of carbonacerous and calcareous schists and chrystalline limestone. The Birch Creek schist and probably most of the meta-igneous rocks associated with it are believed to be pre-Cambrian age (Mertie 1936).

Climate

The climate of the Birch Creek watershed is subarctic continental, with long, cold winters, short, cool summers, and low precipitation (Furbush 1968). In the winter, the streams freeze to the bottom, except for the deeper areas of Crooked Creek and Birch Creek in the Birch Creek flats area. Muskegs, consisting of deep, poorly decomposed, and water-logged organic materials help to regulate streamflows through the partial retention of surface water. Thunderstorms are common during the summer, and frequent or long-lasting storm events significantly increase streamflows.

Fish Populations

The Birch Creek watershed contains populations of slimy sculpin (*Cottus cognatus*), arctic grayling (*Thymallus arcticus*), broad, humpback, and round whitefish (*Coregonus nasus*, *C. pidschian*, and *Prosopium cylindraceum*, respectively); northern pike (*Esox lucius*); burbot (*Lota lota*); and Dolly Varden (*Salvelinus malma*). Of these species, grayling and slimy sculpin are the most common. Char, pike, burbot, and whitefish occur primarily in the lower reaches of Crooked Creek and Birch Creek; however, burbot have been observed at the headwaters of Birch Creek (Simmons, pers. comm. 1985) and whitefish in the tributaries to upper Birch Creek. Sheefish (*Stenodus leucichthys*), chinook, coho, and chum salmon (*Oncorhynchus tshawytscha*, *O. kisutch*, and *O. keta*, respectively) occur in the lower reaches of Birch Creek.

Birch Creek is the receiving water for all of the streams previously described. The creek originates at the confluence of Porcupine and Mammoth creeks and flows about 19 km to the bridge at Central, then about 96 km to the confluence with Crooked Creek. The average stream gradient of Birch Creek is less than 1%.

Wide flood plains and dry flood channels are prevalent along Crooked Creek. Crooked Creek has been mined from its headwaters to the confluence of Boulder Creek.

The headwaters of Mastodon Creek are on the north side of Mastodon Dome at 1,340 m elevation. The creek flows 10.3 km through an asymmetric valley, with a steep wall on the east side. The average stream gradient is 3.5%.

At the mouth of Mastodon Creek, the valley floor is about 365 m wide, and about 3.2 km upstream the valley narrows to about 180 m. The bedrock on Mastodon Creek is primarily quartzite schist and mica schist (Matthew 1940).

Independence Creek also flows from the north side of Mastodon Dome, about 2.5 km east of Mastodon Creek. The creek flows through an asymmetric valley that is steeper on the northwest side. The valley floor is about 60 m wide, the average gradient is 2%, and the creek is about 9 km long. There was one active placer mine on Independence Creek in 1984; however, the area had been mined extensively in the past.

Miller Creek flows from the north side of Eagle Summit and joins Mammoth Creek below the confluence of Mastodon and Independence creeks. The Miller Creek valley is rather narrow and about 3% gradient. The creek length is about 9.3 km from headwaters to confluence. There was no active mining in Miller Creek during the time that the stream was inventoried; however, extensive placer mining had occurred in the past and there was some limited activity in the creek in 1984 prior to the field effort.

Mammoth Creek is a third-order tributary that flows north from the headwaters at the confluence of Mastodon and Independence creeks about 6.6 km until it joins with

Porcupine Creek to form Crooked Creek. Mammoth Creek flows through a wide, flat valley of about 2% gradient. Willow and other shrubs are prevalent along the streambanks.

Mining in Mammoth Creek is currently limited to the upper reaches; however, past mining had occurred over the entire length of Mammoth Creek.

Ketchem Creek flows from the southeast side of Ketchem Dome north about 4 km, where it joins Holdem Creek. The upper reaches of Ketchem Creek have a gradient of from 3 to 5%. At this point, the valley flattens to about 1% gradient, then enters Crooked Creek flats about 5 km below the confluence with Holdem Creek. The creek meanders through the flats, where it forms a multiple channel, then drains into Medicine Lake. A large part of the bedrock in the upper reaches (above the flats) is intrusive granite (Matthew 1940). Ketchem Creek has been mined extensively in the past. No mining has occurred in Ketchem Creek below where it enters the Crooked Creek flats.

The upper 16 km of Deadwood Creek flow through a narrow valley bounded on both sides by hills. The elevation of the headwaters is about 915 m. The lower 8 km of creek meanders through the Crooked Creek flats. The average stream gradient is 2%.

Mining has been active in Deadwood Creek since the beginning of the Circle Mining District. The creek was worked by drift and hydraulic mining in the early years. In 1938, a dredge was built on the lower part of Deadwood Creek. The dredge was moved out of the district before 1940. Present mining activity on Deadwood Creek is extensive above the Crooked Creek flats.

Porcupine Creek flows from a valley to the north of Porcupine Dome at 915 m elevation. The upper reaches of the creek flow through a narrow valley of about 3% gradient for about 7.2 km, where it joins Yankee Creek. At this point, Porcupine Creek flattens slightly to about 2% gradient, and the valley begins to widen. Bonanza Creek joins Porcupine Creek about 16 km below its headwaters. The Porcupine Creek valley is very wide and flat near the confluence with Bonanza Creek. Porcupine Creek continues flowing to the east about 9 km, where it joins Mammoth Creek to form Crooked Creek. Porcupine Creek has previously been mined almost to the headwaters.

Bonanza Creek flows northeast from the confluence of Grogon Gulch and Caribou Gulch at 730 m elevation, about 9.6 km to the confluence with Porcupine Creek. The creek flows through a rather narrow valley where stream gradient is about 2%. In 1984, active mining extended upstream to the confluence with Rebel Creek; placer mining has occurred previously to the headwaters of Bonanza Creek.

Bedrock Creek has the highest gradient of any of the streams inventoried. The upper reaches above the Steese Highway are about 5% gradient; then the lower 2 km of stream flattens to about 2% gradient. A falls about 1.5 m high, located below the highway, is an apparent barrier to fish passage. Flows in lower Bedrock Creek appear to be highly variable, as evidenced by the extensive network of flood channels, transitory gravel bars, and undercut banks. Bedrock Creek has not been mined, although there are mining claims on the upper reaches. In 1984, there was some exploratory work conducted above the Steese Highway. This work did not appear to significantly affect the water quality of the creek.

The headwaters of Boulder Creek is located above Greenhorn Gulch, at about 760 m elevation. The creek flows northeast about 53 km to the Steese Highway. Boulder Creek flows into Crooked Creek about 1 km below the highway.

Mining activity in Boulder Creek has been confined to the upper reaches near Greenhorn Gulch. Present activity along the creek is limited to exploration. Greenhorn Gulch has been mined extensively in the past, and abandoned tailings are prevalent along both Greenhorn Gulch and upper Boulder Creek.

Flows in lower Boulder Creek are highly variable over the summer. The creek ranges from a turbulent, fast-flowing creek to a slow, shallow waterway with water only a few cm deep over the wider riffles.

Streams inventoried on the west side of Eagle Summit were Ptarmigan, Fish, Bear, and Twelvemile creeks and the North Fork of Birch Creek. All of these creeks flow into Birch Creek, except the North Fork, which flows into Twelvemile Creek about 2 km above Birch Creek.

Present and past placer mining in these tributaries is very limited. Ptarmigan Creek was unmined until August 1983. In 1984, there was limited exploration and mining on Bates Creek, a tributary to Ptarmigan. The other creeks have had some exploratory test pits, which have not shown a profitable amount of gold.

Birch Creek, below the confluence with Twelvemile Creek, is classified as a National Wild and Scenic River under the

Alaska National Interest Lands Conservation Act for approximately 256 km until it passes under the Steese Highway at Milepost 146.

APPENDIX 2

Specific Locations of Study Sites, Including Legal Descriptions

*	Stream	Site Description	Legal Description
1	Crooked Creek	Ca. 100 m above Steese Hwy bridge at town of Central	SW¼SE¼, Sec. 27, T9N, R14E, FM
2	Ketchem Creek	Above mining and above confluence with Holdem CK	SE¼NE¼, Sec. 1, T7N, R14E, FM
3	Ketchem Creek	Below mining at campground, ca. 150 m above Circle Hot Springs Road	SE¼NE¼, Sec. 20, T8N, R15E, FM
4	Deadwood Creek	Above all active mining between 25 Pup and 43 Pup	SW¼SE¼, Sec. 14, T7N, R13E, FM
5	Deadwood Creek	Below all mining, ca. 100 m above Circle Hot Springs Road	NE¼NE¼, Sec. 12, T8N, R14E, FM
6	Boulder Creek	Below confluence with Greenhorn Gulch	NW¼NW¼, Sec. 3, T7N, R13E, FM
7	Boulder Creek	Ca. 100 m below Steese Hwy	SW¼SW¼, Sec. 29, T9N, R14E, FM
8	Bedrock Creek	At the campground at site of USGS crest stage gauges	SW¼SW¼, Sec. 32, T9N, R13E, FM
9	Mammoth Creek	Directly below bridge at Steese Hwy	SE¼ NE¼, Sec. 6, T8N, R13E, FM
10	Independence Creek	Above Russell mine site	NW¼SE¼, Sec. 26, T8N, R12E, FM
11	Independence Creek	Below Russell mine site, below active mining	NE¼NW¼, Sec. 26, T8N, R12E, FM
12	Mastadon Creek	Just upstream of confluence of Baker Gulch	SW¼NW¼, Sec. 4, T7N, R12E, FM

*	Stream	Site Description	Legal Description
13	Mastadon Creek	Below all active mining	SW¼NW¼, Sec. 27, T8N, R12E, FM
14	Miller Creek	Above recent mining, below confluence of Miller Pup	SW¼SW¼, Sec. 16, T8N, R12E, FM
15	Miller Creek	Near mouth of Miller Creek	SW¼NW¼, Sec. 14, T8N, R12E, FM
16	Bonanza Creek	Above Rebel Creek and above active mining	N½SW¼, Sec. 13, T8N, R11E, FM
17	Bonanza Creek	Ca. 200 m above road crossing	E½NW¼, Sec. 5, T8N, R12E, FM
18	Porcupine Creek	Ca. 2 km above confluence with Yankee Creek and above active mining	SW¼SE¼, Sec. 5, T8N, R11E, FM
19	Porcupine Creek	Just upstream of road crossing	SE¼SW¼, Sec. 13, T9N, R12E, FM
20	Ptarmigan Creek	Above bridge over Steese Hwy, below confluence of Bates Creek	NW¼SW¼, Sec. 9, T7N, R11E, FM
21	Fish Creek	Ca. 150 m above Steese Hwy	NE¼NW¼, Sec. 19, T7N, R11E, FM
22	Bear Creek	Ca. 150 m above Steese Hwy	NW¼NW¼, Sec. 26, T7N, R10E, FM
23	Twelvemile Creek	Below Steese Hwy at milepost 88.5	NW¼NW¼, Sec. 27, T7N, R9E, FM
24	Twelvemile Creek	Above the confluence of North Fork Twelvemile Creek	N½NW¼, Sec. 32, T7N, R10E, FM
25	North Fork of Twelvemile Creek	In stream reach with single channel	W½SW¼, Sec. 8, T7N, R10E, FM
26	North Fork of Twelvemile Creek	Ca. 100 m below Steese Hwy	SE¼SW¼, Sec. 29, T7N, R10E, FM

* Numbers are map sites, which appear on figure 1.

APPENDIX 3

Scale for Bottom Substrate Particle Size (Platts et al. 1983)

Sediment Classification	Size, mm
large boulder	>610
small boulder	305 - 609
cobble	76.1 to 304
gravel	4.8 - 76
coarse sediment	0.83 - 4.79
fine sediment	<0.83

APPENDIX 4

Maximum Liklihood Model for Fish Population Estimates (Platts et al. 1983, Zippin 1958)

$$T = \sum_{i=1}^{K} U_i \quad (T = U_1 + U_2 + \ldots + U_K)$$

where T = total number of fish collected
U = number of fish collected in i removal
k = number of removals, or passes

$$R = \frac{\sum_{i=1}^{K} (i-1) U_i}{T}$$

where R = the ratio of fish collected in each pass

$\hat{Q}$ is determined from figure 8 for specific values of R.

$\hat{Q}$ = the proportion of fish captured during all removals.

$$\hat{N} = \frac{T}{\hat{Q}}$$

where $\hat{N}$ = the population estimate.

Confidence intervals for the population estimates are calculated from the formula for the standard error of N:

$$SE(\hat{N}) = \frac{\hat{N}(\hat{N} - T)T}{T^2 - \hat{N}(\hat{N} - T)\ \frac{(k\hat{P})^2}{1 - \hat{P}}}$$

Where:

$\hat{P}$ = the estimated probability of capture during a single removal and is obtained from the graph in figure 9 for specific values of R.

FIGURE 8

ESTIMATED $\hat{Q}$

ESTIMATED PROPORTION OF FISH CAUGHT DURING ALL REMOVALS (ZIPPIN 1958)

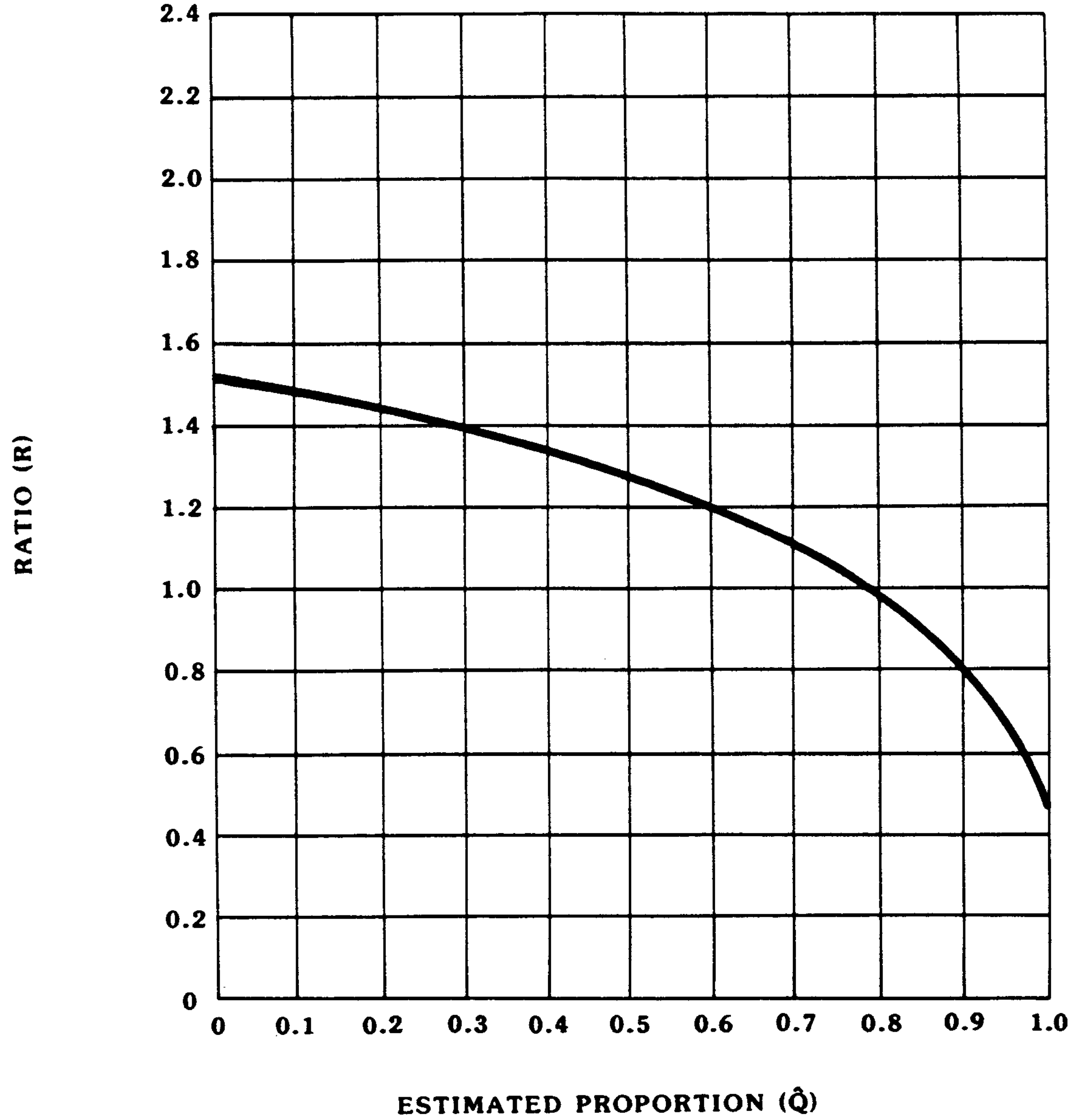
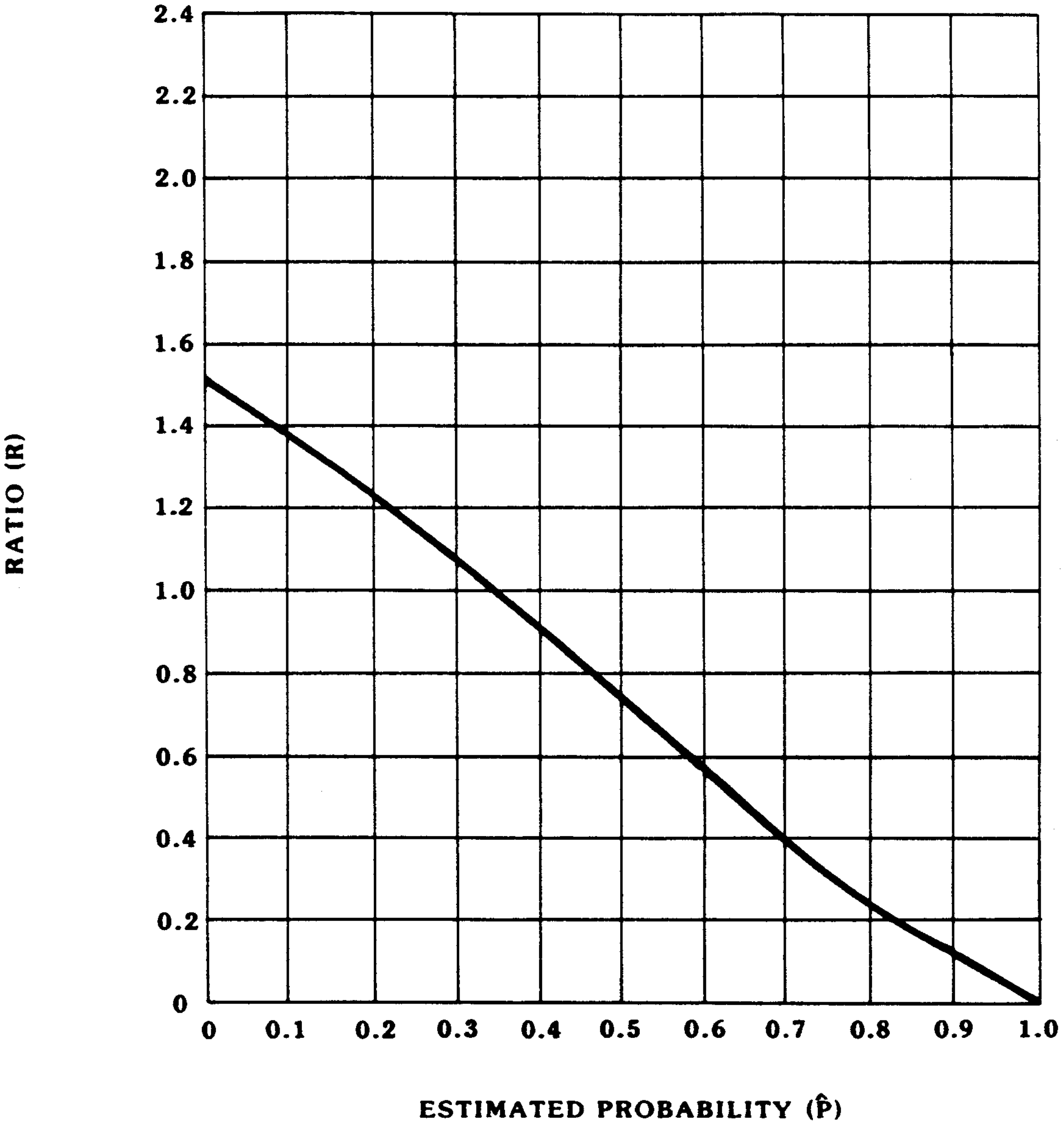


FIGURE 9

ESTIMATED $\hat{P}$

ESTIMATED PROBABILITY OF CAPTURE DURING A SINGLE REMOVAL (ZIPPIN 1958)



APPENDIX 5

Invertebrate Taxonomic Groups
Birch Creek Watershed, 1984

- Ephemeroptera
  - Heptagenidae
    - *Cinygmula*
    - *Epeorus*
  - Ephemerelidae
    - *Ephemerella*
  - Baetidae
    - *Baetis*
  - Siphlonuridae
    - *Ameletus*

- Plecoptera
  - Nemouridae
  - Capniidae
  - Chloroperlidae
    - *Alloperla*

- Trichoptera
  - Rhyacopholidae
    - *Rhyacophila*
  - Glossosomatidae
    - *Glossosoma*
  - Limnephilidae
    - *Limnephilus*
    - *Dicosmoecus*
    - *Ecclisomyia*

- Diptera
  - Tipulidae
    - *Tipula*
    - *Dicronota*
  - Chironomidae
  - Simuliidae
    - *Prosimullium*
    - *Simullium*
  - Empididae
  - Psychodidae

Other semiaquatic or terresterial groups:

- Coleoptera
  - Staphylinidae
- Thysanoptera
- Collombola
  - Sminthuridae
  - Hypogastriridae (Poduridae)

Isotomidae
Amphipoda
    Hyalella azteca
Oligichaeta

APPENDIX 6

Fish Collected in Birch Creek Watershed

Stream	Date	Technique	Sample	Species	Forklength, mm
Bear, DS	8-15-84	MT	(1)	GR	114
	8-17-84	EF	(1)	GR	105, 123, 129, 152, 264
			(2)	GR	114, 132, 140, 153, 186
			(3)	GR	119, 131
Boulder, DS	8-26-84	EF	(1)	GR	185, 195
			(2)		0
			(3)		0
North Fork, DS	8-15-84	MT	(1)	SS	82
			(2)	SS	111, 115, 115, 118
	8-16-84	EF	(1)	GR	111
			(1)	SS	29, 35, 40, 51, 63, 65, 65, 66, 70, 73, 105, 105, 115, 118
			(2)	SS	32, 37, 38, 32, 39, 35, 39, 39, 40, 44, 40, 44, 45, 56, 60, 64, 67, 73, 74, 81, 57
			(3)	SS	35, 33, 36, 34, 38, 42, 45, 53, 40, 44, 57, 63, 65, 62, 70, 71, 77, 115
			(4)	SS	35, 36, 37, 40, 44, 40, 44, 41, 59, 59, 67, 66, 76, 73, 75, 104, 116, 36
				GR	114
North Fork, US	8-29-84	EF	(1)	GR	120, 143, 157, 230
				SS	57, 61, 92, 92, 94, 95, 95, 99
Twelvemile, US	8-14-84	MT	(1)	SS	104
			(2)	SS	110
	8-16-84	EF	(1)	GR	126
				SS	67, 97, 100, 96, 98, 74, 52
				RWF	280
			(2)	GR	134, 147, 161
				SS	53, 55, 49
			(3)	GR	136
				SS	88, 108

Stream	Date	Technique	Sample	Species	Size in mm
Twelvemile, DS	8-16-84	MT	(1)	SS	52
	8-16-84	EF	(1)	SS	29, 30, 34, 47, 59, 60
			(2)	SS	30, 32, 33, 52, 56, 65, 69
			(3)	SS	24, 33, 55, 58, 62, 62, 69

* numbers in parenthesis are either the pass with the electrofisher or the number of the minnow trap.

SS = slimy sculpin, GR = arctic grayling, RWF = round white fish
US = upstream, DS = downstream
MT = minnow trap
EF - electrofisher