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Changes in the benthic community of Lake Creek Mt. resulting from mine tailings contamination

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CHANGES IN THE BENTHIC COMMUNITY OF LAKE CREEK, MT. RESULTING FROM MINE TAILINGS CONTAMINATION

By

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Changes in the benthic community of Lake Creek, Mt. resulting from mine tailings contamination.

Director: Vicki Watson

The benthos of Lake Creek, Lincoln Co., Mt. were sampled in 1984-85 to determine the effects of a 2.5 years old tailings impoundment adjacent to the stream. Sampling results were compared spatially in the 1984-85 data set, and temporally with a baseline data set collected three years prior to installation of the impoundment. Lack of replication in the baseline sampling design precluded the use of two-way ANOVA for analysis of temporal changes. Therefore temporal comparisons were made on the basis of changes downstream of the impoundment relative to changes upstream, as measured over time. Spatial comparisons upstream and downstream were made by one-way ANOVA.

Determination of the effects of the tailings impoundment was confounded by a tailings spill that directly contaminated the downstream stations. The spill was assumed to have had a far larger biological effect than the tailings impoundment itself. Simuliidae and Rhithrogena spp. increased in abundance after the spill, the former responded as an opportunist, the later was a coincidental benefactor since it was in the adult stage during the spill.

The before and after data sets were collected with different sampling gear and had unequal replicate samples within plots. The gradient effect of Bull Lake on Lake Creek was also a concern. These concerns were minimized by utilizing a methodology that analyzed the change in the relationship between control and impact areas over time.

Of 16 taxa analyzed, 10 decreased, two increased, and four showed no significant change in abundance in the impact area relative to the control from 1977-78 to 1984-85. Spatial comparisons above and below the impoundment in 1984-85 showed eight taxa significantly more abundant in the upstream area, five with comparable abundances, and three with greater abundances downstream. The significance of these biotic changes is discussed.

ACKNOWLEDGMENTS

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Finally, I thank my wife, Anita, for her support and perseverance, and my children, Robin, Elizabeth, and Warren, who have never known a time when their father was not a student.

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INTRODUCTION

Since the passage of the National Environmental Policy Act in 1969, there has been much progress in our efforts to predict the environmental consequences of developmental actions. Lagging behind has been work on monitoring the environmental changes that follow developmental actions, and on evaluating the accuracy of our impact predictions. Rosenberg et al. (1986), state that scientifically based environmental impact assessments necessarily include a monitoring and assessment phase, but few examples exist. Schindler (1987, p.7), in an address to the Society of Canadian Limnologists, said, "It is time to develop programs to detect early stages of ecosystem degradation...".

The purpose of this study was to investigate the possibility of biological change in Lake Creek, Lincoln County, Montana, resulting from the storage of mine wastes in a 400 acre (162 hectare) area of the riparian zone of Lake Creek. The method used was quantification of macroinvertebrate densities at two control stations upstream of the tailings impoundment and at two treatment stations downstream of it. The stations were compared spatially and temporally, with samples collected before mining began.

The objectives of this research were: 1) to test the hypothesis that the mean number of macroinvertebrates present before mining activity was the same as the mean number present during mining activity, and that the mean number of macroinvertebrates upstream of the tailings impoundment during mining equaled the mean number downstream of the impoundment during mining, 2) to investigate the causes of any measured changes in macroinvertebrate numbers, and 3) to evaluate the accuracy of the Troy Project Asarco Inc. Environmental Impact Statement for predicting biotic changes.

Construction of the Asarco Troy Project began in March 1979 and operation of the facility began in late 1981. The mill is designed to concentrate raw ore to acceptable ratios of mineral and waste through a process of grinding and bulk flotation. The objective is physical separation of waste materials from desired minerals, a process not requiring any chemical or pyrometalurgical alteration. Two stages of crushing and one of grinding reduce the ore to a consistency of fine granular sugar. The ground ore is then introduced into flotation cells where the minerals become coated and attached to air bubbles. Pine oil is the frothing agent used to promote bubble formation. Potassium amyl xanthate is used to coat the mineral particles. The minerals are collected from the surface, dried, and trucked out for shipment by rail to the smelter. The material remaining in the flotation cell is piped to a tailings thickener, where excess water is removed, and then the resultant slurry flows by gravity through a pipeline 9.5 km to the tailings impoundment area (Fig.1).

My first macroinvertebrate collections were in April 1984, two and a half years after tailings were first pumped to the impoundment facility near Lake Creek.

Contamination of Lake Creek by tailings has occurred as spills resulting from pipeline ruptures, and possibly as overland flow from toe ponds bordering the tailings impoundment. A spill occurred in 1981 which discharged into Stanley Creek, a tributary to Lake Creek.

This spill is assumed to have contaminated the Lake Creek control stations to some degree. Another large spill occurred in June 1984 between the April and July macroinvertebrate sampling dates.

Biological monitoring, as an approach to evaluate impacts to aquatic systems, has been done at all levels of taxonomic organization, from bacteria (Bott 1973) to fish (Hocutt and Stauffer 1980). Chemical monitoring is useful in determining specific contaminants, but is only indirectly useful in revealing the nature of biological responses to contamination. Since chemical analyses only take a "snap shot" in time, they are not likely to include pulse events such as those that occurred in 1981 and 1984. The assemblage of organisms present in an aquatic system is a reflection of the sum of conditions occurring prior to sampling. Macroinvertebrates were chosen as biological monitors in Lake Creek since they: 1) are a diverse group providing a wide range of tolerances and sensitivities, 2) they have limited mobility and capacity to escape aversive conditions, and 3) they have a longevity adequate to integrate the preceding conditions comprising a relevant time frame of up to a year or more.

The method of biological monitoring used in this study is but one of many. No method is universally accepted, and new ones are frequently proposed. Most are basically measures of community structure. The number of species in an assemblage and their relative abundance provide insight into such concerns as the number of niches utilized, the pathways of energy through the system, as well as the stability and resilience (Westman 1978) of the system. Early monitoring consisted of listing all species found in an assemblage. Some investigators ignored the total assemblage and successfully monitored disturbances by keying their efforts on single species, known as indicator species. The first paper on this subject was published by Kolkwitz and Marsson (1908) and addressed the association of algae with certain water quality types. Diversity indices seem to have attracted the most attention, probably because diversity is an intriguing concept, and indices provide encapsulated numbers for easy comparison. Diversity indices were originally thought to be capable of identifying polluted conditions simply through a comparison of the calculated diversity value with a reference scale of values ranging from 1, signifying heavily polluted water, to greater than 3 in clean water (Wilhm and Dorris 1968).

Diversity indices were not utilized in this study for the following reasons: 1) there is no basis in nature for the suggestion that collections of organisms are arranged in linear order along a diversity scale (Hurlbert 1971), 2) indices ignore both taxonomic composition of communities and the environmental adaptations and responses of aquatic invertebrates (Godfrey 1978), 3) indices are not universally applicable (Moore 1979), 4) diversity changes with season and time (Green 1979), and 5) the two components of diversity indices, species number and equitability, often vary independently (Green 1979).

A few of the numerous other means of analyzing community structure are with species richness (Sheehan, 1984), Biotic Score (Chandler 1970), trophic organization (Osborne et al. 1979), and statistical methods such as ordination and numerical classification (Gray et al. 1980).

DESCRIPTION OF STUDY AREA

Lake Creek is tributary to the Kootenai River, which it joins about 1 km from the town of Troy in the northwestern corner of Montana. The stream is 27.8 km long as measured from its outflow at Bull Lake (708 m elevation), to the Kootenai River (570 m). About 2 km from the mouth of the stream is a privately operated dam that impounds the stream for 1 km. The average gradient over the total distance is five percent. The distance from Bull Lake to the artificial impoundment is more representative of the stream reach studied, and its gradient is 3.2 percent. According to Ganser (1981), Lake Creek has a sinuosity, or stream to valley length, of 1.4 to 1, an average width of 18 m, and a pool/riffle ratio of 0.9/1.

While Lake Creek begins as the outflow of Bull Lake, the complete drainage basin includes Bull Lake and its source, Ross Creek. The total basin area is 544 sq.km. The highest points in the drainage are Sawtooth Mtn. (6763 ft.) on the west, and Sugarloaf Mtn. (7568 ft.) on the east side of the drainage.

Annual precipitation averages 63.5 cm in Troy, Mt. Projections show Bull Lake receiving 89 cm, and the ridges of the Lake Creek basin averaging up to 229 cm (USDA-SCS

1977). In PreCambrian times the Lake Creek area was contained within the shallow Belt Basin, which explains the predominance of metasedimentary Belt rocks such as quartzite, siltite, and argillite in the basin. The entire Lake Creek valley bottom was covered by the Cordilleran ice sheet which retreated about 10,000 years ago. A major remnant feature of the glaciation is morainal Bull Lake (Kuennan and Gerhardt 1984).

Riparian vegetation is mixed conifer and deciduous types such as hemlock, cedar, Douglas Fir, cottonwood, birch, and alder.

Land use in the drainage is predominantly for timber production, by both Champion International Corporation and the U.S. Forest Service. About one fifth of the drainage is allocated by the U.S. Forest Service to primitive recreation or wilderness. Other uses are mining, grazing, and residential housing. The entire riparian zone is in private ownership, by both individuals and corporations. Private ownership comprises about 15 percent of the drainage, with the remaining acreage held by the U.S. Forest Service.

Lake Creek water is a calcium-bicarbonate type. Typically, oxygen content is high, while turbidity and organic matter content are low. The soft waters of Lake Creek are characterized by low concentrations of dissolved minerals, metals, and nutrients. Alkalinity measurements range from 10 to 50 mg/l CaCO (Mt. Dept. State Lands 1978).

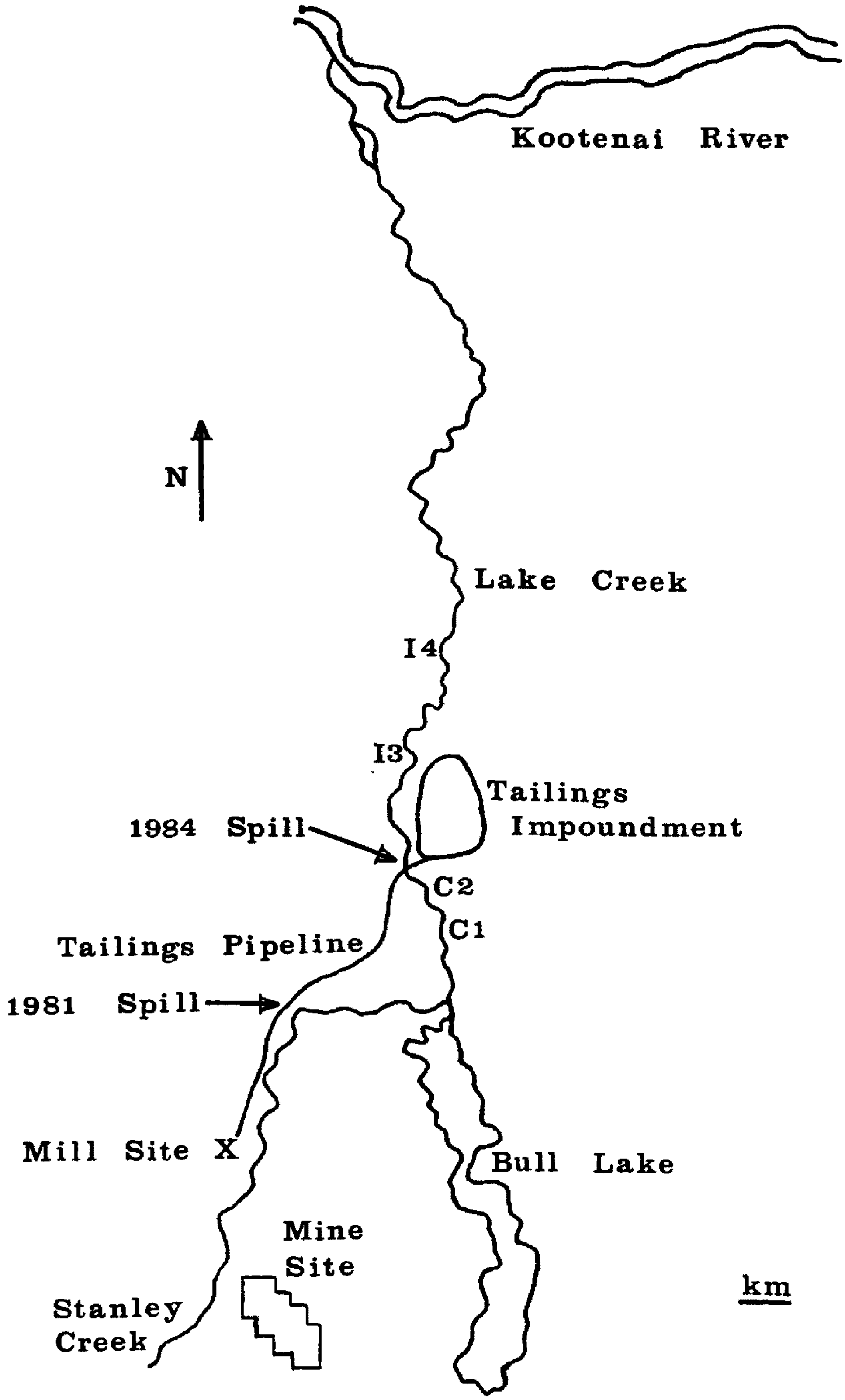

Figure 1. Lake Creek drainage and pertinent features.

METHODS

Study Design

This study was designed as a natural (Allan 1984), or a mensurative (Hurlbert 1984) experiment. No manipulation of the stream environment was employed by the investigator, rather, sampling was designed to test the effects of an external intervention, represented by a mine and waste tailing impoundment located adjacent to the stream.

Natural experiments in lotic systems present serious impediments to proper design. The simple fact that pollutants entering a stream are transported in a single direction precludes one from randomly assigning treatments to experimental units. Hurlbert (1984) calls this a violation of proper experimental design. He argues that it cannot be corrected, and that designs using it are uncontrolled and therefore can only detect significant differences between locations, not significant effects of the discharge.

If this were an ideal field experiment, it could provide answers to the following questions. First, did populations change downstream of the impoundment after mining began? With knowledge of downstream abundances before mining and downstream abundances after mining began, population change can be demonstrated. The only limitation is sampling error caused by within site variability. And second, is a demonstrated population change due to the tailing impoundment or would it have occurred anyway? Comparison of before and after differences downstream of the impoundment with before and after differences upstream provides strong evidence for cause but is not absolute proof. Some uncertainty exists concerning whether or not the direction and degree of change in the control area can be assumed to represent what would have also occurred in the impact area in the absence of the tailings impoundment. The statistical solution is an extreme measure requiring that the stream system itself be replicated. Random treatment of half the replicate streams with tailings would allow a comparison of both treated and untreated impact areas before and after treatment. This solution is rejected due to its obvious impracticality, and the control area is accepted as a reasonable indicator of the direction and degree of change that would have occurred in the impact area in the absence of the impoundment. Some uncertainty in conclusions must be accepted in the interests of practicality.

Data Collection

Benthic samples were collected in Lake Creek on the following dates : April 21, 25, and 26, 1984, July 20 and 21, 1984, October 19, 20, 21, and 22, 1984, February 11, 13, and 14, 1985 and July 20 and 21, 1985. These dates were chosen because they duplicated those used by the Montana Department of State Lands in 1977-78 when collecting the baseline data for the Troy Project Asarco Inc. Environmental Impact Statement. Duplication was necessary in order to make comparisons over time, before and after mine development. The dates were chosen to ensure that sampling encompassed the various stages of macroinvertebrate abundance that occur throughout an annual cycle.

Samples were collected with a homemade modified Hess-type sampler that enclosed 1 square foot (0.09 sq. m) of substrate. The sampler was made of 1.5 mm thick galvanized sheet metal formed into a cylinder measuring 34.39 cm inside diameter. Two mesh covered openings measuring 15 x 20 cm faced upstream allowing current to enter the cylinder. Two like-sized openings on the downstream side of the cylinder allowed through passage of the current, and were covered by a 1000 micron capture net with dimensions of 23 x 38 x 71 cm. The Hess-type sampler enclosed the same area of substrate, and utilized the same mesh size as the

Surber sampler used for the baseline sampling.

To collect samples the sampler was forced into the substrate a minimum of 6 cm. To maintain a close seal with the substrate while sampling, the sampler was held down by the investigator's feet through loops hanging from handles at the top of the sampler. This procedure was meant to minimize insect escapement beneath the sampler. All large rocks enclosed by the sampler were thoroughly brushed and washed in the sampler allowing any attached organisms to wash into the capture net. The remaining finer substrate was then stirred for a minimum of one minute allowing those remaining organisms to wash into the capture net. The contents of the capture net were poured into a holding tray (76 x 50 x 10 cm). The net was then washed and picked with tweezers to remove any clinging organisms. The contents of the tray were filtered from the holding water and preserved in formalin.

A surber sampler, rather than the Hess-type sampler, was used in the baseline study. This difference presents problems with numeric comparisons between periods. The modified Hess sampler used in the 1984-85 collections seals more effectively to the stream bed reducing escapement of insects, and may also collect more of the insects located within the gravel. The improved efficiency suggests an increase in numbers in the 1984-85 collection period that is unrelated to an impact. This increase should be expressed uniformly at both control and impact stations and therefore should not affect the analysis of relative changes in abundance over time.

Macroinvertebrates were picked from the detritus in the lab with the aid of a miniature homemade "sluice-box". The purpose of the box was to allow systematic inspection of the sample by moving the material "particle by particle" from left to right in a conveyer-belt type fashion. Most taxa were identified to the generic level using a dissecting microscope. Species level identification was obtained for taxa in which published keys were available. Simuliids and chironomids were identified only to the family level. All individuals, except for subsamples of simuliids and chironomids, were measured for total length, from head to end of abdomen.

Data Analysis

Two data sets comprise the information used in this study. The first set consists of a series of five replicate samples taken at two sites (one above and one below the proposed tailing impoundment) on four different dates. The samples were collected by the Montana Department of State Lands in April, July, and October 1977, and February 1978, three years prior to the mining activity. The second data set was collected on the same dates as the first set, but in the years 1984 and 1985, two and one half years after mine operations began. Collection of the second data set comprised the fieldwork for this study. Modifications from the baseline design were 1) the inclusion of two additional sampling sites (one above and one below the tailing impoundment), 2) the collection of eight replicates per site rather than five, and 3) the collection of the July series of samples for one additional year (1985).

The two data sets were analyzed for spatial differences (above and below the impoundment), and for temporal differences (before and after mining).

"Before Mining" Data Set

Baseline data were collected at one site upstream and one downstream of the proposed tailing impoundment. No significant tributaries enter Lake Creek between these locations, and the sites were assumed to be similar. In order to test their biological similarity, replication of sites is required since it provides a comparison of error variance and location variance. Therefore the baseline data set is "pseudo-replicated", and the null hypothesis actually being tested is "no difference between sites" rather than "no difference between upstream and downstream areas" (Hurlbert 1984). Given that the baseline experiment was uncontrolled, no attempt was made to demonstrate spatial differences between the upstream and downstream sites.

"After Mining" Data Set

"After mining" data were collected at two sites upstream and two downstream of the tailing impoundment to ensure control that was lacking in the baseline data set. Contrary to classic experimental design, treatments were not allocated randomly. Rather, treatments were necessarily downstream of the impoundment. Also, specific sites were subjectively chosen from the very few riffles located reasonably near the impoundment. According to Stewart-Oaten et al. (1986), nonrandomized experiments are acceptable for detection of environmental impacts since the objective is to answer specific questions (differences in locations in Lake Creek) rather than general ones (differences in the population of all locations). One-way analysis of variance is therefore an appropriate statistical procedure, and the "after mining" data set was analyzed in the manner of Green's (1979) "main sequence 4" in which impact is inferred from spatial pattern alone.

A prerequisite to the use of statistics is knowledge of the type of probability distribution to which the data most accurately conform. The easiest way to determine probability distributions is graphically. Abundances per sample of the eight most common taxa, and the total abundance per sample, were plotted in histograms, and curves were drawn to approximate the patterns of distribution. Most curves were skewed to the right, indicating lognormal distributions. To confirm the assumption that the data are distributed lognormally, they were plotted on lognormal probability paper and a curve visually fit to the points (Armour et al 1983). Straight lines generally fit the data which strongly suggested lognormal distributions. A pre-condition for the use of analysis of variance is that the sample variances be equal. Cochran's C, Bartlett-Box F, and the maximum variance/minimum variance tests were all employed using SPSS/PC+ (1987) to test the null hypothesis that $\sigma 1 = \sigma 2 = \sigma 3 = \sigma 4$. For each taxa analyzed, a regression was run to determine the dependence of the variance on the mean. Log (abundance + 1) and fourth root transformations (Downing 1981) were chosen for each taxon based on which transformation most effectively stabilized the variance. Analysis of variance was run on SPSS/PC+ (1987) for mean abundances of 16 different taxa on five dates at all four sites. When F - values obtained were significant at the five percent level, the Student-Neumann-Keuls test was used to determine which of all possible pairs of means were different.

Since the log transformation of the data did not always clearly depict normal distributions, data were also analyzed by the Kruskall-Wallis nonparametric test.

Comparison of "Before and After mining" data sets

The strongest test to determine changes resulting from mining must incorporate abundances prior to mining. Conventionally, impact effects have been determined by a significant interaction of site and time using two - way analysis of variance, characterized by Green (1979) as the "optimal" design. Comparison of after abundances with before abundances is not statistically valid in this study since the "before mining" data set lacks replication.

While the baseline data is unreplicated in space, it is replicated in time (on four different dates), and the use of these dates as replicates provides an alternative to Green's "optimal" design (Stewart-Oaten et al. 1986). Justification for this change in conventional design involves a re-identification of the population and parameters in question. It is the long term population level, not the population on a particular date, that is relevant to impact assessment. The long term population, called the process mean, by Stewart-Oaten et al. (1986)

varies in an orderly and predictable fashion over time. The actual population, that measured at a point in time, varies in a less orderly and predictable fashion around the process mean. Samples collected on a particular date can only estimate the actual population present on that date. Estimates of the actual population, repeated over time, provide an estimate of the process mean. Requirements of this procedure are: 1) control and impact sites must be sampled simultaneously, 2)there must be no reset of the process mean, and 3)the process means of impact and control sites must not change relative to each other during the study period. When the difference between the process means is constant, the effects of time and location on abundance are additive. If abundances at one site naturally vary much more severely than at the other site, the difference between the process means is multiplicative. Accordingly, when populations of both sites are abundant, differences between sites are greater than when both populations are low. Transformations of counts corrects this problem of scale. Tukey's (1949) "one degree of freedom" test for nonadditivity was applied to determine the success of the log transformation. Following the procedure of Stewart-Oaten et al. (1986), the before and after periods were compared with a t test. Before and after periods were each represented by a single number, which is the average over four dates of the difference in abundance between impact and control stations. A statistically significant result ($\alpha = 0.05$) was interpreted as being due to a stress present in the downstream area and not the control.

RESULTS AND DISCUSSION

The 1984-85 collections were identified to family, genus, or species when possible, and comprised taxa. Sixteen taxa were chosen for analysis of changes in abundance in Lake Creek in relation to tailings contamination. The basis for selection was that the taxa be present in sufficient numbers to allow valid statistical analysis. Transformations were performed on abundances of all taxa since their distributions were nonnormal and their variances dependent on the means. According to Andersen (1965), data transformations cannot eliminate the dependence of the variance on the mean if the mean number of organisms per sample is less than three.

The format of this section is to divide the analysis of each taxon into five parts. In the first part, mean abundances and general characteristics are described from the raw data.

Second, an explanation is given for the choice of transformations used on that particular data set. The log (abundance + 1) and the fourth root transformations were tested. The r^2 values, which indicate the extent to which the variance is dependent on the mean, are reported to clarify the choice of transformations.

Third, specific changes over time are addressed. The baseline study utilized only one control and one impact station, and sampled each four times in a year. The impact study design utilized two control and two impact stations, and sampled them on the same four dates as in the baseline study. The differences in the two designs preclude the use of analysis of variance (ANOVA), so the procedure of Stewart-Oaten et al. (1986) as described in the Methods section, was followed. The written description of the procedure is very difficult to follow. To summarize, the differences between the control and impact sites are computed for each date in the 1977-78 baseline period, and for each date in the 1984-85 post-impact period. The differences are averaged for each of the two periods, and the significance of the difference between the mean of the Before differences and the mean of the After differences is determined with a t test. For simplicity sake, this procedure will be referred to as the difference between the before and after periods. The significance of the differences between before and after periods is given as a t value in which there are three degrees of freedom since four dates are used in the test. At the 95% level of confidence t = 2.447. Significant t values support a rejection of the null hypothesis that the mean difference between control and impact sites in 1977-78 is equal to the mean difference in 1984-85.

Fourth, the results of the one-way ANOVA applied to the data set collected after mining began are described. The significance of these results is determined by F values and described in terms of significantly different groups. Significant differences between control and impact stations support a rejection of the null hypothesis that mean abundance at the control area equals mean abundance at the impact area.

And fifth, a discussion is presented which attempts to explain the results of the analyses described in the first four parts.

A listing of all species comprising the 1984-85 collections is presented in Appendix A, and a summary of the numeric changes in the 16 taxa chosen for detailed analysis is presented in Appendix B.

Trichoptera

Hydropsyche spp.

This genus is made up of many species although none were identified since the larval taxonomy is incomplete (Wiggins 1977). Hydropsyche is a large caddisfly, up to 15 mm in these collections, and filter feeds by means of intricate silken nets. On all sampling dates after mining, the mean numbers of Hydropsyche were higher at control stations 1 and 2 than at impact stations 3 and 4.

The numbers of *Hydropsyche* per sample were log-transformed reducing the raw data r^2 value from 0.88 to 0.39 after the transformation.

In 1977-78, *Hydropsyche* was more common at the impact station than the control station on three of the four dates sampled, while in 1984-85, *Hydropsyche* was more common at the control on all dates. This difference between the before and after periods is significant ($t = -5.19$, $p<0.003$)(Fig.2).

Station 1, on all dates, and station 2, on two of five dates had significantly more *Hydropsyche* than either of stations 3 or 4 (Figs. 3 and 4).

The consistently greater hydropsychid abundance before mining, and the greater abundance upstream of the tailings impoundment during mining, suggests a negative influence at the site of the impoundment. Although this study was designed to eliminate location-effects, if the control stations are part of a lake outlet community, the greater abundance of *Hydropsyche* there may be attributed to location rather than the effect of tailings. Filter feeding insects are typically abundant at lake outlets due to the export of organic material from the lake (Hynes 1970). Valett and Stanford (1987) found *Hydropsyche* abundance in a lake outlet stream in Glacier Park, Montana, to decrease by 78 and 97 percent within 200 and 3400 m (respectively) of the lake outlet. Sheldon and Oswood

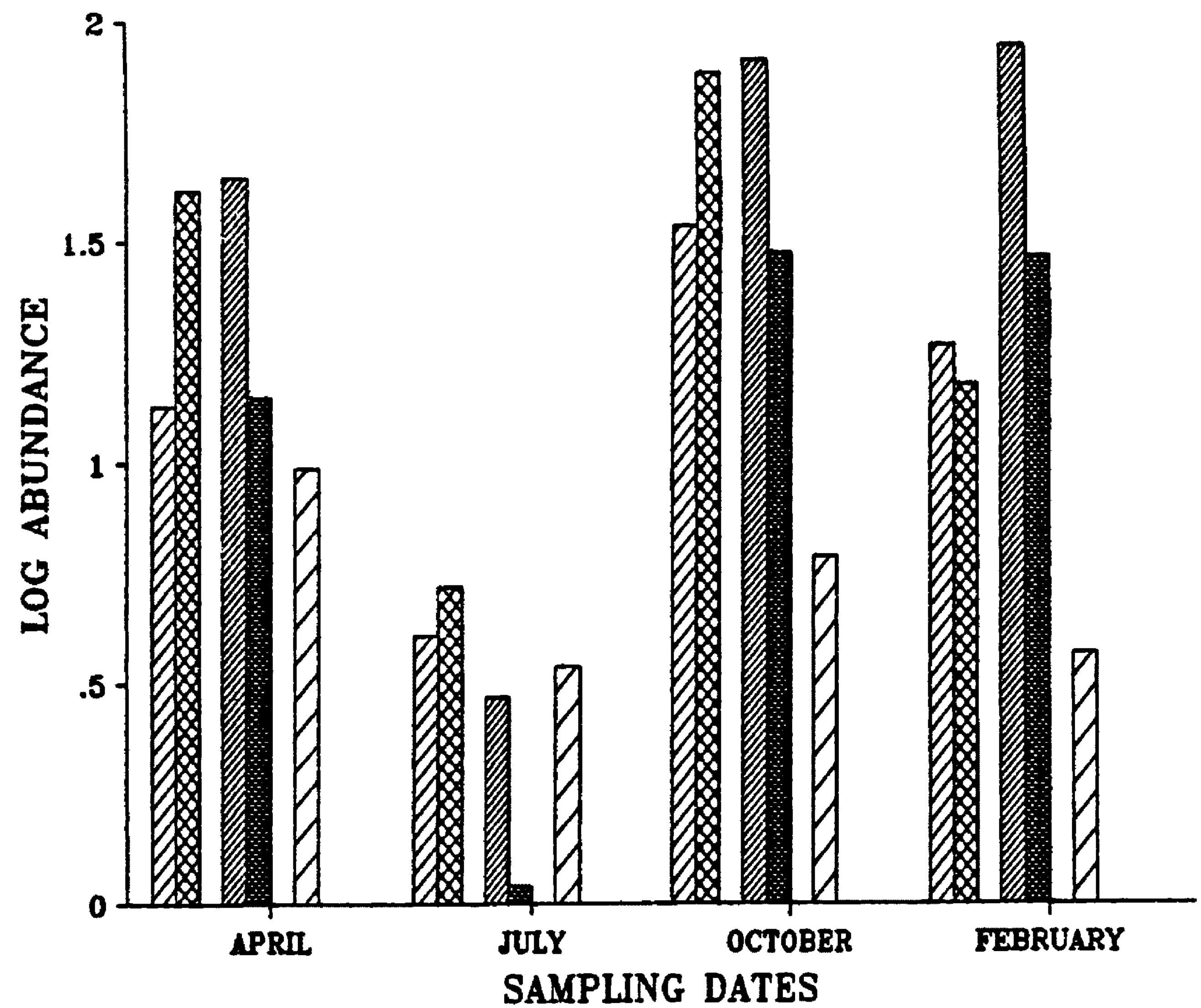

Figure 2. Log abundance of Hydropsyche at control and impact areas in 1977-78, and at control and impact areas in 1984-85. represents the change in the difference between control and impact areas from 1977-78 to 1984-85.

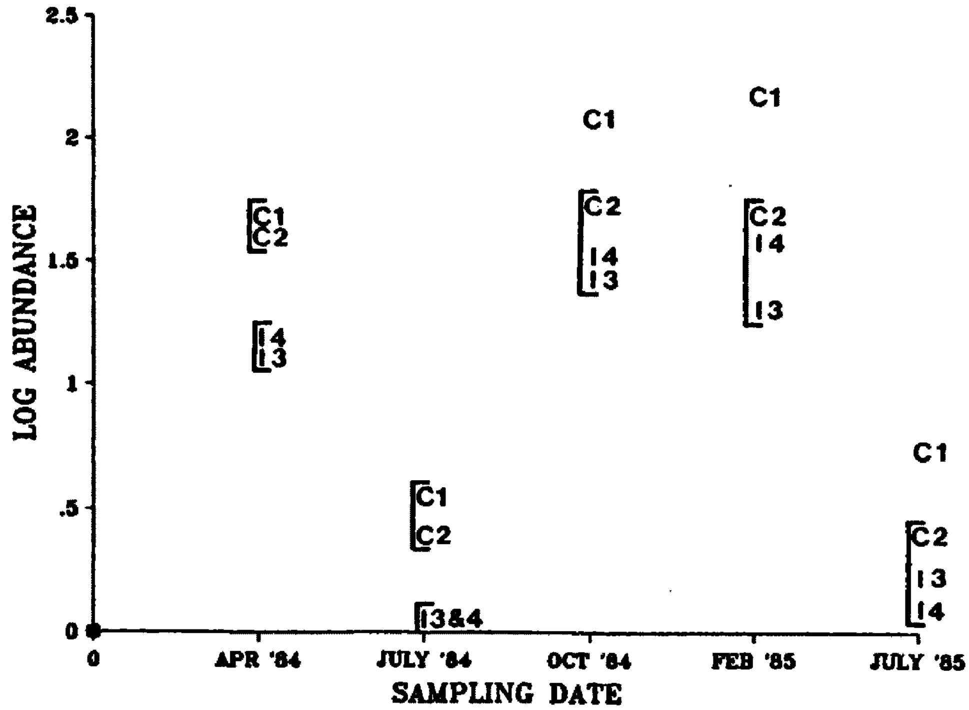

Figure 3. Log abundance of Hydropsyche spp. at four stations in Lake Creek, Mt. in 1984 and 1985. C = control, I = impact, and the brackets denote groups that are not significantly different ($\alpha = 0.05$).

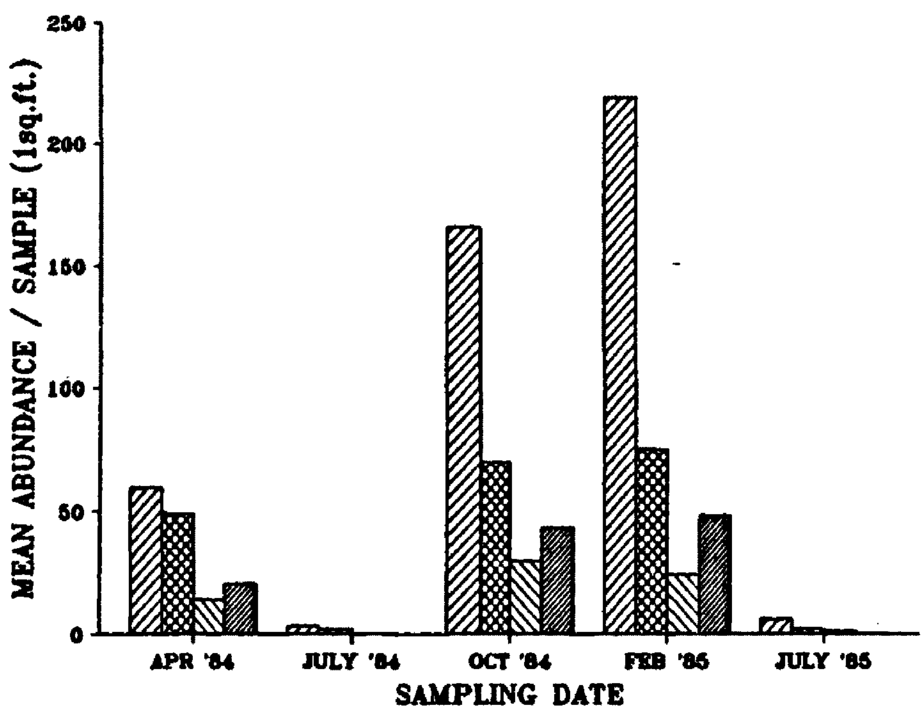

Figure 4. Mean abundance of Hydropsyche spp. at four stations in Lake Creek, Mt. on five sampling dates in 1984-85. Control station 1 = [hatched], control station 2 = [cross-hatched], impact station 3 = [hatched], and impact station 4 = [shaded].

(1977) researched a lake outlet community in western Montana in which hydropsychid and simuliid abundances were seen to decline rapidly within the first 100 m of the stream below the lake. They further theorized that the boundary of the outlet community was constant, even under conditions of increased organic loading. Carlson et al. (1977) also observed the rapid change in a lake outlet community "within a few hundred meters" of a lake in Sweden. Maciolek and Tunzi (1968) measured a 60 percent decrease of seston within a 400 m section of stream below a lake.

The first control station is located about 2000 m downstream of Bull Lake, which is probably well beyond the downstream boundary of the lake outlet community, and therefore should be comparable to the other sample sites in representing a rhithron community. An additional argument against station 1 being within a lake outlet community is that during the study period, simuliids, filter feeding members of lake outlet communities, became very abundant at the two stations farthest from the lake, and remained uncommon at the two nearest Bull Lake. Further, on three of the four dates sampled in the baseline study, Hydropsyche was more common at the downstream station than the upstream station. It is concluded that Hydropsyche have decreased in Lake Creek below the tailing impoundment and the cause is tailing contamination.

Brachycentrus spp.

Two species of Brachycentrus occur in Lake Creek. The larval cases are a characteristic four-sided arrangement of woody material that is fastened to a rock with the opening facing into the current. Their long middle and hind legs are used to reach out and filter food particles from the current, and to scrape periphytic algae from the substrate

The fourth root transformation of Brachycentrus numbers was chosen since it stabilized the variance much more effectively than the log transformation (log: r^2 =.67, $x^{.25}$:r^2 =0.30).

When averaged over the baseline period, Brachycentrus abundance was comparable at control and impact sites. In 1984-85 the two areas were no longer comparable. The control had increased and the impact area had decreased relative to the baseline period, although the difference between the periods was not significant ($p<.05$)(Fig. 5). The lack of significance is probably due to the high variability in differences which was least in April and highest in October.

There were significant differences in numbers of Brachycentrus upstream and downstream of the impoundment in 1984-85 (Figs. 6 and 7). Control station 1 always had the

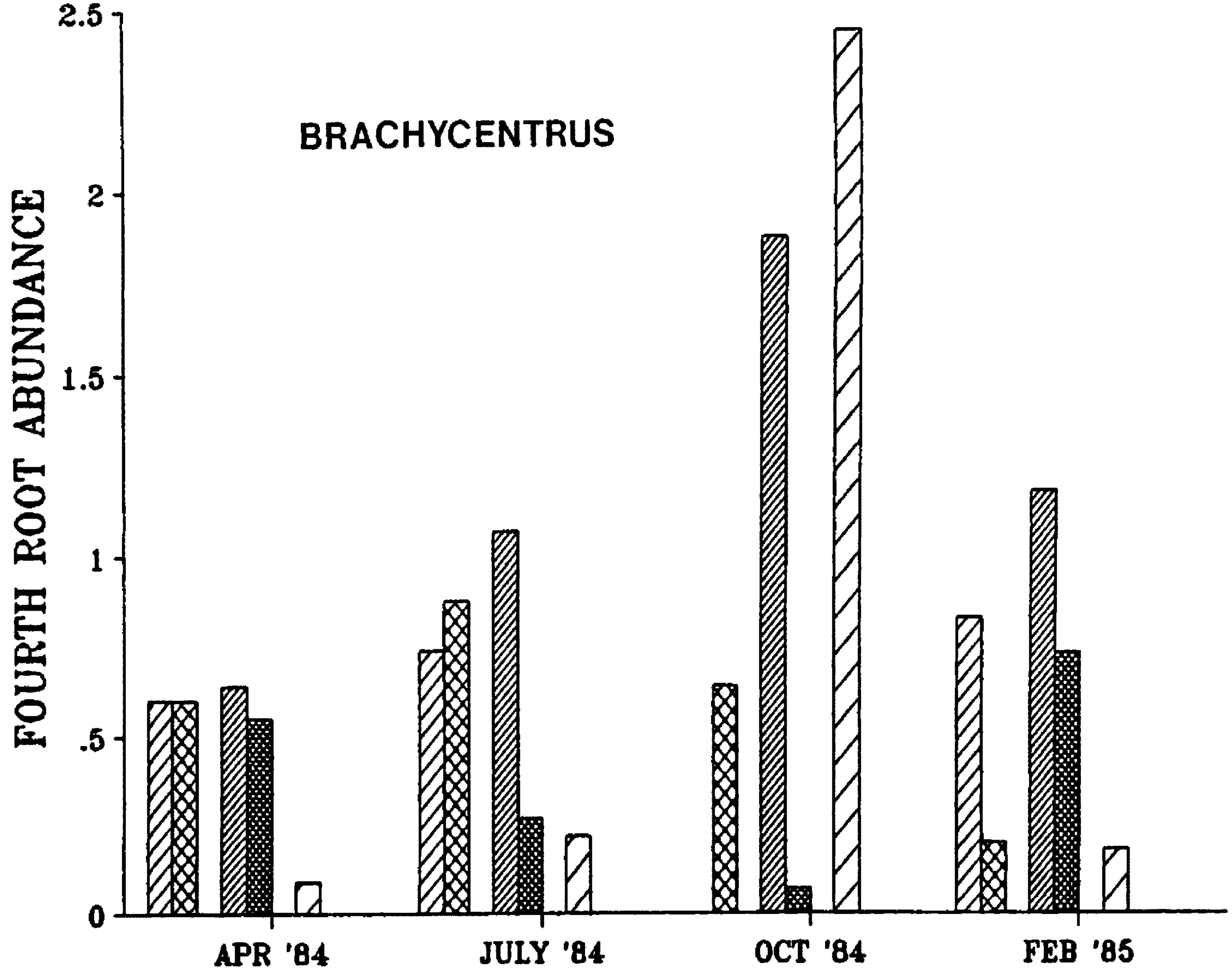

Figure 5. Log abundance of Brachycentrus at control [legend pattern] and impact [legend pattern] areas in 1977-78, and at control [legend pattern] and impact [legend pattern] areas in 1984-85. [legend pattern] represents the change in the difference between control and impact areas from 1977-78 to 1984-85.

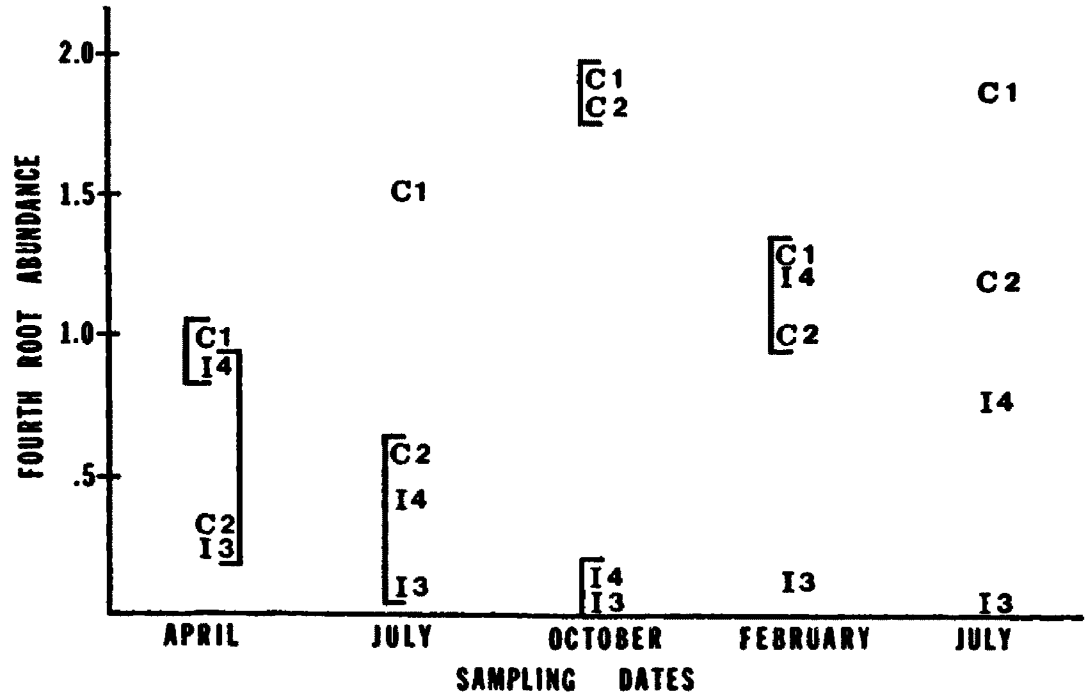

Figure 6. Log abundance of Brachycentrus spp. at four stations in Lake Creek, Mt. in 1984 and 1985. C = control, I = impact, and the brackets denote groups that are not significantly different ($\alpha = 0.05$).

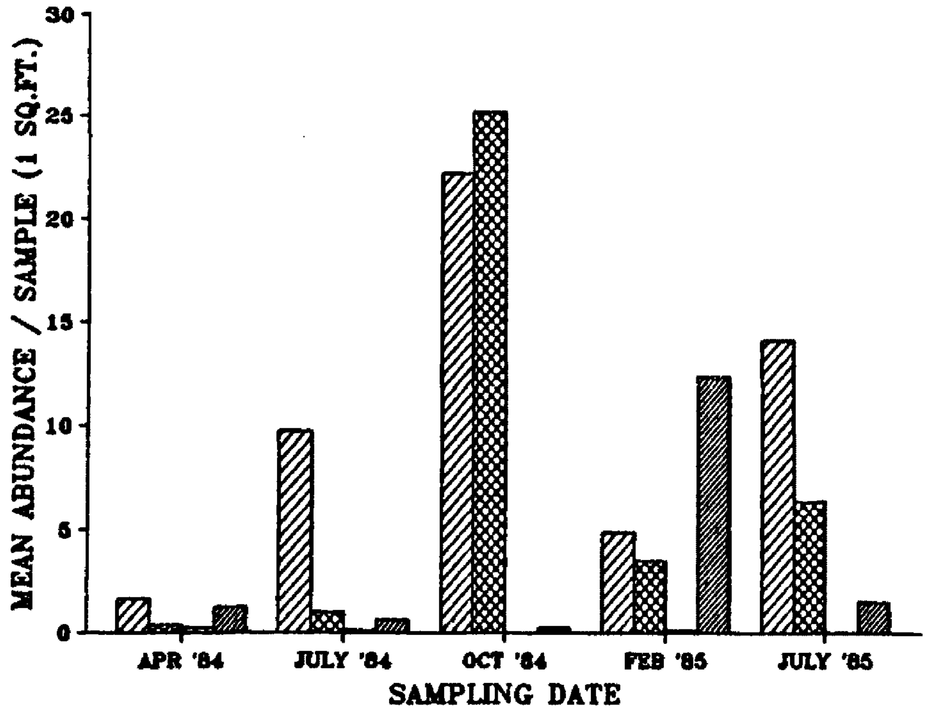

Figure 7. Mean abundance of Brachycentrus spp. at four stations in Lake Creek, Mt. on five sampling dates in 1984-85. Control station 1 = [hatched], control station 2 = [cross-hatched], impact station 3 = [hatched], and impact station 4 = [hatched].

highest abundance, and control station 2 was second on three dates and displaced by impact station 4 on two dates. Impact station 3 always had the fewest numbers of *Brachycentrus*.

The changes in *Brachycentrus* numbers strongly indicate an impact. An inconsistent pattern in 1977-78 between control and impact areas is followed by a consistent pattern in 1984-85 of greater abundance in the control area.

Agraylea spp.

Two species are known to occur in Montana and this one is probably *A. saltesa*. *Agraylea* are free living until the fifth instar when they build a bivalve case made of silk and algal filaments. Nielsen (1948) found a species of Agraylea to pass through the first four instars in 11-21 days. All *Agraylea* collected in 1984-85 were cased. *Agraylea* feed on the cellular contents of filamentous algae (Nielsen 1948). *Agraylea* was present in Lake Creek in very low numbers during baseline sampling (1977-78).

The log-transformation was applied and effectively stabilized the variance, reducing the r^2 value from 0.87 to 0.24.

The difference in abundances at control and impact stations was significantly greater after mining began (t=7.505, p<.0001)(Fig. 8). Numbers of Agraylea per sample were greater at all stations in the 1984-85 collections than the 1977-78 ones, but the increase was most pronounced at the control site. The assumption inherent in this study design is that the two areas will respond to an influence in the same way and to the same degree, meaning the response is additive rather than multiplicative (Stewart-Oaten et al. 1986). Rather than apply the Tukey test for additivity (Tukey 1949), the raw data was reviewed subjectively and it was assumed that the change in abundance was additive at both control and impact areas. Unless the assumption of additivity is false, the failure of the impact area to show the same magnitude of increase as the control area suggests a negative factor acting on it and suppressing it.

In the test of spatial differences after the start-up of mining, control station 1, on every date had significantly more Agraylea than either stations 3 or 4. The same is true of station 2 on four of five dates sampled (Figs. 9 and 10). This nonrandom difference in spatial and temporal distribution of Agraylea suggests an influence in the impact area.

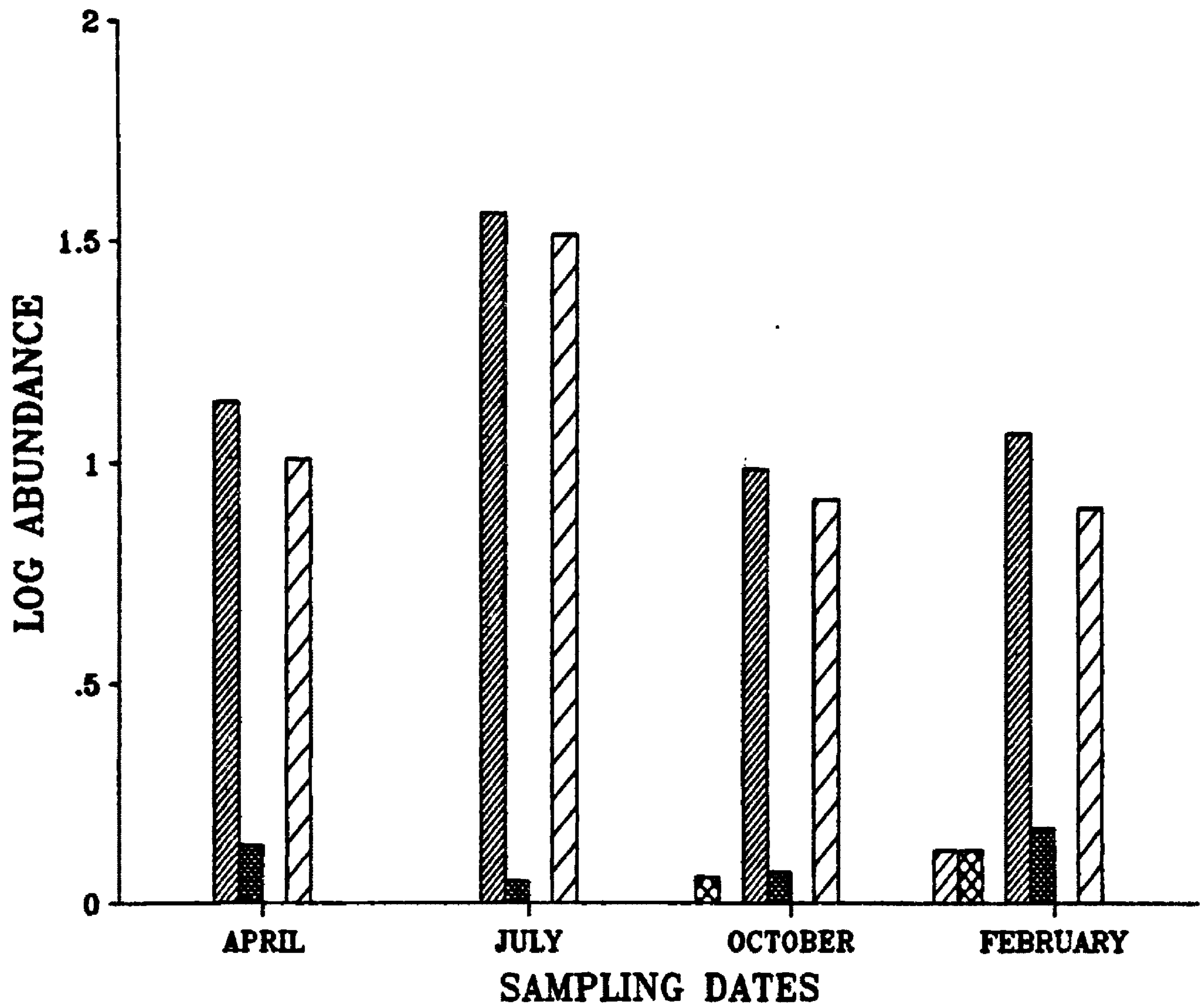

Figure 8. Log abundance of *Agraylea* at control and impact areas in 1977-78, and at control and impact areas in 1984-85. represents the change in the difference between control and impact areas from 1977-78 to 1984-85.

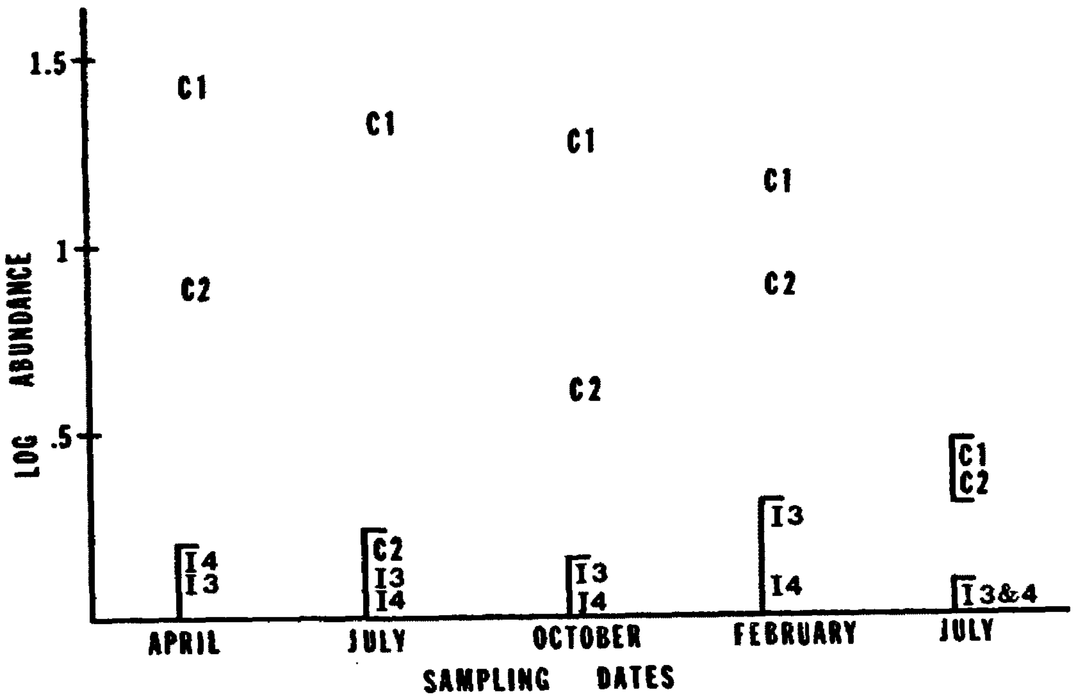

Figure 9. Log abundance of Agraylea at four stations in Lake Creek, Mt. in 1984 and 1985. C = control, I = impact, and the brackets denote groups that are not significantly different ($\alpha = 0.05$).

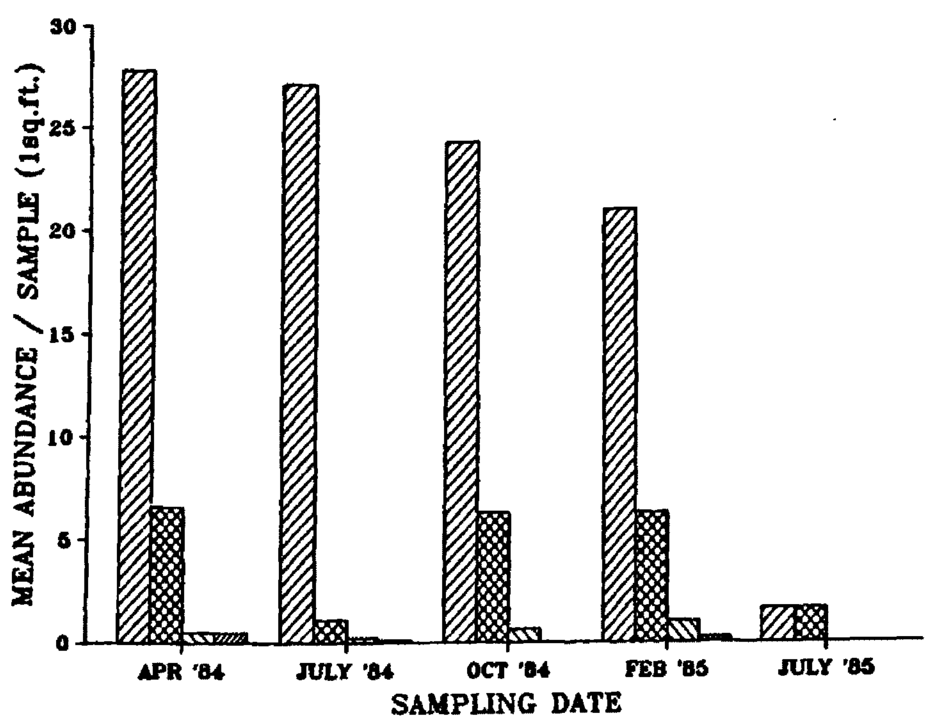

Figure 10. Mean abundance of Agraylea at four stations in Lake Creek, Mt. on five sampling dates in 1984-85. Control station 1 = ▨, control station 2 = ▩, impact station 3 = ▧, and impact station 4 = ▦.

Rhyacophila spp.

At least four species of Rhyacophila (acropedes, angelita, coloradensis, and vepulsa) occurred in the study area. These are free roaming predators, caseless until the final pupal instar (Mackay and Wiggins 1979).

The log-transformation of rhyacophilid numbers successfully stabilized the variance, reducing the r^2 value from 0.72 to 0.0004.

The impact and control stations were less similar in the baseline period than in 1984-85 (Fig. 11). The average change in rhyacophilid abundance after mining began was toward an increase at the control site and a decrease at the impact site, and this change rendered the sites more similar since during baseline sampling the impact site had uniformly more rhyacophilids than the control site. The null hypothesis that the mean differences between before and after periods are equal was rejected ($t=-2.5213$, $p<0.05$). It is assumed that the greater abundance of rhyacophilids at the impact site before mining is real and that the greater abundance at the control site after mining began reflects a cyclical population change in the system acting at all stations. The failure of the impact stations to increase proportionately is due to a factor acting only on the impact area which is assumed to be tailings contamination.

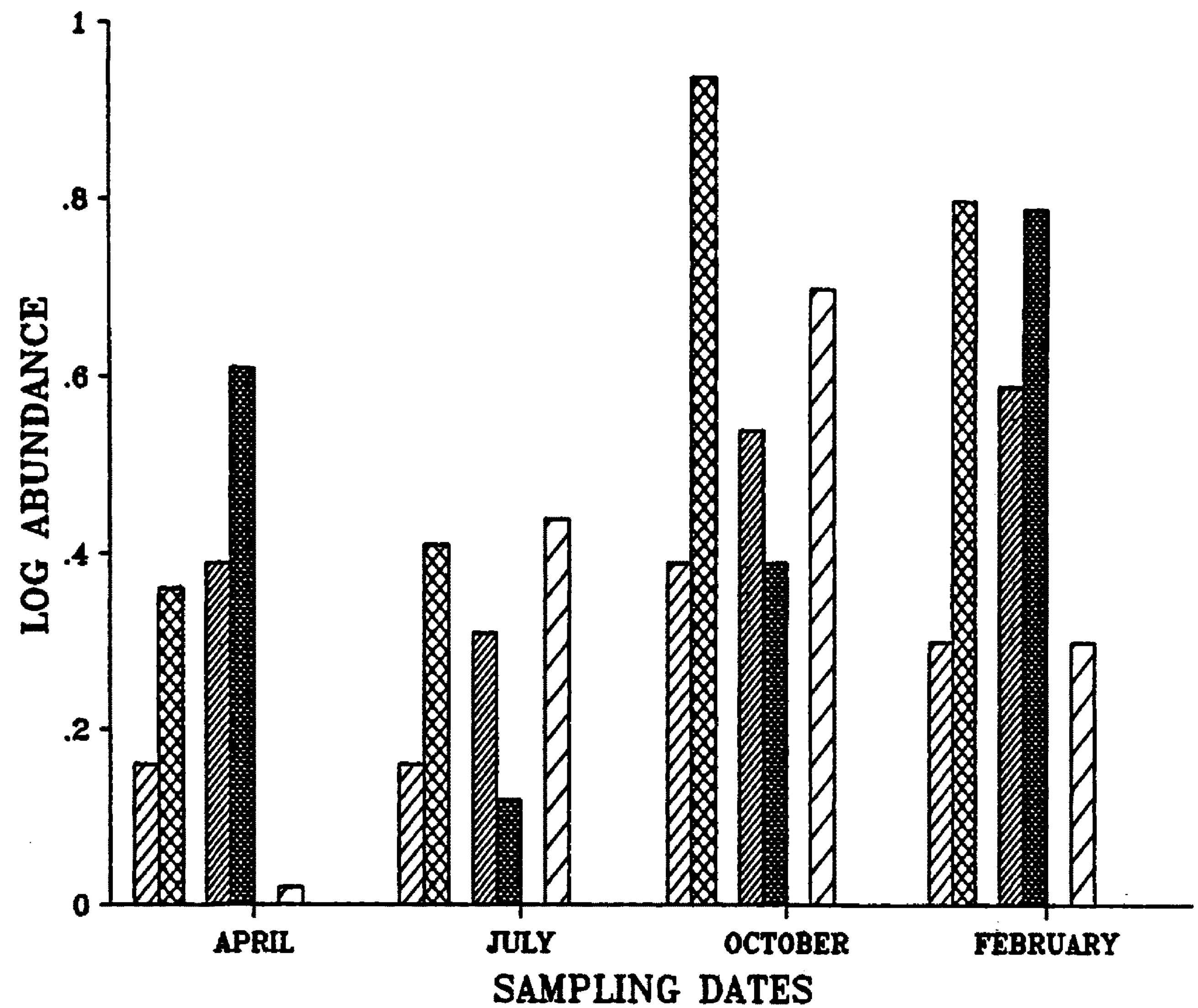

Figure 11. Log abundance of <u>Rhyacophila</u> at control [legend pattern] and impact [legend pattern] areas in 1977-78, and at control [legend pattern] and impact [legend pattern] areas in 1984-85. [legend pattern] represents the change in the difference between control and impact areas from 1977-78 to 1984-85.

The comparison of rhyacophilid abundance above and below the tailings impoundment in 1984-85 provides less meaningful results than did comparisons over time. There are no clear and consistent patterns in the data other than that control and impact areas are not distinguishable. One explanation for this discrepancy between the results of spatial and temporal comparisons involves the fact that rhyacophilids were more abundant in the impact area than the control in 1977-78. Any reduction in rhyacophilids in the downstream area renders that area more similar to the control, with fewer differences to be detected by analysis of variance. Another explanation is the confounding effect that the tailings spill may have had on rhyacophilid numbers. The spill occurred in June 1984, and it was only on the subsequent sample dates in July and October that rhyacophilid numbers averaged lower in the impact than the control area(Figs. 12 and 13). If numbers of rhyacophilids similar to those collected during baseline sampling had been collected on the two dates, then the difference between baseline and the 1984-85 period would not have been significant ($t<2.5$, $p<0.05$).

Ephemeroptera

Mayflies were very common and diverse in the study area and were usually the most common order represented

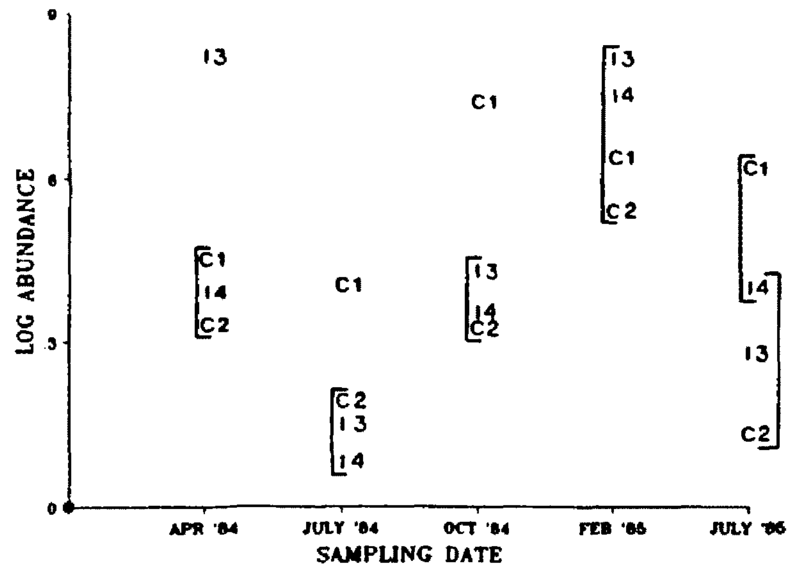

Figure 12. Log abundance of Rhyacophila spp. at four stations in Lake Creek, Mt. in 1984 and 1985. C = control, I = impact, and the brackets denote groups that are not significantly different (= 0.05).

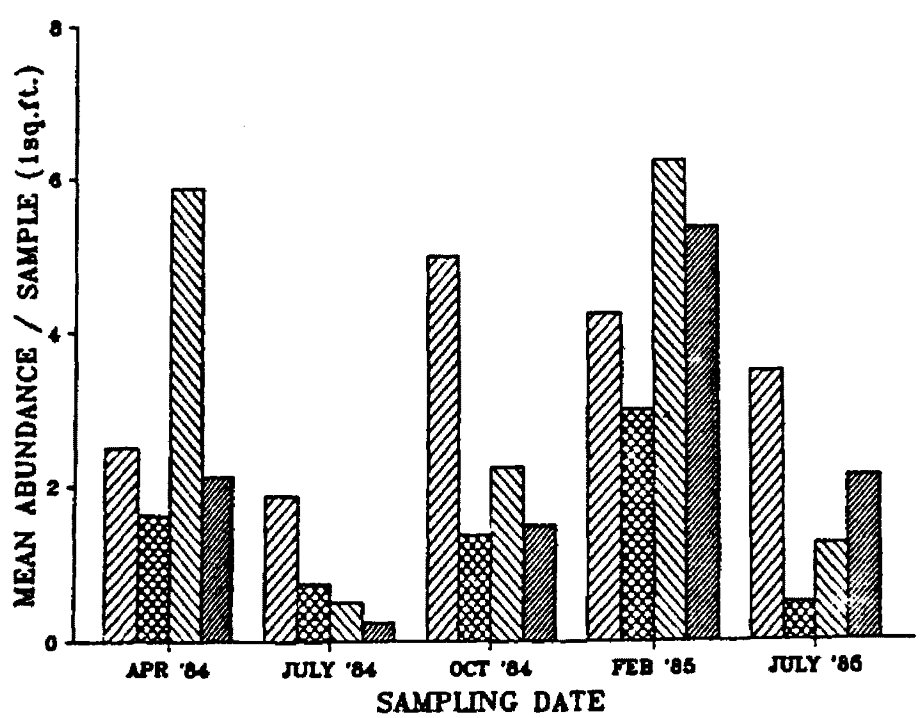

Figure 13. Mean abundance of Rhyacophila spp. at four stations in Lake Creek, Mt. on five sampling dates in 1984-85. Control station 1 = ▨, control station 2 = ▩, impact station 3 = ▧, and impact station 4 = ▩.

(Figs. 51-59). Taxonomic revisions in this order have occurred frequently in recent years. For example, after baseline data collection Ephemerella was removed from the family Baetidae and placed in its own family Ephemerellidae. Since data collection began for this study the subgenus Drunella has been elevated to genus.

Ephemerella spp.

For the purpose of comparing with baseline data this taxon is treated as it was in 1977, in which the four subgenera (Ephemerella, Caudatella, Serratella, and Drunella) known to occur in the study area are pooled into one taxon. The mayflies of this group feed primarily on detritus, diatoms, and algae (Gilpin and Brusven 1970). Drunella doddsi is the largest of the group, with some individuals from these collections up to 13 mm in length. E. (Ephemerella) spp. was most common, and averaged about 4 mm in length. The number of ephemerellids was greatest in the control area in February 1985, averaging 223 individuals/sq.ft., or 2,478/sq.m.

The abundance of Ephemerella at the control and impact sites in 1977-78 was roughly equal when averaged over the year. In 1984-85 ephemerellids were substantially more common in the control area than the impact area. The difference between means in the before and after periods was significant($p<.05$)(Fig.14). Abundance at the control in 1984-85 was substantially greater than in 1977-78 on three of four dates, while impact area abundances in both periods were roughly equal, though slightly greater before mining.

On all dates in 1984-85, the abundance of Ephemerella was greater at both control stations than either impact stations. The difference though was significant ($p<.05$) only in October (Figs. 15 and 16).

The distribution of Ephemerella does not give a pronounced indication of impact, but does reveal spatial and temporal changes that favor the controls. The control and impact sites were significantly more similar before mining than after it began. The change over that period was a substantial increase at the control while the impact area remained relatively unchanged. The increase at the control is likely not attributable to improved sampler efficiency since no similar increase occurred at the impact site. It is more likely that an overall population increase occurred that was not manifested in the impact area due to the suppressing effect of tailings contamination.

Rhithrogena spp.

This genus is in the family Heptageniidae. Its distinctive gills overlap, forming a ventral disk allowing

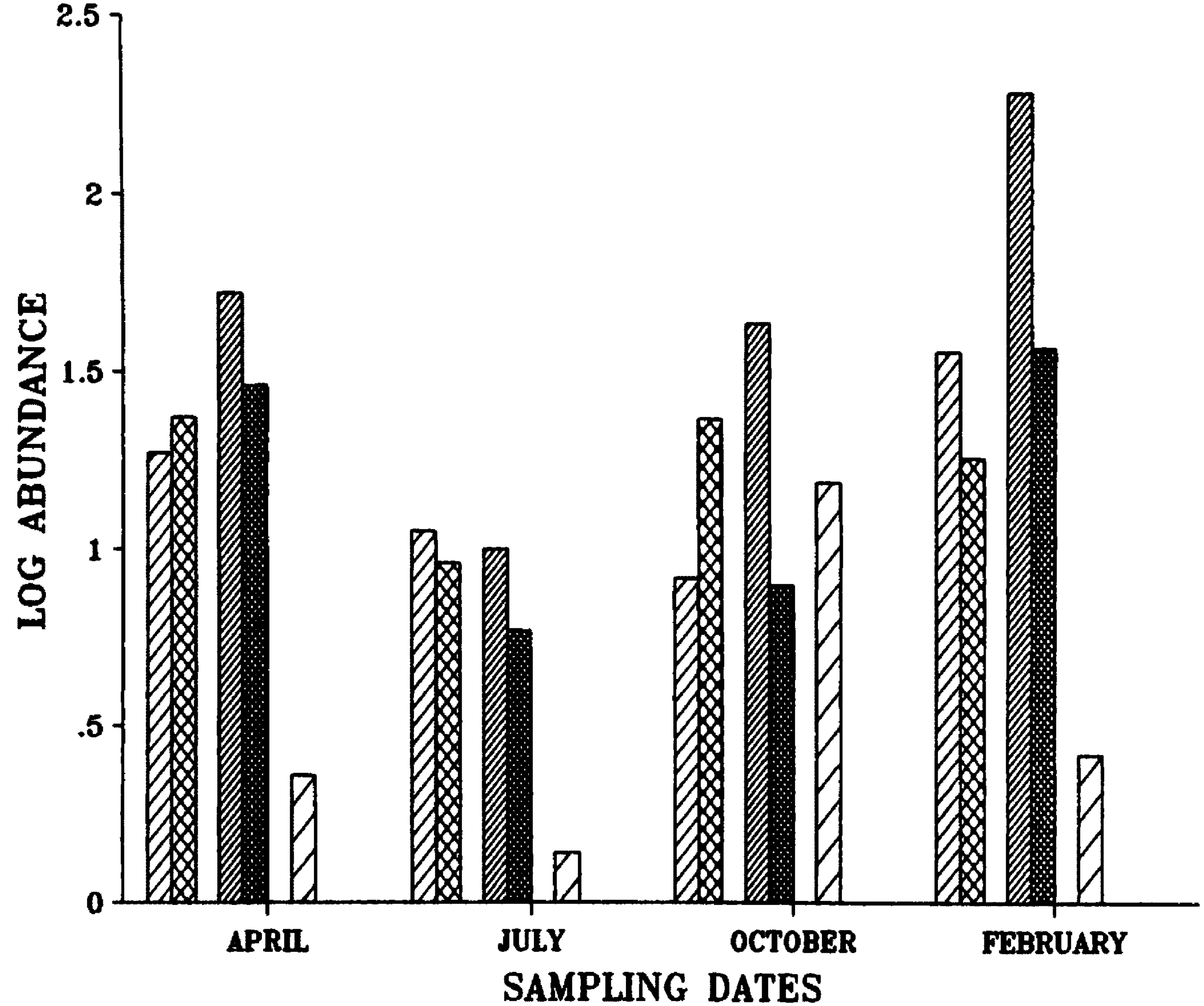

Figure 14. Log abundance of Ephemerella at control and impact areas in 1977-78, and at control and impact areas in 1984-85. represents the change in the difference between control and impact areas from 1977-78 to 1984-85.

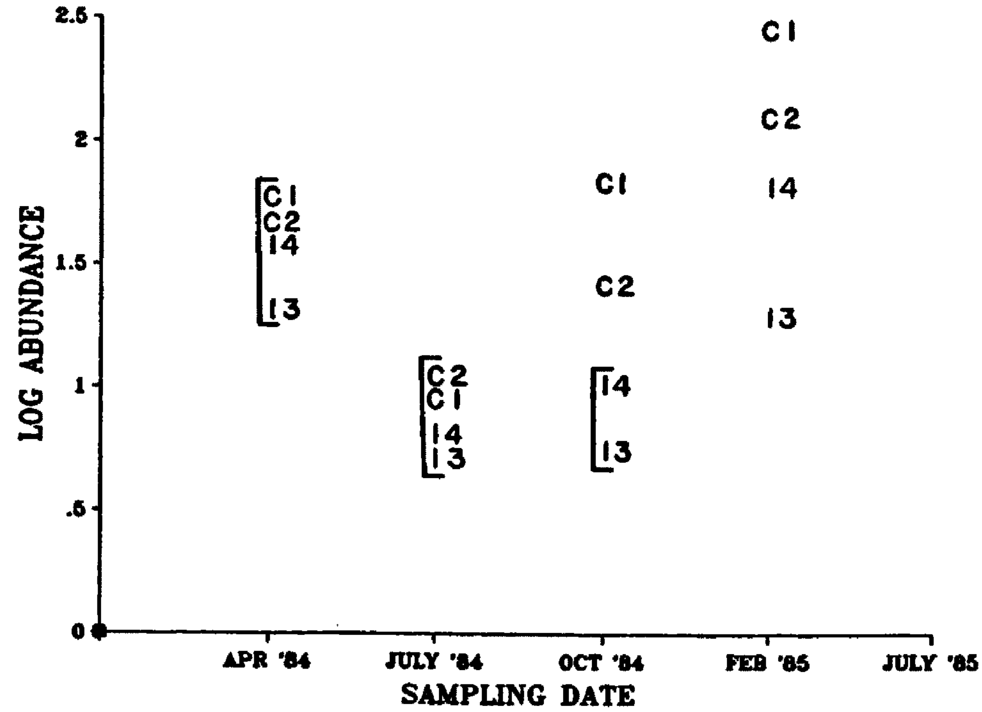

Figure 15. Log abundance of Ephemerella spp. at four stations in Lake Creek, Mt. in 1984 and 1985. C = control, I = impact, and the brackets denote groups that are not significantly different ($\alpha = 0.05$).

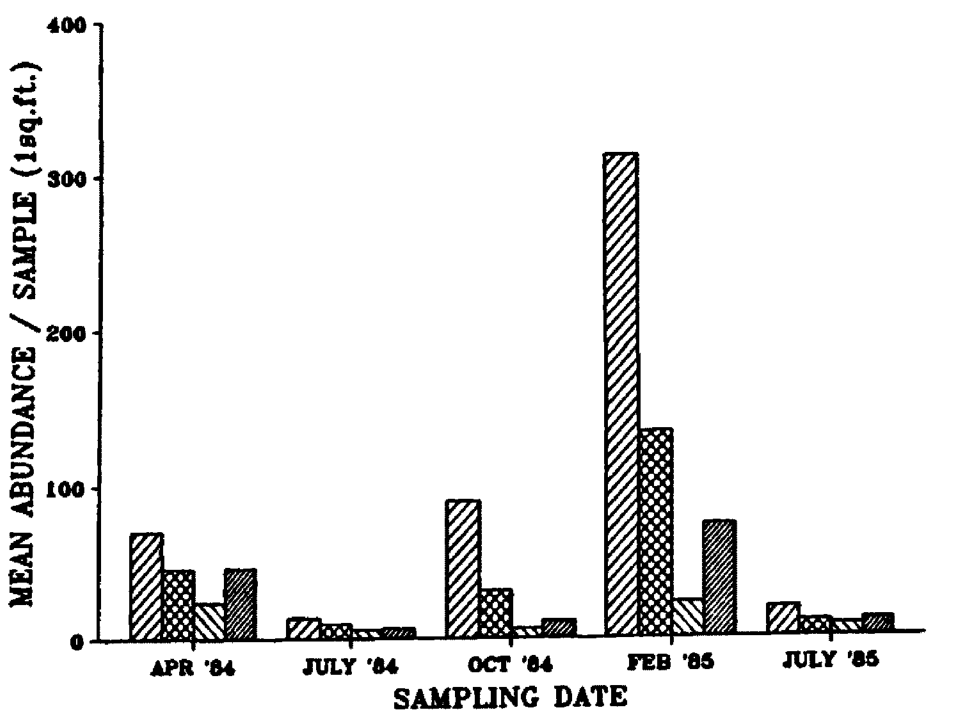

Figure 16. Mean abundance of Ephemerella spp. at four stations in Lake Creek, Mt. on five sampling dates in 1984-85. Control station 1 = [diagonal hatch], control station 2 = [cross-hatch], impact station 3 = [reverse diagonal hatch], and impact station 4 = [dense hatch].

the nymphs to cling to rock surfaces. The nymphs consume detritus, diatoms, and filamentous algae (Gilpin and Brusven 1970).

The log-transformation successfully stabilized the variance, lowering the raw data r^2 from a significant 0.86 to an insignificant 0.01. Rhithrogena was marginally more abundant at the control station than at the impact station in 1977-78, and decisively more abundant at the impact stations than the control in 1984-85 (Fig. 17). Comparison of these differences before and after mining began was not significant ($t=1.8403$). The high variability in differences between dates presumably accounts for the lack of significance.

In 1984-85 Rhithrogena was significantly more abundant at the impact stations than at the control stations on four of five dates (Figs. 18 and 19). This consistent and pronounced distribution is not easily explained. One possibility is the presence of macrophytic vegetation, which was observed at station 1, and it may act to exclude Rhithrogena by interfering with its ability to cling to rock surfaces. Another possibility involves the coincidental emergence of Rhithrogena prior to the tailings spill which may have enabled it to escape the peak of the stress and then recolonize when competitive pressure was greatly reduced. If Rhithrogena emerge in Lake Creek during the

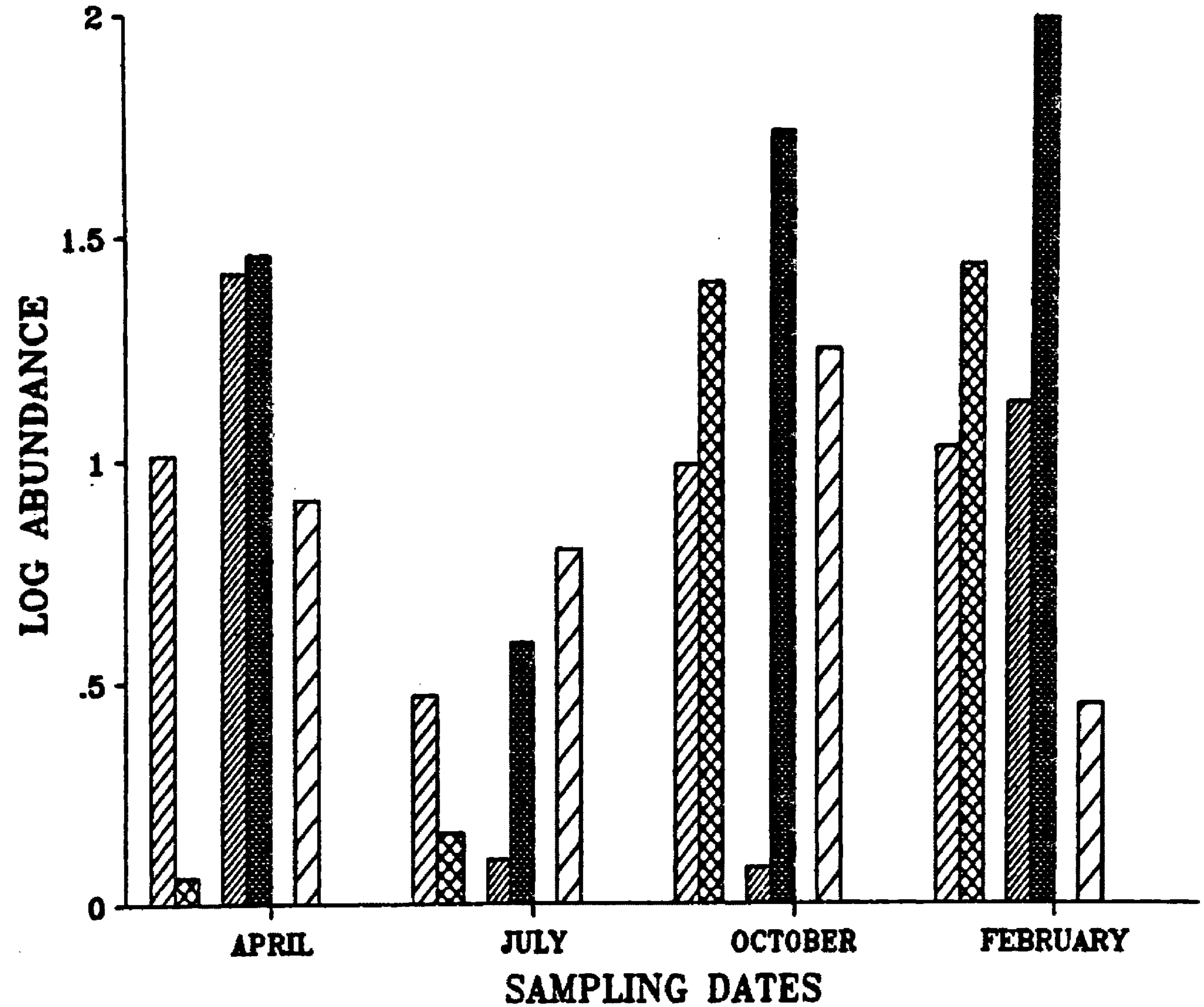

Figure 17. Log abundance of Rhithrogena at control [hatched] and impact [cross-hatched] areas in 1977-78, and at control [dense hatched] and impact [solid] areas in 1984-85. [open hatched] represents the change in the difference between control and impact areas from 1977-78 to 1984-85.

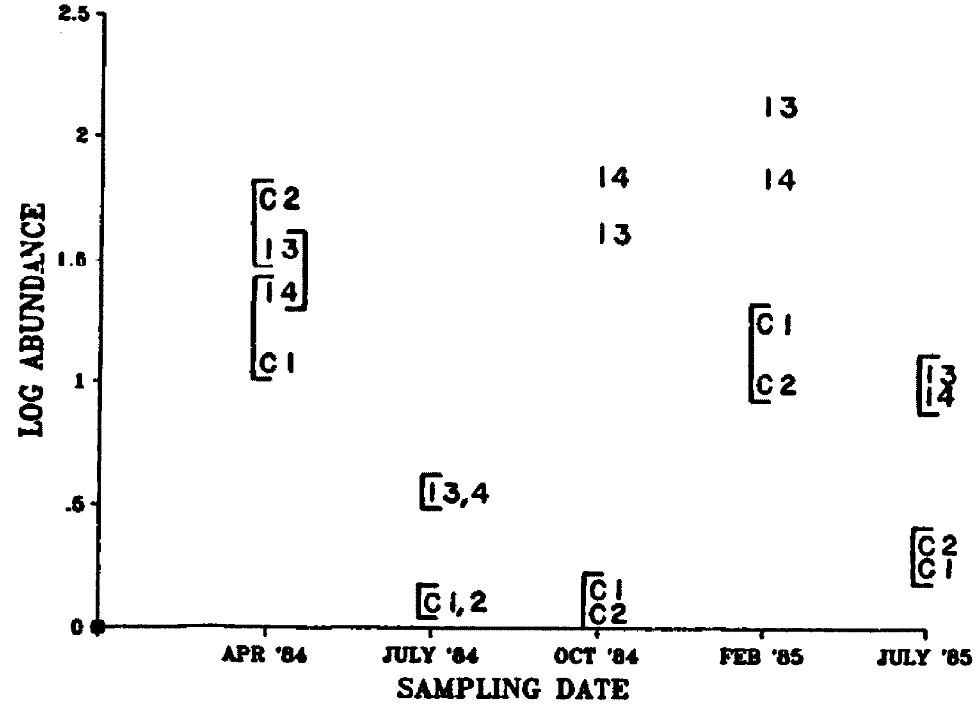

Figure 18. Log abundance of Rhithrogena spp. at four stations in Lake Creek, Mt. in 1984 and 1985. C = control, I = impact, and the brackets denote groups that are not significantly different ($\alpha = 0.05$).

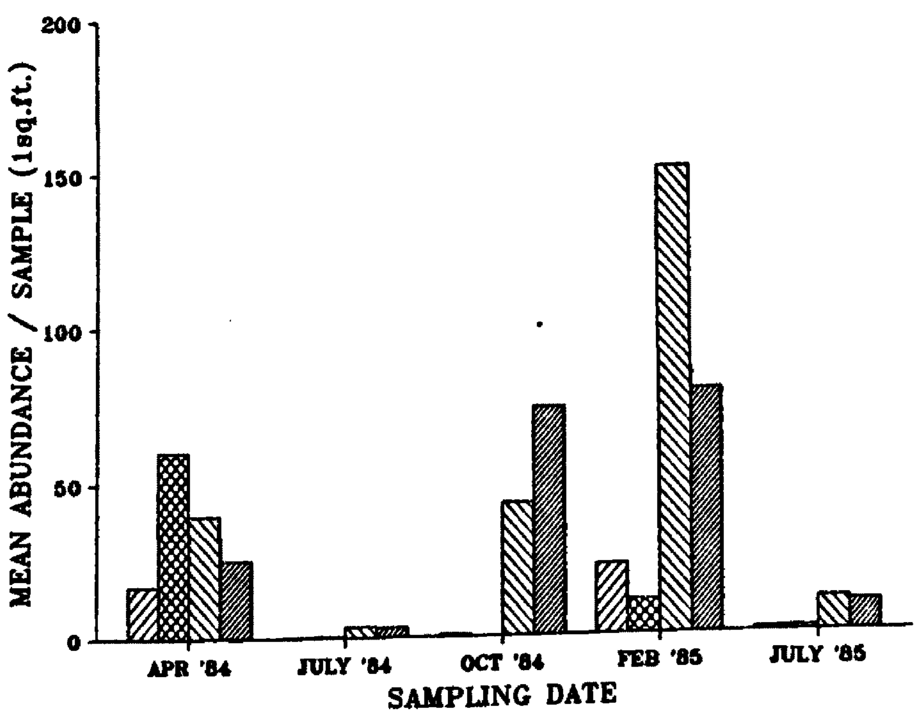

Figure 19. Mean abundance of Rhithrogena spp. at four stations in Lake Creek, Mt. on five sampling dates in 1984-85. Control station 1 = ▨, control station 2 = ▩, impact station 3 = ▧, and impact station 4 = ▦.

first two weeks in June as they do in the Kootenai River (Perry 1983), they would have been in the adult stage during the spill. The average lengths of Rhithrogena from all samples is presented in Figure 20, to illustrate likely emergence time. The difference in lengths between control and impact areas is possibly due to the presence of a second species of Rhithrogena, since length-frequency distributions of Rhithrogena in the impact area were bi-modal. Each area illustrates the progression of the cohort toward summer when it reaches maximum length. Those individuals present in July are either late emergers, or species2 which may emerge later than species1. Early instar growth occurs through late summer and can be followed through the October and February sampling dates. Rhithrogena was more common at the control in April prior to the spill, and much more common in the impact area on all dates after the spill.

Cinygmula spp.

The genus Cinygmula is in the family Heptageniidae. It is a common mayfly in streams with rocky bottoms (Edmunds et al. 1976). Cinygmula emerges in May and early June in the Kootenai River (Perry 1983) which explains its absence in the July collections in Lake Creek.

The log-transformation was successful in stabilizing

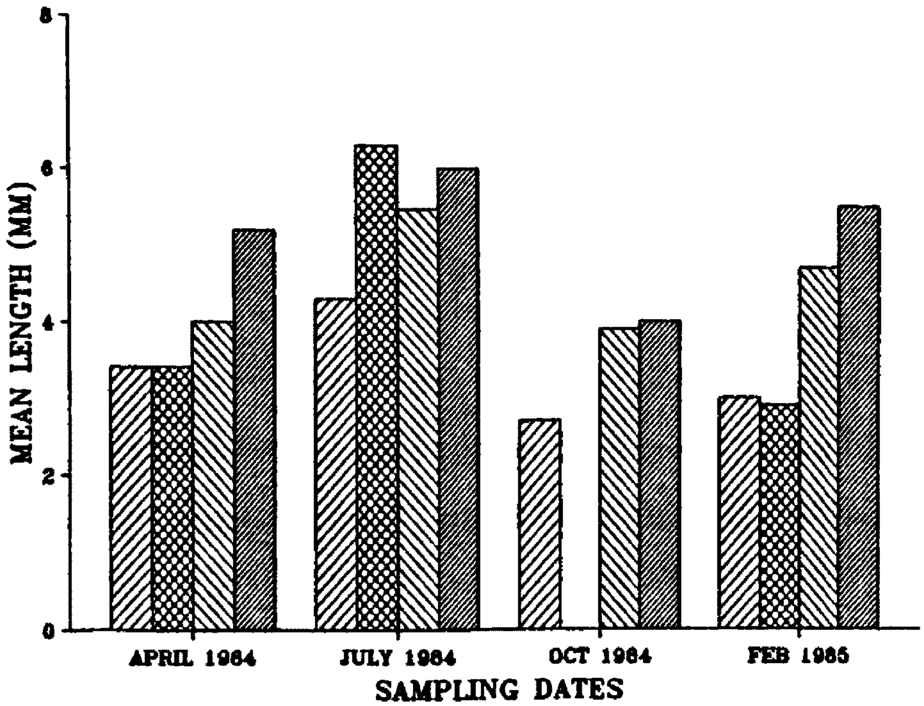

Figure 20. Mean lengths of Rhithrogena spp. at four stations in Lake Creek, Mt., on five sampling dates in 1984-85.

the variance, reducing the r^2 value from 0.67 to 0.06.

In the baseline period, Cinygmula was more abundant at the control site than the impact site on all dates except July. In 1984-85 the relationship was the same as during baseline, except in February when Cinygmula was more abundant at the impact site (Fig. 21). This change was not significant (t=0.9807).

Differences in abundance of Cinygmula between control and impact areas after mining began exhibit a variable pattern (Figs. 22 and 23). No single station had a consistently higher abundance than the others, and impact and control stations were never distinguished as significantly different.

Paraleptophlebia spp.

This genus is in the family Leptophlebiidae. The nymphs feed on detritus and algae. Nymphs were absent from the July collections, presumably because emergence occurs during that period.

The log-transformation stabilized the variance as shown by the reduction in r^2 value from 0.48 in the raw data to 0.13 after transformation.

Control and impact stations in 1977-78 were nearly identical in abundance of Paraleptophlebia. In 1984-85, abundance in the impact area was comparable to 1977-78, but

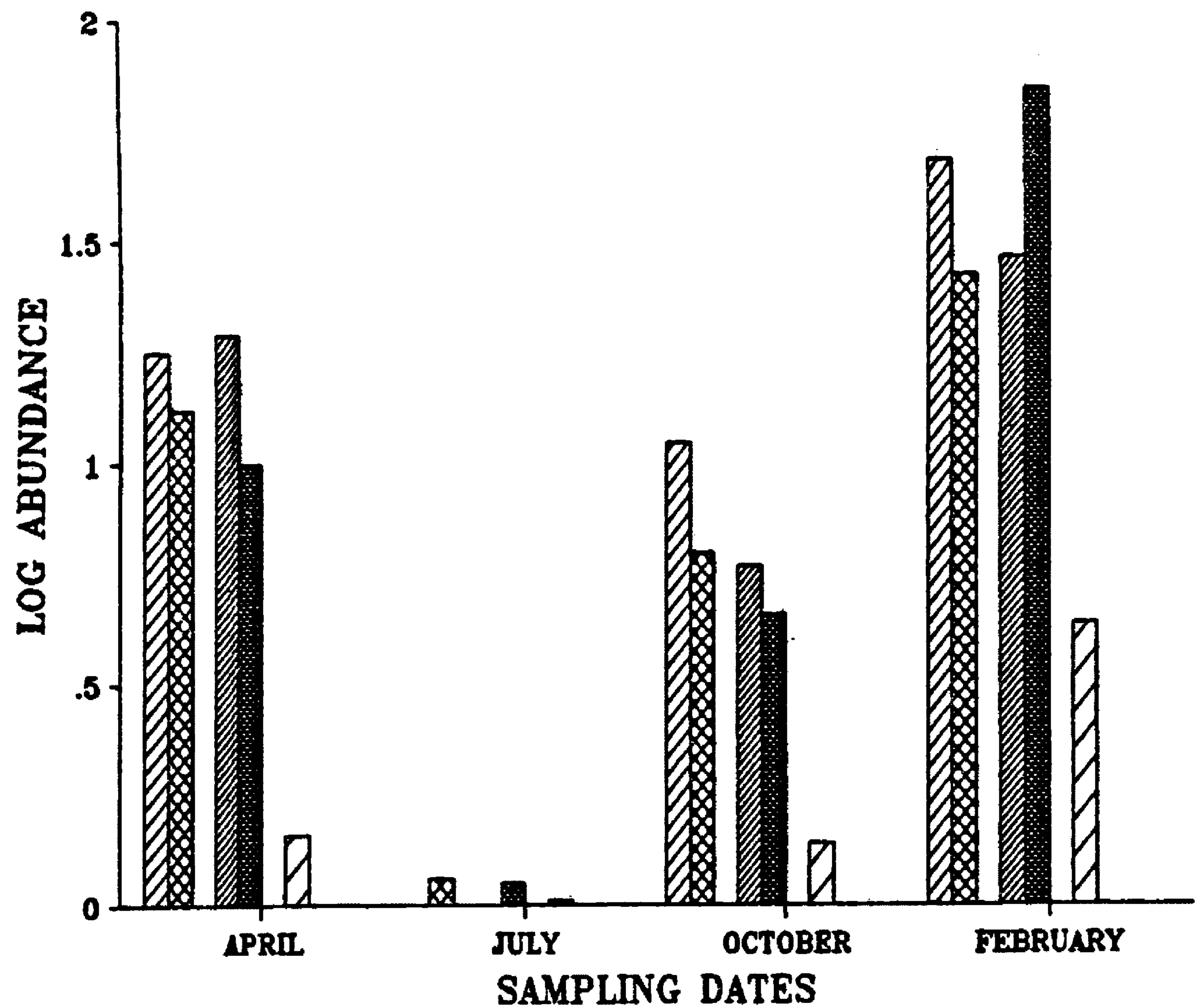

Figure 21. Log abundance of *Cinygmula* at control [hatched] and impact [cross-hatched] areas in 1977-78, and at control [hatched] and impact [shaded] areas in 1984-85. [hatched] represents the change in the difference between control and impact areas from 1977-78 to 1984-85.

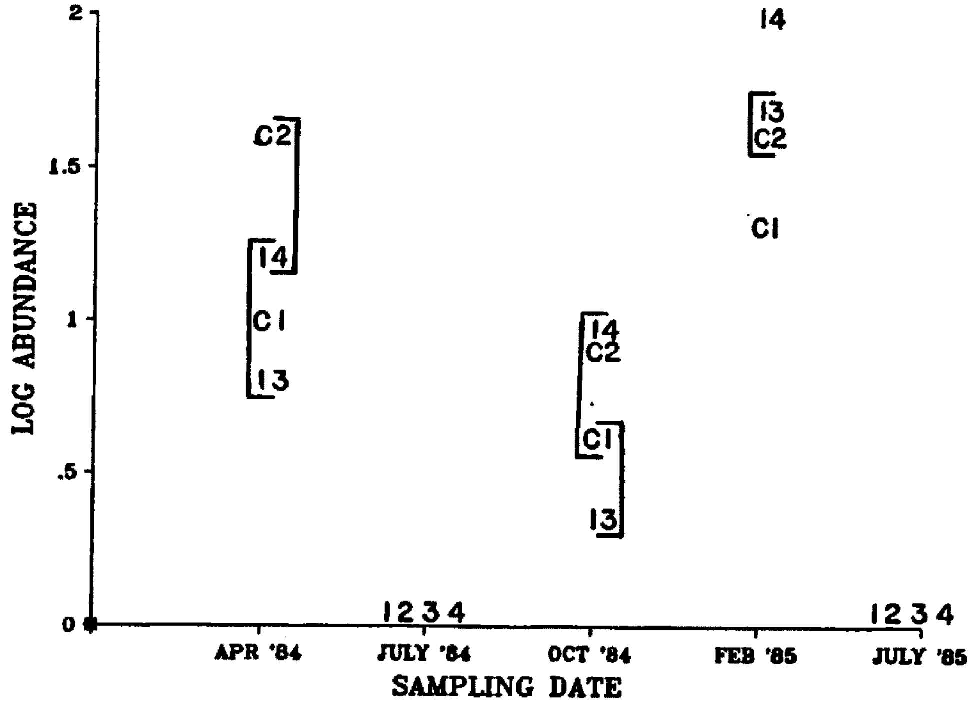

Figure 22. Log abundance of Cinygmula spp. at four stations in Lake Creek, Mt. in 1984 and 1985. C = control, I = impact, and the brackets denote groups that are not significantly different ($\alpha = 0.05$).

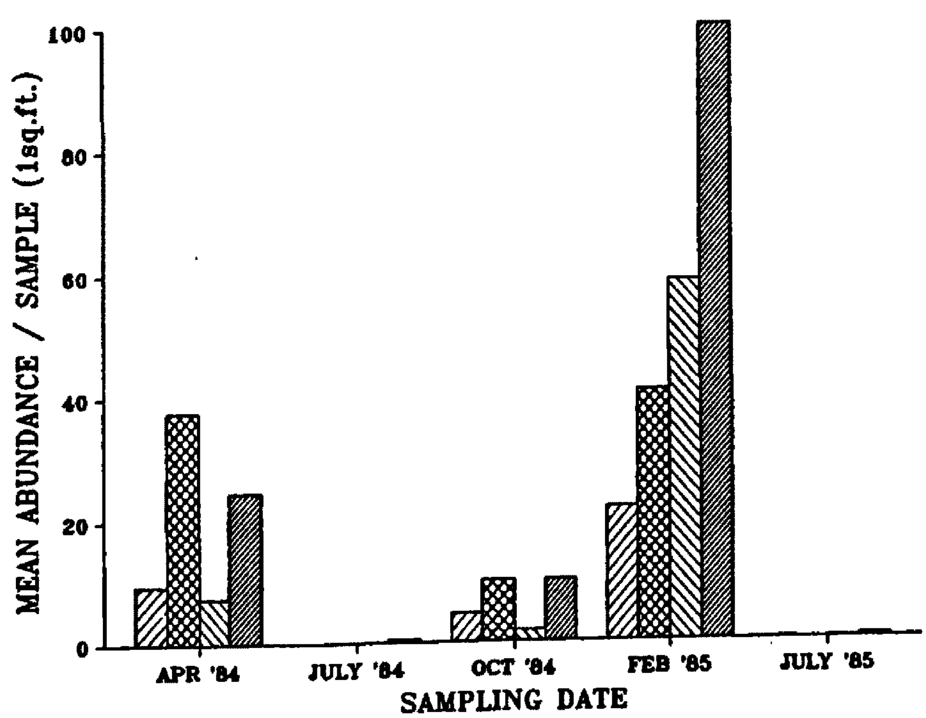

Figure 23. Mean abundance of Cinygmula spp. at four stations in Lake Creek, Mt. on five sampling dates in 1984-85. Control station 1 = [hatch pattern], control station 2 = [crosshatch pattern], impact station 3 = [hatch pattern], and impact station 4 = [shaded pattern].

the control area had substantially greater numbers of Paraleptophlebia than were present in 1977-78. The difference between the periods was significant (t=-2.6677, p<0.04)(Fig. 24).

The spatial distribution of Paraleptophlebia in 1984-85 remained constant on all dates sampled with only one exception. On all dates control stations had greater abundances than impact stations. In April, the control stations comprised a group significantly different than the impact stations (p<.0001). In October and February, control station 2 had significantly more Paraleptophlebia than all others (p<0.0001)(Figs. 25 and 26).

Paraleptophlebia does not demonstrate the same response as Rhithrogena did to the tailings spill. The increase in abundance of Paraleptophlebia from July through February is probably the result of improved sampling efficiency with growth and does not keep pace with the rate of increase at the control site. Speculation on the effects of the spill is tenuous since Paraleptophlebia was so rare in the April 1984 collections. The gradual increase from July through February may be a similar response as shown by Rhithrogena to an empty habitat, but subdued since the parent population was so small. On the other hand, Paraleptophlebia may have emerged early enough to have had the first instars of the next generation exposed to the

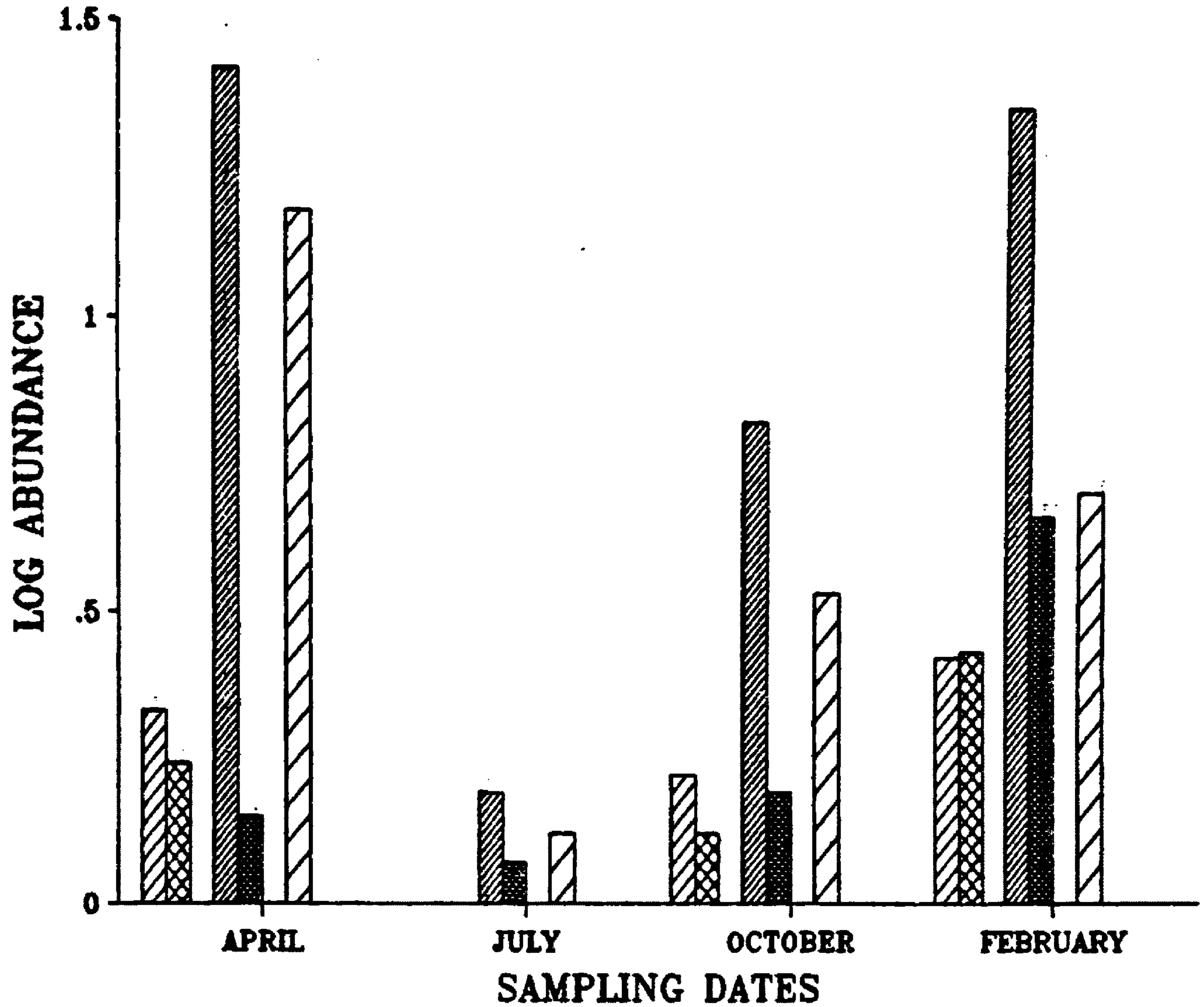

Figure 24. Log abundance of Paraleptophlebia at control and impact areas in 1977-78, and at control and impact areas in 1984-85. represents the change in the difference between control and impact areas from 1977-78 to 1984-85.

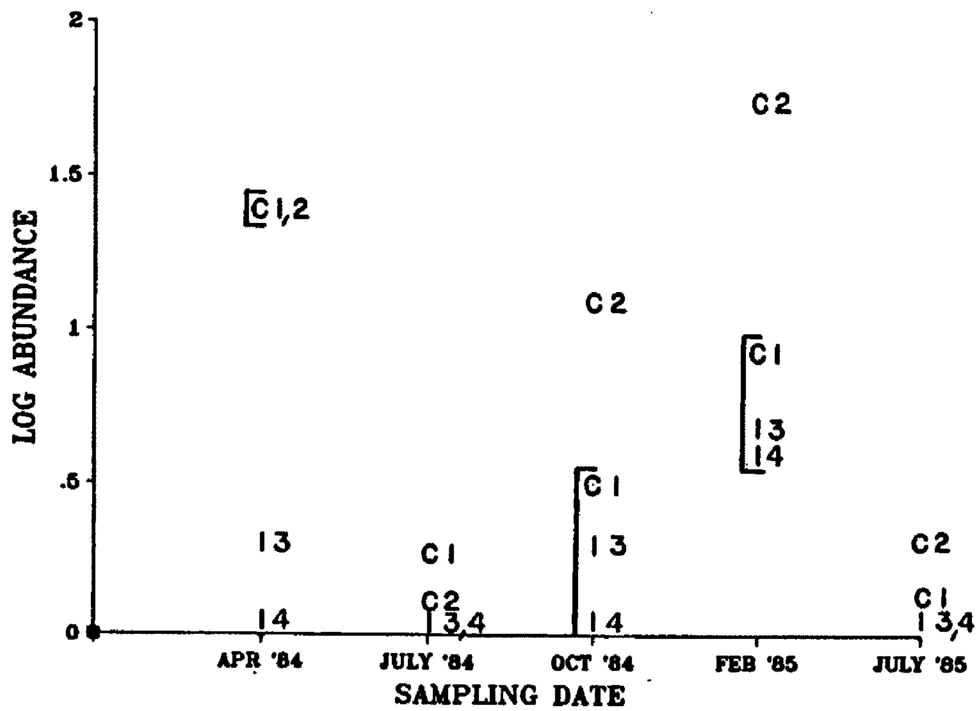

Figure 25. Log abundance of Paraleptophlebia spp. at four stations in Lake Creek, Mt. in 1984 and 1985. C = control, I = impact, and the brackets denote groups that are not significantly different (α = 0.05).

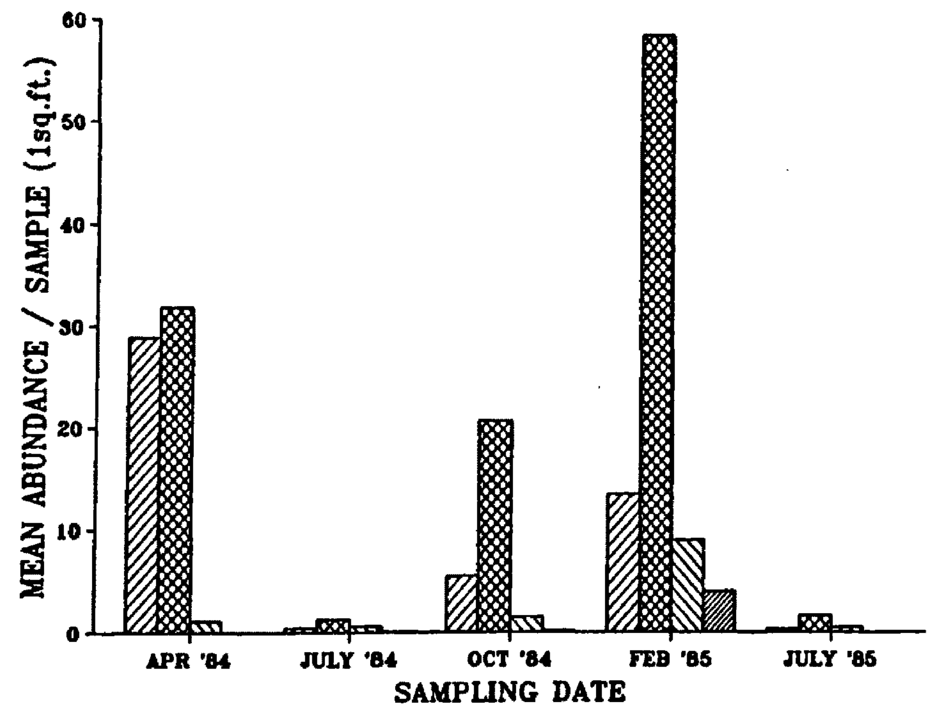

Figure 26. Mean abundance of Paraleptophlebia at four stations in Lake Creek, Mt. on five sampling dates in 1984-85. Control station 1 = [diagonal hatch], control station 2 = [cross hatch], impact station 3 = [reverse diagonal hatch], and impact station 4 = [dense hatch].

spill which reduced their survival.

Baetidae

Baetis was the most common genus present, followed in abundance by *Pseudocloeon*. Members of Baetidae are adapted to fast currents (Nielson 1950) and primarily consume detritus and diatoms (Gilpin and Brusven 1970). Baetids were most common in the impact area during February of both periods, averaging 20 individuals/sq.ft., or 222/sq.m.

After log-transformation, mean counts of Beatidae showed an insignificant correlation with the variance (r^2 = .0017).

On all dates in the baseline study Baetidae was more common at the impact station than at the control. Similarly in 1984-85, Baetidae was more common at the impact stations than the controls on all dates except July, which was the first sampling date following the June tailings spill. The hypothesis that the mean of the before differences equals the mean of the after differences cannot be rejected (t=-0.1687)(Fig. 27).

In the 1984-85 collections the impact area supported a significantly ($p<.0001$) greater number of Baetidae than the control area in both October and February. The remaining three dates show no meaningful differences between sites (Figs. 28 and 29).

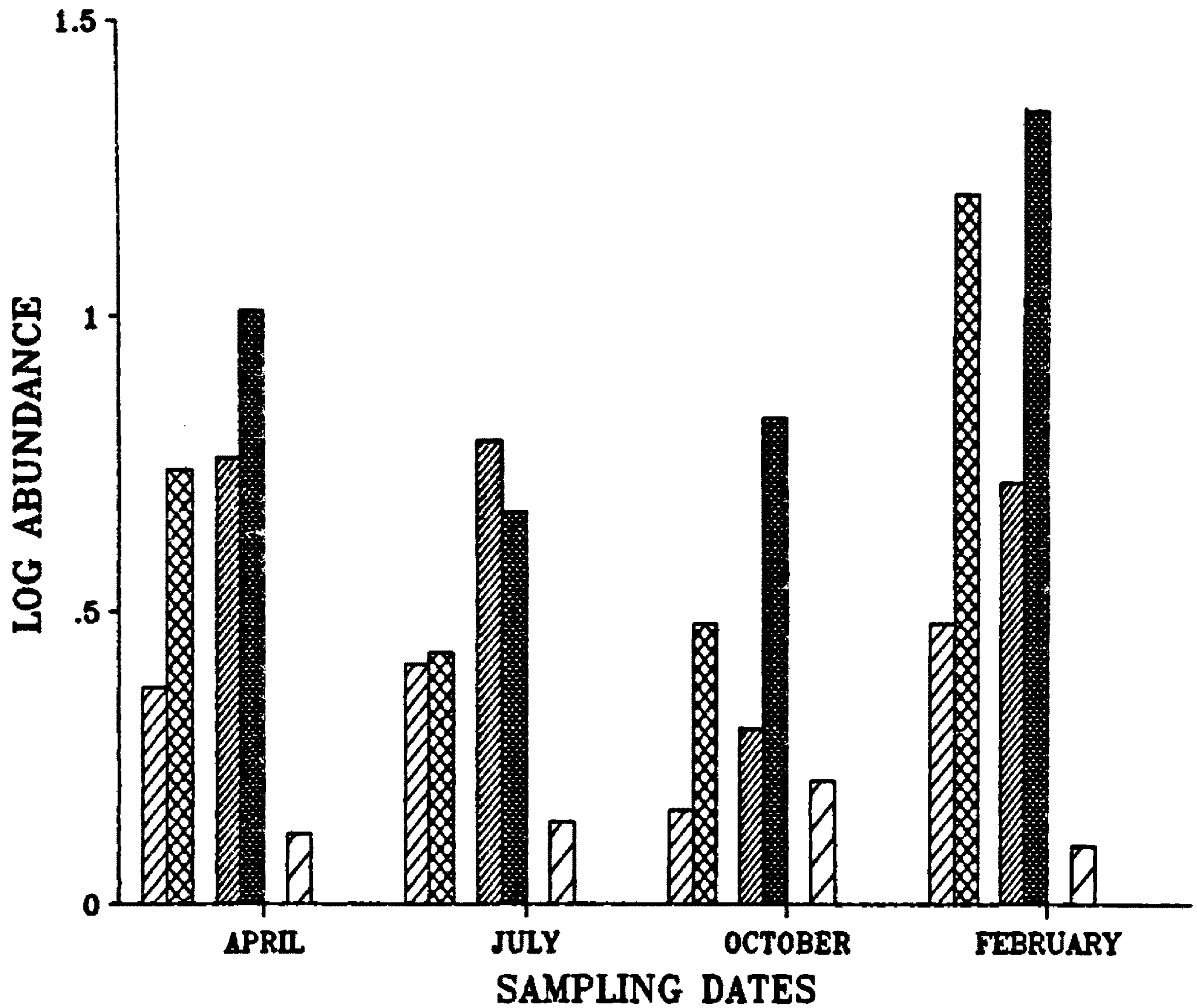

Figure 27. Log abundance of Baetidae at control and impact areas in 1977-78, and at control and impact areas in 1984-85. represents the change in the difference between control and impact areas from 1977-78 to 1984-85.

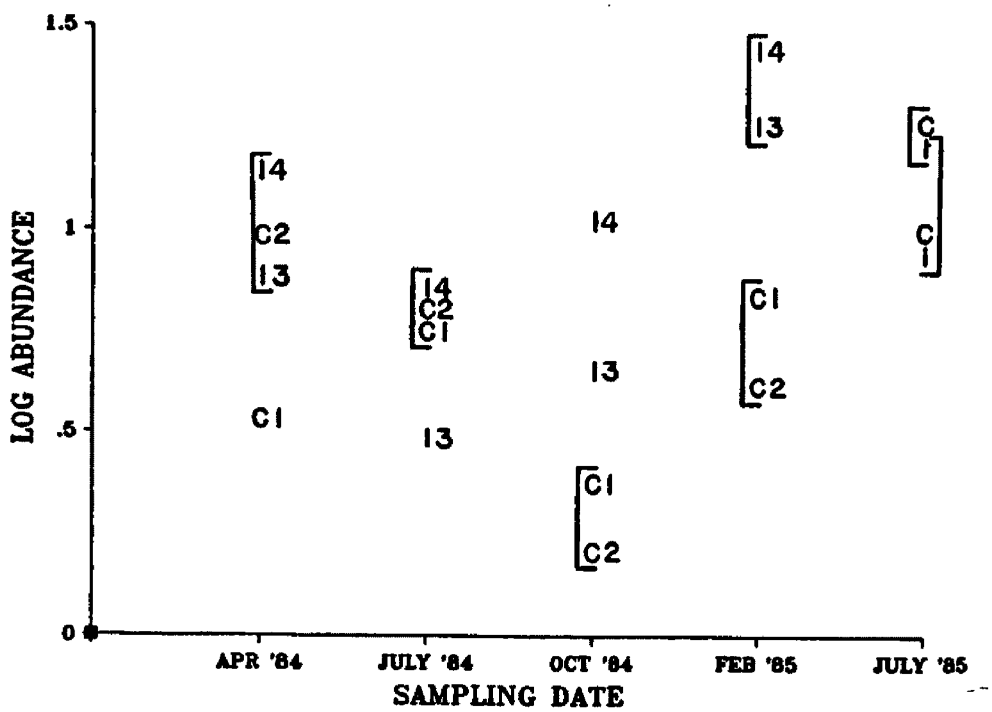

Figure 28. Log abundance of Baetidae at four stations in Lake Creek, Mt. in 1984 and 1985. C = control, I = impact, and the brackets denote groups that are not significantly different ($\alpha = 0.05$).

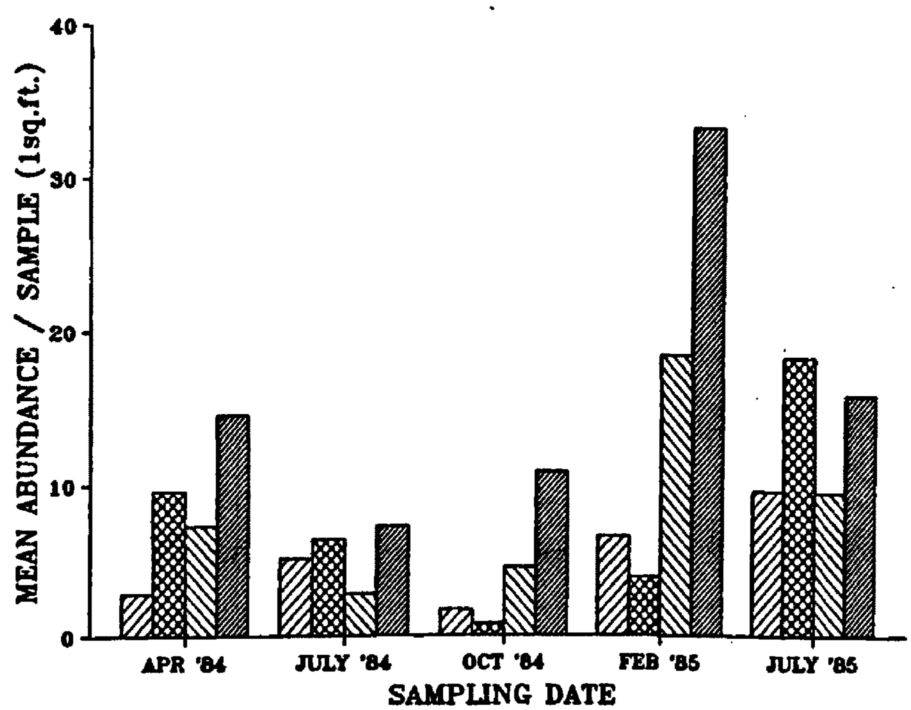

Figure 29. Mean abundance of Baetidae at four stations in Lake Creek, Mt. on five sampling dates in 1984-85. Control station 1 = ▨, control station 2 = ▩, impact station 3 = ▧, and impact station 4 = ▦.

Baetidae was consistently more abundant at the impact site than the control in 1977-78, and that pattern held in 1984-85 except for the July sampling date. The mixed results of the upstream-downstream comparison of 1984-85 support the finding that Baetidae were more abundant downstream of the impoundment, yet impact station 3 had the fewest Baetidae of all stations on three of five dates sampled. These ambiguous results give no clear indication of an impact. Abundances at both control and impact areas on all dates sampled in 1984-85 were greater than in 1977-78. This consistent increase may be the result of improved sampling efficiency. Unlike several of the other taxa which show an increase between baseline and 1984-85 at only the control location, Baetidae increased at both locations.

Diptera

Antocha spp.

Antocha is a genus of craneflies (Tipulidae) found in fast water in silken tubes clinging to rocks (Merritt and Cummins 1978).

The log-transformation was applied to the raw data changing the r^2 value from to .

In the baseline sampling period Antocha was more abundant at the impact site than the control site on three of the four dates sampled, although the average difference was marginal. After mining began, Antocha was much more abundant at the control stations on every date sampled. On average Antocha was more abundant at the control site and less abundant at the impact site in 1984 than it had been in 1977. The difference between before and after periods was significant ($t= -3.027$, $p<0.03$)(Fig. 30).

Comparison of Antocha abundance above and below the tailings impoundment in 1984-85 showed there to be significantly greater numbers at the control stations on three of the five dates sampled (Figs. 31 and 32). The two dates not showing significant differences were July 1984 and 1985. The life cycle of Antocha is such that the larval stage is present in low numbers in July, and demonstration of significant differences is most demanding under small sample sizes.

A change in distribution of Antocha was seen in which abundance was greater in the impact area preceding mining and shifted toward greater abundance in the control area after mining began. In addition the relative changes over time between control and impact sites were opposite: increasing at the control site and decreasing at the impact site. Part of the increase at the control site may be attributed to the Hess sampler, although if that is true then the decrease in the impact area was even greater than what was measured.

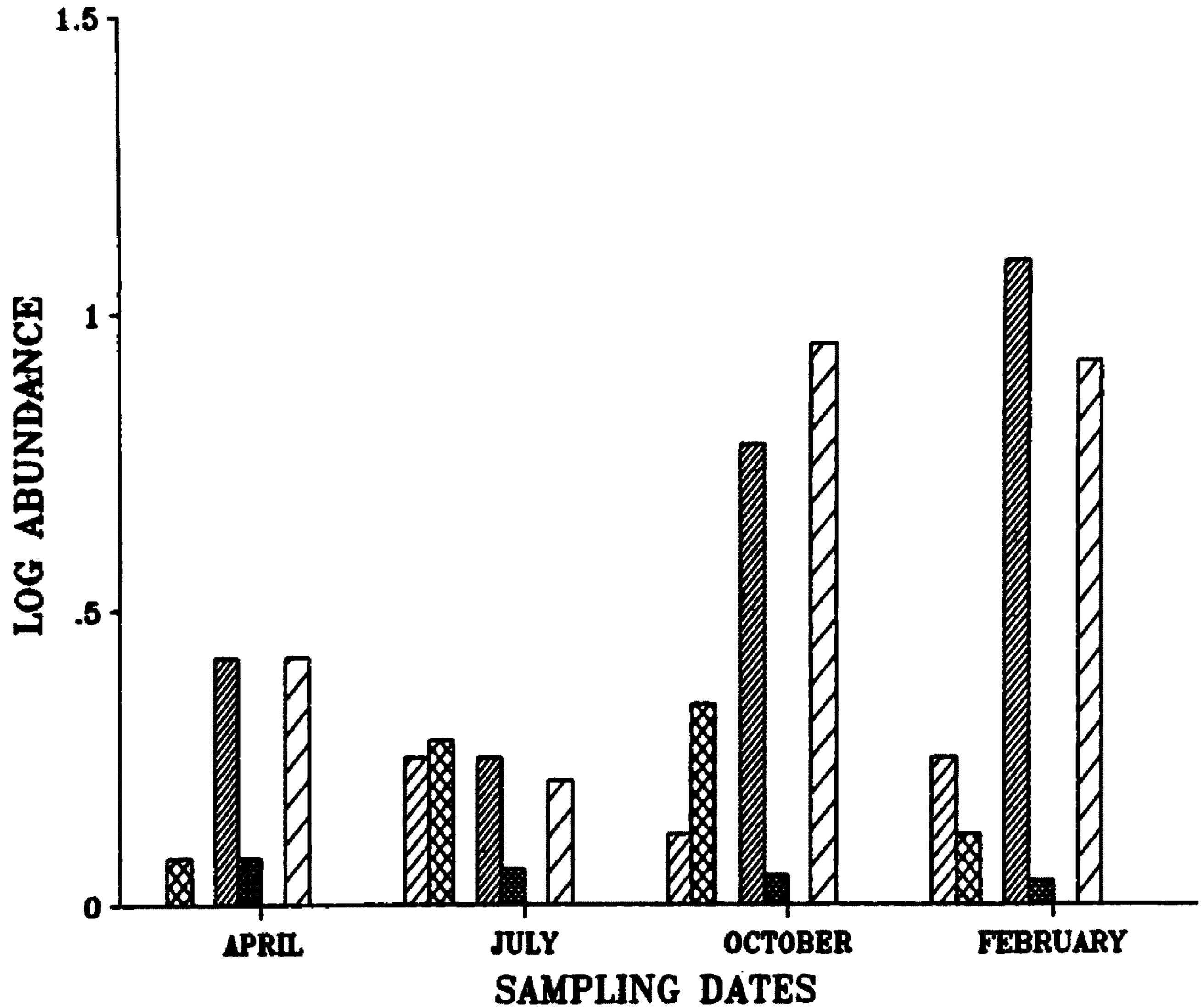

Figure 30. Log abundance of Antocha at control [legend] and impact [legend] areas in 1977-78, and at control [legend] and impact [legend] areas in 1984-85. [legend] *represents the change in the difference between control and impact areas from 1977-78 to 1984-85.*

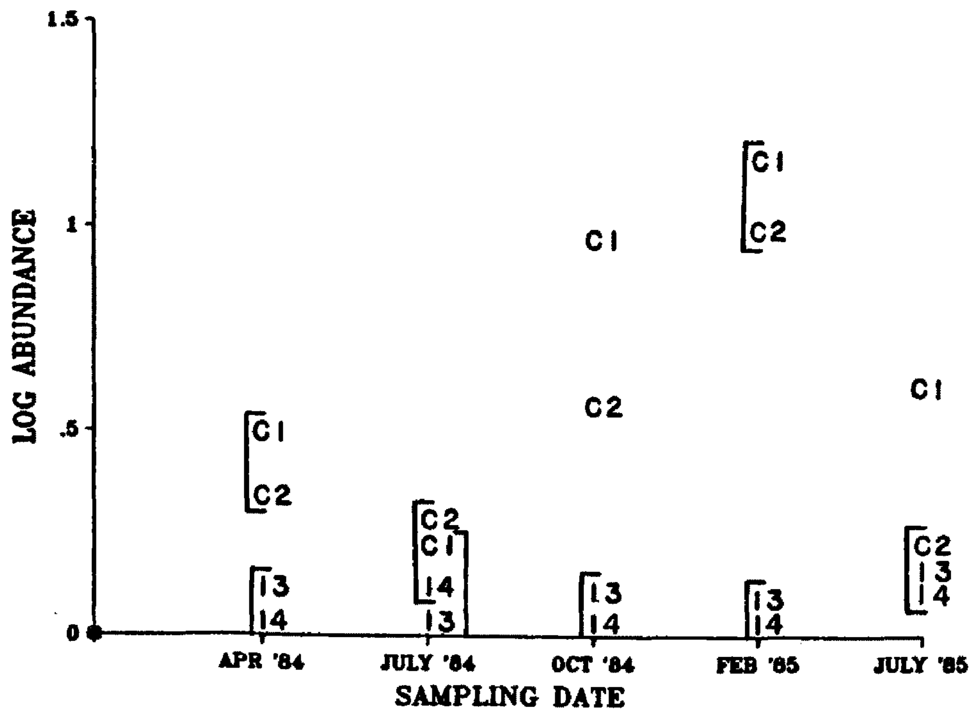

Figure 31. Log abundance of Antocha spp. at four stations in Lake Creek, Mt. in 1984 and 1985. C = control, I = impact, and the brackets denote groups that are not significantly different ($\alpha = 0.05$).

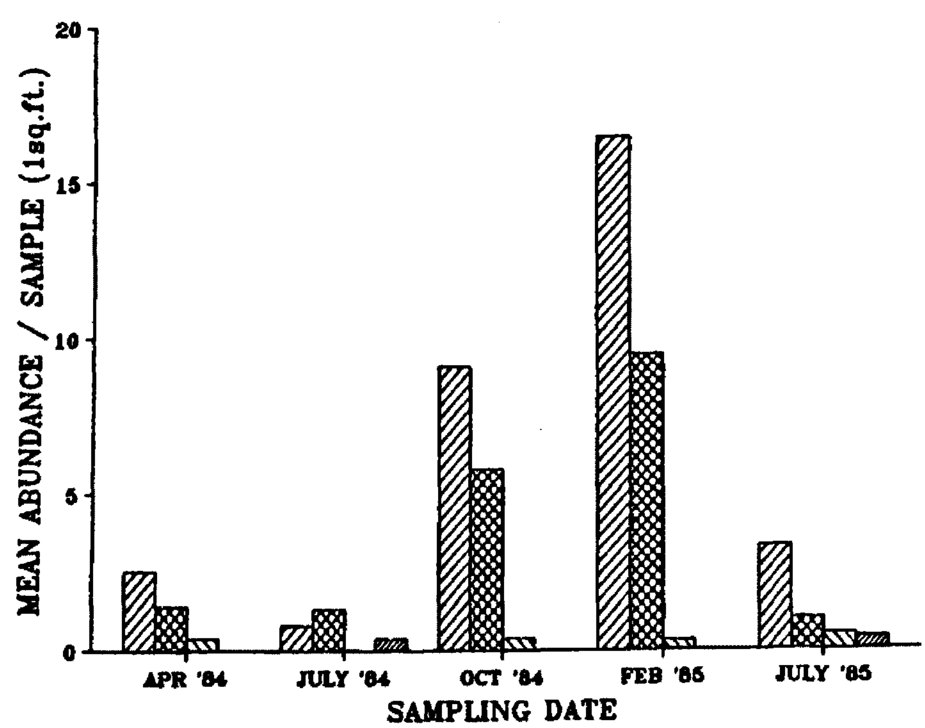

Figure 32. Mean abundance of Antocha spp. at four stations in Lake Creek, Mt. on five sampling dates in 1984-85. Control station 1 = [hatched], control station 2 = [cross-hatched], impact station 3 = [hatched], and impact station 4 = [hatched].

Chironomidae

Chironomids were only identified to the family level for this study, although 11 genera were identified in the baseline study. In many streams, such as the Kootenai River for example, chironomids are numerically dominant, but they never represented more than 20 percent of the total in the 1984-85 collections.

The log transformation clearly stabilized the variance (r^2 =.006).

The abundance of chironomids was substantially greater at the impact site than the control in 1977-78. In 1984-85 the relationship was reversed. The mean difference between the before and after periods was significant ($p<.006$). The abundance in 1984-85 as compared to the baseline, was greatly reduced at all stations and dates (with one exception)(Fig. 33).

Spatial differences in chironomid distribution in 1984-85 were significant ($p<.05$) in only two cases, and otherwise show mean chironomid abundance to be uniformly greater at the control than the impact area, but not significantly so ($p<.05$)(Figs. 34 and 35). The clear and significant reversal in abundance of chironomids from 1977-78 to 1984-85 is inconsistent with the changes observed in other taxa. Improved sampling efficiency in 1984-85

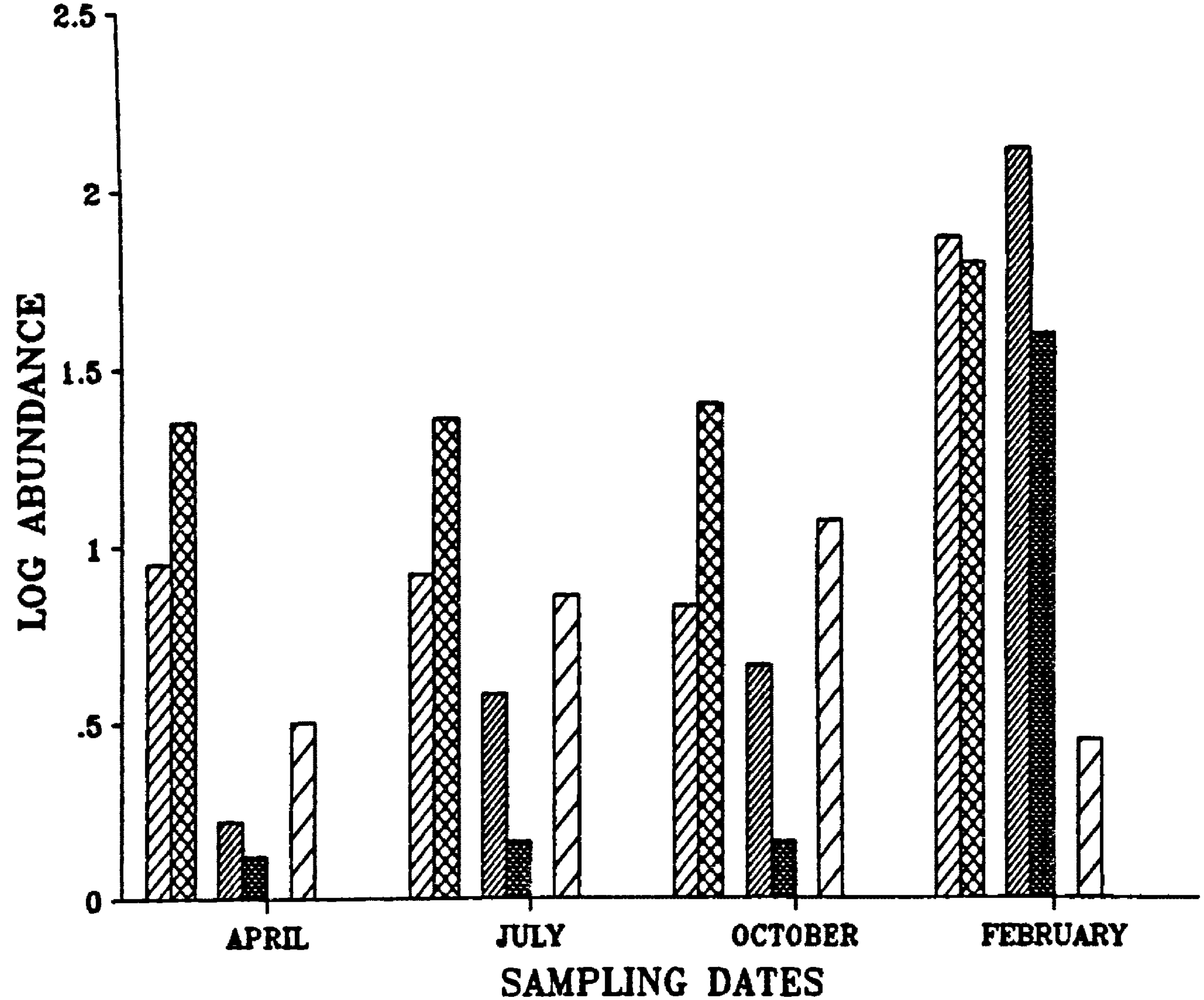

Figure 33. Log abundance of Chironomidae at control [legend pattern] and impact [legend pattern] areas in 1977-78, and at control [legend pattern] and impact [legend pattern] areas in 1984-85. [legend pattern] represents the change in the difference between control and impact areas from 1977-78 to 1984-85.

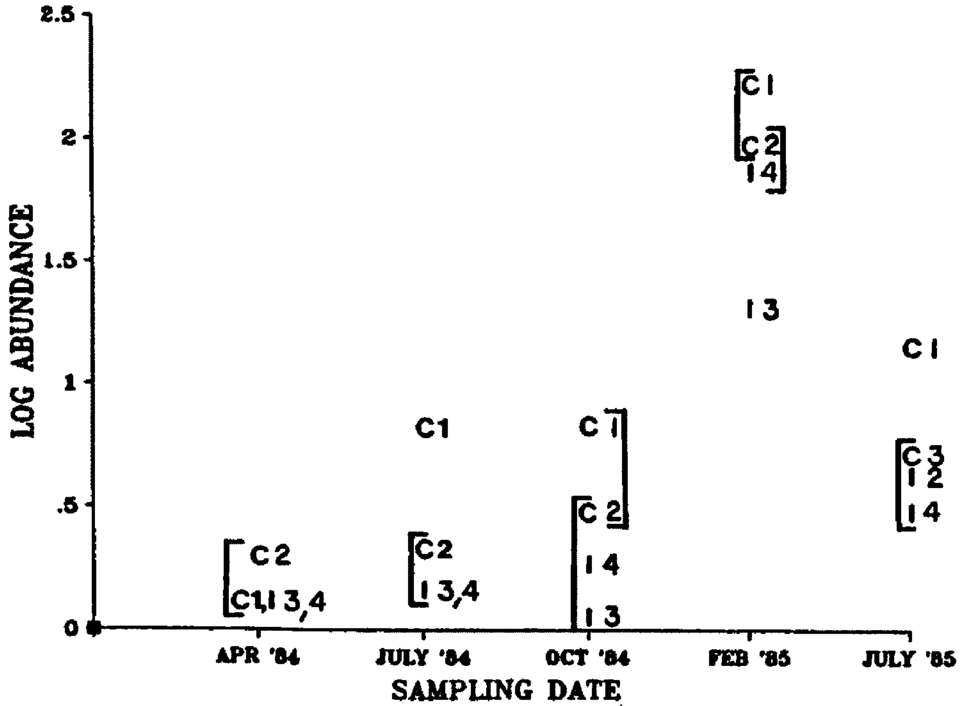

Figure 34. Log abundance of Chironomidae at four stations in Lake Creek, Mt. in 1984 and 1985. C = control, I = impact, and the brackets denote groups that are not significantly different (α = 0.05).

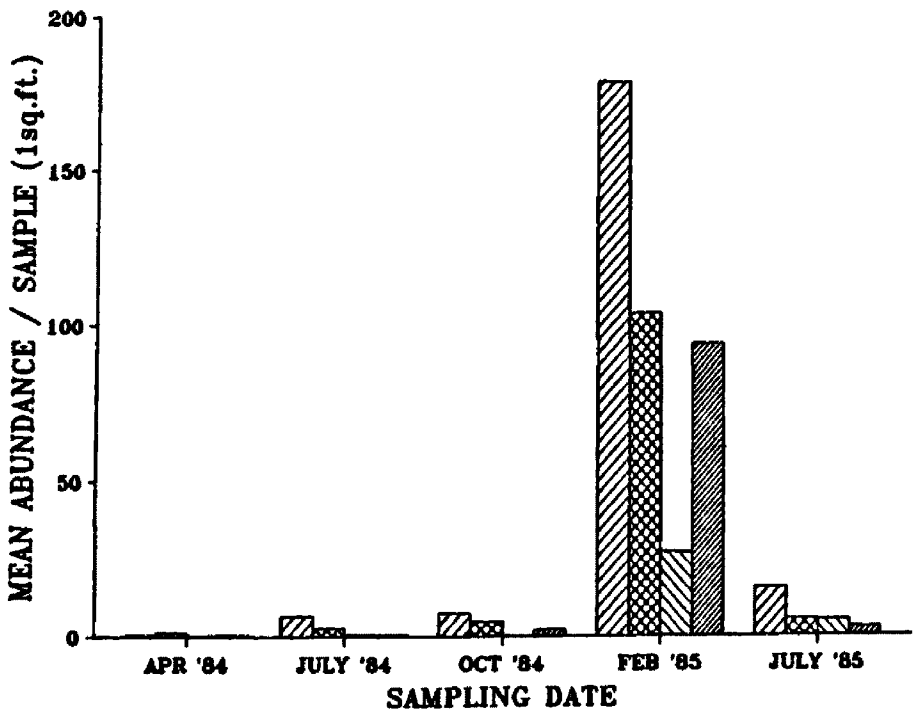

Figure 35. Mean abundance of Chironomidae at four stations in Lake Creek, Mt. on five sampling dates in 1984-85. Control station 1 = [pattern], control station 2 = [pattern], impact station 3 = [pattern], and impact station 4 = [pattern].

accentuates the magnitude of the measured decline in abundance. The impact area showed a proportionately larger decrease suggesting that an overall population decline may have been exaggerated in the impact area due to tailings contamination.

Surber (1959) and Winner et al. (1980) found several species of chironomids that were tolerant of heavy-metal stress. They also reported chironomids to be numerically dominant, comprising up to 96 percent of the individuals in communities exposed to metal pollution. Winner et al. (1980) noted that chironomids may demonstrate enormous diversity in streams (Lehman (1971) found 246 species in the Fulda in Germany) and that heavy-metal stress will decrease that diversity. If the decline of chironomids seen in 1984-85 is not the result of a natural population cycle, it may be that those species present in Lake Creek were sensitive to the effects of tailings contamination. Genus or species level identification of the 1984-85 collections may have clarified the question of sensitivity. The genus *Microspectra* was second most common in 1977-78, and was listed by Winner et al. (1980) as eliminated by heavy metal pollution.

Since chironomids have a demonstrated tolerance to pollution, and short generation times, it is surprising that their numbers did not increase after the tailings spill, similar to the increase in simuliids.

Simuliidae

The genus Simulium is the most common black fly in the study area. Black flies attach themselves to the substrate by silken threads and are capable of movement by belaying from point to point on the thread. Simulium spp. acts as a filter feeder by utilizing its cephalic fans for removing particles from the water.

Simuliids were uniformly uncommon in the baseline period, averaging less than one per sample. During this study period simuliids were seen to erupt into large concentrations, in which one particular sample contained 476 larvae and pupae.

Both log and fourth root transformations were successful in stabilizing the variance. The dependence of the variance on the mean in the raw data was high as indicated by $r^2 = 0.89$. The r^2 value for each transformation was about 0.41. Since the results of the Bartlett's Box F ($p<.27$ vs. $p<.003$) and Max/Min Variance (5.2 vs. 19.6) tests so heavily favored the fourth root transformation, it was the one used.

During 1977, measured simuliid abundance at control and impact stations was equal on three dates, and marginally different on the fourth. In 1984-85 simuliids were substantially more abundant in the impact area than the control. The difference between the before and after periods was significant ($t=2.759$, $p<.04$)(Fig. 36).

In April and July of 1984, control and impact stations were not significantly different, but in October, February, and July 1985, they were significantly different ($p<.0001$)(Figs. 37 and 38).

Simuliid numbers were uniformly low in 1977-78. The control stations, even though they were nearer Bull Lake, had low numbers of simuliids, supporting the earlier contention that these stations are not part of a lake outlet community. The significance of the difference between periods suggests an impact and the significant difference between impact and control areas reinforces the suggestion. On all dates in 1984-85 except April, abundance at the control area was greater than in 1977-78. Increased sampler efficiency and sample size may largely explain that difference. It does not explain why there is a tremendous increase in the impact area in October and February, and only a moderate increase in April and July. The timing and the magnitude of the increases suggest that the tailings spill of June 1984 is primarily responsible. If the effect of the spill was to cause a large, but short term reduction in standing crop, then the organism best adapted for colonization would be favored to fill the empty habitat. Because of their short generation times and

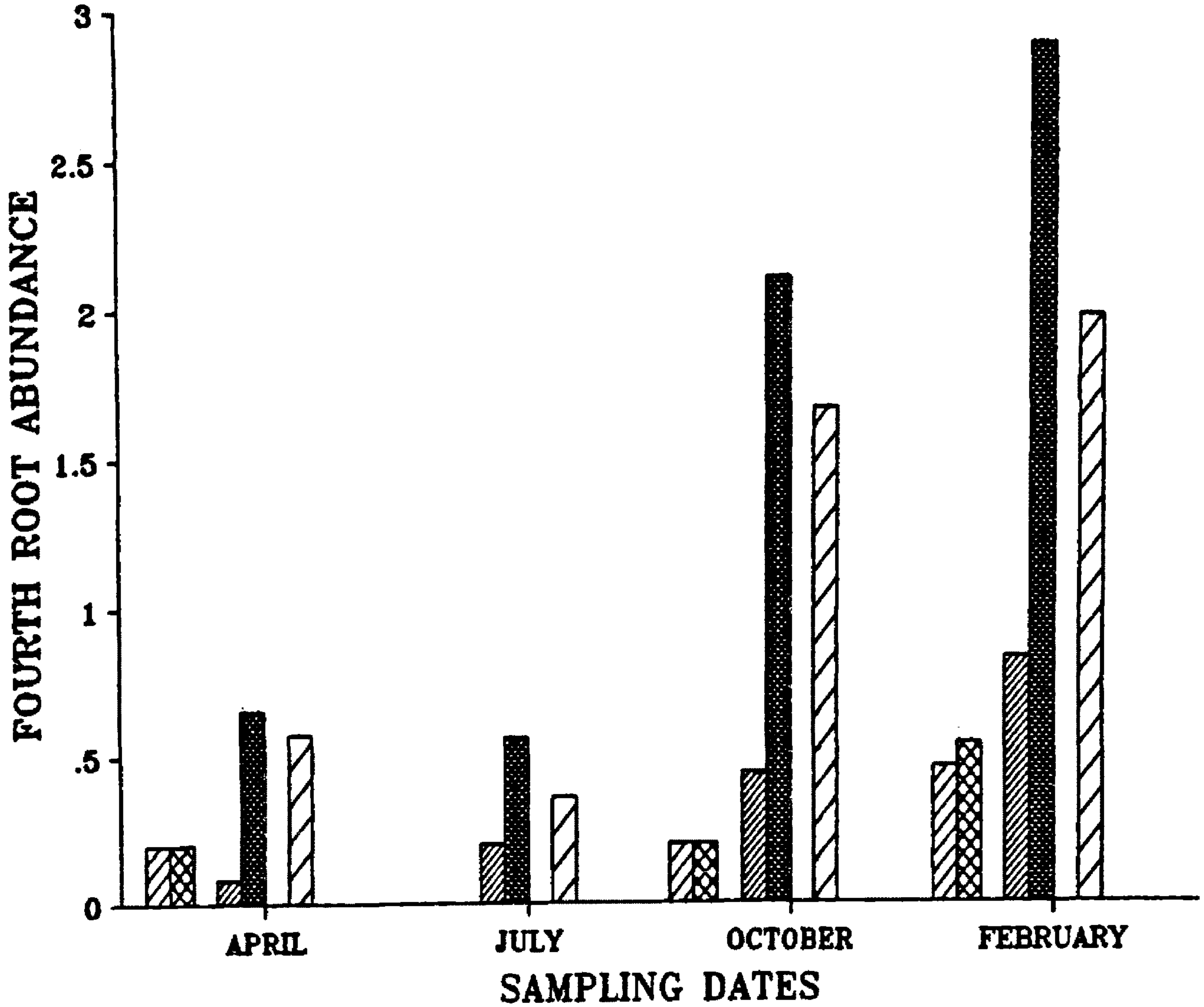

Figure 36. Fourth root abundance of Simuliidae at control and impact areas in 1977-78, and at control and impact areas in 1984-85. represents the change in the difference between control and impact areas from 1977-78 to 1984-85.

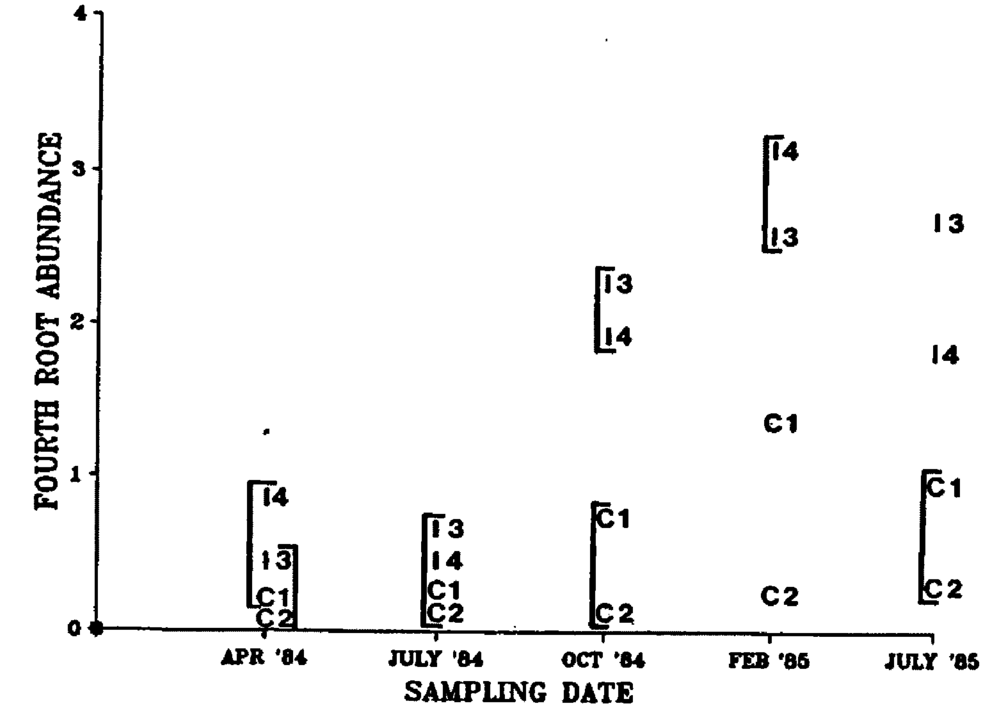

Figure 37. Fourth root abundance of Simuliidae at four stations in Lake Creek, Mt. in 1984 and 1985. C = control, I = impact, and the brackets denote groups that are not significantly different ($\alpha = 0.05$).

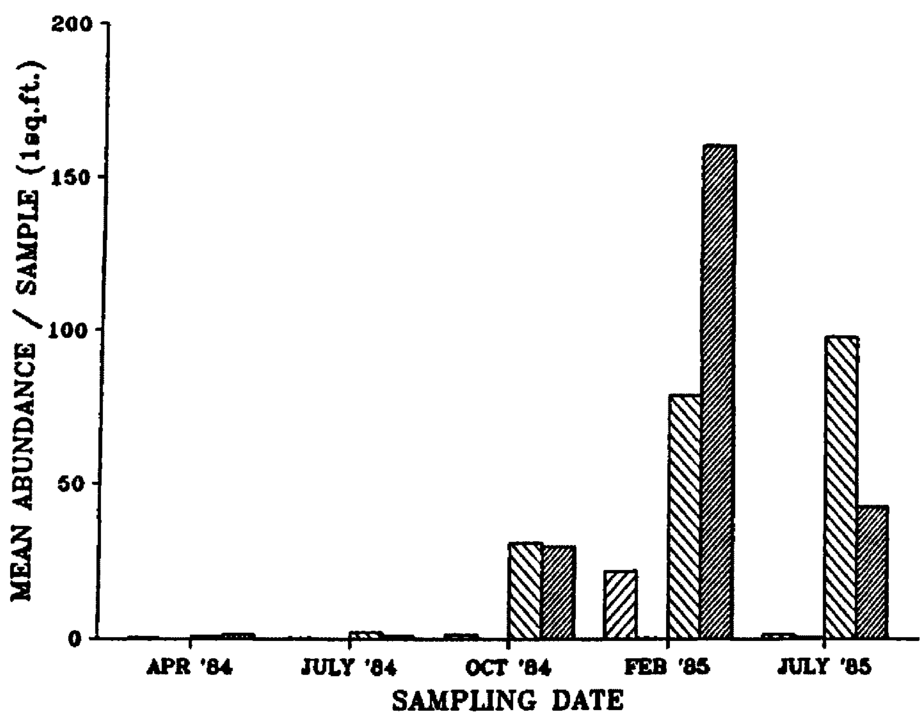

Figure 38. Mean abundance of Simuliidae at four stations in Lake Creek, Mt. on five sampling dates in 1984-85. Control station 1 = [hatched pattern], control station 2 = [crosshatched pattern], impact station 3 = [hatched pattern], and impact station 4 = [shaded pattern].

multivoltine life cycle, simuliids would be so favored (Carlson 1977).

In the April sample which preceded the spill, the difference between control and impact areas was relatively small. The July 1984 sampling was the first after the spill and differences were still small, perhaps because simuliids had not had sufficient time to respond to the open habitat. The simuliid increase was expressed in October, and continued to the end of sampling in July 1985. Harrison (1966) found simuliids to be among the first colonizers, and in large numbers after the resumption of flow in two temporary streams in southern Africa. Patrick (1959) found Simulium to be the first animal established in an artificial stream after it received water from a natural stream. The greater number of simuliids at the impact site in 1984-85 than in 1977-78 may be due to increased sampling efficiency and number, but is more likely the result of suppression of simuliid competitors caused by tailings contamination.

Coleoptera

Heterlimnius corpulentus

Riffle beetles are clingers found in cobbles and gravel. Patterns of distribution in the baseline and 1984-85 periods were similar in that H. corpulentus was substantially more abundant at the control site in both periods. This distribution suggests a gradient, possibly related to Bull Lake, even though the sample stations are assumed to be out of the immediate influence of the lake as argued earlier.

The log-transformation of the raw data was successful reducing the r^2 value from 0.82 to 0.01.

The difference between periods was significant ($t= 4.619$, $p<0.008$)(Fig. 39).

The difference between the control and impact areas in the 1984-85 period was significant ($F= 160$, $p<.0001$). On all dates the control stations had significantly more H. corpulentus than the impact stations (Figs. 40 and 41).

The highly significant results strongly indicate an impact. Uncertainty exists in the form of a possible gradient in distribution that mimics an impact effect. H. corpulentus presents unusual problems for impact detection, since it was abundant in the control area and rare in the downstream area even before mining began. This problem is compounded by the fact that H. corpulentus increased in the impact area in 1984-85 relative to baseline levels. The conclusion of significant differences between periods is based on the assumption that downstream abundances should have increased to the same degree as they did upstream, and the fact that they failed to is due to a downstream

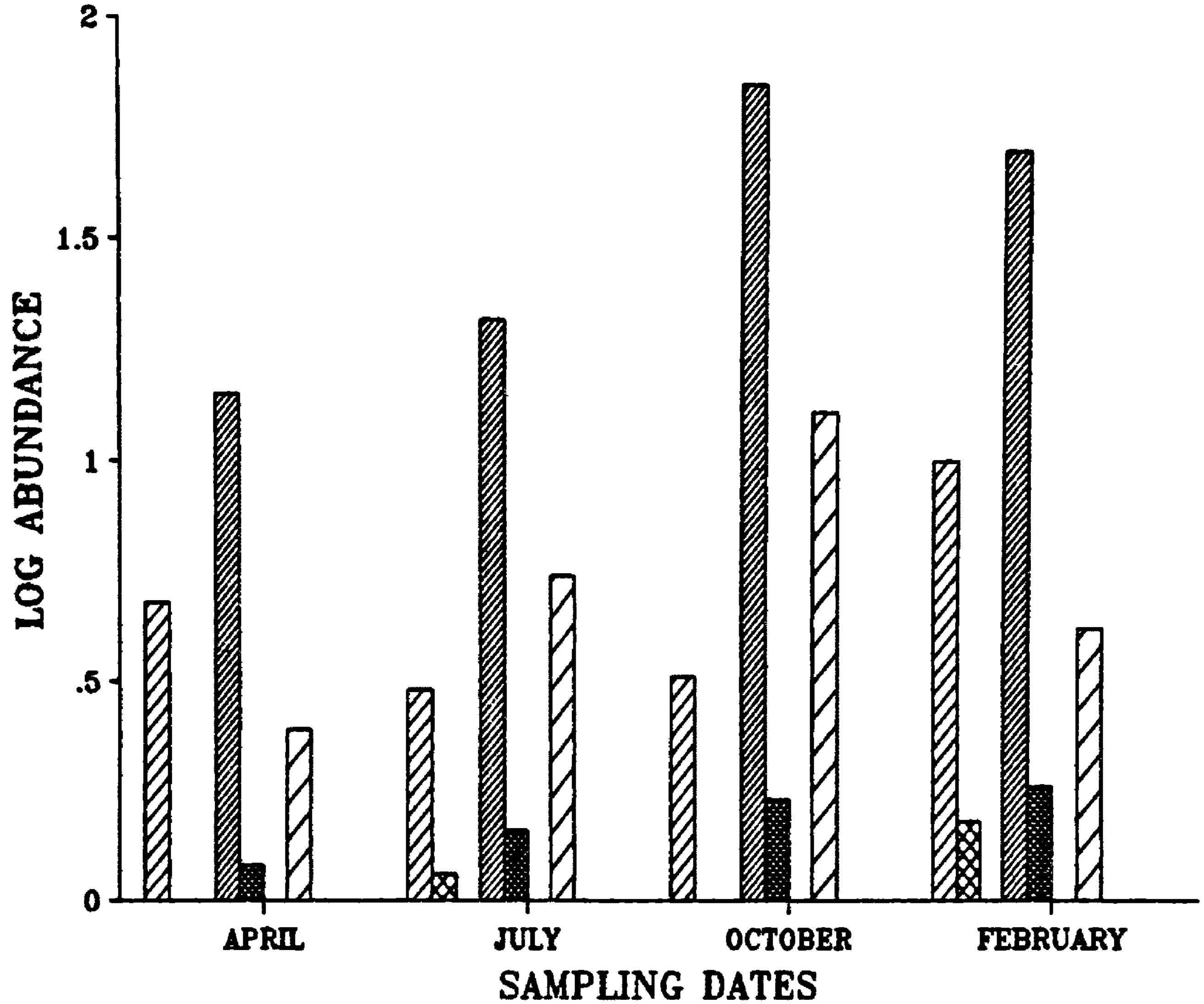

Figure 39. Log abundance of Heterlimnius at control and impact areas in 1977-78, and at control and impact areas in 1984-85. represents the change in the difference between control and impact areas from 1977-78 to 1984-85.

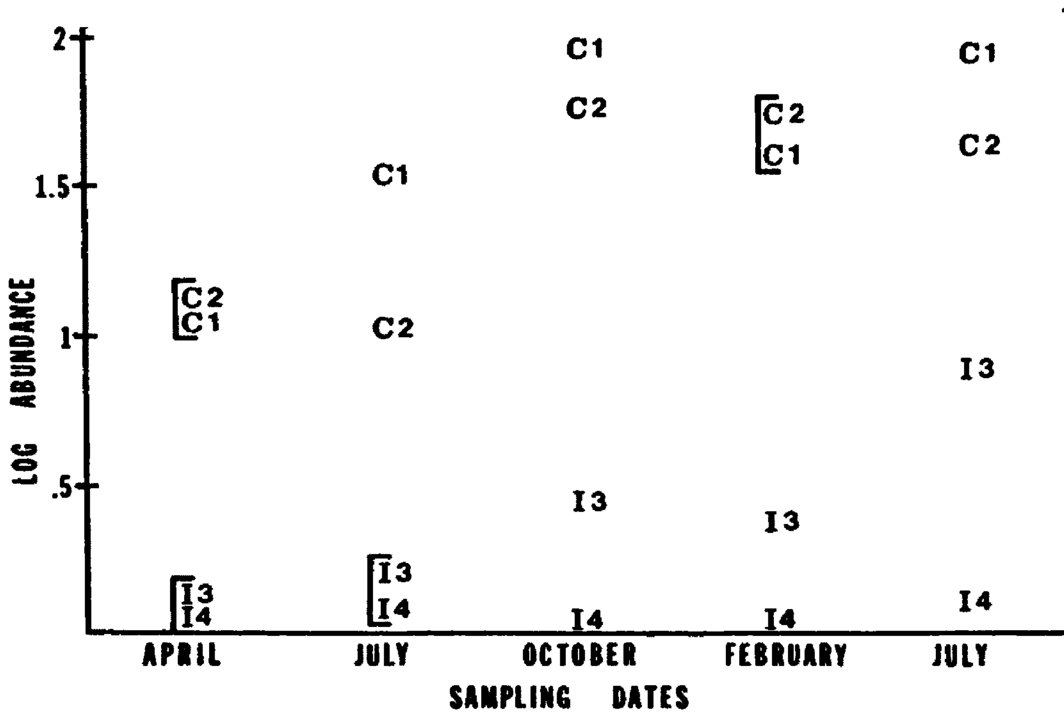

Figure 40. Log abundance of Heterlimnius corpulentus at four stations in Lake Creek, Mt. in 1984 and 1985. C = control, I = impact, and the brackets denote groups that are not significantly different (α = 0.05).

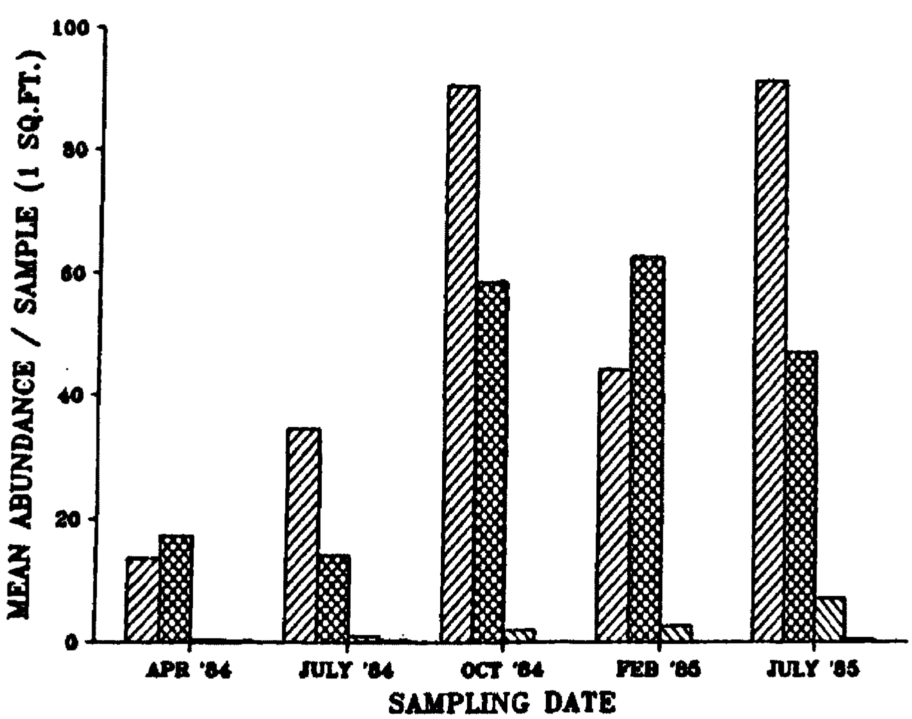

Figure 41. Mean abundance of Heterlimnius corpulentus at four stations in Lake Creek, Mt. on five sampling dates in 1984-85. Control station 1 = ▨, control station 2 = ▩, impact station 3 = ▧, and impact station 4 = ▦.

stress. Another possibility is that the population in the control area is fluctuating on a cycle with greater amplitude than that in the impact area so that the differences are multiplicative (Stewart-Oaten et al. 1986). In such a case 1977-78 would have been the low cycle, 1984-85 the high cycle, and this would explain the increased difference in abundance, rather than effects of tailings contamination. Tukey's test for additivity was not applied to the raw data, but rather a subjective review was made. The numerical changes in both control and impact areas did not appear extreme enough to be multiplicative.

Plecoptera

Perlidae

Claassenia sabulosa and Hesperoperla pacifica were the two most common representatives of this family. These are among the largest aquatic insect predators in Lake Creek.

The log-transformation of perlid abundance successfully stabilized the variance (r = 0.006).

Perlid abundance in 1977-78 was comparable at upstream and downstream stations. In 1984-85 abundance was greater at the impact stations than the controls. This shift did not represent a significant change($t=1.089, p>0.05$)(Fig.42).

Spatial differences in perlid distribution in 1984-85 were not significant ($p>0.05$) and offered little insight

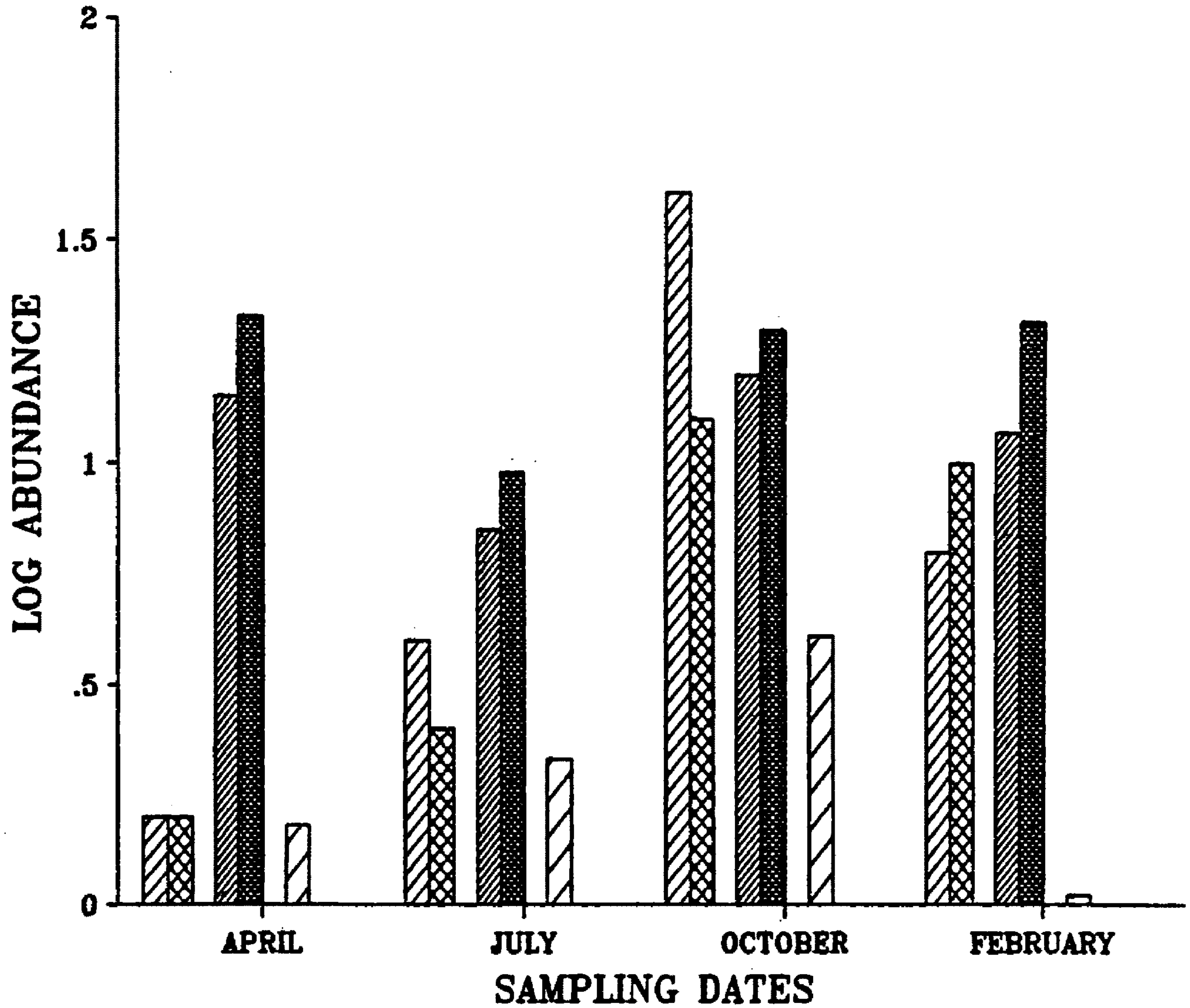

Figure 42. Log abundance of Perlidae at control and impact areas in 1977-78, and at control and impact areas in 1984-85. represents the change in the difference between control and impact areas from 1977-78 to 1984-85.

into impact effects (Figs. 43 and 44).

The slight, although consistently greater abundance of perlids in the impact area in 1984-85 suggests that the increases seen in the simuliids and ephemerellids were not the result of reduced predation by perlids.

Chloroperlidae

Sweltsa spp. is the most common member of this family in Lake Creek. It is a predator, smaller than the perlids, but much more numerous.

Log-transformation of cholorperlid abundance data successfully stabilized the variance.

During baseline sampling, chloroperlid abundance at control and impact stations was similar. In 1984-85 the number of chloroperlids collected was much greater than during the baseline, but still the control and impact stations were similar (Fig. 45). The difference between periods was not significant ($p<0.05$).

In 1984-85 control and impact stations were never isolated as significantly different pairs ($p>.05$), and therefore demonstrated no impact (Fig. 47). Noteworthy is that in April, control stations averaged about twice as many individuals as impact stations, but on all dates following the tailings spill chloroperlids had higher abundance in the impact area.

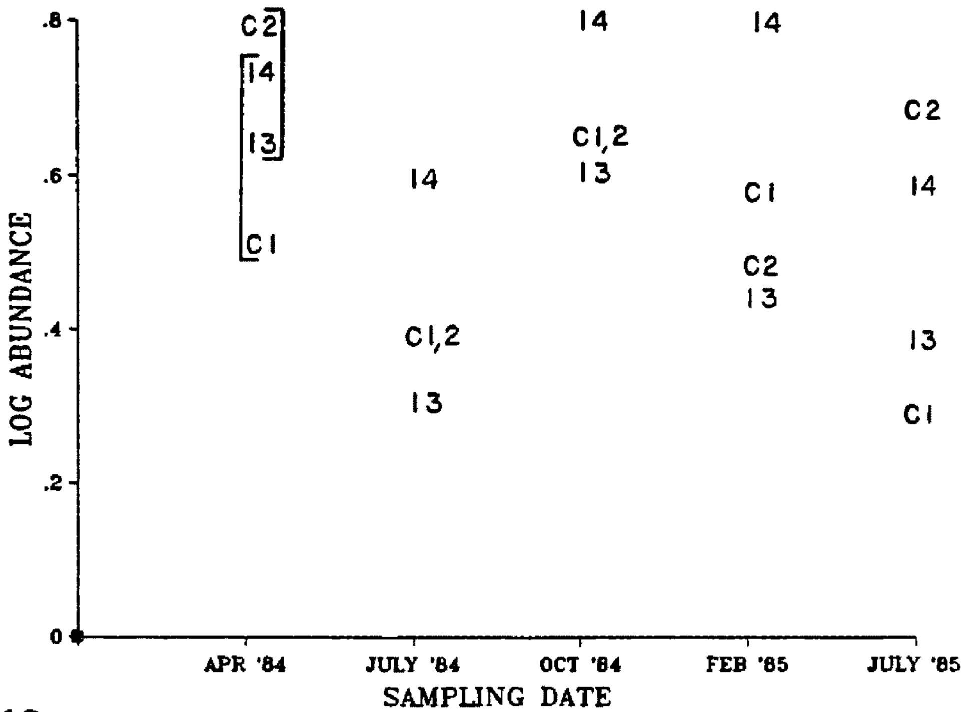

Figure 43. Log abundance of Perlidae at four stations in Lake Creek, Mt. in 1984 and 1985. C = control, I = impact, and the brackets denote groups that are not significantly different (α = 0.05).

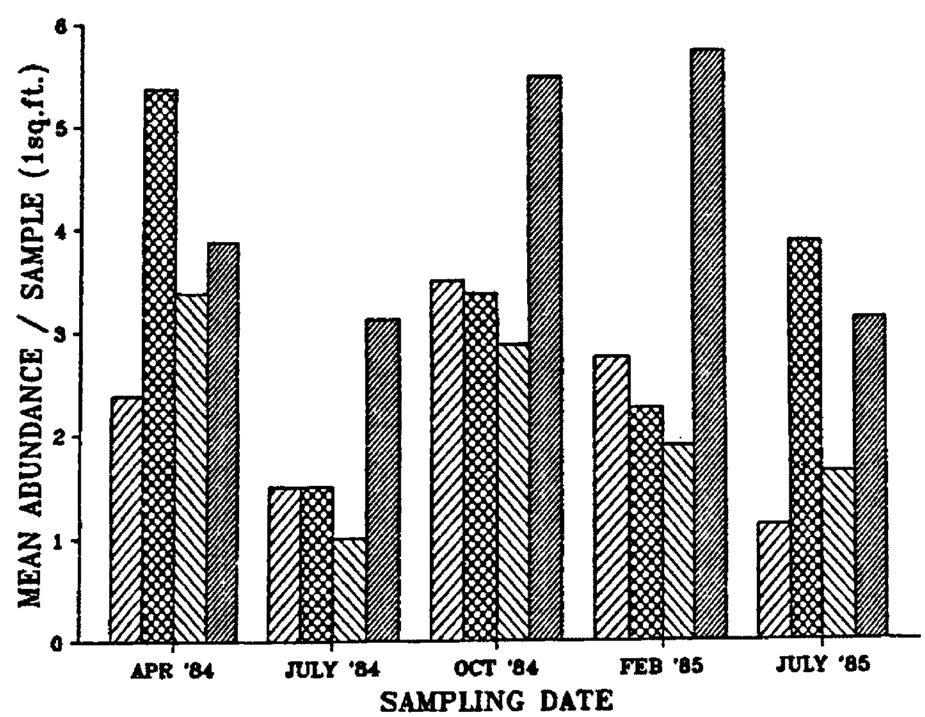

Figure 44. Mean abundance of Perlidae at four stations in Lake Creek, Mt. on five sampling dates in 1984-85. Control station 1 = [hatched symbol], control station 2 = [cross-hatched symbol], impact station 3 = [hatched symbol], and impact station 4 = [shaded symbol].

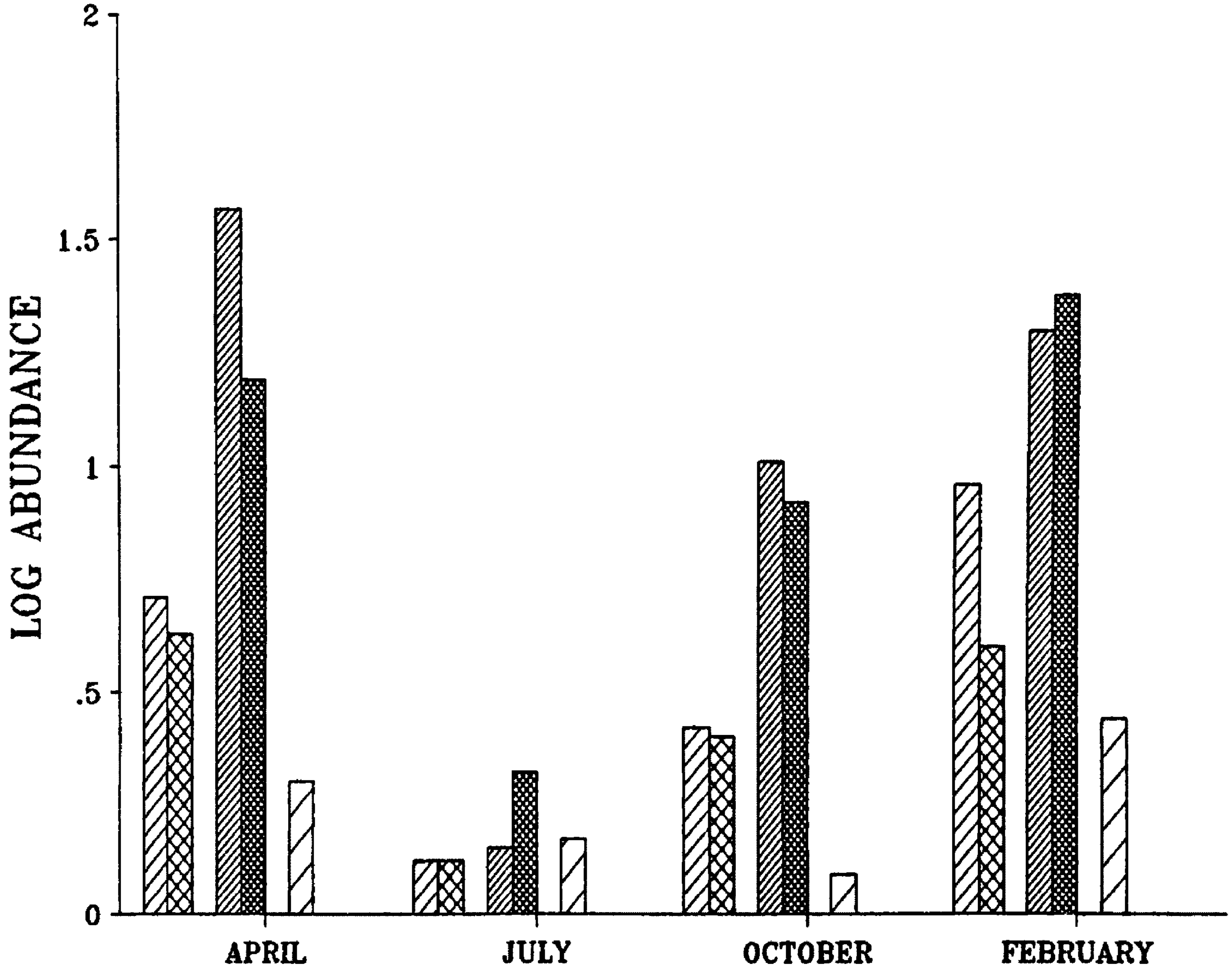

Figure 45. Log abundance of Chloroperlidae at control [legend pattern] and impact [legend pattern] areas in 1977-78, and at control [legend pattern] and impact [legend pattern] areas in 1984-85. [legend pattern] represents the change in the difference between control and impact areas from 1977-78 to 1984-85.

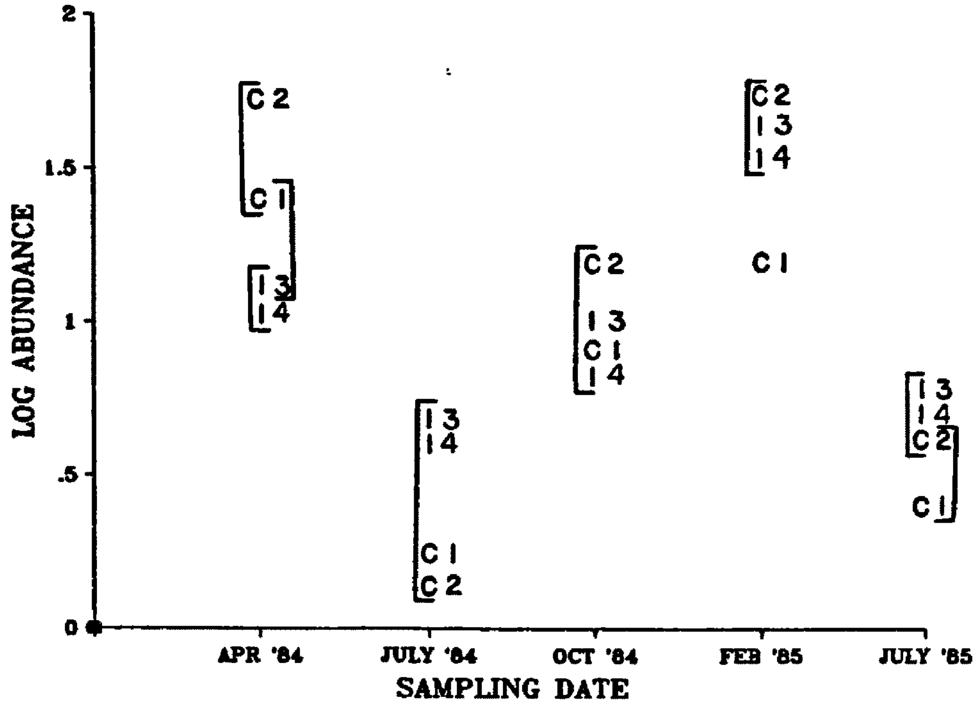

Figure 46. Log abundance of Chloroperlidae at four stations in Lake Creek, Mt. in 1984 and 1985. C = control, I = impact, and the brackets denote groups that are not significantly different ($\alpha = 0.05$).

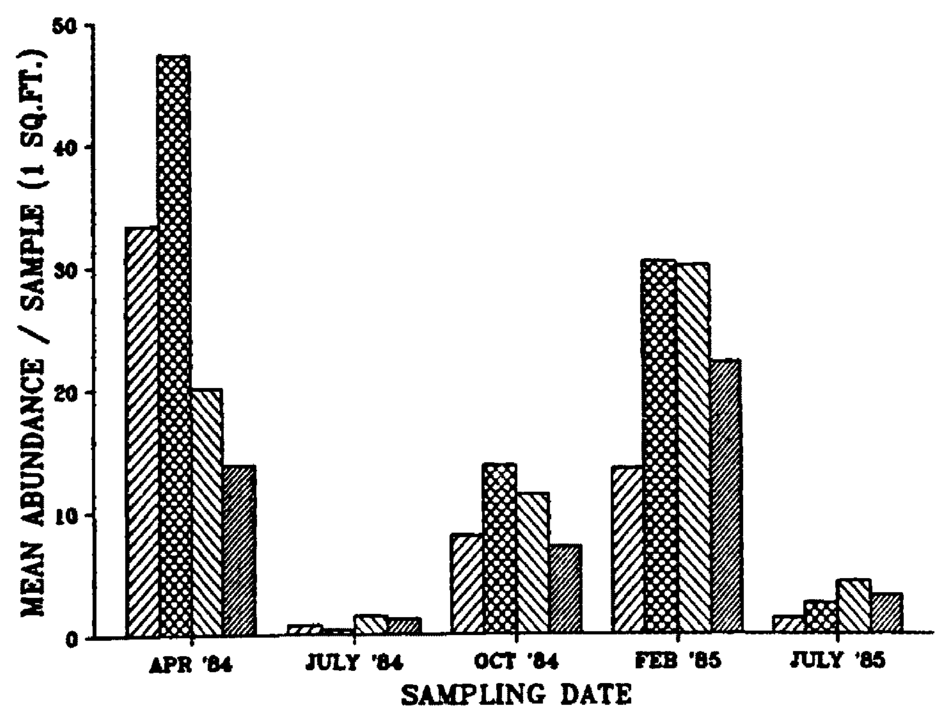

Figure 47. Mean abundance of Chloroperlidae at four stations in Lake Creek, Mt. on five sampling dates in 1984-85. Control station 1 = [hatched pattern], control station 2 = [cross-hatched pattern], impact station 3 = [hatched pattern], and impact station 4 = [shaded pattern].

Total Abundance

The total abundance of macroinvertebrates in Lake Creek is difficult to compare to other streams since the 1000 mesh capture net used in this study is larger than what has generally been used in other studies. The annual mean number of macroinvertebrates per square meter at the 1984-85 control site in Lake Creek was 15,100, while in the nearby Kootenai River in 1979-80 it was 19,600, and in the Fisher River it was 10,700 (Perry 1983).

The total abundance data were log-transformed effectively reducing the dependence of the variance on the mean (r^2 =0.58 to r^2 =0.11).

In the baseline period, the control and impact sites were similar, with the impact site having a slightly greater average abundance. In 1984-85, the control and impact sites were much different, with the control site having substantially more macroinvertebrates on all dates. The difference between periods was significant ($t=-3.7513$, $p<0.009$)(Fig. 48).

In April and July of 1984, the control stations were significantly different than the impact stations ($p<.0001$). In October and February station 1 was significantly greater than all other stations. In October station 2 was significantly greater than station 3, but not station 4, and in February station 2 was not significantly different than either stations 3 or 4 (Figs. 49 and 50).

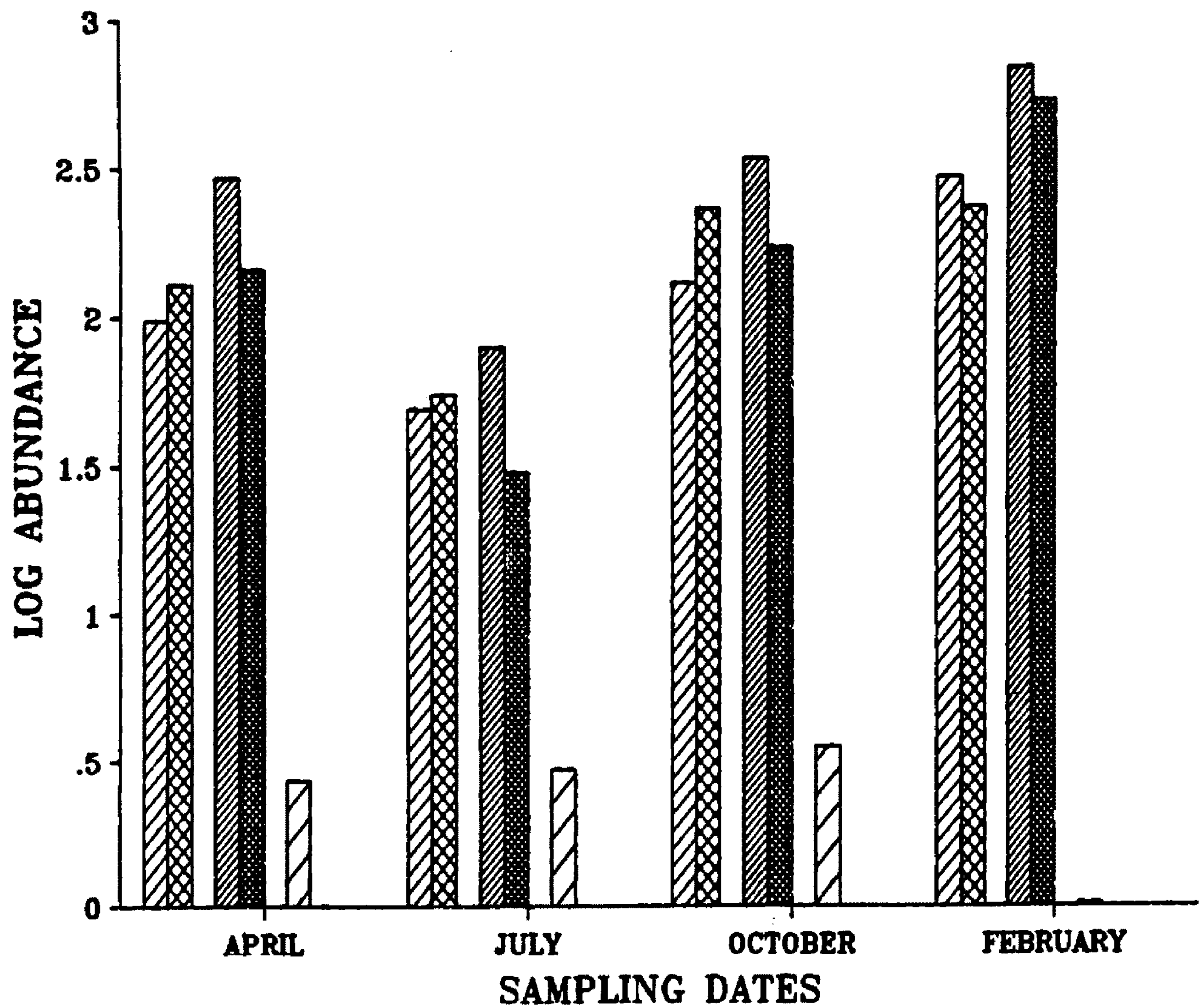

Figure 48. Log of total macroinvertebrate abundance at control [hatched] and impact [crosshatched] areas in 1977-78, and at control [fine hatched] and impact [stippled] areas in 1984-85. [open hatched] represents the change in the difference between control and impact areas from 1977-78 to 1984-85.

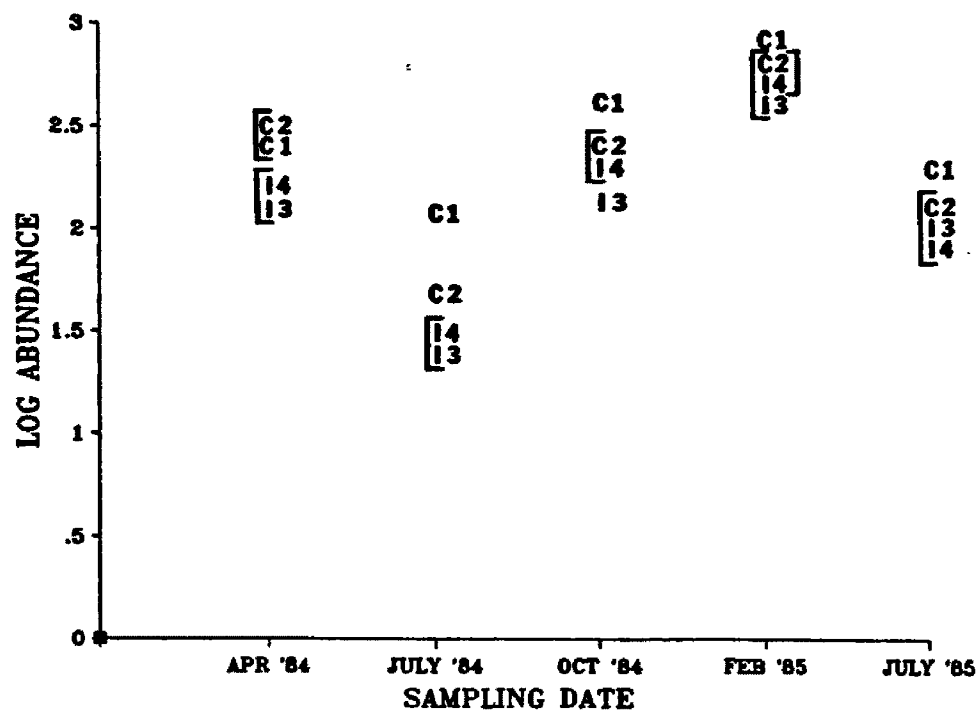

Figure 49. Log of total macroinvertebrate abundance at four stations in Lake Creek, Mt. in 1984 and 1985. C = control, I = impact, and the brackets denote groups that are not significantly different ($\alpha = 0.05$).

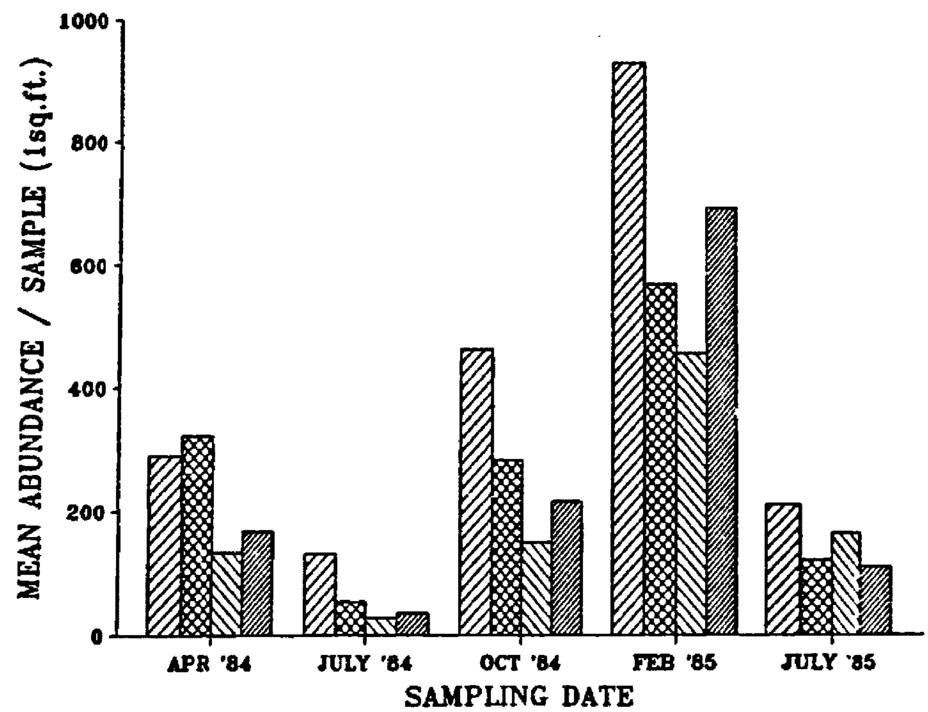

Figure 50. Mean total macroinvertebrate abundance at four stations in Lake Creek, Mt. on five sampling dates in 1984-85. Control station 1 = [hatched pattern], control station 2 = [crosshatched pattern], impact station 3 = [hatched pattern], and impact station 4 = [hatched pattern].

The failure of station 2 to be significantly different than stations 3 and 4 in October and February is due to the large increase in simuliids over that time period. The pattern of slightly higher abundance downstream than upstream in 1977-78 was reversed in 1984-85, when abundance at the control stations was substantially higher than at the impact stations. Abundance at the control was higher in 1984-85 than in 1977-78 on every date. Improved sampling efficiency may largely explain the difference. The measured abundance during the April and February sampling dates was higher in the 1984-85 period than it had been in the baseline period. On the dates immediately following the tailings spill, July and October 1984, abundance in the impact area was lower than it was in 1977, even with improved sampling efficiency.

Total Taxa

Comparison of the total taxa present can be helpful in determining the effects of stress on community structure. Rather than use mathematical diversity indices, the mean number of taxa present at each station was considered. Temporal comparisons of total taxa are not feasible due to differences in taxonomic resolution and methodology, and changes in taxonomy since the 1977-78 baseline.

No transformation was employed since the raw data for number of taxa is normally distributed, and the variance shows no appreciable correlation with the mean (r^2 =.0065).

There were generally more taxa present in 1984-85 at the control stations than the impact stations, but the relationship is only significant ($p<.05$) in October (Fig. 51). On each sampling date there were more taxa found only in the control area than taxa found only in the impact area (Fig. 52). Seven taxa (Dicosmoecus sp., Onocosmoecus sp., Lepidostoma sp., Hydroptila sp., Ameletus sp., and Drunella spinifera) were common in the control area and rare or absent in the impact area. Drunella spinifera was collected in the control area on three dates and never in the impact area. Drunella pelosa is the only taxon consistently in the impact area and not the control.

Community Composition

It is unlikely that the benthic organisms of Lake Creek would all have uniform tolerances to tailings contaminaton. Therefore relative abundances of organisms should change when exposed to the stress of contamination, tolerant ones increasing and intolerant ones decreasing. The percent composition of each major insect order at each sampled station gives a gross indication of species shifts that may be caused by stress.

In April 1977, Ephemeroptera occupied a larger share of

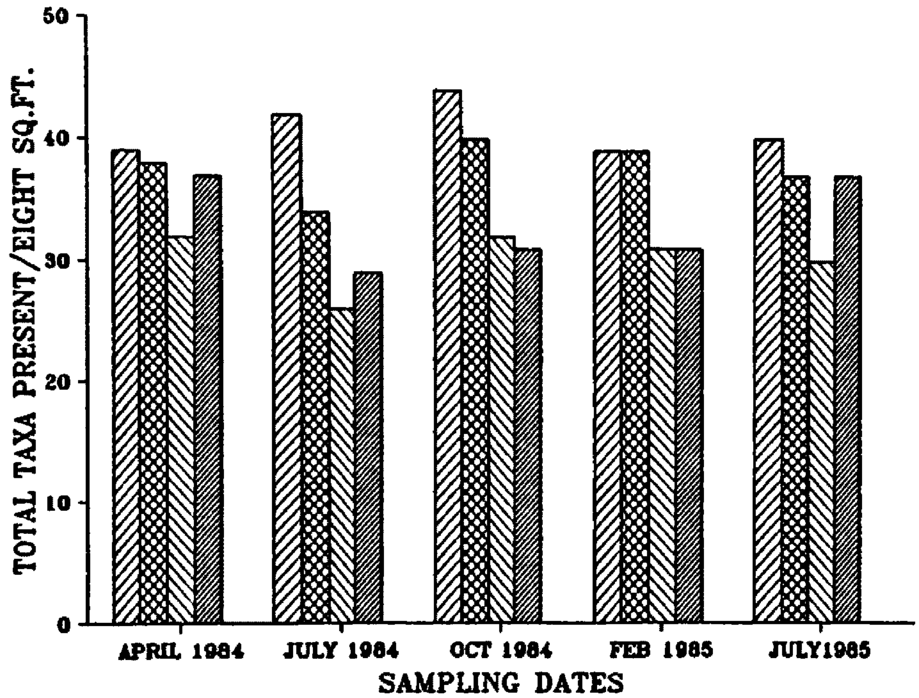

Figure 51. Total number of macroinvertebrate taxa present at four stations in Lake Creek, Mt. on five sampling dates in 1984 and 1985. [hatched] = control(1), [crosshatched] = control(2), [hatched] = impact(3), and [hatched] = impact(4).

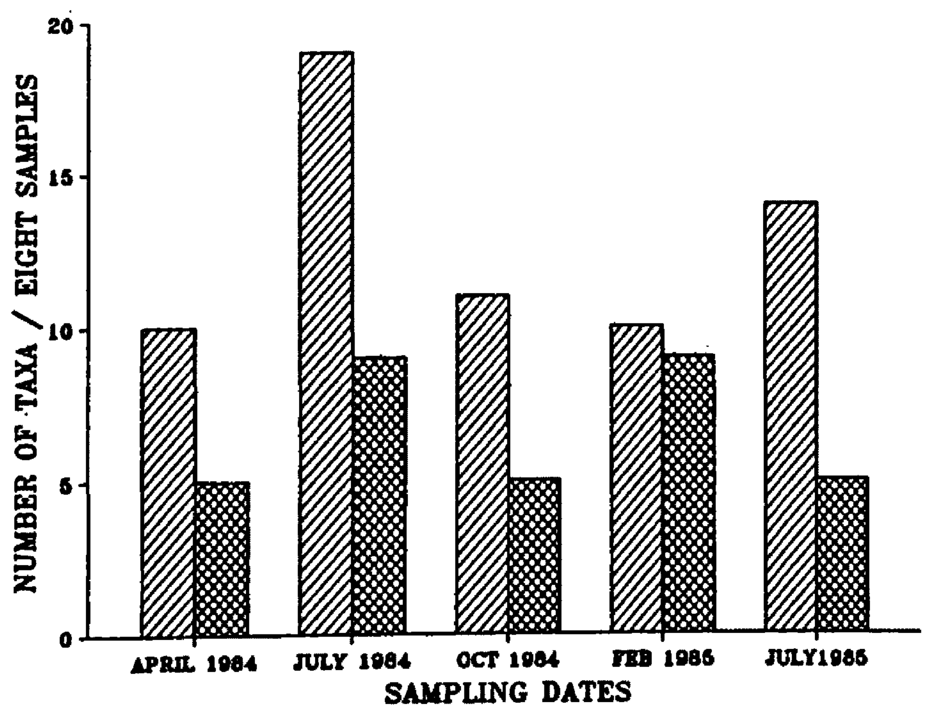

Figure 52. Number of macroinvertebrate taxa found only in the control [hatched] area, or only in the impact [crosshatched] area of Lake Creek, Mt. on five sampling dates in 1984-85.

the control community than of the impact community, while Trichoptera occupied a larger share of the impact community than of the control community. In 1984, both cases were reversed. Diptera, primarily chironomids, were more important in 1977 than 1984 (Figs. 53 and 54). In July the relationships between orders were the same as they had been in April for both periods (Figs. 55 and 56). One exception was the nearly forty percent share the "other" category held in the control area in 1984. Heterlimnius corpulentus is primarily responsible for this increase.

In October 1977, the upstream and downstream areas were quite similar in community composition (Fig. 57). In October 1984, the control and impact areas were quite dissimilar (Fig. 58). The share held by Ephemeroptera in the control is similar for both periods (25 percent), but in the impact area in 1984 the share held by Ephemeroptera had increased to over 45 percent. Trichoptera held a smaller share in both areas in 1984 as compared to 1977, but the decrease was much greater in the impact area. Again the "other" category had increased in the control area in 1984.

In February 1978, the upstream and downstream areas were again very similar (Fig. 59). In February 1985 the relative proportions of the community that each order held were similar to 1978 (Fig. 60).

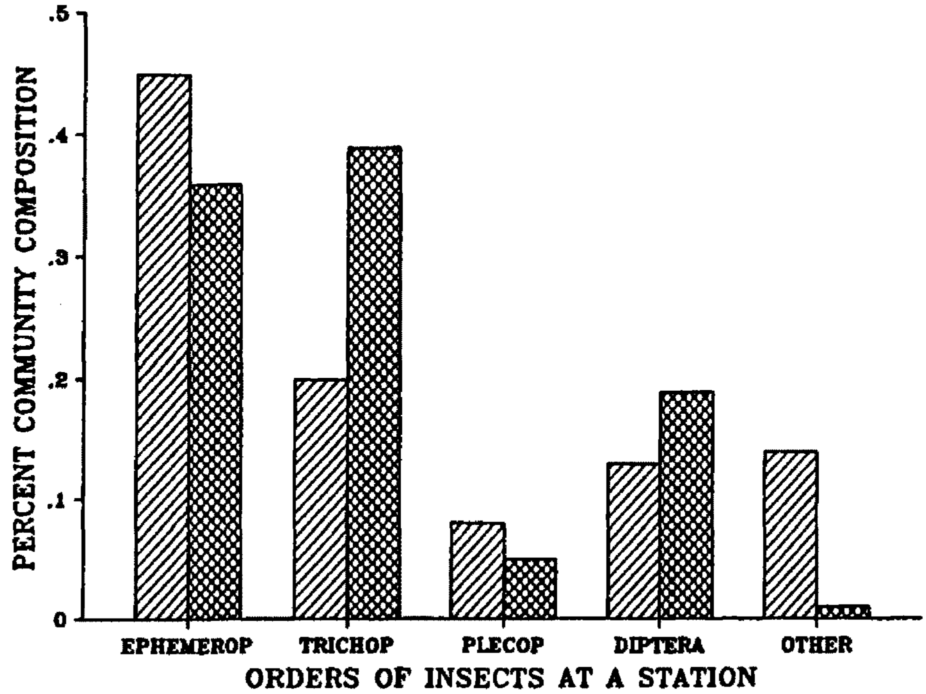

Figure 53. Percent community composition of control and impact areas in Lake Creek, Mt. in April 1977.

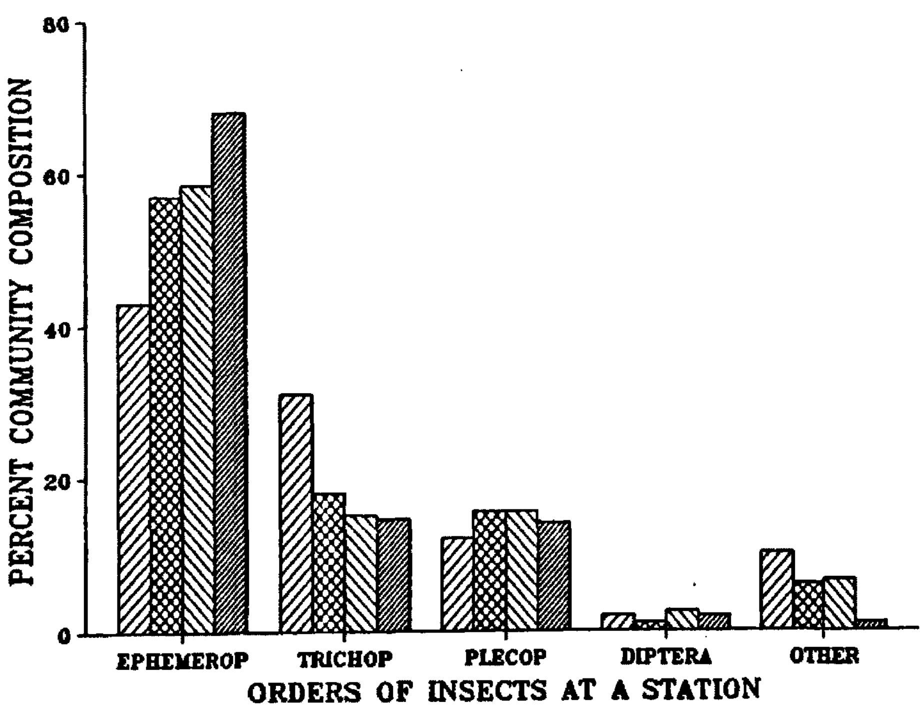

Figure 54. Percent community composition in Lake Creek, Mt. at control(1), control(2), impact(3), and impact(4) sampling stations in April 1984.

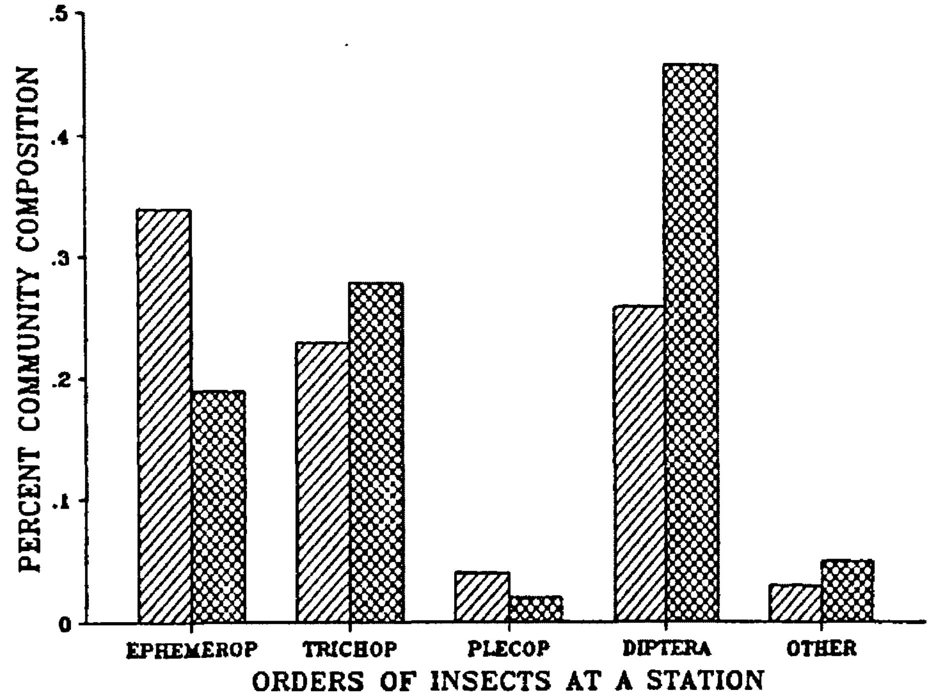

Figure 55. Percent community composition of control and impact areas in Lake Creek, Mt. in July 1977.

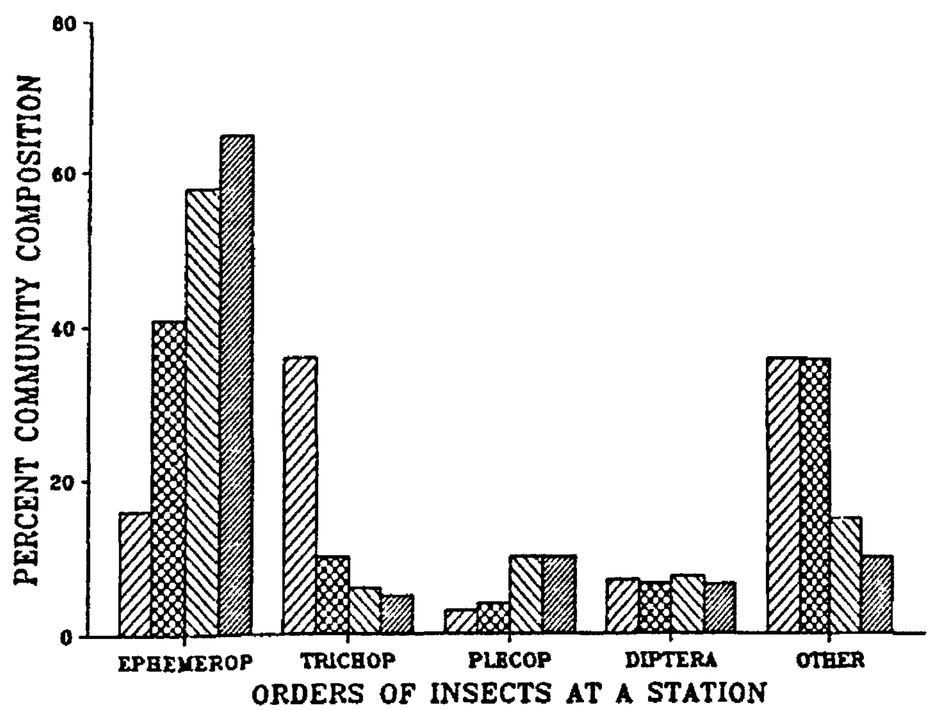

Figure 56. Percent community composition in Lake Creek, Mt. at control(1), control(2), impact(3), and impact(4) sampling stations in July 1984.

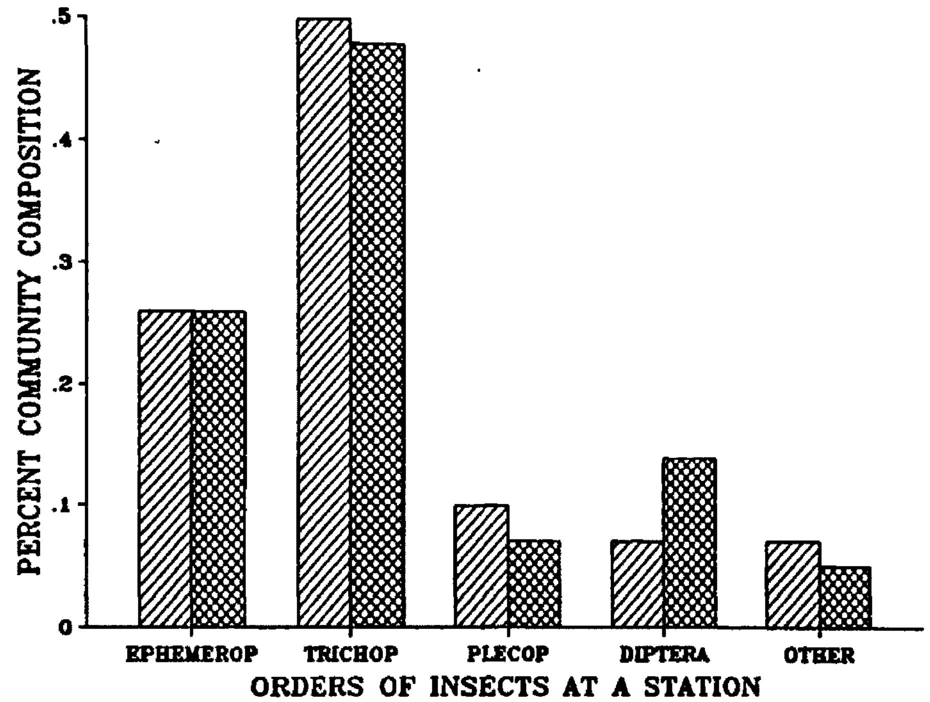

Figure 57. Percent community composition of control and impact areas in Lake Creek, Mt. in October 1977.

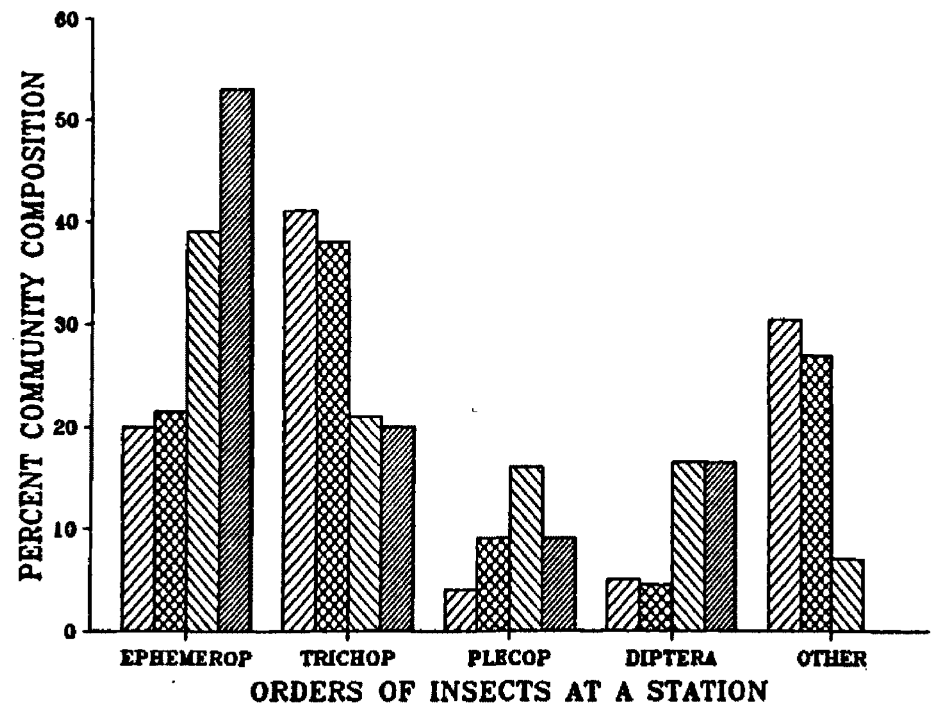

Figure 58. Percent community composition in Lake Creek, Mt. at control(1), control(2), impact(3), and impact(4) sampling stations in October 1984.

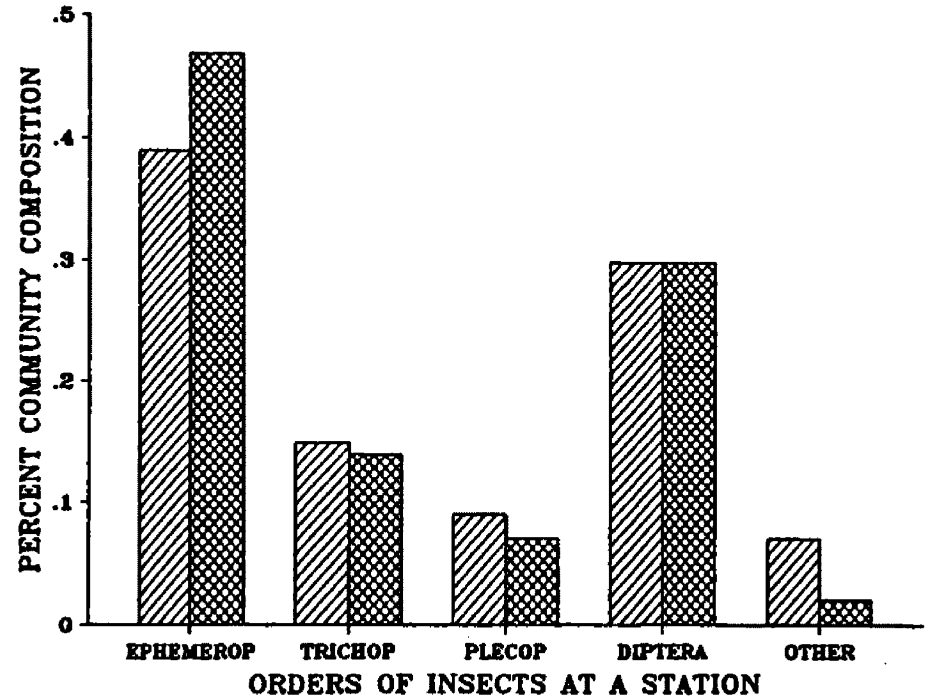

Figure 59. Percent community composition of control and impact areas in Lake Creek, Mt. in February 1978.

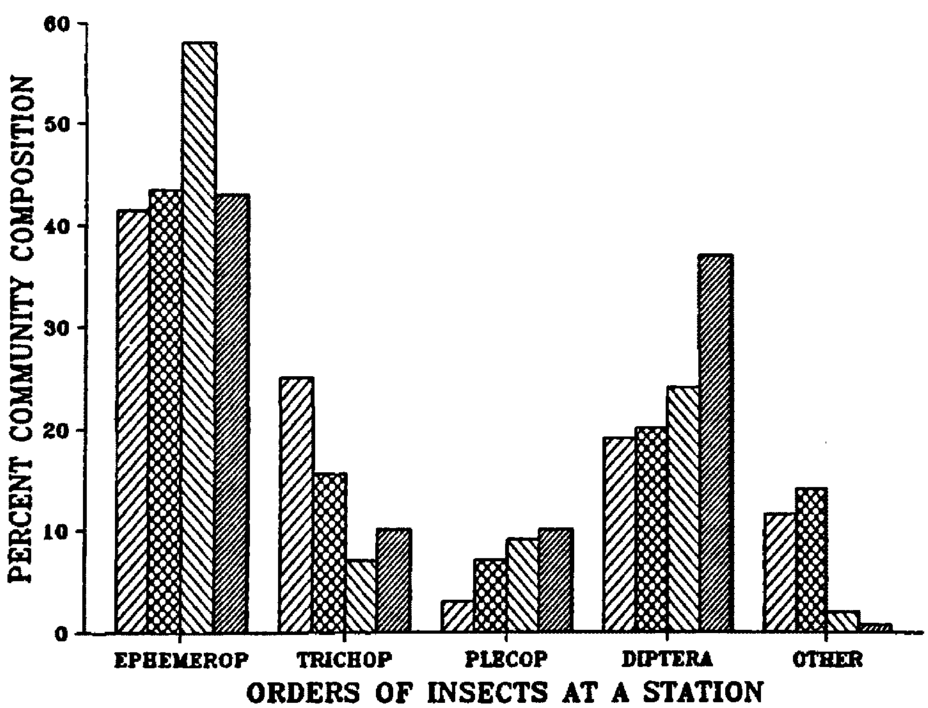

Figure 60. Percent community composition in Lake Creek, Mt. at control(1), control(2), impact(3), and impact(4) sampling stations in February 1985.

Effects on Growth

Chronic, sub-lethal stress should result in impairment of some physiological functions. A likely parameter to be affected by stress is growth. Fiance (1978) found *Ephemerella funeralis* to have greater average lengths in a control are of stream than in an area that had been experimentally acidified. To test the effect of chronic contamination in Lake Creek, average lengths of three taxa, *Brachycentrus* spp., *Paraleptophlebia* spp., and *Rhithrogena* spp., were compared between control and impact areas. No significant differences ($p<0.05$) in length were found. Differences due to bimodal length distributions were seen, but these were rejected as growth related, and attributed to the presence of different species mixes between areas.

SUMMARY AND CONCLUSIONS

This study was designed to evaluate the effects of a project for which an environmental impact statement had been written prior to project development. Lash et al. (1974, p. 10) describe an environmental impact assessment as "The process of doing predictive studies of an action and analyzing and evaluating the result...". Larkin (1984) refers to the second phase as "post-mortem" studies of which few examples can be found. Changes in the invertebrate community of Lake Creek, Lincoln County, Mt., resulting from 2.5 years of mining activity were evaluated. The taxa chosen for analysis of the effects of tailings contamination demonstrated many varied and statistically significant differences, both temporally and spatially. Many factors combine to complicate the measurement of biotic changes. Temporal changes are to be expected over a period of seven years (1977 to 1984), as are spatial differences, especially in a lake outlet stream, even in the absence of a disturbance. Population fluctuations are a natural occurrence, and it is the nature of streams to change in a longitudinal direction. Further, it is possible that the biological response to short pulse contamination from tailings to be within the range of normal variation in Lake Creek. Finally, it is difficult to detect small differences in average abundances based on samples taken from populations with patchy distributions.

Summary of Biotic Changes

Significant changes in the differences in abundance between control and impact areas from 1977-78 to 1984-85 were measured in 12 of the 16 taxa analyzed. In all but one (Simuliidae) of these 10 taxa the change was toward a greater disparity between control and impact areas.

Significant differences in abundances between areas during the 1984-85 period were measured in 11 taxa. Eight taxa had higher abundances in the control and three had higher abundances in the impact area. All of these differences appear attributable to tailings contamination. It is very unlikely that the significant temporal and spatial differences in so many taxa is a chance occurrence. Furthermore, the changes are generally explainable in terms of the spill event that occurred during the sampling period.

Influence of Tailings Impoundment versus Tailings Spill

It is not possible to separate the effects of the tailings impoundment from those of the tailings spill, although it is assumed that the spill was of much greater influence.

Only one sampling date, April 1984, is available for analyzing conditions prior to the spill. In April 1984, six of 16 taxa were significantly more abundant in the control, none were more abundant in the impact area. On the sampling dates following the spill a shift occurred in which nine taxa were significantly more abundant in the control and three were more abundant in the impact area.

In July 1985, 13 months after the spill, 11 taxa had higher mean densities in the impact area than had been measured in July 1984. In the control area a general increase was also measured in July 1985 versus July 1984, but was apparent in only seven taxa, while two taxa decreased in number. The increases in both areas suggest a general population increase in Lake Creek macroinvertebrates from July 1984 to July 1985. The greater response in the impact area relative to the control might represent initial recovery from the spill of June 1984. Whether or not the increase in the impact area relative to the control was sustained beyond July 1985 is not known due to termination of sampling. Only multiple years of sampling can validate recovery to pre-spill abundances.

The toxicity of the tailings spill into Lake Creek is unknown. The reductions in populations after the spill may be due to mortality, or drift as a mechanism of avoidance.

Accuracy of EIS

The Troy Project EIS makes no detailed predictions of the potential changes in macroinvertebrate populations in Lake Creek. On page 325 (Vol. 1), it is stated that the cumulative effect of ASARCO activities on aquatic productivity should not be significant provided reasonable precautions are taken. In addition, no acute biological toxicity was predicted from metals seeping out of the tailings pond into Lake Creek. Oxidation, sorption to soil particles, and dilution with Lake Creek water were identified as the reasons metals would not exceed water quality criteria in Lake Creek. Severe impacts were predicted from a failure of the slurry pipeline.

Due to the June 1984 spill, it was not possible to test the prediction that the tailings impoundment would not cause low level chronic impacts to Lake Creek. The spill of 1981 contaminated the control stations and made the test of differences upstream and downstream of the impoundment less rigorous, or more conservative. Nonetheless, of the 16 taxa analyzed were more abundant in the control area relative to the impact area in April 1984 than April 1977. Without the 1981 spill this difference may have been more pronounced.

The prediction of severe impacts from a pipeline failure was tested and confirmed.

The general predictions made in the EIS appear consistent with the results of this study. Such generalities may have improved pre-development decision making, but a quantitative reference with which to gauge limits of acceptable biological change would have aided management throughout the life of the project.

Significance of Impacts

Section 102(c) of NEPA requires that environmental impact statements be prepared for Federal actions significantly affecting the quality of the environment (US Congress 1970). What constitutes significant impacts are a source of debate. Buffington (1976) defines an impact as significant if it "...results in a change that is measurable in a statistically sound sampling program and if it persists, or is expected to persist, more than several years at the population, community or ecosystem level. The biotic changes in Lake Creek were demonstrated by statistically sound methods (Stewart-Oaten et al. 1986, Green 1979). Their persistence is unknown due to termination of sampling.

Duinker and Beanlands (1986) describe significant impacts in an ecological sense as irretrievable loss of ecosystem components such as populations (gene pools) or species. None of the biotic changes measured in Lake Creek up to July 1985 appear to be extreme enough to risk local extinction. The absence of extreme changes at this point does not preclude more severe changes later. Lake Creek may be in what Bormann (1982) categorized as Stage 1 or 2 in which an ecosystem serves as a sink for pollutants without having significant biological changes.

Any discussion of significant impacts involves value judgements concerning the components that are lost. The biotic changes measured in this study do not clearly translate into reduced outputs (i.e. fish, wildlife, water, etc.) to society from Lake Creek. It is clear that changes did occur in Lake Creek as a result of the tailings storage facility. This link between the facility and biotic change makes the continued ecological health of Lake Creek a valid concern. I propose that any statistically significant changes are also biologically significant, until long term monitoring proves them otherwise.

Recommendations for Further Research

Remaining to be clarified is the extent to which Bull Lake influences the benthos of Lake Creek. While the literature suggests that lake influences are restricted to a short distance of an outlet stream, the distributions of *Agraylea*, *Heterlimnius*, and others in Lake Creek raises doubts. Thermographs at all sampling stations are recommended to determine lake effects on temperature and reveal possible differences between stations.

In addition, it is recommended that benthic samples be taken every 300 m from the upper control station to Bull Lake during winter or early spring. The purpose of these samples is to depict a gradient from Bull Lake and identify a downstream boundary of the lake outlet community.

Monitoring of the benthic community should continue, and the sampling design should include replicate stations upstream and downstream of the impoundment. At least winter, spring, and fall periods should be sampled. Summer sampling is least important since at that time a large percentage of aquatic insects are in the adult stage or in early instars too small to sample effectively. Physical parameters such as stream width, depth, velocity, and discharge, should be measured at each station in order to identify habitat differences between stations and flow differences between years.

Other than a repetition of past spill events, the most serious concern is longterm seepage from the tailings impoundment into Lake Creek. Movement of contaminants out of the impoundment, if it occurs, may be a slow process that has not yet affected Lake Creek (or the benthos collected in 1984-85). Therefore a study of the groundwater dynamics and water budget of the tailings impoundments area is necessary to identify potential problems.

Appendix A. List of taxa collected in Lake Creek, Mt., in 1984-85.

Trichoptera
- Agraylea
- Arctopsyche grandis
- Brachycentrus
- Dicosmoecus
- Ecclisomyia
- Glossosoma
- Hydropsyche
- Hydroptila
- Lepidostoma
- Micrasema
- Neophylax
- Onocosmoecus
- Rhyacophila acropedes
- Rhyacophila vagrita
- Rhyacophila angelita

Plecoptera
- Acroneuria
- Claassenia sabulosa
- Hesperoperla pacifica
- Isoperla fulva
- Nemoura
- Pteronarcys californica
- Skwalla paralalla
- Sweltsa

Ephemeroptera
- Baetis
- Caudatella
- Cinygmula
- Drunella doddsi
- Drunella flavilinea
- Drunella spinifera
- Drunella pelosa
- Epeorus albertae
- Epeorus longimanus
- Ephemerella
- Paraleptophlebia
- Pseudocloeon
- Rhithrogena
- Serratella tibialis

Diptera
- Antocha
- Ceratopogonidae
- Chironomidae
- Dicranota
- Empididae
- Hexatoma
- Psychodidae
- Simuliidae

Coleoptera
- Heterlimnius corpulentus
- Lara avara
- Narpus

Annelida

Pelycypoda

Appendix B. Summary of temporal (1977-78 to 1984-85) and spatial (upstream vs. downstream) changes in abundance in the benthic community of Lake Creek, Lincoln, Co., Montana.

	TEMPORAL		SPATIAL	
Taxon	Change in Abundance in Impact Area Relative to Control Area	Signif-icant?	Comparison of Abundance in Control and Impact Areas	Signif-icant?
Hydropsyche	Decrease	Yes	C > I (always)	Yes
Brachy-centrus	Decrease	No	C > I (usually)	Yes
Agraylea	Decrease	Yes	C > I (almost always)	Yes
Rhyacophila	Decrease	No	C = I	NA
Ephemerella	Decrease	Yes	C > I	No
Rhithrogena	Increase	No	C < I	Yes
Cinygmula	Little Change	No	C = I	No
Paralepto-phlebia	Decrease	Yes	C > I	Yes
Baetidae	Little Change	No	C < I (usually)	Yes
Antocha	Decrease	Yes	C > I (almost always)	Yes
Chironomidae	Decrease	Yes	C > I	No
Simuliidae	Increase	Yes	C < I	Yes

Appendix B. (continued)

	TEMPORAL		SPATIAL	
Taxon	Change in Abundance in Impact Area Relative to Control Area	Signif- icant?	Comparison of Abundance in Control and Impact Areas	Signif- icant?
Heterlimnius corpulentus	Decrease	Yes	C > I (usually)	Yes
Perlidae	Increase	No	C = I	No
Chloro- perlidae	Little Change	No	C = I	No
Total Abundance	Decrease	Yes	C > I (usually)	Yes
Total Taxa	NA		C > I (always)	Yes

Appendix C. Macroinvertebrate tissue analysis for whole body loads of Cu and Cd.

Tissues of five families of aquatic insects were analyzed for concentrations of copper and cadmium. The purpose of this analysis was to obtain information on body loads of metals which could be related to measured changes in macroinvertebrate abundance. The analysis was a preliminary survey rather than an exhaustive study.

Collections were only made downstream of the tailings impoundment in February 1985. Organisms were chosen primarily for their large size, which simplified the collection of adequate wet weights of individuals for analysis. The macroinvertebrates were collected in a nylon kicknet, and frozen shortly thereafter. Analysis was done by standard flame aspiration technique with an atomic absorption spectrophotometer at the Gordon Environmental Laboratory of the University of Montana.

The results are:

SAMPLE	ug Cu/g	ug Cd/g
Pteronarcys	96.6	1.89
Pteronarcys	45.9	<1.6
Pteronarcys	53.2	<1.6
Pteronarcys	41.4	<1.6
Hydropsychidae	17.3	<1.6
Hydropsychidae	22.6	<1.6
Perlidae	40.1	<1.6
Perlidae	40.9	<1.6
Ephemeroptera	84.2	<1.6
Tipulidae	32.1	3.57
(repeat)	----	3.26
(repeat)	----	3.15

Appendix D. Location of macroinvertebrate sampling stations in Lake Creek, Mt., 1984-85.

Control Station 1 (C1)

Legal description: NE 1/4 Sec 7, T29N, R33W

The riffle sampled was located about 1100 m upstream of the ASARCO Mine access road that crosses Lake Creek, or about 400 m upstream of the old washed-out bridge.

Control Station 2 (C2)

Legal description: SE 1/4 Sec 6, T29N, R33W

The riffle sampled was located about 500 m upstream of the ASARCO Mine access road that crosses Lake Creek, or about 100 m downstream of the old washed-out bridge.

Impact Station 3 (I3)

Legal description: NW 1/4 Sec 31, T29N, R33W

The riffle sampled was located near the northern boundary of the tailings impoundment, which is also about 300 m upstream of a dirt road that branches off Forest Road 384 and leads down to Lake Creek.

Impact Station 4 (I4)

Legal description: NW 1/4 Sec 29, T30N, R33W

The riffle sampled was located about 200 m upstream from the junction of Porcupine Creek and Lake Creek.

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