CN 083

REGIONAL COPPER-NICKEL STUDY
ERIE MINING PROJECT
BIOLOGICAL SAMPLING

Prepared by the Minnesota
Environmental Quality Board
in cooperation with Erie Mining
Company.

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October, 1978

PRELIMINARY DRAFT REPORT, SUBJECT TO REVIEW

ABSTRACT

Biological sampling was undertaken in Bob and Dunka Bays of Birch Lake and Unnamed Creek east of Erie Mining Company's Dunka Pit to determine the effect of elevated heavy metal levels in these water bodies.

The benthic invertebrate communities in Unnamed Creek were significantly different from other similar streams in the region. Fluctuating flows and shifting sand substrates are probably the factors causing invertebrate diversity and density to be lower in Unnamed Creek than in similar streams in the region. In other aspects such as invertebrate functional group composition and primary production, Unnamed Creek resembled other streams of the region.

Within Unnamed Creek several differences in the periphyton communities were noted between upstream and downstream stations. These differences may have been the result of high nickel concentrations at the upstream station.

Phytoplankton production in Bob Bay appears unaffected by heavy metals. However, the density of the benthic invertebrate, *Tanytarsus*, is significantly less in Bob Bay than in Dunka Bay which is unaffected by heavy metals.

Clams in Bob Bay have accumulated significant amounts of copper, while water lilies have accumulated significant amounts of copper and nickel. The source of these accumulated metals (water or sediments) is not known.

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INTRODUCTION TO THE REGIONAL COPPER-NICKEL STUDY

The Regional Copper-Nickel Environmental Impact Study is a comprehensive examination of the potential cumulative environmental, social, and economic impacts of copper-nickel mineral development in northeastern Minnesota. This study is being conducted for the Minnesota Legislature and state Executive Branch agencies, under the direction of the Minnesota Environmental Quality Board (MEQB) and with the funding, review, and concurrence of the Legislative Commission on Minnesota Resources.

A region along the surface contact of the Duluth Complex in St. Louis and Lake counties in northeastern Minnesota contains a major domestic resource of copper-nickel sulfide mineralization. This region has been explored by several mineral resource development companies for more than twenty years, and recently two firms, AMAX and International Nickel Company, have considered commercial operations. These exploration and mine planning activities indicate the potential establishment of a new mining and processing industry in Minnesota. In addition, these activities indicate the need for a comprehensive environmental, social, and economic analysis by the state in order to consider the cumulative regional implications of this new industry and to provide adequate information for future state policy review and development. In January, 1976, the MEQB organized and initiated the Regional Copper-Nickel Study.

The major objectives of the Regional Copper-Nickel Study are: 1) to characterize the region in its pre-copper-nickel development state; 2) to identify and describe the probable technologies which may be used to exploit the mineral resource and to convert it into salable commodities; 3) to identify and assess the impacts of primary copper-nickel development and secondary regional growth; 4) to conceptualize alternative degrees of regional copper-nickel development; and 5) to assess the cumulative environmental, social, and economic impacts of such hypothetical developments. The Regional Study is a scientific information gathering and analysis effort and will not present subjective social judgements on whether, where, when, or how copper-nickel development should or should not proceed. In addition, the Study will not make or propose state policy pertaining to copper-nickel development.

The Minnesota Environmental Quality Board is a state agency responsible for the implementation of the Minnesota Environmental Policy Act and promotes cooperation between state agencies on environmental matters. The Regional Copper-Nickel Study is an ad hoc effort of the MEQB and future regulatory and site specific environmental impact studies will most likely be the responsibility of the Minnesota Department of Natural Resources and the Minnesota Pollution Control Agency.

INTRODUCTION

The April, 1975 discovery of elevated copper and nickel levels in a small unnamed creek adjacent to Erie Mining Company's Dunka Pit in northeastern Minnesota (Eger, MDNR personal communication) raised concerns over the effects of these metal concentrations on the aquatic biota of this creek and Birch Lake into which "Unnamed Creek" flows. Studies by the State of Minnesota and Erie Mining Company indicate that these metals enter Unnamed Creek via seeps carrying leachate from mineralized gabbro stockpiles (mineralized gabbro is a rock formation containing copper and nickel sulfides). Further studies on the origin and movement of these metals are presently underway.

Although the toxicity of copper and nickel to aquatic organisms has been well documented in the laboratory, it is difficult to apply these results directly to a field situation. In order to determine if there were any effects on the Unnamed Creek biota, Erie Mining Company initiated a biological study in 1975. No conclusions were drawn from the results of this survey (Barr Engineering Co., 1976). A qualitative survey of the benthic invertebrates of Unnamed Creek conducted by the MEQB Regional Copper-Nickel Study (Regional Study) indicated some differences between stations sampled, (Johnson et al. 1976) but the reasons for these differences could not be determined. During this survey and subsequent sampling, it was found that other mining stresses in addition to high copper and nickel concentrations could be major factors influencing the aquatic ecosystem. These stresses were channelization to drain water away from the gabbro piles more rapidly, and fluctuating discharge from intermittent mine dewatering.

Prior to 1976, no biological sampling had been conducted in Birch Lake to determine the effect of heavy metals entering the lake from Unnamed Creek. Several studies have been initiated by Erie Mining Company and the State of Minnesota to determine heavy metal concentrations in the water and accumulation in the lake sediments.

Further interest in the Dunka Pit operation developed with initiation of the Regional Study in 1976, since the Dunka Pit area presents an opportunity to study the biological effects of an open pit mining operation along the gabbro contact. As a result, the Regional Study in cooperation with Erie Mining Company initiated an intensive study to determine the impacts pf heavy metals and other mining practices on the aquatic biota of Unamed Creek and Birch Lake. In this program the Regional Study was responsible for sampling and report preparation while Erie Mining provided financial support for sample analysis.

LITERATURE REVIEW

Toxicity of Copper and Nickel to Periphyton and Benthic Invertebrates

The toxicity of copper to aquatic organisms is well documented (EIFAC 1976, Beck and Thatcher 1973, EPA 1976, EPA 1973). However, the toxicity of nickel has been less intensively studied (EPA 1973, EPA 1976). In recent years it has been discovered that copper and nickel toxicity increases with decreases in chemical parameters such as: pH, alkalinity/hardness, and total organic carbon (EPA 1976, EIFAC 1976). Therefore, it is difficult to apply available laboratory data to natural situations unless test conditions duplicate field conditions. Also, the lack of water quality data in some studies causes problems in the application of these data.

Copper and nickel are generally more toxic to fish than invertebrates (Nehring 1976, Warnick and Bell 1969) or algae (EIFAC 1976) although Sprague et al. (1965) predicted that mayflies were as sensitive to copper as salmon but that trichopterans and dipterans were less sensitive than salmon. Table 1 summarizes laboratory toxicity data from the literature for benthic invertebrates. Relatively soft water (30-70 mg/l $CaCO_3$) was used in all these tests. Copper toxicity (LC 50) ranges from .02 to 13.9 mg/l and nickel toxicity (LC 50) ranges from 4.0 to 64.0 mg/l depending on species and test conditions.

Limited data exist in the literature on the toxicity of copper and nickel to diatoms, the dominant periphytic algal group. A summary of copper toxicity showed toxic levels ranging from .005 to 2.0 mg/l depending on species and test conditions (Table 2).

Few field studies have been conducted on the overall effects of heavy metals to stream communities. Field studies by Geckler et al. (1976) revealed that heavy metal effects under natural conditions generally occur at lower levels than predicted from laboratory tests in similar water. In general, heavy metal pollution causes reduced diversity and productivity. When copper and zinc levels in the Miramichi River system (New Brunswick) reached approximately four times the lethal limit determined in the laboratory for Atlantic salmon, no benthic macroinvertebrates were collected by Sprague et al. (1965). As copper and zinc dropped to .3 to 1.5 times

times the lethal limit, blackflies, midges, and caddisflies began repopulating the river. Mayfly populations in polluted sections did not resemble control stations until the copper and zinc dropped to 0.7 to 2.6 times the lethal limit. These investigators concluded that mayflies were as sensitive to these metals as were fish, and that caddisflies and midges were at least 1.5 times more resistant than mayflies. Thorp and Lake (1973) studied the effect on macroinvertebrates of cadmium-zinc pollution as a result of mining and found a decrease in species diversity and abundance. They found invertebrates in the orders Hemiptera and Arachnida to be highly tolerant of this pollution. Surber (1960) found the chironomid *Cricotopus bicinctus* to be highly resistant in Michigan Rivers to wastes containing chromium, cyanides, and copper. Other common invertebrates observed by Surber included the annelids *Limnodrilus* spp. and *Tubifex* spp. and the midge *Pentapedilum* spp. Butcher (1946) also found chironomids to be resistant to heavy metal pollution. He found that chironomids, the first invertebrates to recolonize, reappeared at a copper concentration of 120 µg/l. Chironomids were the dominant group found at stations with high copper concentrations in Shayler Run, Ohio (Winner et al. 1975). Diversity, species number, and abundance also decreased in areas of high concentrations in this stream. Highest copper concentrations were 119.9 µg/l with an alkalinity of 195.5 mg/l $CaCO_3$. Recovery was observed in Shayler Run at a copper concentration of 23 µg/l. Similar results were obtained by Geckler et al. (1976) in earlier Shayler Run sampling.

Species composition shifts were the major effect observed on Shayler Run periphyton communities (Geckler et al. 1975). *Cocconeis placentula* was replaced in areas of high copper concentration by *Nitzschia palea*, Navicula minima, and N. seminulum var. hustedtii. Cladophora glomerata was also eliminated where copper concentrations were high, and was replaced by the filamentous blue-green algae Schizothrix calciocola, Cosmarium granatum, and C. subprotumidum.

A study of the flora in sections of the Ystwyth and Clarach rivers in Wales polluted by heavy metals found variable tolerance of bryophytes and algae (McLean and Jones 1975). Diatom species composition was different in polluted sections of these streams. Diatoma hiemale var. mesodon dominated highly polluted zones while Fragilaria capucina var. lanceolata was dominant in other zones. The macrophyte Fontinalis was found intolerant of metal pollution while Scapania was tolerant.

Butcher (1955) observed that a copper effluent greatly reduced the algal flora in the River Churnet. Chlorococcum, Achnanthes affinia and Stigeocloneum tenue replaced the normal Nitzschia palea-Cocconeis downstream from the effluent.

Stigeocloneum tenue tolerated 0.8 mg/l Cu in the River Mulde (Schroeder 1939, cited in Whitton 1970). Copper levels of 1.5 mg/l were tolerated by Fragilaria verescens, Synedra Ulna, Neidium biculatum, Navicula veridula, Cymbella naviculiformis. Achnanthes affinis, Nitzschia palea, and Cymbella ventricosa were collected at copper levels of 2.0 mg/l Cu. Unfortunately, no data on hardness were presented in this study. Palmer (1964) found that Achnanthes tolerated .4 mg/l in Indianapolis, but again no hardness data were presented.

Palmer (1959) listed the following species as tolerant of copper pollution: Achnanthes affinis, Asterionella formosa, Calothrix braunii, Chlorococcum botyrides, Cymbella naviculiformis, C. ventricosa, Navicula viridula, Neidium visulcatum, Nitzschia palea, Scenedesmus obliquus, Stigeocloneum tenue, Symploca erecta.

Diatoms were the most sensitive algal group to copper (500 μg/l) tested by Mahoney and Palmer (1956, cited in Cairns et al. 1972). Blue-green and green were the next most sensitive groups, respectively.

Wixson (1970) proposed that Synedra, Navicula, and Cymbella be used to indicate mining pollution composed of lead, zinc, and copper in Missouri. Wixson found that Cymbella was the most sensitive diatom genera and was rarely found in polluted streams while Synedra and Navicula appeared tolerant. Synedra was the dominant genus close to the effluent.

Besch et al. (1972) investigated periphytic diatom communities in a soft river polluted by zinc and copper. Dominant diatom species were rated according to their heavy metal tolerance based on the field collections and literature. Their conclusions were that diatom communities were good indicators of average pH and that heavy metals are indicated by dominance of species tolerant of a given metal level.

Patrick et al. (1975) reported that in March and April diatom diversity was poor at 2 μg/l nickel and was completely replaced by blue-green algae at 8 to 10 μg/l. In May and July there was an increase in blue-green and green algae at 2 μg/l as well as at 8 to 9 μg/l. While these are the only available data on diatom sensitivity to nickel, other investigators have noted toxic effects on other algal groups at 50 μg/l to 1500 μg/l (Bringman and Kuhn 1959a,b cited in Cairns et al. 1972).

Bioaccumulation of Heavy Metals

The bioaccumulation of heavy metals has been observed in periphyton, macrophytes, invertebrates, and fish. Hutchinson et al. (1975) found that copper and nickel were not biomagnified (i.e. transferred at increasing levels through the food chain), but did find that at each trophic level copper and nickel levels were higher in the tissue than in the sediments or water. Because of this ability to accumulate heavy metals, the use of aquatic organisms to indicate heavy metals has been proposed by various investigators (Nehring 1976, Ray and White 1977). The feasibility of this has not yet been completely determined nor has the biological significance of heavy metal accumulation been determined.

Other Stress

Several other factors are important in the Unnamed Creek ecosystem. These are channelization, fluctuating flows, shifting substrate, and generally poor natural habitat.

Channelization has been found to reduce diversity and abundance of benthic invertebrates by reducing habitat diversity and stability (Hansen 1971, Etnier 1972). Changes in substrate from cobble to shifting sand are often responsible for reduced secondary productivity after channelization projects (Arner et al. 1976). If substrates can be maintained during channelization, impacts on invertebrates and algae can be minimized (Duvel et al. 1976). If mitigation measures such as increasing habitat diversity are taken, the impact of channelization can be reduced (Lund 1976). Other effects from channelization are loss of streamside vegetation, increased temperature, reduction in stream length, and possible impact on downstream areas resulting from these effects.

Fluctuating flows have a major impact on aquatic ecosystems by reducing the available habitat for aquatic organisms. Kroger (1973) found a total loss of benthic invertebrates inhabiting the zone periodically exposed by low flows below a dam. In periodically exposed areas, density and diversity have been found to be lower than in continuously flooded zones (Fisher and LaVoy 1972). The overall effect of fluctuating flows on benthic communities is dependent on total area exposed during low flow, duration of the exposure, and rate of change in water level. Kroger (1973) postulated that if the rate of decrease in flow in the Snake River, Wyoming, did not exceed 2.8 m^3/sec per day invertebrates would be able to migrate to deeper water. Some survival can be expected in exposed zones depending on the duration of the exposures. Fisher and LaVoy (1972) found that a station exposed 13 per cent of the time was similar to stations continually flooded. Many invertebrates are able to survive drought periods by burrowing deep into the bottom sediments (Larimore et al. 1959).

Shifting bottom substrates are unstable and of limited value for colonization by invertebrates and periphyton. Gammon (1970) rated shifting sand as the poorest possible substrate for macroinvertebrates. The paucity of plants and macroinvertebrates in the River Camel, England, was considered a result of the unstable shifting nature of the substrate (Nuttall 1972). Stable rubble and boulder substrates are the preferred habitat of invertebrates (Wene and Wickliff 1940, Bell 1968, Crisp and Crisp 1974).

As substrate particle size decreases or increases from rubble, invertebrate abundance and diversity decrease in most cases (Smith and Moyle 1944). An exception would be a silt substrate which can support very large invertebrate populations although diversity is generally low (Hynes 1970).

Recovery of Impacted Streams

Recolonization of impacted stream areas by aquatic insects is generally rapid after a stress is discontinued. Downstream drift (Waters 1964) and upstream migration of adult stages (Hultin et al. 1969) and immature stages (Bishop and Hynes 1969) are sources of recolonizing invertebrates (Williams and Hynes 1976). In large impacted areas, with no upstream source for colonizing invertebrates, recolonization by flying invertebrates from other streams or watersheds becomes important (Williams and Hynes 1976). Rapid recolonization of invertebrates has been observed in many situations after stress has been eliminated: (drought-stricken streams - Larimore et al. 1954; flood streams - Hoopes 1974; fluctuating streams and ponds - Kroger 1973, Patterson and Fernando 1969; dredged streams - Crisp and Gledhill 1970; and channelized streams - Crisp and Crisp 1974). Cairns et al. (1971) found that recovery was rapid when no residual toxicants remain in the ecosystem and there are areas present which can provide organisms for recolonization.

Few data are available on the long-term effects of heavy metals on the aquatic biota. Accumulation of metals in the sediments may pose a problem after a heavy metal effluent is discontinued; however this depends on the form of the metals.

METHODS

Research Area

The research area is located adjacent to Erie Mining Company's Dunka Pit, in the northwest quarter of the USGS Babbitt NE Quadrangle, 7.5 minute series, 1969 (Figure 1). Dunka Pit is approximately 2.5 miles long, 0.25 miles wide, and 350 feet deep. The pit follows the strike of the iron formation (N 30 E). The iron formation dips to the southeast below the basal mineralized zone of the Duluth Gabbro Complex in the Dunka Pit area (Eger et al. 1977). Unnamed Creek flows in a northerly direction along the east side of Dunka Pit and empties into Bob Bay of Birch Lake, which lies directly north of the Dunka Pit. Unnamed Creek near the pit is a first order stream but becomes a second order stream when two small tributaries join the main creek before it reaches Bob Bay (Figure 2). This Unnamed Creek and its tributaries drain from bog areas although most of the water in the main creek and the small western tributary is from mine dewatering.

Upper reaches of Unnamed Creek were channelized during the winter of 1976 to improve drainage around the gabbro stockpiles. Most of this area is lowland deciduous and coniferous forest with some open grassy areas. Downstream, the creek becomes less defined as it traverses areas of thick tag alder before flowing through a large bog area. The eastern tributary enters Unnamed Creek in this bog. Unnamed Creek becomes a well-defined stream again after leaving the bog. Heavy growths of tag alder overhang the stream from the bog to its mouth in Bob Bay. Much of the surrounding area is upland deciduous and coniferous forest, through which the western tributary flows before joining the main creek. Several seeps from gabbro and wasterock stockpiles enter Unnamed Creek along its course (Figure 2).

Sampling Stations

Unnamed Creek - Four sampling stations were located along Unnamed Creek (Rable 3 and Figure 2). Three of these stations had been sampled by Barr Engineering Company in 1975. One additional station on Unnamed Creek was sampled during the current study in 1976 (EM-1A). No upstream control stations were located on Unnamed Creek since the creek's upper reaches had been severely impacted by channelization during the winter, 1976. EM-2 was selected as a control station since it received mine dewatering but had low metal concentrations in comparison to the main creek.

Other Stream Stations - Six Regional Study monitoring stations were chosen for comparison with Unnamed Creek. All six stations were within 17 km. of Unnamed Creek (Figure 1). These stations were selected for the following reasons:

1) KC-1 - an unimpacted headwater stream (second order).
2) F-1 - a headwater stream (second order) which has elevated copper concentrations.
3) P-5 - an impacted (taconite mine dewatering) headwater stream (second order).
4) D-1 - an impacted (taconite mine dewatering) third order stream.
5) SR-1 - an unimpacted fourth order stream.
6) BB-1 is on Unnamed Creek approximately 150 m. downstream from EM-1.

The location of these sites is described in another report (Regional Copper-Nickel Study 1977).

Birch Lake - Four lake sampling stations were located in Bob Bay as well as two stations located in Dunka Bay of Birch Lake to serve as control stations (Table 4 and Figure 2). Dunka Bay receives mine drainage but does not have a heavy metal input. Four other biological monitoring stations were also situated on Birch Lake (Figure 1 and Regional Copper-Nickel Study 1977).

Field and Laboratory Procedures

Regional Study staff collected all samples; in addition, they analyzed chlorophyll samples. All taxonomic analyses were performed by Ecology Consultants Inc., Fort Collins, Colorado. The sample log is presented in Appendix 1.

Periphyton (Unnamed Creek) - Artificial substrates were employed for the quantitative study of periphyton because they allow standardized quantitative sampling (Sladeckova 1962, Weber 1973). Qualitative samples were also collected since all periphyton species may not colonize artificial substrates.

Three glass slide racks were suspended in Unnamed Creek approximately 30 cm. below the water surface depending on water level fluctuations. After a three-week colonization period, two slides from each rack were placed in a slide box for taxonomic analysis and two in a polypropylene bottle containing 10 ml. acetone saturated with $MgCO_3$ for chlorophyll analysis. Samples were kept cold and dark until returned to the laboratory where taxonomy slides were scraped into 250 ml. amber bottles containing Lugol's solution. Chlorophyll samples were kept dark in a freezer prior to analysis.

A sedimentation count on an inverted microscope and a species proportional count from a permanent slide (Weber 1973) were made from each slide collected for taxonomic analysis. Organisms were identified to the lowest taxonomic level possible. Chlorophyll a, b, c, and pheophytin concentrations were determined following standard procedures (ALPHA 1975) except that acetone was saturated with $MgCO_3$ prior to addition to the sample.

Qualitative periphyton samples were collected by scraping various substrates (e.g. wood, rock, vegetation) and pipeting periphyton from sand and silt substrates. Samples were placed in 250 ml. amber bottles containing Lugol's solution (1 percent final concentration). A species proportional count was made from a permanent slide prepared from the original sample.

<u>Phytoplankton</u> - Water was collected at all stations in Birch Lake with an integrated sampler. This sampler consisted of a 2 m. section of 38.1 mm. PVC plastic pipe threaded on each end. Water samples were collected by lowering the integrated sampler vertically, with both ends open, until the upper end extended two to three inches above the water's surface. That end was then capped and the sampler raised until the lower end remained two to three inches below the water surface. The lower end was then capped and the sampler removed from the water. Water in the sampler was drained into an 8 liter carboy and mixed before three 1 liter samples were

withdrawn. These samples were kept in a cooler with cool-paks until they reached the laboratory.

Each 1 liter water sample was filtered through an 0.45 μm. Gelman Type A glass fiber filter. Filters were frozen in light tight polypropylene bottles containing 10 ml. of acetone saturated with $MgCO_3$ until final analysis. Chlorophyll content of each sample was determined according to standard procedures (ALPHA 1976) using a Beckman DU-2 spectrophotometer.

Benthic Invertebrates (Unnamed Creek) - Artificial substrates and drift nets were used to collect quantitative samples of benthic invertebrates in Unnamed Creek. Artificial substrates are widely used for monitoring aquatic biota because they reduce variability between sampling stations by providing a standard substrate (Beak et al. 1973). Drift sampling provides a measure of secondary productivity and also provides a method of collecting organisms from a variety of upstream habitats (Elliot 1970). Qualitative invertebrate samples were also collected since artificial substrates and drift nets may be selective.

At each stream station, six modified Hester/Dendy samplers (Weber 1973) were suspended so that the bottom of the sampler touched the stream bottom. After a six-week colonization period, the samplers were retrieved and returned to the laboratory. Samplers were scraped, sieved through a #40 U. S. Standard sieve and preserved in 5-10 percent formalin.

Drift collections were made when Hester/Dendy samplers were placed into and retrieved from the streams. Two to six drift nets with an upstream opening of 0.025 m^2, length of 2.4 m, and 440 μm mesh size were placed at each station for 24 hours. Nets were set at some time during the daylight hours. Samples were removed from the nets, concentrated in a #40 U. S. Standard sieve, and preserved in 5-10 percent formalin.

Formalin was removed from drift and Hester/Dendy samples by washing through a #40 U.S. Standard sieve. Prior to sorting large samples were subsampled (Weber 1973). After sorting, organisms were identified to the lowest possible taxonomic level except for the following groups: Nematoda, Annelida, Decapoda, and Pelecypoda. These groups were identified to class only.

Qualitative stream sampling was done at the time of drift collections. Two man-hours were spent examining the various habitat types (e.g. pool/riffle; silt; rubble; sand; wood; vegetation) at each sampling station and collecting all invertebrates observed. In addition to picking organisms directly from logs and rocks, the kick-net sampling method was employed wherever feasible. Samples were preserved in 5-10 percent formalin. Qualitative and quantitative samples were analyzed with the same techniques.

<u>Benthic Invertebrates (Birch Lake)</u> - Benthic invertebrates were collected in Birch Lake with a Petite Ponar dredge (15.2 x 15.2 cm.). The small dredge was used so that a greater number of replicates could be collected and analyzed. Six replicate samples were collected at each lake station. Samples were sieved through a #40 U. S. Standard sieve in the field and the remaining sample preserved in 5-10 percent formalin. Analysis procedures were the same as that used for drift and Hester/Dendy samples.

Heavy Metal Analysis - In 1976 aquatic macrophyte samples were collected from Unnamed Creek, Bob Bay and Dunka Bay (Table 5). SCUBA was employed in the bays to collect samples. After samples were collected, they were placed in plastic bags with water from the collection sites. Further macrophyte samples were collected, in 1977. These samples consisted of Nuphar variagetum from Bob and Dunka Bays.

Samples were split in the field laboratory; half of the sample was shipped to laboratories for analysis (clams to Minnesota Department of Natural Resources Chemistry Laboratory; macrophytes to University of Minnesota Soil Science Laboratory), and the remainder was retained in the laboratory for identification. In 1977 macrophyte samples were analyzed by Barringer Laboratories, Toronto, Canada. Macrophyte samples were analyzed for the following metals: Ni, Cu, Zn, P, K, Al, An, Fe, Mg, Mo, Mn, and B. Clams were analyzed for Ni, Cu, Zn, Cd, and Pb.

Water Quality and Quantity Parameters - General water quality and quantity parameters and metals concentrations were determined by the Regional Study at the following stations sampled biologically: EM-1, EM-2, EM-3, LBD-3, LBB-3, LBB-4, LBB-5, LBB-6. Additional water quality data are available for upstream sites on Unnamed Creek and for area lake and stream sites from the Regional Study. Sediment data were collected in 1977 in Unnamed Creek, Bob Bay and Dunka Bay, and will be discussed later in this report.

RESULTS

Unnamed Creek

Water Quality - Water quality data from Unnamed Creek are presented in Tables 6 and 7. Comparative water quality data from Regional Study water quality monitoring stations, including Unnamed Creek, are presented in Table 8.

Data in these tables indicate that at the stations sampled biologically, pH, alkalinity, DOC, and DIC values were slightly higher than at EM-6, which is located above any seeps. Specific conductance and sulfate concentrations were considerably higher at the downstream stations than at EM-6. The concentration of copper was approximately twice as high at EM-6 as it was at EM-1-3 the downstream station, while nickel was 10 times higher in the downstream areas. Nickel was also higher at EM-3 than at EM-1 (Table 6). Also according to Eger et al. (1976) nickel concentrations are flow dependent; when discharge is low, nickel concentrations are high.

When comparing Unnamed Creek to other streams in the area, it appears to be quite similar (except in metal concentration) to the Partridge and Dunka rivers, but quite different, in most respects, from Filson and Keeley creeks. The observed similarity between Unnamed Creek and the Partridge and Dunka rivers is probably because all three rivers receive input from taconite mine dewatering.

Total copper concentrations in Unnamed Creek are higher than those found in all streams listed in Table 7 with the exception of Filson Creek. Total nickel concentrations are from 10 to 100 times higher in Unnamed Creek than in other area streams.

Water Quantity - Unnamed Creek water levels constantly fluctuated during the study as indicated by Figure 3 and Table 9. Fluctuations occurred frequently as a result of erratic pumping from Dunka Pit (see 011 and 012 discharges in Table 9). Discharge varied between 0.5 and 10.0 CFS during the period from July to September, 1976.

These fluctuating flows caused the loss of the control station, EM-2. Normally, the 012 discharge into this tributary creek is continuous, but because of the drought and hydrologic changes within the pit, pumping became intermittent in early August, 1976. This intermittent pumping resulted in the creek becoming dry at EM-2 after the artificial substrates had been in place for two weeks. Sampling was discontinued at this point and not resumed. Discharge at other stations, though fluctuating widely, was adequate for continuous sampling.

Periphyton-Chlorophyll - Chlorophyll a values in Unnamed Creek are generally low, particularly at EM-3 and EM-1A (Figure 4). Mean chlorophyll a concentrations were calculcated by averaging all chlorophyll values available between July 27 and October 14 (Table 10). Mean chlorophyll a increases as one moves downstream on Unnamed Creek. There is little difference between the mean chlorophyll a concentrations in Unnamed Creek sites overall and other Regional Study sites (Table 10).

The high variability in chlorophyll a values (Figure 4) makes it impossible to determine if there are real differences between stations. Sources of this variability include natural variability, sampler placement, fluctuating flows, sample handling, instrument error, and operator error. Instrument error may have been significant, as problems were noted by the operators during analysis. A major factor in this error may have been fluctuating electric line voltage (Beckman Instruments, Inc. personal communication).

Periphyton - Cell Counts - Diatoms comprised 96.5 to 99.5 percent of the periphyton cells colonizing glass slides in Unnamed Creek (Table 11). This is similar to the 87 percent overall average for periphytic diatoms reported in the Regional Copper-Nickel Study Area (Regional Copper-Nickel Study 1978). No differences are evident in the diatom percentage at the three stations on Unnamed Creek.

There is a trend in total cell counts between EM-1 and EM-3 (Table 12). A decrease is evident in the first two sampling periods moving from EM-1 to EM-3. A one-way analysis of variance of the data from each date separately indicated these differences were significant ($P>.01$). In the following two periods the number of cells colonizing glass slides was not significantly different ($P>01$) at the three stations except at EM-1A on September 23 which was significantly higher ($P<.01$) than the other two sites.

In late September cell counts were approximately equal at the three Unnamed Creek stations and at P-5, KC-1, and F-1 (Table 13). In contrast, BB-1 had a much greater periphyton population on this date than the Unnamed Creek stations located upstream.

Periphyton - Number of Taxa and Diversity - Table 14 presents the mean number of diatom taxa collected on glass slides in Unnamed Creek. In the first two sampling periods the number of taxa decreased between EM-1 and EM-3. During the next two sampling periods the difference between stations was much less although EM-3 continued to be lower. A larger number of taxa was found at all Unnamed Creek stations than were found at Regional Study stations (Table 15).

The number of diatom species collected in qualitative samples followed a similar pattern (Table 16). The fewest taxa were consistently found at EM-1. However, the greatest number of taxa was found at EM-1a instead of EM-1. In July, before EM-2 dried up, 40 taxa were found there, fewer than were found at EM-1 and EM-1a but more than at EM-3.

A nested analysis of variance (Appendix 3) comparing the three Unnamed Creek sites, EM-1, EM-1A and EM-3, to three other Regional Study stations, KC-1, F-1, P-5 was performed on data from late September. This test indicated that the Unnamed Creek sites had a significantly higher ($P<.01$) number of taxa than the Regional Study sites in late September. No significant differences ($P>.05$) were noted within either group of sites.

Shannon-Weiner diversity (Table 18) also tended to decrease from EM-1 to EM-3. Diversity of diatom communities was significantly greater ($P<.01$) in Unnamed Creek than in other streams in the Regional Copper-Nickel Study Area (Table 18) according to a nested analysis of variance (Appendix 3) which compared EM-1, EM-1A, and EM-3 as a group to F-1, KC-1, and P-5 as a group for late September data. This difference in diversity is primarily the result of a reduction in the dominance of a single species, Achnanthes minutissima, which was dominant throughout the Study Area (Regional Copper-Nickel Study 1978).

Periphyton-Dominant Taxa - The dominant diatom taxa collected in quantitative samples are listed in Table 19. Dominant taxa are those taxa which comprise at least 5% of the sample. The most abundant diatom at all stations on Unnamed Creek was A. minutissima (Table 20). In addition to being the most abundant taxon at each station, A. minutissima was also the most abundant taxon in each sampling period except October. In October Diatoma tenue var. elongatum became the most abundant diatom taxon.

Table 21 and Figures 6 and 7 present a comparison of selected diatom taxa from Unnamed Creek stations and Regional Study stations. A. minutissima was the dominant taxon in the entire Regional Copper-Nickel Study Area and as indicated on Table 21 and Figure 5, it was less abundant at Unnamed Creek stations than at Regional Study stations. A. minutissima was also much higher at BB-1 than at the upstream Unnamed Creek stations. D. tenue var. elongatum was consistently found in Unnamed Creek but rarely at Regional Study stations. Eunotia spp., an acidophilus diatom, was approximately equal in relative abundance at KC-1 and the Unnamed Creek stations. At other sites Eunotia spp. was low in abundance. Tabellaria flocculosa, another acidophilous diatom, was somewhat less abundant in Unnamed Creek than in other streams of the region. All species which occurred as dominants in Unnamed Creek also were reported as dominants in the Regional Copper-Nickel Study Area (Regional Copper-Nickel Study 1978).

D. tenue var. elongatum was the most abundant species collected qualitatively in Unnamed Creek (Table 22). This taxon was most abundant at EM-3 and least abundant at EM-1. A. minutissima, although a dominant, was not as important in qualitative samples as it was in quantitative samples. Both A. minutissima and D. tenue var. elongatum were most abundant in the October samples.

Fragilaria construens was most abundant at EM-1 and least abundant at EM-3. The relative abundance of Navicula notha was about equal at all stations. N. notha was most abundant in July samples and least abundant in October samples.

Table 23 compares the relative abundance of selected taxa collected qualitatively at Regional Study stations and Unnamed Creek stations. Eunotia spp. and Tabellaria flocculosa are more abundant at Regional Study stations. A. minutissima was higher at BB-1 than at the upstream Unnamed Creek stations while the abundance of A. minutissima was about equal at KC-1 and Unnamed Creek stations. Unnamed Creek stations had far greater abundances of D. tenue var. elongatum than Regional Study stations.

Benthic Invertebrates - Number of Organisms - The mean number of organisms collected on Hester/Dendy samplers and in drift nets is shown in Tables 25 and 26. An increase in the number of organisms colonizing Hester/Dendy samplers can be noted between EM-3 and BB-1. BB-1 had two to ten times more organisms than did other Unnamed Creek sites. An analysis of variance (Appendix 3) of log transformed data from October indicated there were significant differences ($P<.01$) in the mean number of organisms on Hester-Dendy samplers at the three Unnamed Creek sites.

The increase in the mean number of organisms was not seen in drift samples although BB-1 had the highest drift rate in late September-October when all sites were sampled. In late July before EM-2 dried up, substantially greater numbers of drifting organisms were collected at EM-2 than at other Unnamed Creek sites (Table 26).

Unnamed Creek sites generally had a lower number of organisms than Regional Study sites in either Drift or Hester/Dendy samples (Tables 25 and 26). A nested analysis of variance (Appendix 3) of log transformed data from late September and October was performed to compare the Unnamed Creek sites EM-1, EM-1A and EM-3 to Regional Study sites KC-1, P-5 and BB-1. Significant differences ($P<.01$)in the mean number of organisms in Hester/Dendy and drift samples was evident between these two groups of sites.

Benthic Invertebrates - Number of Taxa and Diversity - The mean number of invertebrate taxa and mean diversity are listed in Tables 27 and 28. Shannon-Weiner diversity of Hester/Dendy samples from the three Unnamed Creek sites was approximately equal although the number of taxa was greatest at EM-1. Shannon-Wiener diversity in drift samples from EM-1, EM-1A, and EM-3 was also approximately equal. In late July EM-2 had higher diversity than the other Unnamed Creek sites. The greatest number of taxa was also collected at EM-2 during that sample period. A general decrease in the number of taxa was observed at all sites between July and October.

A nested analysis of variance (Appendix 3) comparing Unnamed Creek sites (EM-1, EM-1A, and EM-3) to Regional Study sites (P-5, SR-1, BB-1) was performed. Significant differences ($P<.01$) in drift diversity, and the number of taxa in drift samples during late September and October, were evident between the groups. No significant differences in the mean diversity of Hester/Dendy samples was observed.

Further t-tests were performed on the data from EM-1 and P-5 to determine if any significant differences existed between the diversity and number of organisms at these stations which are both on headwater streams receiving mine dewatering. Significant differences ($P<.01$) were found in drift diversity, number of taxa in drift and number of taxa in Hester/Dendy samples. It should be noted that the diversity values from Unnamed Creek were calculated on samples which often contained fewer than 100 organisms which could cause error in interpretation.

Benthic Invertebrates - Dominant Taxa - The number of taxa collected qualitatively at Erie Mining sites are listed in Table 29. EM-2 had the highest number of taxa collected in July while the smallest number were collected at EM-3 in October. Table 30 presents the dominant invertebrate taxa (those comprising at least 5% of the sample) identified in drift and Hester/Dendy samples from Unnamed Creek. The dominant organisms were relatively consistent between sites and sampling methods. One exception was the greater abundance of *Lepidostoma* (Trichoptera) in Hester/Dendy samples than in drift. *Thienemaniella*, a chironomid, tended to be more common in drift while *Parametriocnemus*, another chironomid, was more common in Hester/Dendy samples. Overall *Hydropsyche slossonae*, *Simulium* spp., and *Conchapelopia* were generally the most common invertebrates collected in drift and Hester/Dendy samples.

The most abundant taxa collected qualitatively are presented in Table 31. As in quantitative samples the most commonly collected taxon was *Hydropsyche slossonae*.

Table 32 presents the dominant invertebrates found in drift and Hester/Dendy samples from Regional Study sites. The most significant difference in drift samples from Unnamed Creek and Regional Study sites was the presence of *Chimarra* at P-5 and D-1, sites which receive mine dewatering. This invertebrate was not found in Unnamed Creek. *Pseudocloeon* was also found as a dominant at P-5 and SR-1 but not in Unnamed Creek.

The dominance of Stenonema and Microtendipes at sites KC-1 and D-1, and the dominance of Stenonema and Acroneuria at F-1 was not observed in Unnamed Creek. Other dominant taxa in Hester/Dendy samples were similar to Unnamed Creek.

Benthic Invertebrates - Functional Groups-- Eight invertebrate functional groups have been defined by Cummins (1975, 1976) and Merrit and Cummins (1978) based on general invertebrate feeding habits (Table 32). Cummins (1975; 1976) discussed the similarity of streams of similar stream order on the basis of functional group composition even when the dominant taxa are different (see discussion for further details).

Invertebrate taxa collected in the present study and the Regional Study were assigned to functional groups by Cummins (Michigan State University personal communication). In analyzing the functional group data the first five groups listed in Table 33 were used. These are the groups which provide the most information about trophic conditions in streams.

Figures 6 and 7 present the relative abundance of the first five benthic invertebrate functional groups in Hester/Dendy and drift samples. Hester/Dendy samples at EM-1 and EM-1A were dominated by collector-gatherers and collector-filter feeders. Substantially fewer filter-feeders were found at EM-3 although other groups were approximately equal at all three Erie sites.

Filter-feeding invertebrates were also dominant in drift samples from EM-1 and EM-1A during all sampling periods and at EM-3 and EM-2 in late July. The relative abundance of shredders of dead plant material generally increased between late July and October while groups such as the shredders of live plant material decreased. Shredders also were more abundant at EM-1A and EM-3 than at EM-1. Scraper invertebrates were uncommon in all Unnamed Creek samples.

The functional group composition of Unnamed Creek sites is clearly different from the Regional Study site SR-1 when comparing drift samples (Figure 7) but not Hester/Dendy samples (Figure 6). Unnamed Creek sites most closely resemble the Regional Study site KC-1 (Figures 6 and 7). Other Regional sites included in Figures 6 and 7 all resemble the Unnamed Creek sites during one time period or another; yet, as can be observed in Figures 6 and 7, all sites were variable so it is difficult to make generalizations. One difference is the lack of scrapers at Unnamed Creek sites and their presence at Regional Study sites in both drift and Hester/Dendy samples. For example, scrapers comprised 16% of the invertebrate community at F-1, a small headwater stream. In contrast at P-5, another headwater stream, scrapers comprised only five percent of the invertebrate community. Another difference is the lower total percentage in Unnamed Creek for the five functional groups, indicating a higher percentage of predators in Unnamed Creek.

<u>Benthic Intertebrates - Comparison to Previous Data</u>--A comparison of data collected from Unnamed Creek by Barr Engineering Company in 1975 and the current study appears in Table 34. A greater number of organisms and taxa were collected in the present study than in the 1975 study. The difference in taxa is primarily the result of identifying chironomids to the genus level in the present study. The most abundant taxa were similar in both years with <u>Hydropsyche</u> spp. and chironomids the most common taxa.

The 1975 data indicate little difference exists between EM-1 and EM-3. EM-2 does, however, appear to be somewhat different from the other two stations. A higher number of organisms and taxa were collected at EM-2 and the most abundant taxa included <u>Paraleptophlebia</u> (Ephemeroptera) and

Ptilostoma (Trichoptera) which were rare at EM-1 and EM-3.

Birch Lake

Water Quality - The water quality parameters listed in Table 35 are generally higher in Bob Bay than Dunka Bay except at LBB-6. Alkalinity, specific conductance and dissolved organic carbon are slightly lower at LBB-6 than at LDB-3, its corresponding station on Dunka Bay. Nickel concentrations were much higher in Bob Bay than in Dunka Bay while copper concentrations were only slightly higher in Bob Bay.

Little difference for all parameters exists between surface and bottom samples from sites in Bob Bay and Dunka Bay except for LDB-2 where alkalinity and sulfate were higher on the bottom.

Phytoplankton - Chlorophyll a values for Bob Bay and Dunka Bay are presented in Table 36 and Figure 8. All stations on Bob Bay, Dunka Bay and Birch Lake appear similar except LBB-6 which had the lowest recorded chlorophyll a values. High variability is evident, as shown by the confidence intervals in Figure 8, especially in October.

Benthic Invertebrates - In Bob Bay, invertebrate populations were highest in October with lower but approximately equal densities in August and November (Table 37). Invertebrate densities were lowest on all dates at LBB-6 which was the deepest station located at the junction of Bob Bay and Birch Lake. Stations LBB-3, LBB-4, LBB-5, had approximately equal population densities for each sampling date except at LBB-4 in October which had the highest density observed in Bob Bay (4493/m^2).

Highest invertebrate densities in Dunka Bay were recorded in November with densities of 6485/m^2 and 9067/m^2 at LBD-2 and LBD-3 respectively. In August, Dunka Bay invertebrates were less numerous than at sites LBB-3 and LBB-4. At LBD-2 invertebrate densities were approximately equal to LBB-3 and LBB-5; the invertebrate abundance at LBD-3 was approximately equal to that at LBB-4 in August.

The number of taxa varied from 8 at LBB-6 in November to 23 at LBD-2 in October (Table 37). In general, more taxa were collected at Dunka Bay stations than at Bob Bay stations. Overall, forty and forty-one invertebrate taxa were collected from Dunka and Bob bays respectively. Procladius, a chironomid, was the most widespread and abundant invertebrate in Dunka and Bob bays. Tanytarsus, another chironomid, had the highest densities for any one sampling date, 6644/m^2 at LBD-3 in November. The abundance of Tanytarsus was significantly higher in Dunka Bay than in Bob Bay in November and was largely responsible for the high November invertebrate densities in Dunka Bay. Other common and widespread taxa included:

1) Hexagania limbata found in varying numbers at each station on each date;
2) Sialis ranged from 7-100/m^3 and was found during all sampling periods;
3) Ablabesmyia a chironomid found at all sites except LBB-3;
4) Sphaeriidae collected at each station on at least two dates.

Several taxa were more common in Bob Bay than Dunka Bay. These included: Ceratopogonidae, Chaoborus, Polypedilum, Psectrocladius, and Tanypus. Of those taxa (for which at least 100/m^2 were found in a single collection) only Cricotopus was not found in Dunka Bay while Endochironomus and Einfeldia were found only in Dunka Bay.

Benthic invertebrate diversity (Table 38) ranged from .163 (LBD-3, November) to 3.32 (LBB-4, October). The low diversity at LBD-3 in November was again a result of the extremely high number of Tanytarsus spp. Diversity at all stations increased between the August and October sampling dates. Between October and November, the change in diversity was variable. No clear trends are evident within or between bays based on invertebrate diversity.

Heavy Metals Analysis

The heavy metal content of macrophytes collected in 1976 can be found in Appendix 2. Because there was no replication of samples, these data will not be discussed. Copper and nickel values are presented in Table 39 for clams, water lilies, water and sediments from Bob Bay, Dunka Bay and Birch Lake. Concentrations of both metals are generally higher in Bob Bay than in Dunka Bay or Birch Lake. The concentration of nickel in the water of Bob Bay is four times as high as that in Dunka Bay while the concentration of nickel in the sediments is 15 times higher in Bob Bay than in Dunka Bay. Copper concentrations are significantly higher ($P<.05$) in clam and plant tissue in Bob Bay than in Dunka Bay and nickel concentrations are significantly higher ($P<.05$) in plant tissue in Bob Bay.

The Regional Copper-Nickel Study (1978) found significant positive correlations between the concentration of copper in sediments and in clam tissue ($r = .90$, $P <.01$) and plant tissue ($r = .92$, $P<.5$). There were also significant correlations between nickel in plant tissue and in water ($r = .91$, $P<.05$) and in sediment ($r = .99$, $P<.01$).

DISCUSSION

Unnamed Creek

According to Cummins (1975; 1976) stream ecosystem structure and function should be similar in streams of nearly equal stream order although the species in each stream may be different. This theory is based on the fact that streams of equal order have similar physical characteristics (e.g. discharge, gradient, channel morphology). Small headwater streams (first and second order) are generally narrow and shaded by riparin vegetation. This vegetation provides the primary food source to consumer organisms. Primary production in these streams is generally low. In larger streams (third, fourth and fifth order) primary production increases as the effect of shading decreases. Therefore changes in the invertebrate community are expected as the food sources change.

Because Unnamed Creek is a small, heavily shaded headwater stream, one would expect the Unnamed Creek communities to resemble other headwater streams in the region. In many ways Unnamed Creek is similar to other impacted (P-5) and unimpacted (KC-1 and F-1) headwater streams. Primary production in Unnamed Creek as measured by chlorophyll a and cell counts was approximately equal to primary production in other streams (Tables 10 and 13). The dominant diatom taxa in Unnamed Creek are also similar to other headwater streams with the exception of Diatoma tenue var. elongatum (Tables 21 and 24). The dominance of this taxa is probably a result of the high conductivity, a condition favored by this taxa (Lowe 1973). Other taxa such as Achnanthes minutissima were dominant in Unnamed Creek but less abundant than in other streams in the region.

Invertebrate functional group composition in Unnamed Creek was similar to other streams. Unnnamed Creek had larger populations of shredders in October in both Hester/Dendy and drift samples than other Regional Study sites (Figures 9 and 10). This may be the result of sampling later in the fall, a time of increasing shredder population, in Unnamed Creek than at Regional Study sites.

In light of the high natural varibility in populations of aquatic organisms it is important to consider impacts in terms of detectable changes. Observed changes must account for a greater statistical variation from the "norm" than would be expected naturally before the existance of an "real" impact can be established.

While these similarities do exist, a number of major biological differences between Unnamed Creek and other streams in the region are evident. Most of these differences indicate that Unnamed Creek is stressed. Low invertebrate population size, diversity of drifting invertebrates, and the number of invertebrate taxa all indicate stress conditions (Gaufin 1973). These differences are evident even when Unnamed Creek sites are compared to P-5, a station located on a headwater stream and affected by mine dewatering. Therefore it would appear that Unnamed Creek is adversely affected by one or a combination of factors not seen in other streams sampled by the Regional Study. These factors were high nickel concentrations, fluctuating flows, and poor natural substrate.

It should be noted that two parameters, the number of diatom taxa and diatom diversity were higher in Unnamed Creek than in other headwater streams in the region. These differences are probably the result of Achnanthes minutissima being less dominant in Unnamed Creek than at other Regional Study sites.

Several biological parameters were observed to increase between EM-3 and EM-1 chlorophyll a, periphyton cell counts, number of diatom taxa, and the number of invertebrates colonizing Hester/Dendy samplers (Figure 9). In the case of chlorophyll a and periphyton cell counts, this pattern was most obvious in early sampling periods (Figure 7 and Table 12). Water quality differences between EM-1 and EM-3 are negligible, with the exception of nickel which is significantly higher at EM-3 than at EM-1 (Table 6). The variations in nickel concnetrations which can be noted on Table 6 are a result of the changes in flow which affect the ambient concentration of nickel.

Nickel concentrations are consistently above 100 µg/l and reached a peak of 422 µg/l at the begining of the first sampling period. Gerhart and Davis (1978) reported that 100 µg Ni/l was sometimes toxic to phytoplankton while 400 µg Ni/l was more consistently toxic in Birch Lake water, which is somewhat softer than Unnamed Creek water. Hutchinson (1973) observed toxic effects on Scenedesmus acuminata, a green alga, at a level of 100 µg Ni/l. Talrick et al. (1975) observed shifts from diatoms to blue-green and green algae and reduced diatom diversity at nickel levels of 4 to 9 µg/l.

In contrast to algae, invertebrates are quite resistant to nickel as toxic concentrations are generally above 1000 µg Ni/l (Table 1). An exception is Tanytarsus disimilis which has been affected at 130 µg Ni/l.

Based on these data, therefore, it is highly possible that nickel was causing biological effects on the Unnamed Creek periphyton during the time of sampling. However, there are other data which are contradictory. The dominant taxa in Unnamed Creek, Achnanthes minutissima, was considered by Besch et al. (1972) to be sensitive to copper-zinc pollution. Additional taxa such as Eunotia spp., A. linearis and Tabellaria spp. are also considered sensitive to heavy metals by Besch et al. and are found in Unnamed Creek.

Shifts from diatoms to blue-green and green algae as a result of heavy metal pollution were reported by Patrick (1978) and Patrick et al. (1975). Therefore, the diatom percentage observed in Unnamed Creek (90%) which is higher than reported for the region in general (Regional Copper-Nickel Study 1978) would seem to indicate a lack of heavy metal stress in Unnamed Creek.

In summary, while few differences exist between the invertebrate community at the three Unnamed Creek sites, there are major differences between Unnamed Creek and other streams in the region as well as between EM-2 and the other Unnamed Creek sites. The most significant conditions causing these differences are probably fluctuating flows and lack of suitable substrate in Unnamed Creek. Because of the frequency and duration of low flows in Unnamed Creek, invertebrate populations are limited to those areas of the stream that remain continually submerged. Fisher and LaVoy (1972) found very few insects in zones of fluctuations except for chironomids. Peterson and Fernando (1969) showed an appreciable decline in the invertebrate population with increased exposure time of the substrate. This may explain the low numbers of invertebrates found in Unnamed Creek compared to other streams in the region. Also, the shifting sand substrate found in Unnamed Creek is not conducive to invertebrate populations. Bell (1968) reported low populations in sandy substrates.

When a standard substrate (Hester/Dendy) was employed in sampling, species diversity was not significantly different in Unnamed Creek than in other streams in the region. Diversity of drift was significantly lower in Unnamed Creek. This would seem to indicate that substrate may be a factor limiting the development of the invertebrate community. It may also indicate that water quality (i.e. heavy metals) is not a major factor affecting the invertebrate community.

One interesting difference was noted during the analysis of the data. Stations BB-1 and EM-1 appear quite different even though they are located within 150 m of each other. BB-1 generally had higher invertebrate numbers than EM-1 (Tables 25 and 26). Also, larger periphyton populations (Table 13) were found at BB-1 as well as somewhat different dominant diatom species (Table 21). These differences may be due, in part, to a backwater effect from Bob Bay. During periods of low flow, water from Bob Bay may flow back into the lower reaches of Unnamed Creek as far as BB-1 and thereby have a stabilizing effect on the water levels at BB-1. Other causes of the observed differences may have been the substrate immediately upstream from BB-1. This substrate, consisting of large boulders, could provide habitat for more individuals and different species of aquatic organisms which were then captured at BB-1.

Birch Lake

The addition of copper and nickel to Bob Bay via Unnamed Creek does not appear to be influencing phytoplankton populations in the bay. Chlorophyll a concentrations are similar in Bob Bay, Dunka Bay and Birch Lake. The concentrations of copper and nickel in Bob Bay are below those reported by Gerhart and Davis (1978) to affect phytoplankton productivity in Birch Lake water. Copper concentrations in Bob Bay water ranged from 1.0 to 3.0 μg/l; Gerhart and Davis reported no detrimental effects at concentrations less than 50 μg/l. Nickel concentrations ranged from less than 1.0 to 61.0 μg/l in Bob Bay which is far lower than the 100 μg/l Gerhart and Davis reported as critical in Birch Lake.

There was no clear effect on benthic invertebrates in Bob Bay from copper or nickel. The only significant difference between Bob Bay and Dunka Bay was in the number of Tanytarsus spp. collected. Anderson et al.(1977) found that Tanytarsus disimilis was more sensitive to heavy metals than other aquatic insects, which could account for the lower abundance of this organism in Bob Bay. The LC-50 reported by Andersen et al. for copper was 16.3 μg/l. This value is much higher than the concentrations reported in the water from Bob Bay and therefore it is doubtful that the difference between the two bays can be explained by looking at concentrations in the water. However, concentrations of copper in the sediments is three times higher in Bob Bay than Dunka Bay and nickel concentrations are approximately 15 times higher in Bob Bay. The combination of higher concentrations of both metals in Bob Bay sediments may account for the lower number of Tanytarsus spp. in Bob Bay.

Another difference between the two bays which could influence the abundance of Tanytarsus spp. is a difference in substrates. Sediments in Dunka Bay are primarily sand and coarse detritus while those in Bob Bay are primarily silt and finely divided detritus.

Clams in Bob Bay are accumulating significant amounts of copper in their tissue while the macrophyte tissues are accumulating both copper and nickel. While it is unclear whether the source of these metals is the sediments, the water, or both, it is obvious that the metals are biologically active because they are accumulated. Copper and nickel are both known to be toxic to molluscs and macrophytes (Arthur and Leonard 1970, Besch and Roberts Pichette 1970 etc.). Unfortunately, the relationship between the tissue levels and toxicity of heavy metals is unknown. Therefore no prediction can be made regarding the long term effects of the accumulation.

SUMMARY

Sampling in Unnamed Creek located east of Erie Mining's Dunka Pit revealed significant differences between the biological communities of Unnamed Creek and other similar streams in the region. Parameters such as: the number of organisms drifting, the diversity of drift samples, the number of drifting invertebrate taxa, the number of organisms colonizing Hester/Dendy samples, and the number of taxa colonizing Hester/Dendy samples were all lower in Unnamed Creek than in other streams sampled by the Regional Study. Periphyton diversity and the number of periphyton taxa was significantly higher in Unnamed Creek, primarily due to a decrease in the relative dominance of *Acnanthes minutissima* in this creek.

In other ways Unnamed Creek was not different from other streams. Chlorophyll *a*, periphyton cell counts, dominant diatom taxa, invertebrate functional group composition and invertebrate diversity (Hester/Dendy) were similar to streams sampled by the Regional Study.

Within Unnamed Creek there were several changes between EM-3, the upstream station, and EM-1 the downstream station. While many of these differences are statistically significant there are no preoperational data available to indicate that the three sites had similar biological communities, although it would appear intuitively true. Primary production (chlorophyll *a* and cell counts), the number of periphyton taxa and the number of organisms colonizing

Hester/Dendy samplers increased between EM-3 and EM-1. The nickel concentrations at EM-3 were significantly higher than the concentrations at EM-1 and were high enough (100 to 400 μg/1) to affect the periphyton community.

It appears that fluctuating flows and the shifting sand substrate are probably the most important factors causing the low invertebrate diversity and density. It is impossible to separate the effects of these factors from the effects of heavy metals.

In Bob Bay of Birch Lake, no effect on phytoplankton production was evident. However, benthic invertebrate density in Bob Bay was significantly less than in Dunka Bay. This was the result of a single genus, Tanytarsus, a genus sensitive to heavy metals which was abundant in Dunka Bay but not Bob Bay.

Clams (Anodonta) from Bob Bay have accumulated significant amounts of copper in their tissue while water lilies (Nuphar variegatum) from Bob Bay have accumulated significant amounts of copper and nickel. Whether the source of these metals is the sediments or the water is unclear at this time.

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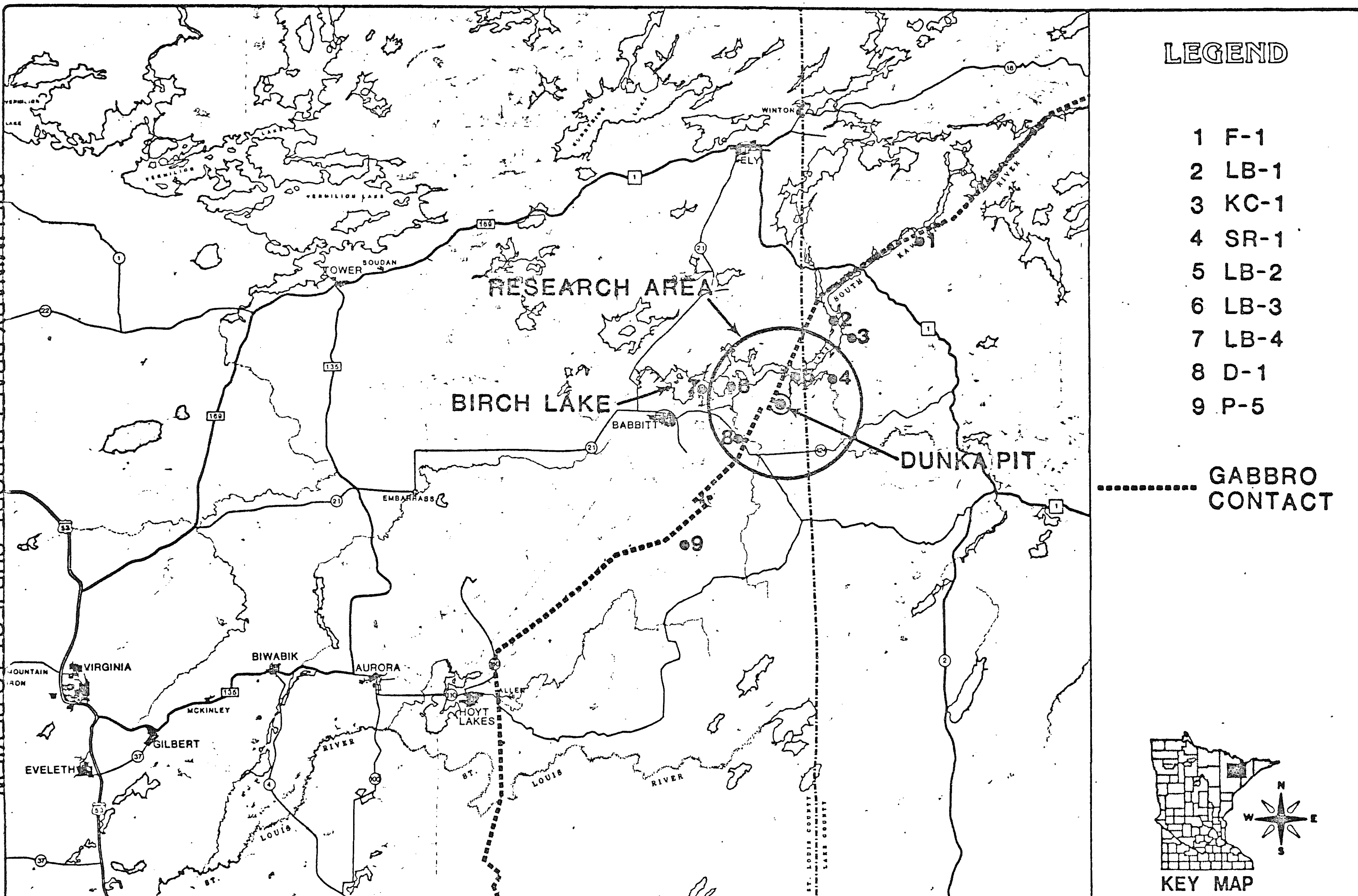
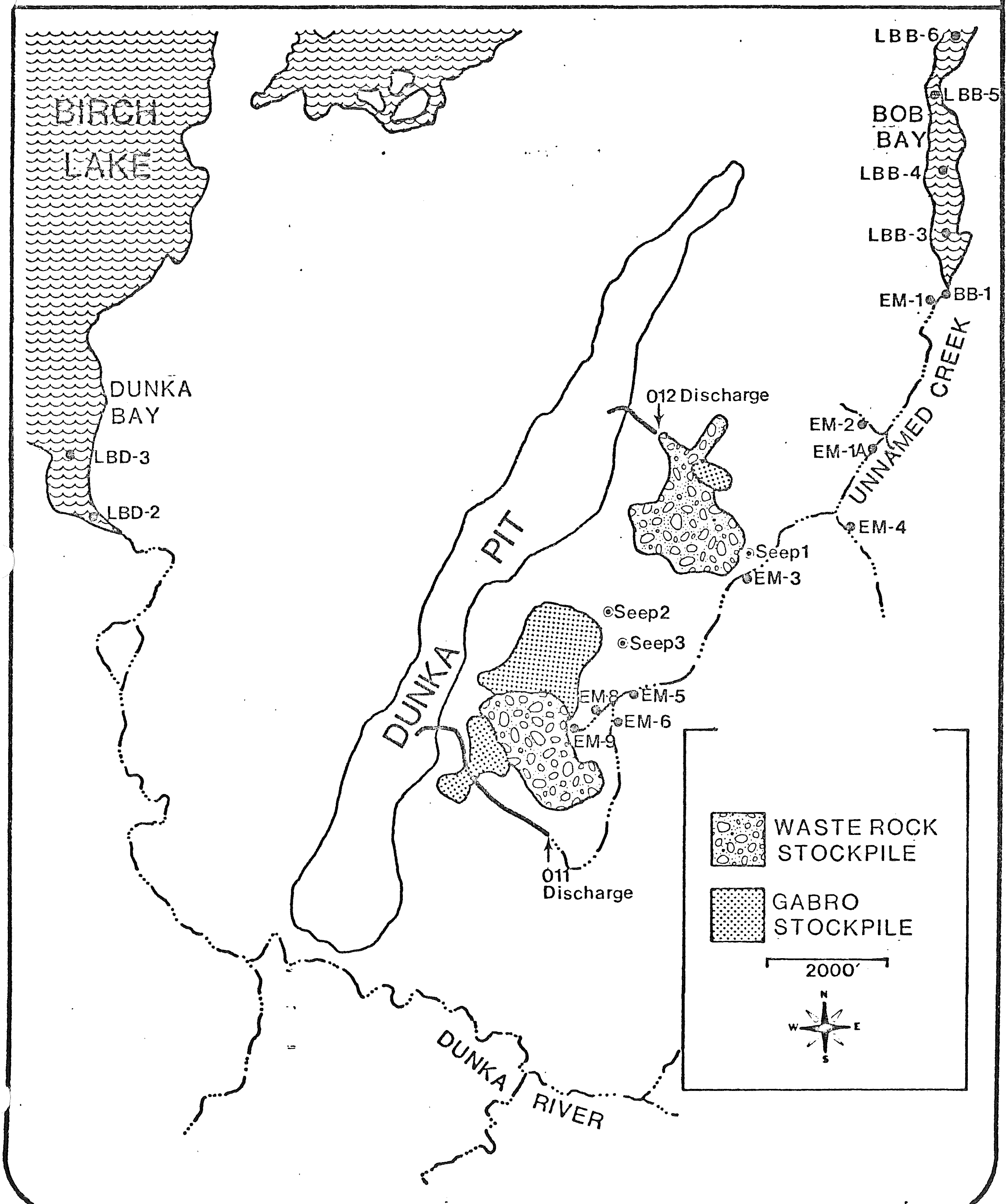


MEQB REGIONAL COPPER-NICKEL STUDY

FIGURE 1. LOCATION OF ERIE MINING RESEARCH AREA

Figure 2. Location of sampling stations, in relation to Dunka Pit, waste rock piles, gabbro piles, and seeps.



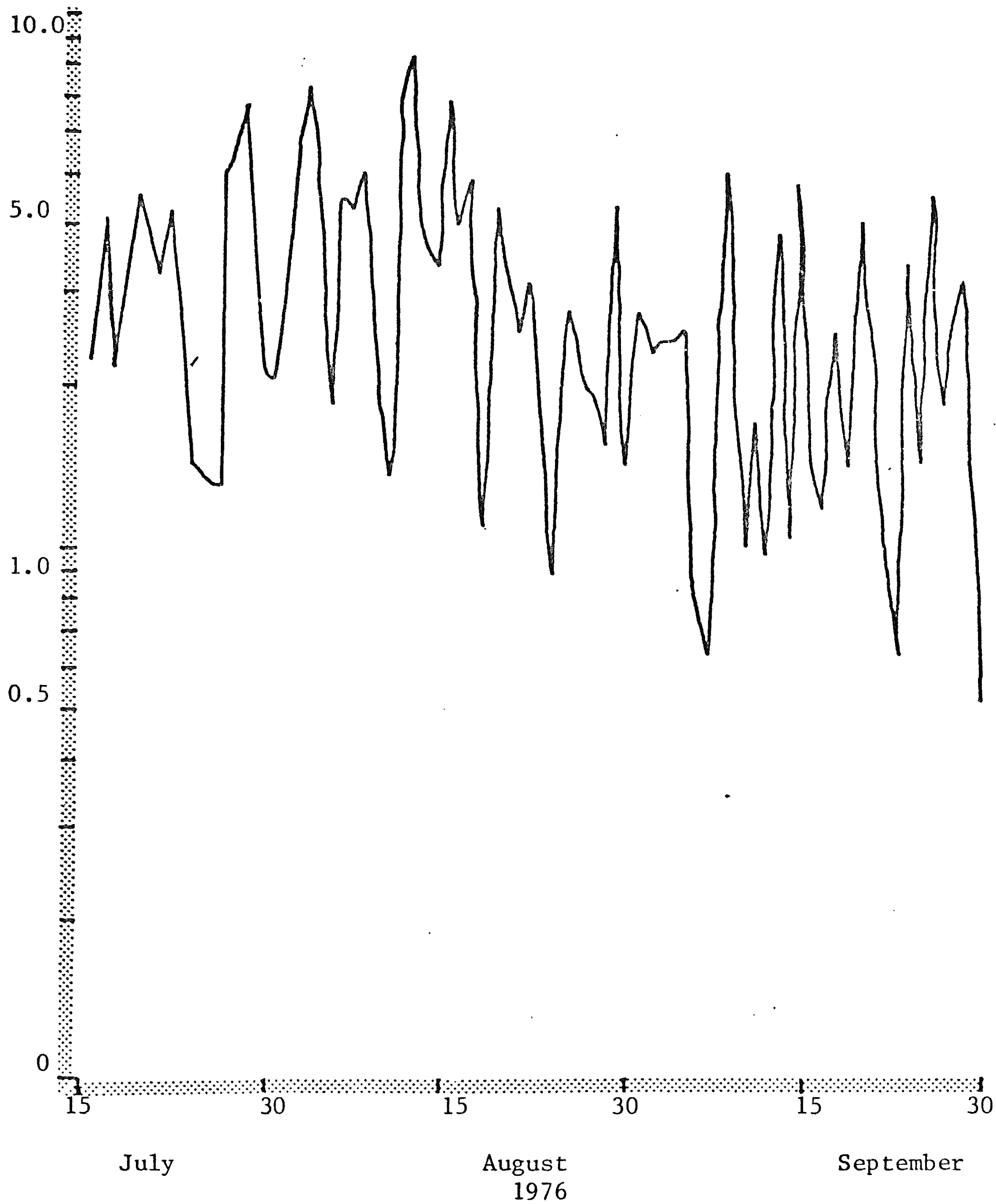


Figure 3. Mean daily discharge at station EM-1, July-September, 1976 (from Eger et al. 1977).

Figure 4. Mean chlorophyll a values for Unnamed Creek stations and P-5 (Partridge River). Vertical bars indicate two standard deviations on each side of the mean.

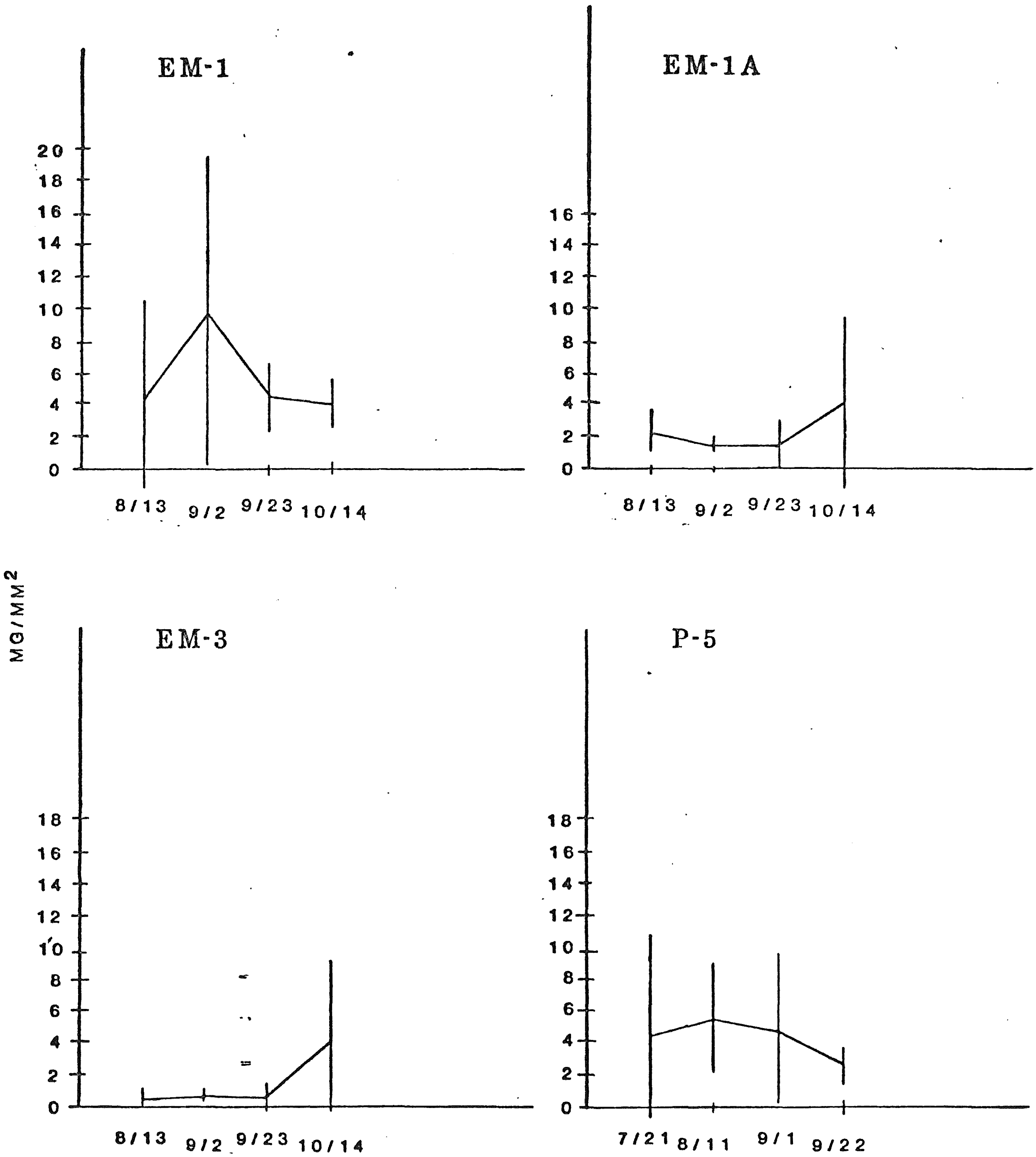


Figure 5. Percent relative abundance of selected dominant taxa collected on glass slide artificial substrates in 1976.

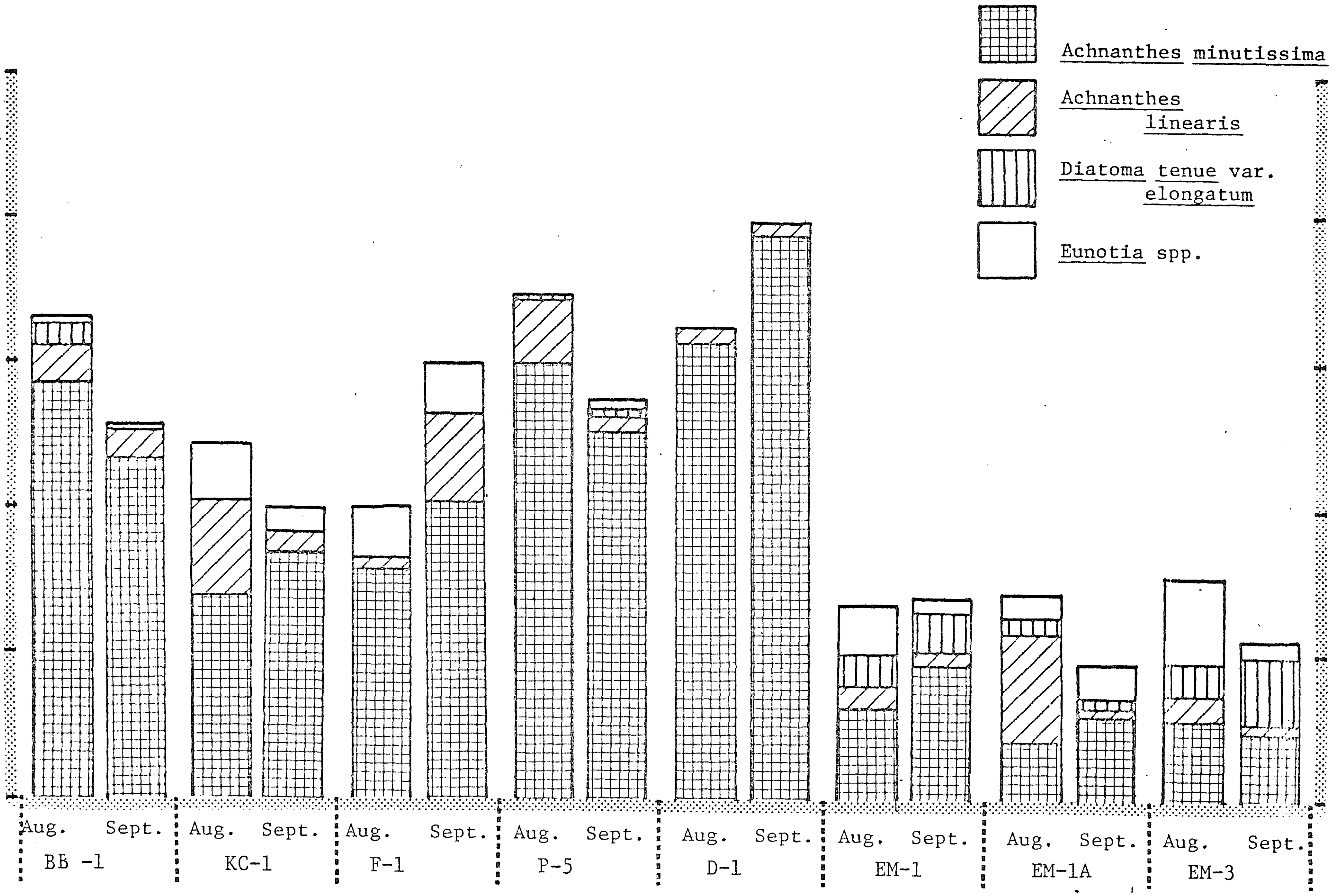


Figure 6. Percent relative abundance of invertebrate functional groups in colonizing Hester/Dendy samplers at Unnamed Creek sites and Regional Study sites during 1976.

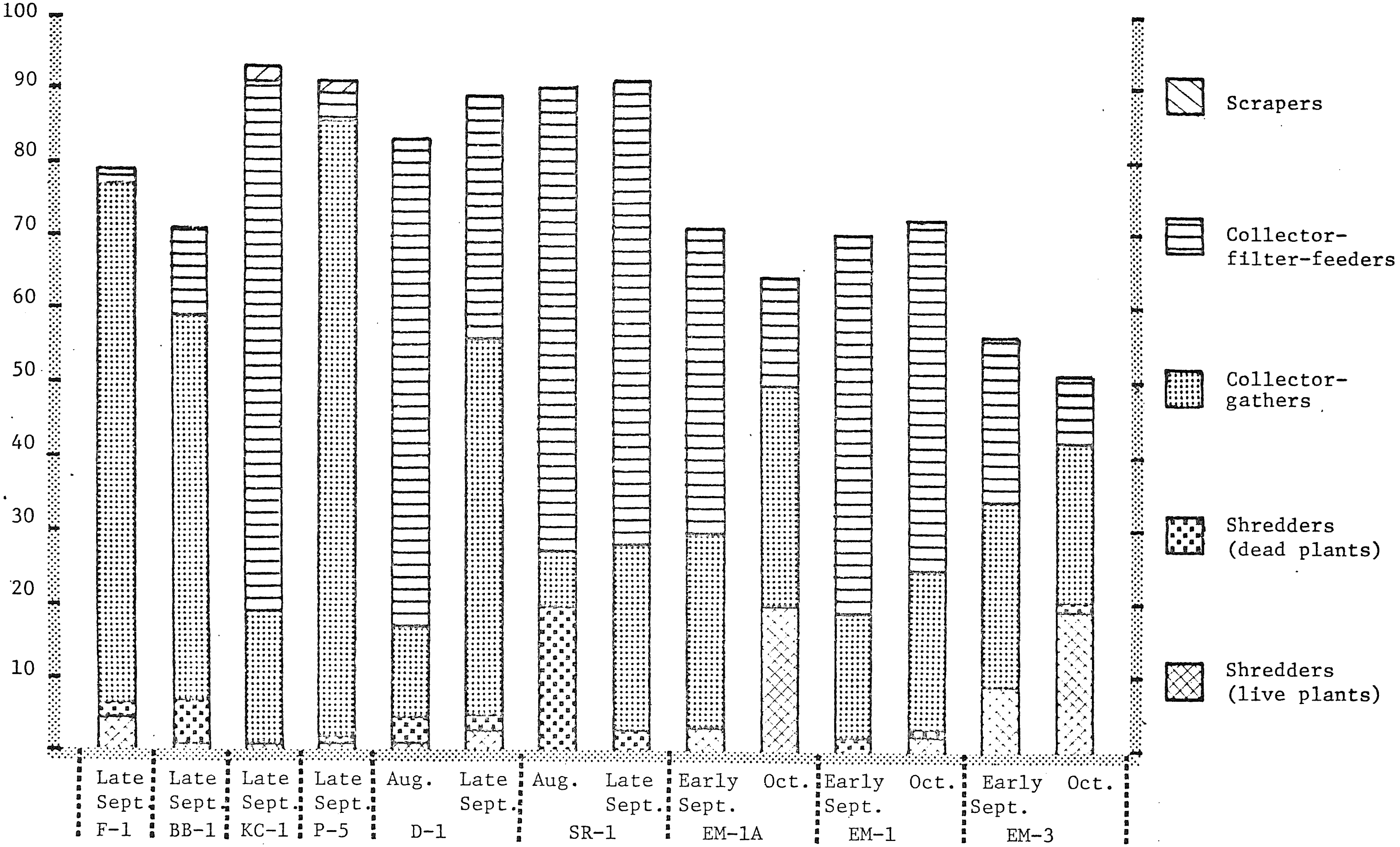


Figure 7. Percent relative abundance of invertebrate functional groups collected in drift net in Unnamed Creek and at Regional Study sites during 1976.

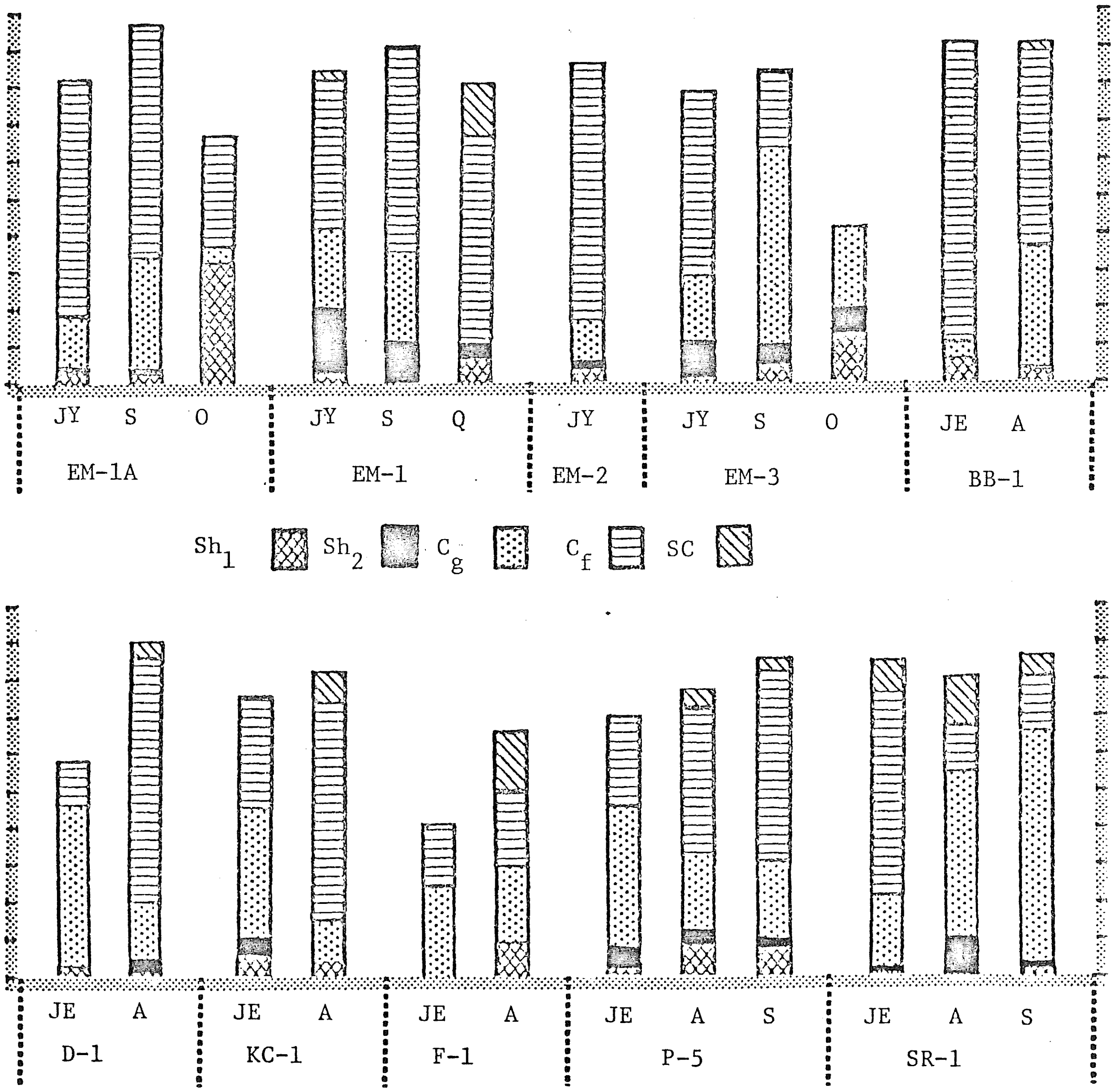


Figure 8. Chlorophyll a from Bob Bay, Dunka Bay and Birch Lake
(LB-3 from Regional Copper-Nickel Study 1978)

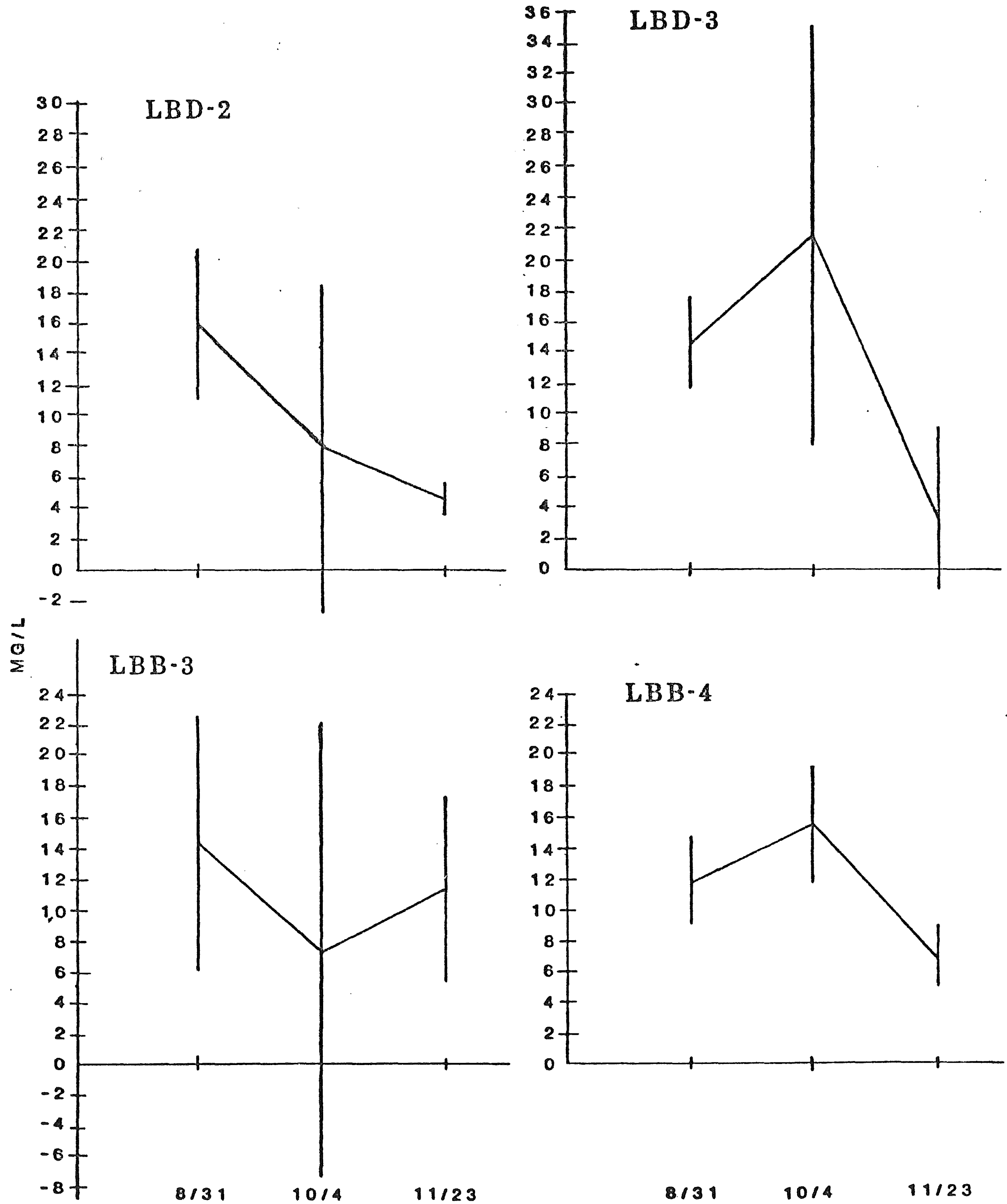


Figure 8 (continued)

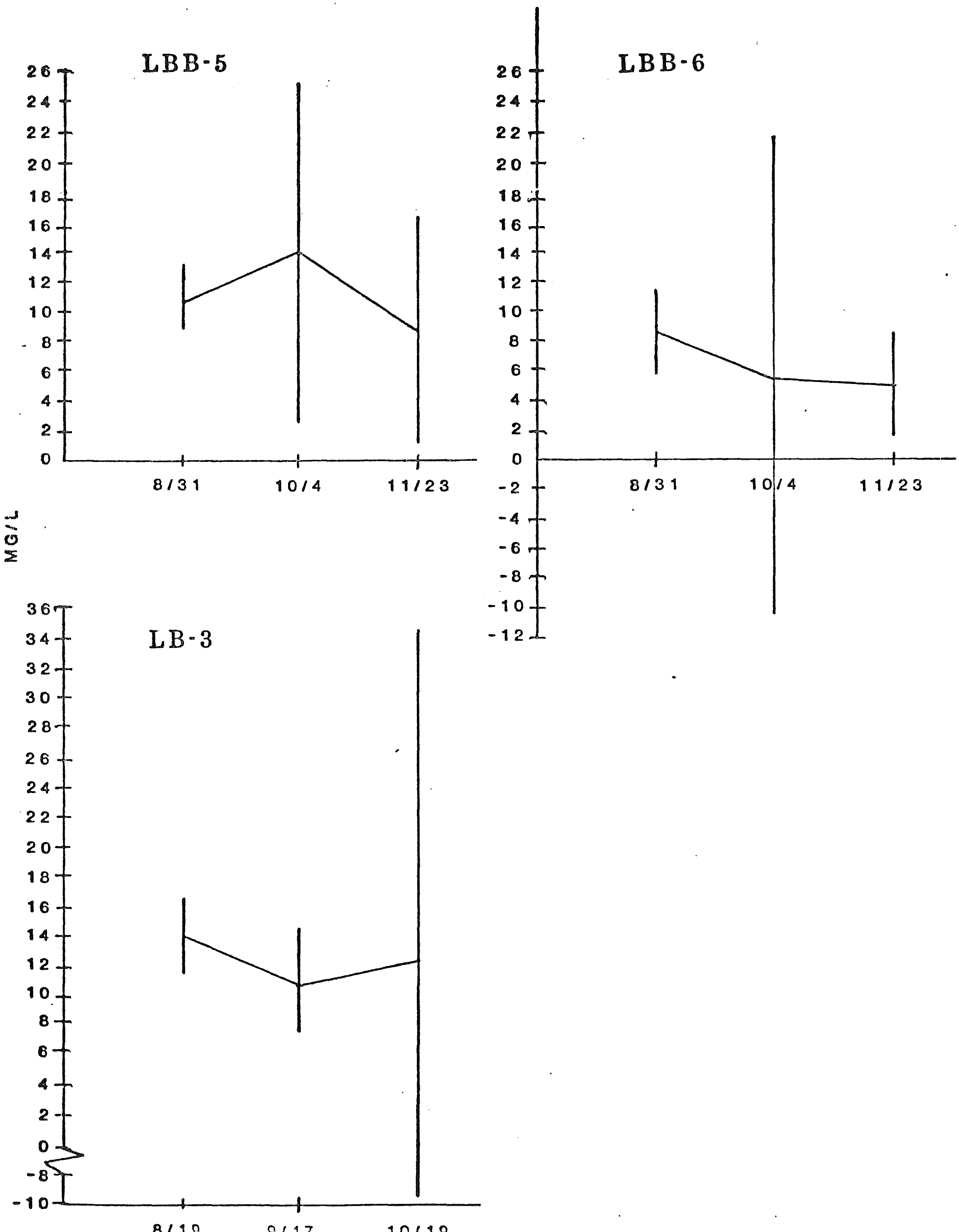


Figure 9. Changes in biological communities between stations EM-1 and EM-3

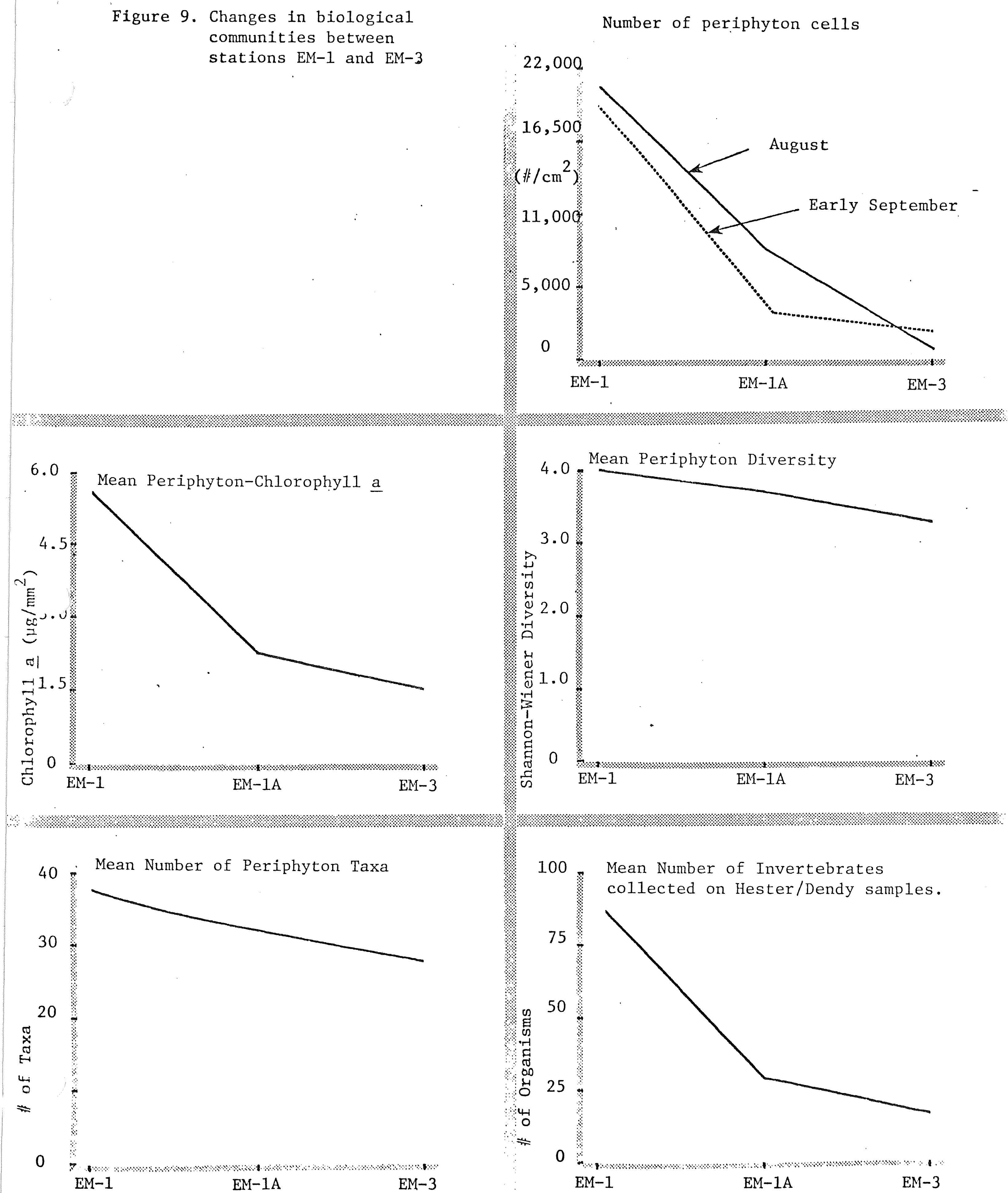


Table 1. Some copper and nickel toxicity values for benthic invertebrates.

Organism	Toxicity mg/l TLm or LC_{50} Copper	Nickel	Type of Test	Alk/Hard	pH	Reference
Ephemerella grandis	.18-.20	---	14 day flow through	30-70	7.0-7.2	Nehring, 1976
Pteronarcys californica	10.1-13.9	---	14 day flow through	30-70	7.0-7.2	Nehring, 1976
				30-70	7.0-7.2	
Caddisfly	12.1-6.2	48.4-30.2	24-96 hr static	50	7.6	Rehwoldt et al., 1973
Damsel fly	10.2-4.6	26.4-21.2	24-96 hr static	50	7.6	Rehwoldt et al., 1973
Chironomus spp.	.65-.03	10.2-8.6	24-96 hr static	50	7.6	Rehwoldt et al., 1973
Amnicola spp(adult)	4.5-9.3	26.0-11.4	24-96 hr static	50	7.6	Rehwoldt et al., 1973
Gammarus spp.	1.2-.91	15.2-13.0	24-96 hr static	50	7.6	Rehwoldt et al., 1973
Nais spp.	2.3-.09	16.2-14.1	24-96 hr static	50	7.6	Rehwoldt et al., 1973
Acroneuria lycorias	8.3	33.5	96 hr static	40	7.25	Warnick and Bell, 1969
Ephemerella subvaria	.32	---	48 hr static	40	7.25	Warnick and Bell, 1969
				40	7.25	
Ephemerella subvaria	---	4.0	96 hr static	40	7.25	Warnick and Bell, 1969
Hydropsyche betteni	32.0	64.0	14 day static	40	7.25	Warnick and Bell, 1969
Nais spp.	1.0-2.0	---	24 hr static			Learner and Edwards, 1963
Gammarus pseudolimnaeus	.020	---	96 hr acute	43	7.7	Arthur and Leonard, 1970
Physa integra	.039	---	96 hr acute	43	7.7	Arthur and Leonard, 1970
Campeloma decisum	1.7	---	96 hr acute	43	7.7	Arthur and Leonard, 1970

Table 2. Toxicity of copper to diatoms.

ORGANISM	TOXIC LEVEL (mg/ℓ)	TYPE OF TEST	REFERENCE
Nitzschia linearis	.795-.815	120 hr static	Patrick, Cairns, and Scheier, 1968
Nitzschia palea	.0125	No growth for 4 days	Nielson and
	.005	prevents growth	Winn-Anderson, 1978
Gomphonema parvulum	2.0	static-toxic in 3 days	Palmer and
Nitzschia palea	2.0	" " " " "	Maloney, 1955
Asterionella spp.	.12-.20	concentration to kill in cooling tower experiment	Maquire et al., 1956
Nitzschia spp.	.50	" " "	" " "
Synedra spp.	.36-.5	" " "	" " "

Table 3. Sampling stations on Unnamed Creek.

Station Designation	Location	Description	Justification
EM-1	Mouth of Unnamed Creek. Located at USGS gauging station.	large boulders, moss covered on downstream side; fine sand among boulders; leaves, twigs, branches caught between boulders; maximum depth approximately 1 m.	Good natural habitat-comparable to habitat at EM-2; Heavy metal levels lower than at other main channel stations
EM-2	Western tributary which contains water pumped from north end of Dunka pit (012 discharge)	small boulders & occasionally large boulders; fine sand among rocks; leaves, twigs & branches caught among rocks; depth approximately 30 cm.	Control station; receives mine water but heavy metal levels low. Good natural habitat
EM-1a	Immediately upstream from the western tributary	fine sand, small rocks, leaves, branches on bottom: maximum depth approximately .7 m.	Fair natural substrate; Heavy metal levels not diluted by western tributary
EM-3	Upstream from eastern tributary. Located at USGS gauging station	large moss covered boulders; find sand among boulders; eddies containing twigs and leaves; depth .5 m.	Upstream station with highest heavy metal level; fair natural substrate

Table 4. Sampling stations in Bob Bay and Dunka Bay.

STATION DESIGNATION	LOCATION	DESCRIPTION	JUSTIFICATION
LBD-2	Approximately 150 yds from mouth of Dunka River	Depth: 2M Substrate: sand, corase detritus	Control site
LBD-3		Depth: 1.5M Substrate: sand, coarse detritus	Control site
LBB-3		Depth: 1M Substrate: silt, fine and coarse detritus	
LBB-4		Depth: 1.4M Substrate: silt, fine detritus	A gradient of heavy metals concentrations in water and sediments in Bob Bay was expected with highest concentrations at LBB-3 and LBB-5.
LBB-5		Depth: 2M Substrate: silt, fine detritus	
LBB-6	In Birch Lake just outside Bob Bay mouth	Depth: 3M Substrate: silt	Birch Lake and Bob Bay mixing zone.

Table 5. Stations where samples were collected for analysis of metal levels in tissue.

STATION	MACROPHYTES	CLAMS
EM-1	X	
EM-Seep 1	X	
EM-2	X	
EM-Seep 2	X	
EM-3	X	
EM-Seep 3	X	
EM-4	X	
EM-5	X	
EM-6	X	
EM-8	X	
EM-9	X	
LBD-2	X	
LBD-3	X	X
LBB-3	X	
LBB-5	X	X

Table 6. Water quality data from Unnamed Creek stations (Eger et al., 1977).

PARAMETER		7/1/76	7/15/76	7/27/76	8/12/76	8/26/76	9/8/76	9/21/76
pH	EM-1	7.5	7.5	7.59	7.55	7.36	7.9	8.0
	EM-2	7.5	7.5	7.60	7.65	8.3	8.4	8.05
	EM-3	7.5	7.5	7.70	7.71	7.82	8.3	8.1
Alkalinity (mg/l as $CaCO_3$)	EM-1	76	92	113	97	105	117	109
	EM-2	81	92	108	99	108	127	118
	EM-3	84	93	97	88	104	102	106
Specific Cond. (μmhos/cm)	EM-1	393	905	787	604	694	775	600
	EM-2	526	905	1130	1080	1180	1100	1140
	EM-3	410	910	847	500	725	467	617
Dissolved Oxygen	EM-1	8.6	---	7.8	7.95	8.6	8.3	8.9
	EM-2	8.6	7.2	7.65	8.3	9.0	---	11.4
	EM-3	8.6	8.5	9.4	7.05	8.3	---	11.0
Temperature (°C)	EM-1	18	20	---	17	19.1	12.2	8
	EM-2	14.5	16	---	18	19	---	7.7
	EM-3	16.5	16	---	19.5	17.5	16	9.8
Dissolved Organic Carbon (DOC)	EM-1	12.7	17.0	18.5	27.4	21.0	28.1	10.0
	EM-2	10.3	14.1	15.0	16.4	21.8	29.2	10.0
	EM-3	10.5	20.3	16.5	17.4	21.0	24.6	7.5
Dissolved Inorganic Carbon (DIC)	EM-1	19.2	13.4	18.0	13.7	14.2	9.4	27.0
	EM-2	18.7	13.7	19.5	12.7	14.4	10.0	27.0
	EM-3	21.1	11.0	15.5	13.0	14.4	9.1	18.0
Copper, Total (mg/l	EM-1	.004	.006	.007	.004	.003	.004	.002
	EM-2	.005	.005	.005	.006	.004	.005	.004
	EM-3	.005	.006	.006	.003	.003	.003	.002
Nickel, Total (mg/l)	EM-1	.106	.161	.171	.087	.105	.130	.100
	EM-2	.031	.081	.042	.049	.055	.064	.059
	EM-3	.194	.360	.422	.099	.194	.110	.127

Table 7. Comparison of mean water quality values at EM-1 and EM-6 for the period 7/1 to 9/21/76 (from Eger et al., 1976).

PARAMETER \ STATION	EM-6			EM-1		
	n	$\overline{X}$	S	n	$\overline{X}$	S
pH	7	7.81	.30	7	7.63	.23
Alkalinity (mg/l as $CaCO_3$)	7	93	7	7	101	14
Specific Conductance (μmho/cm^2)	7	387	91	7	680	166
Dissolved Oxygen (mg/l)	6	8.3	1.2	6	8.4	.4
Sulfate (mg/l)	6	95	41	7	281	88
Dissolved Organic Carbon (mg/l) (DOC)	7	14.8	5.9	7	19.2	6.9
Dissolved Inorganic Carbon (mg/l) (DIC)	7	15.1	5.8	7	16.4	5.7
Copper Total (mg/l)	7	.008	.004	7	.004	.002
Nickel Total (mg/l)	7	.010	.008	7	.123	.032

Table 8. Comparative mean 1976 water quality values from Regional Copper-Nickel Study water quality monitoring stations.

PARAMETER \ STATION	FILSON CREEK F-1	KEELEY CREEK KC-1	PARTRIDGE RIVER P-5	DUNKA RIVER D-1	UNNAMED CREEK BB-1	STONY RIVER SR-1
Alkalinity (mg/1)	12.76	15.08	134.50	64.47	87.50	40.27
pH	6.15	6.11	7.70	7.12	7.30	7.22
Temperature (C^{o})	8.39	7.42	7.44	11.41	7.38	9.33
Copper Total (mg/1)	10.89	2.57	2.96	2.68	4.04	.90
Nickel Total (mg/1)	7.11	3.46	5.19	1.86	101.77	1.33
TOC (mg/1)	23.53	20.35	-----	14.5	9.75	12.83
Conductivity (μmho/cm)	36.76	44.92	408.73	333.15	517.82	89.89
Turbidity (NTU)	2.23	2.48	14.10	3.10	1.21	2.58

Table 9. Mean daily flow, Unnamed Creek,
September 11-15, 1976 (from Eger et al., 1977).

DISCHARGE (cfs)

DATE	011	EM-8	EM-3	012	EM-1
9/11/76	0.0	0.1	1.8	1.9	1.3
9/12/76	7.4	0.1	0.9	1.9	6.8
9/13/76	0.4	0.1	4.1	1.9	8.3
9/14/76	6.5	0.1	1.0	1.6	3.9
9/15/76	0.0	0.1	4.2	1.0	3.3

Table 10. Mean chlorophyll values for periphyton colonizing glass slides at Unnamed Creek sites, and at Regional Study sites from August through October, 1976.

STATION	CHLOROPHYLL a (μg/mm^2)
EM-1	5.25
EM-1a	2.00
EM-3	1.50
P-5	4.57
KC-1	3.67
F-1	3.36
BB-1	6.00

Table 11. Percent of diatoms colonizing glass slide artificial substrates in Unnamed Creek in 1976.

Date	STATION EM-1	EM-1A	EM-3
8/13	96.5%	98.5	98
9/2	97.6	98.4	99
9/23	98.9	98.8	99.5
10/14	98.8	99	99.1

Table 12. Total periphyton cell counts for glass slides exposed for three-week intervals in Unnamed Creek during 1976.

TAXA	STATION / DATE	EM-1 $\overline{X}$	EM-1 S.D.	EM-1A $\overline{X}$	EM-1A S.D.	EM-3 $\overline{X}$	EM-3 S.D.
Bacillariophyta	8/13	20478	7900	8600	5824	807	478
	9/2	18275	8927	3135	971	2063	172
	9/23	10800	7097	37240	12525	10165	2788
	10/14	31096	27455	32340	18998	39397	22378
Chlorophyta	8/13	477	285	44	51	5	3
	9/2	397	354	17	8	8	8
	9/23	85	85	342	295	42	18
	10/14	288	228	198	205	343	289
Cyanophyta	8/13	250	158	75	111	8	10
	9/2	53	13	27	21	11	15
	9/23	32	16	85	103	10	16
	10/14	76	83	112	131	10	16
Euglenophyta	8/13	8	13	4	8	-----	-----
	9/2	-----	-----	-----	-----	2	4
	9/23	-----	-----	-----	-----	-----	-----
	10/14	-----	-----	-----	-----	-----	-----
Cryptophyta	8/13	3	8	-----	-----	-----	-----
	9/2	7	16	2	4	-----	-----
	9/23	-----	-----	-----	-----	-----	-----
	10/14	-----	-----	-----	-----	-----	-----
Pyrrhophyta	9/2	-----	-----	3	5	-----	-----
TOTAL	8/13	21217	7949	8728	5934	820	487
	9/2	18732	3999	3183	983	2083	183
	9/23	10917	7196	37667	12564	10216	2797
	10/14	31460	27754	32650	19240	39750	22609

Table 13. Comparison of total cell counts (#/mm 2 glass slide surface) on Unnamed Creek and adjacent streams in late September, 1976

EM-1	EM-1A	EM-3	BB-1	P-5	KC-1	F-1
109	376	125	1829	373	70	412

Table 14. Mean number of diatom species colonizing glass slides exposed for three-week intervals during 1976.

Date	STATION		
	EM-1	EM-1A	EM-3
8/13	40.3	35.5	29.5
9/2	39.5	35.8	28.2
9/23	32.2	31.3	27.7
10/14	37.4	28.3	27.3

Table 15. Mean number of diatom species collected from glass slide artificial substrates in late September, 1976.

Station	Mean Taxa
EM-1	32.2
EM-1A	31.3
EM-3	27.3
BB-1	25.0
KC-1	24
F-1	21.7
P-5	26.7
D-1	13.0

Table 16. Number of diatom species collected qualitatively in Unnamed Creek.

Date	Station			
	EM-1	EM-2	EM-1A	EM-3
Late July	48	40	47	15
Early August	37	--	45	37
October	44	--	46	26

Table 17. Number of diatom species collected qualitatively at Regional Study Sites near Unnamed Creek.

Date	Station				
	KC-1	BB-1	P-5	D-1	SR-1
Mid-August	27	26	37	19	12
Late September	23	26	--	--	10

Table 18. Diatom diversity ($d = \Sigma P_i \log_2 P_i$) for sites on Unnamed Creek and Regional Study site. Samples collected from glass slide artificial substrates.

Station	Mid-Aug	Early-Sept	Late-Sept	Mid-Oct
EM-1	4.15	4.37	3.84	4.01
EM-1A	4.18	4.15	3.39	3.23
EM-3	4.01	3.20	3.36	2.97
BB-1	2.71	----	3.02	----
KC-1	3.87	----	3.31	----
P-5	2.82	----	2.93	----
D-1	2.84	----	1.33	----
F-1	3.73	----	3.16	----

Table 19. Dominant diatom taxa collected on glass slides in Unnamed Creek (dominants comprise >5% of the sample). Species in parentheses indicate the important species within the genus which was dominant.

DATE	Station EM-1	EM-1A	EM-3
Mid-August 1976	Achnanthes linearis A. minutissima Eunotia spp. Navicula (notha)	A. minutissima Cocconeis placentula Denticula tenuis Navicula (notha)	A. minutissima Eunotia spp. Navicula (notha) Nitzschia (ignorata)
Early September 1976	A. linearis A. minutissima Diatoma tenue v. elongatum Eunotia spp. F. construens Navicula (notha) Nitzschia (linearis)	A. minutissima Denticula tenuis F. construens Navicula (notha) Nitzschia (linearis)	A. minutissima Navicula (notha)
Late September 1976	A. minutissima Denticula tenuis F. construens Navicula (notha)	A. minutissima Eunotia spp. Diatoma tenue v. elongatum Navicula (notha) Nitschia spp.	A. minutissima Diatoma tenue v. elongatum Navicula (notha) Nitschia spp.
October 1976	A. minutissima Denticula tenuis Diatoma tenue v. elongatum Fragilaria construens F. crotenensis Navicula spp. Nitzschia spp.	A. minutissima Diatoma tenue v. elongatum Navicula spp. Nitzschia spp.	A. minutissima Diatoma tenue v. elongatum Navicula spp. Nitzschia spp.

Table 20. Mean percent relative abundance of dominant diatoms collected from glass slide artificial substrates Means were calculated by average data from all dates at each site and by averaging data from sites at each date.

Taxa	Average across dates			Average across sites			
	EM-1	EM-1A	EM-3	Aug.	Early Sept.	Late Sept.	Oct.
Achnanthes minutissima	28.275	28.75	34.50	21.53	30.83	46.23	23.43
A. linearis	1.65	5.75	1.175	7.06	3.00	1.00	.367
Eunotia spp.	2.975	3.95	4.925	7.63	4.07	3.06	1.03
Diatoma tenue var. elongatum	5.075	12.80	15.725	3.70	4.10	4.87	32.13
Denticula tenuis	9.05	4.225	2.00	7.43	5.63	3.4	3.9
Navicula spp.	9.15	9.475	14.05	11.36	10.5	12.7	9.0
Nitzschia spp.	7.325	7.05	7.15	10.20	6.76	5.66	6.06

Table 21. Comparison of percent relative abundance of some dominant diatom taxa collected quantitatively at Unnamed Creek sites and at Regional Study sites.

DATE	TAXA	BB-1	KC-1	P-5	D-1	EM-1	EM1A	EM3
August	*Achnanthes linearis*	5.5	13.4	8.8	2.2	2.7	14.9	3.6
	A. minutissima	57.3	28.4	60.1	62.6	13.4	8.0	11.4
	Diatoma tenue v. *elongatum*	3.0	0	0	0	4.4	2.1	4.6
	Eunotia spp.	.5	8.4	.4	.1	6.4	3.3	13.2
	Tabellaria flocculosa	.4	4.7	2.5	0	.6	1.2	1.3
	Navicula spp.	2.3	2.3	3.0	1.9	6.5	14.3	13.3
Late-September	*A. linearis*	3.7	2.6	2.3	1.5	1.6	1.1	.3
	A. minutissima	46.9	34.3	50.7	78.3	18.8	11.8	10.4
	Diatoma tenue v. *elongatum*	0	0	.1	0	5.4	.6	8.6
	Eunotia spp.	.4	3.2	.5	0	2.0	5.1	2.1
	Tabellaria flocculosa	4.2	1.7	5.9	2.3	1.7	.8	.9
	Navicula spp.	5.5	4.6	.4	.4	11.3	6.9	19.9

Table 22. Dominant diatom taxa collected qualitatively at Unnamed Creek Stations. Numbers in parentheses refer to Achnanthes spp.

Station	July	September	October
EM-1	Achnanthes minutissima 4.6 (3.1) Diatoma tenue var. elongatum 12.7 F. Construens 12.3 Navicula notha 11.1 Nitzschia spp. 9.0	A. minutissima 7.3 (6.2) F. construens 18.8 F. crotonensis 6.5 Nitzschia linearis 5.0 Nitzschia spp. 7.7	A. minutissima 4.0 (6.7) Denticula tenuis 6.7 D. tenue var. elongatum 8.2 F. construens 16.5 F. crotonensis 6.3 Nitzschia linearis 5.9
EM-1A	A. minutissima 3.1 (1.5) Diatoma tenue var. elongatum 6.8 F. construens 20.9 Melosira varians 11.8 Navicula notha 6.4 Nitzschia spp. 614	A. minutissima 3.6 (4.7) Diatoma tenue var. elongatum 10.3 F. construens 8.7 F. crotonensis 9.9 Nitzschia linearis 5.5	A. minutissima 2.7 (9.7) D. tenue var. elongatum 21.0 F. construens 12.0
EM-3	A. minutissima 5.5 (4.4) Diatoma tenue var. elongatum 13.3 F. capucina 9.2 N. notha 10.0 Nitzschia spp. 5.9 Synedra ulna 5.2	A. minutissima 15.7 (15.7) D. tenue var. elongatum 7.4 F. construens 14.7 Nitzschia spp. 6.0	A. minutissima 5.7 (8.8) D. tenue var. elongatum 54.8
EM-2	A. minutissima 1.5 (1.9) Diatoma tenue var. elongatum 5.2 F. construens 37.7	Not Sampled	Not Sampled

Table 23. Average percent relative abundance of selected diatom taxa collected qualitatively in Unnamed Creek.

TAXA	STATION		
	EM-1	EM-1A	EM-3
Achnanthes minutissima	10.6	8.4	18.6
Diatoma tenue var. elongatum	8.2	12.7	25.2
Fragilaria construens	15.9	13.9	5.7
Navicula notha	4.6	3.1	4.9

Table 24: Comparison of percent relative abundance of selected diatom taxa collected in qualitative periphyton samples in late September, 1976.

TAXA	STATION				
	BB-1	KC-1	EM-1	EM-1A	EM-3
Achnanthes minutissima	22.8	7.3	4.0 (6.7)	2.7 (9.7)	5.7 (8.8)
Diatoma tenue var. elongatum	<1	0	8.2	21.0	54.8
Fragilaria construens	7.7	18.2	16.5	12.0	0
Eunotia spp.	<1	17.5	1.2	4.1	1.9
Tabellaria flocculosa	<1	10.2	1.2	2.0	1.1

Table 25. Mean number of organisms collected on Hester/Dendys from Unnamed Creek and at Regional Study sites during 1976.

Station	M-Aug.	E-Sept.	L.-Sept.-Oct.
EM-1	--	95.2	84.5
EM-1A	--	40.5	16.5
EM-3	--	19.5	18.2
BB-1	--	--	190.0
D-1	98.3	--	36.7
KC-1	--	--	91.3
P-5	--	--	375.3
SR-1	--	--	--
F-1	--	--	181.0

Table 26. Mean number of organisms collected in drift nets from Unnamed Creek and at Regional Study sites during 1976

Station	E.-July	L.-July	M.-Aug.	E.-Sept.	L.-Sept.-Oct.
EM-1	--	20.3	--	99.5	23.0
EM-1A	--	68.5	--	316.5	16.0
EM-2	--	437.0	--	--	--
EM-3	--	136.6	--	84.0	61.7
BB-1	99.3	--	--	--	84.0
D-1	230.7	--	176.7	--	--
KC-1	252.0	--	78.0	--	--
P-5	193.3	--	1058.7	--	1518.5
SR-1	250.0	--	194.0	--	251.3
F-1	--	--	810	--	--

Table 27. Mean Diversity ($D=\Sigma P_i \log_2 P_i$) number of taxa of benthic invertebrates collected on Hester/Dendy samplers from Unnamed Creek and at Regional Study sites during 1976. Number of taxa are in parentheses.

Station	M.-Aug.	E.-Sept.	L.-Sept/Oct.
EM-1	--	2.34 (10.2)	2.21 (10.5)
EM-1A	--	2.38 (8.8)	2.21 (6.3)
EM-3	--	2.52 (8.2)	2.07 (6.3)
BB-1	--	--	2.19 (10.3)
SR-1	3.10 (14.0)	--	2.21 (13.0)
D-1	2.16 (14.3)	--	2.58 (10.3)
P-5	--	--	1.95 (19.0)
KC-1	--	--	1.93 (11.0)
F-1	--	--	2.81 (12.3)

Table 28. Mean Diversity ($D=\Sigma P_i \log_2 P_i$) and number of taxa of benthic invertebrates collected in drift nets from Unnamed Creek and at Regional Study sites during 1976. Number of taxa are in parentheses.

Station	L.-July	M.-Aug.	E.-Sept.	L.-Sept./Oct.
EM-1	1.98 (10.3)	--	3.05 (11.0)	2.18 (7.0)
EM-1A	2.60 (8.3)	--	2.04 (15.5)	2.04 (5.0)
EM-2	3.03 (19.5)	--	--	--
EM-3	2.92 (12.2)	--	2.52 (13.5)	2.08 (5.0)
BB-1	--	--	--	3.11 (11.7)
SR-1	--	3.53 (18.0)	--	3.34 (22.0)
D-1	--	3.23 (15.7)	--	--
P-5	--	3.71 (23.3)	--	3.82 (28.0)
KC-1	--	2.19 (6.0)	--	--
F-1	3.25 (20.7)	3/25 (20.7)	--	--

Table 29. Number of taxa collected in qualitative samples from Unnamed Creek in 1976.

Station	DATE Late July	E. Sept.	Oct.
EM-1A	20	17	23
EM-1	--	24	19
EM-2	25	--	--
EM-3	14	21	11

Table 30. Dominant invertebrate taxa collected in Hester/Dendy and drift samples from Unnamed Creek. Dominant taxa comprise at least 5% of any sample.

Date	EM-1		EM-1A		EM-3		EM-2
	Drift	Hester/Dendy	Drift	Hester/Dendy	Drift	Hester/Dendy	Drift
Late July	Similium Cricotopus Conchapelopia Hydropsyche slossonae Eukiefferiella Tanytarsus	Not Sampled	H. slossonae Simulium Conchapelopia Thieneman-niella	Not Sampled	Simulium H. slossonae Nilotanypus Cricotopus Conchapelopia Tanytarsus B. flavistriga grp.	Not Sampled	H. slossonae Tanytarsus Conchapelopia H. Bettini Hydropsyche
Early Sept.	Simulium H. slossonae Cricotopus Baetis phyllis H. Bettini Nilotanypus Hydropsyche	H. slossonae Concha-pelopia Parametri-ocnemus Tanytarsus	H. slossonae Thieneman-niella Simulium	H. slossonae Orthocla-dinae Lepidostoma Similium Concha-pelopia	Thienemanniella Conchapelopia H. slossonae	Conchapelopia Lepidostoma H. slossonae Baetis	Not Sampled
[illegible]t.	H. slossonae Conchapelopia H. bettini	H. slossonae Parametri-ocnemus Concha-pelopia H. bettini	Dytiscidae Lepidostoma Ablabesmyia Tipula Pelecypoda	Concha-pelopia Lepidostoma H. slossonae	Dytiscidae Conchapelopia Corixidae Paralepto-phlebia mollis	Conchapelopia Lepidostoma Paralepto-phlebia H. slossonae	Not Sampled

Table 32. Dominant organisms in August and September drift and September Hester/Dendy samples collected at Regional Study sites during 1976.

	F-1	KC-1	P-5	BB-1	D-1	SR-1
August Drift	Baetis Hydropsyche Simulidae	Hydropsyche Chironomidae	Pseudocloeon Baetis Hydropsyche Chimarra Eukiefferiella	Not sampled	Hydropsyche Chimarra Reotanytarsus	Baetis Pseudocloeon Hydropsyche
Sept. Drift	Not sampled	Not sampled	Paraleptophlebia Chimarra Cricotopus	Baetis Hydropsyche	Not sampled	Paraleptophlebia Hydropsyche
Sept. Hester/ Dendy	Stenonema Acroneuria Optioserrus Lepidostoma	Microtendipes Stenonema Oligochaeta	Oligochaeta Parametriocnemus	Parametriocnemus Conchapelopia Oligochaeta Psectrocladius Microtendipes	Microtendipes Stenonema Paraleptophlebia Conchapelopia	Microtendipes Leptophlebia Conchapelopia

Table 33. Invertebrate functional groups and their primary food sources (Cummins 1975, 1976)

FUNCTIONAL GROUP	INGESTED MATERIAL
Shredders of dead plant material	Detritus 1-4 mm; mainly leaf litter
Shredders of living plant material	Living vascular hydrophytes and macroalgae
Collector-gatherers	Detritus 1 mm; on or within the substrate
Collector-filterers	Detritus 1 mm; suspended in the water
Scrapers	Periphyton
Piercing Herbivores	Vascular hydrophytes and macroalgae
Piercing Predators	Animal body fluids
Engulfing Predators	Animal tissue

Table 34. Comparison of samples collected from Unnamed Creek by Barr Engineering Company in September 1975, and current study in September, 1976.

Hester-Dendy Samples

Station	1975 No. of Org.	1975 No. of taxa	1976 No. of Org.	1976 No. of taxa
EM-1	23.7	9	84.5	26
EM-2	48.8	14	--	--
EM-3	48.8	10	18.2	23

Qualitative Samples

Station	1975 No. of Org.	1975 No. of taxa	1976 No. of org.	1976 No. of taxa
EM-1	109	16	517	24
EM-2	162	18	--	--
EM-3	84	6	244	21

Dominant Taxa

	1975 Hester/Dendy	1975 Qualitative	1976 Hester/Dendy	1976 Qualitative
EM-1	*Hydropsyche* Chironomidae	*Hydropsyche* *Baetis*	*Hydropsyche* Chironomidae	*Hydropsyche* *Simulium*
EM-2	Chironomidae *Hydropsyche* *Paraleptophlebia*	*Hydropsyche* *Baetis* *Ptilostoma* Chironomidae	---	---
EM-3	Chironomidae *Hydropsychidae*	*Hydropsyche* *Simulium* *Baetis*	Chironomidae *Lepidostoma* *Hydropsyche* *Baetis*	*Hydropsyche* *Hydropsyche* *Baetis*

Table 35A. Water quality parameters from Bob Bay and Dunka Bay stations August 31, 1977 (from Eger et al., 1977).

PARAMETER \ STATION	S LBB3	B LBB3	S LBB4	B LBB4	S LBB6	B LBB6	S LDB2	B LDB2	M LDB2	S LDB3	B LDB3
Depth (m)	0.5	1.5	0.5	1.5	0.5	1.5	0.5	1.5	1.0	0.5	1.5
pH	7.9	7.8		7.8	7.75	7.6	7.2	7.0	7.35	7.4	7.25
Alkalinity (mg/1)	42	45		34		22	26	40		26	26
Spec. Cond.(μmhos/1)	209	220	179	190	99	90	121	145		114	91
SO_4 (mg/1)	105	108	92.7	96.1	92.1	125	6.4	16.7	---	6.3	7.2
Dissolved (mg/1) Organic Carbon	17.0	15.8	16.8	17.6	15.2	16.7	13.6	10.5	---	15.4	18.8
Dissolved (mg/1) Inorganic Carbon	11.0	10.5	10.9	10.4	17.6	7.2	8.4	10.8	---	7.8	7.7
Copper, Total (mg/1)	.003	.002	.002	.002	.001	.004	.001	.001	.001	.001	.001
Nickel, Total (mg/1)	.022	.022	.021	.019	ND	0.46	ND	ND	ND	ND	ND

ND = Not detectable

S = Surface

B = Bottom

Table 35B. Water quality parameters from Bob Bay and Dunka Bay stations October 4, 1976 (from Eger et al., 1977).

STATION / PARAMETER	S LBB3	B LBB3	S LBB4	B LBB4	S LBB6	B LBB6	S LDB2	B LDB2	S LDB3	B LDB3
Depth	0.5	1.5	0,5	1.5	0.5	1.5	0.5	1.5	0.5	1.5
pH	8.20	8.19	8.23	8.21	7.80	7.90	7.4	7.7	7.61	7.70
Alkalinity	58.9	87.4	51.3	51.3	31.4	29.4	31.4	33.2	31.4	31.4
Spec. Cond.	--	--	280	275	100	100	82	92	105	105
SO_4	--	--	--	--	--	--	--	--	--	--
Dissolved Organic Carbon	11.8	12.7	10.1	12.0	9.8	11.8	20.3	12.6	12.7	13.1
Dissolved Inorg. Carbon	12.3	18.8	9.3	9.8	4.2	3.7	4.1	5.4	5.5	5.2
Copper, Total	.0013	.0016	.0014	.0016	.0010	.0012	.0012	.0016	.0010	.0012
Nickel, Total	.039	.061	.025	.025	.002	.003	--	--	.002	.005

Table 35C. Water quality parameters from Bob Bay and Dunka Bay Stations November 24, 1976 (from Eger et al., 1977)

STATION / PARAMETER	S LBB3	B LBB3	S LBB4	B LBB4	S LBB6	B LBB6	S LBB2	B LBB2
Depth	.5	1.5	.4	1.5	.5	1.5	.5	1.5
pH	7.5	7.60	--	--	7.50	7.70	7.05	7.27
Alkalinity	--	--	--	--	--	--	--	--
Spec. Cond.	125	135	--	--	120	115	155	185
SO_4	21	26	--	--	17	16	20	22
Dissolved Organic Carbon	17	--	--	--	16	18	16	12
Dissolved Inorganic Carbon	--	--	--	--	--	--	--	--
Copper, Total	.0017	.0039	--	--	.0021	.0111	.0079	.0044
Nickel, Total	.005	.014	--	--	.003	.015	.004	.003

Table 36 Mean chlorophyll *a* ($\mu g/ml$) values from Bob Bay, Dunka Bay, and Birch Lake (from Johnson et al., 1978) for samples collected between August and November, 1976.

STATION	CHLOROPHYLL *a*
LBB-3	10.97
LBB-4	11.35
LBB-5	11.17
LBB-6	6.41
LBD-2	9.5
LBD-3	13.28
LB-3	12.46

Table 37. Number of invertebrates collected from Bob and Dunka bays of Birch Lake in 1976

TAXA / Date / Site	LBB-3			LBB-4			LBB-5			LBB-6			LBD-2			LBD-3		
	8/31	10/4	11/24	8/31	10/4	11/24	8/31	10/4	11/24	8/31	10/4	11/24	8/31	10/4	11/24	8/31	10/4	11/24
Ephemeroptera for 3 reps. (X)																		
Hexagenia limbata	50	50	57	312	488	603	466.	1270.	517	108	574	201	50	438	646.	72	86	43
Caenis spp.	79	36		22	172		14	43						43	43	36	29	
Odonata																		
Libellulidae							7.											
Tetragoneuria spp.	14	14		7														
Trichoptera														7				
Hydroptilidae	7																	
Molanna spp.	7																	
Mystacides spp.					29		7											
Neureclipsis spp.			101			43		22	57					14				57
Oecetis spp.			29	29			7	22		7								
Phylocentropus spp.	29																	
Phylocentropus placidus	74	43					7							7				
Phryganea cinerea	14	57																
Polycentropus spp.											29							
Polycentropus centralis				7														
Megaloptera																		
Sialis spp.	7			22	57		57	22	29	14	29	14		22	100	7	14	72

Table 37 cont'd

TAXA / Date / Site	LBB-3			LBB-4			LBB-5			LBB-6			LBD-2			LBD-3		
	8/31	10/4	11/24	8/31	10/4	11/24	8/31	10/4	11/24	8/31	10/4	11/24	8/31	10/4	11/24	8/31	10/4	11/24
Hemiptera																		
Corixidae					29			50										
Coleoptera																		
Dubiraphia spp.														7	29			
Dubiraphia bivittata													7					
Diptera																		
Ablabesmyia spp.				29	115	43	7	50		22	57	29	7	65	86	14	14	
Cardiocladius spp.											172							
Chaoborus spp.	7	244		115			115	86	100	481	86	201	36			65		
Chironomidae																		
Chironomus spp.	7		115	122	230	259					29		93	43		158	215	230
Chironomini							7						29					
Clinotanypus spp.	14						7						7	14				
Conchapelopia spp.			187						86					14	57			
Coelotanypus spp.			14	22	57	43	1.4	65		57	57	87		36	57		7	
Cricotopus spp.			201															
Cryptochironomus spp.					115			29	57		29			22			36	57
Cryptocladopelma spp.								101			29						79	
Dicrotendipes spp.		14	14	287	201			43	43					7	316		631	847
Endochironomus spp.													36		1794		36	57
Einfeldia spp.													14			165		

Table 37 cont'd

TAXA \ Date \ Site	LBB-3			LBB-4			LBB-5			LBB-6			LBD-2			LBD-3		
	8/31	10/4	11/24	8/31	10/4	11/24	8/31	10/4	11/24	8/31	10/4	11/24	8/31	10/4	11/24	8/31	10/4	11/24
Epicocladius spp.															43			
Glyptotendipes spp.		14					7				29	14	43	79	29	14	459	100
Micropsectra spp.											115						596	
Microtendipes spp.											57							57
Nilotanypus spp.			57					22										
Orthocladinae	7																	
Pagastiella spp.		29			718			172				7		57	57		100	
Palpomyia group spp.			86	7	115	43	14		43						29	22		
Paracladopelma spp.									230		29							57
Phaenopsectra spp.																72		
Polypedilum spp.		14		7	115	43	22	22		22	57						14	
Procladius spp.	1492.	545	373	1076	1062	746	287.	416.	230	43	86	86	682	495.	1292	344	947	560
Psectrocladius spp.				7		588			187									114
Pseudochironomus spp.	7																	
Simulium spp.		14																
Stictochironomus spp.														93				
Thienemanniella spp.														7				
Tanypus spp.	115	409	129	86	115	101							43	57			36	
Tanytarsus spp.	57	588	344	151	832	316	7	86	387				172.	660.	1349	617	2073	6644

Table 37 cont'd

TAXA / Date / Site	LBB-3			LBB-4			LBB-5			LBB-6			LBD-2			LBD-3		
	8/31	10/4	11/24	8/31	10/4	11/24	8/31	10/4	11/24	8/31	10/4	11/24	8/31	10/4	11/24	8/31	10/4	11/24
Oligochaeta	93	43	531	22	29			57					237		114	43	50	100
Hirudinea																	7	
Nematoda																7	7	
Amphipoda																		
<u>Hyalella azteca</u> ->														29	387		50	
Sphaeriidae	43	258	14	22	14	129	29	43		50	144		57	29	57	50	158	72
TOTAL #/m^2	2123	2372	2252	2622	4493	2957	1081	2621	1966	804	1608	639	1513	2245	6485	1686	5644	9067
TAXA	19	16	15	19	18	12	18	19	12	10	17	8	15	23	18	15	22	15

Table 38. Diversity ($D = -\Sigma P_i \log_2 P_i$) of benthic invertebrates in Bob Bay and Dunka Bay during 1976.

STATION \ DATE	8/31	10/4	11/23
LBB-3	1.73	2.47	3.26
LBB-4	2.59	3.32	2.89
LBB-5	2.50	2.81	3.10
LBB-6	2.03	3.10	2.36
LBD-2	2.71	2.91	2.96
LBD-3	2.81	2.96	1.63

Table 39.

Mean copper and nickel values from

Bob Bay, Dunka Bay and Birch Lake

		STATION						
		LBB-1	LBB-2	LBB-5	LDB-2	LDB-3	LB-2	LB-4
Nuphar (ppm)	COPPER	4.08	6.96	—	1.12	—	—	—
	NICKEL	18.26	8.23	—	.09	—	—	—
Clams (ppm)	COPPER	—	—	2.08	.79	.80	.78	1.39
	NICKEL	—	—	.41	.51	.68	.33	.69
Water (ppb)	COPPER	8.15	5.75	1.93	2.37	1.77	2.60[1]	2.57
	NICKEL	67.2	60.91	8.55	2.36	2.43	3.20	3.46
Sediments (ppm)	COPPER	82.0	92.0	91.67	34.0	35.0	22.0	33.0
	NICKEL	1100.0	496.0	461.0	24.0	38.0	46.0	39.0

1. Median value

Appendix 1. Sample log

Code Number	Site	Sample Type	Replicate	Date	Sample Status
EM-0001	EM-3	Periphyton Chlorophyll	A2	8-13-76	Chlorophyll analysis complete
EM-0002	EM-1	"	B1	"	" " "
EM-0003	EM-3	"	B1	"	" " "
EM-0004	EM-3	"	C2	"	" " "
EM-0005	EM-3	"	A1	"	" " "
EM-0006	EM-1	"	A2	"	" " "
EM-0007	EM-1a	"	A1	"	" " "
EM-0008	EM-1a	"	B2	"	" " "
EM-0009	EM-1	"	C1	"	" " "
EM-0010	EM-1a	"	C1	"	" " "
EM-0011	EM-1a	"	B1	"	" " "
EM-0012	EM-1a	"	A2	"	" " "
EM-0013	EM-3	"	C1	"	" " "
EM-0014	EM-1	"	A1	"	" " "
EM-0015	EM-3	"	B2	"	" " "
EM-0016	EM-1a	"	C2	"	" " "
EM-0017	EM-1	"	B2	"	" " "
EM-0018	EM-1	"	C2	"	" " "
EM-0019	EM-1	Periphyton Sedimentation	A1	"	Transferred
EM-0020	EM-1	"	A2	"	"
EM-0021	EM-1	"	B1	"	"
EM-0022	EM-1	"	B2	"	"
EM-0023	EM-1	"	C1	"	"

Appendix 1 cont'd

Code Number	Site	Sample Type	Replicate	Date	Sample Status
EM-0024	EM-1	Periphyton Sedimentation	C2	8-13-76	Transferred
EM-0025	EM-1	"	A1	"	"
EM-0026	EM-1a	"	A2	"	"
EM-0027	EM-1a	"	B1	"	"
EM-0028	EM-1a	"	B2	"	"
EM-0029	EM-1a	"	C1	"	"
EM-0030	EM-1a	"	C2	"	"
EM-0031	EM-3	"	A1	"	"
EM-0032	EM-3	"	A2	"	"
EM-0033	EM-3	"	B1	"	"
EM-0034	EM-3	"	B2	"	"
EM-0035	EM-3	"	C1	"	"
EM-0036	EM-3	"	C2	"	"
EM-0037	LBD-2	Dredge	E	8-31-76	"
EM-0038	LBD-2	"	C	"	"
EM-0039	LBD-2	"	D	"	"
EM-0040	LBD-2	"	F	"	"
EM-0041	LBD-2	"	A	"	"
EM-0042	LBD-2	"	B	"	"
EM-0043	LBD-3	"	B	"	"
EM-0044	LBD-3	"	F	"	"
EM-0045	LBD-3	"	E	"	"
EM-0046	LBD-3	"	A	"	"
EM-0047	LBD-3	"	C	"	"
EM-0048	LBD-3	"	D	"	"
EM-0049	LBB-5	"	E	"	"

Appendix 1 cont'd

Code Number	Site	Sample Type	Replicate	Date	Sample Status
EM-0050	LBB-5	Dredge	B	8-31-76	Transferred
EM-0051	LBB-5	"	A	"	"
EM-0052	LBB-5	"	C	"	"
EM-0053	LBB-5	"	F	"	"
EM-0054	LBB-5	"	D	"	"
EM-0055	LBB-6	"	A	"	"
EM-0056	LBB-6	"	C	"	"
EM-0057	LBB-6	"	D	"	"
EM-0058	LBB-6	"	E	"	"
EM-0059	LBB-6	"	F	"	"
EM-0060	LBB-6	"	B	"	"
EM-0061	LBB-4	"	D	"	"
EM-0062	LBB-4	"	C	"	"
EM-0063	LBB-4	"	B	"	"
EM-0064	LBB-4	"	A	"	"
EM-0065	LBB-4	"	F	"	" called 0064 by ECI
EM-0066	LBB-3	"	B	"	"
EM-0067	EM-3	Qualitative Invertebrate		7-27-76	"
EM-0068	LBB-4	Dredge	E	8-31-76	"
EM-0069	LBB-3	"	D	"	"
EM-0070	LBB-3	"	C	"	"
EM-0071	LBB-3	"	A	"	"
EM-0072	LBB-3	"	E	"	"
EM-0073	LBD-3	Chlorophyll	C	"	Chlorophyll analysis complete
EM-0074	LBB-6	"	B	"	"
EM-0075	LBB-5	"	C	"	"

Code Number	Site	Sample Type	Replicate	Date	Sample Status		
EM-0076	LBB-6	Chlorophyll	C	8-31-76	Chlorophyll	analysis	complete
EM-0077	LBB-3	"	C	"	"	"	"
EM-0078	LBD-3	"	A	"	"	"	"
EM-0079	LBB-6	"	A	"	"	"	"
EM-0080	LBD-2	"	C	"	"	"	"
EM-0081	LBB-5	"	A	"	"	"	"
EM-0082	LBD-3	"	B	"	"	"	"
EM-0083	LBD-2	"	A	"	"	"	"
EM-0084	LBB-3	"	A	"	"	"	"
EM-0085	LBB-4	"	C	"	"	"	"
EM-0086	LBB-4	"	B	"	"	"	"
EM-0087	LBD-2	"	B	"	"	"	"
EM-0088	LBB-5	"	B	"	"	"	"
EM-0089	LBB-3	"	B	"	"	"	"
EM-0090	LBB-4	"	A	"	"	"	"
EM-0091	LBB-5	Phytoplankton	A	"		Stored	
EM-0092	LBB-5	"	B	"		"	
EM-0093	LBB-5	"	C	"		"	
EM-0094	LBD-2	"	A	"		"	
EM-0095	LBD-2	"	B	"		"	
EM-0096	LBD-2	"	C	"		"	
EM-0097	LBB-3	"	A	"		"	
EM-0098	LBB-3	"	B	"		"	
EM-0099	LBB-3	"	C	"		"	
EM-0100	LBB-4	"	A	"		"	
EM-0101	LBB-4	"	B	"		"	
EM-0102	LBB-4	"	C	"		"	

Ap[illegible]ix 1 cont'd

Code Number	Site	Sample Type	Replicate	Date	Sample Status
EM-0103	LBD-3	Phytoplankton	A	8-31-76	Stored
EM-0104	LBD-3	"	B	"	"
EM-0105	LBD-3	"	C	"	"
EM-0106	LBB-6	"	A	"	"
EM-0107	LBB-6	"	B	"	"
EM-0108	LBB-6	"	C	"	"
EM-0109	EM-3	Drift	A	7-27-76	Transferred
EM-0110	EM-1	"	A	7-24-76	"
EM-0111	EM-1	"	B	"	"
EM-0112	EM-1	"	C	"	"
EM-0113	EM-1	"	D	"	"
EM-0114	EM-1	"	E	"	"
EM-0115	EM-1	"	F	"	"
EM-0116	EM-2	"	A	"	"
EM-0117	EM-2	"	B	"	"
EM-0118	EM-3	"	B	"	"
EM-0119	EM-3	"	C	"	"
EM-0120	EM-3	"	D	"	"
EM-0121	EM-3	"	E	"	"
EM-0122	EM-2	Qualitative Invertebrate		"	"
EM-0123	LBB-3	Dredge	F	8-31-76	"
EM-0124	EM-1a	Qualitative Invertebrate		7-27-76	"
EM-0125	EM-2	Qualitative Periphyton		"	"
EM-0126	EM-3	"		"	"
EM-0127	EM-1a	"		"	"

Appendix 1 cont'd

Code Number	Site	Sample Type	Replicate	Date	Sample Status		
EM-0128	EM-1a	Drift	A	7-28-76	Transferred		
EM-0129	EM-1a	"	B	"	"		
EM-0130	EM-1a	"	C	"	"		
EM-0131	EM-1a	"	D	"	"		
EM-0132	EM-1	Qualitative Invertebrate		"	Lost by ECI		
EM-0133	EM-1	Qualitative Periphyton		"	Transferred		
EM-0134	EM-1a	Chlorophyll	C1	9-02-76	Chlorophyll	analysis	complete
EM-0135	EM-1a	"	B1	"	"	"	"
EM-0136	EM-1a	"	C2	"	"	"	"
EM-0137	EM-1a	"	A1	"	"	"	"
EM-0138	EM-1a	"	B2	"	"	"	"
EM-0139	EM-1a	"	A2	"	"	"	"
EM-0140	EM-1	"	B2	"	"	"	"
EM-0141	EM-1	"	C2	"	"	"	"
EM-0142	EM-1	"	C1	"	"	"	"
EM-0143	EM-3	"	A2	"	"	"	"
EM-0144	EM-3	"	B1	"	"	"	"
EM-0145	EM-3	"	C2	"	"	"	"
EM-0146	EM-1	"	A1	"	"	"	"
EM-0147	EM-1	"	B1	"	"	"	"
EM-0148	EM-3	"	B2	"	"	"	"
EM-0149	EM-3	"	A1	"	"	"	"
EM-0150	EM-1	"	A2	"	"	"	"
EM-0151	EM-3	"	C1	"	"	"	"
EM-0152	EM-1	Periphyton Sedimentation	A1	"	Transferred		

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Appendix 1 cont'd

Code Number	Site	Sample Type	Replicate	Date	Sample Status
EM-0153	EM-1	Periphyton Sedimentation	A2	9-02-76	Transferred
EM-0154	EM-1	"	B1	"	"
EM-0155	EM-1	"	B2	"	"
EM-0156	EM-1	"	C1	"	"
EM-0157	EM-1	"	C2	"	"
EM-0158	EM-1a	"	A1	"	"
EM-0159	EM-1a	"	A2	"	"
EM-0160	EM-1a	"	B1	"	"
EM-0161	EM-1a	"	B1	"	"
EM-0162	EM-1a	"	C1	"	"
EM-0163	EM-1a	"	C2	"	"
EM-0164	EM-3	"	A1	"	"
EM-0165	EM-3	"	A2	"	"
EM-0166	EM-3	"	B1	"	"
EM-0167	EM-3	"	B2	"	"
EM-0168	EM-3	"	C1	"	"
EM-0169	EM-3	"	C2	"	"
EM-0170	EM-3	Hester-Dendy	D	"	"
EM-0171	EM-1a	"	F	"	"
EM-0172	EM-1a	"	B	"	"
EM-0173	EM-1	"	B	"	"
EM-0174	EM-1	"	C	"	"
EM-0175	EM-3	"	F	"	"
EM-0176	EM-1	"	A	"	"
EM-0177	EM-1	"	D	"	"
EM-0178	EM-3	"	C	"	"
EM-0179	EM-1a	"	E	"	"

Ap[illegible]dix 1 cont'd

Code Number	Site	Sample Type	Replicate	Date	Sample Status
EM-0180	EM-1a	Hester-Dendy	C	9-02-76	Transferred
EM-0181	EM-1	"	E	"	"
EM-0182	EM-3	"	E	"	"
EM-0183	EM-1	"	F	"	"
EM-0184	EM-1a	"	D	"	"
EM-0185	EM-3	"	B	"	"
EM-0186	EM-3	"	A	"	"
EM-0187	EM-1a	"	A	"	"
EM-0188	EM-3	Drift	B	9-08-76	"
EM-0189	EM-1	Chlorophyll	A1	9-23-76	Chlorophyll analysis complete
EM-0190	EM-1	"	B1	"	" " "
EM-0191	EM-1	"	C2	"	" " "
EM-0192	EM-1	"	C1	"	" " "
EM-0193	EM-1	"	A2	"	" " "
EM-0194	EM-1	"	B2	"	" " "
EM-0195	EM-1a	"	B1	"	" " "
EM-0196	EM-1a	"	A1	"	" " "
EM-0197	EM-1a	"	B2	"	" " "
EM-0198	EM-1a	"	C1	"	" " "
EM-0199	EM-1a	"	A2	"	" " "
EM-0200	EM-1a	"	C2	"	" " "
EM-0201	EM-3	"	A1	"	" " "
EM-0202	EM-3	"	C2	"	" " "
EM-0203	EM-3	"	B2	"	" " "
EM-0204	EM-3	"	C1	"	" " "
EM-0205	EM-3	"	A2	"	" " "
EM-0206	EM-3	"	B1	"	" " "

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Code Number	Site	Sample Type	Replicate	Date	Sample Status
EM-0207	EM-3	Periphyton Sedimentation	A1	9-23-76	Transferred
EM-0208	EM-3	"	A2	"	"
EM-0209	EM-3	"	B1	"	"
EM-0210	EM-3	"	B2	"	"
EM-0211	EM-3	"	C1	"	"
EM-0212	EM-3	"	C2	"	"
EM-0213	EM-1	"	A1	"	"
EM-0214	EM-1	"	A2	"	"
EM-0215	EM-1	"	B1	"	"
EM-0216	EM-1	"	B2	"	"
EM-0217	EM-1	"	C1	"	"
EM-0218	EM-1	"	C2	"	"
EM-0219	EM-1a	"	A1	"	"
EM-0220	EM-1a	"	A2	"	"
EM-0221	EM-1a	"	B1	"	"
EM-0222	EM-1a	"	B2	"	"
EM-0223	EM-1a	"	C1	"	"
EM-0224	EM-1a	"	C2	"	"
EM-0225	LBB-3	Dredge	A	10-04-76	"
EM-0226	LBB-3	"	B	"	"
EM-0227	LBB-3	"	C	"	"
EM-0228	LBB-3	"	D	"	"
EM-0229	LBB-3	"	E	"	"
EM-0230	LBB-3	"	F	"	"
EM-0231	LBB-3	Chlorophyll	A	"	Chlorophyll analysis complete
EM-0232	LBB-3	"	B	"	" " " (lable obscure could be 0252)

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Appendix 1 cont'd

Code Number	Site	Sample Type	Replicate	Date	Sample Status
EM-0233	LBB-3	Chlorophyll	C	10-04-76	Chlorophyll analysis complete
EM-0234	LBB-3	Phytoplankton	A	"	Stored
EM-0235	LBB-3	"	B	"	"
EM-0236	LBB-3	"	C	"	"
EM-0237	LBB-4	Dredge	A	"	Transferred
EM-0238	LBB-4	"	B	"	"
EM-0239	LBB-4	"	C	"	"
EM-0240	LBB-4	"	D	"	"
EM-0241	LBB-4	"	E	"	"
EM-0242	LBB-4	"	F	"	"
EM-0243	LBB-4	Chlorophyll	A	"	Chlorophyll analysis complete
EM-0244	LBB-4	"	B	"	" " "
EM-0245	LBB-4	"	C	"	" " "
EM-0246	LBB-4	Phytoplankton	A	"	Stored
EM-0247	LBB-4	"	B	"	"
EM-0248	LBB-4	"	C	"	"
EM-0249	LBB-5	Dredge	A	"	Transferred
EM-0250	LBB-5	"	B	"	"
EM-0251	LBB-5	"	C	"	"
EM-0252	LBB-5	"	D	"	"
EM-0253	LBB-5	"	E	"	"
EM-0254	LBB-5	"	F	"	"
EM-0255	LBB-5	Chlorophyll	A	"	Chlorophyll analysis complete (listed twice)
EM-0256	LBB-5	"	B	"	" " "
EM-0257	LBB-5	"	C	"	sample lost: acetone leaked from bottle in storage
EM-0258	LBB-5	Phytoplankton	A	"	Stored

Appendix 1 cont'd

Code Number	Site	Sample Type	Replicate	Date	Sample Status
EM-0259	LBB-5	Phytoplankton	B	10-04-76	Stored
EM-0260	LBB-5	"	C	"	"
EM-0261	LBB-6	Dredge	A	"	Transferred
EM-0262	LBB-6	"	B	"	"
EM-0263	LBB-6	"	C	"	"
EM-0264	LBB-6	"	D	"	"
EM-0265	LBB-6	"	E	"	"
EM-0266	LBB-6	"	F	"	"
EM-0267	LBD-2	"	A	"	"
EM-0268	LBD-2	"	B	"	"
EM-0269	LBD-2	"	C	"	"
EM-0270	LBD-2	"	D	"	"
EM-0271	LBD-2	"	E	"	"
EM-0272	LBD-2	"	F	"	"
EM-0273	LBD-2	Chlorophyll	A	"	Chlorophyll analysis complete
EM-0274	LBD-2	"	B	"	" " "
EM-0275	LBD-2	"	C	"	" " "
EM-0276	LBD-2	Phytoplankton	A	"	Stored
EM-0277	LBD-2	"	B	"	"
EM-0278	LBD-2	"	C	"	"
EM-0279	LBD-3	Dredge	A	"	Transferred
EM-0280	LBD-3	"	B	"	"
EM-0281	LBD-3	"	C	"	"
EM-0282	LBD-3	"	D	"	"
EM-0283	LBD-3	"	E	"	"
EM-0284	LBD-3	"	F	"	"
EM-0285	LBD-3	Chlorophyll	A	"	Chlorophyll analysis complete

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Code Number	Site	Sample Type	Replicate	Date	Sample Status
EM-0286	LBD-3	Chlorophyll	B	10-04-76	Chlorophyll analysis complete
EM-0287	LBD-3	"	C	"	" " "
EM-0288	LBD-3	Phytoplankton	A	"	Stored
EM-0289	LBD-3	"	B	"	"
EM-0290	LBD-3	"	C	"	"
EM-0291	LBB-6	Chlorophyll	A	"	Chlorophyll analysis complete
EM-0292	LBB-6	"	B	"	" " "
EM-0293	LBB-6	"	C	"	" " "
EM-0294	LBB-6	Phytoplankton	A	"	Stored
EM-0295	LBB-6	"	B	"	"
EM-0296	LBB-6	"	C	"	"
EM-0297	EM-3	Chlorophyll	A1	10-14-76	Chlorophyll analysis complete
EM-0298	EM-3	"	A2	"	" " "
EM-0299	EM-3	"	B1	"	" " "
EM-0300	EM-3	"	B2	"	" " "
EM-0301	EM-3	"	C1	"	" " "
EM-0302	EM-3	"	C2	"	" " "
EM-0303	EM-3	Hester-Dendy	A	"	Transferred
EM-0304	EM-3	"	B	"	"
EM-0305	EM-3	"	C	"	"
EM-0306	EM-3	"	D	"	"
EM-0307	EM-3	"	E	"	"
EM-0308	EM-3	"	F	"	"
EM-0309	EM-3	Periphyton Sedimentation	A1	"	"
EM-0310	EM-3	"	A2	"	"
EM-0311	EM-3	"	B1	"	"
EM-0312	EM-3	"	B2	"	"

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Code Number	Site	Sample Type	Replicate	Date	Sample Status
EM-0313	EM-3	Periphyton Sedimentation	C1	10-14-76	Transferred
EM-0314	EM-3	"	C2	"	"
EM-0315	EM-1	Chlorophyll	A1	"	Chlorophyll analysis complete
EM-0316	EM-1	"	A2	"	" " "
EM-0317	EM-1	"	B1	"	" " "
EM-0318	EM-1	"	B2	"	" " "
EM-0319	EM-1	"	C1	"	" " "
EM-0320	EM-1	"	C2	"	" " "
EM-0321	EM-1	Hester-Dendy	A	"	Transferred
EM-0322	EM-1	"	B	"	"
EM-0323	EM-1	"	C	"	"
EM-0324	EM-1	"	D	"	"
EM-0325	EM-1	"	E	"	"
EM-0326	EM-1	"	F	"	"
EM-0327	EM-1	Periphyton Sedimentation	A1	"	"
EM-0328	EM-1	"	A2	"	"
EM-0329	EM-1	"		"	mistakenly scraped into sample no. EM-0328
EM-0330	EM-1	"	B2	"	Transferred
EM-0331	EM-1	"	C1	"	"
EM-0332	EM-1	"	C2	"	"
EM-0333	EM-1a	Chlorophyll	A1	"	Chlorophyll analysis complete
EM-0334	EM-1a	"	A2	"	(check no. EM-0344)
EM-0335	EM-1a	"	B1	"	Chlorophyll analysis complete
EM-0336	EM-1a	"	B2	"	" " "
EM-0337	EM-1a	"	C1	"	" " "

Appendix 1 cont'd

Code Number	Site	Sample Type	Replicate	Date	Sample Status
EM-0338	EM-1a	Chlorophyll	C2	10-14-76	Chlorophyll analysis complete
EM-0339	EM-1a	Hester-Dendy	A1	"	Transferred
EM-0340	EM-1a	"	B	"	"
EM-0341	EM-1a	"	C	"	"
EM-0342	EM-1a	"	D	"	"
EM-0343	EM-1a	"	E	"	"
EM-0344	EM-1a	"	F	"	ECI reported as 0349
EM-0345	EM-1a	Periphyton Sedimentation	A1	"	Transferred
EM-0346	EM-1a	"	A2	"	"
EM-0347	EM-1a	"	B1	"	"
EM-0348	EM-1a	"	B2	"	"
EM-0349	EM-1a	"	C1	"	(check no. Em-0344)
EM-0350	EM-1a	"	C2	"	Transferred
EM-0351	EM-1a	Drift	C	10-15-76	"
EM-0352	EM-1	"	A	"	"
EM-0353	EM-1	"	B	"	"
EM-0354	EM-1	"	C	"	"
EM-0355	EM-1a	"	B	"	"
EM-0356	EM-1a	"	A	"	"
EM-0357	EM-3	"	C	"	"
EM-0358	EM-3	"	B	"	"
EM-0359	EM-3	"	A	"	"
EM-0360	EM-1	Qualitative Invertebrate		"	"
EM-0361	EM-3	"		"	"
EM-0362	EM-1a	"		"	"
EM-0363	EM-1a	Qualitative Periphyton		"	"

Appendix 1 cont'd

Code Number	Site	Sample Type	Replicate	Date	Sample Status
EM-0364	EM-3	Qualitative Periphyton		10-15-76	Transferred
EM-0365	EM-1	"		"	"
EM-0366	EM-1a	"		9-07-76	"
EM-0367	EM-1	Drift	D	9-08-76	"
EM-0368	EM-1	"	A	"	"
EM-0369	EM-1	"	E	"	"
EM-0370	EM-1	"	B	"	"
EM-0371	EM-1	"	C	"	"
EM-0372	EM-3	"	A	"	"
EM-0373	EM-3	"	D	"	"
EM-0374	EM-3	"	C	"	"
EM-0375	EM-1a	"	A	"	"
EM-0376	EM-1a	"	B	"	"
EM-0377	EM-3	Qualitative Periphyton		9-07-76	"
EM-0378	EM-1a	Qualitative Invertebrate		"	"
EM-0379	EM-3	"		"	"
EM-0380	EM-1	"		"	"
EM-0381	EM-1	Qualitative Periphyton		"	"
EM-0382	LBB-3	Dredge	A	11-23-76	"
EM-0383	LBB-3	"	B	"	"
EM-0384	LBB-3	"	C	"	"
EM-0385	LBB-3	"	D	"	"
EM-0386	LBB-3	"	E	"	"
EM-0387	LBB-3	"	F	"	"
EM-0388	LBB-3	Chlorophyll	A	"	Chlorophyll analysis complete

Appendix 1 cont'd

Code Number	Site	Sample Type	Replicate	Date	Sample Status
EM-0389	LBB-3	Chlorophyll	B	11-23-76	Chlorophyll analysis complete
EM-0390	LBB-3	"	C	"	" " "
EM-0391	LBB-3	Phytoplankton	A	"	Stored
EM-0392	LBB-3	"	B	"	"
EM-0393	LBB-3	"	C	"	"
EM-0394	LBB-4	Dredge	A	"	Transferred
EM-0395	LBB-4	"	B	"	"
EM-0396	LBB-4	"	C	"	"
EM-0397	LBB-4	"	D	"	"
EM-0398	LBB-4	"	E	"	"
EM-0399	LBB-4	"	F	"	"
EM-0400	LBB-4	Chlorophyll	A	"	Chlorophyll analysis complete
EM-0401	LBB-4	"	B	"	" " "
EM-0402	LBB-4	"	C	"	" " "
EM-0403	LBB-4	Phytoplankton	A	"	Stored
EM-0404	LBB-4	"	B	"	"
EM-0405	LBB-4	"	C	"	"
EM-0406	LBB-5	Dredge	A	"	Transferred
EM-0407	LBB-5	"	B	"	"
EM-0408	LBB-5	"	C	"	"
EM-0409	LBB-5	"	D	"	"
EM-0410	LBB-5	"	E	"	"
EM-0411	LBB-5	"	F	"	"
EM-0412	LBB-5	Chlorophyll	A	"	Chlorophyll analysis complete
EM-0413	LBB-5	"	B	"	" " "
EM-0414	LBB-5	"	C	"	" " "
EM-0415	LBB-5	Phytoplankton	A	"	Stored
EM-0416	LBB-5	"	B	"	"

Appendix 1 cont'd

Code Number	Site	Sample Type	Replicate	Date	Sample Status
EM-0417	LBB-5	Phytoplankton	C	11-23-76	Stored
EM-0418	LBB-6	Dredge	A	"	Transferred
EM-0419	LBB-6	"	B	"	"
EM-0420	LBB-6	"	C	"	"
EM-0421	LBB-6	"	D	"	"
EM-0422	LBB-6	"	E	"	"
EM-0423	LBB-6	"	F	"	"
EM-0424	LBB-6	Chlorophyll	A	"	Chlorophyll analysis complete
EM-0425	LBB-6	"	B	"	" " "
EM-0426	LBB-6	"	C	"	" " "
EM-0427	LBB-6	Phytoplankton	A	"	Stored
EM-0428	LBB-6	"	B	"	"
EM-0429	LBB-6	"	C	"	"
EM-0430	LBD-2	Dredge	A	"	Transferred
EM-0431	LBD-2	"	B	"	"
EM-0432	LBD-2	"	C	"	"
EM-0433	LBD-2	"	D	"	"
EM-0434	LBD-2	"	E	"	"
EM-0435	LBD-2	"	F	"	"
EM-0436	LBD-2	Chlorophyll	A	"	Chlorophyll analysis complete
EM-0437	LBD-2	"	B	"	" " "
EM-0438	LBD-2	"	C	"	" " "
EM-0439	LBD-2	Phytoplankton	A	"	Stored
EM-0440	LBD-2	"	B	"	"
EM-0441	LBD-2	"	C	"	"
EM-0442	LBD-3	Dredge	A	"	Transferred
EM-0443	LBD-3	"	B	"	"

Appendix 1 cont'd

Code Number	Site	Sample Type	Replicate	Date	Sample Status
EM-0444	LBD-3	Dredge	C	11-23-76	Transferred
EM-0445	LBD-3	"	D	"	"
EM-0446	LBD-3	"	E	"	"
EM-0447	LBD-3	"	F	"	"
EM-0448	LBD-3	Chlorophyll	A	"	Chlorophyll analysis complete
EM-0449	LBD-3	"	B	"	0448 and 0449 combined
EM-0450	LBD-3	"	C	"	Chlorophyll analysis complete
EM-0451	LBD-3	Phytoplankton	A	"	Stored
EM-0452	LBD-3	"	B	"	"
EM-0453	LBD-3	"	C	"	"

Appendix 2. Heavy Metal Data

Table 1. Heavy metal concentrations in clams collected from Bob Bay and Dunka Bay.

Table 2. Heavy metal concentrations in aquatic macrophytes collected from Unnamed Creek, Bob Bay and Dunka Bay in 1976.

Table 3. Heavy metal concentrations in the tissue of Nuphar variagatum in 1977.

Appendix 2.
Table 1. Heavy metal concentrations in clams collected from Bob Bay and Dunka Bay in 1976.

Station	Conc. (mg/kg) Cu	Ni	Zn	Cd	Pb	Hg
DB-2	.59	.414	8.88	0.059	1.48	0.40
	.74	.889	13.70	0.096	.44	0.24
	1.10	.219	5.90	0.047	.18	0.24
DB-3	.55	.110	10.82	0.047	.11	.08
	1.14	.076	9.11	0.048	.48	0.86
	.64	.897	8.33	0.051	.51	0.09
	.96	.929	9.14	0.058	.32	0.09
	.89	1.065	8.58	0.059	.41	0.14
	.60	.985	6.72	0.045	.24	0.07
BB-5	2.77	.451	7.07	0.084	.16	.05
	2.30	.299	10.00	0.060	.21	.06
	1.90	.531	12.97	0.051	.25	.08
	2.65	.190	11.59	0.078	.31	.13
	1.93	.214	10.06	0.047	.11	.08
	.91	.771	6.74	0.048	.14	.06

Table 2.
Heavy metal concentrations in aquatic macrophytes
collected from unnamed creek, Bob Bay and Dunka Bay in 1976.

Sample #	Collection Site	Species
26	LBD-3	Callitriche Palustris
35	LBB-5	Gramineae
36	LBB-3	Sparganium spp.
37	"	Potamogeton spp.
38	"	P. Richardsonii
39	"	Nuphar variagatum
40	"	Sparganium spp.
41	"	Sagittaria spp.
42	"	Scirpus of americanus
43	"	N varigatum
44	LBB-5	Gramineae
45	"	Sparganinm spp.
46	"	Sagittaria spp.
47	LBD-2	N. variagatum
119	BB-1	Carex spp.
120	BB-1	unident
121	EM-1	Carex spp.
122	EM-1	unident
123	EM-Seep 3	Juncus spp.
124	"	Carex spp.
125	"	Typha Latifolia
126	EM-Seep 2	Carex spp.
127	"	Carex spp.
128	"	Caltha spp.
129	EM-4	Callitriche palustris
130	"	Unident
131	"	Carex cf. comosa
132	"	Unident
133	EM-2	Sagittaria spp.
134	"	Unident
135	"	Unident
136	EM-4	Carex spp.
137	EM-2	Carex spp.
138	"	T. latifolia
139	EM-3	Carex spp.
140	"	Sagittaria spp.

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Table 2 - continued

141	EM-3	Sparganium sp
142	EM-1A	Callitriche palustris
143	"	Caltha spp.
144	"	Sparganium spp.
145	"	Carex spp.
146	EM-9	T. latifolia
147	"	Unident
148	EM-5	Glyceria grandis
149	"	Gramineae
150	"	G. grandis
151	EM-8	Eleocharis acicularis
152	"	T. latifolia
153	"	G. grandis
154	EM-8	Carex spp.
155	EM-6	Carex spp.
156	"	Gramineae
157	EM-Seep 1	Carex cf. comosa
158	"	G. grandis

Appendix 2 Table 2 cont'd

ELEMENTS IDENTIFICATION	P %	K %	CA %	AL PPM	NA %	FE PPM	MG %	ZN PPM	CU PPM	MO PPM	MN PPM	B PPM	NI (PPM)
026...GP-266...	0.641	1.73	0.673	1067.	1.331	3968.	0.227	125.9	13.9	**********	1335.2	37.6	9.0
035............	0.190	2.28	0.110	408.	0.091	1836.	0.084	27.8	15.8	**********	486.2	6.5	18.0
036............	0.394	3.12	0.731	390.	0.725	3313.	0.405	24.0	10.3	**********	460.0	15.7	45.0
037............	0.362	3.98	1.012	260.	0.327	3216.	0.356	49.6	12.9	**********	606.6	25.9	140.0
038............	0.428	3.14	0.984	580.	0.235	4855.	0.301	39.7	12.1	10.1	671.3	24.9	385.0
039............	0.336	3.24	1.463	167.	1.252	865.	0.281	36.2	4.8	**********	518.6	26.1	31.5
040............	0.951	3.02	1.185	873.	1.019	7205.	0.524	63.4	15.8	11.3	788.8	33.3	122.0
041............	0.718	2.39	0.684	1060.	0.617	7494.	0.311	38.5	14.4	13.5	389.3	23.6	151.0
042............	0.122	1.73	0.188	133.	0.059	550.	0.164	29.5	12.8	**********	202.3	10.2	14.5
043............	0.303	1.90	1.243	85.	0.537	306.	0.166	30.0	5.3	**********	176.8	21.2	8.0
044............	0.190	1.20	0.220	505.	0.086	1761.	0.121	33.5	20.2	10.1	598.6	11.3	35.0
045............	0.109	2.04	0.623	135.	0.118	495.	0.462	15.4	10.6	**********	614.0	14.6	6.5
046............	0.333	4.22	0.664	391.	0.637	2464.	0.389	43.5	9.1	**********	488.7	26.4	2.0
047............	0.387	1.95	1.033	346.	1.165	1389.	0.175	24.3	5.0	**********	306.8	26.2	1.0
119............	0.227	1.27	0.540	1034.	0.062	2473.	0.298	46.2	29.7	11.8	678.1	11.3	175.0
120............	0.699	0.45	0.941	1474.	0.077	6499.	0.245	105.2	50.5	19.2	3231.0	49.8	1875.0
121............	0.217	1.53	0.272	919.	0.074	2144.	0.176	41.8	22.4	**********	302.4	6.8	112.0
122............	0.289	1.20	0.368	1381.	0.121	2952.	0.282	56.8	34.9	12.4	615.9	10.0	211.0
123............	0.427	1.05	0.517	2787.	0.367	4366.	0.390	46.5	173.4	13.5	335.8	8.7	780.0
124............	0.341	1.15	0.552	1534.	0.171	4423.	0.335	43.6	111.3	13.5	324.5	9.4	414.0
125............	0.338	4.75	0.869	1003.	0.405	1645.	0.560	35.0	58.2	**********	461.9	13.9	333.0
126............	0.749	0.84	0.374	4172.	0.086	**********	0.200	45.9	78.2	19.8	1131.6	12.5	126.0
127............	0.412	1.55	0.500	2897.	0.059	4767.	0.275	56.8	69.8	11.8	623.9	9.9	81.0
128............	0.179	5.22	1.682	326.	**********	649.	0.681	18.9	15.1	**********	157.1	25.3	18.0
LOW S CK 11/29	0.254	2.16	0.903	72.	**********	197.	0.418	33.8	9.9	**********	65.5	14.6	
129............	0.800	1.71	0.633	1206.	0.512	6712.	0.296	53.6	13.9	15.8	3409.8	26.1	162.0
130............	0.223	0.86	0.216	211.	**********	1322.	0.203	43.9	17.8	10.7	754.1	8.6	13.3
131............	0.162	0.48	0.214	157.	0.055	1776.	0.133	32.5	8.4	**********	542.8	7.8	6.0
132............	1.060	2.10	0.822	1320.	0.217	**********	0.339	40.0	13.1	15.8	1311.3	23.6	43.0
133............	0.619	4.09	0.533	127.	0.440	442.	0.465	60.9	16.6	**********	157.1	29.6	11.0
134............	0.347	1.32	1.237	1282.	0.351	3825.	0.602	85.7	57.3	15.8	719.2	53.7	158.0
135............	0.179	2.06	0.290	231.	0.123	417.	0.240	30.6	12.4	**********	90.6	13.1	7.5
136............	0.099	1.89	0.354	235.	0.153	395.	0.230	29.2	20.7	**********	190.2	11.3	11.0
137............	0.092	1.66	0.225	218.	0.116	343.	0.152	23.2	17.3	**********	111.7	10.0	7.5
138............	0.202	2.13	1.433	134.	0.111	249.	0.699	15.6	7.8	**********	780.3	13.9	5.5
139............	0.243	1.50	0.455	681.	0.057	2598.	0.177	50.3	19.0	**********	349.7	8.9	268.0
140............	0.266	2.15	1.044	562.	0.136	3015.	0.951	62.4	37.7	16.4	373.6	23.8	308.0
141............	0.369	3.07	1.066	362.	0.435	1635.	0.761	70.5	30.6	10.7	754.7	25.6	220.0
142............	0.741	1.00	0.942	1296.	0.446	5970.	0.388	117.5	40.2	17.5	2339.4	25.3	975.0
143............	0.205	2.31	2.246	140.	0.089	419.	1.003	26.5	9.8	**********	404.4	34.2	87.5
144............	0.374	5.10	0.924	489.	0.580	2314.	0.692	96.6	22.0	12.4	813.8	24.9	152.0
145............	0.233	1.16	0.329	66.	0.067	282.	0.257	23.6	6.8	**********	444.4	5.5	21.0
146............	0.483	2.51	1.235	469.	0.675	5054.	0.521	24.0	48.2	**********	686.7	16.0	152.0
147............	0.549	1.27	0.611	553.	0.311	5496.	0.384	30.1	83.7	13.5	513.6	13.6	252.0
148............	0.143	1.56	0.507	103.	0.067	542.	0.231	31.0	9.6	10.1	347.8	8.9	24.0
149............	0.158	1.54	0.516	281.	**********	712.	0.308	75.8	34.9	**********	368.6	9.1	248.0
150............	0.227	2.58	0.578	160.	0.079	741.	0.291	57.1	20.2	11.8	241.0	8.4	38.0
LOW S CK 11/29	0.259	2.26	0.936	70.	**********	197.	0.417	36.7	11.3	**********	67.5	14.7	
151............	0.366	1.59	0.614	982.	0.290	3298.	0.350	122.2	78.0	13.5	1010.6	14.7	1850.0
152............	0.202	2.15	0.512	128.	0.300	417.	0.325	42.8	14.3	**********	266.4	9.9	141.0
153............	0.095	0.58	0.434	143.	0.261	411.	0.296	44.5	13.6	**********	547.8	6.5	134.0
154............	0.194	1.31	0.852	200.	0.327	698.	0.464	58.1	24.6	10.7	991.4	17.5	685.0
155............	0.180	0.96	0.540	342.	0.104	1969.	0.244	44.3	27.3	12.4	201.0	13.9	35.5
156............	0.296	0.62	0.494	569.	0.077	3704.	0.209	46.0	34.4	11.3	313.8	13.4	59.5
157............	0.123	1.44	0.286	192.	0.086	646.	0.465	36.2	13.3	**********	302.4	9.9	26.5
158............	0.201	1.09	0.284	148.	0.141	1452.	0.456	60.5	10.8	12.4	277.1	10.0	39.0

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Appendix 2.
Table 3. Heavy metal concentrations in the tissue of
Nuphar variagatum in 1977

	CU PPM	ZN PPM	MN PPM	FE PPM	AL PPM	TI PPM	V PPM	BE PPM	CO PPM	CD PPM	CR PPM	NI PPM
VEG BB1-1-	4.07	40.5	230	314	88.9	3.20	1.01	N.D.	N.D.	N.D.	5.18	24.4
1-1-2	2.79	36.2	158	176	94.8	N.D.	.904	.005	N.D.	N.D.	4.33	19.7
1-1-3	3.45	34.2	286	225	83.0	0.14	.975	N.D.	0.5	N.D.	4.91	26.4
3-1	4.22	38.0	143	234	85.3	4.20	1.01	N.D.	N.D.	N.D.	6.21	18.7
3-2	3.53	30.8	141	204	50.0	4.61	.942	N.D.	N.D.	N.D.	6.95	12.5
3-3	46.7	24.9	194	226	64.6	0.35	1.01	.004	N.D.	N.D.	35.3	167
6-1	6.93	36.4	197	314	100	6.19	1.63	.008	N.D.	N.D.	10.4	20.4
6-2	3.38	16.3	104	125	29.2	1.89	.751	.004	N.D.	N.D.	4.90	10.2
6-3	4.25	17.5	149	217	79.4	1.89	.943	.006	N.D.	N.D.	5.03	13.8
DB2-1-1	0.75	14.4	573	340	70.5	0.04	.854	.004	N.D.	N.D.	0.78	N.D.
2-1-2	1.06	19.3	388	235	55.8	0.04	.810	.004	N.D.	N.D.	1.10	N.D.
2-1-3	1.10	14.5	590	362	82.4	0.35	.871	.006	N.D.	N.D.	0.97	N.D.
2-3-1	1.21	14.2	788	338	94.2	0.35	.882	.006	N.D.	N.D.	0.90	N.D.
2-3-2	1.36	16.4	626	501	106	0.96	.999	.004	N.D.	N.D.	0.83	N.D.
2-3-6	1.21	19.8	680	360	82.4	0.35	1.03	.004	N.D.	N.D.	1.19	N.D.
2-6-1	1.29	16.4	841	543	141	N.D.	1.12	.008	N.D.	N.D.	4.36	N.D.
2-6-2	1.51	15.4	856	393	115	0.04	.971	.006	N.D.	N.D.	0.69	N.D.
2-6-3	1.21	19.5	510	323	88.3	0.35	.947	.004	N.D.	N.D.	1.33	N.D.
BB-2-6-2	7.17	22.8	81.8	204	52.4	7.11	.639	N.D.	N.D.	N.D.	N.D.	9.3
BB-2-5-5	6.61	23.3	89.1	178	47.6	7.33	.567	N.D.	N.D.	N.D.	N.D.	7.6
BB-2-3-2	7.09	18.2	149	178	52.4	3.33	.601	N.D.	N.D.	N.D.	N.D.	7.8

	MO PPM	SE PPM	NA PPM	MG PPM	CA PPM	P PPM	SR PPM	BA PPM	K PPM	SI PPM	B PPM
VEG BB1-1-	7.0	N.D.	3120	1660	8760	3780	62.5	92.6	10600	39.4	N.D.
1-1-2	6.4	N.D.	2420	1780	9880	3940	63.7	60.7	23300	24.7	N.D.
1-1-3	5.5	N.D.	2730	1750	10900	3940	77.7	49.5	21600	35.8	0.79
3-1	6	N.D.	726	1650	9170	4770	29.0	54.6	22000	49.4	21.2
3-2	5	N.D.	3950	1610	11500	4100	48.0	68.0	20200	39.4	11.6
3-3	4.6	N.D.	2710	1680	13800	3400	74.1	93.0	14200	52.4	0.55
6-1	7	N.D.	2720	2940	24600	7360	80.4	109	25600	116	48.2
6-2	2.3	N.D.	2200	1410	13600	2880	61.3	74.2	12800	34.4	25.0
6-3	1.8	N.D.	3060	1550	14900	3540	56.9	81.3	14200	40.8	20.2
DB2-1-1	7.9	N.D.	2720	1380	12800	3090	80.8	92.4	18500	33.8	22.1
2-1-2	10.5	N.D.	779	1550	11100	4110	48.9	54.2	20000	36.5	20.0
2-1-3	7.6	N.D.	2630	1370	12500	2790	84.5	102	18500	35.0	6.63
2-3-1	4.8	N.D.	3040	1430	16700	2210	10.0	10.1	11400	30.1	9.54
2-3-2	8.3	N.D.	959	1470	11100	2580	5.14	4.5	17000	43.5	15.5
2-3-6	13.7	N.D.	1190	1660	12700	2990	6.28	6.1	17000	34.4	26.6
2-6-1	1.6	N.D.	1830	1500	14900	2220	147	73.7	12800	33.8	19.6
2-6-2	8.6	N.D.	2690	1570	13800	2620	130	111.	15600	36.0	22.0
2-6-3	9.6	N.D.	1410	1500	12100	2950	86.4	62.8	15600	28.4	15.9
BB-2-6-2	N.D.	N.D.	2850	1820	14100	4620	63.7	71.9	17600	52.3	18.5
BB-2-5-5	N.D.	N.D.	2850	1880	15100	4780	84.5	78.4	19100	48.1	20.1
BB-2-3-2	N.D.	N.D.	3100	1660	19600	3610	121	130	16600	48.1	18.5

APPENDIX 3

Statistical Analyses

Table 1. Stations used in various nested analyses of variances.

Table 2. Sample analysis of variance used to compare Unnamed Creek stations to Regional Study stations. Data used in this analysis were the number of organisms colonizing Hester-Dendy samplers.

Table 3. Diatom data from glass slide samplers, used in analyses of variance.

Table 4. Data from Hester-Dendy samplers used for analyses of variance.

Table 5. Data from drift samples used in analyses of variance.

Statistical Analyses

Data from other streams sampled in late September, 1976 were compared to data from Erie mining sites to see if Erie sites as a group appeared to have been affected by the combination of heavy metals, channelization, etc.

Not enough data were available to allow comparisons on other dates. The other sites used in the analyses were either low order sites (BB1, KC1, F1, P5) or a nearby site impacted by taconite mining. Because not all types of data were available for late September, 1976, the sites compared to Erie sites were different for data from diatometers, Hester-Dendy samplers, or drift nets. Parameters analyzed were number of taxa and Shannon-Wiener diversity for diatoms, and number of organisms (total density), diversity, and number of taxa for drift and Hester-Dendy samplers.

Analysis of variance was used to test for differences between Erie sites and the non-Erie sites chosen. A log transformation was used to reduce the differences between variances in the number of organisms per sampler. Since only three Erie sites were sampled, and more than three of the other sites were sampled with Hester Dendys and diatometers, the non-Erie sites were analyzed first for these types of data. A simple one-way analysis of variance was used to determine if there were significant differences among the non-Erie sites for the parameters being examined. The sites used for each comparison are shown in Table 1.

In most cases, there were no significant differences among the non-Erie sites (using an alpha level of 0.01) so three sites were selected randomly for inclusion in the analysis of variance. In the case of the number of organisms found on Hester-Dendys, there were significant differences among the non-Erie sites. The number of organisms drifting was clearly lower at D1 and F1, which had very low flows at the time of sampling, compared to the other sites. Therefore, only the other three sites, where flows were higher, were chosen for comparison to the Erie sites.

The comparison of three Erie sites with three non-Erie sites for all parameters was made using a nested model for analysis of variance:

$$Y_{ijk} = E_i + S_{ij} + \Sigma_{ijk},$$

where E_i is the treatment effect, (Erie or non-Erie) and S_{ij} is the site effect, and k is the index of the sample replicate. The program used (Ivan, U. of M. Applied Stat.) handled the unbalanced design (for diatoms and Hester-Dendy's, more samples were collected at Erie sites than at the other sites) by treating the problem as a balanced data set with missing values. The analysis of variance table for one analysis (log number of organisms in Hester-Dendy samplers) is shown in Table 2.

Appendix 3

Table 1. Stations used in various nested analyses of variance

	Diatoms			H-D		Drift		
Para-meters	No. of Taxa	Diver-sity	No. of org.	Diver-sity	No. of taxa	No. of org.	Diver-sity	No. of taxa
Sites compared to Erie site	lccl P5 Fl	kcl P5 Fl	BB1 kcl P5	BB1 D1 kcl	BB1 D1 kcl	BB1 P5 SR1	BB1 P5 SR1	BB1 P5 SR1
P of F observed	$p<.05$	NS* $p>.05$	$p<.05$	NS $p>.05$	NS $p>.05$	$p<.05$	$p<.01$	$p<.05$

* NS = Not significant

Appendix 3

Table 2. Sample analysis of variance used to compare Unnamed Creek stations to Regional Study stations. Data used in this analysis were the number of organisms colonizing Hester-Dendy samplers.

Source	DF	SS	MS	F	(df = 1, 4
E	1	6.3941	6.3941	9.326	$p<.05$
S	4	2.7422	.6855		
Error-1	21	1.8588	.08851		
Total	26	10.995			

Appendix 3
Table 3. Diatom data from glass slide samplers
used in analyses of variance 9

Station					
Name	No.	Date	Replicate Index	No. of Taxa	S.W. Diversity Log_2
EMIA	54	6	1	33	3.0741
EMIA	54	6	2	30	3.5929
EMIA	54	6	3	31	3.4982
EMIA	54	6	4	32	3.1755
EMIA	54	6	5	31	3.3614
EMIA	54	6	6	31	3.6481
EM1	55	6	1	35	4.1155
EM1	55	6	2	39	4.4871
EM1	55	6	3	28	3.8054
EM1	55	6	4	34	3.9594
EM1	55	6	5	31	3.2607
EM1	55	6	6	26	3.4180
EM3	57	6	1	27	3.3328
EM3	57	6	2	33	3.3173
EM3	57	6	3	28	3.2822
EM3	57	6	4	31	3.5865
EM3	57	6	5	22	3.2802
EM3	57	6	6	29	3.3805
KC1	19	6	1	28	3.2519
KC1	19	6	2	23	3.4005
KC1	19	6	3	21	3.2926
F1	16	6	1	23	3.2055
F1	16	6	2	19	2.8451
F1	16	6	3	23	3.4226
P5	22	6	1	20	2.8795
P5	22	6	2	42	3.4299
P5	22	6	3	18	2.4893

Appendix 3
Table 4. Data from Hester-Dendy Samplers used for analyses of variance.

STATION Name	No.	Date	Replicate Index	No. of Organisms	No. of Taxa	S.W. diversity Log_2
EM1A	54	6	1	11	5	2.1867
EM1A	54	6	2	15	6	1.6923
EM1A	54	6	3	18	7	2.4115
EM1A	54	6	4	6	3	1.4591
EM1A	54	6	5	27	8	2.5518
EM1A	54	6	6	22	9	2.9540
EM1	55	6	1	57	10	1.8299
EM1	55	6	2	81	11	2.4291
EM1	55	6	3	192	13	2.2471
EM1	55	6	4	98	10	2.0655
EM1	55	6	5	37	8	2.3313
EM1	55	6	6	42	11	2.3740
EM3	57	6	1	11	7	2.5503
EM3	57	6	2	24	8	2.5739
EM3	57	6	3	44	11	2.5988
EM3	57	6	4	20	6	1.9805
EM3	57	6	5	7	3	1.1488
EM3	57	6	6	3	3	1.5850
BB1	17	6	1	151	7	1.8947
BB1	17	6	2	192	11	2.2730
BB1	17	6	3	227	13	2.4056
D1	26	6	1	20	9	2.6464
D1	26	6	2	37	11	2.7668
D1	26	6	3	53	11	2.3211
KC1	19	6	1	97	13	2.3835
KC1	19	6	2	92	5	.8956
KC1	19	6	3	85	15	2.4995
P5	22	6	1	797	20	.9811
P5	22	6	2	203	18	2.4812
P5	22	6	3	126	19	2.3807
F1	16	6	1	47	16	3.4153
F1	16	6	2	35	14	3.1971
F1	16	6	3	33	7	1.8107