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Biological Effects of Mining Wastes in the Northwest Territories

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Operations Directorate, Central Region,

1973

ABSTRACT

Studies to determine the effects of mine wastes on aquatic biota were carried out at four Northwest Territories mining operations during the summer of 1972: Giant and Con (gold) mines near Yellowknife and the Echo Bay and Terra (silver-copper) mines on Great Bear Lake. At each mining study site, assessments were made of: water quality of the mine wastes and in the receiving waters; effluent toxicity; metal contamination of sediments, invertebrates and fish; and benthos diversity in the receiving waters.

Water quality analyses revealed that the Giant Mine was discharging high levels of arsenic (2.9 - 12.8 ppm), copper (0.73 - 9.9 ppm) and zinc (0.034 - 1.90 ppm) into Yellowknife Bay on Great Slave Lake. The Con Mine's final discharge into Great Slave Lake had substantially lower levels: arsenic (0.02 - 0.038); copper (0.002 - 0.012). The effect on the inland region between the mines and Great Slave was converse; only a portion of a low discharge creek was affected by Giant's discharge while the effect of the Con Mine's effluent extended over 5 inland lakes.

Analyses of the Echo Bay mill effluent revealed high levels of arsenic (1.0 - 4.4 ppm) and turbidity (5000 - 8840 JTU) entering Great Bear Lake. Other parameters measured for the mine wastes and in the receiving waters were not greatly above background levels. The only parameters above an acceptable level in Ho-Hum Lake, the tailings basin for the Terra Mine, was arsenic (4.2 ppm). Metals levels in the Camsell River (which discharges into Great Bear Lake) above and below the outlet of Ho-Hum Lake did not differ significantly.

Giant Mine wastes entering Yellowknife Bay were found to be acutely toxic with 96 hour LC50's for ninespine sticklebacks, white suckers, and rainbow trout ranging from 9.3 to 24 percent by volume. Discharge from the tailing ponds, minewater and thickener overflow appeared to be sources of this toxicity with arsenic, copper and possibly cyanide the lethal agents. In contrast to the Giant Mine decanted water from the Con tailing pond (Pud Lake) resulted in no measurable mortality to fish over the four day test period. Wastes from the Echo Bay and Terra mines were deemed moderately toxic. LT50's ranged from 24 to greater than 96 hours.

Fish inhabiting water bodies affected by the Giant and Con Mine wastes tended to possess higher concentrations of arsenic, zinc, copper, lead, cadmium and nickel. Metal levels in fish from LaBine Bay and Ho-Hum Lake were higher than background. Metal contamination of invertebrates collected in the Yellowknife region re-

vealed high metal levels.

Bottom sediments along the Giant Mine effluent route and a substantial area of Yellowknife Bay contained high levels of arsenic, copper, zinc, nickel, lead and cadmium. The distribution of these metals in Yellowknife Bay is believed to be strongly influenced by water currents. High levels were also found in lakes affected by the Con Mine wastes stemming from Pud Lake. Metal concentrations in the sediments collected at the final Con Mine discharge point in Yellowknife Bay were only slightly above those established as background. Levels of arsenic, copper, zinc, nickel, lead, cobalt and uranium determined for sediments collected off the Echo Bay mine revealed that the immediate area has been affected by the mine effluent discharge. Arsenic, copper, nickel and lead in Ho-Hum Lake were above background. Levels in the Camsell River above and below the lake outlet did not differ significantly.

Benthic organisms along the Giant Mine effluent route (Baker Creek) were absent, indicating a high degree of pollution. Analyses of benthos in Yellowknife Bay indicated that a substantial portion of the bay is moderately polluted. Inland lakes affected by the Con Mine wastes were highly polluted whereas, benthos in Great Slave Lake are not so affected. Great Bear Lake, in the region of the Echo Bay Mine, was found to support a limited benthic fauna. Despite a limited benthic community in Ho-Hum Lake, regions of the Camsell River above and below the lake outlet were not significantly different.

ACKNOWLEDGEMENTS

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INTRODUCTION

Until recently, mining activity in the Northwest Territories has been limited by the high cost of transportation. Only mining of gold and uranium oxide, which can be produced in small quantities and fetch high market prices, has been economically feasible. Exploration and development has increased in the past few years with new operations established on Great Bear and Great Slave Lakes. Several other large mineral deposits have been discovered and only await favourable market prices and transportation facilities. With the current development of Canada's north for its oil and gas reserves and the provision of access routes along the Mackenzie River valley an increase in mining activity is expected to follow.

In view of these developments investigations into the biological effects of waste disposal from mining operations on Great Slave and Great Bear Lakes were carried out in 1971 and 1972. During 1971 a study was conducted on the Cominco lead-zinc mine at Pine Point by Stein and Miller (1972). Locations for the present study were: Giant Yellowknife Mines Ltd. and Con (Cominco) Mines Ltd., near Yellowknife, Echo Bay Mining Ltd. at Port Radium and Terra Mining and Exploration Ltd. on the Camsell River. Previous studies on these mines by Bérubé et al. (1972) and Roy and Vézina (1973) dealt with the physical and chemical nature of the effluents as well as waste containment.

Objectives of the 1972 study were: to determine the toxic and chemical nature of the mine wastes; to assess the effects of mine wastes on sediment chemistry and benthic organisms in the receiving water bodies; to determine the extent of metal contamination in fish tissue from the mine wastes; and to provide biological rationale for control of mine waste disposal in the Northwest Territories.

MATERIALS AND METHODS

Studies were carried out on the Giant, Con, Echo Bay and Terra Mines (Fig. 1) on a rotational basis from May to September, 1972. Sampling periods for the Giant and Con mines were from May 23 to June 30, July 17 to August 11 and September 5 to 22. The Echo Bay and Terra sampling periods were from July 1 to 16 and August 11 to September 4. Sampling and experimental locations established during the mine studies are shown in Figures 2, 3, 4 5.

WATER CHEMISTRY

Water samples were collected from selected locations along the mine effluent routes and in the receiving water bodies. Samples of the mine wastes were also taken. As soon after collection as possible, the samples were sent by air to be analysed by the Water Quality Division, Environment Canada, Calgary. Analyses performed included a full range of water quality parameters, including major heavy metals. The laboratory methods were those outlined by Traversy (1971). In addition, basic water chemistry was carried out in the field using a Hach water chemistry kit.

Samples of the Echo Bay mill effluent and minewater as well as water from the Camsell River were also sent to the Atomic Energy of Canada Ltd., Whiteshell Nuclear Research Establishment, Pinawa, Manitoba, for radio-chemical analyses. Samples were analysed for total alpha and beta counts and specific nuclides.

ACUTE TOXICITY

Cage Bioassays: These were static acute toxicity bioassays (Fig. 6) carried out in Yellowknife under field conditions using the apparatus described by Falk (1973). Fish were collected in Yellowknife Bay (Fig. 2) using a small mesh beach seine and held in Grace Lake for a minimum of 48 hours before testing where they were allowed to feed on natural food organisms. Ninespine stickle-backs (Pungitius pungitius) and white suckers (Catastomus commer-soni) were used as the test species. Ten fish were introduced to each of the six cages containing the test material and observed at geometric time intervals to 96 hours. Cage bioassays were run at the ambient water temperature of Grace Lake. Dissolved oxygen and pH were measured using a Hach kit. For each multiple concentration cage bioassay a 96 hour LC50 was determined by the method outlined by Litchfield and Wilcoxon (1949). The 96 hour LC50 is the concentration of toxicant causing 50 percent mortality in 96 hours.
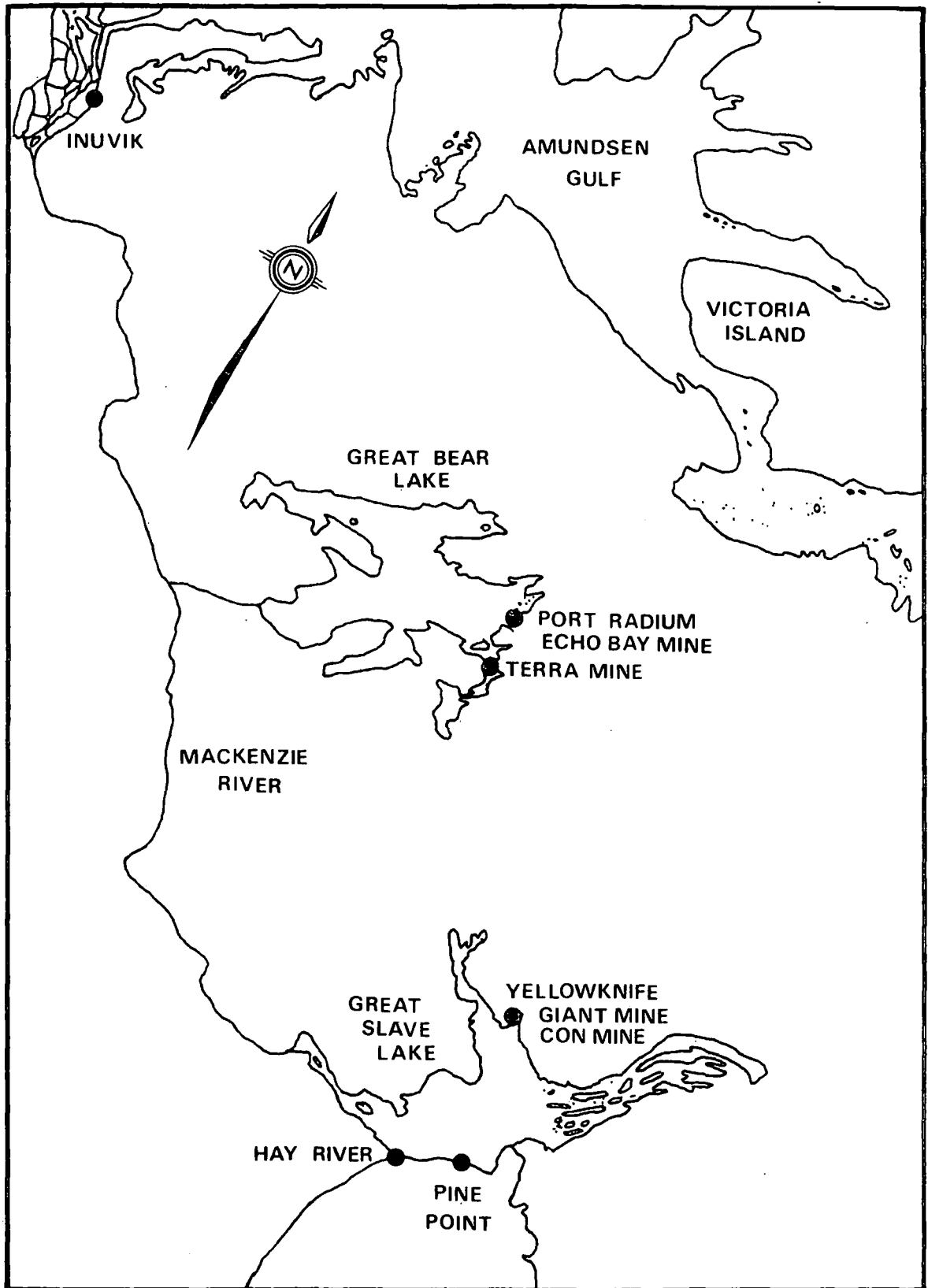
Figure 1.　Locations of the four Northwest Territories mining
operations studied during 1972.

YELLOWKNIFE
RIVER

TAILINGS
PONDS

BAKER
CREEK

GIANT
MINE

N

1 MILE

LATHAM
ISLAND

CITY OF
YELLOWKNIFE

YELLOWKNIFE
BAY
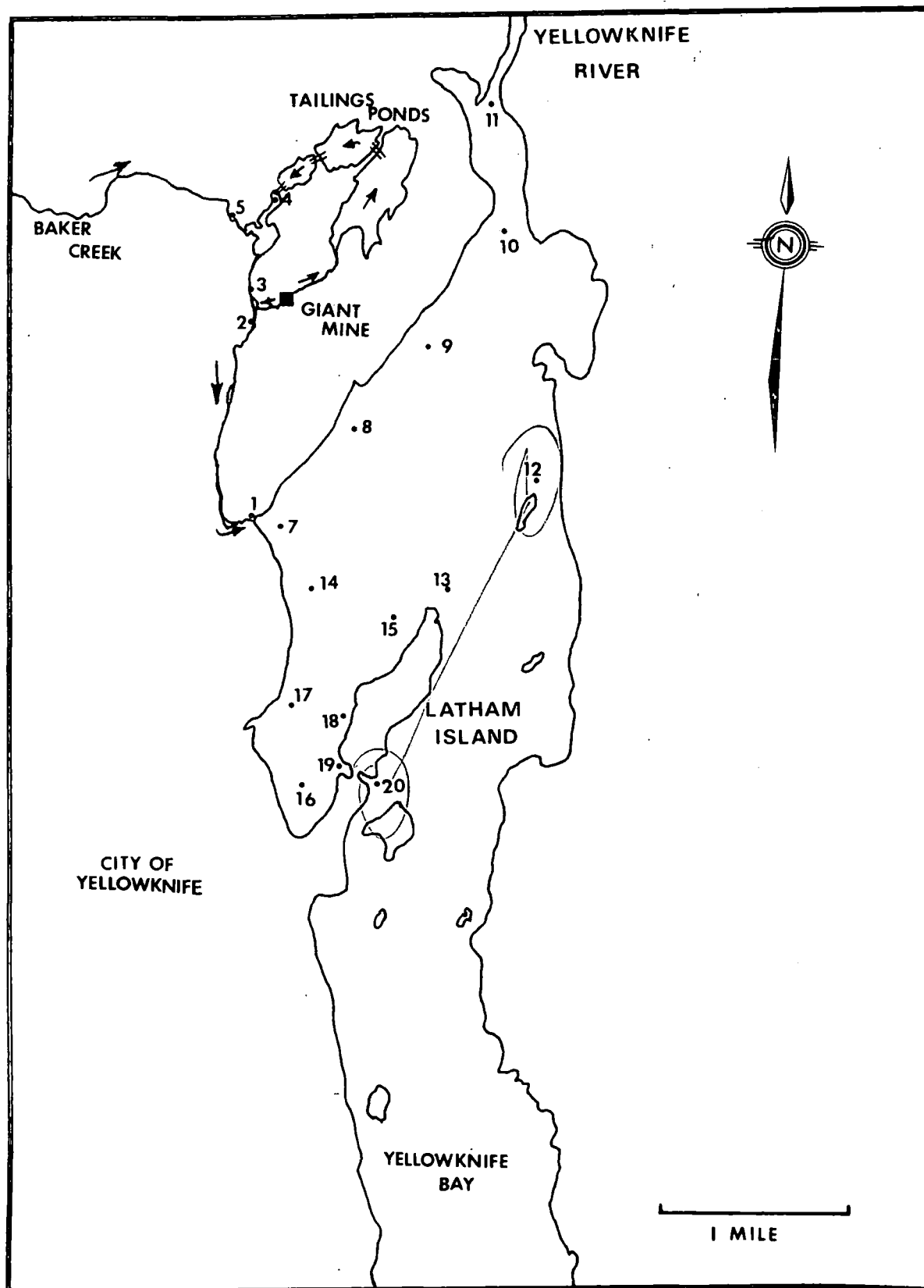
Figure 2. Locations of the Giant mining operation, tailings
ponds, effluent routes and sampling stations
established during 1972.
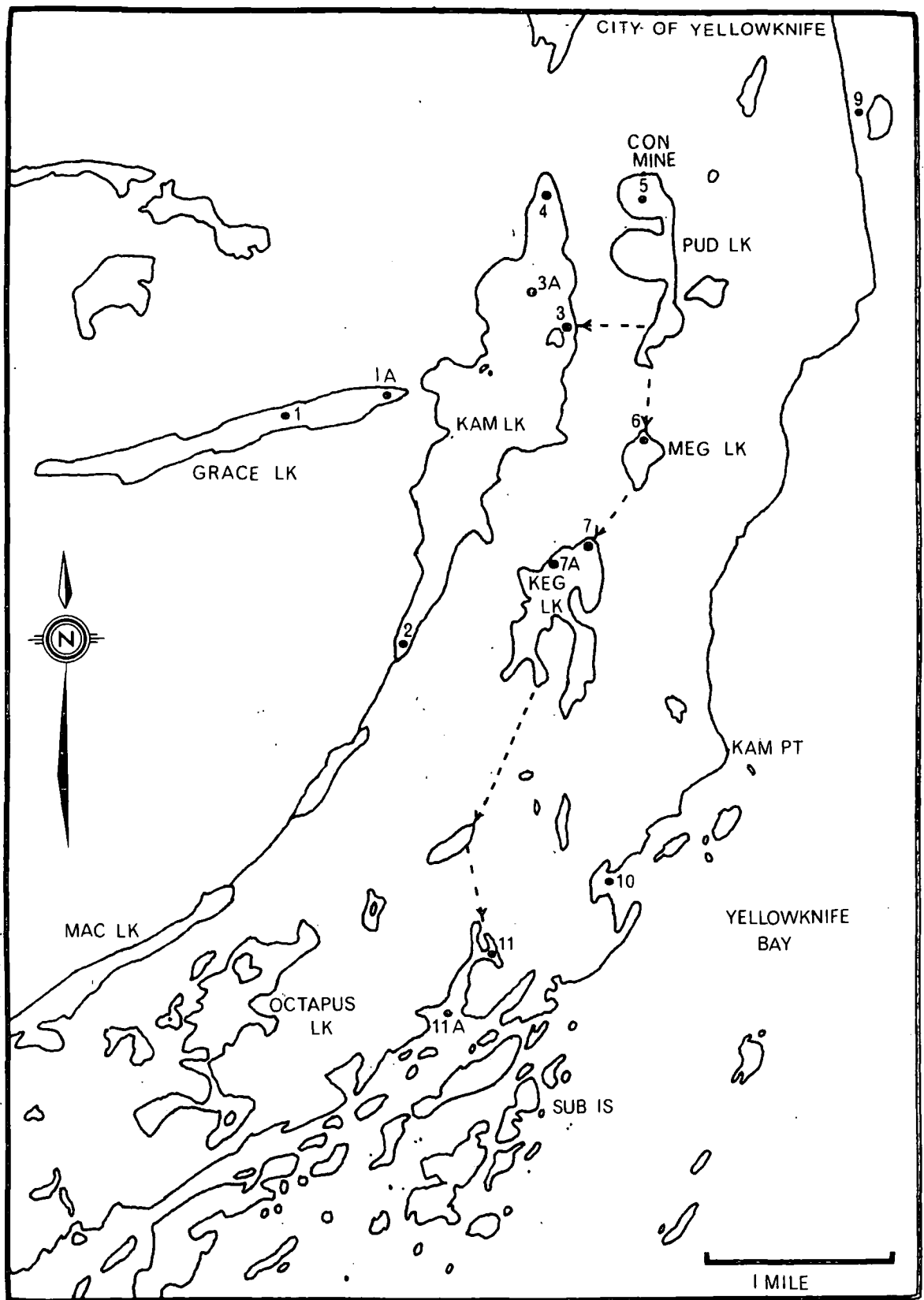
Figure 3.   Locations of the Con mining operation, effluent
routes and sampling stations established during
1972.
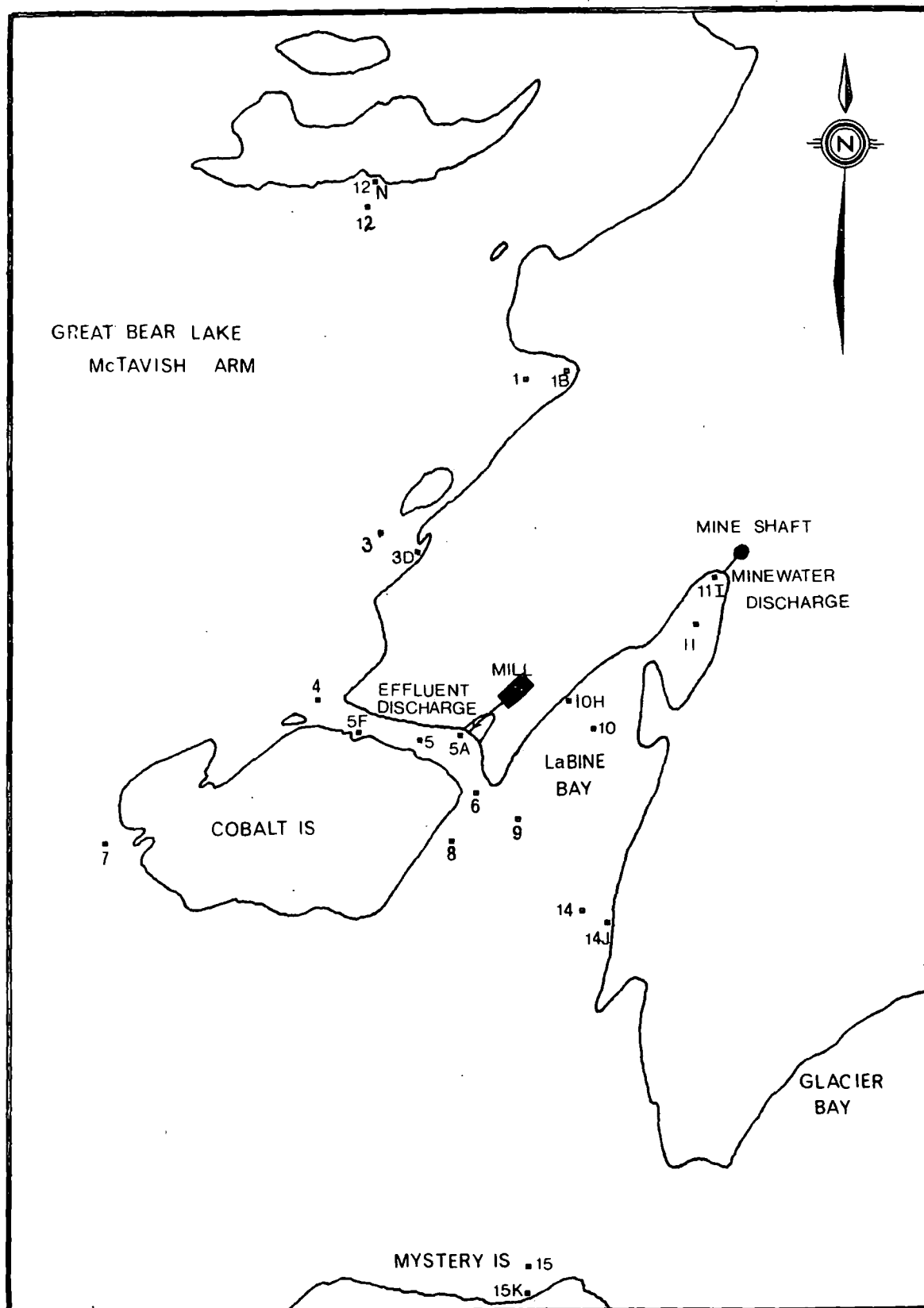
Figure 4. Locations of the Echo Bay mining operation discharge points and sampling stations established during 1972.
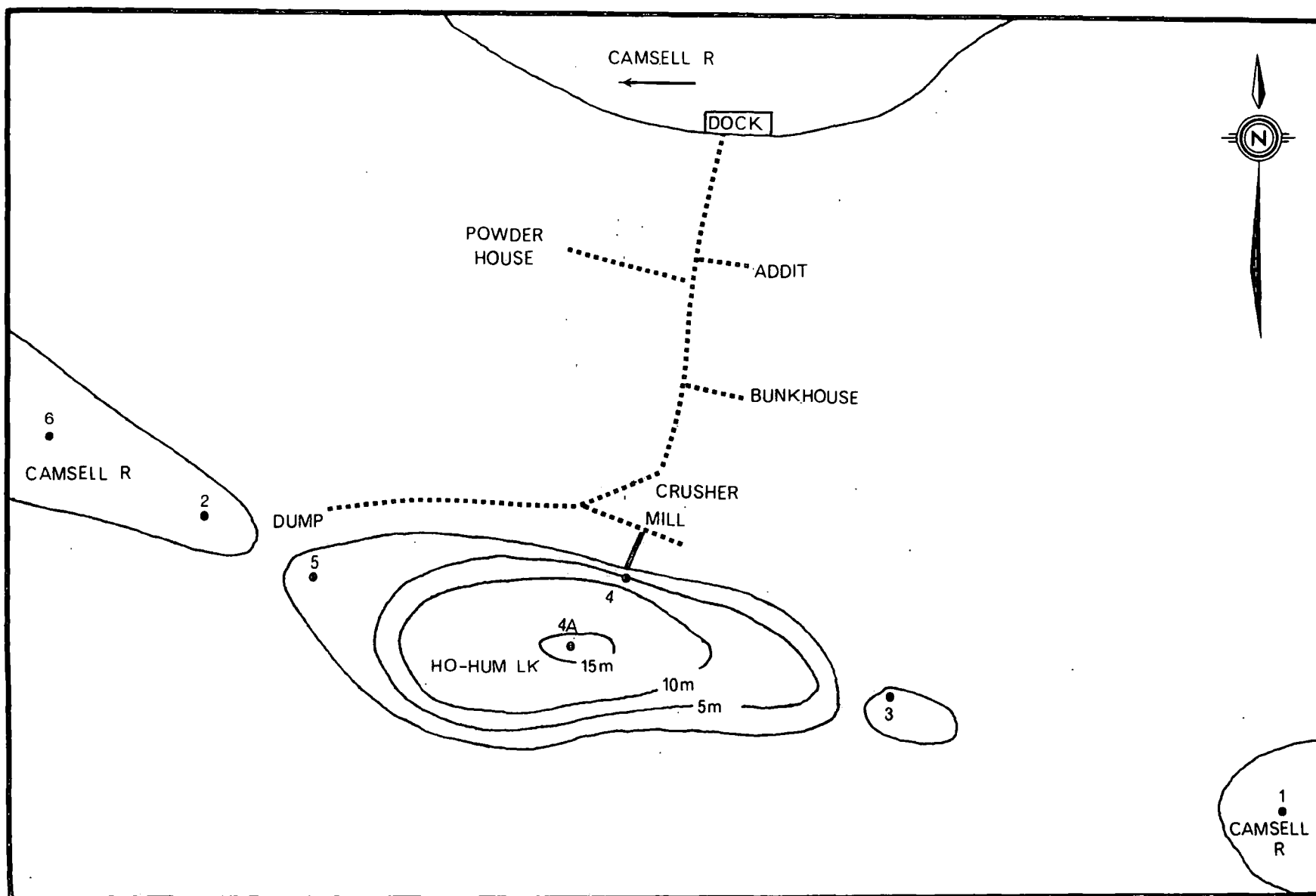
Figure 5.   Locations of the Terra mining operation and
sampling stations established during 1972.
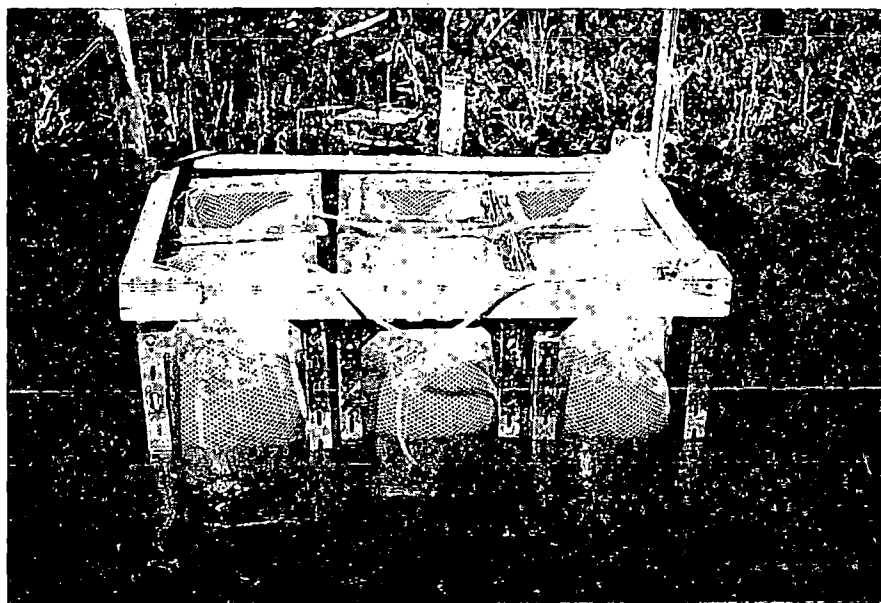
Figure 6. Apparatus used for conducting acute toxicity
bioassays under field conditions.

Bucket Bioassays: These were static acute toxicity bioassays carried out at the Echo Bay and Terra mines using plastic buckets as the test vessels. Fish were collected in Yellowknife Bay and transported to the test location. Sticklebacks, suckers, shiners (Notropis hudsonius) and lake chub (Coesius plumbius) were used as the test species. These bioassays were run at ambient air temperatures with experimental procedures similar to those for the cage bioassays. For each bucket bioassay concentration a LT50 was calculated using the method outlined by Litchfield (1949).

Comparative Bioassay: In order to compare the results from experiments using sticklebacks to those using suckers, a comparative bioassay was carried out. Both species were subjected to a single concentration of toxic waste and observed at regular intervals until they were all dead. Median survival times in minutes were determined and compared by the methods given by Litchfield (1949).

Laboratory Bioassay: Samples of mine wastes from the Giant, Echo Bay and Terra mining operations were sent to Dr. J. Sprague, University of Guelph. Dr. Sprague was contracted by Fisheries Service to conduct acute toxicity bioassays on these samples under controlled laboratory conditions. Methodology pertaining to these experiment is given in Appendix B.

Caged Fish Experiments: These experiments were carried out during the Giant and Con Mine investigations. At each sampling period, five fish were placed in each of two cages at locations along and around the mouth of Baker Creek. During the third sampling period cages were also placed at two locations in Pud Lake. Small minnow traps (0.64 cm mesh) with holes plugged served as cages. Sticklebacks and suckers were used as the test species. For each location mediam survival times (LT50) were calculated using the method outlined by Litchfield (1949).

FISH CONTAMINATION

Fish samples were collected throughout the summer from each
of the following areas:

> Mouth of Baker Creek, Great Slave Lake
> Back Bay, Great Slave Lake
> Sub Islands region, Great Slave Lake
> Grace Lake
> Kam Lake
> Martin Lake
> Ho-Hum Lake
> Camsell River
> LaBine Bay, Great Bear Lake

Sampling was by means of nylon gill net gangs, consisting of 25
yard sections of 1½, 2, 3, 4, 5 and 5½ inch meshes (stretched
measure). Nets were checked periodically until the required num-
ber of 3 - 5 "pooled" samples had been captured. Three fish of
the same species and of similar length constituted a pooled sample.
Captured fish were measured (fork length) and sexed. The liver and
one skinned fillet muscle were taken from each fish in the pooled
sample and frozen pending analysis by the Inspection Branch,
Fisheries and Marine Service, Winnipeg. Each pooled sample was
ground to homogenize the three fish tissues. Lead, copper, cad-
mium, chromium, zinc and nickel were then analysed by atomic ab-
sorption using a Perkin-Elmer Model 800 spectrophotometer. Analy-
tical methods were derived from the Perkin-Elmer Analytical Hand-
book. Arsenic levels were determined by ultraviolet visible
spectrophotometry (A.O.A.C. approved). Selenium analyses was by
the fluorometric measurement of the selenium 2, 3 - diaminophtha-
lene complex.

INVERTEBRATE CONTAMINATION

In addition to fish invertebrates, including amphipods, snails
and water beetles were collected from water bodies around Yellow-
knife. Several individuals were included in one sample and after
being ground together were analysed by the Inspection Laboratory
for trace metals using the methods outlined above.

SEDIMENT CONTAMINATION

Sediment samples were taken using a 6-inch Eckman dredge from
stations established at the four mining operations (Figs. 2, 3, 4
and 5. Samples were placed in labelled plastic bags, frozen and
submitted to the Winnipeg Inspection Laboratory, for metal analyses.
Two methods were used: 1) leaching in 1N ammonium acetate at a
pH of 7.0 and 2) digestion with aqua regia at 40°C. Results from

the ammonium acetate leaching represent the level of exchangeable cations present in the sediment. Results for the aqua regia digestion represent the level of the element in mineral form and the exchangeable elements absorbed on the particulate matter. They do not include the concentration of the elements contained in any silicate minerals.

The wet sample was allowed to air dry and was ground with a mortar and pestle. Analyses were done on a portion of the sediment passing through a standard No. 10 sieve. The ammonium acetate was added to a weighed portion of the dried sediment, shaken and allowed to stand overnight. The sample was then filtered through a No. 42 Whatman filter. Analyses by atomic absorption were done on the filtrate after being brought up to volume with 1N ammonium acetate. Aqua regia was added to a weighed portion of the dried sediment, shaken and allowed to stand overnight in a water bath at 40° C. The sample was then filtered and analysed as described above.

Sediment samples were also forwarded to Bondar-Clegg and Co. Ltd., Ottawa, for similar analyses. Their method of preparation involved the digestion of the dry weighed sediment in a 3:1 HNO_3 -HCl acid mixture for 2½ hours at 90°C. The solution was then diluted to volume, mixed well, allowed to settle and then analysed for Cu, Zn, Pb and Ni by atomic absorption. Arsenic was determined colorimetrically following a HNO_3 - $HClO_4$ digestion using silver diethyldithiocarbonate as the complexing agent. Complementary metal analysis check from selected stations in Yellowknife Bay was conducted by the Water Quality Division of Environment Canada, Calgary. Sediment samples from the Echo Bay Mine were also sent to the Department of Geology, University of Calgary for uranium analysis by fluorometry. These results were checked by Bondar-Clegg and Co. Ltd., using XRF.

BENTHOS

Benthic samples were collected each sampling period from stations established along the effluent routes and in the receiving water bodies at the four mining operations studies (Figs. 2, 3, 4 and 5). Samples were also taken from control areas assuming that the conditions of these areas prevailed prior to and/or were not affected by the mining operations. Replicate samples were obtained from each station using an Ekman dredge (6 inch). Grid sampling was also necessary at Echo Bay stations 1B, 3D, 5F, 10H, 11I, 13N, 14J and 15E where the bottom consisted of rock or large boulders. This method involved washing all rocks over 1 inch in diameter in two $0.25m^2$ areas into a bucket. The number of rocks and average size were recorded. Individual grab or grid samples

were washed on location in a metal sieve (40 meshes/inch), trans-
ferred to labelled plastic bags and preserved in 70 percent ethyl
alcohol and rose bengal (100 mg/1). Rose bengal is a vital stain
which facilitates easy sorting since the organisms are dyed and
easily recognized (Lackey and May 1971). Samples were then re-
turned to the laboratory, washed a second time in a 300 micron
sieve and sorted in a white enamelled tray. Visible organisms
were separated into taxonomic groups, counted and stored in 70
percent ethyl alcohol.

Identification to genus followed with the exception of Nema-
todes and Oligochaetes which remained at the class levels.
Oligochaete samples were sent to Ottawa for identification to
species. Chironomidae were mounted in Turtox and then identified
according to the provisional key by Hamilton and Saether, Fresh-
water Institute, Winnipeg. The Chironomid sub-family Orthocladi-
nae were not identified to genus due to the difficulty
in discerning characteristic features. However, similar Ortho-
cladinae were attributed numerical values to differentiate the
genera.

Major taxonomic groups were averaged and illustrated by
station. This was repeated for Chironomidae at the generic level.
A matrix form was assembled using genus and cumulative number of
individuals per station as the two variables. Diversity indices
were calculated for each grab and successive cumulative totals
per station. Finally, information analysis was performed using
the matrix data. Since Oligochaeta and Nematoda identification
to genus was not possible at the time of analysis, they were ex-
cluded from the diversity index and information theory calcula-
tions.

Through species diversity indices (Wilhm and Dorris 1966,
1968; and Wilhm 1970), quantitative comparisons between samples
could be made. These mathematical values are equated with the un-
certainty that exists as to the species of an organism selected at
random from a benthic community. The uncertainty would be greatest
when the number of species present is high and the abundance rela-
tively equal to the number of species. A stable unpolluted en-
vironment exhibits this because predation and competition for food
and space prevents any one species from flourishing. When pollu-
tion is introduced the number of species decreases since pollution-
sensitive ones perish. This reduces interspecific competition.
Tolerant organisms monopolize on nutrients and materials needed
to sustain life causing an increase in abundance of these
"pollution-tolerant" species. The diversity index decreases since
more certainty exists in selecting an individual at random from
such a community. The theory of diversity is independent, except
in the order of magnitude, of the levels of taxonomic classifica-

Bullshit

tion (Pielou 1969). For the purpose of our analysis, generic levels were used since identification to species was extremely difficult. *Not done*

What the fuck did this mean

Often interpretation of diversity indices appears vague since both number and abundance are measured with single parameters. This can result in diversity values which are identical for both a sample with a few species but a great abundance or with many species but low abundance. In addition, diversity indices do not take into account the presence or absence of any particular taxon. Information analysis is based on a hierarchial method where individuals are progressively fused by their similarity in attribute structure (Williams et al.1966). In the information formula:

$$I = pn \cdot \log n - \sum_{J=1}^{P} (a_j \cdot \log a_j + (N-a_j) \log (N-a_j))$$

where N is the total number of organisms,
   p is the number of genera,
   aj is the number of individuals in the jth genera of the sample and
   "I" is the information statistic measuring the disorder of the group.

define entropy

Two groups are joined into a new "I" value when upon fusion they result in the lowest state of disorder. In this case stations with similar taxonomic representations (diversity) are fused due to the low degree of difference (or disorder) between these stations. Progressively, stations with more dissimilar taxonomic representations are fused. This sympatric association continues until all of the study stations are fused. This method has proved to be effective in defining areas of a river affected by pulp mill effluent (Gregory and Loch MS 1973).

RESULTS AND DISCUSSION

WATER CHEMISTRY

Arsenic: High concentrations of arsenic were found to be associated with the Giant mill effluent (11 - 200 ppm), minewater (0.08 - 176 ppm) and thickener overflow (18 ppm). The wide ranges are attributed to the inherent variability of these wastes and grab sampling. Of interest to the present study is the discharge of wastes into Yellowknife Bay. In this regard arsenic concentrations in the mouth of Baker Creek ranged from 2.9 to 12.8 ppm. Arsenic, in this water, decreased from 12.8 ppm in April to 2.9 ppm in June. This was probably due to the initial release of tailings at break-up in early May which had accumulated throughout the winter and subsequent normal functioning of the tailings ponds during summer. Arsenic concentrations reported by Bérubé et al. (1972) fell within the ranges given above.

The average value for arsenic determined from 11 stations in Yellowknife Bay was 0.061 ppm. The lowest concentration was along the north and east shores of Yellowknife Bay and the highest was in Back Bay. This average is greater than that reported by Grainge March to October, 1968. He recorded average monthly arsenic levels ranging from 0.007 to 0.022 ppm. However, maximum levels of 0.098 to 0.297 ppm were higher than that found in the present study. Prior to process changes in the Hot Cottrel dust collectors and lime treatment of the tailings ponds to precipitate soluble arsenic in 1967 levels in Yellowknife Bay were much higher.

In contrast to the levels of arsenic found in the Giant Mine wastes the Con Mine wastes, which are comprised of both mill effluent and minewater, were relatively lower in arsenic. This may be explained in part by dilution of mill effluent by the minewater and also by the absence of a roasting circuit. Arsenic levels along the effluent route were above abckground levels (e.g. Grace Lake (0.024 - 0.05 ppm) and in Yellowknife Bay (0.007 - 0.011 ppm). These levels were 0.1 - 2.3 ppm in Pud Lake, 0.4 - 4.8 ppm in Kam Lake and 2.4 - 3.7 ppm in Keg Lake. Bérubé et al. (1972) reported levels of 3.6 and 8.4 ppm arsenic for Con mill effluent and the final discharge into Yellowknife Bay, respectively.

The Echo Bay mill effluent and minewater arsenic levels were 1.0 - 4.4 ppm and 0.8 - 1.0 ppm, respectively. Vézina (pers. comm.) found levels to be somewhat lower: mill effluent 0.76 ppm; minewater 0.16 ppm. Arsenic concentrations in Great Bear Lake ranged between 0.004 and 0.04 ppm with no relation of the sampling station location to the distance from the waste discharges.

Arsenic levels determined from Terra mill effluent and mine-water samples were 6.0 - 11.0 and 4.9 ppm, respectively. Vézina (pers. comm.) found 3.7 ppm arsenic in the mill effluent. Levels in Ho-Hum Lake were 4.2 ppm at the center and 0.4 ppm near the outlet. In the Camsell River levels were between 0.011 and 0.056 ppm above and below Ho-Hum Lake.

McKee and Wolf (1963) report that arsenic is harmful to various fish species at concentrations between 1.1 and 10 ppm depending on other parameters including temperature, dissolved oxygen, hardness and pH. Surber and Meehan (1931) found that important fish-food organisms can tolerate up to 2 ppm arsenic trioxide.

Using these levels as general guidelines it is apparent that the Giant Mine and Echo Bay Mine are discharging effluent into natural receiving waters that contain arsenic concentrations that at times may be acutely toxic to aquatic organisms. However, the literature is somewhat ambiguous on toxic and tolerable levels of arsenic and it is difficult to make a definite statement on toxic levels. A more detailed analysis of toxicity follows in the "Acute Toxicity" section.

Copper: Copper sulphate is used in the Giant and Con milling processes at rates of 200 and 300 lb per day, respectively (Bérubé et al. 1972). This accounted for high concentrations of copper found in the Giant mill effluent (17 - 19 ppm), tailings pond outlet (8.3 ppm) and at the mouth of Baker Creek (0.73 - 9.9 ppm). Copper levels in minewater and thickener overflow were not significant. Bérubé et al. (1972) reported similar levels. The average copper concentration for 11 stations sampled in Yellowknife Bay was 0.013 ppm (0.008 - 0.003 ppm). Highest values were off the mouth of Baker Creek and in Back Bay while the lowest was in the north and east parts of Yellowknife Bay.

In contrast to Giant, the Con mill effluent had a much lower copper level (0.2 ppm). However, concentrations along the effluent route were higher. These were 0.14 - 1.03 ppm in Pud Lake, 0.021 - 1.80 ppm in Kam Lake and 0.066 - 0.30 in Keg Lake. Copper in Yellowknife Bay in the region of the final discharge point was not significantly different from background levels in other areas of Yellowknife Bay and Grace Lake. Bérubé et al. (1972) found a much higher concentration in the mill effluent (31 ppm) while copper levels along the effluent route were similar to the present findings.

Copper levels in the Echo Bay mill effluent and minewater were 0.001 - 0.002 ppm and 0.001 - 0.052 ppm, respectively. Vézina (pers. comm.) recorded similar low levels. In Great Bear Lake

immediately adjacent to the mining operation copper was less than
0.001 ppm. Copper levels in the Terra Mine wastes and Ho-Hum
Lake were also low.

The toxicity of copper varies not only with fish species but
also with physical and chemical properties of the water. In hard
water toxicity of copper is reduced by precipitation of copper
carbonate and other insoluble compounds. Ellis and Ladner (1935)
found that the toxicity of copper to fish varies greatly depending
on the presence of magnesium salts and phosphates. The sulphates
of copper and zinc and of copper and cadmium are synergistic in
their effects on fish. Copper concentrations from 0.1 to 1.0 ppm
have been found to be non-toxic to most fish (McKee and Wolf 1963).
On the other hand, concentrations of 0.015 to 3 ppm have been re-
ported to be toxic to fish and other aquatic life, particularly in
soft water. Lucas (1971) interpreted the lethal and safe levels
of copper to be 0.01 - 5.0 ppm and 0.005 - 0.25 ppm, respectively.
The incipient lethal level, that concentration beyound which the
fish cannot survive for an indefinite period of time, was found to
be 0.048 ppm for Atlantic salmon (Salmo salar) (Sprague 1964).
Doudoroff and Katz (1953) found that although fish could survive
8 hours at 8 ppm zinc alone and 0.2 ppm copper alone, most fish
died within 8 hours when exposed to 1.0 ppm zinc and 0.025 ppm
copper simultaneously. In hard water this synergism does not ex-
ist.

It appears from previous findings that copper concentrations
entering Yellowknife Bay through Baker Creek are sufficiently high
to be acutely toxic to fish. The question arises however, if the
hardness of these wastes (discussed later) would act to reduce its
lethal quality. There also remains the possibility that despite
dilution with Yellowknife Bay water there may be sublethal effects
on fish in the area. Levels of copper at the final discharge points
from the Con, Echo Bay and Terra Mines were low enough to be of
minimal concern.

Zinc: Zinc levels in the mill effluent from the Giant oper-
ation where zinc dust is used at a rate of 100 pounds per day
(Bérubé et al. 1972) ranged from 2.2 to 0.685 ppm. Zinc concentra-
tions in other wastes were 0.17 - 2.2 ppm in minewater, 0.035 ppm
in thickener overflow and 0.009 ppm in the discharge from the tail-
ings pond system. At the mouth of Baker Creek, zinc ranged from a
high of 1.9 ppm in May to a low of 0.034 ppm in June. Similar
levels were reported by Bérubé et al. (1972). In Yellowknife Bay
zinc ranged from 0.001 to 0.008 ppm.

Levels of zinc in the Con Mine waste and along the effluent
route were lower than those from Giant. These were 0.013 for the

mill effluent, 0.001 - 0.038 ppm in Pud Lake, 0.007 - 0.054 ppm in Keg Lake, 0.004 - 0.021 ppm in Kam Lake and 0.02 - 0.038 ppm at the final discharge point in Yellowknife Bay. The above levels were lower than those of 45 ppm for mill effluent and 0.29 ppm for Pud Lake reported by Bérubé et al. (1972). Background levels in Grace Lake and Yellowknife Bay were found to be less than 0.01 ppm.

With the exception of 0.12 ppm for the Echo Bay minewater discharge, zinc levels in the Echo Bay and Terra Mine wastes and the associated water bodies were less than 0.01 ppm. Similar low values were reported by Vézina (pers. comm.).

In soft water 0.1 to 1.0 ppm zinc has been reported to be lethal to fish and is thought to exert its toxic action by forming insoluble compounds with the mucous that covers the gills (McKee and Wolf 1963). Calcium is antagonistic to such toxicity. Jones (1938) found that for mature fish the lethal limit for zinc in water containing 1 ppm calcium is only 0.3 ppm while in water of 50 ppm calcium as much as 2 ppm zinc is not toxic. The antagonistic effect of hardness with zinc toxicity has been confirmed by Cairns and Scheier (1958) and the synergistic effect of hardness has been given earlier. Lucas (1971) reported the lethal and safe concentrations for zinc to be 0.01 - 10.0 ppm and 0.010 - 0.050 ppm, respectively. For Atlantic salmon the incipient lethal level for zinc was 0.6 ppm (Sprague 1964).

It has been found that there is little toxic action of zinc precipitated from solution in alkaline water (McKee and Wolf 1963). The toxicity of zinc salts is increased at lower dissolved oxygen levels and although an increase in temperature decreases survival the lethal threshold concentration of zinc is not affected. Doudoroff (1956) experimented with the toxicity of metal cyanide complexes towards minnows. He found that zinc-cyanide complexes, dissociated in very dilute solutions, which have been found to be even more toxic than comparable solutions of cyanide without zinc.

It appears that levels of zinc at the final discharge points from the Con, Echo Bay and Terra mining operations are within acceptable levels. Those determined from the mouth of Baker Creek, however, were high enough to warrant immediate concern. From previous literature zinc concentration entering Yellowknife Bay is considered to be acutely toxic but the lethal quality may be reduced or nullified by water hardness.

Lead: According to McKee and Wolfe (1963) concentrations of lead less than 0.1 ppm are not dangerous for aquatic life. It appears that concentrations found at the Giant, Con, Echo Bay and

Terra mining operations are low enough to be of little concern.

Cyanide: Although not determined in the present study due to analytical difficulties, cyanide is used during the Giant and Con mining processes at rates of 950 and 500 - 600 pounds per day, respectively. According to Bérubé et al. (1972) cyanide levels at the final discharge points were 0.1 and 0.002 ppm, respectively, for the Giant and Con mine wastes. Cyanide is not used in the Echo Bay and Terra milling processes. The toxicity of cyanides towards fish is affected by pH, temperature, dissolved oxygen and concentrations of minerals. Concentrations as low as 0.05 ppm have been reported to be lethal to fish and 0.025 ppm is considered unsafe in surface water (McKee and Wolfe 1963).

Chloride: Chlorinity is closely related to total salinity and its effects on osmosis. In this regard freshwater fish cannot tolerate excessive changes in salinity since they lack the necessary physiological mechanisms. Concentrations as low as 400 ppm chloride have been reported as lethal to most fish, while some fish survive in 2000 ppm chloride (McKee and Wolfe 1963).

Levels of chloride in the mouth of Baker Creek (25.5 - 240 ppm), the Echo Bay Mine wastes (5 - 27 ppm) and the Terra Mine wastes (10.3 - 276 ppm) are low enough to warrant minimal concern. However, the levels of chloride in the Con mill effluent (3,135 ppm), Pud Lake (882 - 1,870 ppm), Kam Lake (588 - 6,100 ppm), Keg Lake (1,240 - 1,886 ppm) and in Yellowknife Bay near the final discharge point (223 - 870 ppm) were sufficiently high to cause undesirable effects. Background levels were 5.5 - 7.9 ppm in Grace Lake and 5.0 - 6.4 ppm in Yellowknife Bay. The above values were similar to those reported by Bérubé et al. (1972) and Vézina (pers. comm.).

Hardness: In the present study hardness values in the mine wastes varied greatly, among the four mining operations. At the Giant Mine hardness values were 390 - 813 ppm in the mill effluent, 57.7 - 3,776 ppm in the minewater and 124 - 427 ppm in the mouth of Baker Creek. Hardness values along the Con Mine effluent route were 1,884 - 2,251 in Pud Lake, 728 - 1,751 ppm in Kam Lake, 1,347 - 1,972 ppm in Keg Lake and 303 - 933 ppm at the final discharge point in Yellowknife Bay. The Echo Bay and Terra Mine waste hardness values were 50.3 - 108 ppm and 37.2 - 321 ppm, respectively. These results are similar to those found by Bérubé et al. (1972) and Vézina (pers. comm.). The significance of these levels will be discussed under the following section on toxicity.

Turbidity: Turbidity of water is attributed to suspended and colloidal matter; the effect of which is to disturb clarity.

and diminish the penetration of light. Excessive turbidity in water affects some fishes in the following ways: 1) by interfering with the penetration of light it acts against photosynthesis and thereby decreases primary productivity upon which fish-food organisms depend; 2) at very high concentrations particulate matter can be directly lethal to fishes through suffocation; 3) by excluding light turbidity makes it difficult for fish to find food; and 4) through settling it causes suffocation of fish eggs and fish food organisms.

Turbidity levels at the final discharge points from the Giant, Con and Terra mining operations were generally low enough to warrant little concern that detrimental effects from turbidity would result. High turbidity values in the mouth of Baker Creek in May after breakup of the tailings ponds, however, warrant some concern that suspended material may have an adverse effect on fish and benthic communities in Yellowknife Bay. Turbidity levels in excess of 7,000 JTU were recorded for the Echo Bay mill effluent discharge into Great Bear Lake. These levels were sufficiently high to warrant concern that this discharge is having an adverse effect on the fish and benthic communities adjacent to the mining operation.

pH: The symbol pH is used to designate the logarithum (base 10) of the reciprocal of the hydrogen ion concentration. McKee and Wolfe (1963) report that the pH values for most inland waters containing fish range between 6.7 and 8.6. The permissible range for fish depends upon many other factors such as temperature, dissolved oxygen and the content of various anions and cations. It has been concluded that direct lethal effects are not produced within a range of 5 to 9.5 but from a standpoint of productivity it is best to maintain the pH in the range of about 6.5 to 8.2 (McKee and Wolfe 1963). The pH values associated with mine wastes at their final discharge points fell within these limits and tended to be on the basic side of neutral. The absence of low pH values associated with the minewater and other mine drainage precludes the possibility of acid leeching.

Other parameters: Water quality parameters determined from samples collected during this study are summarized in a separate data report (Falk et al. 1973). Those not presented above were either not considered as severe pollutants or were found in concentrations not warranting great concern.

There exists the possibility of other pollutants which were not measured during this study but considering the mineralogy of the ore and the concentrating processes, their presence in high

concentrations is not likely. Chemicals used in the milling pro-
cesses such as lime and xanthates which, being moderately toxic,
are not of major concern here. Relevance of the high levels of
parameters given in this section are discussed in detail under
appropriate sections on effluent toxicity sediment and fish con-
taminations and effects on benthic communities in the receiving
waterbodies.

ACUTE TOXICITY

Giant Mine: Results from both field and laboratory multi-
concentration bioassays carried out on the Giant Mine wastes are
summarized in Table 1. Further results from laboratory bioassays
are covered in Sprague and Hicks (1973). The data indicate that
Baker Creek water entering Yellowknife Bay is acutely toxic to
fish. Sources of this toxicity are decanted water from the tail-
ings ponds and mine water. Thickener overflow, although not tested,
may also contribute to this toxicity. At the discharge point from
the third tailings pond, 96 hour LC50's were 14.8 and 6.2 percent
respectively, for sticklebacks and trout. The LC50's at the mouth
of Baker Creek were 9.3-17.8, 24 and 22.5 percent, respectively
for stickleback, suckers and trout. Minewater LC50's were 88 per-
cent for stickleback and 75 percent for trout. There was a general
decrease in toxicity from the tailings pond outlet to the mouth of
Baker Creek, presumably through dilution. It became apparent that
LC50's increased from early to mid-June, then decreased to September.
This may be attributed to the initial release of a large volume of
fluid from the tailings ponds after break-up in mid-May and their
subsequent normal functioning. As the discharge in Baker Creek
decreased over the summer, decanted water from the tailings ponds
would be diluted to a lesser extent and hence more toxic.

As mentioned previously, an experiment was conducted to com-
pare the relative toxicity tolerances of stickleback and suckers.
Results from this experiment are given in table 2. Suckers were
found to be more tolerant (LT50 = 40 min) than stickleback (LT50 =
26.5 min). The difference, as determined by a t-test was significant
at P = 0.05. As a result, sucker LC50's and LT50's may be multi-
plied by 0.6625 to correct for this greater tolerance.

The tolerance of rainbow trout used in the laboratory bio-
assays is expected to be less than fish species tested in the field.
However, direct comparisons of LC50's cannot be made due to differ-
ences in sampling date, storage time and experimental conditions.

Results from caged fish experiments carried out along and
around the mouth of Baker Creek are summarized in table 3. Again

Table 1. Results from field and laboratory bioassays carried out on mine wastes, 1972.

Collection	Testing	Test Material	Fish	Mean Length (mm)	Temp. °C	Liters/gm per fish/day	96 Hour LC50 %	Confidence Limits (P = .95)%	S
1-8-72	1-8-72	Giant #3 tailings pond discharge	Sucker	71.0	14-17	0.12	14.8	10.8 - 20.3	1.66
7-8-72	14-8-72	Giant #3 tailings pond discharge	Rainbow Trout	-	10	1.9 - 2.5	6.2	4.6 - 8.3	5.01
12-6-72	12-6-72	Mouth of Baker Ck	Stickleback	38.3	14	1.25	9.3	5.03- 17.2	2.71
20-6-72	20-6-72	Mouth of Baker Ck	Stickleback	38.2	15	1.25	17.8	15.1 - 20.9	1.45
7-8-72	7-8-72	Mouth of Baker Ck	Sucker	72.4	17.5	0.16	24.0	13.3 - 43.3	1.96
7-9-72	7-9-72	Mouth of Baker Ck	Stickleback	35.1	11-13	1.25	13.0	9.5 - 17.9	1.45
12-6-72	30-6-72	Mouth of Baker Ck	Rainbow Trout	-	10	1.9 - 2.6	22.5	12.0 - 41.0	2.25
7-0-72	7-9-72	Giant mine water	Stickleback	37.8	11-13	1.00	88.0	73.3 -100 1	1.23
12-6-72	30-6-72	Giant mine water	Rainbow Trout	-	10	2.0 - 2.3	75.0	55 -102	16.3
15-7-72	22-7-72	Echo Bay mine water	Rainbow Trout	-	10	2.4	>32	-	-
15-7-72	22-7-72	Echo Bay mill effluent	Rainbow Trout	-	10	2.2	88	52 -150	4.66
19-8-72	25-8-72	Echo Bay mill effluent	Rainbow Trout	-					
8-7-72	19-7-72	Terra mine water	Rainbow Trout	-	10	2.7	>32	-	-
8-7-72	22-7-72	Terra mine water	Rainbow Trout	-	10	2.7	>32	-	-

Table 2. Results from an experiment designed to compare the toxi-
city tolerance of ninespine stickleback and white suckers.

Fish	Mean Length (mm)	Test Material	Test Conc %	LT50 min	Confidence Limits (P = .95)	Temp °C
Stickleback	19.1	Baker Ck	100	40	3.8-50.4	12
Suckers	86.8	Baker Ck	100	26.5*	22.1-21.8	12

*Significant difference at P = 0.05.

the toxic nature of Baker Creek water is clearly demonstrated.
Median survival times increased from an average of 2 hours at the
exit from the tailings ponds to 14 hours near the mouth of Baker
Creek. Inside the dyke, at the mouth of Baker Creek, median sur-
vival times increased to 57 and 54 hours. Outside the dyke, fish
generally survived the 96-hour duration of the experiments. A
change of LT50 over the summer was similar to that for the LC50
values. It was noted that survival times around the mouth of
Baker Creek were variable, especially due to an intrusion of water
from Yellowknife Bay caused by strong NE winds. Median survival
times of 82 and 96 hours for the August experiment using suckers
may be explained by this.

As noted in the previous section on water chemistry, levels
of arsenic, copper and zinc are well above background. These
elements either by themselves or in combination, influence the
toxic nature of Baker Creek water. High levels of arsenic, copper
and zinc found at the tailings ponds correlated well with the high
level of toxicity shown by the bioassays and caged fish experiments
during that time. Lower levels of toxicity found later in the
summer corresponded well with reduced levels of these elements.
In addition to the above mentioned elements, cyanide may also con-
tribute to the toxic nature of Baker Creek water, either by itself
or by forming complexes with other elements. Evidently, the hard-
ness of water at the mouth of Baker Creek was not sufficient to
precipitate or bind toxic elements and render the water non-toxic.
Other parameters, not determined in the present study may also be
responsible for the toxic nature of Baker Creek water. In any
event it is expected that with a reduction of arsenic, copper and
zinc levels and ensuring that cyanide is within acceptable levels,
the toxic nature of Baker Creek would be significantly reduced.

Con Mine: In contrast to the Giant Mine wastes, those
tested from the Con effluent route were not acutely toxic. A
sample of the drainage between Pud and Kam Lakes, tested in June,

Table 3 . Results from caged fish experiments carried out along and around the mouth of Baker Creek.

			No. Fish Alive			
Date	Fish	Location	Start	96 hrs	LT50 hrs	Temp $^{\circ}$C
30/5/72	Stickleback	A	10	4(6*)	85	3 - 4
		B	10	0(5*)	96	5
		C	10	1(1*)	72	5
		D	10	0	2	7
		E	10	0(1*)	2	12
		H	10	2(1*)+	32	9
		Control J	26	0	1	14
		Control	10	10	-	5
2/8/72	Sucker	C	10	10	96	15
		D	10	6	82	15
		E	10	6	96	14
		F	10	0	14	13
		G	10	0	9	17.5
		I	10	0	14	17.5
		Control	10	10	-	15
1/9/72	Stickleback	B	10	0(7*)	70	10
		D	10	0(4*)	70	-
		E	10	0	3	-
		J	10	0	3	-
		Control	10	10	-	-

* Escaped
+ Alive at 40 hrs

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was found not to be lethal to stickleback after 96 hours of exposure at 16 - 19.5° C. On September 10 caged stickleback were placed at two locations in Pud Lake. Results from this experiment are given in table 4. The LT50 for caged fish placed in the north basin of Pud Lake in close proximity to the effluent discharge was less than 6 hours. Stickleback placed in the south basin of Pud Lake, however, survived the 96 hour test period.

Table 4. Results from caged fish experiments carried out in Pud Lake.

| | No. Fish Alive | | | | |
Location	Start	6	96 hrs	LT50 hrs	Temp °C
Con Effluent	20	0	0	6	-
Pud Lake	20	20	20	96	8
Control	20	20	20	-	-

The non-toxic nature of water eminating from Pud Lake may have been predicted from the previous section on water chemistry. Arsenic, copper and zinc levels were much lower than those found in Baker Creek. An explanation of these low levels and non-toxic nature of the wastes may be the high water hardness values associated with the Con Mine wastes. By binding or precipitating arsenic, copper, zinc and other elements, toxicity may be reduced considerably. It is interesting to note that high levels of chlorinity and specific conductance had no measurable adverse effects on stickleback over the 4 day test periods.

Echo Bay Mine: Results from laboratory and field bioassays carried out on Echo Bay Mine wastes are summarized in tables 1 and 5 respectively. In relation to the Giant and Con Mine wastes, mill effluent from the Echo Bay Mine was of moderate toxicity. Suckers, shiners and lake chub survived 72 hours in the mill effluent and mine water in July. In contrast, sticklebacks tested with mill effluent during August revealed LT50's of 30 and 36 hours. Similar values were obtained from a sample of mill effluent forwarded to Yellowknife for supplementary testing. From this sample, an LT50 of 24 hours was found for both 75 and 87.5 percent concentrations. Laboratory bioassays using rainbow trout revealed 96 hour LC50's for the mill effluent and mine water to be 88 and 32 percent, respectively. The mill effluent value was obtained by combining the results from the July and August samples. The LC50 for the mine water was not established since an insufficient sample was tested.

Table 5. Results from bucket bioassays carried out using Echo Bay mill effluent and mine water.

Date	Location	Test Material	Conc. %	Fish	Duration hrs	LT50 hrs	Survival %	Temp °C
12/7/73	Echo Bay	Mill Effluent	100	Suckers Shiners Lake Chub	72	–	100	8
		Mine Water	100	Same	72	–	100	8
		Control	–	Same	72	–	100	8
17/8/72	Echo Bay	Mill	100	Stickleback	96	30	0	11
		Effluent	100	Same	96	36	0	11
		Control	–	Same	96	–	100	11
21/8/72	Yellowknife	Mill	100	Stickleback	48	32	17	18
		Effluent	87.5	Same	48	24	0	18
			75	Same	48	24	0	18
		Control	–	Same	48	–	100	18

The low acute toxicity of the mill effluent may be expected, owing to the chemical nature of the waste. Low levels of heavy metals were found in samples of the mill effluent. An increase in toxicity from July to August may be explained in part by increased water temperature. Toxicants usually exert a more pronounced effect at higher temperatures. A higher level of arsenic for the August sample may have also had an effect on toxicity. Turbidity was extremely high for the mill effluent samples and is also felt to have an adverse effect on fish survival. Differences in acute toxicity between the July and August samples may have also been due to factors not measured during this study. For example, mill reagents such as xanthates have been shown to be moderately toxic (Hawley 1972) and may be responsible for this toxicity alone.

Terra Mine: Results from field and laboratory bioassays carried out on the Terra Mine wastes are summarized in tables 6 and 1 respectively. As with the Echo Bay Mine, mill effluent may be considered moderately toxic. In the field sticklebacks, shiners and suckers subjected to a 50 percent concentration of mill effluent during July survived a 72 hour exposure. In August sticklebacks were subjected to 100 percent concentrations of mill effluent and mine water. After a 96 hour exposure in mill effluent and minewater during August, LT50's were 24 and 96 hours, respectively. Due to insufficient samples, exact laboratory values of LC50's were not available. They were, however, greater than 32 percent.

The moderately toxic nature of the Terra mill effluent and that from Echo Bay may have been predicted from the chemical composition. Low levels of heavy metals were found to be associated with the Terra mill effluent. An increase in toxicity from the July to August sample may be explained in part by increased temperature, or most likely by the greater test concentration. A higher level of arsenic for the August sample may also have had an effect on the toxicity. Turbidity which was found to be very high for the mill effluent samples is felt to have an adverse effect on fish survival. Differences in toxicity between the July and August samples may also have been due to factors not measured such as mill reagents or may be a result of grab sampling. In any event, the presence of whitefish and northern pike in Ho-Hum Lake precludes the possibility of acutely toxic wastes entering the Camsell River.

FISH CONTAMINATION

Arsenic: The toxicity of the arsenous ion (As +++) is largely due to interference with enzymatic activity in the cells of those tissues in which it concentrates, mainly the liver, kidney and intestinal walls (Monier-Williams 1949; Drill 1958). The largest

Table 6.   Results from bucket bioassays carried out at the Terra mining operation.

Date	Material	Test Conc. %	Fish	Duration hrs.	LT50 hrs.	Survival %	Temp °C
8/7/72	Mill Effluent	50	Sticklebacks Shiners Suckers	72	–	100	8
	Control		Same	72	±	100	8
15/8/72	Mill Effluent	100	Stickleback	96	24	33	11-14
	Mine Water	100	Same	96	96	50	11-14
	Control	–	Same	96	–	60	11-14

MUSCLE ▨   LIVER ☐

AVERAGE LEVEL OF ARSENIC PPM

| | OFF MOUTH OF BAKER CK | BACK BAY STN 18 | MARTIN LK | GRACE LK | KAM LK | SUB IS REGION |
| | LABINE BAY | ECHO BAY '71 | CAMSELL R | HO HUM LK | PINE POINT '71 | MACKENZIE R '71 |

NA NA   NA NA   NA NA   NA NA   Tr Tr Tr   NA NA   NA   NA

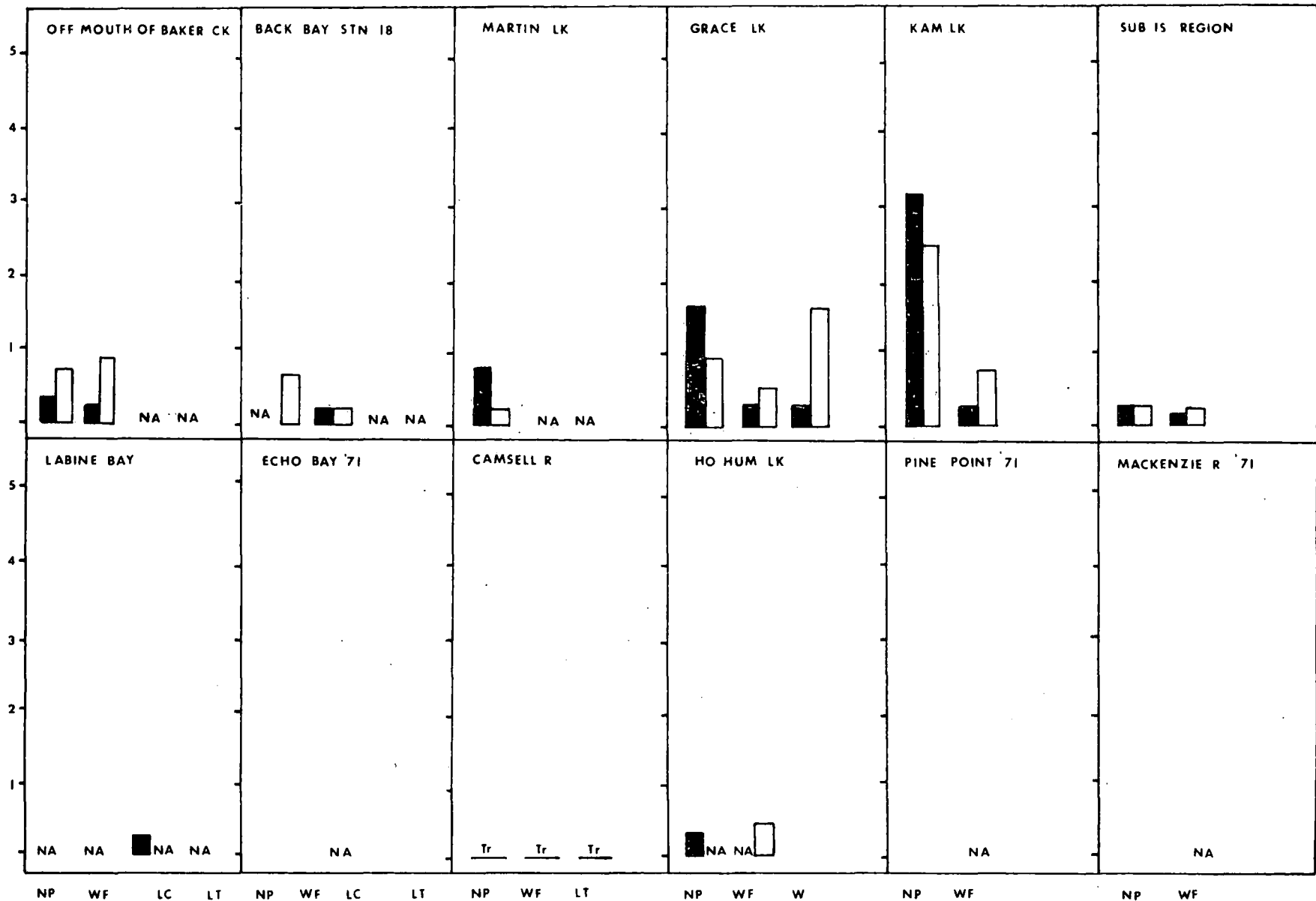NP WF LC LT   NP WF LC LT   NP WF LT   NP WF W   NP WF   NP WF

Figure 7: Levels of arsenic determined from fish muscle and liver samples, 1971-1972.
(NP = northern pike: WF = whitefish: LC = lake cisco: LT = lake trout:
W = walleye: NA = not analysed: Tr = trace).

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quantity of arsenic occurs in the fat fraction of these organs
(Vinogradov 1953). Like mercury and lead, arsenic is a cumulative
poison. It is absorbed into the body tissues and is suspected of
being carcinogenic. Bowen (1966) and Shutte (1964) found that 0.3
ppm dry weight of arsenic can be considered as a natural background
level in fish tissue. Concentrations of arsenic found in Great
Lake fishes fell in the range of 5.6 to 80 ppb (Lucas et al. 1968).
These values are 10-1000 times lower than those in marine samples
(Vinogradov 1953). The Canadian Food and Drug Directorate has set
5 ppm arsenic as a maximum level in dressed fish muscle tissues
for human consumption.

·Arsenic levels in the waters surrounding Yellowknife have
been monitored by the Department of Public Health for the past
several years. However, fish from these areas where arsenic is
considered a possible health hazard have not, to our knowledge,
been examined for arsenic or other heavy metals with the exception
of mercury. As fish from these areas, especially Yellowknife Bay
form a significant source of food for the native population, it
would appear that a yearly monitoring program may need to be established.

Comparative histograms of arsenic concentrations in fish from
areas sampled in 1971 and 1972 are illustrated in figure 7. The
mean arsenic concentration in pike muscle from the mouth of Baker
Creek was 0.31 ppm, while whitefish and suckers carried 0.22 and
0.28 ppm, respectively. These values approach the natural level
of 0.30 ppm described by Bowen (1966) and Shutte (1964). Pike and
whitefish livers from this area were found to contain 0.70 and
0.87 ppm arsenic. Fish from Back Bay carried insignificant amounts
of arsenic in their liver and muscle tissue, usually less than 0.2
ppm.

Fish from Grace Lake contained more arsenic than did fish
from areas with the exception of Kam Lake. Pike and walleye liver
from Grace Lake contained 0.96 and 1.62 ppm arsenic. Muscle tissue
for these species averaged 1.69 and 0.29 ppm, respectively. White-
fish liver and muscle tissue from Grace Lake averaged 0.53 and 0.28
ppm, respectively. Pike and whitefish from the Sub Islands were
found to contain mean liver concentrations of 0.32 and 0.24 ppm,
respectively and muscle concentrations of 0.51 and 0.20 ppm. These
values should be considered natural background levels and not dir-
ectly attributed to mine waste discharge. Pike from Kam Lake were
found to contain the highest amount of arsenic in the liver and
muscle tissue from all sample areas, 2.6 (1.7-3.3) and 3.2 (2.2-4.4)
ppm, respectively. The upper range in pike muscle tissue is approach-
ing the maximum acceptable level of 5 ppm set by the Canadian Food
and Drug Directorate. Whitefish liver and muscle averaged 0.80

(0.30-1.15) and 0.28 (0.20-0.34) ppm arsenic, respectively. A combination of seepage from Pud Lake and fallout from the roasting stacks could be attributed to the higher than usual amounts of arsenic detected in the fish sampled from Kam Lake. Arsenic in fish from LaBine Bay on Great Bear Lake and from the Camsell River system carried only trace amounts of arsenic. Whitefish liver from Ho-Hum Lake contained 0.48 ppm while a pike liver sample yielded 0.34 ppm arsenic.

It is apparent that fish from the vicinity of the gold mining operations have accumulated arsenic more readily than did fish from the more northerly sample locations. It should be remembered that arsenic is a cumulative toxin and yearly monitoring of arsenic concentrations in fish tissue in the Yellowknife area may be needed.

Copper: In general there is less copper than zinc in the tissues of fishes (Vinogradov 1953). It is not considered a cumulative systemic poison as most of it is excreted by the body and very little is retained. Excess copper, known to be stored in mammalian livers may be stored in fish livers as well (Schroeder 1956). The physiological action of copper appears to be involved in metabolism since the utilization of iron by the blood-forming organs does not occur properly in the absence of copper (McKee and Wolf 1963). There is usually more copper in milt than in roe. In the eggs it increases with development as it is absorbed from the medium. Young fish have been found to contain more copper than mature fishes (Vinogradov 1953).

Copper values up to 80 ppm in liver tissue from British Columbia trout are not exceptional (Warren et al. 1971). The concentration of copper in liver tissue from the Great Lakes ranges from 1.5 to 28 ppm (Lucas et al. 1968). This can be considered similar to that in marine fish (2-15 ppm) Vindogradov 1953). Bowen (1966) stated that levels of 8 ppm copper in dry fish tissue can be regarded as natural in origin. The Canada Food and Drug Directorate has set a maximum level of 100 ppm in dressed fish muscle tissue. Shutte (1964) indicates that copper occurs naturally in marine animals from 4 to 50 ppm.

Copper concentrations in fish liver and muscle tissue from the mouth of Baker Creek and Back Bay are illustrated in figure 8. Mean copper content in pike, sucker and whitefish livers from the mouth of the creek were found to be 0.31, 39.7 and 14.2 ppm, while the muscle contained 0.06, 18.5 and 0.03 ppm, respectively. Fish liver from Back Bay contained 13.0 and 14.9 ppm for whitefish and pike. These values can be considered similar to the copper content found in liver and muscle tissue from Grace Lake. However white-
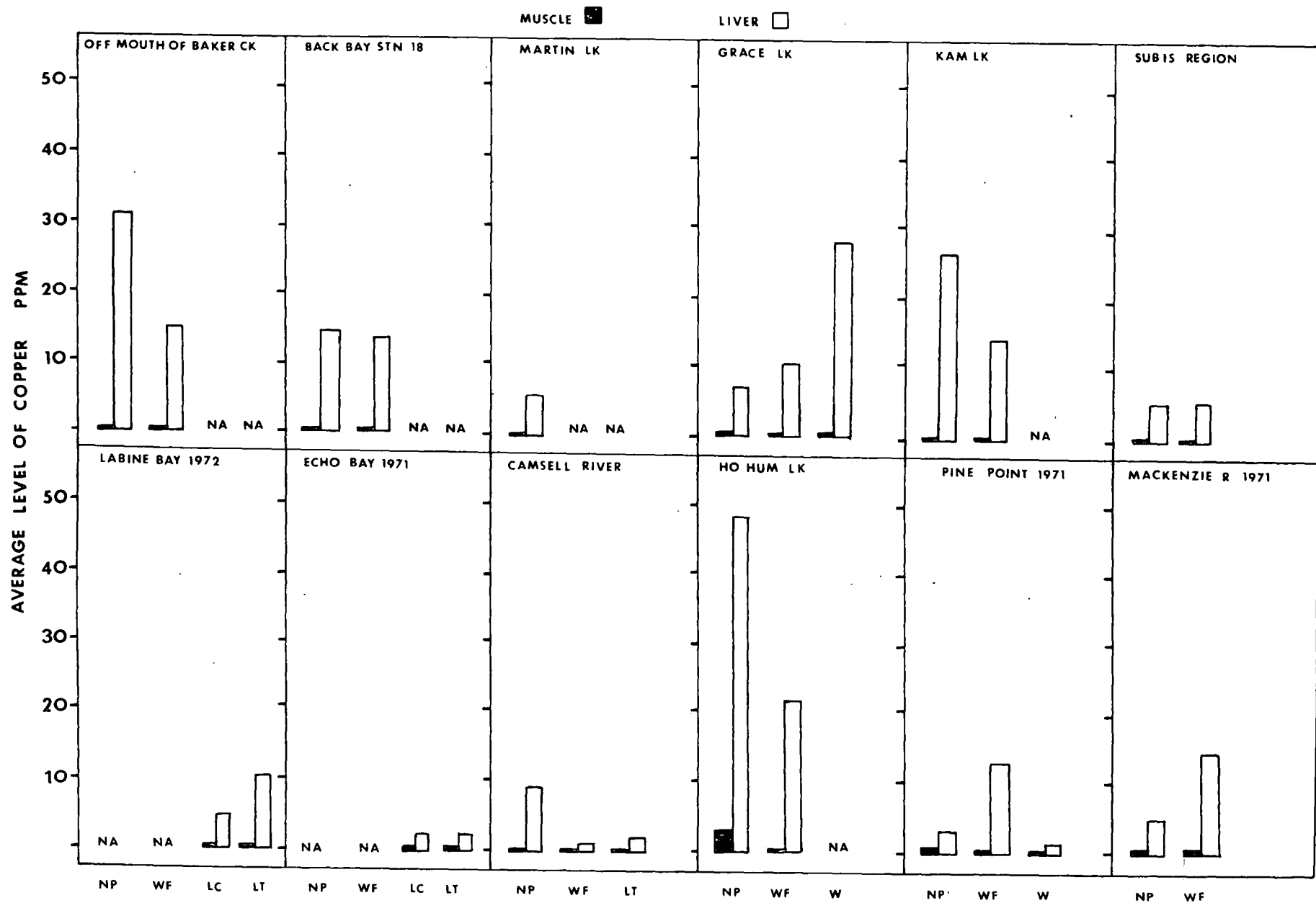
Figure 8. Levels of copper determined from fish muscle and liver samples, 1971-1972.
(NP = northern pike: WF = whitefish: LC = lake cisco: LT = lake trout:
W = walleye: NA = not analysed: Tr = trace).

fish, trout and pike livers from the Camsell River had only 1.2, 2.5 and 9.2 ppm copper, respectively. These are considerably lower than the copper values for fish liver from the Yellowknife area. Muscle tissue from the Camsell River system contained amounts of copper very similar to muscle tissue from the Yellowknife area. This demonstrates the fact that copper is accumulated and stored in fish livers in agreement with the hypothesis of Schroeder (1956), which states that excess copper known to be stored in mammalian livers may be stored in fish livers as well.

Whitefish and pike from Kam Lake contained 14.5 and 27.1 ppm copper in their livers, respectively. Muscle tissue of these fishes carried 0.23 and 0.21 ppm. Copper concentrations from the Sub-Islands region of Yellowknife Bay for these two species was 5.8 and 5.7 ppm and 0.19 and 0.21 ppm in the liver and muscle tissue, respectively. Lake trout and cisco contained liver concentrations of 11.2 and 4.0 ppm copper with 0.59 and 0.38 ppm in the corresponding muscle tissue from Echo Bay. In 1971, cisco liver contained 1.78 ppm copper while the trout liver harboured 1.76 ppm. Muscle 5issue in that year contained 0.28 and 0.18 ppm in cisco and trout, repectively. Copper content in fish muscle from Ho-Hum Lake was indifferent to fish from the other above mentioned areas. Northern pike liver contained the highest amount of copper, 26.9 to 70.9 ppm with a mean of 48.9 ppm. Whitefish liver averaged 21.2 ppm.

As is indicated by figure 8, copper content in fish muscle tissue of the species examined is independent of the area sampled. Liver tissue showed more variability in the copper content from each area and can be used with more reliability than muscle as an indicator of possible copper contamination.

Zinc: Zinc concentrates in the gills, gut and liver, and most of it is subsequently lost if the fish is transferred to zinc free water (Skidmore 1964). Toxic effects of zinc on fish have been described by Weiss and Bolts (1957), as the production of gill mucus precipitates, which reduces effective respiration. This may be considered chronic, whereby it induces stress which leads to death at a later time. Most of the literature which refers to zinc poisoning in fish indicates that stress and/or death is caused by the metal disrupting or destroying gill tissue.

Weiss and Bolts (1957) also found that larger fish were more resistant to zinc poisoning and suggested acclimitization as an important consideration. Zinc concentrates in the livers of fish but remains relatively constant in muscle tissue (Hannerz 1968). He found that whitefish, rainbow trout and lake trout had 10.9, 7.2 and 3.2 times as much Hg in the liver as in muscle tissue. A simi-

lar phenomena may exist with regards to the liver: muscle zinc concentration ratio. Zinc is usually more extensively found in the livers of whitefish and cisco which are bottom and plankton feeders, respectively. Values for pike, walleye and perch, which are predatory species, have been found to be several magnitudes lower (Hannerz 1968).

Background levels of zinc in fish muscle and liver tissue have been reported by Warren et al. (1971). They hypothesized that concentrations of 40 ppm zinc in British Columbia fish livers could be considered exceptional. Lucas et al. (1968) found zinc concentrations ranged from 11 to 48 ppm in fish liver from lakes Michigan, Superior and Erie. Zinc levels varied little between species and lake. This range for zinc is similar to the range (33-73 ppm) reported for marine samples (Vinogradov 1953) and to the value (20 ppm) reported for freshwater fish (Chapman et al. 1968). Bowen (1966) indicated that 80 ppm zinc in dry tissue can be considered natural in origin, while the Canadian Food and Drug Directorate has set a tolerance level of 100 ppm zinc in dressed fish muscle tissue.

Concentrations of zinc found in fish liver and muscle tissue taken from fish collected in 1971 and 1973 are presented in figure 9. Zinc concentrated more readily in liver rather than muscle tissue in fish captured from all areas during this investigation. As indicated in figure 9, zinc appears to accumulate in the liver 4 to 8 fold over muscle tissue. Mean zinc concentrations from fish liver collected from the mouth of Baker Creek was highest in northern pike (60.5 ppm), followed by whitefish (52.7 ppm) and longnose sucker (31.0 ppm). Muscle tissue from northern pike, whitefish and sucker yielded 14.8, 9.5 and 19.4 ppm, respectively. Concentrations of zinc in liver tissue from Back Bay yielded 67.8 ppm and 61.5 ppm for whitefish and pike, respectively. These can be considered similar to those values taken from fish at the mouth of Baker Creek. Zinc in fish from the vicinity of the Giant Mine discharge can be considered similar to other areas of Great Slave Lake and the Mackenzie River System. However, walleye liver from Grace Lake, which is unaffected by mine waste drainage contained zinc in the range of 59.5 to 176.0 ppm with a mean of 106.1 ppm. A similar situation was found to exist in northern pike livers from the Camsell River system, 102.4 to 277.2 ppm with a mean of 162.3 ppm. Values from the Camsell River may be considered natural in origin. Those from Grace Lake may also have resulted from walleye moving from Kam to Grace Lake. The absence of walleye from Kam Lake and the connection between the lakes supports this hypothesis. Muscle tissue from these areas contained zinc at 7.1 and 9.7 ppm, respectively. It is interesting to note that fish with the highest zinc concentrations in liver tissue usually had the lowest concentration in muscle tissue.
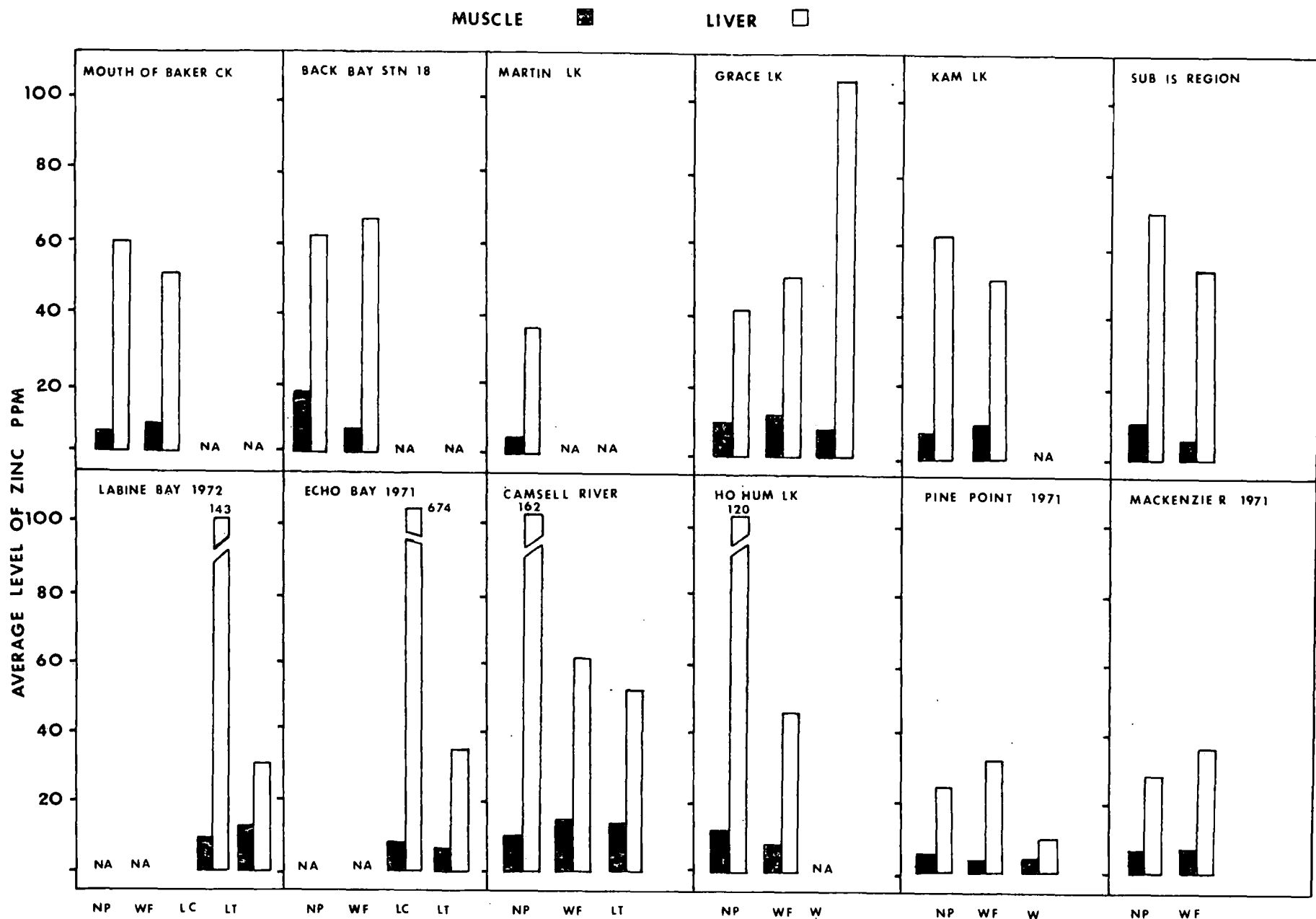
Figure 9. Levels of zinc determined from fish muscle and liver samples, 1971-1972.
(NP = northern pike: WF = whitefish: LC = lake cisco: LT = lake trout:
W = walleye: NA = not analysed: Tr = trace).

Although the zinc concentrations from fish at the mouth of
Baker Creek cannot be considered exceptional, it should be noted
that the longnose sucker was not captured at any other location
in Yellowknife Bay. Other sport and commercially sought species
such as walleye and whitefish were virtually non-existent at the
creek mouth, whereas the sucker was taken in abundance. Northern
pike appeared to exist in similar numbers when compared to other
areas in Yellowknife Bay.

As Kam Lake received discharge from the Con Mine tailings
pond, (Pud Lake) fish were sampled for heavy metal analyses.
Whitefish and northern pike contained 49.5 and 61.6 ppm zinc in
the liver tissue, respectively. Both species carried 7.7 ppm in
their muscle tissue. These values cannot be considered exceptional
and are similar to those values found in other areas in the study.
The pike populations from Kam Lake appeared somewhat stunted.
Several pike were observed to be out of proportion with respect
to their head size: body length ratio as well as having a longer
and narrower body. Also noted was an absence of stomach contents
in the fish sampled. Despite seining in the shallow areas of Kam
Lake no small or young-of-the-year fish were caught. With the ab-
sence of younger-age classes and the presence of older uniform sized
fish it is reasonable to assume that recruitment has been eliminated
in Kam Lake. It should be noted that Kam Lake also receives sewage
from the city of Yellowknife.

Zinc concentrations in lake trout and lake cisco livers from
Great Bear Lake were 31.9 and 143.3 ppm, respectively. Muscle
tissue means were 15.7 and 8.2 ppm for trout and cisco. In 1971,
two cisco liver pooled samples (5 fish per sample) yielded 977
and 376 ppm. A pooled trout liver sample during the same year
gave 37.2 ppm. From these data it is obvious that the cisco ac-
cumulate the suspended zinc more readily than do the lake trout.
This would indicate that zinc is acquired from the food chain of
the cisco, probably the plankters, which are their primary food
source. LaBine Bay on Great Bear Lake was extremely heavily popu-
lated with lake ciscoes throughout the summer, while the trout
population appeared to fluctuate in numbers, as indicated by our
gill net catch. As was mentioned earlier, zinc will gradually
decrease in fish if they are returned to zinc-free water (Skidmore
1964). The possibility does exist that the trout population is not
stable in the bay and by moving to and from the area zinc remains
in satisfactory concentrations. This is a reasonable explanation,
as the trout feed voraciously on the cisco, and undoubtedly accumu-
late zinc through this food source.

It was somewhat of a surprise to find a fish population ex-
isting in Ho-Hum Lake, as it is the main tailings pond for the

Terra Mine. Mean zinc concentrations in whitefish and northern
pike liver were 55.6 and 120.4 ppm, respectively. Muscle concen-
trations for whitefish and pike averaged 7.2 and 10.2 ppm, respec-
tively. These values are similar to those found in whitefish and
pike in the uncontaminated Camsell River, and should be considered
natural in origin. The whitefish and pike populations in the lake
appeared healthy. It was noticed however, that during sampling in
August, many of the female whitefish were either barren or contained
smaller and fewer eggs than whitefish taken from the Camsell River.
This together with the absence of younger-age classes indicates
that reproduction of the fish populations is limited.

Lead: Lead tends to deposit in bone as a cumulative poison.
Since the majority of lead salts such as the carbonate and hydroxide
are insoluble and the sulfate is only sparingly soluble, lead will
not remain suspended in natural waters. It is not among the metals
considered essential to the nutrition of animals (McKee and Wolf
1963). Studies concerning the effect of water containing lead
salts on fish indicate that a film of coagulated mucous forms,
first over the gills and then over the entire body of the fish,
probably as a result of a reaction between lead and an organic
constituent of mucous (McKee and Wolf 1963). The death of the
fish is caused by suffocation due to this obstructive layer. Warren
et al. (1971-b) stated that lead in concentrations greater than 1.2
ppm in British Columbia trout livers was exceptional. A natural
level of lead in marine animals has been established at 0.5 ppm
(Shutte 1964). It should be noted that this concentration was
highest in calcareous tissues and fish bones. The Canadian Food
and Drug Directorate has established a tolerance level of 10 ppm
lead in dressed fish muscle tissue.

Lead concentrations found in muscle and liver tissue from
fish sampled during 1971 and 1972 are illustrated in figure 10.
Longnose sucker from the mouth of Baker Creek averaged lead con-
centrations of 0.97 (0.19-2.3) ppm in liver tissue and 0.08
(0.04-0.10) ppm in muscle tissue. Pike from the same area averaged
0.08 (0.05-0.10) ppm in liver and 0.07 (0.02-0.10) ppm in muscle
tissue. An example of different feeding types of fishes accumulat-
ing different concentrations of lead from the same area is shown
by the sucker and pike liver values from the mouth of Baker Creek.
Suckers, which are bottom feeders, contained approximately 100
times the amount of lead as did pike, which are strictly predators.
Whitefish and pike from Back Bay contained an average of 0.91 and
0.57 ppm lead in their liver with 0.38 and 0.46 ppm in their muscle
tissue, respectively.

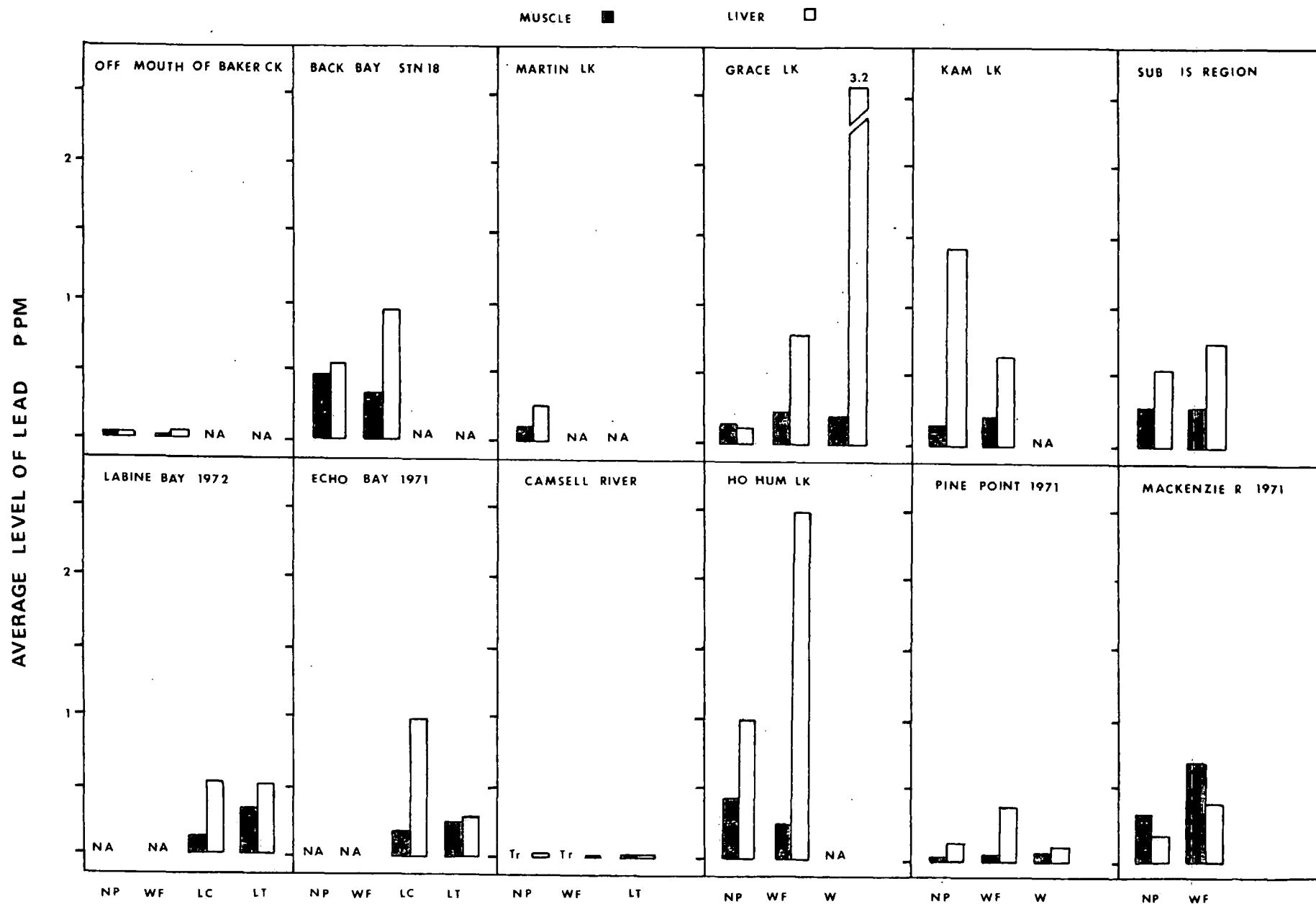Walleye sampled from Grace Lake, which is unaffected by mine

MUSCLE ■   LIVER ☐

AVERAGE LEVEL OF LEAD PPM

| OFF MOUTH OF BAKER CK | BACK BAY STN 18 | MARTIN LK | GRACE LK | KAM LK | SUB IS REGION |

3.2

| LABINE BAY 1972 | ECHO BAY 1971 | CAMSELL RIVER | HO HUM LK | PINE POINT 1971 | MACKENZIE R 1971 |

NP WF LC LT   NP WF LC LT   NP WF LT   NP WF W   NP WF W   NP WF

37

Figure 10. Levels of lead determined from fish muscle and liver samples 1971-1972. (NP= northern pike: WF= whitefish: LC- lake cisco: LT= lake trout: W= walleye: NA= not analysed: Tr= trace).

seepage contained surprisingly high levels of lead in the liver
tissue, 3.2 ppm (0.98-8.7). The muscle contained normal amounts
of 0.22 ppm. Pike and whitefish exhibited 0.13 and 0.78 ppm lead
in their liver and 0.17 and 0.27 ppm in their muscle tissue, re-
spectively. It may be that walleye have moved into Grace Lake
from Kam Lake since lead concentrations were similar. Whitefish
and pike in Kam Lake contained 0.67 and 1.41 ppm lead in their
livers with 0.22 and 0.18 ppm in their muscle tissue. Pike liver
from Kam Lake can be considered exceptional in lead content, with
a range of 1.1-1.8 ppm in the fish sampled. Fish collected from
the Sub Islands region yielded minimal lead concentrations and
should be considered as natural in origin.

Lake trout liver from Great Bear Lake at LaBine Bay carried
0.52 ppm lead, while the muscle averaged 0.31 ppm. Lake cisco
averaged 0.64 and 0.18 ppm lead in their liver and muscle tissue
respectively. Lead appeared more readily in fish liver from
Ho-Hum Lake than the other sample areas. Whitefish exhibited 2.5
(1.4-4.0) ppm while pike contained 1.0 (0.91-1-1) ppm.

Several fish samples have approached or exceeded the level
of 1.2 ppm lead proposed by Warren et al. (1971). Whitefish from
Ho-Hum Lake, pike from Kam Lake, sucker from the mouth of Baker
Creek, and walleye from Grace Lake exceeded this level with re-
gards to their liver concentration.

Cadmium: In the elemental form, cadmium is insoluble in
water. It occurs in nature largely as the sulfide salt or cadmium
blend, often as an impurity in lead-zinc ores (McKee and Wolf 1963).
Christensen and Olson (1957) stated that cadmium has probably more
lethal possibilities than any of the other metals. Besides caus-
ing acute poisonings which may be lethal, the metal and its com-
pounds may cause insidious chronic disease of serious character
developing over a number of years. Lucas et al. (1968) found
cadmium levels ranged from 0.06 to 1.4 ppm in fish liver of the
Great Lakes. Average concentration of cadmium in these fish was
found to be 0.4 ppm.

Levels of cadmium found in fish sampled during 1971 and 1972
are shown in figure 11. Pike and whitefish from the vicinity of
the mouth of Baker Creek contained liver concentrations of 0.70 and
0.21 ppm cadmium, respectively. In Back Bay these two species of
fish carried 0.84 and 0.10 ppm, respectively. When comparing the
values for cadmium from these areas to other areas, they appear to
be substantially higher. Perhaps this increase can be attributed
to waste discharge from Giant Mine, but using cadmium levels found
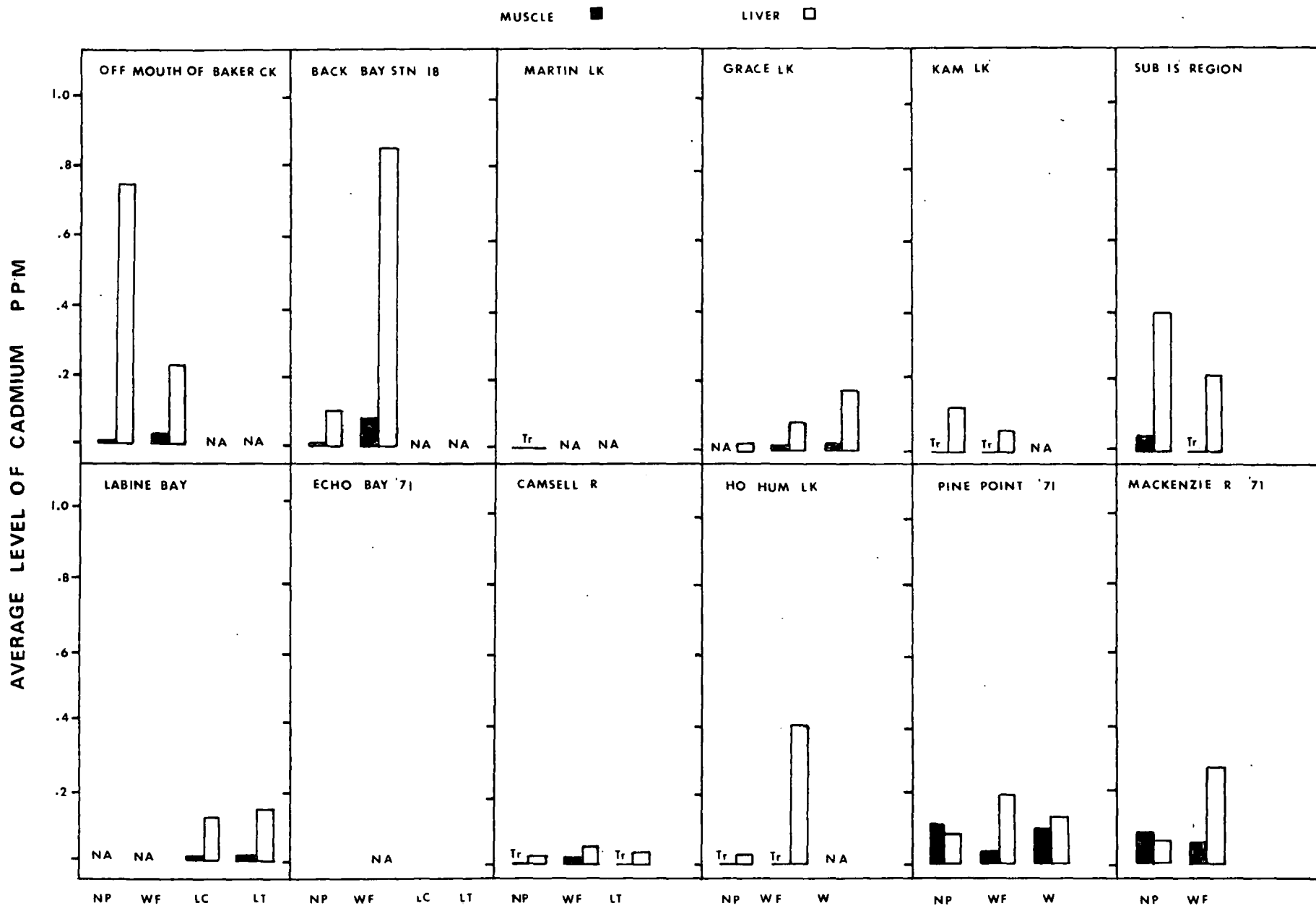by Lucas et al. (1968) they cannot be considered exceptional.

Figure 11. Levels of cadmium determined from fish muscle and liver samples, 1971-1972. (NP= northern pike: WF= whitefish: LC= lake cisco: LT= lake trout: W= walleye: NA= not analysed: Tr= trace).

Fish collected from the remaining sample areas excluding Ho-Hum Lake and a single sample from the Sub Islands region were found on the average to contain less than 0.2 ppm cadmium. A pooled sample of northern pike from the Sub Islands was found to carry a liver concentration of 1.64 ppm. Five other pike samples from this area each contained less than 0.15 ppm. Whitefish from Ho-Hum Lake carried 0.41 ppm cadmium in the liver with only trace amounts found in the muscle tissue.

Nickel: As a pure metal, nickel is not a problem in water pollution, as it is not affected by, or soluble in water (McKee and Wolf 1963). Many nickel salts, however, are highly soluble and may be discharged to surface or ground waters. Nickel appears to be less toxic to fish than copper, zinc, and iron. Systematic poisoning to human beings by nickel or nickel salts is almost unknown (McKee and Wolf 1963). Background levels of 1 ppm nickel in dry fish tissue has been described by Bowen (1966). Shutte (1964) indicated at 0.4 to 25 ppm nickel in marine animals can be considered natural in origin.

Nickel concentrations in fish liver and muscle tissue from areas sampled in 1971 and 1972 are illustrated in figure 12. Concentrations in sucker and pike sampled from the mouth of Baker Creek can be considered natural in origin as less than 0.5 ppm nickel was found in both liver and muscle tissue. Whitefish and pike liver from Back Bay was found to contain considerably more nickel (7.3 and 3.7 ppm, respectively) as did the muscle tissue from these fishes, 4.4 and 2.9 ppm. These values should not be considered exceptional. Only one walleye liver sample from Grace Lake was analysed for nickel and it harboured 13.7 ppm. This was the highest nickel value found in fish for all sample areas. It may be considered natural in origin. Walleye from a supposedly uncontaminated lake (Grace) usually contained as much of or more heavy metals in the liver than did fish from suspected contaminated areas. Walleye were not captured at other locations as they appeared indigenous only to Grace Lake. Northern pike and whitefish from Kam Lake averaged 9.0 and 4.2 ppm nickel in liver tissue with relatively similar values of 3.2 and 3.6 ppm found in fish liver from the Sub Islands region of Yellowknife Bay. Fish from LaBine Bay on Great Bear Lake as well as from Ho-Hum Lake contained less than 1.0 ppm nickel in liver and muscle tissue. This is considered as a natural background level and is not attributed to any mine waste contamination.

Uranium: Marine and freshwater organisms take up radioactive isotopes along with stable isotopes of many elements used in their life processes (Waldichuk 1961). Silt and detritus loaded with
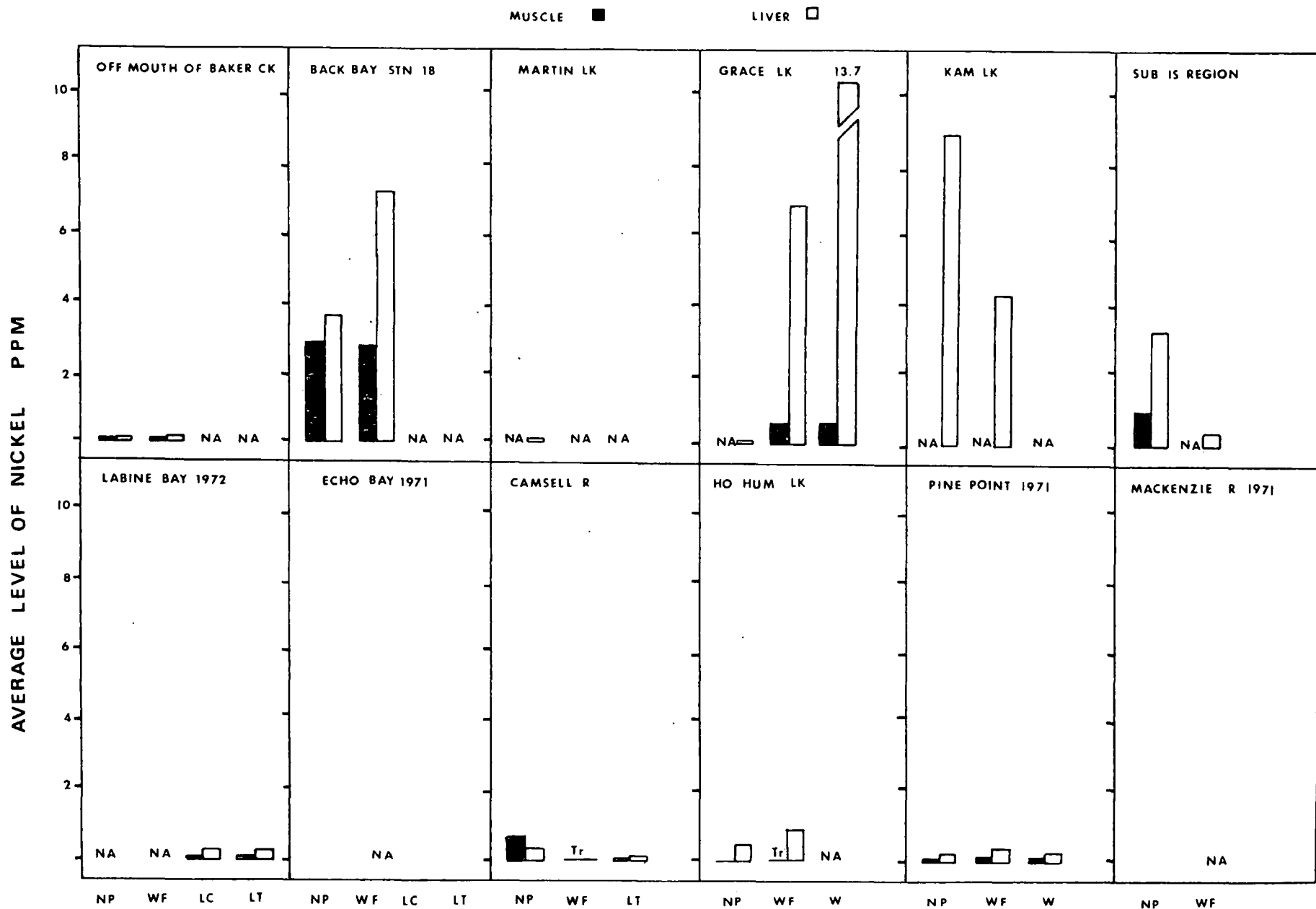
Figure 12. Levels of nickel determined from fish muscle and liver samples, 1971-1972. (NP= northern pike: WF= whitefish: LC= lake cisco: LT= lake trout: W= walleye: NA= not analysed: Tr= trace).

radioactivity are an important consideration in the ecology of
benthic organisms. Invertebrates and fish may ingest with their
food some of the inanimate material coated with radioisotopes.
Most of the radioactive substance ingested in this way will leave
the intestinal tract, but some of it will be incorporated into the
tissue of the predatory animal (Korring 1960).

Results from uranium analyses carried out on fish tissues
from the LaBine Bay and Camsell River areas are given in table 7.
Uranium levels in a sample of lake trout muscle and liver tissue
from the Camsell River were 0.29 and 0.18 ppm, respectively. These
are considered natural in origin, as Terra Mine does not emit
radioactive wastes. Trout from Echo Bay on Great Bear Lake carried
0.19 and 0.12 ppm uranium in muscle and liver tissues, respectively.
Muscle and liver uranium concentrations in lake cisco were found to
be 0.11 and 0.12 ppm, respectively. These values are not considered
exceptional, as they are lower than values from an uncontaminated
reference area.

A detailed summary of results from metal analyses carried out
on fish liver and muscle samples is covered in a separate data re-
port (Falk et al. 1973).

INVERTEBRATE CONTAMINATION

Apart from fish absorbing metals in solution by the passing
of water over the gills, metal contamination may result from the
ingestion of metals through the food chain. The benthic community,
which remains relatively stable in a given area compared to the
fish community, is suspected of accumulating significant amounts of
metals. This accumulation of metals in invertebrates is linked
closely with the fact that they are directly associated with the lake
substrata, in which heavy metals will concentrate in a metal con-
taminated area. This accumulation of heavy metals in the lake
bottom is clearly demonstrated in the following sediment contam-
ination section of the report. It is reasonable to conclude that
upon being consumed in the food chain of a higher order predator,
a transfer of heavy metals from the primary to secondary consumer
occurs.

Literature on metal contamination and uptake by the inverte-
brate fauna is limited. Mathis and Cummings (1970) found metal
concentrations in clams to exceed concentrations observed in water.
With the exception of magnesium, lithium and iron, concentrations
in clams and bottom sediments were of the same order of magnitude.
The following ranges (ppm) for metals in clams were found in the
Illinois River study by Mathis and Cummings: Zn (25-175), Pb

(1.0-7.5) Cu (.25-4.0), Ni .5-3.0), (d (.2-1.5).

Table 7. Results from uranium analyses carried out on
sediment and fish samples collected around the
Echo Bay Mine and in the Camsell River, 1972.

| | | | Uranium level (ppm) | |
| | | | Bondar-Clegg | Univ. of Calgary |
Mine	Location	Sample		
Echo Bay	Stn 1	Sediment	2	–
	3	Sediment	110	–
	4	Sediment	230	–
	5	Sediment	260	185
	5A	Sediment	30	10
	6	Sediment	1620	790
	8	Sediment	1820	1015
	9	Sediment	4	–
	11	Sediment	90	25
	15	Sediment	4	–
	LaBine Bay	Lake trout muscle	0.194	–
		Lake trout liver	0.121	–
		Lake cisco muscle	0.108	–
		Lake cisco liver	0.122	–
Terra	Camsell River	Sediment	2	–
		Lake trout muscle	0.290	–
		Lake trout liver	0.240	–
		Lake trout liver	0.121	–

*
ppb

Unfortunately members of the invertebrate community were not
sampled for metal contamination analyses. Samples were taken only
when they were readily obtainable. Snails were sampled from two
lakes which were affected by the Con Mine operations, (Kam and Keg)
and four areas which were unaffected by seepage from mining oper-
ations (Vee, Madeline, a portion of Great Slave and the Camsell
River). Heavy metals in snails with the exception of arsenic and

and copper were not markedly different for any of the sampled areas. Arsenic in snails from Keg and Kam lakes was 79.7 and 48.6 ppm, respectively. Replicate analyses were done on each sample to ensure accuracy. These values (Table 8) are considered extremely high, as snails from the unaffected areas averaged less than 7.0 ppm arsenic. The snails from Kam and Keg lakes were found to carry substantial amounts of copper as well, 35.0 and 22.5 ppm, respectively. Snails from other areas averaged less than 6.0 ppm copper. Although the values do not exceed natural levels of copper in aquatic organisms, copper uptake is indicated in snails from Kam and Keg lakes.

SEDIMENT CONTAMINATION

Previous studies conducted on sediment contamination using core samplers have indicated that most trace metals are concentrated in the organically rich, fine-grained surfacial sediments (Collinson and Shimp 1972). Since an Ekman dredge was used in the present study sediment samples may be considered as being composed of both surface (new) and sub-surface (old) sediments and organic carbon and associated this with human activities in the surrounding watershed. Also the concentration of trace elements such as bromine, chromium, copper, lead and zinc generally increase as the amount of organic carbon increases. Sediment contamination will be discussed using the results of the aqua regia digestion method of analyses. Results of the amonium acetate leaching method will not be elaborated since the level of the element in mineral form and the exchangeable elements absorbed on a particulate matter is of interest to the present study. These results, together with those presented in this section are summarized in a separate data report (Falk et al. 1973).

Arsenic: Literature pertaining to arsenic contamination of lake and river sediments indicates a wide range of opinions as to natural arsenic background levels. Hamence (1967), suggested sediments with an arsenic content greater than 75 ppm could be considered exceptional. Arsenic levels of 3-190 ppm were found from 192 stations evenly distributed over the Black Sea (Philipchuk and Stevast'yanou 1968). Shutte (1964) stated that 6 ppm arsenic is natural in soils (dryland) and that it exists in shales to 13 ppm. Frye and Shimp (1973) established a natural baseline of 8 ppm arsenic in southern Lake Michigan bottom sediments.

The summary of arsenic analyses carried out on sediment samples collected along the Giant Mine waste discharge route and in Yellowknife Bay are illustrated in figure 13.

Table 8. Results from metal analyses carried out on invertebrates collected during 1972.

Location	Organism	As	Pb	Zn	Cu	Ni	Cr	Hg	Cd
Yellowknife									
-Keg Lake	Snails	79.70	0.90	11.24	22.5	2.69	-	-	0.08
-Kam Lake	Snails	48.60	1.14	17.87	35.0	5.47	-	-	0.10
-Vee Lake	Snails	4.82	0.68	14.8	1.1	0.08	-	-	0.04
-Madeline Lake	Snails	3.08	2.44	30.9	4.0	1.67	-	-	0.26
-Latham Island	Snails	13.52	0.10	17.5	9.7	2.15	-	-	0.14
-Graham Lake	Water beetles	5.42	0.10	21.0	8.0	0.50	0.05	0.5	-
	Amphipods	3.45	0.30	70.0	3.9	0.20	0.05	Tr	-
Camsell River	Snails	6.10	2.56	37.9	10.6	1.28	-	-	0.13

*Metal level (ppm)

*
Tr = Trace

[handwritten annotations: "Gastropoda", "species ?", "Coleoptera"]
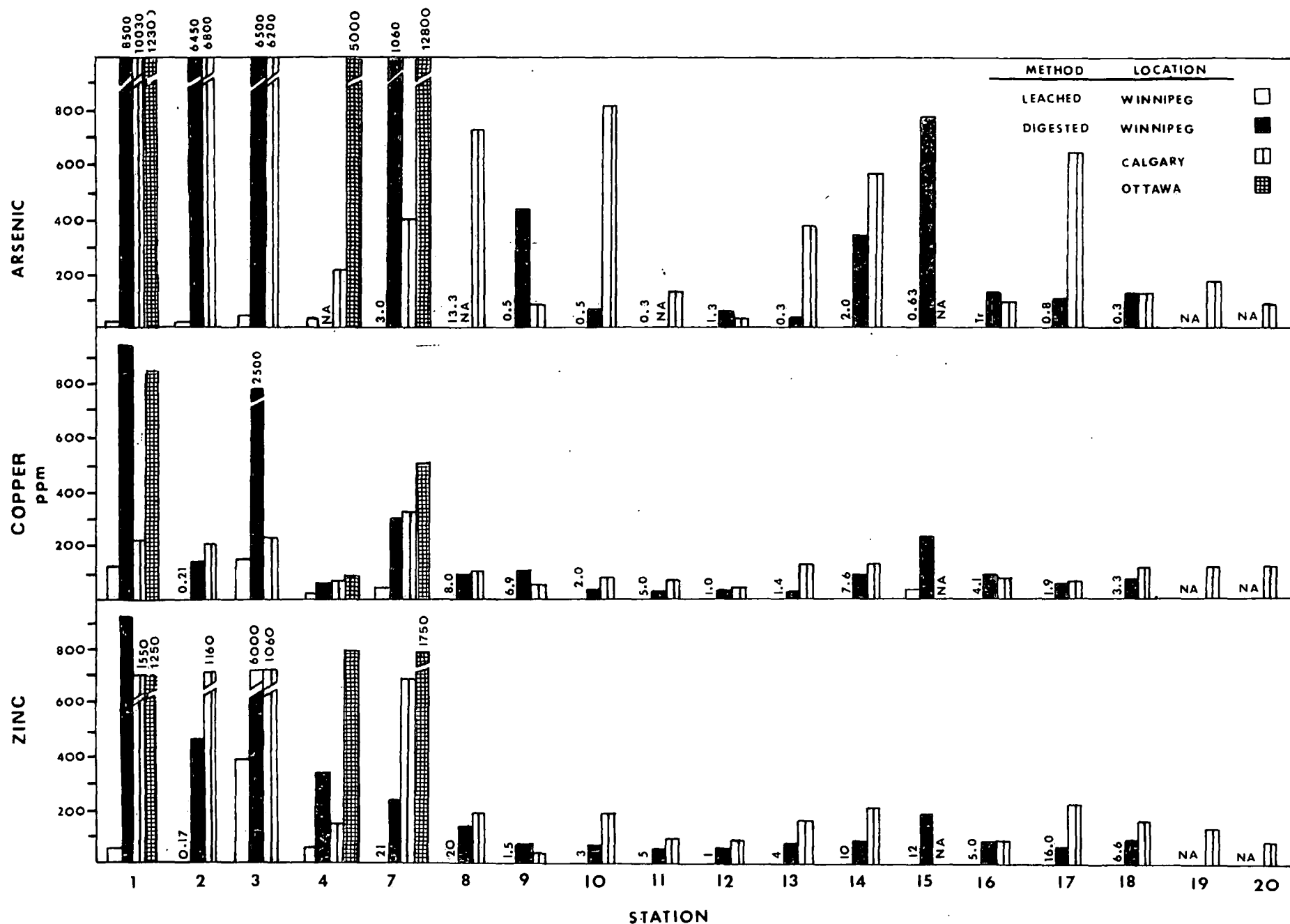
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Figure 13. Levels of arsenic, copper and zinc determined for sediment samples collected from the Giant Mine stations, 1972. (NA= not analysed: Tr= trace).

As was demonstrated by the water chemistry, arsenic is indeed a major by-product at the Giant gold mine. Waste water carrying the arsenic winds its way through Baker Creek and into Yellowknife Bay on Great Slave Lake. Sediment also showed extremely high levels of arsenic in Baker Creek as well as 100 meters off the creek mouth into Yellowknife Bay (Sta. 7). Station 1 sediment contained an average arsenic level of 10,300 ppm, with stations 2, 3 and 4, also in the creek harbouring 6600, 6350 and 3700 ppm, respectively. Station 7 which was direct offshore from the mouth of Baker Creek was also found to contain extremely high arsenic levels. Three separate laboratories found an average of 7900 ppm arsenic in sediment from this station. Sediment samples from these previous stations (1, 2, 3, 4 and 7) are considered severely contaminated by arsenic. It has been established that a current flows in a counter-clockwise direction in the vicinity of the 1972 sampling sites (Grainge 1963). When looking at the arsenic content in sediment samples to the north end of the Bay at stations 8, 9, 10, 11 and 12, we find the levels reach natural averages of less than 200 ppm at all but one station. The remaining 8 stations in Yellowknife Bay appear to separate into two quite distinct groups. Stations 13, 14, and 15 and 17 have much higher arsenic values (372, 576, 770, 616 and 90 ppm, respectively. This is demonstrated by comparing the metal histograms at each station in figure 13. Arsenic, as well as copper and zinc concentrations are high at stations 1 to 7 then drop off at stations 8, 9, 10, 11 and 12, then rise quite noticeably at 13, 14, 15, then develop again at 16 before rising at 17 and tailing off at stations 18, 19 and 20.

A summary of arsenic analyses on sediment samples collected during the Con Mine Study is presented in figure 14. Sediment (Sta. 1) from Grace Lake contained 105 ppm arsenic. This is considerably lower than most areas, yet northern pike from this lake contained higher amounts of arsenic in liver and muscle tissue than did pike from heavily arsenic-laden areas, e.g. Mouth of Baker Creek. By observing the arsenic content of stations 2, 3, 3A (Kam Lake) it can be seen that arsenic is distributed throughout most of the lake, especially at the mouth of the overflow creek from Pud Lake (16,700 ppm). Sediment from the tailings pond (Pud Lake) was found to contain 2500 ppm arsenic, while Keg Lake (Sta. 7A) which is approximately 1 mile along the southward effluent route yielded sediment contamination of 3300 ppm.

From stations at Mosher Island, 10 and 11 in the Sub Islands region of Yellowknife Bay, it was found that more natural levels of 68, 60 and 114 ppm arsenic existed in bottom sediment. Stations 9 and 10 are not directly affected by mine waste because of the high rock outcrops between Yellowknife Bay and the mining operation.
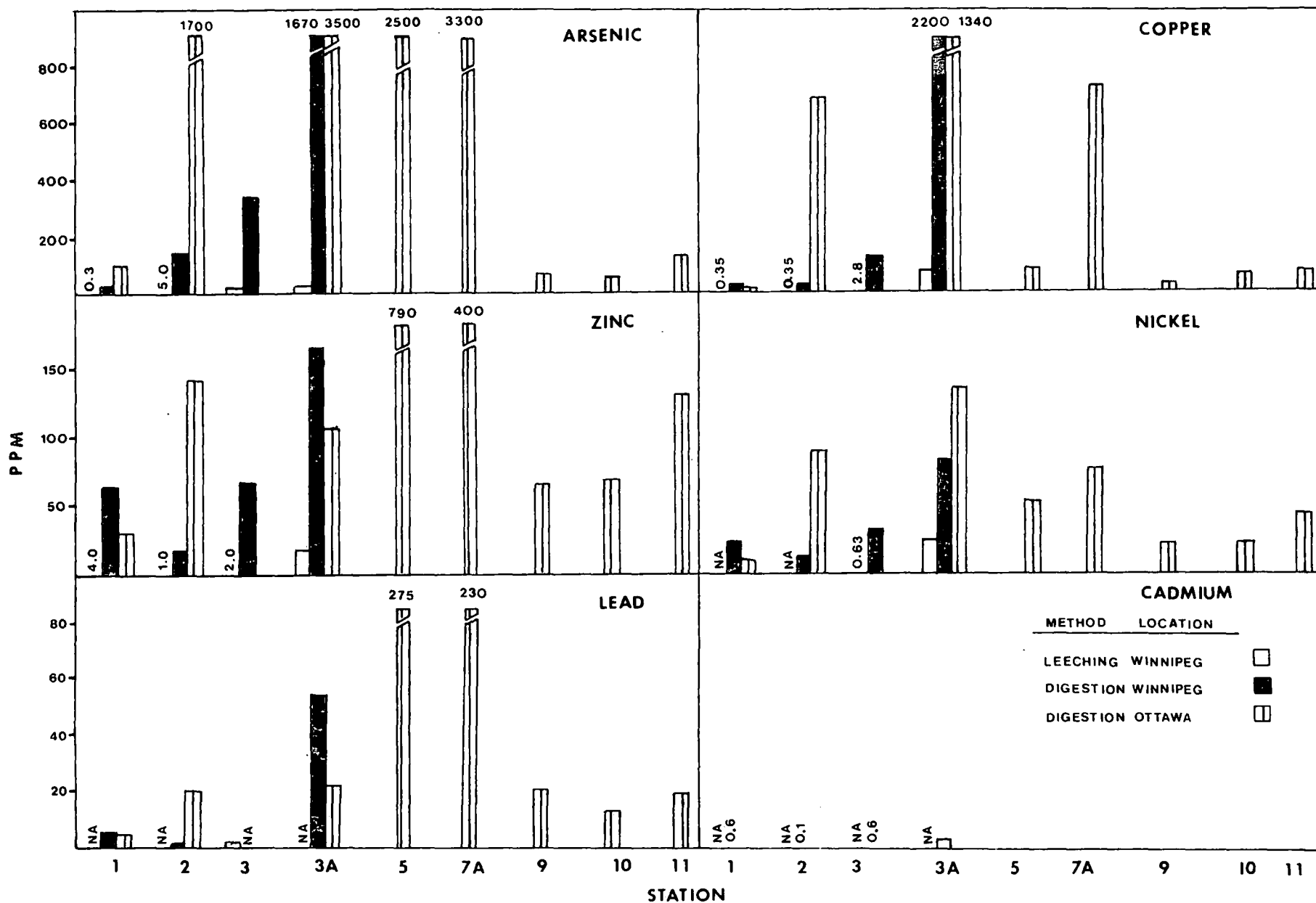
Figure 14. Levels of metals determined for sediment samples collected from Con Mine stations, 1972. (NA= not analysed).

If a contaminant was to reach the Sub Islands, station 11 would be the first recipient and since arsenic at this station was noticeably higher than at stations 9 and 10, it would appear that this area receives, to a limited extent, seepage from Con Mine.

Arsenic analyses on sediment from Echo Bay are illustrated in figure 15. Stations 4 and 6, at both ends of the channel between Cobalt Island and the mainland were found to contain similar high levels of arsenic, 3100 ppm. The substrate found in the channel was composed of a combination of fine grey clay, wood fibres and raw sewage. Stations 8 and 9 located at the entrance to LaBine Bay contained equally high arsenic contents of 4700 and 3200 ppm. Due to the depth further out in LaBine Bay (100 m) we were unable to obtain more sediment samples to define a zone of effluent influence. Station 15, offshore of Mystery Island, harboured only 16 ppm arsenic in bottom sediments, which indicates it is not adversely affected by the Echo Bay effluent. The low trace element concentration of other metals in this sediment also supports the fact that this station remains unscathed by man's activities in the area.

Analyses of sediment for arsenic determination at the Terra mining operation are shown in figure 16. Sediment from station 4, which is located in Ho-Hum Lake, 50 meters from the effluent discharge contained 5000 ppm arsenic. As the lake is bowl-shaped with a gradual declination to 50 meters, and similar substrate at all stations, we can assume that arsenic in the sediment of Ho-Hum Lake is in the range of 5000 ppm.

Sediment from station 3 (upstream in Camsell River) contained 8 ppm arsenic, while station 2 (recipient of any waste from Ho-Hum Lake during overflow periods) yielded 90 ppm. Station 6, located in what was considered a zone of recovery, harboured 22 ppm. Although the value from station 2 is probably attributed to seepage, it is not considered exceptional as overflow from Ho-Hum Lake is not a regular occurrence (not observed or reported during 1972). All other metal concentrations from station 2 with the exception of arsenic, were very similar to those of station 1. A dike across the area of possible overflow would resolve the problem of future waste seepage at this mining operation.

Copper: Copper has been found in sediments from non-industrial streams in a range of 3.5-11.2 ppm (Collinson and Shimp 1972). Baseline ranges for copper in southern Lake Michigan bottom sediments has been established at 15-30 ppm (Frye et al. 1973 Shimp et al.).
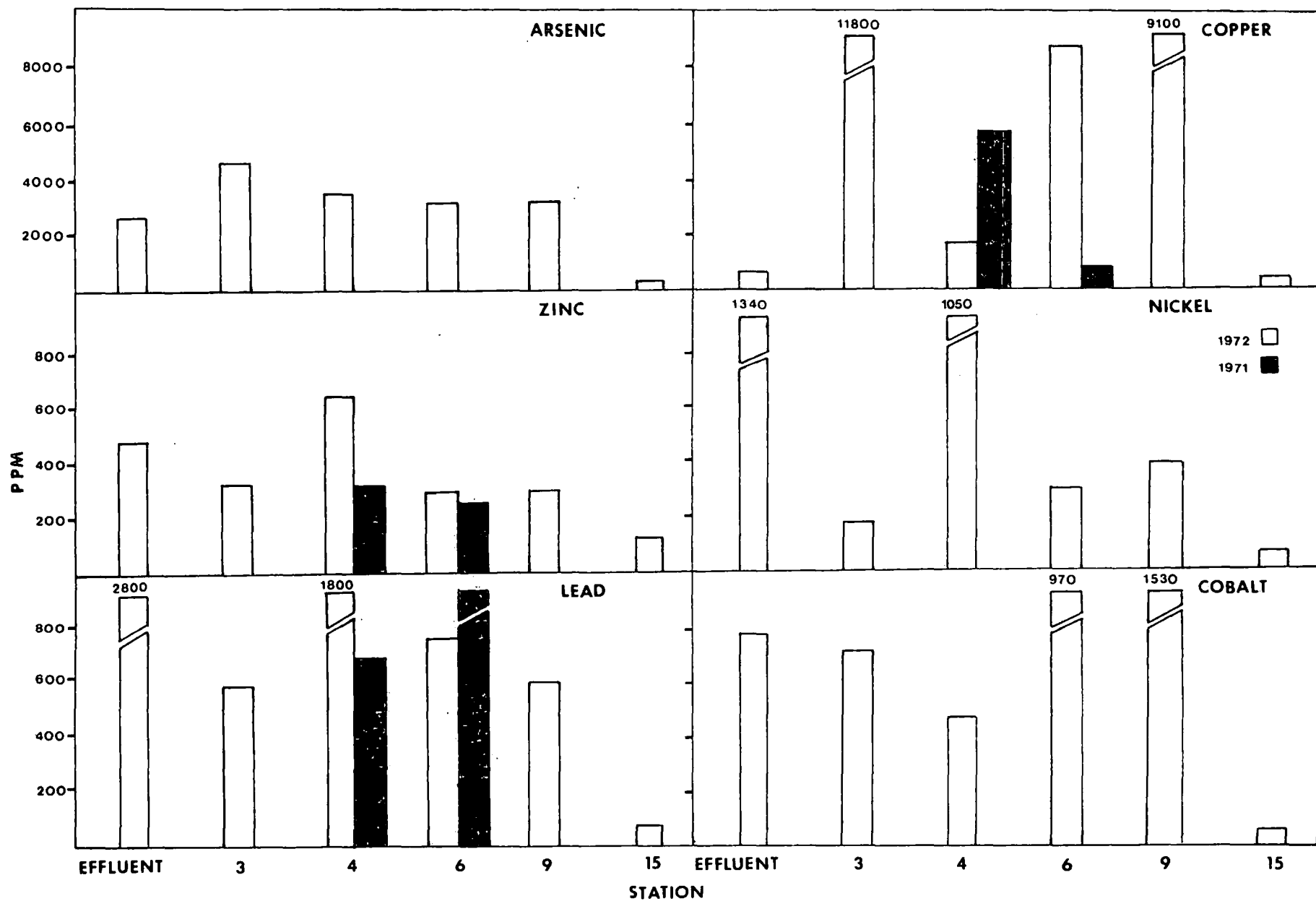
Figure 15   Levels of metals determined for sediment samples collected from Echo Bay Mine stations, 1971-1972.

(1971) found copper concentrations between 17 and 65 ppm in southern Lake Michigan bottom sediments. Sediments from uncontaminated reference waters in the Thunder Bay District of Ontario were found to contain natural levels of 150 ppm copper (German 1972). Shutte (1964) has described copper up to 100 ppm in soils as natural in origin.

The summary of copper analyses carried out on sediment samples collected along the Giant waste discharge route and in Yellowknife Bay is presented in figure 13. Copper in sediment samples from Baker Creek, stations 1, 2, 3 and 7 can be considered exceptional, with concentrations exceeding 830, 134, 236 and 306 ppm, respectively. (All analyses have been checked by 2 or perhaps 3 different laboratories). Even though station 4 did not appear to contain high copper content, it cannot be considered uncontaminated, as the sample was taken from a fast-moving section of water at the outlet of the tailings area and little settling could have taken place. Stations 8, 9, 10, 11, 12, 16, 18, 19 and 20 can be considered similar as usually less than 120 ppm copper was located in the sediment analyses. It appears that a current through stations 13, 14, 15 and 17 carried and deposits copper from the mouth of Baker Creek to that vicinity of Yellowknife Bay. This is clearly demonstrated by the histograms in figure 13.

Copper analyses from sediments collected during the Con Mine study are shown in figure 14. Grace Lake sediment (station 1), contained an insignificant amount of copper, 25 ppm. Stations 2 and 3 in Kam Lake did not appear to contain high levels of copper. Sediment from station 3A in Kam Lake, however, at the Pud to Kam Lake drainage creek contained exceptional levels of 1340-2200 ppm copper. This is confusing, as sediment from Pud Lake contained only 73 ppm copper. An explanation for this might be that copper is carried through the tailings system of Con into the more quiescent receiving waters, as station 7A (Keg Lake) also harboured higher than usual copper amounts in the sediment, 750 ppm. Stations 9 and 10 in the Sub Islands region of Yellowknife Bay contained natural sediment concentrations of less than 37 ppm. Station 11, which would be the first area in Great Slave Lake to be contaminated carried nearly twice as much copper as did other stations more removed from that area (9 and 10). This value is not considered unusual, although seepage to the station 11 area is indicated .

Copper analyses from Echo Bay sediment samples are shown in figure 15. Stations 4 and 6, located at both ends of the Cobalt Island channel contained unusually high amounts of 1650 and 8600 ppm, respectively. Current-influenced stations, 8 and 9, also
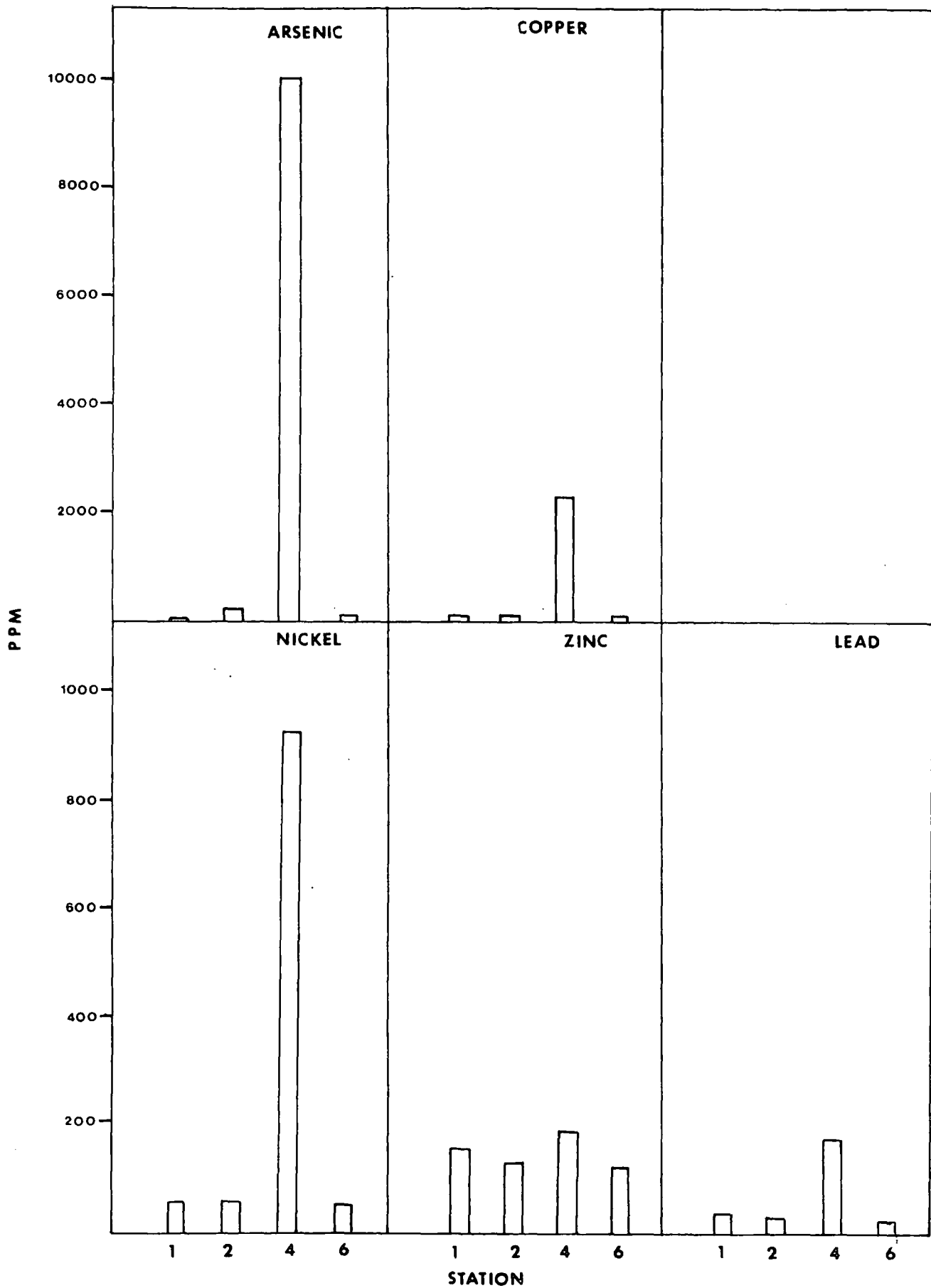
Figure 16. Levels of metals determined for sediment samples collected from Terra Mine stations, 1972.

harboured 790 ppm and Keg Lake (station 7AO, 400 ppm (fig. 14).
Grace and Kam Lakes (stations 1, 2, 3, 3A) contained less than
150 ppm zinc in sediment. Stations 9, 10 and 11, in the Sub
Islands region of Yellowknife Bay had zinc contents of 63, 68 and
130 ppm. It would appear that station 11 does receive limited
seepage from Con Mine, but does not contain zinc in the sediment
at a content which is exceptional.

Zinc analyses carried out on Echo Bay sediment samples col-
lected during 1972 are illustrated in figure 15. Values obtained
from stations 4 and 6 are considered exceptional, with concentra-
tions averaging near 600 ppm. Levels at stations 8 and 9 were
found to be 330 and 300 ppm zinc, respectively. These values are
approaching the critical level. The reference station (15) con-
tained 143 ppm zinc.

Zinc concentrations in sediment samples from the Terra Mine
study were found to be very similar for all stations (fig. 16).
Station 4 (Ho-Hum Lake) contained 195 ppm zinc in sediment while
stations in the Camsell River, both upstream and downstream from
any possible contamination yielded approximately 150 ppm zinc.

Nickel: Previous work by researchers on levels of nickel in
sediments appear to agree that 50 ppm is a natural level and that
deviations of 50 per cent plus or minus from the average be con-
sidered as normal.

Although nickel concentrations from stations in Baker Creek
(fig. 17) are generally higher than levels found in Yellowknife
Bay, only stations 1 and 3 contained nickel in concentrations which
could be considered exceptional, 120 and 244 ppm, respectively.
The remaining stations contained usually less than 30 ppm nickel
in the sediments sampled in 1972.

Nickel analysis results on sediment from the Con study are
given in figure 14. Stations 3A (Kam Lake) and 7A (Keg Lake) contained
slightly higher than average concentrations in sediment, 100 and
77 ppm, respectively. Other sample areas yielded sediment with
normal nickel concentrations. Station 11 in Yellowknife Bay which
would receive waste from the Con Mine contained 43 ppm nickel.
This value is not considered exceptional, yet other stations in the
proximity of station 11 yielded less than 25 ppm nickel in sediment.
This would indicate that some seepage has occurred in the past,
though none was observed during the 1972 investigation.

Analyses of nickel in sediment from Echo Bay are shown in
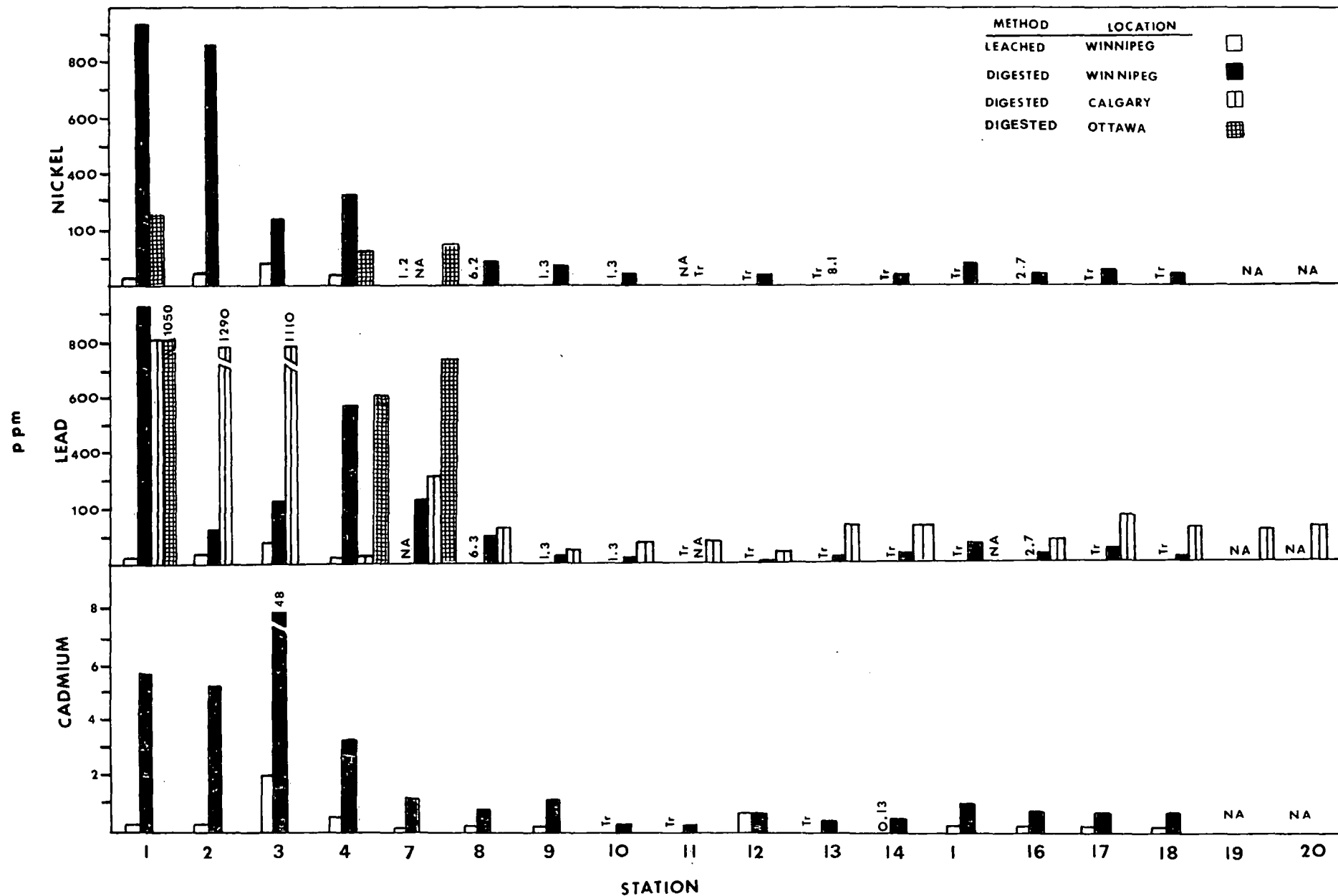figure 15. Values from stations 4, 6, 8 and 9 can be considered

Figure 17. Levels of nickel, lead and cadmium determined for sediment samples collected from Giant Mine stations, 1972. (NA= not analysed: Tr= trace).

exceptional with levels of 1050, 300, 190 and 385 ppm, respectively.
Station 15, off Mystery Island, contained only 26 ppm nickel.
Nickel is considered a contaminant in sediment of Great Bear Lake
at this mine.

A summary of nickel analyses on sediment collected from
the Terra mining operation during 1972 is presented in figure 16.
Ho-Hum Lake was found to contain 930 ppm nickel in sediment.
Nickel is not considered a problem in the Camsell River sediment,
as similar concentrations, (approximately 50 ppm) were found in both
upstream and downstream stations from Ho-Hum Lake.

Lead: Lead concentrations in a range of 12.9-27.1 ppm have
been found in sediments from non-industrial affected streams
(Collison and Shimp 1972). Frye et al. (1973) set baseline stand-
ards of 15-30 ppm lead in southern Lake Michigan bottom sediments,
while Shimp et al. (1971) described 25-133 ppm lead as being natur-
al in origin for the same area. Warren et al. (1971-a) have des-
cribed 20 ppm lead in soils as natural, while Vinogradov (1959)
indicated 10 ppm as the normal lead content. Swaine (1955) sug-
gested a range of 20-200 ppm lead as natural in soils.
Comparative histograms of lead concentrations from each station
in the Giant study are illustrated in figure 17. Sediments from
stations 1, 2, 3 and 4 in Baker Creek and 7 at the creek mouth
were found to contain lead levels which are considered exceptional
(all 3 laboratories averaged 500 ppm lead). It is obvious that
sediment from Baker Creek and the immediate area of the creek mouth
(radius of at least 50 m) is adversely affected by lead discharged
in the Giant effluent. The remaining stations in Yellowknife Bay
harboured insignificant amounts of lead sediment, usually less
than 60 ppm.

All Con Mine stations, with the exceptions of Pud Lake
(sta. 5) and Keg Lake (sta. 7A) contained normal levels of lead,
less than 25 ppm (fig. 14). Pud Lake harboured 275 ppm lead in
sediment, while Keg Lake carried 230 ppm. These values are not
considered exceptional. They demonstrate the fact that lead is
transported from Pud Lake to Keg Lake and at the present time,
does not affect the Sub Islands of Yellowknife Bay.

As was the case with other metals in sediment at Echo Bay,
lead was found in abnormally high amounts in the Cobalt Island
channel area of Great Bear Lake, (fig. 15). Values of lead in the
sediment from these areas averaged greater than 500 ppm. The ref-
erence station, (15) was found to contain only 37 ppm, which is
considered normal.

Lead was not a significant contaminant of the receiving

waters at the Terra mining operation (fig. 16). Ho-Hum Lake sediment contained 182 ppm lead, while Camsell River had less than 30 ppm in sediment. Both upstream and downstream stations, 1 and 2 respectively, contained similar levels of lead.

Cadmium: Cadmium has been found in sediments of non-industrial streams of the Illinois River up to 0.4 ppm (Mathis and Cummings 1970). Warren et al. (1971-a) have suggested that 0.5 ppm cadmium in soils is natural in origin. This agrees fully to the acceptable level established by Vinogradov (1959).

Cadmium was analyzed only in sediments from the Giant and Con mining operations (fig. 17). Amounts in Baker Creek sediment as high as 48 ppm were unexpected. Sediment from other stations along Baker Creek fell in the range of 1.2-5.8 ppm. These values are considered high and contribute to the degradation of the aquatic ecosystem of Baker Creek. Station 15 contained a cadmium level of 1.1 ppm, which is slightly above the suggested natural limit.

Cadmium in sediment from station 3A, (Con Mine study) where the Pud to Kam overflow creek empties into Kam Lake, was found to be 1.5 ppm, (fig. 14). This level exceeds maximum limits set by other researchers.

Chromium: Baseline ranges of chromium in southern Lake Michigan bottom sediments have been established at 20-40 ppm (Frye et al. 1973). Analyses of bottom sediments from stations on both the Giant and Con studies yielded results that fitted this range (figs. 14 and 17).

Cobalt: Warren et al. (1971-a) have indicated that cobalt in soils at a concentration of 5-15 ppm could be considered natural. Swaine (1955) suggested that the range for cobalt in uncontaminated soils was 1-40 ppm. Baseline ranges of cobalt in southern Lake Michigan bottom sediments have been established at 10-22 ppm (Frye et al. 1973).

Echo Bay sediment samples were analyzed for cobalt content (fig. 15). Stations 4, 6, 8 and 9 contained amounts of cobalt which are considered exceptional, 450, 970, 700 and 1530 respectively. Station 15 yielded a normal sediment content of 27 ppm. It is unfortunate that a more defined zone of influence could not be designated in LaBine Bay due to the great depth of water encountered in that area.

Uranium: Dyck (Pers. comm. 1972) described 5 ppm uranium as background in stream sediment at the Beaver Lodge mining operation on Lake Athabasca. Also, a detailed survey east of the Echo Bay

Mine area, where mine effluent had no effect, gave background
values of 23 and 17 ppm in stream and lake sediments, respectively.
Allen (Pers. comm. 1972) indicated that natural background levels
of uranium in lake sediment of the Slave-Bear Province area are
about 2 and 8 ppm, respectively.

A summary of uranium analyses carried out on lake sediment
at the Echo Bay and Terra mining operations is presented in table
9. Confirmation analyses were done by two laboratories on several
samples to ensure accuracy. Both sets of analyses were relatively
comparable.

Stations in the Cobalt Island channel yielded very high
levels, with the exception of station 5A which was located just
offshore of the effluent discharge. Stations 6 and 8, which are
influenced directly by water current, carried 1620 and 1820 ppm
uranium, respectively. Stations 4 and 5, in the area of the channel
which was not directly affected by current contained sediment con-
centrations of 230 and 260 ppm uranium. The lower concentration
of 30 ppm at station 5A appears to be explainable by its very sandy
character, whereas other stations were high in clay and organic
matter, which permits greater absorption of uranium. Station 11,
located near the minewater discharge into LaBine Bay was found
to contain 90 ppm uranium in the sediment. It would appear that
the uranium is absorbed from the water into the sediment quite
rapidly after discharge, as station 9 which was in the general
vicinity of station 8, but in much deeper water (100 m) was found
to carry a sediment concentration of 4 ppm uranium, which is con-
sidered as background. Reference stations 1 and 3 were found to con-
tain 2 and 4 ppm uranium in sediment. From these results, values
of uranium in the Cobalt Island channel would definitely be an-
omalous and most likely due to mine effluent. Sediment from the
Camsell River system (sta. 2) which would be affected by seepage
from the Terra tailings area (Ho-Hum Lake) was found to carry a
background level of 2 ppm sediment.

Uranium contamination of the lake sediments is believed to
primarily have resulted from the past mining operations by Eldorado
Nuclear Ltd. Prior to 1960 this mine was a major producer of ur-
anium oxide. Despite the fact that a different ore body is current-
ly being mined the proximity of the two lead us to believe that
radioactive contamination may result. To this end Echo Bay mill
effluent and minewater and water from the nearby Camsell River were
analysed for radioactive content. The results (table 9) revealed
total alpha and beta counts above background. In addition, radio-
active thorium, radium and potassium were identified. Counts are
below the maximum permissible concentration in water of 100 pCi/l
set by the International Commission on Radiological Protection.

Table 9. Results from analyses performed by the Atomic Energy
Commission of Canada, Pinawa, on Echo Bay Mine
wastes and water from the Camsell River.

Parameter (pCi/1)	Sample and location		
	Echo Bay Mill Effluent	Echo Bay Minewater	Camsell River Water
Total Beta count	35.2	18.7	2.78
Total Alpha count	1.01	0.08	0.02
Specific Nuclides	^{232}Th	^{232}Th	
	^{226}Ra	^{226}Ra	None
	40K	40K	

Of concern to the present study is that through continued
discharge of these wastes concentrations of radioactive wastes in
aquatic organisms may occur. Further study is necessary to de-
fine the nature and magnitude of this phenomenon.

BENTHOS

Benthic organisms form an integral part of aquatic ecosy-
stems and are useful parameters in the study of water pollution.
Their presence and abundance demonstrates not only whether an area
is polluted but also to what degree. Benthic organisms are good
qualitative pollutant indicators and have been roughly divided into
three groups; pollution-sensitive, pollution-tolerant and moderately
tolerant organisms (Cairns and Dickson 1971). One must be careful
in employing such a general classification for it ignores the
biology of individual species within each grouping. Very little
is known by pollution biologists about many of the organisms that
are lumped as "pollution tolerant" or whatever. Therefore it is
essential to employ, in addition to general qualitative classi-
fications, quantitative measures which operate at a more objective
level in pollution assessment.

In this section both qualitative and quantitative assess-
ments are made in broad terms with little reference to individual
samples. Generic lists by mine, station and sample are covered
in a separate data report (Falk et al. 1973).

Giant Mine: Qualitative results (figs. 18 and 19) show
that pollution-tolerant Chironomidae (midge flies) and Oligochaeta
(aquatic worms) predominated at stations where organisms were pres-
ent at all. Stations along Baker Creek were devoid of any organ-
isms and it is evident that this area is extremely polluted and
could not sustain even the hardiest benthic organism. Benthos
present in considerably high numbers in Yellowknife Bay were
Amphipoda (scuds), Pelecypoda (clams), Gastropoda (snails) and
Nematoda (roundworms). These organisms, considered moderately
tolerant, have been found in great numbers in all areas of Yellow-
knife Bay and most areas of Great Slave Lake (Rawson 1953). This
implies that care be exercised when describing an area as affected
on the basis of abundance of such organisms. According to Rawson
(1953), the pollution-sensitive Ephemeroptera (mayflies) were
common at a depth of four meters in Yellowknife Bay. Their ab-
sence in the present study suggests that some changes in mayfly
distribution may have occurred since.

Since stations along Baker Creek lacked any organisms they
were excluded from the data matrix and subsequent calculations.
Stations 7 and 14, nearest the mouth of Baker Creek showed the
lowest number of genera and indeed few individuals. At station
14, diversity may have been limited due to the substrate which
was comprised entirely of sand, making it an unstable environment.
Station 20, originally intended as a control showed a lower diver-
sity than expected. This may be due to industrial activity in the
area and fuel spills which occur frequently. Diversity increased
progressively with distance from the mouth of Baker Creek, with
high diversity to the north and east in Yellowknife Bay.

Qualitative observations on the benthic composition were
substantiated by calculations of diversity index and information
theory. Diversity indices, for all mines studied, were based on
individual samples taken throughout the sampling season and on
their cumulative totals. The upper values (fig. 18) represent
the asymptotic or cumulative numbers and are more accurate since
they are independent of sample size (Wilhm 1970).

For the purposes of this report the scale of the genera
diversity index has been divided into three ranges: low (2),
intermediate (2-3) and high (3). Since these ranges are based
on genera diversity indices they cannot be correlated with Wilhm
and Dorris' (1968) proposed classification for species diversity
index (Pielou 1969). The number of genera are compared to the
index of diversity in figure 20. As expected, the lowest diver-
sity values occurred at stations 7 and 14 while the highest val-
ues prevailed at the zones along the northwest shore of Yellow-
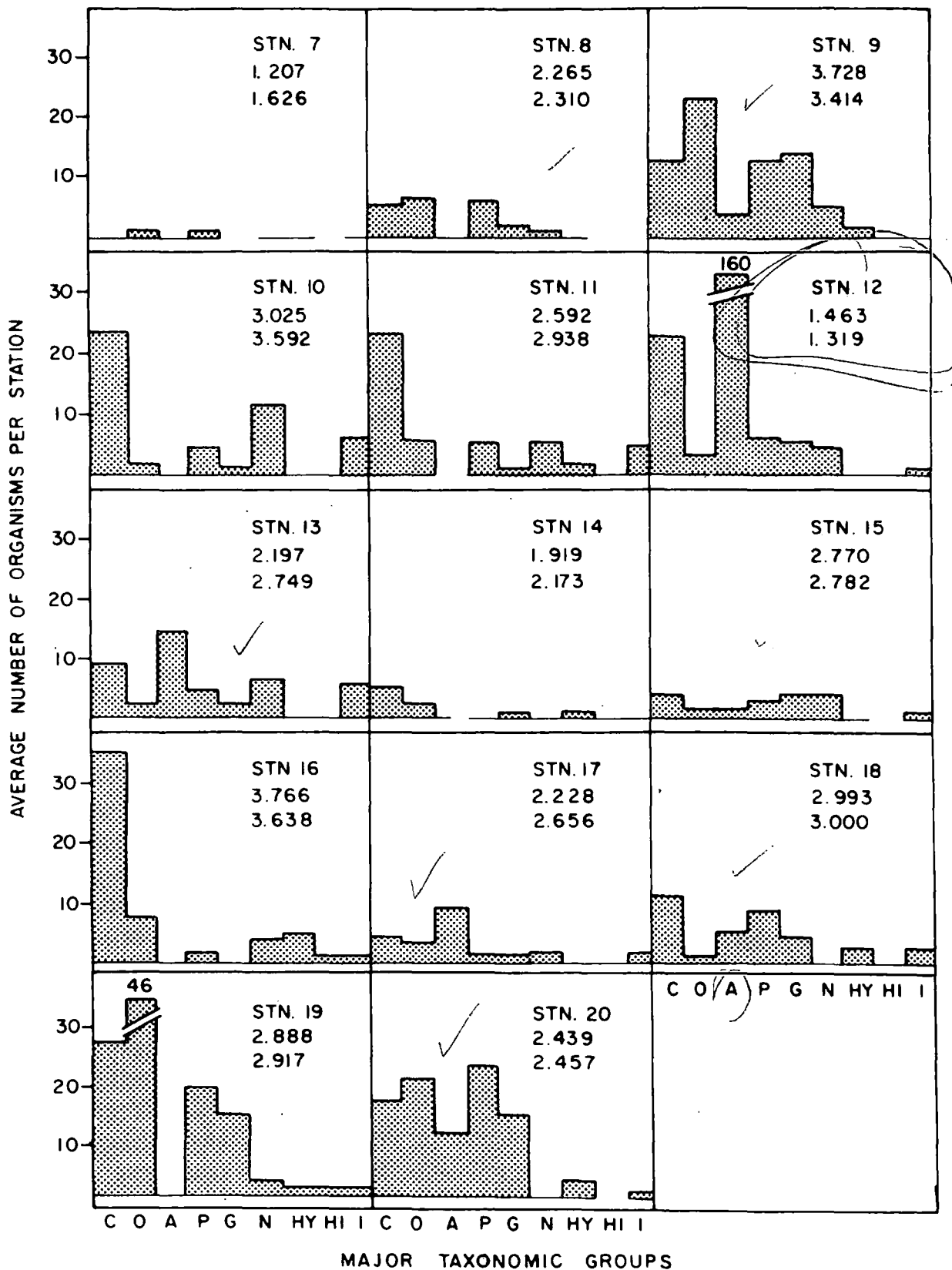
Figure 18. Average composition by major taxonomic groups for each
Giant Mine station (C=Chironomidae; O=Oligochaeta;
A=Amphipoda; P=Pelecypoda; G=Gastropoda; N=Nematoda;
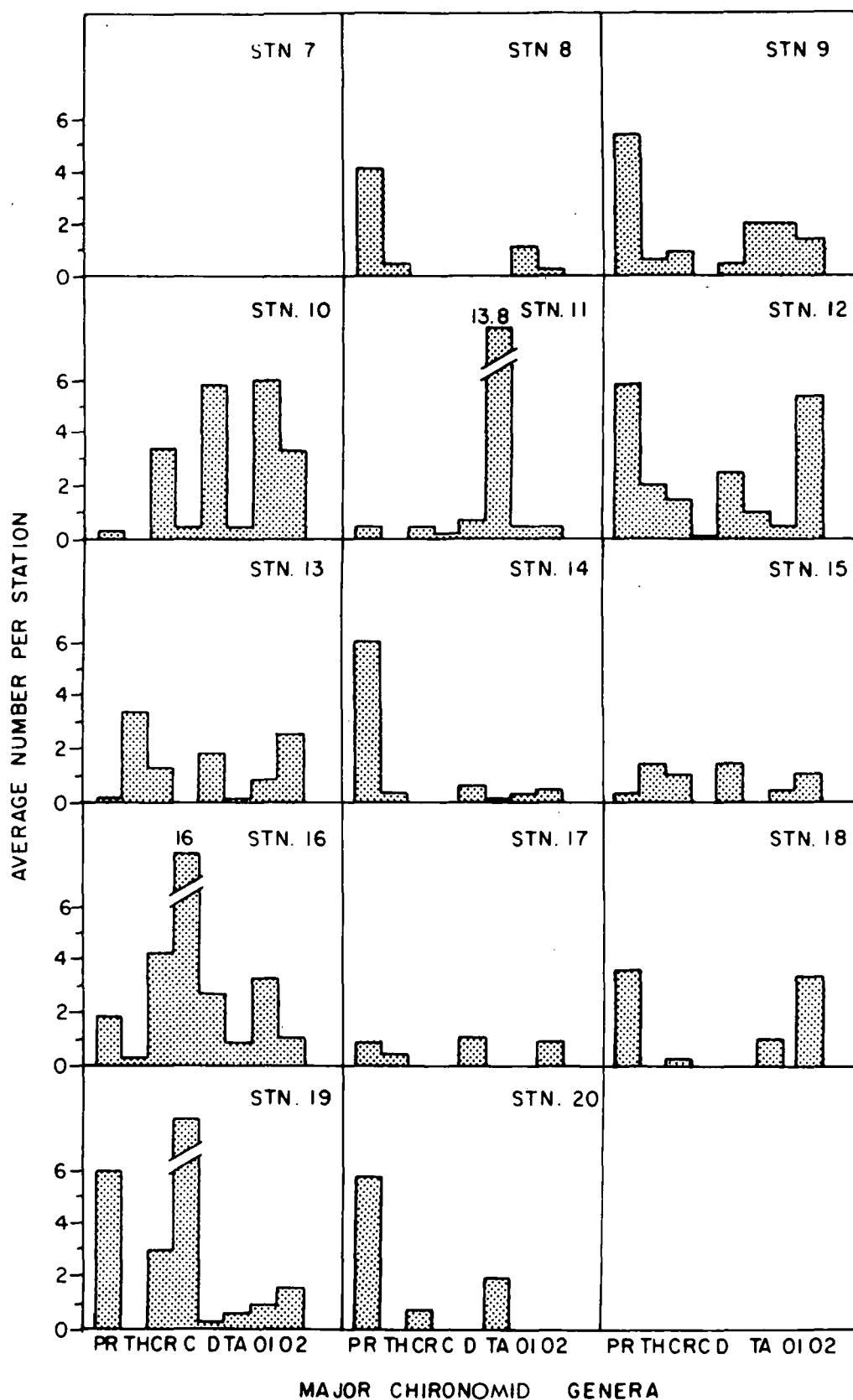HY=Hydracarina; HI=Hirudinea; I=Insecta).

Figure 19. Average composition by major Chironomidae genera for each Giant Mine station (C=Chironomus; PR=Procladius; T=Thien Group; CR=Cryptochironomus; D=Dicrotendipes; T=Tanytarsus; 01=Orthocladinae #1; 02=Orthocladinae #2).
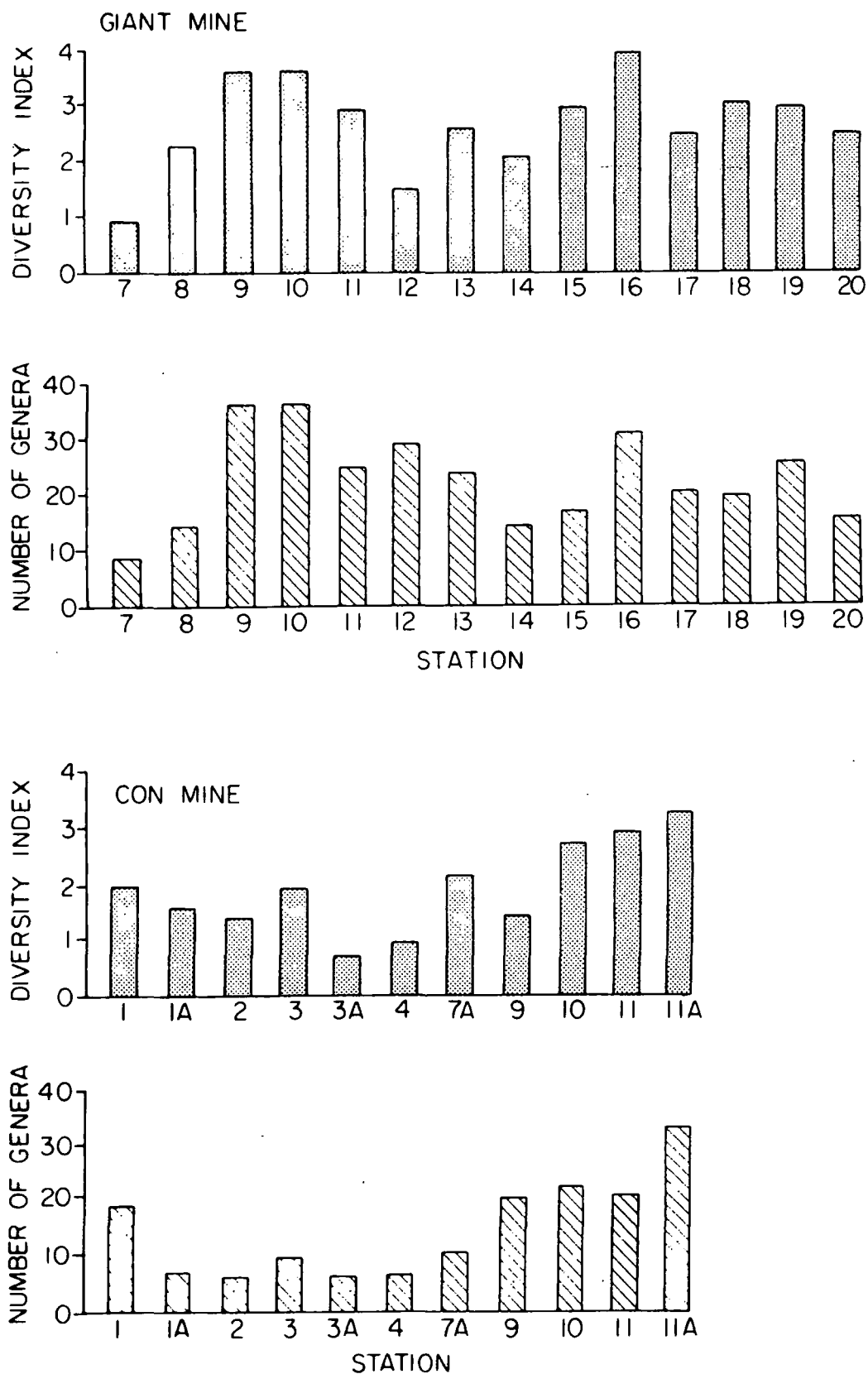
Figure 20. Comparisons of the number of genera and index of
diversity for Giant and Con Mine stations.

knife Bay and the southeast shore of Back Bay (fig. 18). Stations 13, 15, 17 and 20 had intermediate values. Station 12 is not necessarily polluted, as stipulated by the diversity index, but contains an overabundance of Pontoporeia. Since Pontoporeia normally constitutes 62 percent of the total faunal community at Great Slave Lake (Larkin 1948) it appears that this area contains a regular population distribution.

The information analysis dendogram (fig. 21) demonstrates the fusion of stations with a similar benthic community structure. Figure 22 shows, schematically, the distinct separation (at the 300 information level) into three areas: 1) stations closest to the outfall and in the zone of the current; 2) stations north of the point of discharge and 3) stations sampled along Latham Island. The three groupings parallel the breakdown of diversity values for the same area. Information analysis is a more sophisticated method of quantitative analysis because it considers the relative abundance of particular genera while diversity indices do not. Station 12 exemplifies a shortcoming of the diversity index. This station, according to both qualitative observation and information-analysis separation, is relatively stable. Diversity index, on the other hand, considers it severely polluted.

It has been previously established that a counter-clockwise current exists in the Back Bay area of Yellowknife Bay where stations 13, 15 and 17 are located (Grainge 1963). Since a similarity in diversity exists among these stations it may be assumed that this current effectively channels the effluent in a southerly direction from the mouth of Baker Creek (fig. 22). The separation of stations 13, 15 and 17 from stations 16 and 19 indicates that this may be the case. Qualitative observations on the study area for Giant Mine indicate that stations along Baker Creek and near its mouth are most affected by the effluent. The areas within the current flow are also affected although the diversity of genera does increase considerably. Stations north and south of these areas appear to have the most diverse fauna with more groups and relatively equal numbers within each group.

Basically, both the diversity index and information-analysis support the qualitative analysis and establish a definite pattern of polluting effects on the study area. Baker Creek is severely polluted in the vicinity of the discharge into Yellowknife Bay. Moderately polluted stations occur intermittently in Yellowknife Bay and may be definitely correlated with a counter-clockwise current in the vicinity of Back Bay. Other stations appear in equilibrium and unaffected by the discharge from Baker Creek.

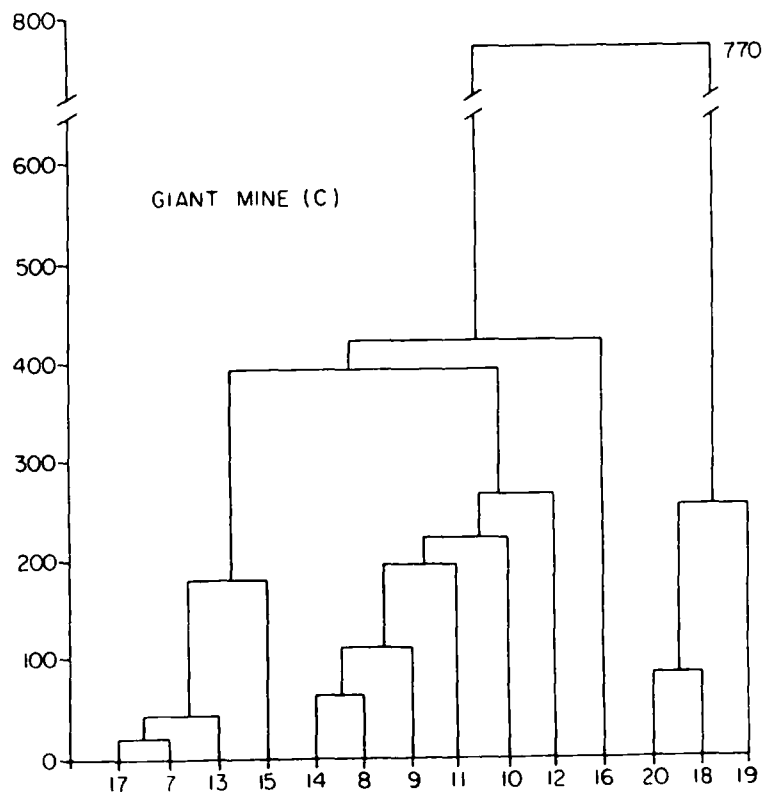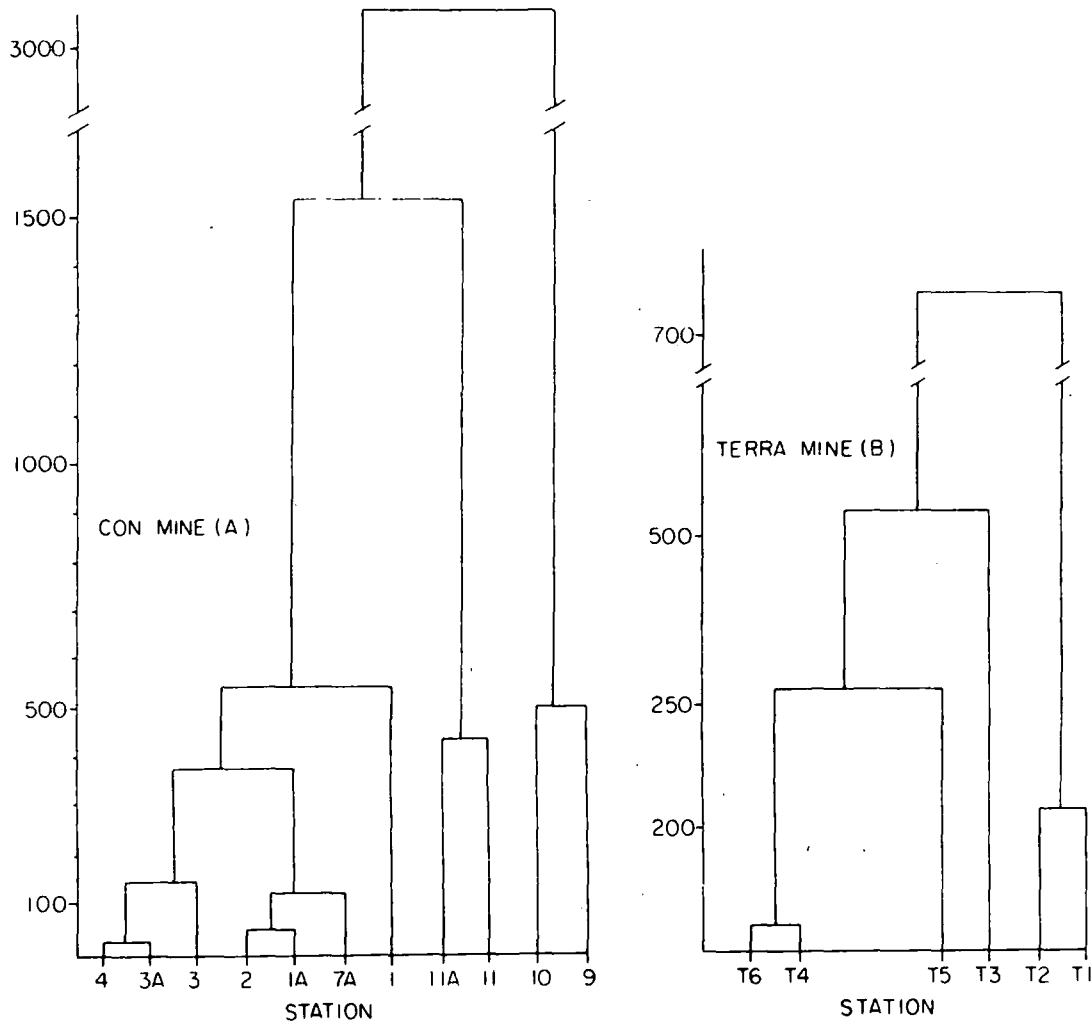Con Mine: The average composition of major taxonomic groups

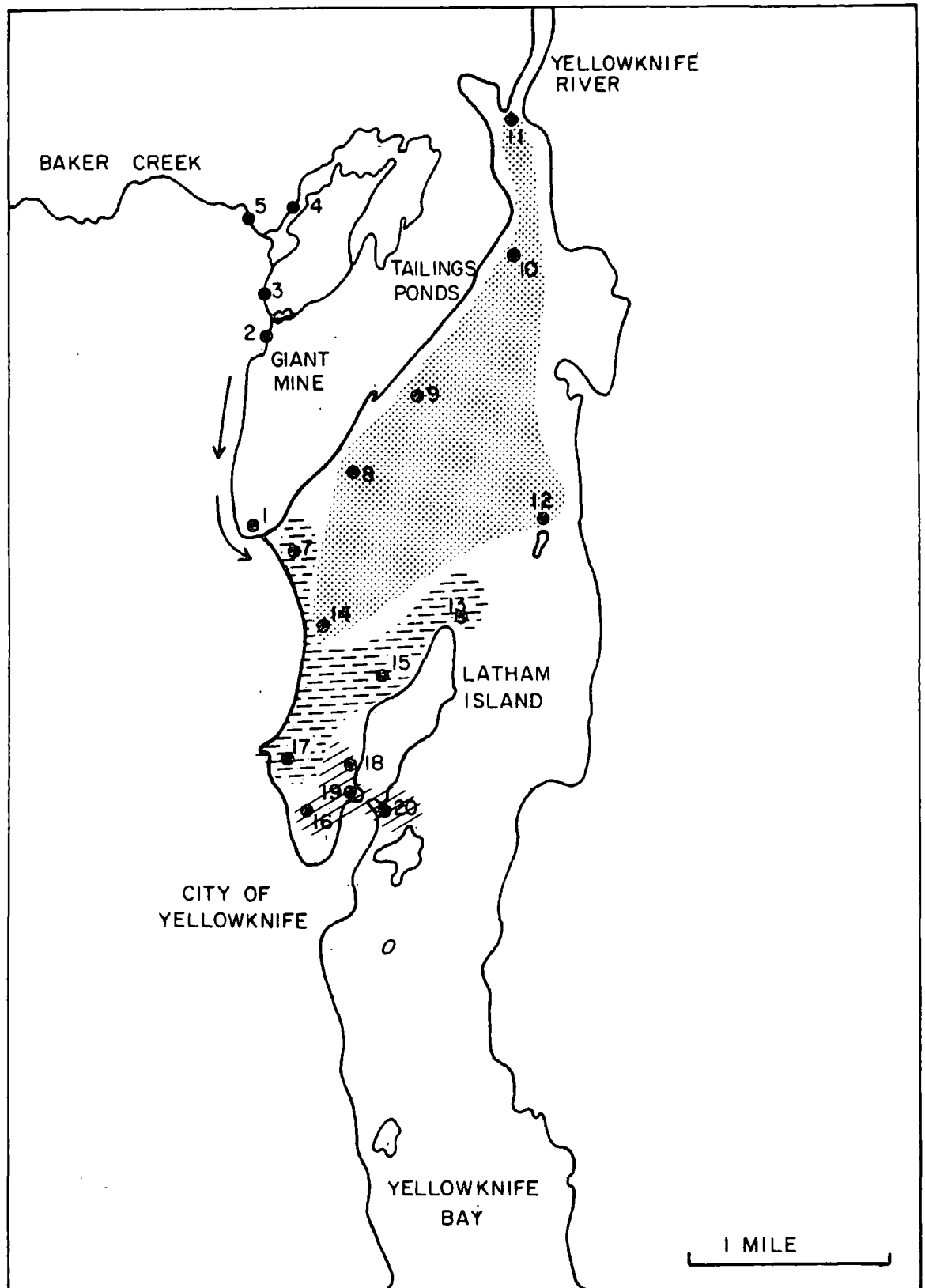Figure 21. Information dendograms illustrating the fusion of similar stations sampled during the Giant, Con and Terra Mine studies.

Figure 22. Map of the Giant Mine study area illustrating stations grouped together by information theory analyses.
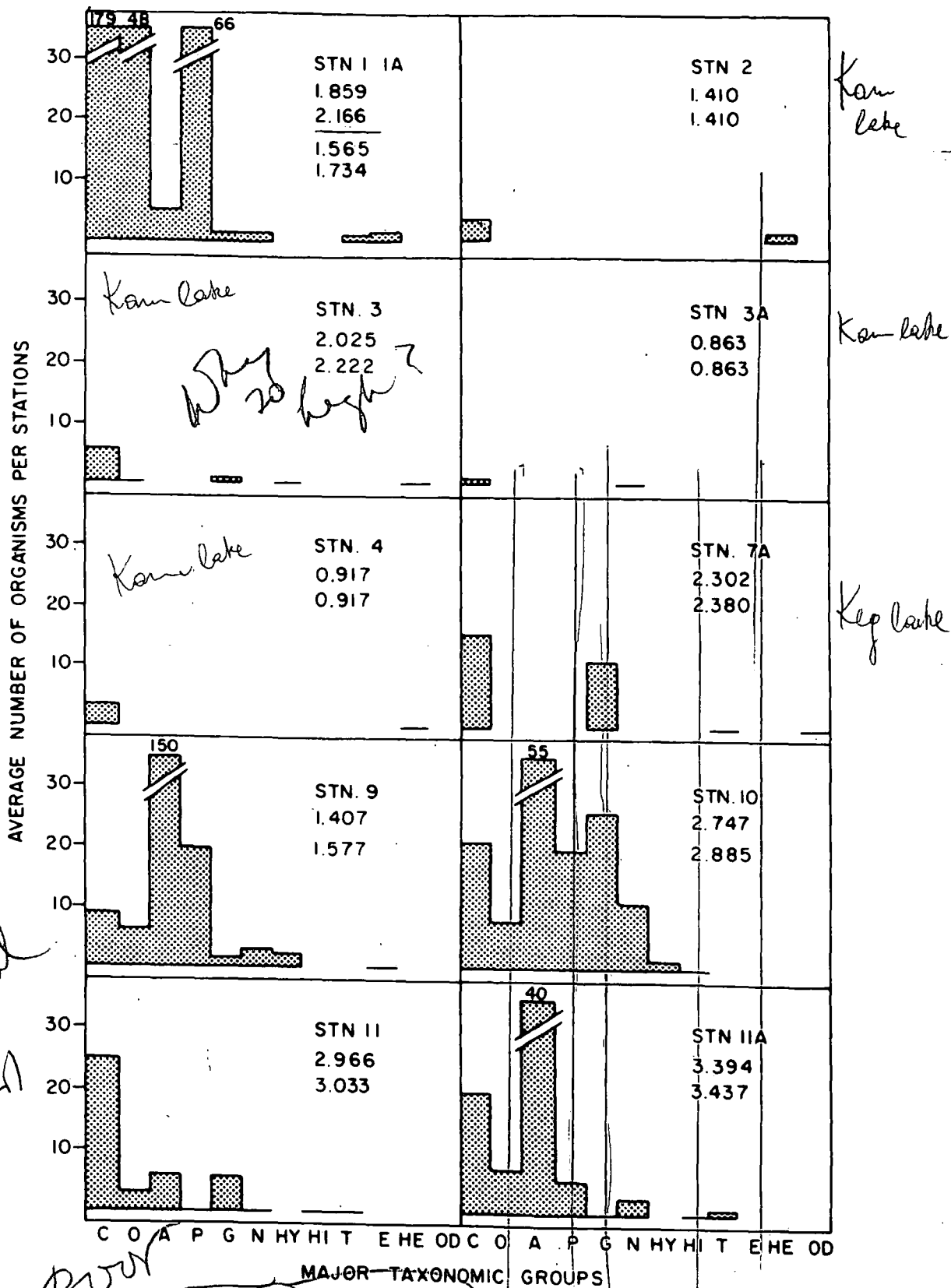
as well as the average composition of Chironomidae genera for Con
Mine stations are shown in figures 23 and 24 respectively. Station
5, in Pud Lake, lacked benthic organisms and was excluded from the
results and calculations. Stations in Kam Lake demonstrated an
extremely low number of genera which was expected, since both a
sewage outlet near station 4 and a groundwater outlet from Pud Lake
near station 3 empties into the lake. Pollution-tolerant Chirono-
midae predominated in this lake, suggesting a severe pollution
problem. Stations 7 and 7A in Keg Lake showed an increase in the
abundance of the groups present, but the fact that only two groups
prevailed in this lake indicates that drainage from Pud Lake has
adversely affected Keg Lake. Diversification increased with dis-
tance from the point of discharge. Stations 11 and 11A, in the
Sub Islands region, showed a marked increase in the number of groups
and the relative abundance of each group. These stations showed
similar diversification to stations 9 and 10 in Yellowknife Bay
and appeared unaffected by the effluent. As stated before, Ponto-
poreia is the dominant genus in Yellowknife Bay (Larkin 1948). Re-
sults of the present study supported this conclusion.

Station 1 on Grace Lake was considered a control station.
It contained a large number of organisms. Diversity at station
1A on Grace Lake was limited since the substrate contained 55 per
cent rock, 30 per cent coarse sand and 15 per cent fine sand. This
type of substrate composition cannot sustain a faunal population
in equilibrium. Qualitative observations on Con Mine study area
indicate that Pud, Kam and Key Lakes are severely hampered by the
effluent discharge. Stations in Yellowknife Bay appear unaffected
by Con Mine effluent while the control stations in Grace Lake, al-
though unstable, cannot be correlated to the mine effluent dis-
charge.

Quantitative analysis verified the qualitative observation.
The diversity index ranged from very low values (2) at stations
in Kam Lake to apparently unaffected areas (3) in Yellowknife
Bay (fig. 23). Keg Lake had an intermediate diversity value. The
fact that station 9 has a low diversity value again demonstrates
the inadequacy of diversity indices. This station contains an
abundance of Pontoporeia which is considered a common feature in
Yellowknife Bay (Rawson 1953). The diversity index could not dis-
tinguish this aspect since it based the value on the relative a-
bundance of all genera present (fig. 20).

Information-analysis, on the other hand, qualified this dis-
crepancy (fig. 21) by fusing stations 9 and 10; demonstrating that
both have similar community diversity structures. The final fusion
with station 11A, which according to diversity index is unpolluted,
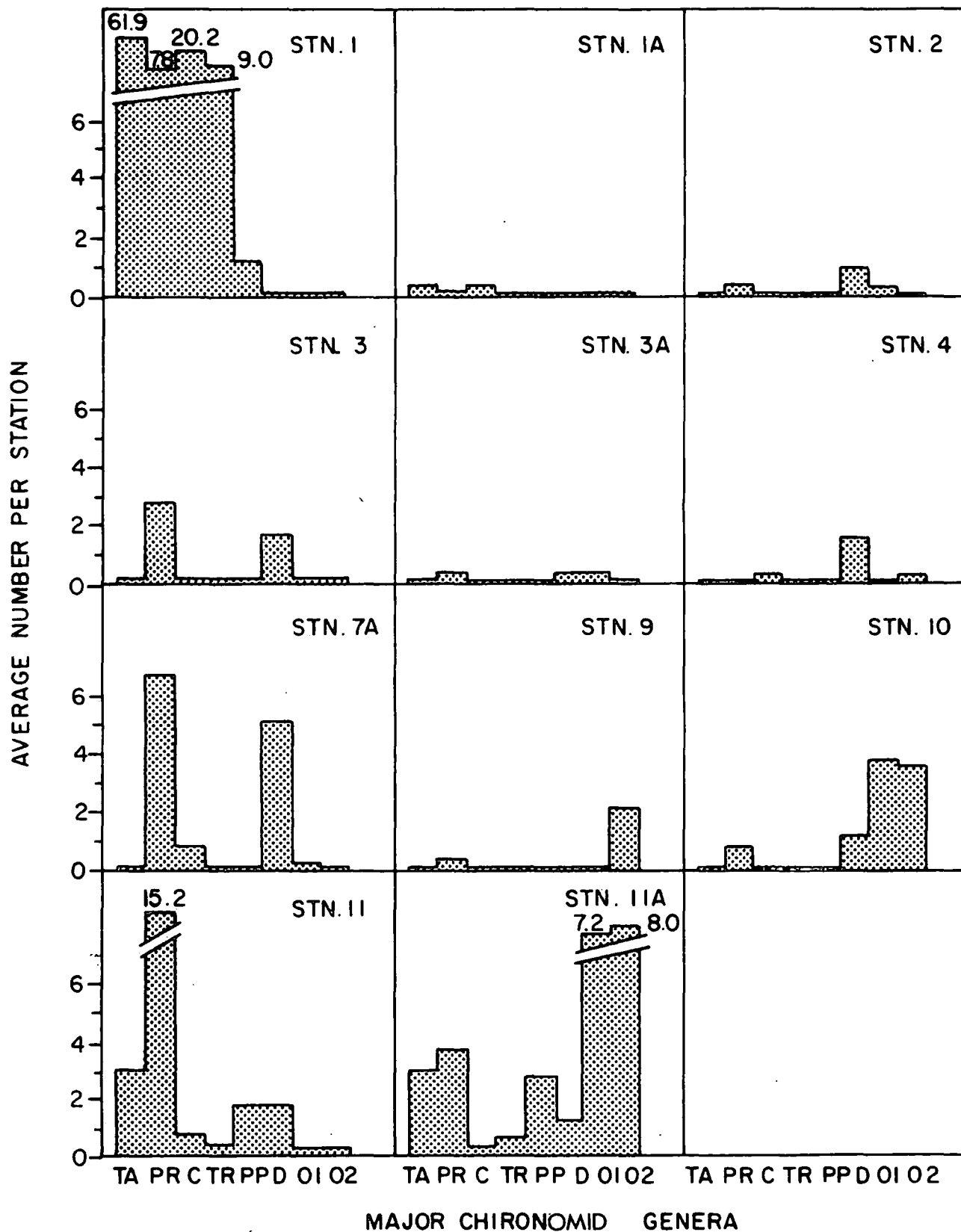suggests that these stations (9 and 10) are relatively clean water-

Figure 23. Average composition by major taxonomic groups of
benthic organisms for each Con Mine station
(C=Chironomidae; O=Oligochaeta; A=Amphipoda;
P=Pelecypoda; G=Gastropoda; N=Nematoda; HY=
Hydracarina; HI=Hirudinea; T=Trichoptera; E=
Ephemeroptera; HE=Hemiptera; OD=Odonata).

Figure 24. Average composition by major Chironomidae genera
for each Con Mine station (C=Chironomus; PR=
Procladius; D=Dicrotendipes; TA=Tanytarsus; TR=
Trekilos; PP=Polypedilum; O1=Orthocladinae #1;
O2=Orthocladinae #2).

bodies. The information-analysis dendogram showed a distinct separation into three areas at the 900 level: 1) stations located in Kam Lake, Grace Lake and Keg Lake which were considered extremely polluted by the diversity index; 2) stations 11 and 11A, in the Sub Island region, considered unpolluted by the diversity index and 3) stations along the west shore of Yellowknife Bay. Figure 25 represents these separations schematically.

Both qualitative and quantitative results from the Con Mine study substantiate each other and indicate that Pud Lake, connected to Kam and Keg Lakes, adversely affects these areas. Grace Lake, although quantitatively fused with the latter lakes, cannot be affected by the effluent because the water movement is towards Kam Lake. Other stations sampled in Yellowknife Bay contain a great number of genera, and being relatively equal in number, are not considered to be adversely affected by the Con Mine operation.

Echo Bay: Great Bear Lake has been described as a biological desert, particularly in the eastern region, with productive areas limited to shallow bays and shorelines (Miller 1947). The lake sediments are unsuitable for benthic organisms. This, coupled with the limited growing season, low water temperature, and poor nutrient supply, results in a reduced benthic population. Despite both grab and grid sampling at stations located at some distance from the effluent discharges, few taxonomic groups and individual genera were found. Each station sustained only a few groups of organisms in either negligible or overabundant numbers (figs. 26 and 27). As a result quantitative analyses were not performed.

Some degree of assortment did occur in LaBine Bay at stations 10 and 14. Unfortunately, diversification was not varied enough to be considered in equilibrium. Station 5A in the vicinity of the mill effluent outfall contained no benthic organisms, suggesting that pollution could be the cause. The fact that the substrate was composed of fine sand, producing an unstable environment, refuted this assumption. Station 5F, a shore grid site, contained a large number of Trichoptera. Since these organisms are pollution-sensitive, effluent discharge in this area cannot be considered adverse to benthic organisms. Evidently, dilution of the toxic materials and suspended solids is sufficient to permit these organisms to survive. Other stations revealed that Chironomidae (Diamesa sp, Orthocladinae) and Oligochaeta (Rsodalis, Enchytraedae) predominated over any other organisms present. Both are termed pollution-tolerant organisms. They are also considered tolerant to the barren substrates characteristic of the regions sampled.
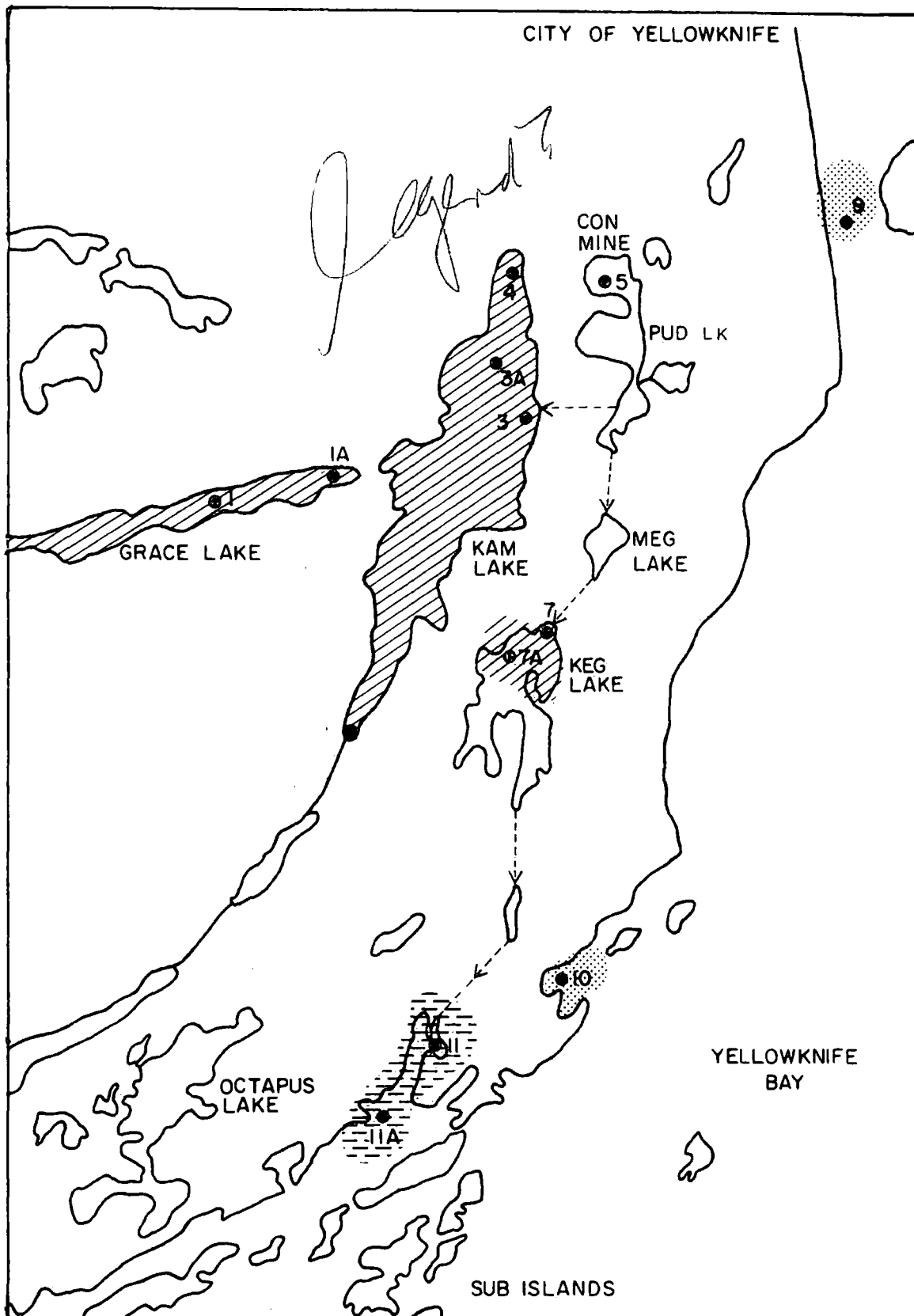
Figure 25. Map of the Con Mine study area illustrating stations
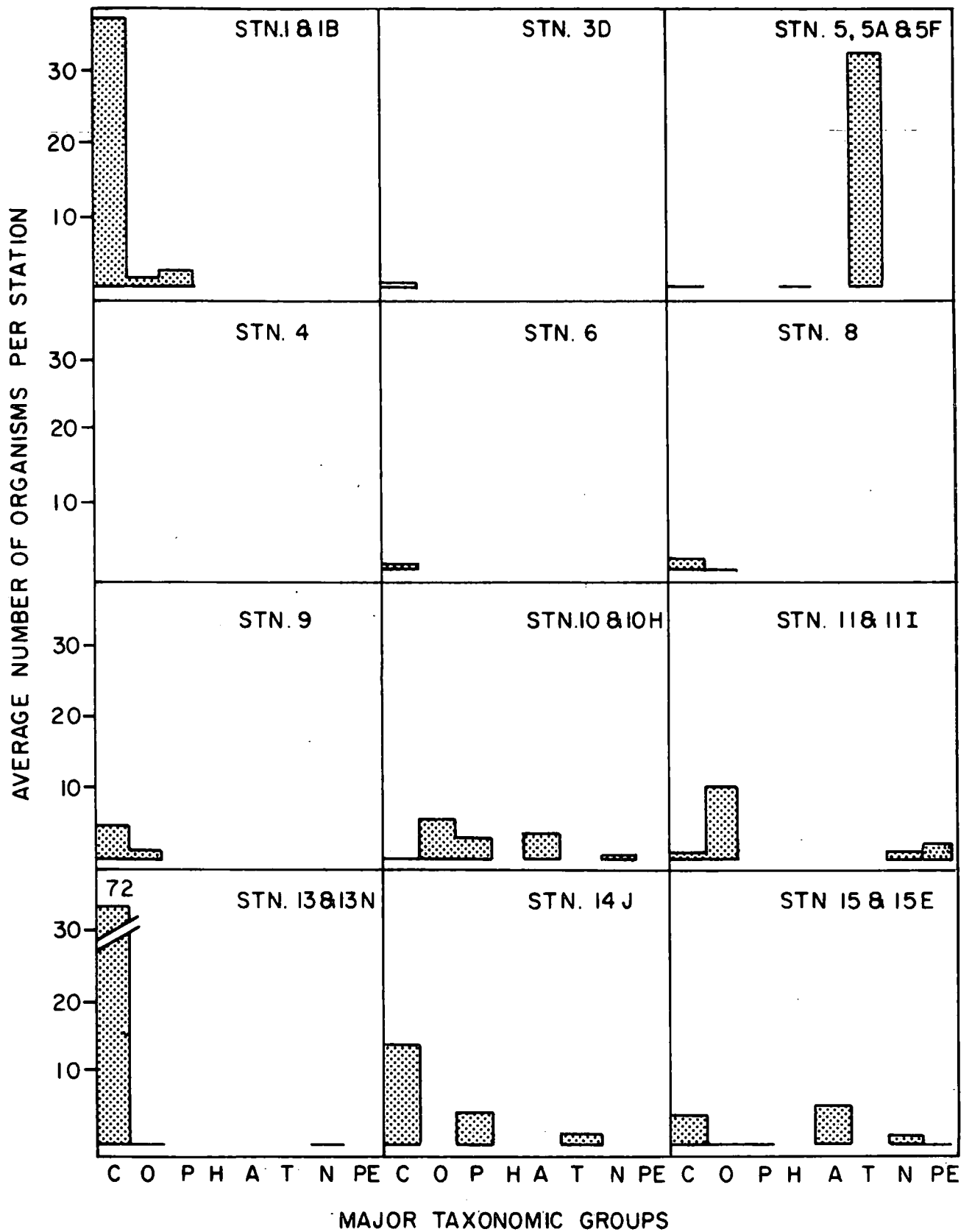grouped together by information theory analyses.

Figure 26. Average composition by major taxonomic group of benthic organisms for each Echo Bay Mine station (C=Chironomidae; O=Oligochaeta; P=Pelecypoda; H=Hydracarina; A=Amphipoda; N=Nematoda; PE= Plecoptera; T=Trichoptera).
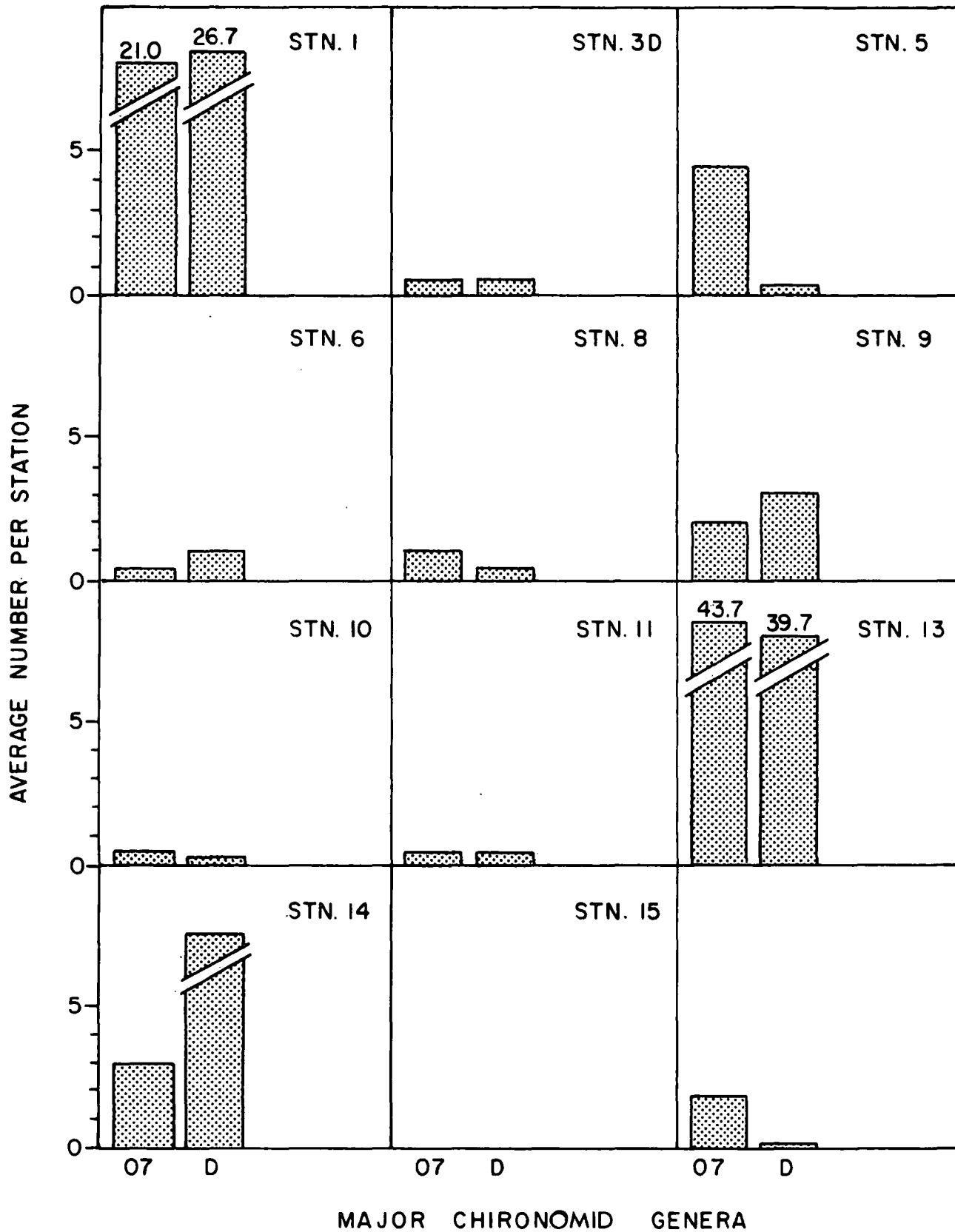
Figure 27. Average composition by major Chironomidae genera
for each Echo Bay Mine station (07=Orthocladinae
#7; D=Diamesa).

In general, qualitative analysis indicated that benthos diversification in the vicinity of the Echo Bay Mine was low. This may be attributed to the harsh environmental conditions of Great Bear Lake more more than to the effects of the mill effluent.

Terra Mine: Major components of the benthic community for Terra Mine stations are illustrated in figures 28 and 29. It is evident and expected that station 4, in Ho-Hum Lake (fig. 28) is the most severely affected with only three individuals being found. Station 5, located near the lake outlet, was also affected with moderately tolerant Pelecypoda predominating. Other major groups for station 5 were pollution-tolerant Chironomidae and Oligochaeta. Stations sampled in the Camsell River appeared to be in equilibrium. With the presence of pollution-sensitive Ephemeroptera at station 3 the lake may be considered unaffected. Basically, quantitative analysis indicated that Ho-Hum Lake was severely polluted while the lake above Ho-Hum Lake and stations along the Camsell River were not.

Diversity indices performed on the data resulted in values less than 2 for stations in Ho-Hum Lake and values of 3 or more for stations 1 and 6 in the Camsell River. Station 2 appeared to be moderately polluted (fig. 28). This could be due to the fact that a low muskeg region is located between stations 5 and 2. Since water was observed to move from Ho-Hum Lake through the muskeg to the Camsell River it may be assumed that seepage is concentrated in the area of station 5. Station 3 had the highest diversity value (3.52) and is a good example of benthic stability.

The information-analysis dendogram (fig. 21) did not support diversity indices in all instances. For example, station 4 with two groups was fused to station 6 which contained 21 groups. These two stations were merged since the theory of information-analysis deals with percentages rather than densities. On this basis, the percentage of Procladius and Orthocladinae #6 at station 4 were comparable to the percentage of these organisms at station 6. Also, the relatively low numbers of other groups present at station 6 were proportionately negligible to the total. This makes them comparable to the zero values at station 4. A better method of analyzing the matrix data for Terra Mine may have been to omit station 4 since it is qualitatively obvious that the area is polluted and concentrate on fusing other stations. The discrepancy in the information-analysis lies in the fact that the number of stations and samples were limited.

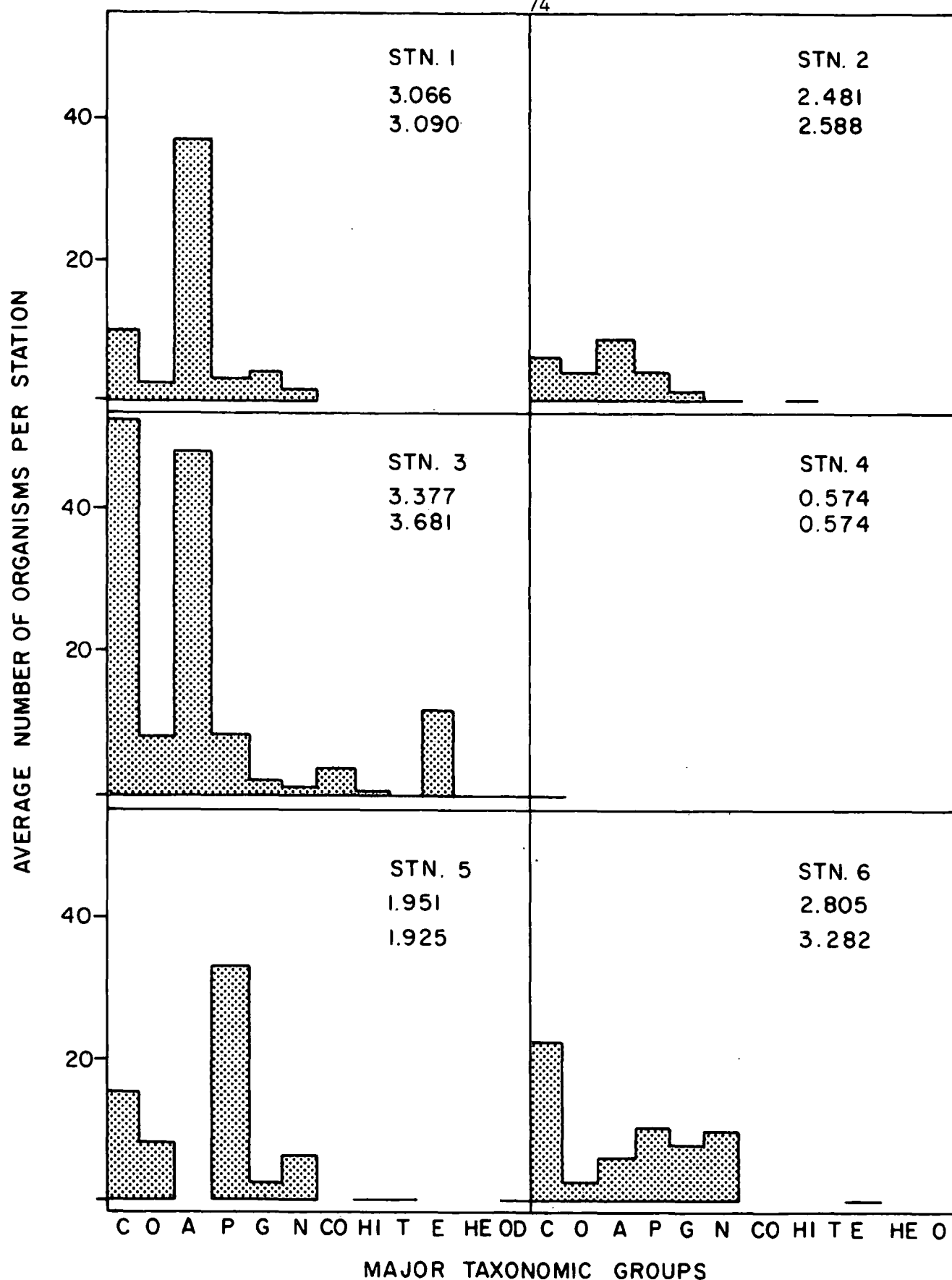At the 300 level the dendogram separated the study area into three distinct zones (fig. 30). Omitting station 4, the

Figure 2.8. Average composition by major taxonomic groups of
benthic organisms for each Terra Mine station
(C=Chironomidae; O=Oligochaeta; A=Amphipoda; P=
Pelecypoda; G=Gastropoda; N=Nematoda; CO=Coleoptera;
HI=Hirundinea; T=Trichoptera; E=Ephemeroptera; HE=
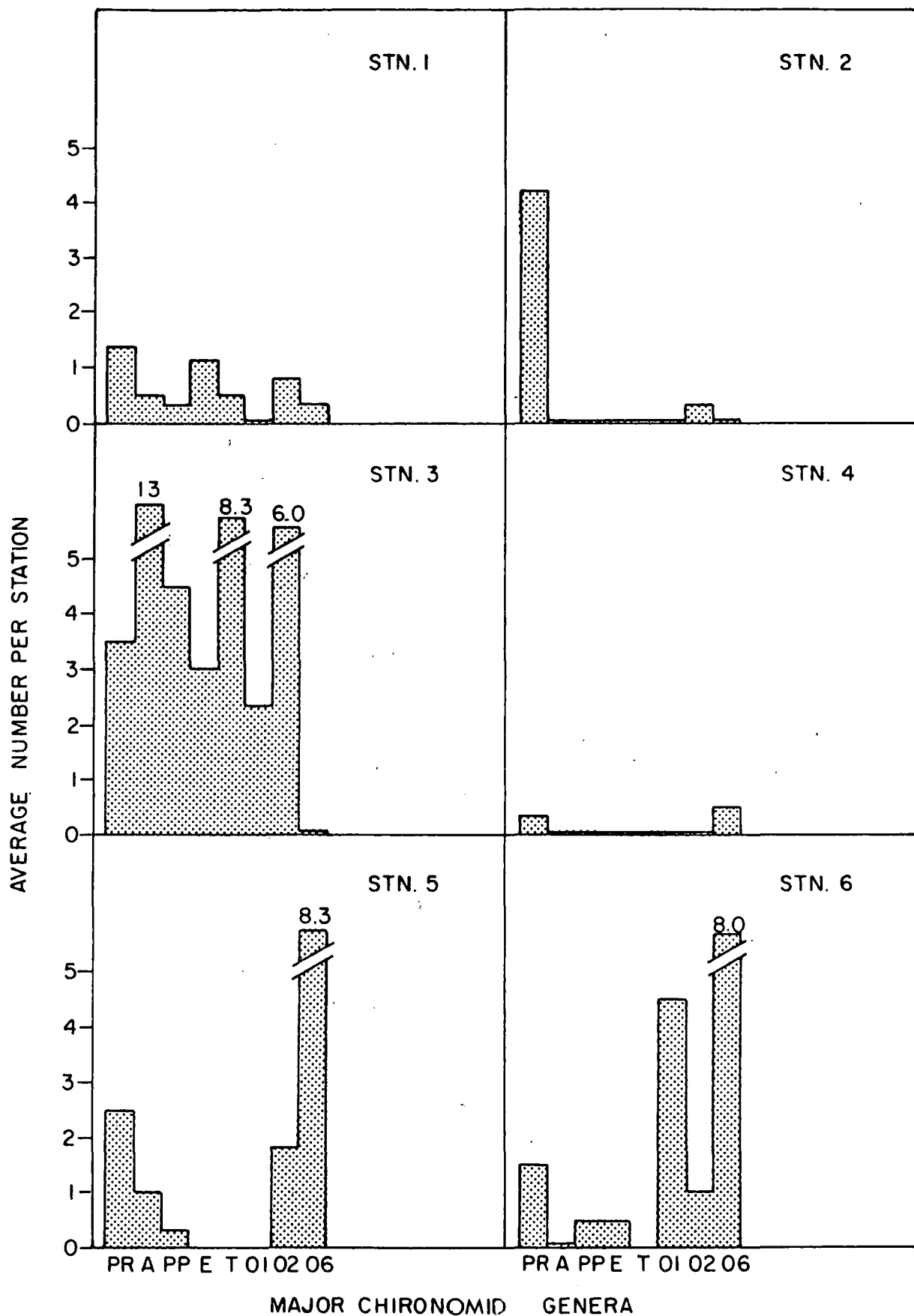Hemiptera; OD=Odonata).

Figure 29. Average composition by major Chironomidae genera
for each Terra Mine station (PR=Procladius; A=
Aklaklesmia; PP=Polypedium; E=Endocheronomies;
T=Trikelos; 01, 02, 06=Orthocladinae #'s 1, 2 and
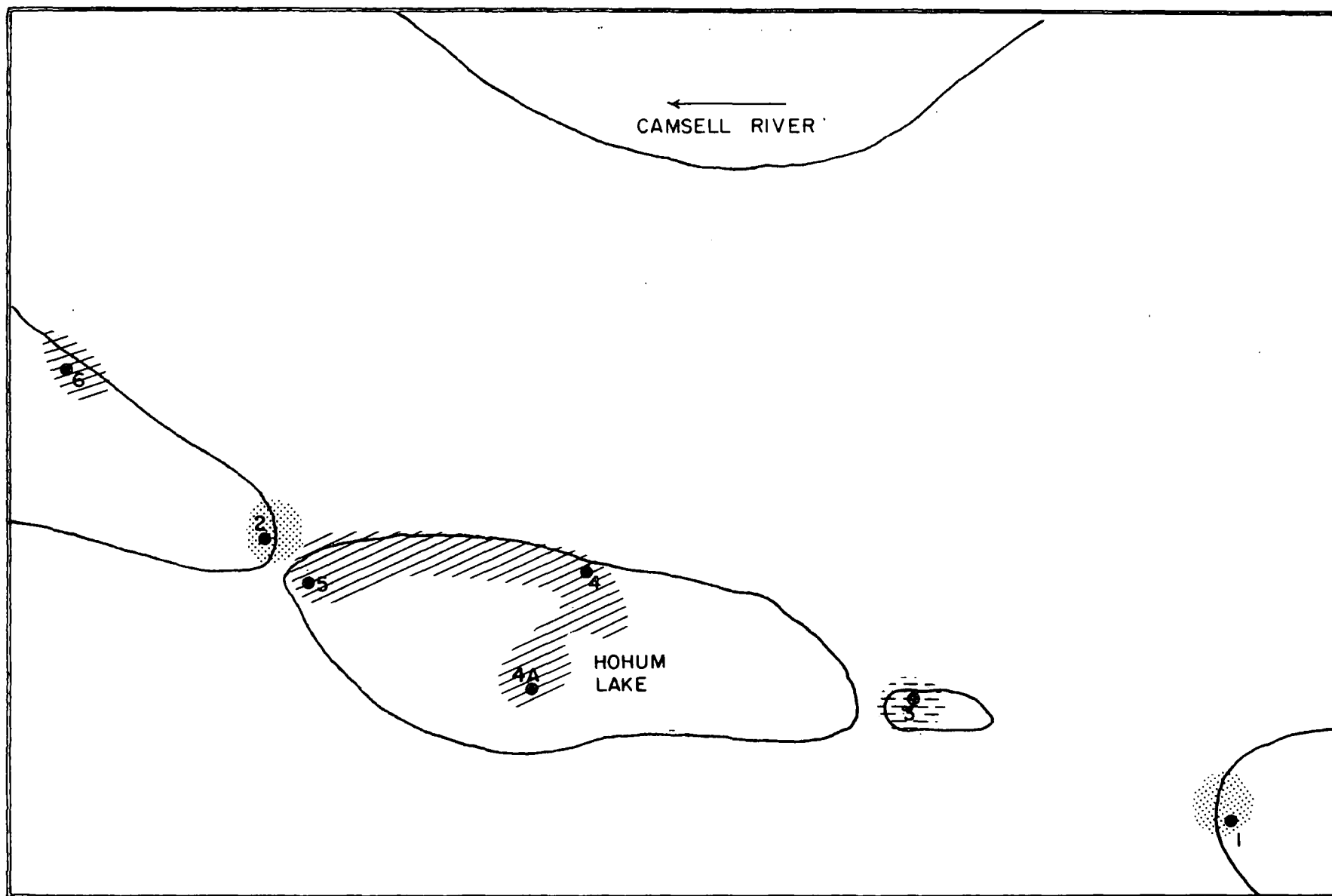6).

CAMSELL RIVER

HOHUM
LAKE

Figure 30. Map of Terra Mine study area illustrating stations
grouped together by information theory analysis.

areas of similar structure were: 1) stations 5 and 6 located on
Ho-Hum Lake and Camsell River, respectively; 2) control station 3
and 3) stations 1 and 2 along the Camsell River. Figure 30 dis-
plays these separations schematically. A dichotomy exists between
the results of the quantitative analysis. Whereas the diversity
index indicated station 5 as being polluted and station 6 as un-
polluted, information-analysis fused the two. Perhaps the over-
abundance of Pelecypoda at station 5 accorded that station a low
diversity value while actually the proportion of Pelecypoda was
comparable to that of station 6.

It is evident through both qualitative and quantitative
investigation that Ho-Hum Lake has been severely polluted through
the discharge of mill effluent. Stations along the Camsell River,
however, are not affected since significant differences do not ex-
ist between stations 1 above and 2 below Ho-Hum Lake.

SUMMARY

GIANT MINE

1. This is a gold mining and milling operation located approximately two miles north of Yellowknife Northwest Territories. It has been in production since 1948.

2. Mill effluent is discharged into a series of three tailings ponds. The decanted water passes into Baker Creek which flows into Yellowknife Bay. Additional liquid wastes include minewater and thickener overflow which are released into Baker Creek.

3. Sampling and experiments were carried out in the Giant Mine study area from May 23 to June 30, July 17 to August 11 and September 5 to 22, 1972.

4. Analyses of the Giant Mine wastes from the mouth of Baker Creek revealed high levels of arsenic (2.9 - 12.6 ppm), copper (0.73 - 9.9 ppm), and zinc (0.034 - 1.9 ppm) entering Yellowknife Bay. These levels were found to vary with respect to time of year.

5. Giant Mine wastes, entering Yellowknife Bay, were found to be acutely toxic to fish. At the mouth of Baker Creek 96 hour LC50's were 9.3 - 17.8, 24 and 22.5 percent by volume, respectively for sticklebacks, suckers and rainbow trout. At the discharge point from the tailings ponds LC50's were 14.8 for sticklebacks and 6.2 percent for trout. Minewater LC50's were 88 and 75 percent for sticklebacks and trout, respectively. Arsenic, copper and possibly cyanide are believed to be the lethal agents.

6. Fish sampled in Yellowknife Bay close to the mouth of Baker Creek possessed higher levels of arsenic, copper and cadmium than those from other areas of Great Slave Lake. Variability, however, was great and questionable significance was attached to the results.

7. Sediments in a large region of Yellowknife Bay off Baker Creek contained arsenic, copper, lead, zinc, cadmium and nickel levels well in excess of background.

8. Baker Creek, from the tailings outlet to past the mouth, was considered severely polluted since a benthic fauna was absent. A large segment of Yellowknife Bay was deemed to be

moderately polluted as shown by indices of benthic diversity.
Information theory analyses supported this and gave suppor-
tive evidence that a current in Yellowknife Bay greatly affects
the dispersion of Giant Mine wastes emanating from Baker
Creek.

CON MINE

1. This is a gold mining and milling operation located approx-
mately one mile south of Yellowknife. It has been in pro-
duction since 1938.

2. Mill effluent and minewater are discharged into Pud Lake.
Decanted water flows west towards Kam Lake and south through
a series of ditches and lakes to Yellowknife Bay.

3. Sampling and experiments were carried out in the Con Mine
study area from May 23 to June 30, July 17 to August 11 and
September 5 to 22, 1972.

4. Analysis of the Con Mine wastes along the effluent routes
revealed high levels of arsenic, copper and chloride. How-
ever, concentrations of these and other parameters measured
were within acceptable levels upon entering Yellowknife Bay.

5. In contrast to the Giant Mine those wastes emanating from
the Con Mine tailings pond were not acutely toxic.

6. Fish sampled in Kam Lake possessed higher levels of ar-
senic, copper, zinc, lead, cadmium and nickel than those of
the same species sampled from control areas. Variability
among samples was large.

7. Sediments collected from lakes affected by the Con Mine
wastes contained levels of arsenic, copper, lead, zinc, copper,
cadmium and nickel above those considered to be background.

8. Both qualitative and quantitative analyses of benthic
organisms in the lakes affected by the Con Mine wastes re-
vealed that the lakes were highly polluted. Yellowknife Bay
in the region of the final mine waste outlet was not severely
affected.

ECHO BAY MINE

1. This is a silver-copper mining and milling operation loc-
ated at Port Radium on Great Bear Lake. It was the original
site of an uranium oxide mine until 1964 when the present op-
eration commenced.

2. Mill effluent and minewater is discharged directly into
Great Bear Lake without prior containment or treatment.

3. Sampling and experiments were carried out in the Echo Bay
Mine study area from July 1 to 16 and August 11 to September
4, 1972.

4. Analysis of the Echo Bay Mine wastes revealed high levels
of arsenic (0.8 - 4.4 ppm) and turbidity (5,000 - 8,840 JTU)
entering Great Bear Lake. These parameters together with
others determined were within acceptable levels in the re-
ceiving water.

5. The Echo Bay mill effluent was found to be moderately
acutely toxic with LT50's ranging from 24 to greater than 96
hours.

6. Fish collected off the Echo Bay mining operation during
1971 and 1972 possessed higher levels of arsenic, copper,
lead, zinc and cadmium than those from control areas.

7. Sediments collected in the vicinity of the Echo Bay Mine
contained extremely high concentrations of uranium, cobalt,
arsenic, lead, zinc, copper, cadmium and nickel as compared to
those considered to be natural in origin.

8. Great Bear Lake in the immediate vicinity of the effluent
discharge was found to support a limited benthic fauna. Sam-
pling failed to supply organisms in sufficient quantities to
draw valid conclusions. High turbidity, metal levels and un-
stable substrate conditions caused by the mill effluent are
believed to constitute an unfavourable environment for habi-
tation.

TERRA MINE

1. This is a silver-copper mining and milling operation loc-
ated near the mouth of the Camsell River on Great Bear Lake.
It has operated intermittently since 1969.

2. Mill effluent and minewater are discharged into Ho-Hum Lake which has been set aside as a tailings pond. Decanted liquid passes through a muskeg region into the Camsell River.

3. Sampling and experiments were carried out in the Terra Mine study area from July 1 to 16 and August 11 to September 4, 1972.

4. Analysis of water from Ho-Hum Lake revealed high levels of arsenic (4.2 ppm) with other parameters not greatly exceeding background. Water quality parameters determined above and below the outlet of Ho-Hum Lake were not significantly different.

5. The Terra mill effluent was found to be moderately toxic with LT50's ranging from 24 to greater than 96 hours. With the presence of northern pike and whitefish in Ho-Hum Lake the possibility of an acutely toxic waste entering the Camsell River does not exist.

6. Fish collected in Ho-Hum Lake possessed higher levels of arsenic, copper, lead, cadmium and nickel than did those from the Camsell River.

7. Sediments in Ho-Hum Lake contained high levels of arsenic, copper, nickel, lead and zinc. Levels of these metals, above and below the lake outlet were not significantly different.

8. Despite a limited benthic community in Ho-Hum Lake, regions of the Camsell River appeared unaffected by the mine wastes. Stations located above and below the lake outlet were viewed as qualitatively and quantitatively similar.

RECOMMENDATIONS

1. It is strongly recommended that immediate steps be taken to prevent the continued discharge of deleterious wastes by the Giant Mine into Yellowknife Bay. Control measures which may be necessary to ensure this are enlargement of the tailings ponds to permit settling during the winter months and treatment of the tailings ponds to bind or precipitate the toxicants. If arsenic, copper and cyanide were reduced to acceptable levels it is believed that the toxicity of these wastes would be reduced. It is further recommended that alterations be made to the existing tailings dykes to prevent direct seepage into Yellowknife Bay.

2. It is recommended that control measures be undertaken to ensure that the degree of pollution and area affected by the Con Mine wastes does not increase. The ability of Kam Lake to act efficiently as both a receiver of mine wastes and a sewage lagoon is questionable.

3. A monitoring program should be established to determine levels of arsenic present in fish tissues adjacent to Yellowknife on a continuing basis. This will ensure that the consumption of arsenic contaminated fish does not occur in the future. The Inspection Branch, Fisheries and Marine Service should perhaps carry out this program.

4. Due to the discharge of wastes acutely toxic to fish it is urgently recommended that the Echo Bay mill effluent discharge into Great Bear Lake cease immediately. An alternative to the present practice may be to pump the effluent to a small lake (Garbage Lake) located near the mining operation. In any event, containment and possibly treatment of the mine wastes are strongly urged.

5. Despite an apparent absence of deleterious effects on the Camsell River from the Terra mining operation there exists a possibility that prolonged drainage from Ho-Hum Lake may have a significant effect in the future. This may arise from continued discharge into Ho-Hum Lake or an increase in production. In this regard an effective dyke separating Ho-Hum Lake from the Camsell River is recommended.

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