The Use of a Biomonitoring System in Acquiring Baseline Water Quality Data for a Metal Mining Operation in Northeastern New Brunswick

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Abstract:

A study was undertaken, during the summer of 1988, to determine the usefulness of a simple, cost-effective biomonitoring system for acquiring baseline water quality data for a reopening base metal mine, *Margaritifera margaritifera* (Pelecypoda: Margaritiferidae), *Elliiptio complanata* (Pelecypoda: Unionidae) and *Nephelopsis obscura* (Hirudinea: Erpobdellidae) were transported and deployed in a northeastern New Brunswick brook receiving metal laden run-off from mining wastes for exposure periods from between 5 to 70 days at several locations downstream of the mine site. All three species accumulated copper and zinc to levels in excess of that detected in ambient water samples *Margaritifera margaritifera* was the most effective integrator of copper and zinc, but was less tolerant of elevated ambient concentrations of trace metals. At stations influenced by the mine site, tissue concentrations of zinc were significantly higher than at control locations. Several interesting interstation trends were observed that may be related to changes in the speciation and bioavailability of copper and zinc. Coincident mortality and rapid uptake of trace metals emphasizes the need to further explore the relationship between the rate of uptake of trace metals and toxicity.

In addition to the application of freshwater molluscs and leeches as biomonitoring agents, epilithic algal samples collected at three locations downstream of the mine site revealed high levels of copper and zinc. Caged fingerling brook trout (*Salvel inus fontinalis*) were also deployed and observed over a 10-day period to delineate a zone of acute toxicity.

Introduction :

Baseline data and environmental monitoring are essential components of environmental impact assessment (EIA). While baseline data provides information on specific environmental parameters prior to the development phase of a project, monitoring attempts to identify and quantify project impacts (States et al., 1978).

Since baseline information provides a benchmark against; which project impacts can be measured, it is imperative that the methodologies employed in baseline studies and project monitoring be consistent and their results amenable to compar ison. Beanlands (1988) identifies a lack of focus and inadequately defined objectives as common problems plaguing baseline studies. as applied to ETA. Beanlands and Duinker (1983) further draw attention to the fact that impact significance is seldom quantitatively defined in EIA. insufficient or inadequate baseline information only serves to exacerbate this Latter problem. Clearly, there is a need to simplify and streamline baseline studies and ensure their relevance and applicability to subsequent monitoring efforts,

The current study was undertaken to explore the usefulness of a biomonitoring program in acquiring baseline water quality data for the receiving waters of a reopening base metal mining and milling operation in northeastern New Brunswick . Because levels of copper and zinc in Forty Mile **Brook** exceed background concentrations, it is essential that base li ne condit io ns be established such that the effects on ambient water quality of renewed mining activities and associated water quality reclamation plans can be quantitatively assessed. The freshwater bivalves, Margaritifera margaritifera (Margaritiferidae) (Linnaeus, 1758) and Elliptio complanata (Unionidae) (Lightfoot, 1786), and the leech Nephelopsis obscura (Erpobdellidae) Verrill, 1872, were employed as biomonitoring tools.

The potential value of aquatic organisms in attenuating fluctuations in ambient levels of contaminants through their integration in biological tissues over time is well documented in the literature (Phillips, 1980; Cairns, 1984; Metcalfe et al., 1984; Bradley and Sprague, 1985; Goldberg, 1986; Mouvet et al., 1986; Phillips, 1986; Memmert, 1987; Vymazal, 1987; Lynch and Popp, 1988; de Lurdes et al., 1989). Because of their size, sedentary nature, and relative tolerance to a wide range of contaminants, bivalves have been used extensively as "bioaccumulators". A very large literature exists documenting the use of marine bivalves, particularly the blue mussel (Mytilus edulis) and oysters (Crassotrea sp.) in monitoring conservative marine pollutants. In freshwater systems, however, the application of bivalves as biomonitoring tools is more recent and less extensive. Much of the literature focuses on the ability of freshwater pelecypods, principally Elliptio complanata, to bioaccumulate trace organic contaminants that may not consistently appear at detectable levels in ambient water samples (Curry, 1978; Heit et al., 1980; Kauss and Hamdy, 1985; Rice and

White, 1986; Metcalfe and Chariton, 1989). The uptake of metals by freshwater bivalves has also been reported in the literature (Foster and Bates, 1978; *Jones* and Walker, 1979; Graney **et** al., 1983; Graney et al., 1984; Zadory, 1984; Bias and Karbe, 1985; Green and Hinch', 1986; Hemelraad et al. , 1987; Hinch and Stephenson, 1987), but few references exist documenting the use of freshwater bivalves in monitoring changes in the bioavailability of metals resulting from mining activities (Tessier et al., 1984; Czarnezki, 1987).

Direct proportionality between ambient environmental concentrations and tissue burdens should not be assumed . In addition to the influence of physico-chemical variables on uptake kinetics, the partitioning of contaminants between environmental compartments may also exert a significant influence on bioaccumulation. Tessier et al. (1984) report that ingestion of sediments and suspended particulate material may provide an important route of trace metal uptake by filter-feeding freshwater pelecypods. Predatory leeches (Hirudinea), on the other hand , represent another trophic level and are presumed to accumulate metals from different environmental compartments. The use of leeches as freshwater biomonitors has only recently been reported in the literature (Metcalfe et al., 1984; Hall and Jacob, 1987; Metcalfe et al., 1987) however no reference to the uptake of trace metals by leeches could be found.

Site Description:

The site of the **current** study is Forty Mile Brook located in the base metal mining district of northeastern New Brunswick (Fig. 2). Forty Mile Brook flows in a southerly direction some 55 km from its source, 50 km west of Bathurst, to its confluence with the Nepisiguit, a major Atlantic salmon (Salmo salar) and brook trout (Salvelinus font-) river system. Where it meets the Nepisiguit, Forty Mile Brook can be classified as a fourth order stream. Available hydrological data report a second order mean annual discharge of 0.289 m^3/s (Canada. Inland Waters Directorate, 1987). Stream depth seldom exceeds 1.5 m and, at its mouth, the brook is approximately 10 m in width. Except for several small ponded areas near the mid reaches of the brook, stream velocity is moderate and swift in some stretches. The water is only very slightly coloured (humic acid < 10), moderately soft (hardness < 50 mg/L) and possesses a low alkalinity (total alkalinity < 30 mg/L) with a circumneutral pH (Canada, Environmental Protection Service, 1974; Canada. Inland waters Directorate, 1989). Since the final effluent from tailings ponds is limed, receiving water hardness, directly below the mine site, tends to be significantly higher than further downstream.

The study area is quite remote and accessible only by secondary resource roads. Although extensive clear cuts abound in the general vicinity of the brook, its shorelines have not recently been disturbed by logging practices. The only direct human impacts on the brook are a result of past mining activities located near the headwaters.

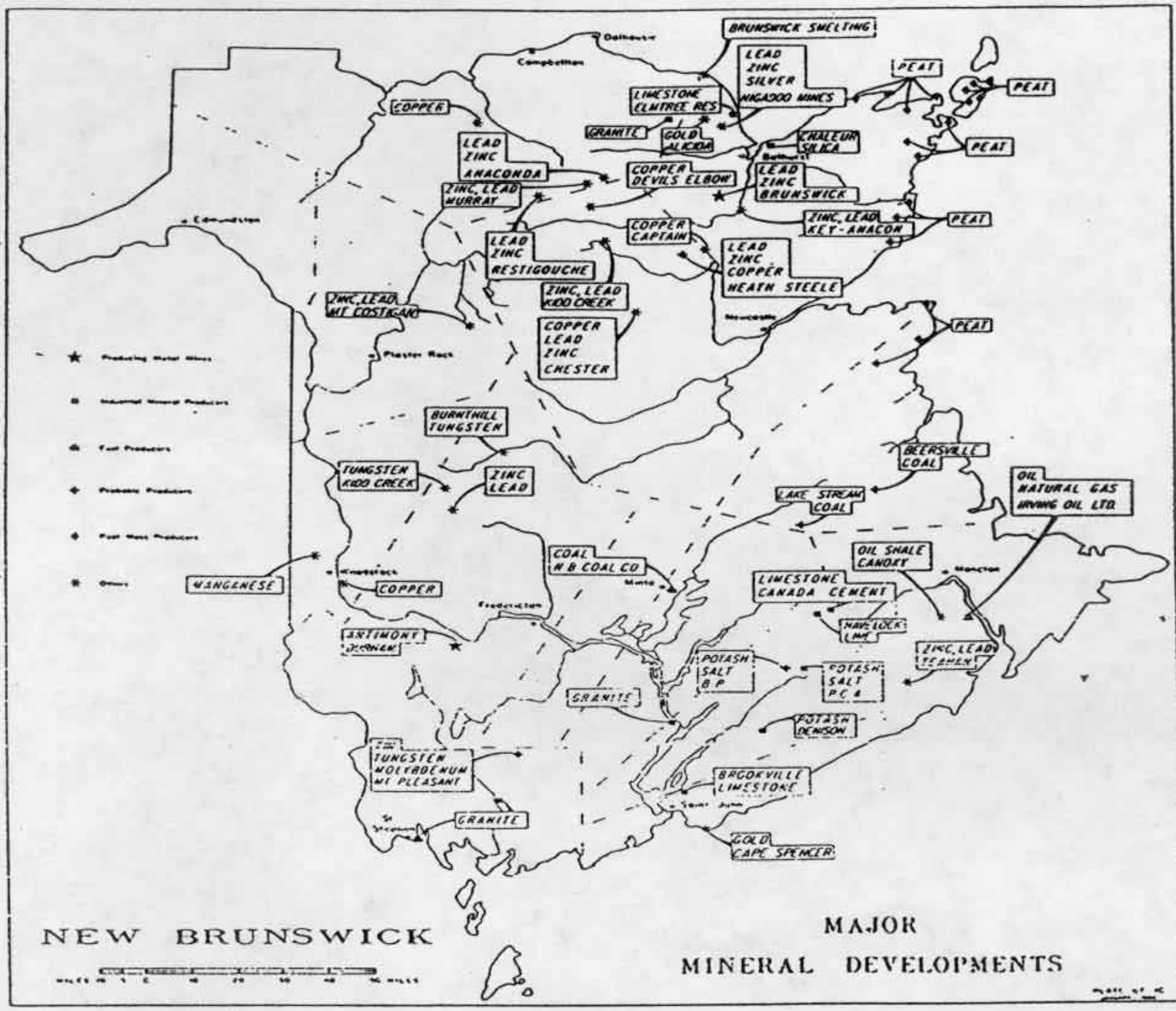
The mining of pyritic ores rich in lead, zinc, copper and silver has been a major industrial activity in northeastern New Brunswick since the early 1950's. Figures 1 and 2 illustrate the extent of mining operations and mineral deposits in this region. The area also supports a significant recreational salmonid fishery (New Brunswick. Department of Natural Resources,1987).

As a result of acid mine drainage, leaching from tailings and waste rock, thiosalt generation from milling process effluents, and the fine grained ores and associated low water recycling capabilities, certain local watercourses have been stressed by acidification, siltation and metal_ loadings (Montreal Engineering, 1973; Pollock et al., 1977; Hildebrand, 1984).

Anaconda--Caribou Mines, located at the headwaters of Forty Mile Brook, extracted copper rich ores from open pit mines between November, 1970 and November. 1971 and from September, 1973 to September , 1974 . During the summers of 1982 and 1983 some 60,000 tonnes of gossen material was heap leached to recover gold. Since that time, Anaconda-Caribou has remained inoperative, yet leaching from waste rock piles and tailings ponds has posed a serious threat to the environmental quality of Forty Mile Brook.

Resources Exploration of Australia purchased all the rights to the site from Anaconda Copper Limited in 1986, following the completion of a series of economic, technical and environmental

Figure 1:



Source: NRNB, 1987

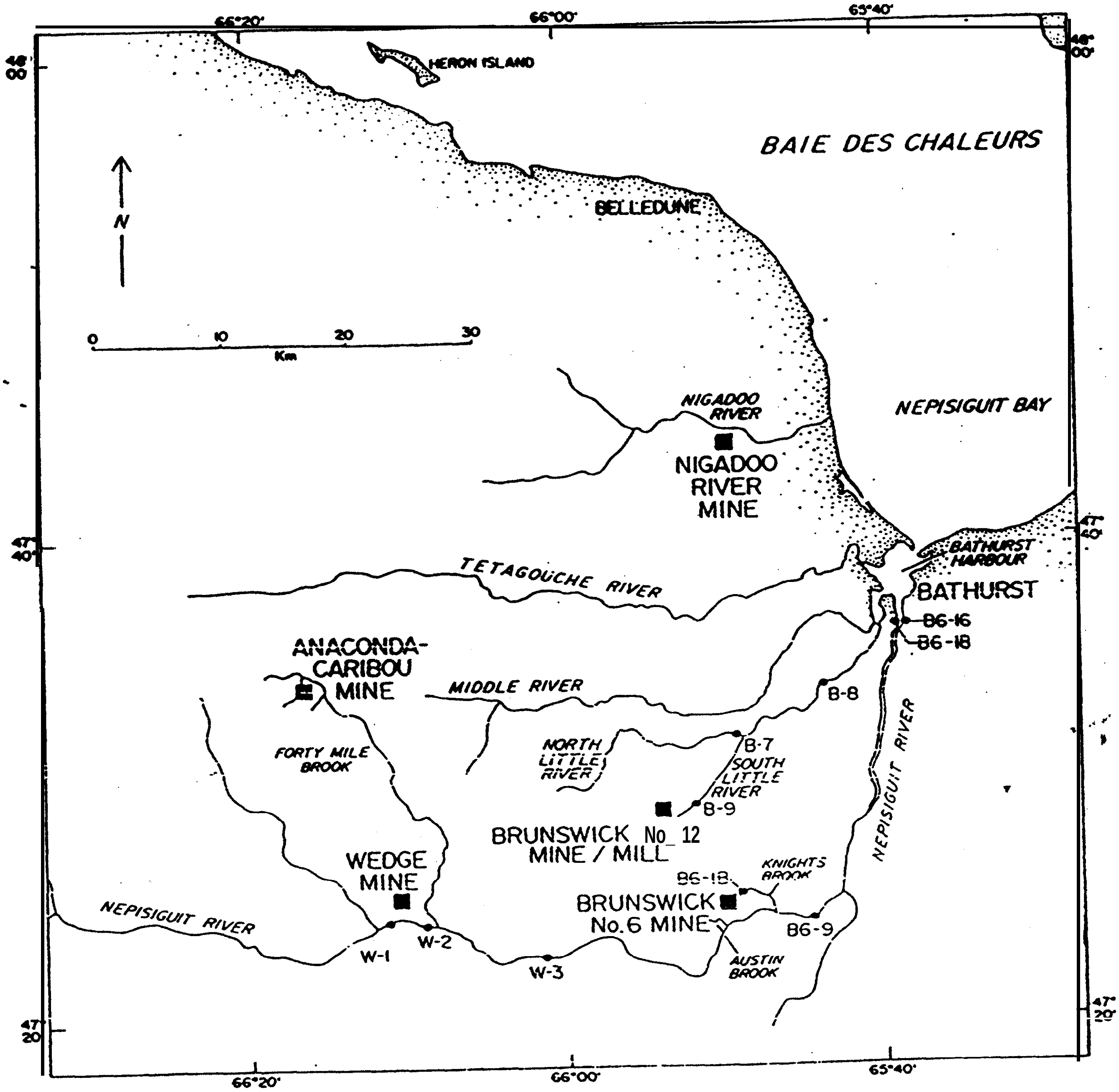


FIGURE 2:- THE BATHURST DRAINAGE BASIN - INDUSTRIAL ACTIVITY

Source : Hi ldebrand, 1984

feasibility studies. This resulted in the creation of Caribou-New Brunswick Mining Limited (CNBM) and preparations were undertaken to revive a 2,000 tonne per day mine, producing lead/zinc concentrate. The anticipated lifetime of the mine, which entered production in October , 1988, will approach 20 years. The new operation hats incorporated a two-fold reclamation plan which provides for the reclamation of disturbed lands and the rehabilitation of Forty Mile Brook.

To date, investigations on the environmental quality ofthe brook have focused primarily on the analyses of grab water samples for trace metals (Canada. Environmenta l Protect ion Service , 1974; Parker, 1988) and ecological surveys of benthic Fauna (Montreal Engineering, 1980). These surveys have beer: restricted principally to the headwaters and mouth regions of Forty Mile Brook . The results of these studies suggest that the upper reaches , directly downstream of the mine site, are contaminated with zinc and copper,rendering this portion of the brook virtually devoid of aquatic lift;. Members of the local trout anglers association, however , have observed the occurrence and upstream progression of brook trout near the confluence with the Nepisiguit (Arsenault, 1988).

No studies have been undertaken to elucidate the downstream gradient of metal contamination, nor to delineate a ***zone of*** toxicity for the sensitive and economical ly significant , endemic salmonid populations. Such information, if effectively gathered , would provide a more comprehensive assessment of the current baseline environmental condition of Forty Mile Brook. Furthermore, baseline studies would serve to establish reference points against which future environmental monitoring of changes in water quality resulting from the new operations and rehabilitation efforts could be contrasted.

Methodology:

On July 2% 1988 approximately 230 Margaritifera márgaritifera specimens a large riverine pelecypod endemic to Atlantic Canada) were collected? 'by wading, from the middle St. Andrews River, Colchester County, Nova Scotia. Some 220 Elliptio complanata individuals (a ubiquitous, slow water unionid bivalve found throughout eastern North America) were also collected, by snorkeling, from the northwest portion of Shubenacadie--Grand Lake, Hants County, Nova Scotia. Specimens were selected from single popufations and care was taken to insure uniformity of size (E. complanata - 7.5 cm to 9.5 cm and M. margaritifera - 8.0 cm to 10.0 cm). Shells were canserved and annual growth rings were later counted to determine the age of the organisms (E. complanata - 13 yrs to 24 yrs and M. margaritifera - 11 yrs to 20 yrs). There was little correlation between age and size.

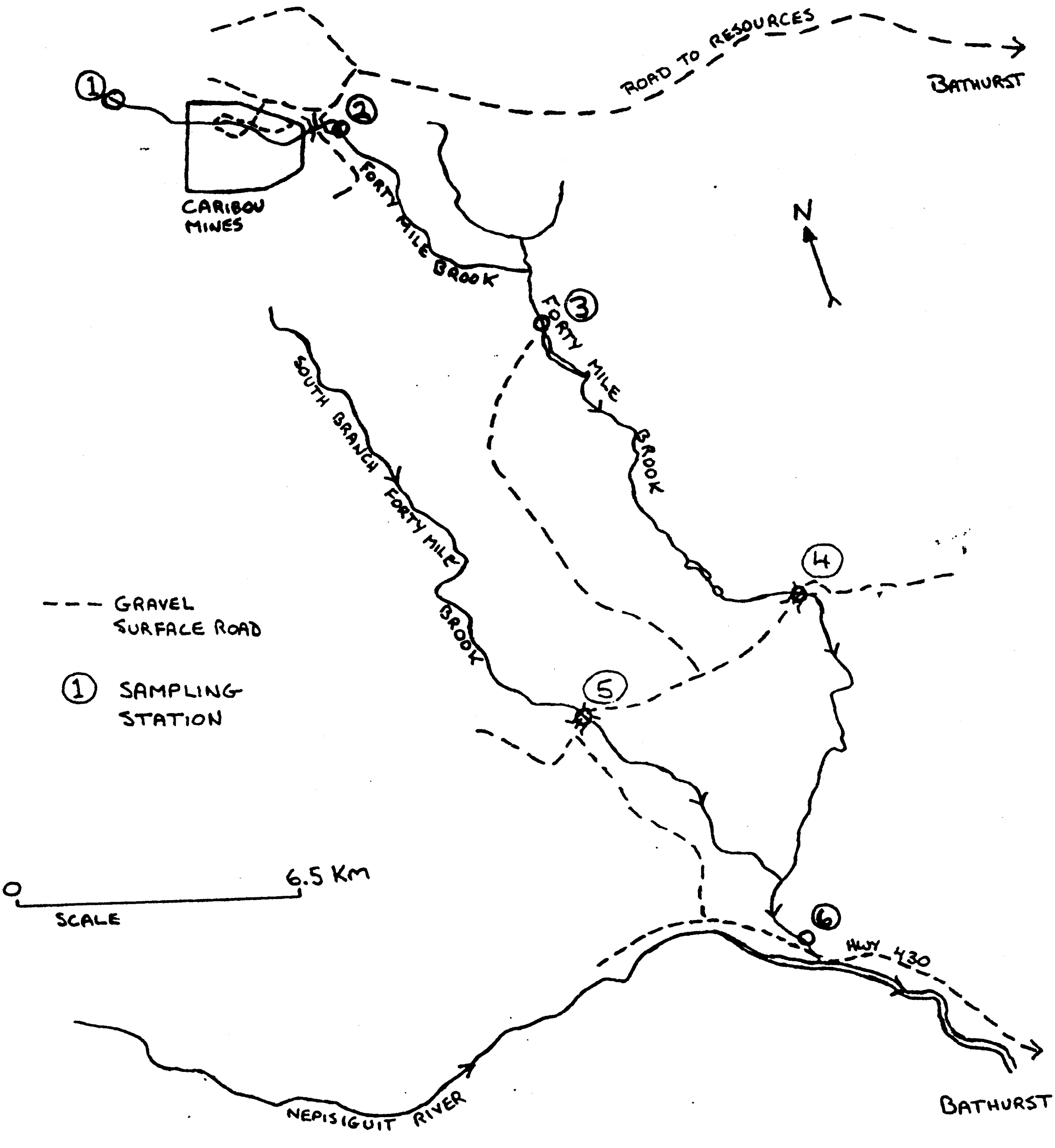
The specimens were placed in contaminant-free polyethylene bags filled with water from their home environments and placed on ice. Within 24 hours, the clams were deployed at six stations within the Forty Mile Brook watershed, four downstream of the mine site (stations 2,3,4, and 6), one upstream control (stat ion

1) and a second control (station 5) on the lower South Branch of Forty Mile Brook (Fig. 3). One hundred per cent survival was recorded during transportation and deployment.

The clams were placed in plastic muffin trays enclosed with fine nylon squid netting and secured to the bottom with plastic pegs. Minimum contact with brook substratum was achieved by containing clams in the plastic trays which also maintained the animals inan upright filtering position. Six specimens of each species were collected from station 3 following 5, 10, 15, 20 and 70 days exposure to Forty Mile Brook. This same procedure was to be repeated at station 2, however, all _M. margaritifera_ were dead after 5 days exposure and only six _E. complanata_ survived an exposure period of 10 days at station 2. At all other stations, six individuals of each species were retrieved at exposure periods of 20 and 70 days. Upon recovery, whole clams were shucked, placed in contaminant-free polyethylene sample bags and kept frozen, pending analysis. Because of the large number of samples, the sectioning of each individual would not have been feasible.

Because of the difficulty of trapping leeches, only small numbers of the leech (_Nephelopsis obscura_) were collected from Lucky Lake , a shallow marsh located approximately 7 km northeast of the mine site in a different watershed. Six Leeches were placed in each of three cages consisting of 60 cm long by 10 cm in diameter PVC plastic cylinders which were capped at both ends and had four large openings covered with nylon screen. The cages

Figure 3: Location of biomonitoring stations



were deployed at stations 3, 4, 5 and 6. Because the cage located at station 6 was lost and Certain leeches **appeared to** be distressed after 10 days exposure, all other cages were retrieved at day 10.

Four specimens from each sampling unit (a sampling unit is defined as a given species at a given station following a given exposure period) were thawed, blotted to remove excess water and mucus, homogenized using an autotron, subsampled, acid digested twice via aqua regia and analyzed on a plasma emission spectrophotometer for 24 metals. Further subsamples were dried for 24 hours and weighed. Fresh weight/dry weight ratios were then calculated.

Lobster hepatopancreas homogenate prepared by the National Research Council of Canada was used as a standard reference material to establish the accuracy of the procedure.

At the time of deployment specimens of all three biomonitoring species were retained as controls, (shucked), frozen and analyzed as per above.

Simple analysis of variance and, where necessary? multiple range tests were applied to identify significant differences in copper and zinc accumulation between stations and between exposure periods for each species of clam_ A "t" test was used to establish the existence of a significant difference in bioaccumulation between the two species of clams. Statistical significance was assumed at the 5% level. ($p<0.05$).

Caged, hatchery reared, fingerling brook trout(<u>Salvelinus</u>

fontinalis) (averaging 2.5 g each) were deployed at all six stations (10 fish per cage, 1 cage per station) and observations on morbidity and mortality were recorded.

Two 1 L water samples were collected at each station in July, 1988 and repeated in October, 1988. One sample from each location was filtered using 0.45 u Millipore filters to provide a measure of dissolved metal content in the sample, while an unfiltered one provided 8 measure of the total metal concentrations. Both samples were acidified and plasma emission spectroscopy was again employed to analyze for trace metals. Additional water samples were taken and immediately analyzed for-- PI-3, conductivity and acidimetric alkalinity (indicator end point).

An extensive analysis of the sediments for trace metals was not. performed, as the substratum of Forty Mile Brook was generally composed of sand arid gravel, or rocks. An algal mat of varying thickness does, however, over lay the sediments and was sampled, frozen, homogenized, digested and analyzed for trace metals.

Results and Discussion:

Following three replicate analyses of standard lobster hepatopancreas homogenate, recovery of copper and zinc was calculated to be 79% and 83%, respectively.

Both species of freshwater pelecypod (*M. margaritifera* and *E. complanata*) and the leech (*Nephelopsis obscura*) displayed at least some tendency to bioaccumulate most of the metals examined. Certain metals, such as manganese, iron and aluminum, appeared in high concentrations both in water and tissue samples at all stations and in the tissues of organisms retained as controls. Because of the absence of any significant interstation differences and their relatively low toxicities and high concentrations in natural waters, these metals are not considered in this discussion. The results for lead and cadmium were erratic, but concentrations were consistently low and often below the detection limit (0.0001 ppm for sample solutions). Only copper and zinc appeared in appreciable concentrations and exhibited statistically significant differences in bioaccumulation between stations and different exposure periods-

Figures 4 and 5 illustrate whole organism, dry weight tissue concentrations of zinc and copper, respectively, for both clam species at exposure periods of 20 and 70 days. The results indicate that, following 70 days exposure, tissue levels of zinc and copper were significantly higher than after an exposure period of only 20 days. Tissue concentrations of zinc and copper between downstream stations (stations 3,4 and 6) were rather erratic and only the results for the uptake of zinc by E. complanata showed significant interstation differences_

The levels of zinc in station 6 E. complanata specimens were found to be significantly higher than at stations 3 and 4. Station 6, however, is the experimental station furthest downstream from the mine and it would be expected that the

Figure 4: Tissue Zn burden at 5 sampling stations

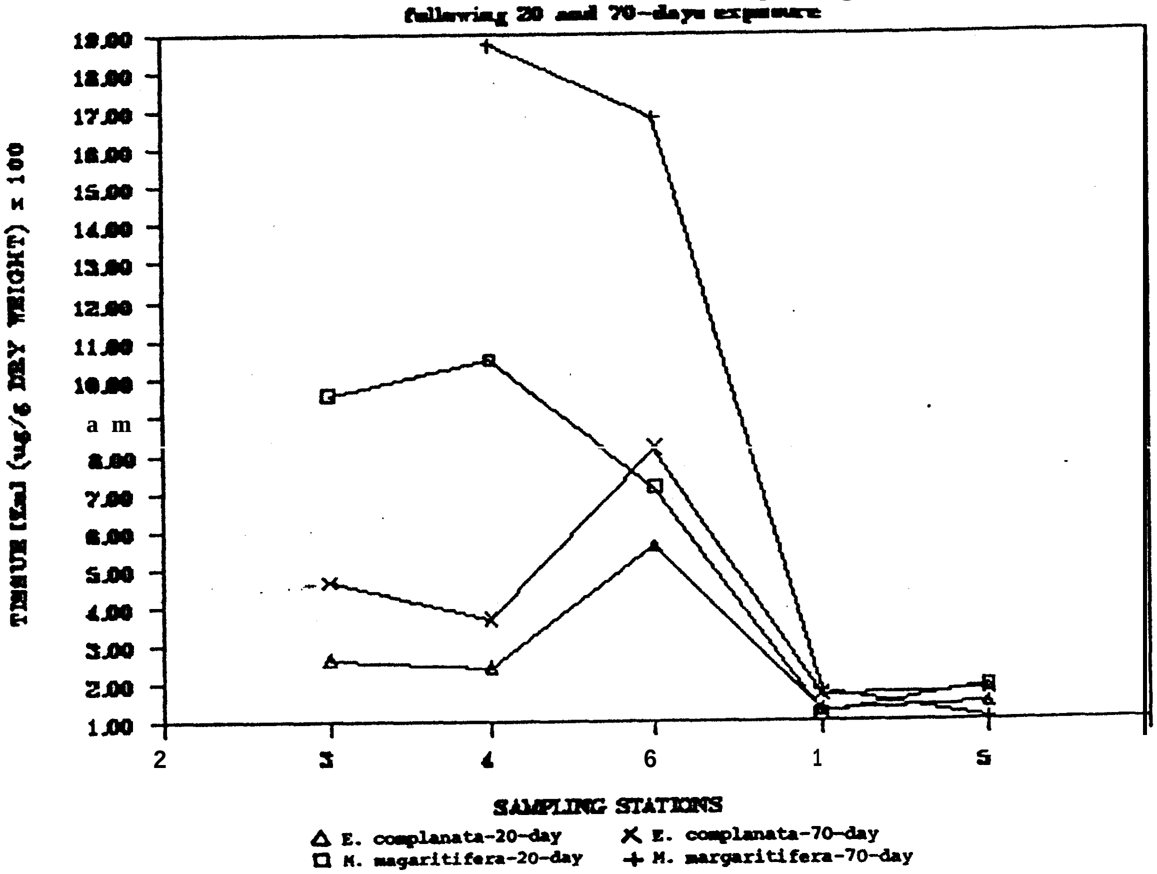
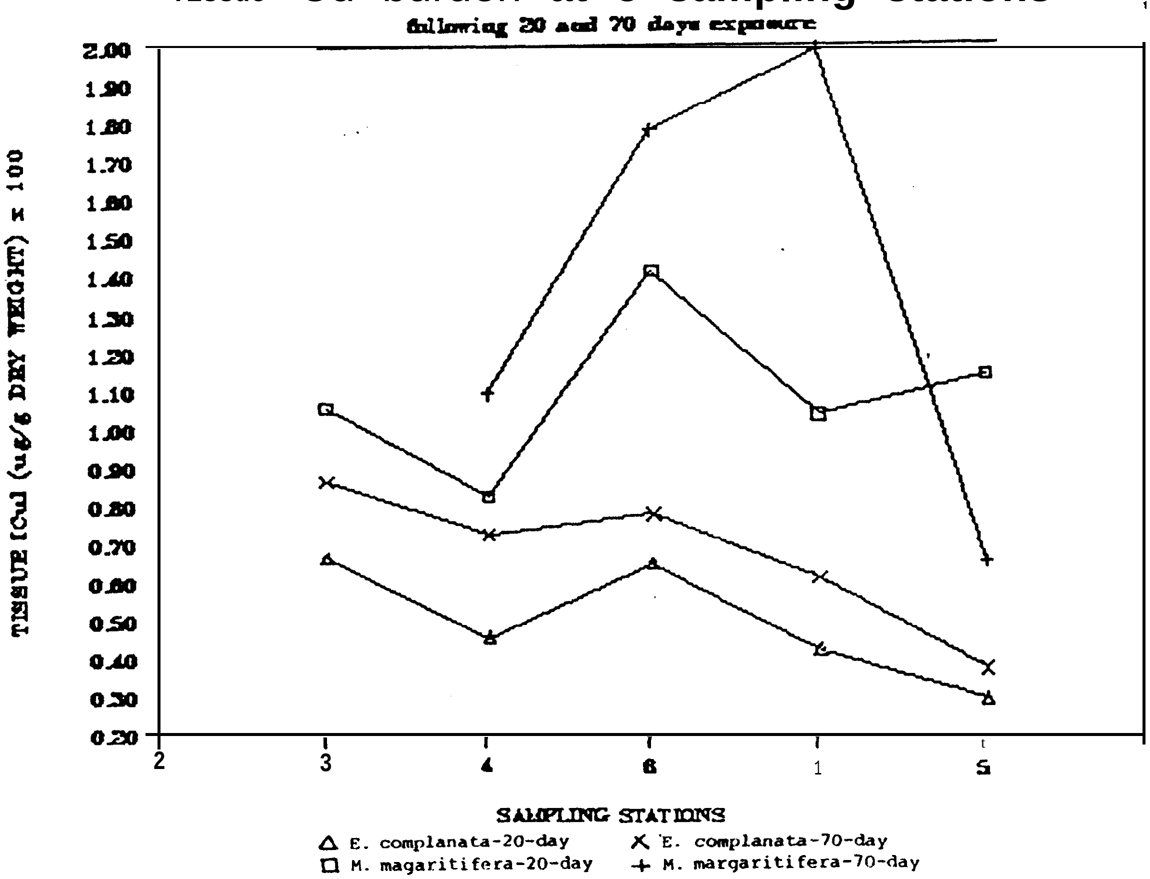


Figure 5: Tissue Cu burden at 5 sampling stations



results of tissue analyses for this station would be lower than for stations 3 and 4. This same anomaly was apparent for the uptake of copper by M. margaritifera and to a lesser extent E. complanata at station 6 for both 20 and 70 day exposure periods (Fig. 5). The statistical significance of this, however, cannot be proven- Clearly, there was no increase in either dissolved or total copper and zinc concentrations in water samples taken from station 6 (Fig. 6 and 7). Since the increases in the tissue concentrations of copper and zinc at station 6 occur at exposure periods of both 20 and 70 days, experimental error, or differences in the size, weight, age, or reproduct ive state of the individual organisms pooled for analysis are not Likely to factor in the explanation of these results,.

Hardness. alkalinity and pH are parameters which are known to influence the toxicity and uptake of trace metals (Cote, 1971; Weatherley et al., 1980; Spear, 1981; Graney et al., 1.984; Eradiey and Sprague, 1985), but historical water chemistry data for Forty Mile Brook show no significant variation in these parameters between station 6 and upstream sampling locations. Conductiviiies at station 6 (Table 1) conform well to a gradient that decreases with increasing downstream distance from the mine site.

One possible conclusion might be that a change in the speciation of copper and zinc at station 6 resulted in an increased bioavailability of these metals. Sedlacek et al. (1989) report that the presence of humic acids often reduces the

Figure 6: Ambient Cu and Zn concentrations

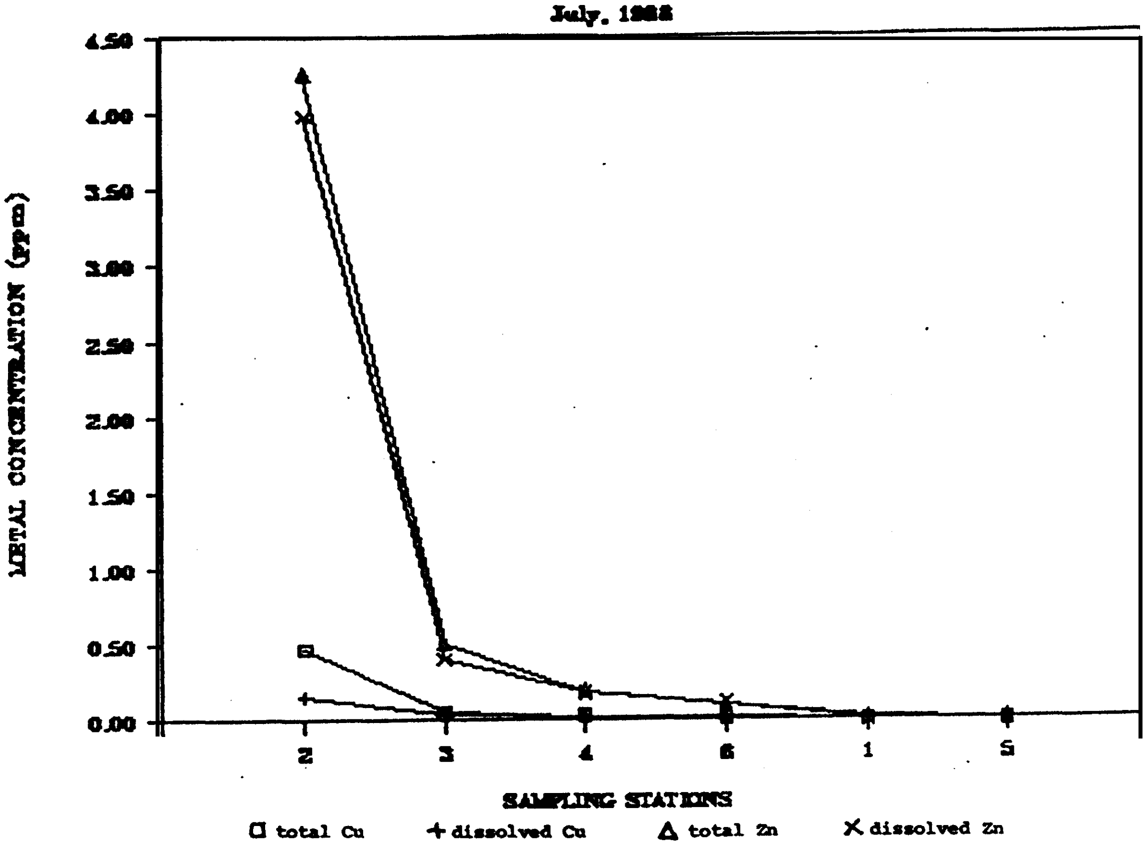


Figure 7: Ambient Cu and Zn concentrations

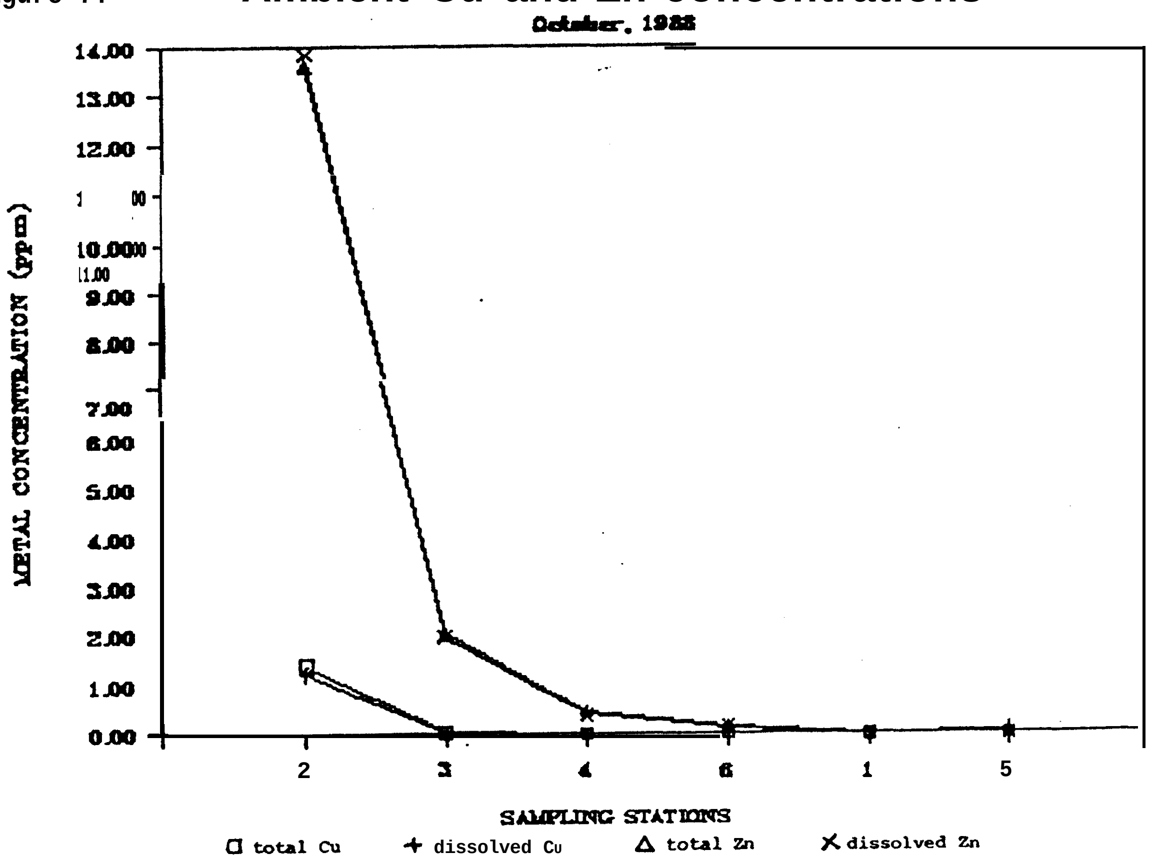


Table 1: Physico-chemical measurements of Forty Mile Brook

station	pH	alkalinity (mg/L) PA	alkalinity (mg/L) TA	conductivity (umhos/cm)	dissolved oxygen (mg/L)	temperature July 30, 1988 (°C)
1	7.1	0	12.8	65	8.85	18.5
2	6.9	0	32.0	230	9.90	17.5
3	6.8	0	11.2	93	9.40	21.5
4	7.1	0	6.4	74	9.24	20.7
5	7.2	0	9.6	42	8.90	20.2
6	7.3	0	6.4	66	8.82	20.9

uptake of trace metals by aquatic organisms. Again historical water chemistry data do not expose significant variations in the humic acid content of Forty Mile Brook between station 6 and upstream sites (Canada. Environmental Protection Service. 1974).

A more in depth investigation of trace metal speciation in Forty Mile Brook and the effects of different molecular weight fractions of humus on the tracemetal uptake kinetics of freshwater pelecypods is required before the anomalous results obtained for station 6 can be adequately explained.

Table 2: Concentrations of copper and zinc in control organisms (ug/g dry weight)

Elliptio complanata Copper	*Elliptio complanata* Zinc	*Margaritifera margaritifera* Copper	*Margaritifera margaritifera* Zinc
153	147	254	155

Levels of copper in the tissues of control organisms were high (Table 2) and exceeded tissue copper concentrations from animals exposed to Forty Mile Brook. In addition at control station 1, upstream of the mine site, bioaccumulation of copper exceeded that at downstream locations. This might suggest that copper, alone, is not a significant problem in Forty Mile Brook, and might occur naturally in relatively high concentrations . At station 2, however, copper concentrations in ambient water samples exceeded effluent guidelines (0.030 ppm) recommended by the Northeastern New Brunswick Mine Water Quality Program (Montreal Engineering, 1973) for base metal mines in the regi on . In addition, all 30 *M. margaritifera* specimens deployed at station 2 were dead within 5 days and only 6 of 30 *E. complanata* survived 10 days exposure at station 2. Table 3 presents the results of analyses performed on clams recovered dead from station 2.

Table 3: Concentrations of copper and zinc in the tissues of clams recovered dead from station 2 (ug/g dry weight)

Elliptio complanata				*Margaritifera margaritifera*	
Copper		Zinc		Copper	Zinc
5d	10d	5d	10d	5d	5d
79.6	243	385	860	611	2,865

Copper and particularly zinc were rapidly accumulated at station 2. Spear (1981) reports that it is difficult to directly link zinc bioaccumulation with toxicity to aquatic organisms, however, bioaccumulation may result in a toxic response if uptake reaches a critical rate. At station 2 it would appear that such a critical rate was attained and the affected organisms' capacity to sequester the toxic effects of trace metals was surpassed.

Figures 8 and 9 illustrate the rates of zinc and copper bioaccumulation for both E. complanata and M. margaritifera over the 70 day exposure period at station 3. Margaritifera margaritifera accumulated significantly higher concentrations of both copper and zinc at all exposure times. Clearly, M. margaritifera is a much more effective integrator of trace metals than is E. complanata, however, the former species was found to be less tolerant of higher concentrations of trace metals in ambient water. Survival of E. complanata at stations 2 and 3 exceeded that of M. margaritifera. The results seem to indicate that threshold body burdens of zinc and copper were not attained for either species of clam after 70 days exposure.

It would seem evident from the results that there is merit in pursuing the notion of a mathematical relationship between trace metal toxicities and rates of uptake. Based on limited results, rates of uptake at station 2 appeared to be quite rapid and the toxic effects pronounced, whereas at station 3, rates of uptake were more moderate and toxicity was greatly reduced.

Figure 8: Tissue dry weights of Zn at Station 3

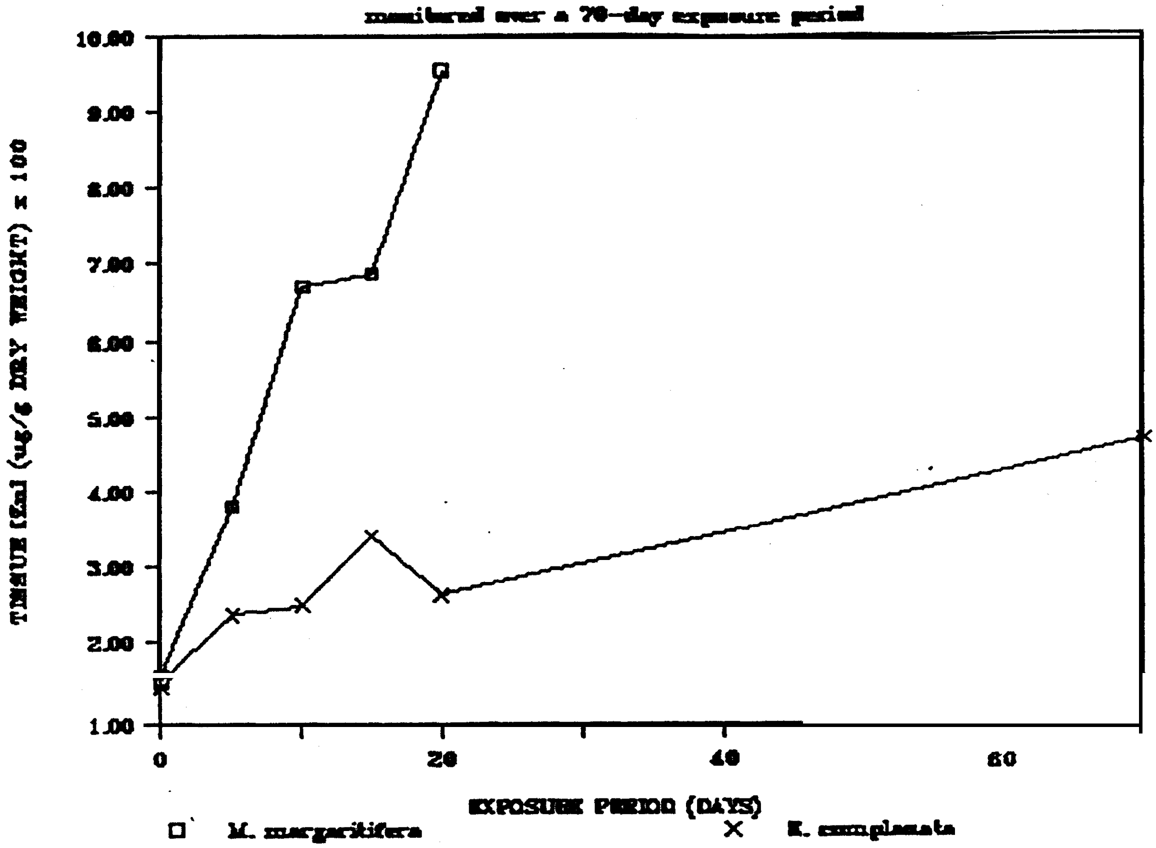
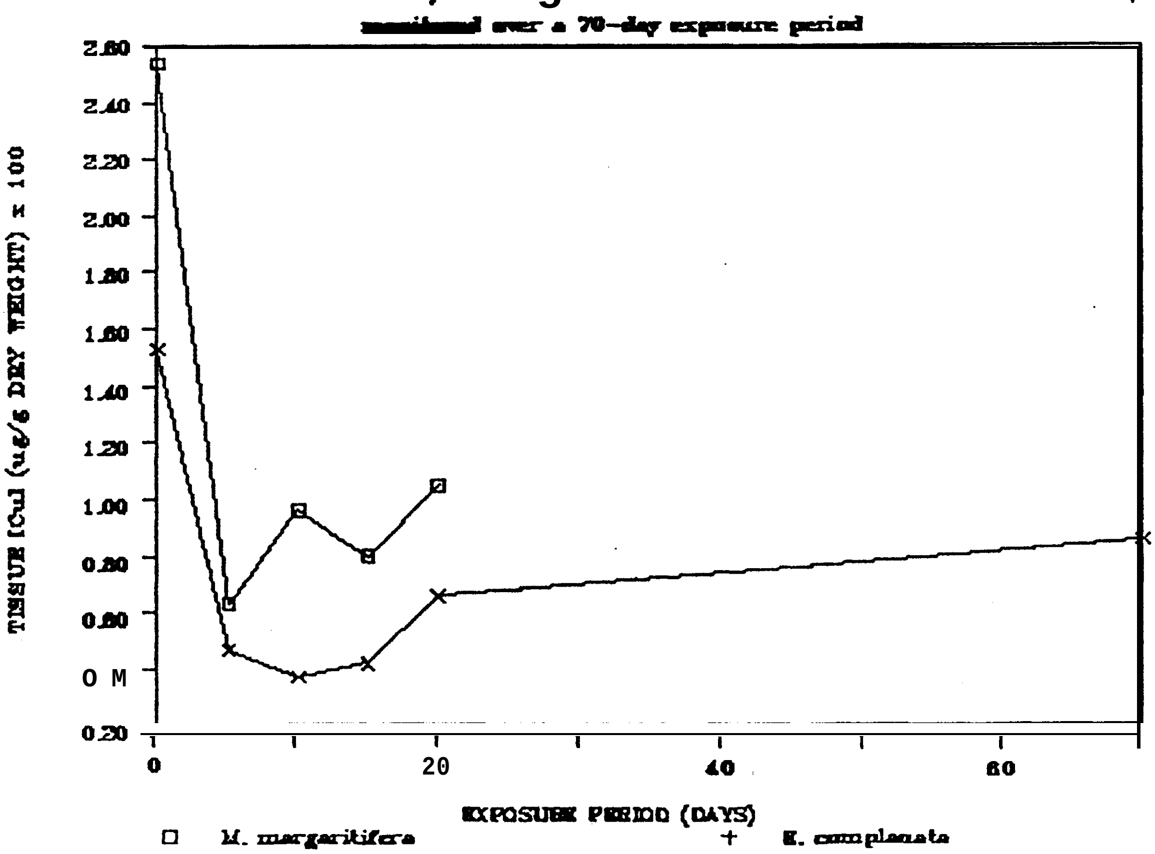
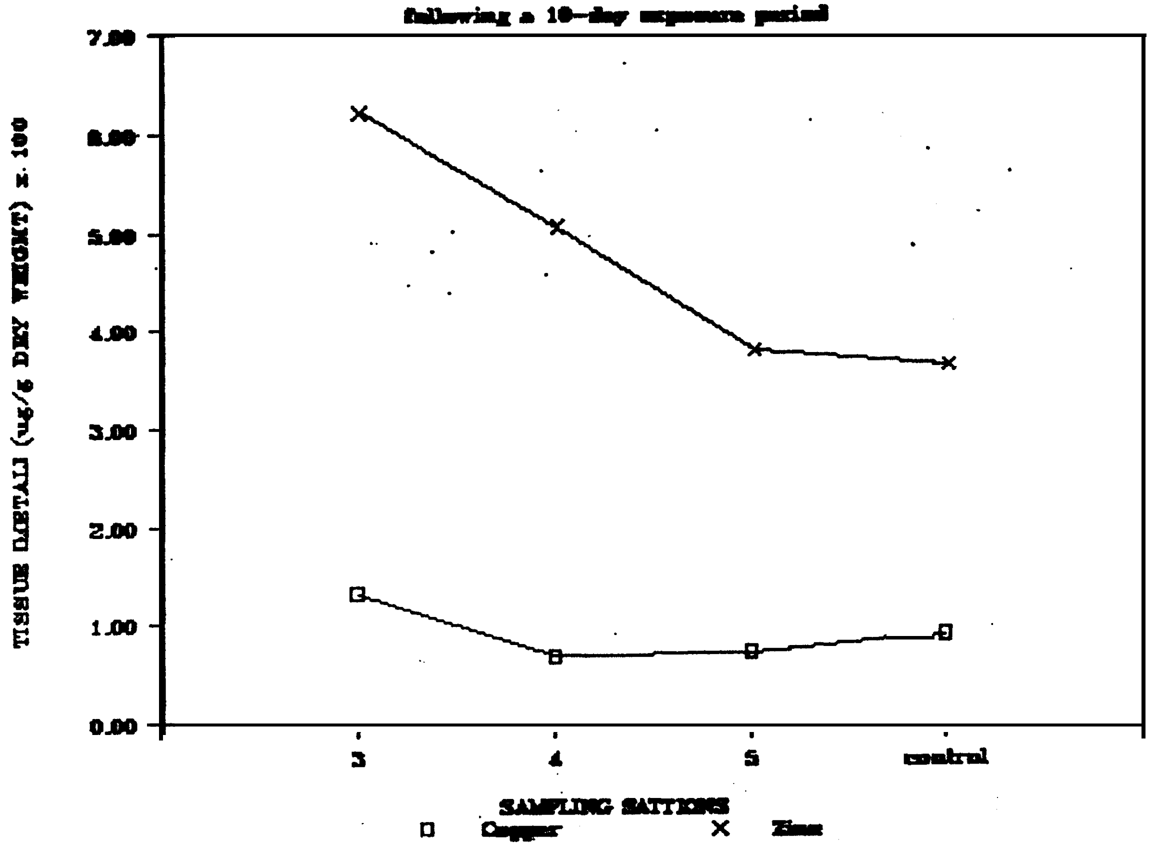


Figure 9: Tissue dry weights of Cu at Staion 3



Leech Cu and Zn tissue burden



Results for the uptake of copper and zinc by the leech (Nephelopsis obscura) are presented in Figure 10. Because of the difficulties in locating and capturing sizeable numbers of leeches , was only possible to deploy a limited number of leech cages, namely at stations 3,4,5 and 6. The cage at station 6 was disturbed by vandals and could not be recovered. A lack of vigour was observed in many of the leeches exposed to Forty Mile Rrook following 10 days exposure. This prompted a decision to retrieve the three remaining cages after-10 days.

The lack of vigour exhibited by exposed leeches may have been a result of low concentrations of dissolved salts and high water temperatures. Reynoldson and Davies (1980) observed that optimum survival of N. obscura occurred at conductivities ranging between 1584 and 5554 umhos/cm and high mortality at conductivities below 84 umhos/cm. Temperatures in Forty Mile Brook (17.5 °C - 21.5 °C) approached the upper tolerance limit for this species (Linton et al., 1983). Furthermore, the life cycle of N. obscura is thought to be approximately 2 years, with adult animals becoming clitellate in June and July (Peterson, 1983). Following deposition of cocoons, post reproductive leeches become languid and soon die. Although clitellate animals were not observed amongst those captured and no cocoons were deposited in either the leech traps or cages, larger specimens (6 cm -10 cm in length) may have been post reproductive. All these factors may have contributed to the apparent distress of leeches exposed to Forty Mile Brook.

The results of this study demonstrate that experiments with caged leeches are indeed feasible. Care should be taken, however, to ensure that reproductive and post reproductive organisms are not used and that water quality parameters are compatible with the requirements of the organism.

After an exposure period of just 10 days the leeches accumulated significant amounts of zinc at stations 3 and 4, even though levels of zinc were comparitively high in the control organisms. Copper, on the other hand, was not accumulated to levels significantly in excess of those found in the tissues of control organisms. The relatively high concentrations of both copper and zinc in the tissues of control organisms taken from a shallow lake not far from the mine site, would lend further support to the notion that ambient levels of trace metals are naturally high in the waters of this region as a result of the metalliferous geology. The results, however, do indicate that N. obscura is a potentially effective integrator of trace metals, but its tolerance to wide variations in water quality parameters is limited.

Because the dissolved metals fraction accounted for such a large proportion of the total metal content of water samples and because of insufficient data, it was not possible to determine which fraction contributed most significantly to the uptake of metals by the three biomonitoring species employed.

Table 4 lists the results of analyses performed on epilithic algal samples collected from stations 2,3 and 6. At station 2 and 3 copper and zinc concentrations can be reported in unit percentages. Algae have proven to be effective integrators of trace metals (Vymazal, 1987; de Lurdes et al., 1989) and Spear (1981) reports that zinc, as with other trace metals, does not biomagnify and bioaccumulation tends to decrease with each increase in trophic level. The use of periphytic algae as biomonitors of trace metal contamination in mining districts should be further investigated.

Table 4: Concentrations of capper and zinc in epilithic algae from Forty Mile Brook (ug/g dry weight x 1000)

station	copper	zinc
2	15.6	18.8
3	1.73	12.0
6	0.401	4.94

Finally, observations on the morbidity and mortality of fingerling brook trout (Salvelinus fontinalis) are presented in Table 5. Death was defined as complete absence of opercular movement and lack of response to tactile stimulation (prodding).

Table 5: *S. fontinalis* morbidity and mortality in Forty Mile Brook

station	time	observations
1	10 days	- 100% survival, active at bottom of cage, healthy, responsive to vibration.
2	2 hours	- all specimens exhibited severe distress, gills gaping and red, 70% were at surface experiencing loss of equilibrium, unresponsive to -tactile stimulation, 30% motionless on bottom of cage.
	2.5 hours	- 100% mortality.
3	3 hours	- largest specimen demonstrated loss of equilibrium and swam violently in spirals.
	4 hours	- all specimens inactive, gills red and gaping.
	6 hours	- 10% mortality, several specimens exhibited loss of equilibrium.
	24 hours	- 40% mortality, one individual upside down, gills red and gaping-
	4 days	- 80% mortality, 2 of the smallest specimens appeared to have regained vigour and equilibrium.
	10 days	- 1.00% mortality .
4	4 days	-100% survival, healthy, active, responsive_
	10 days	- cage dislodged, fish escaped.
5	10 days	- 100% survival, healthy, active, responsive.
6	10 days	- 100% survival, healthy, active, responsive.

Conclusions:

The primary objectives of this study were to determine whether a simple, cost-effective biomonitoring system would provide an effectual approach to establishing baseline environmental conditions for Forty Mile Brook and to assist in delineating zones of acute and sub-acute toxicity. The monitoring technique employed in this study was based on the accumulation of trace metals in the tissues of aquatic organisms. In this manner, monitoring organisms were expected to act as surrogates for direct water chemistry analyses, amplifying metal concentrations found in ambient water samples and attenuating temporal fluctuations triggered by accidental spills and meteorological events.

Unlike the results obtained for the analysis of copper and zinc in ambient water samples, accumulation of these metals in the tissues of the monitoring organisms did not elucidate a decreasing downstream gradient_ This undoubtedly underscores the need to refine the approach taken in this study . It is herein recommended that:

1) biomonitoring organisms be carefully selected from uncontaminated waters, minimizing differences in age, size and reproductive status;

2) the analysis of specific tissues where metals may be sequestered be investigated; and

3) sampling unit replication be increased to improve the amenability of the data to statistical analysis and to reduce variance.

The erratic interstation results may also be a result of changes in the bioavailability of metals to the biomonitoring organisms. Actual ambient water concentrations of certain metals may decline with increasing downstream distance from the mine site, but the bioavailability of these contaminants may increase due to changes in their speciation. The implications of this may be of importance in the prescription of site specific effluent guidelines or regulations. Furthermore,such downstream effects could not be detected through water chemistry analysis alone..

Lethal toxicity was observed at only two sampling stations (stations 2 and 3),where mortality was recorded in both species of peiecypods employed as biomonitors and in caged brook trout fingerl ings. A rapid rate of uptake of trace metals was observed at these stations, particulary amongst pelecypod specimens which were recovered dead. This lends support to the idea of a relationship between toxicity and rate of uptake. Laboratory stud ies should be initiated to further investigate and develop this concept .

The results of this study do not conclusively demonstrate the usefulness of a biomonitoring system in acquiring baseline water quality data, However, conclusions drawn or inferred from this work confirm that the methods employed merit; further attention and with some refinement would yield additional information.

Cost-effective methods for integrating and compar ing base l ine and follow-up monitoring da ta, as applied to EIA, must be pursued. 3eanlands and Duinker (1983) suggest that one of the reasons environmenta l impact prediction has not achieved its full potential as a management tool is because of the absence of essential feedback mechanisms. All too often baseline data and the results of post project evaluation and compliance monitoring are incongruous. At present baseline studies are undertaken with the objective of providing a foundation for prescribing environmental permits, while follow-up effects monitoring is most often considered in the context of assuring compliance with established permits. The objectives of these two essential components of EIA should be further developed to ensure their greater interrelationship. This would allow practitioners and managers alike to benefit more fully from past experience and would serve to enhance the predictive accuracy of ETA.

Literature Cited:

Arsenault, L. 1988. President, Nepisiguit Trout Protection Association. Personal communication.

Beanlands, G.E. and P.N. Duinker. 1983. An ecological framework for environmental impact assessment in Canada. Institute for Resource and Environmental Studies, Dalhousie University and the Federal Environmental Assessment and Review Office, Halifax. 132 p.

Beanlands, G.E. 1988. Scoping methods and baseline studies in EIA, pp. 33-46 in: Environmental impact assessment: theory and practice, P. Wathern (ed.).Unwin Hyman Publ.,London.

Bias, R. and L. Karbe. 1985. Bioaccumulation and partitioning of cadmium within the freshwater mussel *Dreissena polymorpha* Pallas. Int. Rev. Ges. Hydrobiol. 1: 113-125.

Bradley, R.W. and J.B. Sprague. 1.985. Accumulation of zinc by rainbow trout as influenced by pH, water hardness and fish size. Environ. Toxicol. Chem. 4: 685-694.

Canada. Environmental Protection Service. 1974. 3.973 New Brunswick Mine Water Quality Monitoring Program data. Environment Canada, Environmental Protection Service, Surveillance Section, Atlantic Region. Surveillance Report EPS 5-AR-74-16.

Canada. Inland Waters Directorate. 1387, Historical stream-flow summary: Atlantic Provinces to 1986. Environment Canada, Inland Waters Directorate, Water Resources Branch.

Canada. Inland Waters Directorate. 1989. NAQUADAT, on line search. Environment Canada, Inland Waters Directorate, water Resources Branch, Moncton, N.B.

Cairns, J. 1984. Freshwater biological monitoring: Keynote address, pp 1-14 in: Freshwater biological. monitoring, D. Pascoe and R.W. Edwards (ed.). Pergamon Press, Oxford.

Cote, R.P. 1971. Hardness as a modifying factor in heavy-metal toxicity. Environment Canada, Resource Development Branch. Halifax, N.S. Manuscript Rep. #71-18.

Curry, C.A. 1978. The freshwater clam (*Elliptio complanata*),a practical tool for monitoring water quality. Water Pollut. Res. Canada. 13: 45-52.

Czarnezki, J.M. 1987. Use of the pocketbook mussel, Lampsilis ventricosa, for monitoring heavy metal pollution in an Ozark stream_ Bull. Environ. Toxicol. 38: 641-646.

Foster, R.B. and J.M Bates. 1978. Use of freshwater mussels to monitor point ***source*** industrial discharges. Environ. Sci. Technol. 12: 958-962.

Goldberg, E.D. 1986. The mussel watch concept- Environ. Monit. Assess 7: 91-103.

Graney, R.L., D.S. Cherry and J. Cairns Jr. 1983. Heavy metal indicator potential fit the asiatic clam (Corbicula fluminea) in artificial stream systems. Hydrobiologia 102: 81-88.

Graney, R.L., D.S. Cherry and J. Cairns Jr. 1984. The influence of substrate, pH, diet and temperature upon cadmium accumulation in the asiatic clam (Corbicula fluminea) in laboratory artificial streams. Water Res. 18: 833-842.

Green, R. H. and S.G. Hinch. 1986. Freshwater clams as monitors of variation in environmental_ acidity and trace metal levels, pp. 189-214 in: Proceedings of the Fifth Ontario Ministry of the Environment Technology *Transfer Conference, Sept.,1986.

Hall,K.J. and C. Jacob. 1987. The bioconcentration of chlorophenols by leeches and their use as in situ biological monitors. Can. Soc.Environ.Biol.Newsletter 44(1): 17-36.

Heit, M.,C.S. Klusek and K.M.Miller.1980. Trace element, radionuclide, and polynuclear aromatic hydrocarbon concentrations in Unionidae mussels from northern Lake George, Environ. Sci and Technol. 14: 465-468.

Hemelraad, J., H.A. Kleinveld, A.M. De Roos, D.A. Holwerda and D.I. Zandee. 1987. Cadmium kinetics in freshwater clams. III. Distribution of Cadmium in Anodonta cygnea. ARch. Environ. Contam. Toxicol. 16: 95-101.

Hildebrand, L.P. 1384. An assessment of environmental quality in the Baie des Chaleurs. Environmental Protection Service, Atlantic Region, Surveillance Report, EPS-5-AR-84-8.

Winch, S.G. and L.A. Stephenson. 1987. Size- and age-specific patterns oftrace metal concentrations in freshwater clams from an acid-sensitive and circumneutral lake. Can. J. Zoo?. 65: 2436-2442.

Jones, W.G. and K.F. Walker. Accumulation of iron, manganaese zinc and cadmium by the Australian freshwater mussel Velesunio ambiguus (Phi llipi) and its potential as a biomonitor. Aust . J. Mar. Freshwater Res. 30 : 741-751.

Kauss, P.B. and Y.S. Hamdy. 1985. Biological monitoring of organochlorine contaminants in the St. Clair and Detroit Rivers using introduced clams, Elliptio complanatus. J. Great Lakes Res. 11(3): 247-263.

Linton, L.R., R.W. Davies and F.J. Wrona. 1983. The effects of water temperature, ionic content and total dissolved solids on Nephelopsis obscura and Erpobdella punctata (Hirudinoidea: Erpobdellidae) 2. Reproduction, Holarct. Ecol. 6: 64-68.

de Lurdes, M., S.S. Goncalves and L. da Conceicao. 1989. Metal ion binding of copper (II), zinc (II) and lead (II) by the alga Selenastrum capricornutum Printz. Sci. Total Environ. 78: 155-166.

Lynch, T.R. and J. Popp. 1988. Aquatic insects as environmental. monitors of trace metal contamination: Red River, New Mexico. Water, Air, Soil Pollut. 42: 19-31.

Memmert, U. 1987. Bioaccumulation of zinc in two freshwater organisms (Daphnia magna, Crustacea and Brachydanio rerio, Pisces). Water Res. 21: 99-106.

Metcalfe, J.L., M.E. Fox and J.H. Carey_ 1984. Aquatic leeches (Hirudinea) as bioindicators of organic chemical contaminants in freshwater ecosystems. Chemosphere 13: 143-150.

Metcalfe, J.L., M.E. Fox and J.H. Carey. Freshwater leeches (Hirudinea) as a tool for detecting organic contaminants in the environment. National Water Research Institute, Burlington, ON. NWRI Contribution #88-13.

Metcalfe, J.L. and M.N. Charlton. 1989. Freshwater mussels as biomonitors for organic industrial contaminants and pesticides in the St. Lawrence River. National Water Research Institute, Burlington, ON. NWRI Contribution #89-60.

Montreal Engineering. 1973. Base metal mine management in northeastern New Brunswick. Environmental Protection Service, Atlantic Region. Report EPS-8-WP-73-1.

Montreal Engineering. 1980. Caribou Mine environmental studies . Prepared for Anaconda Copper Ltd. Fredericton, N.B.

Mouvet, C., E. Patte and P. Cordebar. 1986. Utilisation des mousses aquatiques pour l'identification et la localisation precise de sources de pollution metallique multiforms. Acta Oecologia 7: 77-91..

New Brunswick. Department of Natural Resources. 1987. Annual Report. Fredericton, N.B.

Parker, W.R. 1988. Environmental Protection, Environment Canada. Atlantic Region, Dartmouth, N.S. Personal communication.

Peterson, D.L. 1983. Life cycle and reproduction of Nephelopsis obscura Verrill (Hirudinea: Erpobdel lidae) in permanent ponds in northwestern Minnesota. Freshwater Invert. Biol.2: X5-172.

Phillips, D.J.H. 1980. Quantitative biological indicators: their use to monitor trace metals and organochlorinepollution. Applied Science Publishers, London.

Phillips, D.J.H. and D.A. Segar. 1986. Use of bio- indicators in monitoring conservative contaminants: Programme design imperatives. Mar.Pollut. Bull. 17: 10-17.

Pollock, T.L., H.S. Samant and D.A. Lord. 1977. Thiosalts and their measurement in mine mill effluents of northeastern New Brunswick. Environmental Protection Service, Atlantic Region. Surveillance Report, EPS-5-AR-77-8.

Reynoldson, T.B. and R.W. Davies. 1980. A comparitive study of weight regulation in Nephelopsis obscura and Erpobdella punctata (Hirudinoidea). Comp. Biochem. Physiol. 66A: 711-714.

Rice, C.P. and D.S. White. 1987. PCB availability assessment of river dredging using caged clams and fish. Environ. Toxicol. Chem. 6: 259-274.

Sedlacek, J., E. Gessing and T. Kallqvist. 1989. Effect of aquatic humus on uptake of zinc and barium to alga Selenastrum capricornutum. Sci. Total Environ. 82: 703-710.

Spear, P.A. 1981. Zinc in the aquatic environment: chemistry, distribution, and toxicology. National Research Council of Canada, Ottawa, On. NRC No. 17589.

States, J.B., P.T. Huag, T.G. Shoemaker, L.W. Reed and E.B. Reed. 1978. A systems approach to ecological baseline studies. U.S. Department of the Interior. Fish and Wildlife Service, FWS/OBS-78/21.

Tessier, A. P.G.C. Campbell, J.C. Auclair and M. Bisson. 1984. Relationships between the partitioning of trace metals in sediments and their accumulation in the tissues of the freshwater mollusc. Elliptio complanata in a mining area. Can. J. Fish. Aquat. Sci. 41: 1463-1472.

Weatherley, A.H., P.S. Lake and S.C. Rogers. 1980. Zinc pollution and the ecology of the freshwater environment. pp. 337-418 in: Zinc in the Environment Part 1: Ecological Cycling. J.O. Nriagu (ed.). John Wiley and Sons, New York.

Vymazal, J. 1987. Zn uptake by *Cladophora glomerata*. Hydrobiologia 148: 97-101.

Zadory, L. 1984. Freshwater molluscs as accumulation indicators for monitoring heavy metal pollution. Fresenius Z. Anal. Chem. 317: 375-379.