

95-12

Environment Canada

Water Science and
Technology Directorate

Direction générale des sciences
et de la technologie, eau

Environnement Canada

Studies of Effects of Metal Mine Discharges on Benthic
Organisms

By:

T. Reynoldson, A. Mudroch, F. Rosa, J. Azcue

NWRI Contribution # 95-12

TD
226
N87
No. 95-
12

95-12

STUDIES OF EFFECTS OF METAL MINE DISCHARGES ON BENTHIC ORGANISMS¹

Trefor Reynoldson, Alena Mudroch, Fernando Rosa and Jose M. Azcue²

Abstract: Different approaches have been used to assess environmental impact of metal mine discharges. Complete assessment of the impact of the metal mine discharges on aquatic ecosystems must include a biological component in addition to the evaluation of physical and chemical processes. Benthic invertebrates are very appropriate for evaluating the contamination of lake or stream sediments from mining activities. These organisms reside in the sediments or at the sediment/water interface; they do not move a great deal and are therefore spatially representative; their populations are relatively stable in time; their taxonomy is reasonably well established; and their responses to environmental changes have been studied extensively. Experiments with benthic invertebrates under controlled conditions are useful for studying effects of individual processes affecting the quality of the sediments. Results from different sediment toxicity bioassays accompanied by field observations on benthos in streams and lakes in the vicinity of active or abandoned are demonstrated.

Key Words: mining, benthic, invertebrates, toxicity, biological, metal, bioassays.

Introduction

Wastes generated by mining activities, such as tailings and waste rock, contain naturally occurring and potentially toxic elements found in the metal ore, as well as toxic elements and compounds introduced during the various stages during the extraction of the metals from the ore. Guidelines for discharges of metal mine effluents at the present time are restricted to physico-chemical parameters and one fish bioassay. The measurement of chemical concentrations only, does not give any information regarding bio-availability and biological stress. Recently, several authors have suggested a biological approach to developing sediment guidelines (Reynoldson and Zarull, 1993; Chapman, 1986; Armitage et al., 1987; Moss et al., 1987; Johnson and Wiederholm, 1989). There is an evident need to include the biological component in the assessment of the impact of mining activities on aquatic ecosystems.

The examination of ecosystem structural integrity would ideally include all biotic components of the ecosystem, however, such detail is not feasible nor is it necessarily required (IJC, 1987). In sediment assessment the most appropriate group of organisms is the benthic invertebrates (Reynoldson and Zarull, 1993). These organisms reside in the sediments or at the sediment/water interface; they are sessile; their populations are relatively stable in time; their taxonomy is reasonably well established; and their responses to environmental changes have been studied extensively.

Sediment toxicity bioassays and field observations of benthic organisms have been carried out as part of multidisciplinary studies of the effects of mining activities on aquatic ecosystems (Azcue et al., 1994; Mudroch et al., 1992, 1994). In this manuscript we describe sampling and analytical approaches using benthic organisms in two studies on the effects of tailings from two abandoned gold mines, examining community structure and laboratory sediment toxicity tests.

¹ Paper presented at Sudbury 95, Conference on Mining and Environment, Sudbury, Ontario, May 28th - June, 1995

² National Water Research Institute - P.O.Box 5050 - Burlington, Canada L7R 4A6

Material and Methods

Study areas

The first study was carried out in Jack of Clubs Lake at Wells, B.C., part of the Fraser River drainage basin. Jack of Clubs Lake is 2.4 km long and 0.5 km wide, with a mean depth of 19 m and a maximum depth of 63 m. Its flushing rate is extremely rapid, averaging 0.8 years (K.I. Andrews, personal communication). Over the 33 years of operation at Wells, the Cariboo Gold Quartz Mining company produced in excess of five million dollars' worth of gold. The tailings from the milling and gold extraction by Cariboo Gold Quartz Mine were discharged to the northeast end of JCL and modified the original morphometry of the lake. At present, tailings deposits form a 4.5 m thick layer covering approximately 25 hectares of land adjacent to the lake. The Lowhee Creek channel passes through the tailings from the Cariboo Gold Quartz Mine before flowing into the northeast end of Jack of Clubs Lake (Figure 1). During spring runoff the waters of the creek flood an extensive area of the tailings. Most of the sediments that have accumulated in the lake, near the mouth of the creek, remain from the extensive hydraulic mining activities that occurred during the gold rush (Andrews, 1989). A man-made channel dug through the tailings at the northeast end of the lake allows it to discharge to the Willow River which flows for 130 km before joining with the Fraser River (Figure 1).

The second study was conducted in Larder Lake, Northern Ontario, 40km east of Kirkland Lake. Larder Lake has a mean depth and a maximum depth of 12.3 and 33.5 m, respectively. The perimeter of the shore line is 73.7 km. The lake is divided into three morphologically different areas: the west and east arms and the main central basin (Figure 1). The lake receives water from land drainage, four major creeks and the overflow from the gold mine tailings pond and the outflow is through the Larder River, which flows into the southern end of Raven Lake, and is part of the drainage area of the Ottawa River. A gold mine operated for 53 years on the northeast shore of the lake (Figure 1). The total mill production until its closing in 1990 was 38 million tons of ore. It is estimated that about 95% of the material after extraction of the gold was disposed in the tailing pond. Unsubstantiated reports describe a collapse of the tailings dike wall in the 1970's resulting in major deposition of tailings to the lake. Other small slumps in the dike wall were reported in May 1983.

Sampling and analytical methods

In Larder Lake samples for determination of benthic invertebrate community structure were collected using a modified Kajak-Brinkhurst corer with a plexiglas core liner having an inside diameter of 6.6 cm, only the top 10 cm of each core was examined. Thus, the surface area of the sample was 34.2 cm², and the volume was 342 cm³. Samples from Jack of Clubs Lake were taken using either a mini-ponar (23 x 23 cm) or a Birge-Ekman grab sampler, each of which sampled an area of 234 cm². Benthic community structure was examined at 10 sampling stations in Jack of Clubs Lake and 35 stations from Larder Lake. At each station five replicates were collected. Each replicate was extruded into a plastic whirl-pak bag. Sieving of the sample was conducted in the field using a 500 μ m (Larder L.) or 250 μ m (Jack of Clubs L.) mesh sieve. Sieved samples were preserved in 4% formalin for sorting and identification in the laboratory.

A mini-ponar sampler was used to obtain five replicate field samples of sediment for laboratory bioassays with four species of invertebrates. Each replicate sample was placed in a plastic bag and held at 4°C until tests could be conducted. Sediments from Larder L. were tested with a single species, *Tubifex tubifex*, those from Jack of Clubs L. with a suite of four species, *T. tubifex*, *Chironomus riparius*, *Hexagenia limbata* and *Hyalella azteca*.

Tests were conducted, in sets of six to seven, over a period of approximately six months. A clean control sediment from the Canadian Wildlife Bird Sanctuary, Long Point, Lake Erie was also tested with each set of samples to provide biological quality assurance. Complete details of the culture of organisms and conditions for each toxicity test with *C. riparius* and *T. tubifex* are described elsewhere (Reynoldson *et al.* 1991, Day *et al.* 1994, Reynoldson *et al.* 1994). Culture of *H. azteca* was conducted according to the procedure described in Borgmann *et al.* (1989). Eggs of the mayfly, *Hexagenia* spp. (both *H. limbata* and *H. rigida*), were collected during late June and July in 1991 according to the method of Hanes and Ciborowski (1992) and organisms were cultured using the procedure of Bedard *et al.* (1992). Tests with *H. azteca*, *C. riparius* and *T. tubifex* were conducted in 250 mL glass beakers containing 60 to 100 mL of sieved (500 μ m mesh), homogenized sediment with approximately 100 to 140 mL of overlying carbon-filtered, dechlorinated and aerated Lake Ontario water (pH 7.8 to 8.3, conductivity 439 to 578 μ ohms/cm, hardness 119 to 137 mg/L). Tests with the mayfly, *Hexagenia* were conducted in 1 L glass jars with 150 mL of test sediment and 850 mL overlying water. The sediment was allowed to settle for 24 h prior to addition of the test organisms. Tests were initiated with the random addition of 15 organisms per beaker for *H. azteca* and *C. riparius*, 10 organisms per jar for *Hexagenia* spp. and 4 organisms per beaker for *T. tubifex*. Juveniles of *H. azteca* were 3 to 7 d old at test initiation; *C. riparius* larvae were first instars and were approximately 3 d post-oviposition; *Hexagenia* nymphs were 1.5 to 2 months old (approximately 5 to 10 mg wet weight) and *T. tubifex* adults were 8 to 9 weeks old. Tests were conducted at $23 \pm 1^\circ\text{C}$ with a 16L:8D photoperiod (*T. tubifex* 24 h dark). Tests were static with the periodic addition of distilled water to replace water lost during evaporation. Each beaker was covered with a plastic petri dish with a central hole for aeration using a Pasteur pipette and air line. Dissolved oxygen concentrations and pH were measured at the beginning, middle and end of each exposure period. Tests were terminated after 10 d for *C. riparius*, 21 d for *Hexagenia* and 28 d for *H. azteca* and *T. tubifex* by passing the sediment samples through a 500 μ m mesh sieve. Sediment from the *T. tubifex* test was passed through an additional 250 μ m mesh sieve at test completion. Endpoints measured in the tests were survival and growth for *C. riparius*, *Hexagenia* spp. and *H. azteca* and for *T. tubifex* survival and production of cocoons and young. Mean dry weights of *H. azteca*, *C. riparius* and *Hexagenia* spp. were determined after drying the surviving animals from each treatment replicate as a group to a constant weight in a drying oven (60°C).

Statistical Methods

The large number of samples and the number of variables made a multivariate statistical approach the most appropriate for both pattern analyses and relating any effects on biota from sediment variables. Data were stored in three matrices, one for physico-chemical characteristics of sediment, a second for benthic community structure, and the third for sediment toxicity results. Structural pattern and spatial relationship between stations were established by ordination *i.e.*, multi dimensional scaling and cluster analysis (unweighted pair group mean averaging). The Bray Curtis association metric was used for pattern analysis of toxicity data and sediment chemistry and physics. Data analysis was carried out using the SYSTAT (Wilkinson, 1990) and PATN (Belbin, 1993) statistical packages.

Results and Discussion

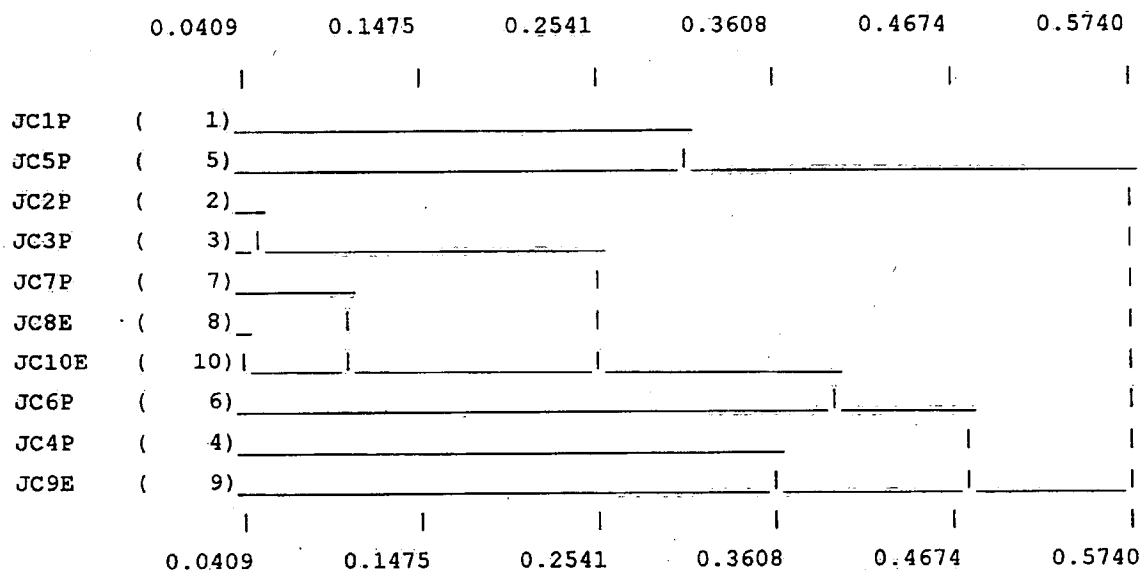
Jack of Clubs Lake

Community structure. A total of fifteen taxa were found excluding the copepods, cladocerans and ostracodes for which the sampling methods were inappropriate. The community was dominated by the Chironomidae (midges) which comprised over 63% of the total organisms found. The next most abundant group was the bivalve molluscs, largely Sphaeriidae, which made up a further 19% of the organisms; other groups were relatively rare overall. The Oligochaeta (segmented worms), which usually are an

important component of the benthic community, although fourth in overall abundance, were not common.

The abundance of the four most abundant taxa (Chironomidae, bivalves, Oligochaete and Diptera) was examined at all the stations (Figure 2). Numerically the midges (Chironomidae) were the most important group, making up from 40 (at station 6) to 80% (at station 2) of the community (Figure 2), they showed no clear spatial trend, although their numbers were comparatively low at station 5. The bivalves may be affected by the tailings as they comprised the lowest proportion of the community at stations 4 and 5. Overall they made up 19% of the benthic community but contributed only 6.5 and 10% at stations 4 and 5 respectively, and their abundance was markedly reduced, particularly at station 5. The Oligochaeta, which can form a major component of the benthic fauna, in Jack of Clubs L. only comprise 3.9% of the total benthic community. Their distribution and abundance were highly variable, ranging from approx. 10% of the community at the deep station 9 to less than 1% at station 7, and at three stations (3, 4 and 6) none were found. This group is particularly sensitive to metal contamination. Other diptera, (except chironomids), were only found at station 1. This station was unlike the other stations in that the sediment was highly organic with large amounts of plant material. This is probably typical of much of the littoral zone of the lake, and may have been the natural condition of stations at the tailings area. From Figure 2 it is evident that there is no dominant effect from the tailings and the stations at the tailings end of the lake (east end) are within the range of variability observed in the remaining stations. In fact a cluster analysis showed stations 1 (west end) and 5 to be most similar and stations 4 (east end) and 9 (deep basin) to group together (Figure 3).

Figure 3. Cluster analysis of benthic invertebrate families in Jack of Clubs Lake.



Sediment Toxicity Tests. Four sediment toxicity tests were performed on samples from the ten stations as well as on clean reference sediment obtained at Long Point in Lake Erie (Figure 4). The test endpoints were growth and survival in *Chironomus riparius* (midge), *Hyalella azteca* (scud) and *Hexagenia limbata* (mayfly) and survival and reproduction in *Tubifex tubifex* (worm). To establish whether or not the test response indicated toxicity the results were compared with data from 238 reference sites in the Great Lakes. The criteria are derived from the mean - 2 SD value from these reference sites (Reynoldson *et al.* 1995).

Reproduction in *Tubifex tubifex* has been shown to be a particularly sensitive to metal

contamination. At none of the ten stations was there any indication of toxicity. Survival in *C. riparius* and growth of *H. limbata* again showed no evidence of toxicity. Survival of *Hexagenia* was slightly reduced at stations 2, 3, 4 and 10. Growth in *C. riparius* was reduced at four stations, all deeper stations 7, 8, 9 and 10.

The last species tested was the amphipod *Hyaella azteca*. The data from this species showed the greatest variation, and both survival and growth were affected at stations within the lake. The test results also showed a marked reduction in survival and growth compared with the reference sediment. Stations 1, 2, 3 and 6 were the most affected. Of these four stations 1, 2 and 3 were located furthest from the tailings and only station 6 was in the vicinity of the tailings. Sediments at station 5, which was closest to the tailings, was one of the least toxic. It is difficult to interpret these results as demonstrating an impact due to tailings as there is little spatial consistency in the results. Results from the Great Lakes have shown *Hyaella* to be the most idiosyncratic of the species tested and particularly responsive to sediment characteristics such as particle size which may account for the observed results. The bioassay results show little evidence of a spatial effect in the vicinity of the tailings and suggest that there is little indication of sediment toxicity in this lake.

Larder Lake

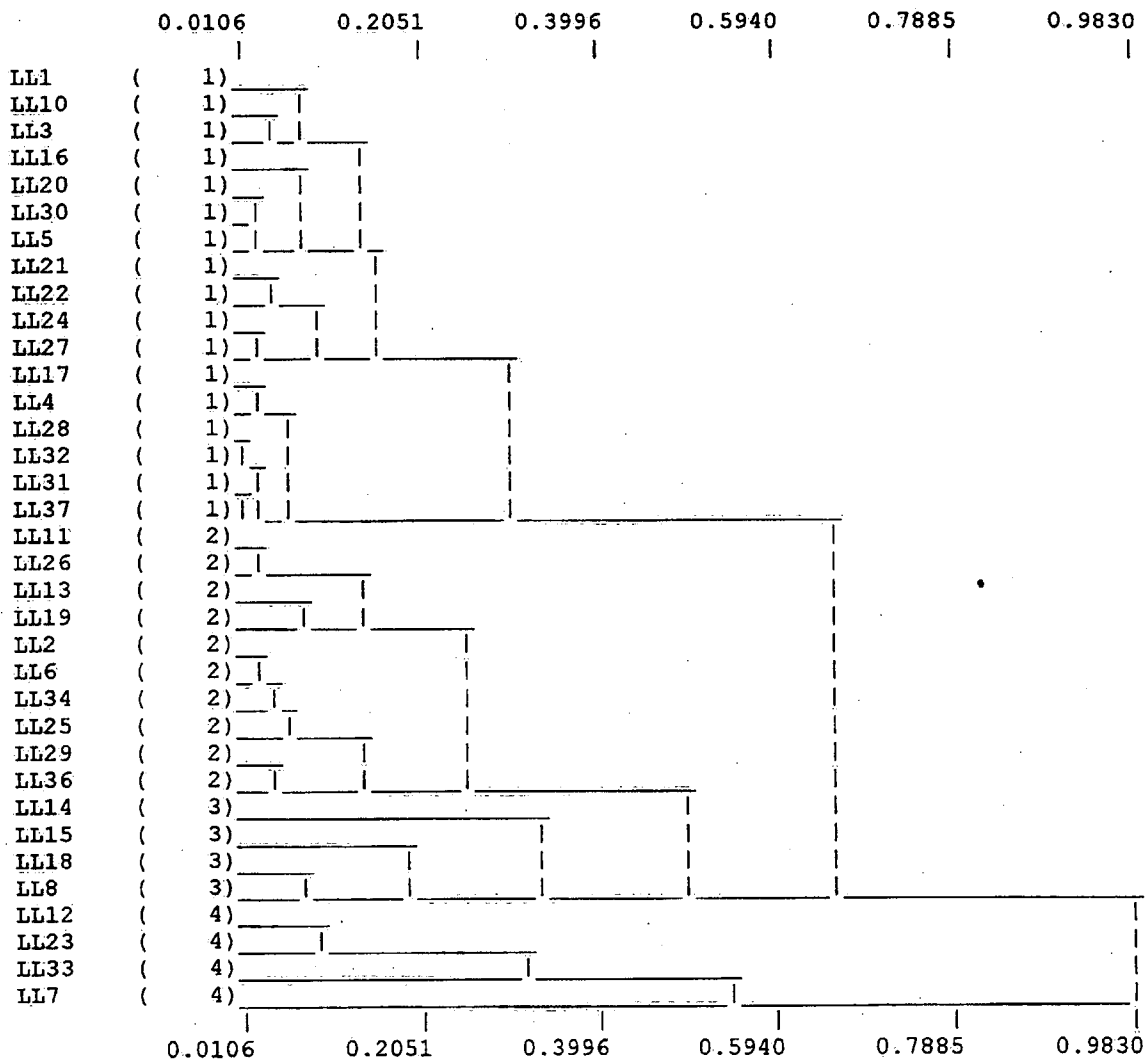
Community structure. The results of sampling at thirty five stations showed a non-existent or sparse benthic invertebrate community. No benthic organisms were found at 18 sampling stations in the lake. From the 45 cores collected at the remaining 15 stations the following number of organisms were found: three oligochaetes, five nematodes, seven amphipods and 16 chironomid larvae. At all but one of the 15 stations at which organisms were found, the maximum density was 1 organisms per 100 cm² (two individuals from 3 replicates). The only sampling station with a greater density of organisms was station 28, where the density was 2 organisms per cm². This station was located at the mouth of one of the larger tributaries. Given the absence of a benthic community, it was difficult to interpret spatial patterns. However, examination of the distribution of the sampling stations where species were entirely absent showed they were proximal to the tailings discharge.

Sediment Toxicity. Our results have shown the benthic community in Larder Lake to be severely impaired, being either absent or represented by extremely low densities (1-2 organisms per 100 cm²). To determine whether this finding was related to sediment toxicity directly or through other mechanisms, the toxicity associated with bulk sediments was estimated by laboratory testing. Sediment samples were obtained at 35 sampling stations for laboratory determination of sediment-associated toxicity as estimated by reproduction of the aquatic oligochaete *Tubifex tubifex*.

The results for numbers of cocoons and young produced are shown (Figure 5) in comparison with the criteria derived from the 238 Great Lakes reference stations. We have shown both the 50th (1 SD) and 95th (2 SD) percentiles for the reference data set. It is evident that there is evidence of significant toxicity at both the 50th and 95th percentiles in Larder Lake. Only four stations show values for one endpoint (cocoons) above the 95th percentile. From these results we would conclude that the sediments in Larder Lake must be considered as toxic and sediment toxicity is the most likely explanation for the absence of benthic invertebrates in the lake.

We have examined both the spatial pattern in sediment toxicity and the relationship between the pattern of toxicity and sediment chemistry using cluster analysis and ordination. The dendrogram (Figure 6) shows the first division to separate four stations - Gp 4 (stations 7, 12, 23, 33). The remaining stations can be separated into three large groups (Figure 6) with different degrees of toxicity (Table 1).

Figure 6. Cluster analysis of sediment toxicity in Larder Lake



There was no apparent spatial pattern to the sediment toxicity. For example the four stations forming the most toxic group were located in the eastern basin (station 7) adjacent to the tailings (station 23) and in the main portion of the west basin (stations 12, 33). Station 23 also adjacent to the tailings and close to station 22 was in the least toxic group (Gp 1). We also attempted to relate the results of the toxicity testing to sediment characteristics but found little correlation with either bulk sediment chemistry or physical characteristics. However, Jackson *et al.* (1995) have shown good correlations between the various metal fractions and reproduction at these stations.

Table 1. Response in sediment toxicity tests in four groups of stations formed by cluster analysis.

Variable	Gp 1	Gp 2	Gp 3	Gp 4
Adults	99.1	98.5	95.0	83.8
Cocoons	25.0	8.7	15.5	3.6
Young	35.8	18.0	5.8	3.4

Conclusions

These two studies provide a startling contrast in the response of two lakes to metal mining tailings. In Jack of Clubs Lake neither the benthic community data nor the sediment toxicity tests suggest any impact from mining activities in the lake. It is likely that this is partially a result of the morphometry of the lake with the tailings deposit, the major inflow and outflow both being located at the east end. Thus effectively isolating the lake from the effects of the tailings deposit. In contrast both the community structure and sediment toxicity tests suggest widespread contamination of the sediments of Larder Lake. It must be concluded that this lake is severely impaired. Because of the wide scale of the contamination remediation in this particular case is probably impractical.

In both these cases it is noteworthy that both field and laboratory data provide corroborative interpretive information. We consider this to be a powerful argument for the use of such an approach as well as the critical importance of reference station information to allow decisions regarding the significance of impacts to be made.

References

- Andrews, K.I. 1989. A Preliminary Investigation of Public Health and Environmental Impacts of Abandoned mine tailings at Wells, B.C., Ministry of Environment, Province of British Columbia.
- Armitage, P.D., Gunn, R.J.M., Furse, M.T., Wright J.F. and D. Moss, The use of prediction to assess macroinvertebrate response to river regulation. *Hydrobiol.* 144: 25-32, 1987.
- Azcue, J.M., A. Mudroch, F. Rosa, G.E.M. Hall, T.A. Jackson and Reynoldson, T., 1994. Trace elements in water, sediments, porewater, and biota polluted by tailings from an abandoned gold mine in British Columbia, Canada. *J. Geochem. Exploration* (in press).
- Bedard, D., A. Hayton and D. Persaud. 1992. Ontario Ministry of Environ. laboratory sediment biological testing protocol. Water Resources Branch, Ontario Ministry of Environment, Ontario, 26p.
- Belbin, L. 1993. PATN, pattern analysis package. Div. Wildlife and Ecology, CSIRO, Australia.
- Borgmann, U., K.M. Ralph and W.P. Norwood. 1989. Toxicity test procedures for *Hyaella azteca* and chronic toxicity of cadmium and pentachlorophenol to *H. azteca*, *G. fasciatus* and *D. magna*. *Arch. Environ. Contam. Toxicol.* 18: 756-764.
- Chapman, P.M. 1986. Sediment quality criteria from the sediment quality triad: an example. *Environ. Toxicol. Chem.* 5: 957-964.
- Day, K.E. and Reynoldson, T.B. 1991. Standard operating procedures (cultures and sediment bioassays methods) for: *T. tubifex*, *C. riparius*, *H. limbata* and *H. azteca*. NWRI report (in press).
- Hanes, E.C. and J.J.H. Ciborowski. 1992. Effects of density and food limitation on size variation and mortality of larval *Hexagenia*. *Can. J. Zool.* 70: 1824-1832.

International Joint Commission (IJC), 1987. Guidance on characterization of toxic substances problems in areas of concern in the Great Lakes Basin. Report from the Surveillance Work Group, Windsor, Ontario, 177pp.

Jackson, J.T., T. Reynoldson, K. Zhou, N. Nguyen, F. Rosa and A. Mudroch. 1995. Selective effects of certain heavy metals on reproductive activities of *Oligochaete tubifex* in lake sediments polluted with mine tailings. Submitted to heavy Metals in the Environ. Conference, Hamburg, Germany, Sept. 1995.

Johnson, R.K. and T. Wiederholm, 1989. Classification and ordination of profundal macroinvertebrate communities in nutrient poor, oligomesohumic lakes in relation to environmental data. *Freshw. Biol.* 21: 375-386.

Moss D. M.T. Furse M.T., Wright J.F. and P.D. Armitage, 1987. The prediction of the macro-invertebrate fauna of unpolluted running water sites in Great Britain using environmental data, *Freshw. Biol.* 17: 41-52,.

Mudroch, A., Hall, G.E.M., Azcue, J., Jackson, T.A., Reynoldson, T., and Rosa, F. 1993. Preliminary report on the effects of abandoned mine tailings at Wells, B.C., on the aquatic ecosystem of Jack o Clubs Lake. NWRI, Contribution 93-23..

Mudroch, A., Rosa, F., T. Reynoldson, Hall, G.E.M., Z. Kezhun, and R. Cooker, 1994. Effects of subaqueous gold mine tailings on Larder Lake ecosystem. NWRI, Contribution 94-03.

Reynoldson, T.B. 1992. Factors influencing the distribution of benthic fauna of Lake Superior: establishing long term monitoring sites. NWRI, Environment Canada.

Reynoldson T. and M. Zarull, 1993. An approach to the development of biological sediment guidelines. In: *Ecological Integrity and the Management of Ecosystems*, Ed: By S. Woodley, J. Kay and G. Francis, St. Lucie Press, 177-200.

Reynoldson, T.B., Thompson, S.P. and Bamsey, J.L. 1991. A sediment bioassay using the turbificid oligochaete worm *Tubifex tubifex*. *Environ. Toxicol. Chem.* 10: 1061-1072.

Reynoldson, T.B., K.E. Day, C. Clarke and D. Milani. 1994. The effects of indigenous animals on chronic endpoints in freshwater sediment toxicity tests. *Env. Tox. Chem.* 13: 973-977.

Reynoldson, T.B., K.E. Day, R.C. Bailey and R.H. Norris. 1995. Methods for establishing biologically based sediment guidelines for freshwater quality management using benthic assessment of sediment. *Australian J. Ecology* (in press).

Wilkinson, L. 1990. SYSTAT: The system for statistics. Evanston, Ill: SYSTAT, Inc.

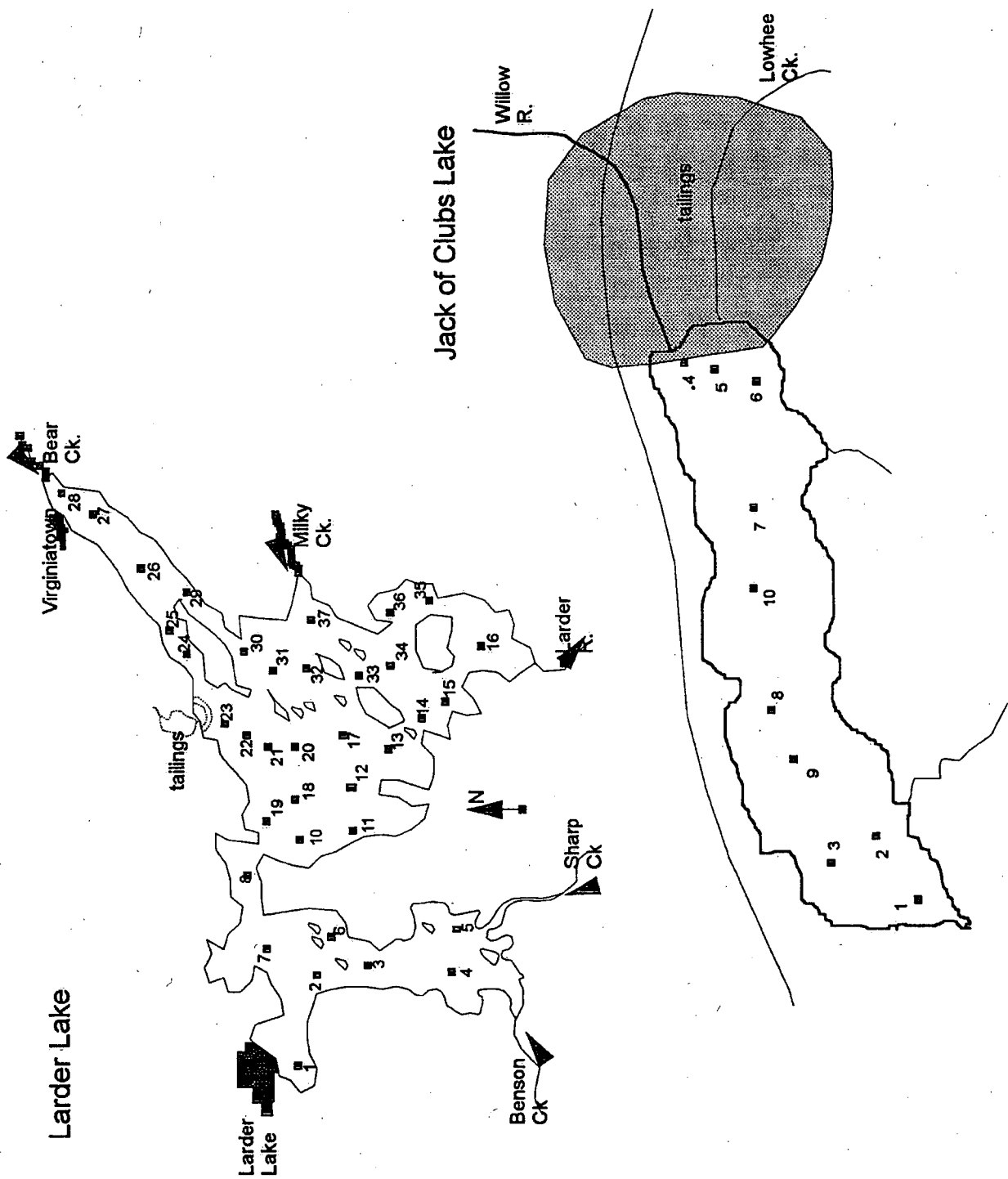


Figure 1. Sampling stations in Larder L. (N. Ontario) and Jack of Clubs L. (B.C.)

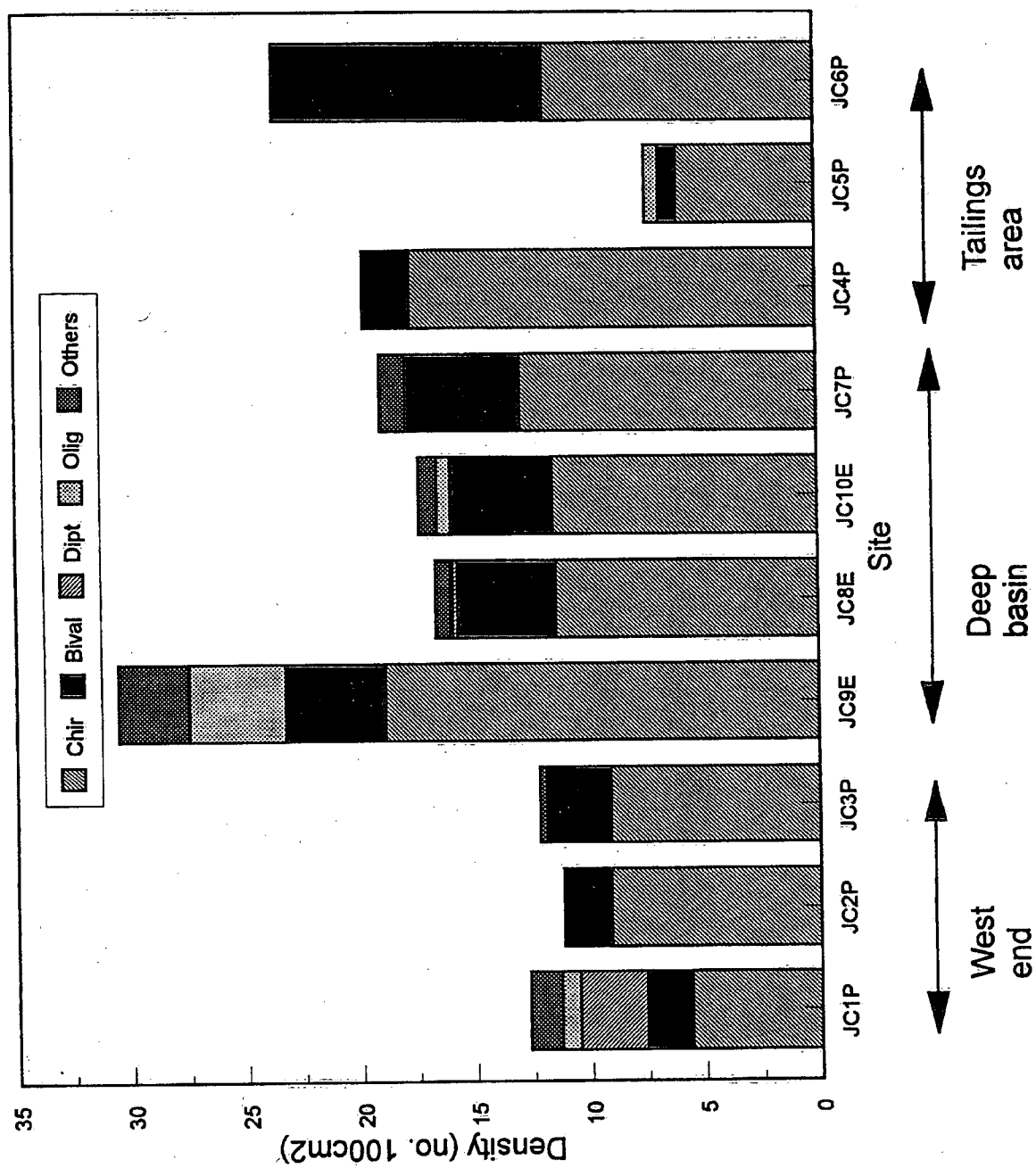
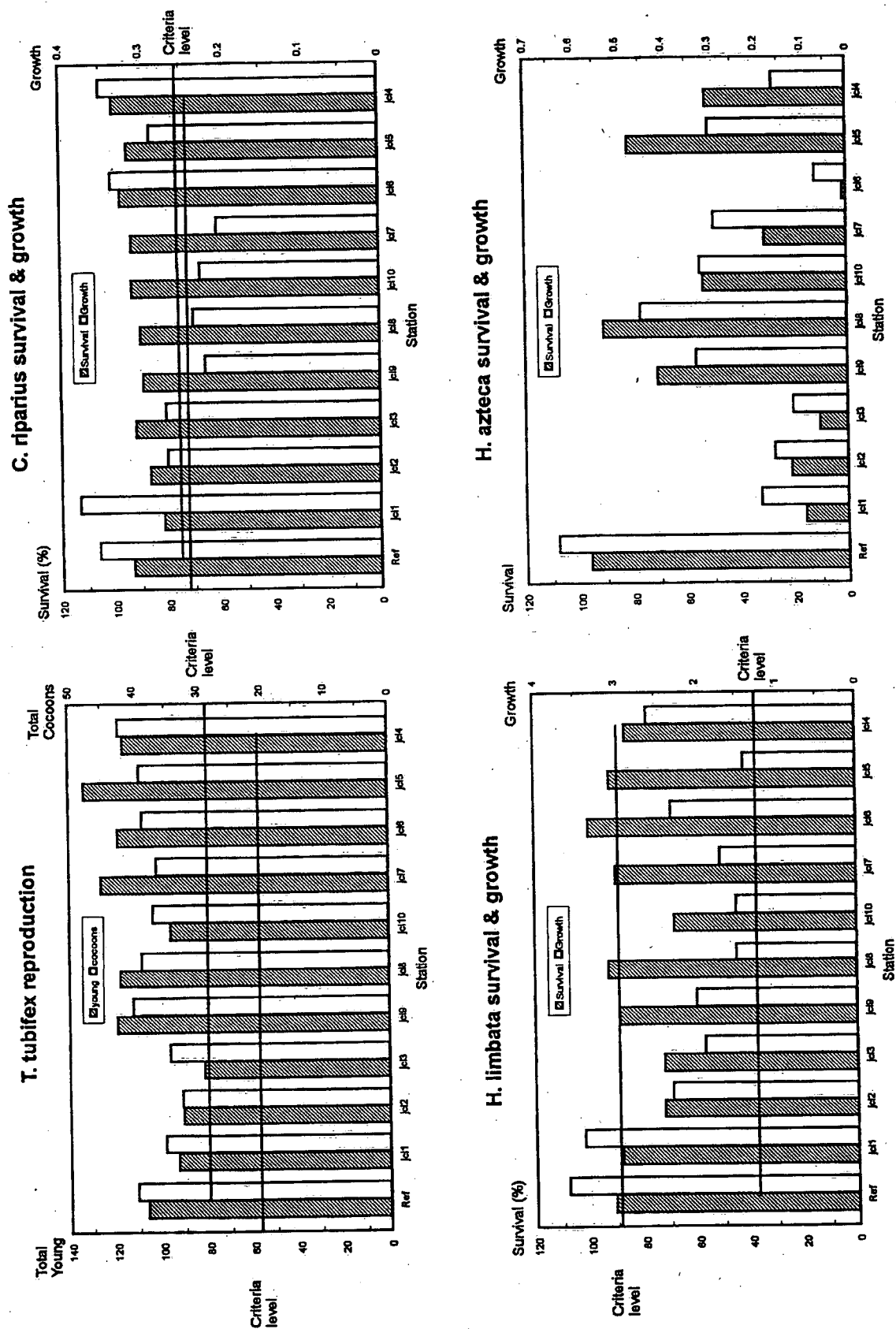


Figure 2. Abundance of major components of the benthic fauna of Jack of Clubs L., B.C.



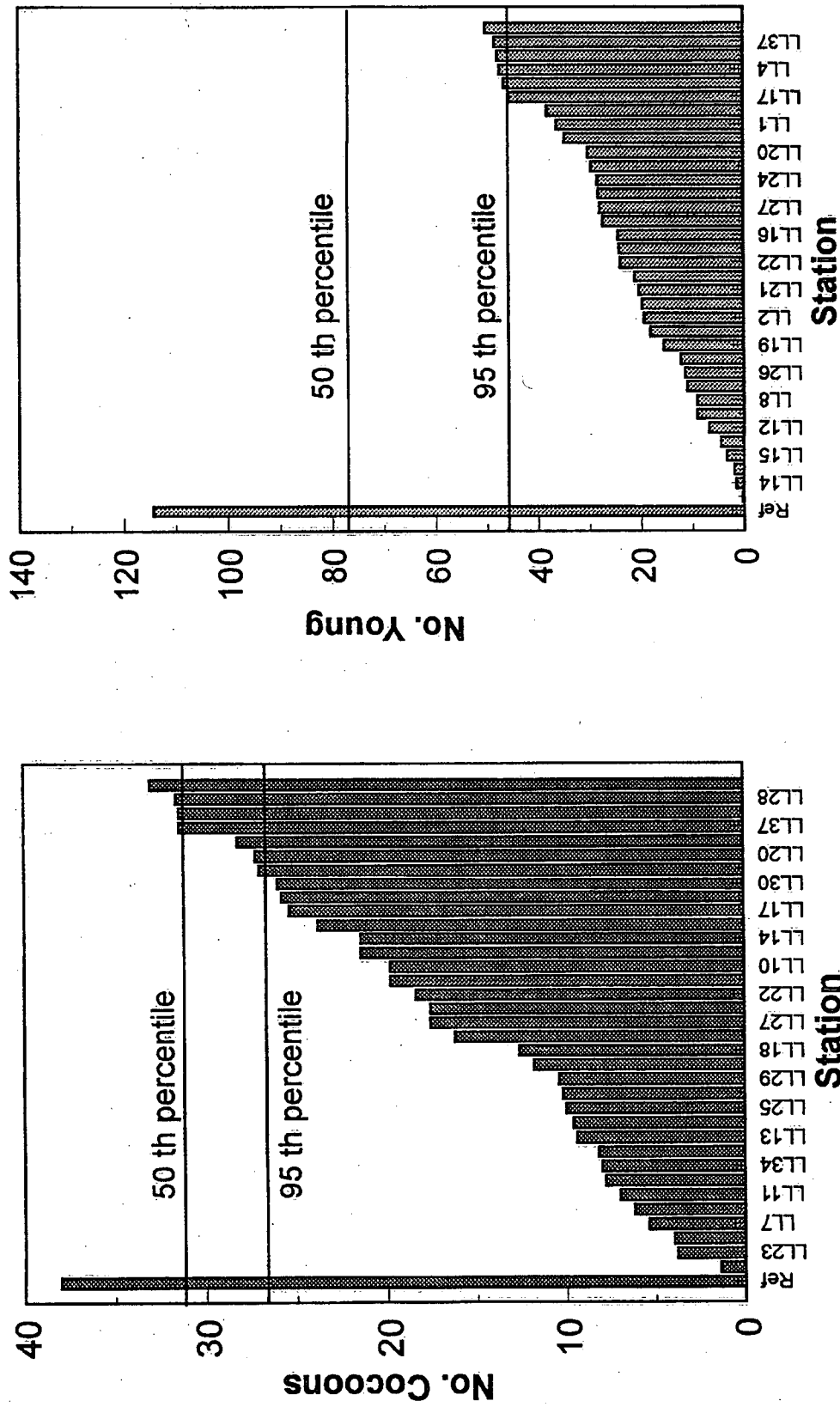


Figure 5. Sediment toxicity (*T. tubifex* reproduction) in Larder L. and comparison with criteria.

Environment Canada Library, Burlington



3 9055 1017 8109 3



Environment
Canada

Environnement
Canada

Canada

Canada Centre for Inland Waters

P.O. Box 5050
867 Lakeshore Road
Burlington, Ontario
L7R 4A6 Canada

National Hydrology Research Centre

11 Innovation Boulevard
Saskatoon, Saskatchewan
S7N 3H5 Canada

St. Lawrence Centre

105 McGill Street
Montreal, Quebec
H2Y 2E7 Canada

Place Vincent Massey

351 St. Joseph Boulevard
Gatineau, Quebec
K1A 0H3 Canada

Centre canadien des eaux intérieures

Case postale 5050
867, chemin Lakeshore
Burlington (Ontario)
L7R 4A6 Canada

Centre national de recherche en hydrologie

11, boul. Innovation
Saskatoon (Saskatchewan)
S7N 3H5 Canada

Centre Saint-Laurent

105, rue McGill
Montréal (Québec)
H2Y 2E7 Canada

Place Vincent-Massey

351 boul. St-Joseph
Gatineau (Québec)
K1A 0H3 Canada