Trace Metals in Sediments and Biota from Strathcona Sound, NWT; Nanisivik Marine Monitoring Programme, 1974 - 1979

B.W. Fallis

Western Region
Department of Fisheries and Oceans
Winnipeg, Manitoba R3T 2N6

May 1982

Canadian Technical Report of Fisheries & Aquatic Sciences No. 1082

Canadian Technical Report of Fisheries and Aquatic Sciences

These reports contain scientific and technical information that represents an important contribution to existing knowledge but which for some reason may not be appropriate for primary scientific (i.e. *Journal*) publication. Technical Reports are directed primarily towards a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of the Department of Fisheries and Oceans, namely, fisheries management, technology and development, ocean sciences, and aquatic environments relevant to Canada.

Technical Reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report will be abstracted in *Aquatic Sciences and Fisheries Abstracts* and will be indexed annually in the Department's index to scientific and technical publications.

Numbers 1-456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. Numbers 457-714 were issued as Department of the Environment, Fisheries and Marine Service, Research and Development Directorate Technical Reports. Numbers 715-924 were issued as Department of Fisheries and the Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

Details on the availability of Technical Reports in hard copy may be obtained from the issuing establishment indicated on the front cover.

Rapport technique canadien des sciences halieutiques et aquatiques

Ces rapports contiennent des renseignements scientifiques et techniques qui constituent une contribution importante aux connaissances actuelles mais qui, pour une raison ou pour une autre, ne semblent pas appropriés pour la publication dans un journal scientifique. Il n'y a aucune restriction quant au sujet, de fait, la série reflète la vaste gamme des intérêts et des politiques du Ministère des Pêches et des Océans, notamment gestion des pêches, techniques et développement, sciences océaniques et environnements aquatiques, au Canada.

Les Rapports techniques peuvent être considérés comme des publications complètes. Le titre exact paraîtra au haut du résumé de chaque rapport, qui sera publié dans la revue *Aquatic Sciences and Fisheries Abstracts* et qui figurera dans l'index annuel des publications scientifiques et techniques du Ministère.

Les numéros 1-456 de cette série ont été publiés à titre de Rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457-714, à titre de Rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715-924 ont été publiés à titre de Rapports techniques du Service des pêches et de la mer, Ministère des Pêches et de l'Environnement. Le nom de la série a été modifié à partir du numéro 925.

La page couverture porte le nom de l'établissement auteur où l'on peut se procurer les rapports sous couverture cartonnée.

Canadian Technical Report of

Fisheries and Aquatic Sciences 1082

May 1982

TRACE METALS IN SEDIMENTS AND BIOTA FROM STRATHCONA SOUND, NWT; NANISIVIK MARINE MONITORING PROGRAMME, 1974-1979

by

B. W. Fallis

Western Region

Department of Fisheries and Oceans

Winnipeg, Manitoba R3T 2N6

This is the 143rd Technical Report

from the Western Region, Winnipeg

Cat. no. Fs 97-6/1082 ISSN 0706-6457

Correct citation for this publication is:

Fallis, B.W. Trace metals in sediments and biota from Strathcona Sound, NWT; Nanisivik Marine Monitoring Programme, 1974-1979. Can. Tech. Rep. Fish. Aquat. Sci. 1082: v + 34 p.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ABSTRACT

Fallis, B.W. Trace metals in sediments and biota from Strathcona Sound, NWT; Nanisivik Marine Monitoring Programme, 1974-1979. Can. Tech. Rep. Fish. Aquat. Sci. 1082: v + 34 p.

The development of the Nanisivik Mine resulted in the federal government initiating a programme to monitor changes in trace metal concentrations in sediments and biota in Strathcona Sound, NWT. The first set of post-operational samples since commencement of production at the mine in October, 1976 were collected in August, 1979. Analytical results indicate that concentrations of lead, zinc, cadmium and arsenic in sediments, seaweed (Fucus vesiculosus) and molluscs (Mya truncata) in the vicinity of the marine terminal (station 3) have increased relative to pre-operational concentrations. Concentrations of lead, zinc and arsenic in sea urchins, (Strongylocentrotus droebachiensis), at station 3 have also increased; however, the post-operational cadmium concentration in sea urchins was slightly less than that recorded prior to production. Increases relative to pre-operational concentrations at station 3 were as follows: mean lead concentrations in sediments, Fucus and Mya rose by 56.0, 57.4 and 1.09 µg/g, respectively, representing 3.8, 28.3 and 1.92 times pre-operational values, while the concentration in sea urchins rose from below the limit of detection to 23.9 µg/g. Mean zinc concentrations in sediments, Fucus, Strongylocentrotus and Mya rose by 595, 405, 213 and 283 µg/g respectively, equivalent to elevations of 4.8, 5.6, 4.3 and 3.7 times pre-operational values. Arsenic concentrations rose 5.4, 10.1, and 0.2 µg/g respectively in sediments, Fucus and Strongylocentrotus, equivalent to 2.4, 1.4 and 1.1 times pre-operational values, respectively.

Concentrations of lead, zinc, cadmium, arsenic and mercury in Serripes groenlandicus from station 3 increased 2.99, 97.4, 0.92, 4.32 and 0.11 µg/g, (19.7, 2.3, 1.9, 1.7 and 4.7 times) respectively, between 1975 and 1979. Metal concentrations in Cardium ciliatum also showed an increase at station 3 during the same time period with lead, zinc, cadmium, arsenic and mercury elevations of 0.37, 33.8, 218, 3.37 and 0.11 µg/g, equivalent to increases of 1.4, 1.7, 2.4, 1.7 and 2.2 times pre-operational levels, respectively.

Comparison of 1979 Fucus metal concentrations at stations 1 and 2 to Bohn's (1979) 1975 pre-operational concentrations at comparable stations, indicated highly significant differences ($P \leq 0.01$) in cadmium and zinc concentrations at station 1 and a significant difference ($P \leq 0.05$) in the concentration of zinc at station 2. Lack of pre-operational data from other stations in the Sound prevented assessing the extent to which trace metals in biota at other stations have changed. Analytical results from samples collected in subsequent years should provide an indication of the zone of influence resulting from trace metal inputs to Strathcona Sound.

Concentrations of lead and zinc in Strongylocentrotus and zinc concentrations in Mya in the vicinity of the marine terminal (station 3) currently exceed the maximum recommended levels (1.0 µg/g Pb, 100 µg/g Zn) for marine animal products established by the Canadian Food and Drug Directorate. Correlations between dry weight of soft tissues, shell height, width, and length and metal concentration in Mya truncata and dry weight, test height, width, and metal concentration in Strongylocentrotus droebachiensis, showed no consistent pattern with respect to the various stations sampled and thus prevented predictions of future concentrations which may be attained in these species. Continued inputs of trace metals to Strathcona Sound may result in elevation of biota concentrations to threshold levels at station 3 (and possibly other stations), beyond which further elevations will be less likely. The toxicological and physiological consequences of such threshold trace metal levels on biota in Strathcona Sound are unknown.

Key words: Monitoring; seaweeds; sea urchins, bivalve molluscs; gastropods; sculpins.

RESUME

Fallis, B.W. Trace metals in sediments and biota from Strathcona Sound, NWT; Nanisivik Marine Monitoring Programme, 1974-1979. Can. Tech. Rep. Fish. Aquat. Sci. 1082: v + 34 p.

L'essor de la mine Nanisivik a entraîné le gouvernement fédéral à créer un programme pour étudier les modifications en concentrations de métaux à l'état de trace dans les sédiments et le biote, dans la Strathcona Sound (T.N.-O.). Les premiers échantillons a être recueillis depuis que la mine est en production (octobre 1976) l' ont été en août 1979. L'analyse révèle que les concentrations en plo mb, en zinc, en cadmium et en arsenic que l'on a trouvées dans les sédiments, la plante marine Fucus vesiculosus et les mollusques (Mya truncata) recueillis dans la voisinage de la station marine 3, sont plus fortes qu'elles ne l'étaient avant l'ouverture de la mine. Les concentrations en plomb, en zinc et en arsenic constatées dans les oursins verts (Strongylocentrotus droebachiensis) à la station 3 sont également plus fortes; sauf pour la concentration en cadmium, qui est légèrement plus faible. Voici les augmentations qui ont été enregistrées à la station 3 par rapport à l'état qui existait avant que la mine fonctionne: la concentration moyenne en plomb dans les sédiments, le Fucus et les Mya a augmenté respectivement par 56.0, 57.4 et de 1.09 µg/g (une augmentation respectivement de 3.8, 28.3 et 1.92), dans les oursins verts, elle est passée de l'état non décelable à 23.9 µg/g. La concentration moyenne en zinc dans les sédiments, le Fucus, les Strongylocentrotus et les Mya; s'est accrue par 595, 405, 213 et 283 µg/g respectivement (une augmentation respectivement de 4.8, 5.6, 4.3 et 3.7); celle en arsenic a augmenté par 5.4, 10.1 et de 0.2 µg/g dans les sédiments, le Fucus et les Strongylocentrotus respectivement (une augmentation respectivement de 2.4, 1.4 et 1.1).

De 1975 à 1979, les concentrations en plomb, en zinc, en arsenic et en cadmium dans les Serripes groenlandicus, à la station 3, a augmenté par 2.99, 97.4, 0.92, 4.32 et 0.11 µg/g respectivement (une augmentation de 19.7, 2.3, 1.9, 1.7 et 4.7). On a aussi noté une augmentation de concentration en métaux dans le Cardium ciliatum, à la station 3, les concentrations en plomb, en zinc, en cadmium, en arsenic et en mercure ayant augmenté par 0.37, 33.8, 218, 3.37 et 0.11 µg/g respectivement (une augmentation de 1.4, 1.7, 2.4, 1.7 et 2.2).

Si l'on compare les concentrations en métaux dans le Fucus notées aux stations 1 et 2 en 1979 à celles de Bohn (1979) notées à des stations comparables en 1975, avant que la mine produise, on constate des différences très importantes ($P \leq 0.01$) dans les concentrations en cadmium et en zinc à la station 1, et une différence importante ($P \leq 0.05$) dans la concentration en zinc à la station 2. N'ayant aucune donnée d'autres stations pour la période d'avant la création de la mine, nous n'avons pu évaluer jusqu'à quel degré les métaux à l'état de trace sont présents dans le biote, à d'autres stations. Les résultats des analyses faites sur les échantillons recueillis dans les années subséquentes devraient indiquer la zone d'influence provoquée par le déversement de métaux dans la Strathcona Sound.

Les concentrations en plomb et en zinc relevés, à proximité de la station 3, dans le Stongylocentrotus, ainsi que celles en zinc dans les Mya, dépassent actuellement les niveaux maximums recommandés (1.0 µg/g Pb, 100 µg/g Zn) par la Direction générale des aliments et drogues, pour les produits d'animaux marins. Les comparaisons que l'on a établies entre les Mya truncata et les Strongylocentrotus droebachiensis du point de vue du poids sec des tissus mous, des dimensions (hauteur, largeur, longueur) du coquillage et des concentrations en métaux, ne révélèrent aucune constance par rapport aux diverses stations échantillonnées; en conséquence, il a été impossible de prévoir quels degrés de concentration atteindront les métaux dans ces espèces à l'avenir. Le déversement continuel de métaux à l'état de trace dans la Strathcona Sound pourrait entraîner des concentrations en métaux dans le biote à des niveaux seuil à la station 3 (peut-être même aux autres stations), niveau seuil dont le franchissement serait peu probable. les incidences toxicologiques et physiologiques de tels niveaux seuils de métaux à l'état de trace dans le biote dans la Strathcona Sound ne sont pas connues.

Mots-clés: Surveillance; plantes marines; oursins verts; mollusques bivalves; gastropodes; chabot du Nord.

INTRODUCTION

In June, 1974, the Canadian government entered into an agreement with Mineral Resources International whereby an 18% equity interest in the development of the Nanisivik lead-zinc mine on Baffin Island was acquired. The development of the mine was viewed as a "pilot project" which would test the feasibility of conducting year-round mining operations in the High Arctic.

In order to assess the potential environmental implications of the development and operation of the mine, the Department of Fisheries and Oceans, Western Region (formerly the Department of the Environment, Fisheries and Marine Service) conducted studies on Strathcona Sound and freshwater lakes in the vicinity of the mine during 1974-76.

Initial assessments of tailings disposal at Nanisivik, undertaken by Watts, Griffis and McOuat Ltd. indicated that the preferable option was to "allow the tailings to settle into a deep area in Strathcona Sound where no marine life is known to exist". The original tailings disposal plan called for direct discharge of tailings into Strathcona Sound at a depth of 46 m. The 1974-76 studies were primarily directed toward acquiring information on the types and abundance of biota in Strathcona Sound below the proposed depth of discharge.

Discussions between industry and government personnel resulted in modification of the original tailings disposal plan. The system adopted utilized the two basins of West Twin Lake as a tailings pond. A pond suitable for use as a treatment area (Fig. 1) was formed by construction of a dyke at the northeast corner of the lake, and a decant structure at the outflow from the treatment pond into Twin Lakes Creek. The treatment pond was intended for use should the effluent entering Twin Lakes Creek not meet the quality criteria stipulated in the water licence issued under the Northern Inland Waters Act.

Although the primary intent of the predevelopment environmental studies was to document the freshwater and marine biota in areas which might be affected by the development, some sediment samples and biota collected in 1974-76 were analysed to determine the existing concentrations of metals prior to development. These samples constitute the baseline with respect to metal concentrations present in Strathcona Sound prior to the commencement of production in the autumn of 1976.

Trace metals associated with the operation of the Nanisivik Mine (73°02'N, 84°32'W) may gain entry into Strathcona Sound by a number of means, the most likely of which are tailings pond discharges into Twin Lakes Creek and accidental spillage of lead and zinc concentrates during the loading of concentrate-carrying ships. Concentrates spilled on land may subsequently be transported to Strathcona Sound via wind action, precipitation or melt water runoff.

Prior to commencement of production at Nanisivik in the fall of 1976 there was considerable discussion amongst scientists of the Department of Indian and Northern Affairs (DIAND), the Fisheries and Marine Service, and the Canadian Wildlife Service within the Department of the Environment (DOE), with respect to the need for an environmental monitoring programme to assess the impacts of trace metals upon marine biota. It was felt that a programme to monitor year to year changes in the concentrations of trace metals (lead, zinc, cadmium, arsenic and mercury) in sediments, seaweed, various marine invertebrates, and fishes would enable the detection of potential long term problems associated with input of metals into Strathcona Sound. Such a programme was envisaged as the responsibility of government, rather than industry; industry has a responsibility to ensure that the terms and conditions of its water licence are adhered to, thereby ensuring maintenance of "acceptable" water quality at the point of discharge from the tailings pond treatment system.

In August, 1979, the first post-operational samples of sediments, seaweed, marine invertebrates, and fishes were obtained from Strathcona Sound for use in undertaking trace metal determinations. This report summarizes the results of analytical determinations performed on samples collected during 1979 and compares these to analyses of samples collected from the vicinity of the marine terminal (station 3) prior to commencement of milling operations at the mine.

MATERIALS AND METHODS

1974-76

Samples of sea urchins and molluscs variously obtained during August of 1975-76 and May of 1976 were collected from the vicinity of station 3 using a modified Ekman dredge (Burton and Flannagan 1973) and a Kolkwitz dredge. The sampling technique precluded selection of organisms by size and as a result it was necessary to group several organisms of similar size together in order to obtain sufficient material for analysis. Samples of seaweed (Fucus vesiculosus) were collected by means of the Kolkwitz dredge and from gill net sets which often removed seaweed from the substrate.

In 1976 samples of Fucus were also collected from Arctic Bay to serve as a "control" for comparison with results of analyses performed on samples collected from Strathcona Sound. Arctic Bay is not subject to the influences of runoff from unnaturally exposed areas of lead and zinc mineralization.

Sediment samples were collected by grab sampling using an Ekman dredge. In September, 1975, an extensive collection of sediment samples was obtained by the Geological Survey of Canada (GSC) using the Canadian Coast Guard Ship d'Iberville and the results from stations located close to monitoring stations are reported herein. It should be noted that owing to variation in the depths from which samples were obtained by the GSC in 1975 and those obtained by this study in 1979, direct comparisons should not be made.

Sample preparation followed methods outlined below for the 1979 samples.

1979

Samples were collected during late August and early September from eight stations established within Strathcona Sound (Fig. 2). Stations were selected on the basis of substrate type and faunal/floral abundance. Each station was marked with a cairn painted orange and a photograph was taken from the helicopter from a distance of about 0.8 km for use in future efforts to locate stations. Photographs are on file in Ottawa and Yellowknife (DIAND), Winnipeg (DFO), and with Dr. Norman Snow (Petro Canada), Calgary. Samples at each station were collected by SCUBA diving from the shoreline of Strathcona Sound.

At each station efforts were made to procure 25 specimens each of Mya truncata and Strongylocentrotus droebachiensis, although in some instances this was not possible. Representatives of other invertebrates were collected to determine the species to species variability in metal concentrations. Specimens of the seaweeds Fucus vesiculosus, Laminaria solidungula and Agarum cribrosum were also collected where possible and analysed for trace metals. Specimens of Myoxocephalus spp. were opportunistically collected for analysis.

Seaweed and invertebrate samples were rinsed in water from East Twin Lake and then in triple-deionized, distilled water before being frozen in plastic bags. Samples were transported to the laboratory in a frozen state and kept frozen until January 1980 at which time they were prepared for analysis.

Sediments

Sediment samples were collected using a K.B. Corer, placed in Whirlpak® bags and frozen. Subsequent to thawing in the laboratory, the samples were freeze-dried for 48 h and then screened through 1.00 mm stainless steel sieves. The <1.00mm fraction was placed in a jar ball mill (Norton Chemical) for 1 h to pulverize and homogenize the sample. All equipment was washed in dilute Alconox solution, 1 molar HCl solution and then rinsed in triple-deionized water and air dried between samples.

Seaweed

Samples of Fucus were either washed prior to analysis in two 500 mL baths of triple-deionized water or left unwashed and simply drained to remove excess fluids. The resulting slime was retained and freeze-dried for analysis. The plants were subdivided into new growth (terminal 1-4 cm), old growth and stipe. The assessment of new growth in Fucus was subjective, based upon new growth having lighter coloration than the remainder of the plant. Where sample quantities from individual plants did not provide sufficient material to perform an analysis, similar anatomical portions from several plants were combined together and then separated into groups to be washed or left unwashed. Subsequent to determination of wet weights, samples were freeze-dried for 48 h, reweighed and then ground up.

Specimens of Laminaria and Agarum were prepared using similar methods, taking into consideration differences in species growth patterns when dissecting the plants. Some plants were cut longitudinally to evaluate the effect of washing on identical subsamples. On all whole plant analyses, the holdfast was removed to prevent contamination from adhering sediment. Samples were ground in the same manner as the molluscs.

Sea urchins

The test height and diameter of sea urchins, Strongylocentrotus droebachiensis, were measured with calipers and wet weights were determined prior to freeze-drying for 48 h. The dried samples were reweighed and then pulverized with a mortar and pestle prior to grinding. Wherever sample quantities permitted, individual organisms were homogenized separately. However, with smaller organisms, it was necessary to group organisms of similar size together in order to provide sufficient material for analysis.

Molluscs

Molluscs were measured with calipers with respect to shell length, width and height. Measurements of Mya were made with the siphon on the left. The soft body tissues were scraped into an aluminium foil dish using a stainless steel spatula. Shells were refrozen for possible future use in age determinations. Wet weights were determined and the samples were then freeze-dried for 48 h. Subsequent to freeze-drying, samples were homogenized in a Janke and Kunkel type A1051 grinder equipped with a stainless steel knife and cup. Additional grinding with a mortar and pestle was required to obtain good homogenization. Between samples, the grinder was cleaned with Kimwipes® tissues and a jet of compressed air. Stainless steel spatulas were used to transfer sample material from the grinder to Whirlpaks® which were then stored in a desiccator until submission to the lab for analysis. Wherever possible, individual organisms were homogenized for analysis or a number of similar sized organisms were grouped together and homogenized. Where individual homogenates were of sufficient size, subsamples were removed and pooled with subsamples of similar organisms from the same station. These pooled homogenates provided a comparative check on the analytical variability.

Miscellaneous invertebrates

Sea cucumber length and width measurements were made prior to rinsing the entire organism in triple-deionized water to remove excess debris and slime. Starfish (Leptasterias polaris) samples were measured with respect to greatest length and body width and rinsed in triple-deionized water to remove excess slime prior to weighing. Sea cucumbers and starfish were freeze-dried and homogenized in a manner similar to the molluscs and sea urchins.

Fishes

After determination of total length and weight, samples of Myoxocephalus spp. were rinsed in triple-deionized water. The skin was removed and a fillet was cut from each side taking care to exclude any bones. The entire liver was then excised and each tissue weighed separately. Samples were oven-dried at 100°C for 24 h prior to digestion and analysis.

Chemical analyses

The seaweed, invertebrate, and fish samples were analysed in the Freshwater Institute by the Industry Services Section, using flame atomic absorption spectroscopy for cadmium, zinc and lead and flameless atomic absorption spectroscopy for arsenic and selenium. Where sample size was sufficient, triplicate analyses were performed. National Bureau of Standards reference material was analysed throughout (Appendix I). Mercury determinations were made according to Hendzel and Jamieson (1976) and Knechtel and Fraser (1979). Details of analytical techniques are presented in Appendix II.

Sediment samples were analysed by the Toxicology Laboratory of the Freshwater Institute following the methods of Mullin and Riley (1956), Armstrong and Uthe (1971) and Vijan and Wood (1974, 1976). Analytical determinations were done in duplicate. Standards, blanks and N.B.S. reference material were analysed in a similar fashion to the other samples.

Owing to initial concerns about the variability associated with the triplicate determinations for lead in organisms, several samples were checked independently by the Toxicology Laboratory without prior knowledge of the previous analytical results obtained. This check revealed very close agreement with the mean values of triplicate analyses performed by the Industry Services Laboratory (Appendix III).

Statistical analyses

Statistical analyses were limited to stations 1, 2, 3 and 4 for Mya and stations 1, 3, 5 and 7 for Strongylocentrotus. Only results from analyses of individual organisms were used in the statistical analyses. In order to realistically utilize analytical results which were below the limit of detection, data were analysed treating values below the limit of detection as the absolute value of the detection limit. One way analyses of variance were performed on each of the aforementioned data sets with respect to metal concentrations, thereby revealing general significant differences ($P \leq 0.05$) in metal concentrations in similar organisms between stations.

Unequal replicates between stations were accounted for by employing harmonic means as described by Snedecor and Cochran (1967). The difference between mean metal concentrations at various stations, were then compared to the least significant difference (LSD) criterion; values greater than the LSD value being considered significant. An additional test of the significance of the mean metal concentrations between stations was performed using Q, a criterion based on the tables of the Studentized Range. The Q criterion is a more rigorous test of difference between means in that a larger difference is required to establish significance than with the LSD criterion.

Correlation coefficients were determined for trace metals at each station with respect to individual organism body measurements. Owing to the relatively small sample sizes from most stations and the large variability in sample sizes between stations for a particular species, regression analyses of metal concentrations on body measurements were not undertaken.

RESULTS

Tabulations of data are arranged by station in order of increasing distance from the mouth of Twin Lakes Creek as summarized below. It should be noted that only station 3 was sampled prior to commencement of production at the mine. As previously discussed the 1974-76 study was aimed at determining the abundance and diversity of organisms within Strathcona Sound and not initially intended as the pre-operational phase of a metal monitoring programme.

Station	Year(s) Sampled	Distance from Mouth of Twin Lakes Creek (km)
3	1974,75,76,79	1
2	1979	4.5
4	1979	5.8
7	1979	7.5
6	1979	9.3
8	1979	14.5
1	1979	15.0
5	1979	18.0

It is important to bear in mind that weather patterns, currents and tidal cycles all influence the dispersion route of waters entering Strathcona Sound via Twin Lakes Creek. Turbid water entering the Sound in 1975, as a result of construction activities in East and West Twin Lakes, was observed to distribute itself along the south shore of Strathcona Sound westwards toward Admiralty Inlet and offshore for a distance of approximately 0.5 km. The daily variation in such a dispersion pattern is unknown, and could markedly influence the availability of trace metals for bioaccumulation in a particular area.

SEDIMENTS

Analyses of samples taken from Strathcona Sound in 1974 are presented along with those for samples collected by Dr. Brian Bornhold of the Geological Survey of Canada during 1975 (Table 1). Only those 1975 stations sampled by Dr. Bornhold which were close to the monitoring station locations are tabulated. Differences in sampling depths prevent direct comparison of 1975 results from stations sampled by the GSC with those sampled by the Department of Fisheries and Oceans.

Although the size fractions analysed were somewhat different with respect to year, gross comparisons are considered meaningful, considering the tendency of trace metals to be most closely associated with the finer particles. Table 1 illustrates that zinc concentrations in the sediments at station 3 are almost five times greater than they were in 1974. Pre-operational zinc concentrations at station 3 were also three times greater than those reported by Campbell and Loring (1980) as being characteristic of coastal sediments in the North Atlantic ocean. This probably reflects leaching from areas of mineralization and transport of particulate material into the sound. The zinc concentration at station 4 has also increased slightly relative to pre-operational levels, whereas all of the other stations show a decline in concentrations. This general decline may be attributed to samples being taken in 1975 from somewhat different depths and locations than the actual monitoring stations. Lead, cadmium and arsenic concentrations in the sediments at station 3 have increased 3.8, 6, and 2.4 times, respectively, relative to pre-operational concentrations.

SEAWEED

Fucus vesiculosus

Pre-operational trace metal concentrations in seaweed are available for station 3 and for Arctic Bay (Table 2). When compared with Table 3 it is seen that lead concentrations (in washed whole plants, minus stipe) have increased by more than 28 times to 59 µg/g, zinc concentrations by 5.6 times to 493 µg/g and cadmium by 2.6 times to 1.66 µg/g relative to concentrations present in 1976. Arsenic and selenium concentrations are slightly higher than those observed in 1976. More noteworthy is the fact that concentrations of all the trace elements monitored in Fucus with the exception of cadmium, are greater at station 3 than at any other station. The differences between station 3 concentrations and the others (excluding station 4) are similar to the differences between the pre-operational and post-operational values for station 3, indicating that the greatest uptake of metals by seaweeds has occurred in the vicinity of the marine terminal and point of entry of Twin Lakes Creek into Strathcona Sound. Metal concentrations at station 4 were somewhat elevated relative to other stations. This is considered to be due to tidal and wind movement of pollutants and the entry of metals into the sound via a small creek close to station 4 resulting from natural leaching of exposed mineralization. Concentrations of trace metals in Fucus from Arctic Bay in 1976 were similar to or lower than concentrations in Fucus collected in 1979 from Strathcona Sound stations distal from the sources of metal input.

Results of the analyses of old and new growth of Fucus vesiculosus indicate the presence of generally greater concentrations of lead, zinc, cadmium and selenium in older portions of the plant. The pattern with respect to arsenic is less clear. There is a trend toward slightly higher arsenic concentrations in new growth which may be due to the mode of binding of this metal. Bohn (1979) has suggested that arsenic and cadmium may be reversibly bonded at the growing tips and that some arsenic "may be rejected in the growing process".

Concentrations of all the trace metals were greater in the stipes of Fucus from station 3 than in total plants (minus stipe), new, or old growth of Fucus from the same station. Similarly cadmium in Fucus stipes from stations 4, 6, 7 and 8 were greater than concentrations in total plants (minus stipe), new, or old growth of Fucus from the respective stations. Arsenic at stations 4, 6 and 7 and selenium at station 4 also exhibited greater stipe concentrations than in other plant portions. Zinc and arsenic concentrations in slime from Fucus vesiculosus at stations 3 and 6 were substantially greater than concentrations of these metals in other plant portions.

Except for work by Bohn (1979), pre-operational data from other stations in the Sound is lacking. Comparison of Bohn's metal levels for Fucus at stations comparable to stations 1 and 2 of this study indicate that a highly significant difference ($P \leq 0.01$) exists between 1975 and 1979 cadmium and zinc concentrations at station 1 whereas no significant difference in arsenic concentrations is apparent. At station 2 a significant difference ($P \leq 0.05$) in zinc concentration in Fucus is evident while no significant difference was present with respect to lead and arsenic concentrations.

Laminaria solidungula and Agarum cribrosum

Although no Laminaria was collected from station 3 during 1979, trace metal concentrations present in a single sample collected during 1976 were close to those observed at other monitoring stations, with the exception of lead, the concentration of which was 2 µg/g greater in the 1976 sample than in 1979. A single specimen of Agarum cribrosum was collected at station 3 in 1979. Analysis of this plant revealed trace metal concentrations less than those present in Fucus, but greater than those present in Laminaria with the exception of the arsenic concentration which was more similar to Laminaria than to Fucus.

SEA URCHINS

Strongylocentrotus droebachiensis

Lead concentrations in sea urchins from station 3, which were below the level of detection in 1976, had increased to in excess of 23 µg/g in 1979 while zinc concentrations showed a highly significant increase ($P \leq 0.01$) to 287 µg/g, more than five times the concentration present in 1976 (Table 4 and 5). Cadmium concentrations on the other hand were almost half what they were in 1976. The reason for the increase in zinc concentration and concomitant decrease in cadmium may be explained through various field and laboratory studies as discussed later.

It is evident from Table 6 that concentrations of lead and zinc in Strongylocentrotus droebachiensis at station 3 are significantly

different from all of the other stations sampled whereas the cadmium concentration in sea urchins at station 3 was not significantly different from other stations sampled. Cadmium concentrations between stations 1 and 7 and 1 and 5 are however significantly different implying the possibility of a population related difference in metal uptake between these three stations. As seen in Table 7 there is a significant correlation between cadmium concentration, test height, test width and dry weight for sea urchins from station 7. This correlation was not evident at station 1.

Selenium concentrations at station 7 were positively correlated with test height and dry weight. Mercury concentrations displayed similar correlations at station 7 and were also positively correlated to test width whereas test width and mercury concentration at station 1 were negatively correlated. Selenium has a protective effect with respect to cadmium and mercury toxicity (Parizek et al. 1971; Magos and Webb 1980) and as such may play an important role at station 1 where the cadmium concentration is double that at station 7.

It is regrettable that many of the sea urchins collected during 1976 had to be pooled in order to provide sufficient material for analysis. While direct comparisons between many of these analytical results and those obtained in 1979 cannot be made, the three sets of pooled samples collected from station 3 in August 1976 can be compared to a similar set for August 1979. This comparison reveals changes similar to those observed for the unpooled data: a more than 30 fold increase in lead concentration to 32.5 µg/g, a sixfold increase in zinc to 287 µg/g, a slight decrease in the cadmium concentration and a modest increase in the arsenic concentration.

Mya truncata

As shown in Table 8 for samples collected in 1979, there is a significant difference ($P \leq 0.01$) in concentrations of lead, zinc, cadmium, arsenic and mercury between stations 1, 2, 3, and 4. Only selenium did not exhibit a significant difference in concentration between stations. The comparison of individual metal concentrations between stations, (Table 9) reveals that concentrations of lead at station 4 were significantly different (using the LSD method) from those at the other 3 stations sampled. Zinc concentrations at station 3 were significantly different from all other stations while the concentrations in Mya from station 4 were significantly different from those in Mya from stations 2 and 1.

The cadmium concentration at station 1 was significantly different from that at all the other stations while the concentrations at stations 2 and 4 also differed significantly. Arsenic concentrations at station 3 differed significantly from those at stations 4 and 1 using the LSD method but showed no difference when compared on the basis of difference between means (D).

Mercury concentrations at station 3 were significantly different from those at stations 2, 4 and 1 by the LSD method.

Samples of individual Mya truncata from station 3 had lead, zinc and cadmium concentrations 1.92 (1.09 µg/g), 3.7 (283 µg/g), and 1.5 (0.83 µg/g) times higher than in a single analysis of three Mya truncata collected in 1975 (Tables 10 and 11). While baseline information for the other monitoring stations is not available, concentrations at such stations in 1979 were notably less than at station 3 with five exceptions, namely the lead concentration at stations 4 and 5; the cadmium concentration at stations 1 and 2; and the arsenic concentration at station 5. The higher lead concentration at station 4 may be due to entry of contaminated surface runoff near the station and to spilled and wind-blown concentrates being carried toward station 4 before settling out. The higher cadmium concentrations in Mya from station 2, relative to station 3 may reflect a lower salinity which promotes greater uptake of cadmium (Jackim et al. 1977). Phillips (1976a,b) also found net uptake of cadmium in Mytilus edulis increased at low salinities. As stated previously, sediment laden discharges from Twin Lakes Creek in 1975 were observed to be distributed along the shoreline toward the mouth of the sound, so conceivably water of lower salinity may characterize station 2 during the open water period. No salinity measurements were made in 1979. O'Hara (1973) has shown that susceptibility of fiddler crabs to cadmium is increased in low-salinity water. Various workers (Bryan 1966; Gardner and Yevich 1970) have found that accumulation of metals can result in tissue destruction which renders the organism unable to accumulate metals above a particular threshold level. The determination of such threshold levels for organisms utilized in this monitoring programme would be useful.

As seen in Table 7 significant positive correlations were found to exist between shell length, shell height and dry weight of Mya and metal concentrations; however, such correlations were not consistent between stations for any particular metal. Shell length was correlated to metal concentration on 3 occasions, height on 4 occasions, and dry weight in two instances. For a particular metal similar positive correlations were never found at more than one station. Had similar correlations been found to be significant for a particular metal at all stations it might have been possible to produce graphs which would have enabled future prediction of metal body burdens at various stations. Plots of log transformed metal concentration versus log dry weight yielded no meaningful trends.

OTHER MOLLUSCS

The limited amount of data for pre- and post-operational concentrations of metals in Serripes groenlandicus and Cardium ciliatum at station 3 (Tables 10 and 11) illustrate that lead has increased relative to pre-operational levels by 19.7 times (2.99 µg/g), and 1.41 times (0.37 µg/g) respectively for each species. Zinc has increased by 2.3 times (97.4 µg/g) and 1.7 times (33.8 µg/g), and cadmium by 1.95 times (0.9 µg/g) and 2.36 times (2.18 µg/g) respectively. In Serripes groenlandicus and Cardium ciliatum, arsenic concentrations exhibited 1.7

fold increases of 4.32 and 3.37 µg/g respectively over 1975 concentrations.

In terms of absolute numbers, zinc concentrations in Mya show the greatest increase of the three species sampled whereas lead concentrations increased most in Serripes relative to the other two species. Cadmium concentrations on the other hand showed a larger increase in Cardium than in Serripes or Mya. These results represent some of the variation in the degree to which individual species accumulate trace metals.

MISCELLANEOUS INVERTEBRATES

The sea star (Leptasterias polaris) and sea cucumber specimens analysed had lower lead concentrations than Strongylocentrotus and Mya specimens from corresponding stations (Table 12). Zinc concentrations were less than those observed for Mya. Zinc concentrations in Strongylocentrotus were exceeded by that of the sea cucumber at station 1. Arsenic concentrations were less than those in Mya and greater than those in sea urchins for all stations. The mercury concentration in sea stars was up to an order of magnitude greater than concentrations in Mya at corresponding stations and up to five times greater than corresponding concentrations in sea urchins.

FISHES

The small number of fishes collected at any one station (Table 12) render comments with respect to station to station variation of little value. Zinc concentrations in muscle samples from station 2 do, however, appear to be higher than at the other stations sampled while the mercury concentration at station 3 is double that at the station with the next highest concentration. It is conceivable that trends in metal accumulation in sculpins may not become apparent until later years. Bohn and Fallis (1978) found that trace metal concentrations in shorthorn sculpins collected from Strathcona Sound prior to production at the mine, were within the ranges reported for marine fishes from more southerly latitudes as is the case with the concentrations in fourhorn (Myoxocephalus quadricornis) and arctic (Myoxocephalus scorpioides) sculpins reported here.

WATER

From Table 13 it is evident that since commencement of production at the mine the concentration of zinc present in the decant leaving the tailings pond has remained relatively constant and well within the allowable limits stipulated in the water licence issued to the mine. However, the concentration of zinc present in Twin Lakes Creek at its point of entry into Strathcona Sound has risen dramatically over the period 1976-1980 from 63 µg/L to 2500 µg/L.

Seepage from emergency tailings dump ponds and leaching of metal from waste rock and tailings spilled in the vicinity of the mill, may account for the elevation of zinc concentrations in water at the mouth of the creek. In addition, concentrates spilled during the loading of ships may have been transported to the creek by the wind. The original water licence issued to Nanisivik Mines in 1976 included a requirement to monitor the water quality in Strathcona Sound 50 ft offshore from the mouth of Twin Lakes Creek and 50 ft offshore from the marine terminal. The 1977 annual report from Nanisivik Mines to the NWT Water Board indicates an average zinc concentration of 70 µg/L (total) at each of these stations during 1977. These two sites were deleted from the required sampling programme in the renewed water licence issued in 1978. The zinc concentration in the surface water of Strathcona Sound offshore from the mouth of Twin Lakes Creek was found to be 4 µg/L (dissolved) during 1974. No water samples for trace metal analyses were taken in 1979.

Table 14 allows one to compare pre-operational trace metal concentrations from Strathcona Sound to those reported from the open ocean and to two Greenland fjords prior to receipt of tailings from the operation of the Greenex (Black Angel) Mine. Pre-operational lead and zinc concentrations in Strathcona Sound were considerably lower than those in the Greenland fjords and only slightly greater than open ocean concentrations.

DISCUSSION

This study has revealed that substantial increases in trace metal concentrations in sediments, seaweeds, sea urchins and molluscs have taken place in the vicinity of the marine terminal (station 3) in the three years since commencement of production at the Nanisivik Mine. It is difficult to predict the extent to which trace metals will continue to accumulate, owing to the complex interaction of variables which may influence the bioaccumulation of metals. Phillips (1977b) enumerated a host of such factors including temperature, salinity, season, relative abundance of metals, ionic form in which the metal is present, competition between metals at the site of uptake, age, sex, size, state of sexual maturity and rate of growth of the organism and availability of metal in sediments and water for uptake by biota. Furthermore, it is unknown at what threshold level a particular trace metal will have sublethal effects on a particular species, and whether such sublethal effects would threaten the continued existence of a population in a particular area.

An extensive body of literature exists dealing with the toxicity of trace metals to marine biota under a variety of environmental conditions; however, little appears to have been done utilizing species indigenous to the High Arctic at temperature, oxygen and salinity regimes characteristic of such latitudes. Recently McGreer et al. (1980) tested the availability of metals from mine tailings for uptake by marine invertebrates. Their studies revealed that zinc was consistently bioaccumulated to higher levels in Mytilus edulis and Macoma balthica for tests conducted at 5°C as opposed to

15°C. Comparison of tailings from the Greenex Mine and Nanisivik Mine revealed that lead and zinc were present in lower concentrations in the liquid phase of Nanisivik tailings than in Greenex tailings and hence Nanisivik Mine effluents are likely to have less metal available for uptake than those emanating from the Greenex Mine.

Concentrations of lead in seaweeds monitored in association with the Greenex Mine (Appendix IV) have exhibited a continued increase in lead concentrations since 1974, reaching levels of 53 µg/g wet weight (≈175 µg/g dry wt) in 1976. This concentration is almost three times greater than that present in Fucus from station 3 in Strathcona Sound (59.5 µg/g dry wt). Station 3 lead concentrations in Fucus have increased more than 28 times over pre-operational concentrations while zinc, cadmium and arsenic concentrations have increased 5.6, 2.6 and 1.4 times respectively.

Bryan (1971) has shown that concentrations of heavy metals in Fucus vesiculosus tend to increase with distance from the growing tips. The reasons for such a gradient of metals in the tissues has been attributed to the low rate of metal accumulation, synthesis of more binding sites, and possible contamination of other parts of the plant with adhering fine particles and algal growth. Bryan and Hummerstone (1973) found that concentrations of zinc and lead in Fucus vesiculosus are controlled by a variety of factors including concentrations of metals in the water, seasonal changes, position of the weed in the intertidal zone and the portion of the plant which is analysed. The collective works of Black and Mitchell (1952), Young and Langille (1958) and Gutknecht (1965) have suggested that the concentration of zinc in Fucus changes with respect to that present in sea water, concentration factors of 1000 often being found.

Bryan (1969, 1971) confirmed the relationship between sea water metal concentrations and seaweed concentrations experimentally, using zinc, copper and lead with Laminaria digitata. Bryan found the relationship between sea water concentration and seaweed concentration was not directly proportional since at higher concentrations in the sea water the concentration factor (relating the level in the seaweed to that in the water) was reduced. Bryan (1976) presented data on zinc concentrations in Fucus vesiculosus from contaminated and normal estuaries which indicated a more than five fold difference in zinc concentration in growing tips (101 vs 522 µg/g dry wt) from normal to contaminated areas. Similarly thallus concentrations showed a 26 fold increase (122 vs 3240 µg/g dry wt) and stipes a 57 fold increase (40 vs 2290 µg/g dry wt) relative to the "normal" area.

Based upon the foregoing evidence it appears that continued elevation of trace metals in Fucus will likely occur unless the availability of trace metals is considerably reduced in ensuing years.

Lead concentrations in Strongylocentrotus droebachiensis at station 3 rose from below the limit of detection to more than 30 µg/g in 1979. Concentrations of zinc and arsenic rose 5.8 and 1.1 times to 287 µg/g and 3.05 µg/g respectively. Cadmium concentrations exhibited a slight decline. These concentrations are somewhat higher than lead and zinc concentrations in S. droebachiensis reported by the National Agency of Environmental Protection - Denmark (1978) from the Öresund (6.1 - 11.9 and 166 - 233 µg/g dry wt respectively). Cadmium concentrations in S. droebachiensis from station 3 in Strathcona Sound are, however, less than those from the Öresund.

Some insights into the factors influencing zinc and cadmium uptake as evidenced in the sea urchins at station 3 can be obtained from other published studies. Eisler and Gardner (1973) found that cadmium decreased the uptake of zinc in toxicity studies with Fundulus heteroclitus. Fowler and Benayoun (1974) working with Mytilus galloprovincialis and concentrations of 100 µg/L zinc, illustrated that cadmium accumulation kinetics do not appear to be altered by the presence of zinc. They also showed that most of the cadmium accumulated by marine invertebrates is lost at an extremely slow rate and that neither temperature nor zinc concentration in tissues or the surrounding medium significantly affect the rate of cadmium turnover in Mytilus galloprovincialis. Cadmium and zinc can replace one another on the sulphydryl groups of various proteins resulting in changes in enzymatic activity. The process of metal uptake may thus be intricately linked to the metabolic activity of the animal and competition between the two metals for sulphydryl groups. Friberg et al. (1971) found that exposure to cadmium in the presence of zinc results in higher zinc concentrations in organs. Studies by Jackim et al. (1977) showed that the presence of zinc at concentrations of 500 µg/L significantly decreased cadmium uptake in Mytilus edulis and Mulina lateralis. Furthermore they showed that cadmium is accumulated more from waters with low salinity and that temperature and sediment composition influence cadmium uptake.

Considered together these studies point to a physiological mechanism of metal interaction, which in some species results in inhibition of cadmium uptake by the organism in the presence of highly elevated zinc concentrations. It is conceivable that such a mechanism is present in Strongylocentrotus droebachiensis at station 3. If the concentrations of zinc in the water decrease with increased distance from the sources of metal inputs, a situation permitting greater uptake of cadmium may exist resulting in higher body burdens of cadmium in sea urchins at distance from the sources of input than close to them.

When 1979 Fucus metal concentrations at stations 1 and 2 are compared to Bohn's (1979) 1975 pre-operational concentrations at comparable stations, highly significant differences ($P \leq 0.01$) in cadmium and zinc concentrations at station 1 and a significant difference ($P \leq 0.05$) in the concentration of zinc at station 2 are apparent. The arsenic concentration in Fucus at stations 1 and 2 and the lead concentration at station 2 reported by Bohn (1979) were, however,

not significantly different from concentrations measured by this study in 1979. Analytical results from samples collected in subsequent years should provide an indication of the zone of influence resulting from trace metal inputs to Strathcona Sound. Further results will also permit a better evaluation of whether the significant differences in metal concentrations observed at stations 1 and 2 between 1975 and 1979 are in fact attributable to metal inputs associated with mining activities.

When compared to Appendix V it is clear that lead concentrations in Mya truncata from station 3 in Strathcona Sound are substantially less than those in various molluscs from other parts of the world, although few other workers have analysed Mya truncata.

Station 3 zinc concentrations in Mya truncata from Strathcona Sound (Table 11) are, however, substantially higher than those reported by other workers (Appendix V), while cadmium concentrations are generally similar or less than values from other areas. Ministeriet for Grønland (1977) studies indicated that zinc concentrations in Mytilus edulis doubled to 35 µg/g wet wt (≈116 µg/g dry wt) in 1977, four years after commencement of production at the Greenex Mine. This compares with an increase in zinc concentration of 3.7 times to 388 µg/g (dry wt) for Mya truncata from Strathcona Sound in 1979, three years subsequent to commencement of production. Considering the higher quantities of metals associated with Greenex tailings as compared to Nanisivik tailings and the fact that Greenex tailings are deposited directly in the ocean, it is disturbing to see that such dramatic increases have occurred in the trace metal concentrations of organisms close to the marine terminal in Strathcona Sound.

Schulz-Baldes (1973) found that the highest concentrations of trace elements in shellfish were present in the smallest individuals. The relationship between observed differences in element concentrations between populations may therefore reflect variation in the size of the organisms sampled rather than the actual difference in metal concentrations between stations. Boyden (1974) examined the relationship between trace element concentration and body size in molluscs and found this relationship varies with respect to element and species. Boyden (1974) showed that element concentration was directly related to body weight for lead and zinc in M. mercenaria and cadmium in M. edulis. Element concentrations generally decreased or remained constant with increasing body weight in Boyden's study. The slope of the relationship between element concentration and body weight may serve as an indication of the environmental concentration and availability of the element and as such be a useful tool in monitoring concentrations of trace metals within shellfish. Boyden (1974) points out that in most cases it appears that the regression coefficient relating element content to body weight remains constant regardless of season or environmental element concentration. Bryan (1973) expressed the view that in scallops the concentrations of metals were inversely related to phytoplankton productivity. In this study the relationship discussed by Boyden did not appear to apply.

Although this study was not aimed at determining public health implications of elevated trace metal levels in marine biota from Strathcona Sound, the fact that Inuit in the area have habitually harvested seals and narwhal from these waters, renders a brief comment appropriate.

The ability of trace metals to be concentrated, accumulated, and in some instances bioaccumulated through the food chain is well known (Bowen 1966, 1979). While the rate and degree to which such accumulation takes place varies greatly with respect to the metal, its ionic form and the trophic level of the species in question, it is useful to refer to the list of maximum levels recommended for contaminants in foods (FAO 1973) and the Canadian Food and Drug Act. The latter document states allowable limits for marine animal products of 10, 100, and 5 µg/g for lead, zinc and arsenic respectively. No limits have as yet been recommended for cadmium in food by the Codex Alimentarius Commission although a provisional tolerable weekly intake for man has been set at 0.0067 - 0.0083 mg/kg body-weight. An 80 kg Inuit would have to consume approximately 250 Mya truncata from station 3 to exceed the suggested weekly intake level for cadmium. Inuit in the vicinity of Nanisivik Mine do not currently consume shellfish so such cadmium concentrations do not pose a health problem. If walrus or bearded seals were utilizing the Mya as a food source the situation would be quite different as these animals are utilized as food by Inuit and metal concentrations in food items consumed could be reflected in their tissues. Vibe (1950) found that walruses fed predominantly upon Cardium, Mya and Saxicava with sometimes in excess of 3000 organisms present in a single stomach. The quantities of metals retained and the rate of feeding upon shellfish by a walrus are unknown.

The zinc and arsenic concentrations in individual specimens of Mya truncata currently exceed, by factors of 3.8 and 5.0 respectively, the recommended limits established for marine animal products. As Bryan (1976) has pointed out, arsenic concentrations in marine organisms are often high, but are not considered to pose a threat as the arsenic is often present in an organic form which is less toxic and more prone to be excreted by mammals. Although at this point there is no cause for alarm with respect to public health aspects of metal inputs to Strathcona Sound, further studies to delineate the concentrations of trace elements in tissues of ringed seals from the Strathcona Sound area are warranted in view of the results reported herein.

Environmental pollution arising from the discharge or release of trace metals into lakes, rivers and streams has world-wide implications. Unlike some other pollutants, metals do not degrade, and while their form and state of activity with respect to availability for uptake by various organisms may change, discharges of trace metals in inland waters will ultimately make their way into the world's oceans. Furthermore, the presence of geological and biological processes in marine environments enable metals present in sea water to be concentrated in sediments and living organisms. In several countries efforts have been expended to monitor

the degree of pollution of an area using analyses of water, sediments or biota indigenous to the polluted area (Phillips 1977a,b). Each approach has its inherent problems which must be carefully assessed when interpreting data obtained. The use of indigenous biota in monitoring trace metal pollution has the advantage of providing a "time-averaged value for the relative biological availability of metals at each site studied" (Phillips 1977b).

Monitoring changes in biota trace metal concentrations over time is but the first step to gaining an understanding of the implications of trace metal pollutant discharges to marine biota. Toxicological, physiological and biochemical studies must follow if an understanding of the implications of elevated trace metals to biota indigenous to the receiving waters is to be obtained.

RECOMMENDATIONS

1. Every effort should be expended to obtain future samples for use in trace metal analysis during the latter part of August and early September to avoid introducing variability associated with seasonal changes in biota trace metal concentrations.
2. Samples for salinity determinations should be collected from each sampling station to assist in explaining variability in cadmium and zinc uptake.
3. Organisms should be purged for 24 h or longer in seawater collected from the sampling station to rid themselves of ingested matter.
4. Efforts should be made to collect organisms which are uniformly large so that single organisms provide sufficient material (6 g dry wt) to conduct triplicate trace metal analyses. At least 25 organisms of each target species should be obtained from each station. Subsequent to completion of analyses of samples collected during 1980, sample size requirements should be reassessed.
5. Pending completion of analyses on samples collected during 1980, a decision should be made with respect to the need to collect invertebrate body measurements (test height and diameter of sea urchins, shell length, width and height of bivalve molluscs) other than wet and dry weight.
6. Future efforts with respect to monitoring trace metals in marine organisms from Strathcona Sound should be concentrated along the south half of the Sound. Sediment samples should be taken further offshore from stations 1 - 4 to document the spread of trace metals offshore. Additional marine invertebrates and sculpins should be taken from a point midway between stations 2 and 3, and 3 and 4 to determine "the zone of influence" with respect to elevated levels of trace metals in biota.
7. In an effort to determine point sources of trace metal inputs into Strathcona Sound an assessment of trace metals at several stations along the length of Twin Lakes Creek should be undertaken. Such an assessment would serve to identify areas where natural leaching of metals from exposed mineralization is occurring as well as pinpointing anthropogenic sources of trace metals entering the creek. Consideration should be given to implementing effluent quality criteria at the point of entry of Twin Lakes Creek into Strathcona Sound as well as at the decant structure pending identification of the sources of metal inputs.
8. Samples of fourhorn and shorthorn sculpins should be obtained from the vicinity of station 3 during future sampling and trace metal analyses performed for comparison with pre-operational data.
9. Methodologies employed during the collection, preparation and analysis of samples associated with the 1979 monitoring programme should be adhered to in future years to ensure that results can be compared; however, if better analytical techniques become available which are shown to provide results compatible with those obtained using previous techniques, then these should be adopted.
10. The minor changes in mercury concentrations relative to pre-operational concentrations, and the relatively consistent selenium concentrations in biota throughout the sound, warrant consideration of deletion of these elements from future monitoring.

RECOMMENDATIONS FOR FUTURE RESEARCH BEYOND THE SCOPE OF THE NANISIVIK MARINE MONITORING PROGRAMME

1. Investigations should be undertaken to determine the annual seasonal variation of trace metal concentrations in arctic marine invertebrates.
2. Research should be undertaken to determine rates of depuration with respect to ingested materials in arctic marine invertebrates.
3. Consideration should be given to implementing a study of metal uptake in arctic marine invertebrates using radioactive isotopes so as to obtain a better understanding of the mechanism of metal uptake and depuration in arctic marine organisms.
4. A study of zinc and silicon concentrations in the water at various distances from the marine terminal should be considered as a possible means of delineating the extent of zinc dispersal within Strathcona Sound.
5. To complement the work undertaken in this monitoring programme future research effort should be directed toward opportunistically acquiring samples of marine mammals from Inuit kills for use in trace metal analyses. Such analyses would provide an indication of the extent to which trace metal bioaccumulation is occurring in higher trophic levels of the marine food web.
6. Laboratory studies should be undertaken to delineate threshold or equilibrium levels

with respect to bioaccumulation of trace metals by Mya truncata and Strongylocentrotus droebachiensis under arctic temperature, oxygen and salinity regimes.

7. Physiological studies are needed to assess the implications of elevated lead, zinc and cadmium concentrations on reproduction and survival of various arctic marine invertebrates.
8. Consideration should be given to upgrading the existing laboratory facility near Char Lake on Cornwallis Island. With minimal effort this would enable some of the aforementioned research needs to be addressed, including marine bioassays and invertebrate culture.

ACKNOWLEDGMENTS

This study would not have been possible without the determined efforts of Dr. Norman Snow and Mr. Bryan Kemper who collected the 1979 set of samples and set up the framework under which part of the financial support for the 1979 programme was made available from the Department of Indian and Northern Affairs. Mr. Art Redshaw (DIAND) arranged for the funding required to complete the analyses during 1980. Drs. G.H. Lawler and R.D. Hamilton kindly made it possible for the analytical work to be conducted in the Industry Services, and Fish and Ecosystem Toxicology Laboratories of the Freshwater Institute, Winnipeg. Marilyn Hendzel and Andy Lutz kindly undertook the chemical analyses which form the basis of the report.

Studies conducted during 1974-1976 and part of 1979 were financially supported by the Freshwater Institute through John Loch and Jeff Stein whose foresight it was to implement the baseline studies. The author is grateful to the following people who assisted with collection of various data during 1974-76: A. Burnett, R. Fudge, D. Furnell, S. Harbicht, M. Lawrence, G. Lacho, C. Mack, R. Martin, C. O'Brien, and W. Siemieniuk. Sediment and water analyses in 1974 were performed by Dr. J.C. Van Loon, University of Toronto. Logistic support was provided during all years by Fred Alt and Frank Hunt, Polar Continental Shelf Project, Department of Energy, Mines and Resources, Ottawa; and Roy James and Jim Marshall, Strathcona Mineral Services, Toronto.

Walter Klenner was instrumental in preparing the samples for analysis, measuring organisms and providing comments on the manuscript. Mr. D. Kroeker and Ms. B. Mackenzie assisted with the graphics and computer analyses and Mrs. B. de March provided valuable statistical advice. B. Cohen kindly typed the manuscript.

The manuscript was reviewed by F.A.J. Armstrong, D. Billings, R.D. Hamilton, J. Loch, R. Macdonald, D.P. Scott, J. Stein, D. Stone, J. Thompson, P. Wainright and B. Wilson.

REFERENCES

ARMSTRONG, F.A.J., and J.F. UTHE. 1971. Semi-automated determination of mercury in animal tissue. At. Absorpt. Newsl. 10: 101-103.

ASMUND, G. 1980. Water movements traced by metals, dissolved from mine tailings deposited in a fjord in north west Greenland, p. 347-353. In H.J. Freeland, D.M. Farmer and C.D. Levings (ed.). Fjord oceanography. Plenum Press, New York.

BLACK, W.A.P., and R.L. MITCHELL. 1952. Trace elements in the common brown algae and sea-water. J. Mar. Biol. Assoc. U.K. 30: 575-584.

BOHN, A. 1979. Trace metals in fucoid algae and purple sea urchins near a high Arctic lead/zinc ore deposit. Mar. Pollut. Bull. 10(11): 325-327.

BOHN, A., and B.W. FALLIS. 1978. Metal concentrations (As, Cd, Cu, Pb, and Zn) in shorthorn sculpins, Myoxocephalus scorpius (Linnaeus), and Arctic char, Salvelinus alpinus (Linnaeus) from the vicinity of Strathcona Sound, Northwest Territories. Water Res. 12: 659-663.

BOLLINGBERG, H.J., and P. JOHANSEN. 1979. Lead in spotted wolffish, Anarhichas minor, near a zinc-lead mine in Greenland. J. Fish. Res. Board Can. 36: 1023-1028.

BONDAM, J., and G. ASMUND. 1974. Environmental studies in the Quamarujuk and Agfardlikavsâ Fjords, Umanak District, Central West Greenland. Grønlands Geologiske Undersøgelse Rapport Nr. 65. Report of Activities 1973, 29-33.

BOWEN, H.J.M. 1966. Trace elements in biochemistry. Academic Press, London. 241 p.

BOWEN, H.J.M. 1979. Environmental chemistry of the elements. Academic Press, London. 333 p.

BOYDEN, C.R. 1974. Trace element content and body size in molluscs. Nature (Lond.) 251: 311-314.

BOYLE, E., and J.M. EDMOND. 1975. Copper in surface waters south of New Zealand. Nature (Lond.) 253: 107-109.

BREWER, P.G. 1975. Minor elements in sea water, p. 415-496. In J.P. Riley and G. Skirrow (ed.). Chemical oceanography. Vol. 1. Academic Press, New York.

BRULAND, K.W., G.A. KNAUER, and J.H. MARTIN. 1978a. Zinc in north-east Pacific water. Nature (Lond.) 271: 741-743.

BRULAND, K.W., G.A. KNAUER, and J.H. MARTIN. 1978b. Cadmium in northeast Pacific waters. Limnol. Oceanogr. 23: 618-625.

BRYAN, G.W. 1966. The metabolism of zinc and ^{65}Zn in crabs, lobsters and freshwater crayfish, p. 1005-1016. In Symp. Radioecological Concentration Processes, Stockholm, Sweden. Pergamon Press, Oxford.

BRYAN, G.W. 1969. The absorption of zinc and other metals by the brown seaweed, Laminaria digitata. J. Mar. Biol. Assoc. U.K. 49: 225-243.

BRYAN, G.W. 1971. The effects of heavy metals (other than mercury) on marine and estuarine organisms. Proc. R. Soc. Lond. B. Biol. Sci. 177: 389-410.

BRYAN, G.W. 1973. The occurrence and seasonal variation of trace metals in the scallops Pecten maximus (L) and Chlamys operularis (L). J. Mar. Biol. Assoc. U.K. 53: 145-166.

BRYAN, G.W. 1976. Heavy metal contamination in the sea, p. 185-302. In R. Johnston (ed.).Marine pollution. Academic Press, London.

BRYAN, G.W., and L.G. HUMMERSTONE. 1973. Brown seaweed as an indicator of heavy metals in estuaries in Southwest England. J. Mar. Biol. Assoc. U.K. 53: 705-720.

BURTON, W., and J.F. FLANNAGAN. 1973. An improved Ekman-type grab. J. Fish. Res. Board Can. 30: 287-290.

CAMPBELL, J.A., and D. H. LORING. 1980. Baseline levels of heavy metals in the waters and sediments of Baffin Bay. Mar. Pollut. Bull. 11: 257-261.

DUINKER, J.C., R.F. NOLTING, and H.A. Van Der SLOOT. 1979. The determination of suspended metals in coastal waters by different sampling and processing techniques (Filtration, Centifugation). Neth. J. Sea Res. 13: 282-297.

EISLER, R., and G. R. GARDNER. 1973. Acute toxicology to an estuarine teleost of mixtures of cadmium, copper and zinc salts. J. Fish. Biol. 5: 131-142.

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS (FAO). 1973. List of maximum levels recommended for contaminants by the joint FAO/WHO codex alimentarius commission. First Series. 14 p.

FOOD AND DRUG ACTS AND REGULATIONS, with Amendments to May 26, 1977. Health and Welfare Canada, Ottawa. 187 p.

FOWLER, S.W., and G. BENAYOUN. 1976. Selenium kinetics in marine zooplankton. Mar. Sci. Commun. 2(1): 43-67.

FRIBERG, L., M. PISCATOR, and G. NORDBERG. 1971. Cadmium in the environment. A toxicological and epidemiological appraisal. Karolinska Institute Stockholm, Sweden.

FUGE, R., and K.H. JAMES. 1974. Trace metal concentrations in Fucus from the Bristol Channel. Mar. Pollut. Bull. 5(1): 9-12.

GARDNER, G.R., and P.P. YEVICH. 1970. Histological and hematological responses of an estuarine teleost to cadmium. J. Fish. Res. Board Can. 27: 2185-2196.

GUTKNECHT, J. 1965. Uptake and retention of cesium 137 and zinc 65 by seaweeds. Limnol. Oceanogr. 10: 58-66.

HENDZEL, M.R., and D.M. JAMIESON. 1976. Determination of mercury in fish. Anal. Chem. 48(6): 926-928.

IRELAND, M.P. 1973. Result of fluvial zinc pollution on the zinc content of littoral and sub-littoral organisms in Cardigan Bay, Wales. Environ. Pollut. 4: 27-35.

JACKIM, E., G. MORRISON, and R. STEELE. 1977. Effects of environmental factors on radiocadmium uptake by four species of marine bivalves. Mar. Biol. (Berl.) 40: 303-308.

KNECHTEL, J.R., and J.L. FRASER. 1979. Wet digestion method for the determination of mercury in biological and environmental samples. Anal. Chem. 51(2): 315-317.

MAGOS, L., and M. WEBB. 1980. The interactions of selenium with cadmium and mercury. Crit. Rev. Toxicol. 8: 1-42.

McGREER, E.R., B.J. REID, and G.A. VIGERS. 1980. Availability of metals from inorganic particulates (mine tailings) for uptake by marine invertebrates. A report by E.V.S. Consultants Ltd., project 646. Vancouver, B.C. 30 p.

MENDEN, E.E., D. BROCKMAN, H. CHOUDHURY, and H.G. PETERING. 1977. Dry ashing of animal tissues for atomic absorption spectrometric determination of zinc, copper, cadmium, lead, iron, manganese, magnesium, calcium. Anal. Chem. 49(11): 1644-1645.

MINISTERIET FOR GRØNLAND. 1975. Recipientundersøgelse 1974, Agfardlikavsâ, Quamarujuk. Grønlands Geologiske Undersøgelse Grønlands Fiskeriundersøgelser, Institut for Petrologi. 107 p.

MINISTERIET FOR GRØNLAND. 1976. Recipientundersøgelse 1975-76, Agfardlikavsâ, Quamarujuk. Grønlands Geologiske Undersøgelse Grønlands Fiskeriundersøgelser, Institut for Petrologi. 113 p.

MINISTERIET FOR GRØNLAND. 1977. Recipientundersøgelse 1976-77, Agfardlikavsâ, Quamarujuk. Grønlands Geologiske Undersøgelse Grønlands Fiskeriundersøgelser, Institut for Petrologi. 135 p.

MØLLER, B., and J. PEDERSEN. 1972. Survey of the Quamarujuk Fjord and the Agfardlikavsâ Fjord, August 1972. Case No. R. 72.93. Recipient survey for the Technical Organization of Greenland. The Water Quality

Quality Institute, ATV Poppelgårdvej 10-12 2860 Søborg, Copenhagen, Denmark. 124 p.

MULLIN, J.B., and J.P. RILEY. 1956. The occurrence of cadmium in seawater and in marine organisms and sediments. J. Mar. Res. 15: 103.

NATIONAL AGENCY OF ENVIRONMENTAL PROTECTION - DENMARK. 1978. Danish marine monitoring methods and data. Part II. The concentrations of selected heavy metals in bottom vegetation and bottom invertebrates. The Water Quality Institute, ATV-11, Agern Alle, DK-2970 Hørsholm. 104 p.

O'HARA, J. 1973. The influence of temperature and salinity on the toxicity of cadmium to the fiddler crab, Uca pugilator. Fish. Bull. 71: 149-153.

PARIZEK, J., I. OSTADALOVA, J. KALOUSKOVA, A. BABICKY, and J. BENES. 1971. The detoxifying effects of selenium interrelations between compounds of selenium and certain metals, p. 85-122. In W. Mertz and W.E. Cornatzer (ed.) Newer trace elements in nutrition. Dekker, Inc. New York, N.Y.

PATTERSON, C., D. SETTLE, and B. GLOVER. 1976. Analysis of lead in polluted coastal seawater. Mar. Chem. 4: 305-319.

PHILLIPS, D.J.H. 1976a. The common mussel Mytilus edulis as an indicator of pollution by zinc, cadmium, lead and copper. I. Effects of environmental variables on uptake of metals. Mar. Biol. (Berl.) 38(1): 59-69.

PHILLIPS, D.J.H. 1976b. The common mussel Mytilus edulis as an indicator of pollution by zinc, cadmium, lead and copper. II. Relationships of metals in the mussel to those discharged by industry. Mar. Biol. (Berl.) 38(1): 71-80.

PHILLIPS, D.J.H. 1977a. The common mussel Mytilus edulis as an indicator of trace metals in Scandinavian waters. I. Zinc and cadmium. Mar. Biol. (Berl.) 43(4): 283-291.

PHILLIPS, D.J.H. 1977b. The use of biological indicator organisms to monitor trace metal pollution in marine and estuarine environments - a review. Environ. Pollut. 13: 281-317.

PHILLIPS, D.J.H. 1979. Trace metals in the common mussel, Mytilus edulis and in the alga, Fucus vesiculosis (L.) from the region of the Sound (Øresund). Environ. Pollut. 18: 31-43.

POPHAM, J.D., D.C. JOHNSON, and J.M. D'AURIA. 1980. Mussels (Mytilus edulis) as 'point source' indicators of trace metal pollution. Mar. Pollut. Bull. 11: 261-263.

PRESTON, A., D.F. JEFFERIES, J.W.R. DUTTON, B.R. HARVEY, and A.K. STEELE. 1972. British Isles coastal waters: the concentration of selected heavy metals in seawater, suspended matter and biological indicators. A pilot survey. Environ. Pollut. 3: 69-82.

SCHULZ-BALDES, M. 1973. Die Miesmuschel Mytilus edulis als Indikator für de Bleikonzentration in Weserastuar und in der Deutschen Bucht. Mar. Biol. (Berl.) 21: 98-102. (English Abstract)

SEGAR, D.A., J.D. COLLINS, and J.P. RILEY. 1971. The distribution of the major and some minor elements in marine animals. Part II: Molluscs. J. Mar. Biol. Assoc. U.K. 51: 131-136.

SNEDECOR, G.W., and W.G. COCHRAN. 1967. Statistical methods. 6th ed. Iowa State University Press, Ames, Iowa. 593 p.

STUKAS, V.J., and C.S. WONG. 1981. Stable lead isotopes as a tracer in coastal waters. Science (Wash., D.C.) 211: 1424-1427.

VIBE, C. 1950. The marine mammals and the marine fauna in the Thule District (Northwest Greenland) with observations on ice conditions in 1939-41. Medd. Groenl. 150(6): 1-116.

VIJAN, P.N., and G.R. WOOD. 1974. An automated submicrogram determination of arsenic in atmospheric particulate matter by flameless atomic absorption spectrophotometry. At. Absorpt. Newsl. 13(2): 33-37.

VIJAN, P.N., and G.R. WOOD. 1976. An automated submicrogram determination of selenium in vegetation by quartz tube furnace atomic absorption spectrometry. Talanta 23: 89-94.

YOUNG, E.G., and W.M. LANGILLE. 1958. The occurrence of inorganic elements in marine algae of the Atlantic Provinces of Canada. Can. J. Bot. 36: 301-310.

BRYAN, G.W. 1966. The metabolism of zinc and ^{65}Zn in crabs, lobsters and freshwater crayfish, p. 1005-1016. In Symp. Radioecological Concentration Processes, Stockholm, Sweden. Pergamon Press, Oxford.

BRYAN, G.W. 1969. The absorption of zinc and other metals by the brown seaweed, Laminaria digitata. J. Mar. Biol. Assoc. U.K. 49: 225-243.

BRYAN, G.W. 1971. The effects of heavy metals (other than mercury) on marine and estuarine organisms. Proc. R. Soc. Lond. B. Biol. Sci. 177: 389-410.

BRYAN, G.W. 1973. The occurrence and seasonal variation of trace metals in the scallops Pecten maximus (L) and Chlamys opercularis (L). J. Mar. Biol. Assoc. U.K. 53: 145-166.

BRYAN, G.W. 1976. Heavy metal contamination in the sea, p. 185-302. In R. Johnston (ed.).Marine pollution. Academic Press, London.

BRYAN, G.W., and L.G. HUMMERSTONE. 1973. Brown seaweed as an indicator of heavy metals in estuaries in Southwest England. J. Mar. Biol. Assoc. U.K. 53: 705-720.

BURTON, W., and J.F. FLANNAGAN. 1973. An improved Ekman-type grab. J. Fish. Res. Board Can. 30: 287-290.

CAMPBELL, J.A., and D. H. LORING. 1980. Baseline levels of heavy metals in the waters and sediments of Baffin Bay. Mar. Pollut. Bull. 11: 257-261.

DUINKER, J.C., R.F. NOLTING, and H.A. Van Der SLOOT. 1979. The determination of suspended metals in coastal waters by different sampling and processing techniques (Filtration, Centifugation). Neth. J. Sea Res. 13: 282-297.

EISLER, R., and G. R. GARDNER. 1973. Acute toxicology to an estuarine teleost of mixtures of cadmium, copper and zinc salts. J. Fish. Biol. 5: 131-142.

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS (FAO). 1973. List of maximum levels recommended for contaminants by the joint FAO/WHO codex alimentarius commission. First Series. 14 p.

FOOD AND DRUG ACTS AND REGULATIONS, with Amendments to May 26, 1977. Health and Welfare Canada, Ottawa. 187 p.

FOWLER, S.W., and G. BENAYOUN. 1976. Selenium kinetics in marine zooplankton. Mar. Sci. Commun. 2(1): 43-67.

FRIBERG, L., M. PISCATOR, and G. NORDBERG. 1971. Cadmium in the environment. A toxicological and epidemiological appraisal. Karolinska Institute Stockholm, Sweden.

FUGE, R., and K.H. JAMES. 1974. Trace metal concentrations in Fucus from the Bristol Channel. Mar. Pollut. Bull. 5(1): 9-12.

GARDNER, G.R., and P.P. YEVICH. 1970. Histological and hematological responses of an estuarine teleost to cadmium. J. Fish. Res. Board Can. 27: 2185-2196.

GUTKNECHT, J. 1965. Uptake and retention of cesium 137 and zinc 65 by seaweeds. Limnol. Oceanogr. 10: 58-66.

HENDZEL, M.R., and D.M. JAMIESON. 1976. Determination of mercury in fish. Anal. Chem. 48(6): 926-928.

IRELAND, M.P. 1973. Result of fluvial zinc pollution on the zinc content of littoral and sub-littoral organisms in Cardigan Bay, Wales. Environ. Pollut. 4: 27-35.

JACKIM, E., G. MORRISON, and R. STEELE. 1977. Effects of environmental factors on radiocadmium uptake by four species of marine bivalves. Mar. Biol. (Berl.) 40: 303-308.

KNECHTEL, J.R., and J.L. FRASER. 1979. Wet digestion method for the determination of mercury in biological and environmental samples. Anal. Chem. 51(2): 315-317.

MAGOS, L., and M. WEBB. 1980. The interactions of selenium with cadmium and mercury. Crit. Rev. Toxicol. 8: 1-42.

McGREER, E.R., B.J. REID, and G.A. VIGERS. 1980. Availability of metals from inorganic particulates (mine tailings) for uptake by marine invertebrates. A report by E.V.S. Consultants Ltd., project 646. Vancouver, B.C. 30 p.

MENDEN, E.E., D. BROCKMAN, H. CHOUDHURY, and H.G. PETERING. 1977. Dry ashing of animal tissues for atomic absorption spectrometric determination of zinc, copper, cadmium, lead, iron, manganese, magnesium, calcium. Anal. Chem. 49(11): 1644-1645.

MINISTERIET FOR GRØNLAND. 1975. Recipientundersøgelse 1974, Agfardlikavsâ, Quamarujuk. Grønlands Geologiske Undersøgelse Grønlands Fiskeriundersøgelser, Institut for Petrologi. 107 p.

MINISTERIET FOR GRØNLAND. 1976. Recipientundersøgelse 1975-76, Agfardlikavsâ, Quamarujuk. Grønlands Geologiske Undersøgelse Grønlands Fiskeriundersøgelser, Institut for Petrologi. 113 p.

MINISTERIET FOR GRØNLAND. 1977. Recipientundersøgelse 1976-77, Agfardlikavsâ, Quamarujuk. Grønlands Geologiske Undersøgelse Grønlands Fiskeriundersøgelser, Institut for Petrologi. 135 p.

MØLLER, B., and J. PEDERSEN. 1972. Survey of the Quamarujuk Fjord and the Agfardlikavsâ Fjord, August 1972. Case No. R. 72.93. Recipient survey for the Technical Organization of Greenland. The Water Quality

Quality Institute, ATV Poppelgårdvej 10-12 2860 Søborg, Copenhagen, Denmark. 124 p.

MULLIN, J.B., and J.P. RILEY. 1956. The occurrence of cadmium in seawater and in marine organisms and sediments. J. Mar. Res. 15: 103.

NATIONAL AGENCY OF ENVIRONMENTAL PROTECTION - DENMARK. 1978. Danish marine monitoring methods and data. Part II. The concentrations of selected heavy metals in bottom vegetation and bottom invertebrates. The Water Quality Institute, ATV-11, Agern Alle, DK-2970 Hørsholm. 104 p.

O'HARA, J. 1973. The influence of temperature and salinity on the toxicity of cadmium to the fiddler crab, Uca pugilator. Fish. Bull. 71: 149-153.

PARIZEK, J., I. OSTADALOVA, J. KALOUSKOVA, A. BABICKY, and J. BENES. 1971. The detoxifying effects of selenium interrelations between compounds of selenium and certain metals, p. 85-122. In W. Mertz and W.E. Cornatzer (ed.) Newer trace elements in nutrition. Dekker, Inc. New York, N.Y.

PATTERSON, C., D. SETTLE, and B. GLOVER. 1976. Analysis of lead in polluted coastal seawater. Mar. Chem. 4: 305-319.

PHILLIPS, D.J.H. 1976a. The common mussel Mytilus edulis as an indicator of pollution by zinc, cadmium, lead and copper. I. Effects of environmental variables on uptake of metals. Mar. Biol. (Berl.) 38(1): 59-69.

PHILLIPS, D.J.H. 1976b. The common mussel Mytilus edulis as an indicator of pollution by zinc, cadmium, lead and copper. II. Relationships of metals in the mussel to those discharged by industry. Mar. Biol. (Berl.) 38(1): 71-80.

PHILLIPS, D.J.H. 1977a. The common mussel Mytilus edulis as an indicator of trace metals in Scandinavian waters. I. Zinc and cadmium. Mar. Biol. (Berl.) 43(4): 283-291.

PHILLIPS, D.J.H. 1977b. The use of biological indicator organisms to monitor trace metal pollution in marine and estuarine environments - a review. Environ. Pollut. 13: 281-317.

PHILLIPS, D.J.H. 1979. Trace metals in the common mussel, Mytilus edulis and in the alga, Fucus vesiculosis (L.) from the region of the Sound (Øresund). Environ. Pollut. 18: 31-43.

POPHAM, J.D., D.C. JOHNSON, and J.M. D'AURIA. 1980. Mussels (Mytilus edulis) as 'point source' indicators of trace metal pollution. Mar. Pollut. Bull. 11: 261-263.

PRESTON, A., D.F. JEFFERIES, J.W.R. DUTTON, B.R. HARVEY, and A.K. STEELE. 1972. British Isles coastal waters: the concentration of selected heavy metals in seawater, suspended matter and biological indicators. A pilot survey. Environ. Pollut. 3: 69-82.

SCHULZ-BALDES, M. 1973. Die Miesmuschel Mytilus edulis als Indikator für de Bleikonzentration in Weserastuar und in der Deutschen Bucht. Mar. Biol. (Berl.) 21: 98-102. (English Abstract)

SEGAR, D.A., J.D. COLLINS, and J.P. RILEY. 1971. The distribution of the major and some minor elements in marine animals. Part II: Molluscs. J. Mar. Biol. Assoc. U.K. 51: 131-136.

SNEDECOR, G.W., and W.G. COCHRAN. 1967. Statistical methods. 6th ed. Iowa State University Press, Ames, Iowa. 593 p.

STUKAS, V.J., and C.S. WONG. 1981. Stable lead isotopes as a tracer in coastal waters. Science (Wash., D.C.) 211: 1424-1427.

VIBE, C. 1950. The marine mammals and the marine fauna in the Thule District (Northwest Greenland) with observations on ice conditions in 1939-41. Medd. Groenl. 150(6): 1-116.

VIJAN, P.N., and G.R. WOOD. 1974. An automated submicrogram determination of arsenic in atmospheric particulate matter by flameless atomic absorption spectrophotometry. At. Absorpt. Newsl. 13(2): 33-37.

VIJAN, P.N., and G.R. WOOD. 1976. An automated submicrogram determination of selenium in vegetation by quartz tube furnace atomic absorption spectrometry. Talanta 23: 89-94.

YOUNG, E.G., and W.M. LANGILLE. 1958. The occurrence of inorganic elements in marine algae of the Atlantic Provinces of Canada. Can. J. Bot. 36: 301-310.

Table 1. Summary of concentrations of trace metals in sediments from Strathcona Sound and Arctic Bay, N.W.T.

Location	Station	Date	Metal Concentration (µg/g dry wt) Pb	Zn	Cd	As	Hg	Mn	Cu	Fe (%)
Coastal & Sound Sediments[1]			18	45	-	-	0.05	310	20	-
Arctic Bay		Aug. 1976[2]	<0.25	61.3	<0.25	-	0.01	156	33.6	1.98
Strathcona Sound	3	Sept. 1974[2]	20	155	0.3	4	0.1	-	12	1.8
		Aug. 1975[2]	18	175	0.2	3	0.1	210	20	2.3
		Aug. 1979[3]	76	750	1.80	9.4	0.03	259	-	2.45
	2(86)[4]	Sept. 1975[5]	20	125	<0.2	11	2	210	35	2.4
		Sept. 1975[6]	10	50	<0.2	7	0.5	210	15	1.8
		Aug. 1979[3]	5.6	23	0.03	2.0	0.006	142	-	1.13
	4(75)[4]	Sept. 1975[5]	20	110	<0.2	14	4	220	40	4.6
		Sept. 1975[6]	20	66	<0.2	11	3	145	20	2.8
		Aug. 1979[3]	9.6	94	0.18	5.1	0.02	270	-	2.24
	7(91)[4]	Sept. 1975[6]	10	53	<0.2	8	0.5	245	15	2.1
		Aug. 1979[3]	10	38	0.02	3.0	0.02	288	-	1.69
	6	Aug. 1979[3]	5.5	30	0.04	3.2	0.01	202	-	1.28
	8(99)[4]	Sept. 1975[5]	20	110	<0.2	9	2	180	35	3.5
		Sept. 1975[6]	15	65	<0.2	5	0.7	210	15	2.0
		Aug. 1979[3]	10	34	0.02	3.4	0.009	262	-	1.96
	1(94)[4]	Sept. 1975[6]	10	72	<0.2	5	0.7	240	15	2.1
		Aug. 1979[3]	3.0	20	0.05	1.7	0.006	160	-	1.37
	5(107)[4]	Sept. 1975[5]	46	100	<0.2	11	2	280	35	3.7
		Sept. 1975[6]	<1	65	<0.2	11	2	330	25	2.5
		Aug. 1979[3]	6.5	40	0.03	4.4	0.01	250	-	1.96

[1] Campbell and Loring (1980).
[2] <180 µm.
[3] <1.00 mm.
[4] Numbers in brackets refer to Sept. 1975 GSC sample numbers - Brian Bornhold - pers. comm., analyses performed by J.C. Van Loon, University of Toronto.
[5] < 2 µm fraction.
[6] total sample.

Table 2. Summary of mean concentrations of trace metals and selenium in seaweeds from Arctic Bay and Strathcona Sound, N.W.T. - August, 1976.

Location	Species	n	Metal Concentration (µg/g dry wt) ± Standard Deviation					
			Pb	Zn	Cd	As	Se	Hg
Arctic Bay	*Fucus vesiculosus*[1]	8	2.11 ± 0.83	23.8 ± 9.68	1.70 ± 0.61	20.4 ± 4.12	0.35 ± 0.12	0.02 ± 0.01
Strathcona Sound Station 3	*Fucus vesiculosus*[1]	2	2.10 ± 0.06	88.4 ± 3.32	0.63 ± 0.06	24.8 ± 2.19	0.24 ± 0.12	0.02
	Fucus vesiculosus[2]	12	1.32 ± 1.08	105 ± 3.62	0.90 ± 0.14	36.4 ± 4.48	0.55 ± 0.22	0.01
	Palmaria palmata[1]	2	0.98 ± 0.05	66.0 ± 3.11	0.96 ± 0.06	3.24 ± 0.28	0.16 ± 0.11	<0.01
	Laminaria solidungula[1]	1	3.19	36.0	0.47	39.9	0.03	0.02
NBS Orchard Leaves	Certified Value		45 ± 3	25 ±3	0.11 ± 0.02	10 ± 2	0.08 ± 0.01	
	Lab Value		47 ± 3 (7)[3]	26 ± 2 (6)	0.22 ± 0.05 (6)	10.3 ± 0.8 (2)	0.09 ± 0.01 (4)	

[1]Analyses based on washed whole plants, minus stipe.
[2]Analyses based on unwashed whole plants, minus stipe.
[3]Bracketed numbers refer to number of determinations.

Table 3. Summary of mean concentrations of trace metals and selenium in seaweeds collected from Strathcona Sound, N.W.T. during August, 1979.

Species	n[1]	Component	Station	Metal Concentration (µg/g dry wt) ± Standard Deviation Pb	Zn	Cd	As	Se	Hg
Fucus vesiculosus	1	T[2]	3	59.5	493	1.66	34.9	0.28	0.02
	5	T[2]	2	1.88 ± 0.18	67.0 ± 4.71	1.82 ± 0.88	23.8 ± 1.67	0.20 ± 0.08	0.01
	4	T[2]	4	6.66 ± 1.24	141 ± 10.6	0.88 ± 0.05	26.4 ± 1.57	0.14 ± 0.02	0.01
	1	T[2]	7	2.45	47.8	0.67	23.2	0.14	0.01
	1	T[2]	6	1.64	93.7	1.28	28.4	0.18	0.02
	1	T[2]	8	1.41	36.5	1.12	26.2	0.12	0.02
	2	T[2]	1	1.19 ± 0.08	52.2 ± 3.32	1.66 ± 0.14	21.2 ± 1.06	0.13 ± 0.03	0.02 ± .01
	2	T[2]	5	1.08 ± 0.13	58.1 ± 0.17	0.94 ± 0.04	24.9 ± 0.17	0.18 ± 0.01	0.02 ± .01
Fucus vesiculosus	1	N[3]	3	27.4	340	1.20	33.0	0.13	0.01
	1	N[3]	2	1.39	59.5	1.76	23.3	0.12	0.01
	2	N[3]	4	3.96 ± 0.16	129 ± 6.84	0.81 ± 0.08	29.9 ± 1.30	0.08 ± 0.02	0.01
	1	N[3]	7	1.07	43.0	0.85	27.3	0.10	0.01
	1	N[3]	6	1.30	95.3	1.19	28.6	0.11	0.01
	1	N[3]	8	0.95	35.5	1.12	24.7	0.09	0.01
	1	N[3]	1	0.95	47.0	1.41	19.2	0.06	0.01
Fucus vesiculosus	1	O[4]	3	80.0	498	1.51	27.0	0.38	0.01
	1	O[4]	2	2.19	68.3	1.36	21.3	0.28	0.01
	2	O[4]	4	8.65 ± 1.67	162 ± 5.66	0.81 ± 0.08	26.4 ± 0.92	0.20 ± 0.01	0.01
	1	O[4]	7	2.46	51.2	0.74	23.7	0.26	0.01
	1	O[4]	6	1.73	94.4	1.22	25.6	0.28	0.01
	1	O[4]	8	1.79	40.9	0.86	22.0	0.23	0.01
	1	O[4]	1	1.23	50.4	1.31	21.5	0.11	0.01
Fucus vesiculosus	1	US[5]	3	82.7	659	1.98	38.5	0.47	0.01
	1	US[5]	4	6.69	152	1.21	32.8	0.23	0.01
	1	US[5]	7	0.69	44.5	1.26	29.3	0.20	0.01
	1	US[5]	6	0.90	88.1	1.84	33.4	0.26	0.03
	1	US[5]	8	1.63	35.9	1.66	26.2	0.28	0.01
Fucus vesiculosus	1	S[6]	3	4.31	610	0.57	76.9	0.04	0.01
	1	S[6]	6	0.69	214	0.87	77.3	0.05	0.01
Fucus vesiculosus	6	H(6)[7]	4	6.76	155	0.79	28.3	0.16	0.01
	7	H(7)[7]	8	1.70	39.1	1.12	25.2	0.16	0.01
Agarum cribrosum	1	T[2]	3	9.45	76.0	0.22	39.7	0.18	0.01
Laminaria solidungula	2	T[2]	2	1.28 ± 1.09	18.5 ± 0.99	1.34 ± 0.06	61.9 ± 2.33	0.04 ± 0.01	0.01
	6	T[2]	4	1.28 ± 0.48	38.8 ± 3.32	0.95 ± 0.25	44.9 ± 8.4	0.05 ± 0.01	0.01
	2	T[2]	6	0.85 ± 0.18	31.8 ± 1.56	0.97 ± 0.01	37.2 ± 1.48	0.04 ± 0.02	0.01
	1	T[2]	5	0.61	19.3	0.56	28.6	0.04	0.01
Laminaria solidungula	2	H(3)[7]	5	0.57 ± 0.07	24.5 ± 0.26	0.39 ± 0.03	32.9 ± 0.73	0.04	0.01

[1]values below the level of detection were treated as absolute numbers. [2]washed total plant minus stipe [3]washed, new growth.
[4]washed, old growth. [5]unwashed stipes. [6]slime. [7]homogenate (of n subsamples).

Table 4. Summary of mean concentrations of trace metals in *Strongylocentrotus droebachiensis*, from Arctic Bay and Strathcona Sound, N.W.T. - 1976.

Location	Group Size	n	Metal Concentration (µg/g dry wt)± Standard Deviation				
			Pb	Zn	Cd	As	Hg
Arctic Bay (August)	3[1]	2[1]	7.23	35.8 ± 1.63	0.89 ± 0.11	4.74 ± 1.12	0.02
Strathcona Sound (May)	1	1	<0.23	45.3	2.50	2.55	0.03
Station 3	2	1	<0.23	50.0	1.30	4.06	0.02
	3	5	2.09 ± 0.86	47.5 ± 7.65	1.20 ± 0.22	2.42 ± 0.98	0.02
	4	2	1.93 ± 0.39	35.7 ± 5.30	1.42 ± 0.09	1.97 ± 0.03	<0.01
	5	2	0.75	34.5 ± 10.7	1.44 ± 0.36	2.47 ± 0.76	0.02
	7	1	1.55	33.1	1.56	1.73	<0.01
	8	1	<0.63	37.7	1.54	3.23	0.04
Strathcona Sound (August)	1	2	<0.50	64.6 ± 19.7	1.43 ± 0.93	5.08 ± 2.35	0.02
Station 3	2	3	<0.13	47.9 ± 3.63	0.92 ± 0.19	2.83 ± 0.99	<0.01
	3	3	0.30	62.2 ± 2.25	0.84 ± 0.31	3.69 ± 0.98	0.02
	4	6	1.77	58.3 ± 8.97	1.04 ± 0.38	3.52 ± 1.14	0.02
	5	2	<0.13	55.7 ± 0.92	1.57 ± 0.20	4.54 ± 1.97	0.01
	8	1	<0.20	55.0	1.19	3.47	<0.01
	9	2	<0.13	55.7 ± 0.91	1.57 ± 0.20	4.54 ± 1.97	0.01

[1]Analysis of two pooled samples each consisting of three organisms.

Table 5. Summary of mean concentrations of trace metals and selenium in sea urchins collected from Strathcona Sound, N.W.T. during August, 1979.

Species	Group size	n[1]	Station	Metal Concentration (µg/g dry wt) ± Standard Deviation					
				Pb	Zn	Cd	As	Se	Hg
Strongylocentrotus droebachiensis	1	17	3	23.9 ± 9.52	278 ± 101	0.72 ± 0.21	3.53 ± 0.43	0.49 ± 0.11	0.04 ± 0.01
	1	1	2	1.22	31.8	0.26	3.11	0.37	0.02
	1	10	7	0.97 ± 0.35	62.3 ± 28.8	0.44 ± 0.39	3.34 ± 0.80	0.51 ± 0.14	0.03 ± 0.02
	1	3	1	1.27 ± 0.36	38.2 ± 6.30	1.07 ± 0.89	3.39 ± 0.23	0.54 ± 0.18	0.04 ± 0.01
	1	11	5	0.75 ± 0.26	47.3 ± 11.1	0.45 ± 0.27	3.85 ± 0.94	0.50 ± 0.16	0.03 ± 0.02
Strongylocentrotus droebachiensis	2	3	3	32.5 ± 6.64	287 ± 80.6	0.77 ± 0.02	3.05 ± 0.36	0.47 ± 0.08	0.03 ± 0.01
	10[2]	1	7	1.21	44.3	0.61	3.24	0.49	0.03
	2	2	1	1.64 ± 0.23	30.7 ± 7.59	0.48 ± 0.34	2.84 ± 0.08	0.55 ± 0.04	0.03 ± 0.01
	11[2]	1	5	0.40	48.3	0.25	4.09	0.48	0.04

[1] values below the level of detection were treated as absolute numbers.
[2] Homogenate of subsamples taken from other samples.

Table 6. Comparison of least significant difference (LSD) and difference between means (D) for mean metal concentrations (µg/g dry wt) in whole bodies of individual *Strongylocentrotus droebachiensis* from Strathcona Sound, N.W.T. - August,1979.

Metal (mean concentration)			Station (n)			
			3	7	1	5
Pb	LSD[1]	6.86	23.9 (17)	0.97 (10)	1.27 (3)	0.75 (11)
	D[1]	9.07				
Zn	LSD[1]	74.7	278 (17)	62.3 (10)	38.2 (3)	47.3 (11)
	D[1]	98.9				
Cd	LSD[1]	0.38	0.72 (17)	0.44 (10)	1.07 (3)	0.45 (11)
	D[1]	0.50				

[1] $P \leq 0.05$, values below the limit of detection treated as the absolute value of the detection limit.

Table 7. Summary of correlation coefficients [1] with respect to metal concentrations[2] and body measurements for *Strongylocentrotus droebachiensis* and *Mya truncata* relative to station location, Strathcona Sound, N.W.T. - August, 1979.

Metal	Species	Measurement	Station (n) 3	2	7	1	5
Pb	*S. droebachiensis*	test height	-0.1309 (17)		-0.3292 (10)	0.2437 (3)	0.2841 (11)
		test width	-0.1810 (17)		-0.6203 (10)	0.5631 (3)	0.3819 (11)
		dry weight	-0.0455 (17)		-0.4265 (10)	0.1493 (3)	0.3531 (11)
	M. truncata	Shell length	-0.1427 (24)			0.5624 (7)	
		Shell width	0.1779 (24)	*-0.4609*[3] (20)		0.2880 (7)	
		Shell height	-0.1920 (24)	0.1369 (14)		0.3004 (6)	
		dry weight	-0.1030 (24)	0.2456 (20)		-	
Zn	*S. droebachiensis*	test height	-0.0713 (17)		0.2039 (10)	0.6709 (3)	0.3514 (11)
		test width	-0.0187 (17)		-0.3328 (10)	0.3741 (3)	0.3136 (11)
		dry weight	0.0641 (17)		0.2197 (10)	0.7391 (3)	0.4491 (11)
	M. truncata	Shell length	0.3749 (24)	-		-0.2514 (7)	
		Shell width	-	-0.1957 (20)		-	
		Shell height	*0.5025*[3](24)	0.2045 (14)		-0.4702 (6)	
		dry weight	*0.4762*[3](24)	0.2860 (20)		-0.5364 (7)	
						-	
Cd	*S. droebachiensis*	test height	-0.1807 (17)		*0.6952*[3](10)	0.2974 (3)	0.4060 (11)
		test width	-0.0629 (17)		*0.8966*[3](10)	-0.0499 (3)	0.5185 (11)
		dry weight	-0.1050 (17)		*0.7229*[3](10)	0.3879 (3)	0.3729 (11)
	M. truncata	Shell length	-	0.3095 (20)		*0.7853*[3](7)	
		Shell width	0.2706 (24)	-		0.4652 (7)	
		Shell height	0.1967 (24)	*0.5677*[3](14)		-	
		dry weight	0.1278 (24)	*0.5438*[3](20)		0.5547 (7)	
As	*S. droebachiensis*	test height	0.1408 (17)		0.5831 (10)	-0.9555 (3)	-0.1694 (11)
		test width	0.2812 (17)		0.5028 (10)	-0.7953 (3)	-0.2734 (11)
		dry weight	0.1936 (17)		*0.6633*[3](10)	-0.9795 (3)	-0.3288 (11)
	M. truncata	Shell length	*0.4203*[3] (24)	0.0363 (19)		0.6382 (7)	
		Shell width	-	0.0510 (19)		0.5557 (7)	
		Shell height	*0.4453*[3] (24)	-0.1776 (13)		0.2317 (6)	
		dry weight	0.3160 (24)	0.0270 (19)		-0.0123 (7)	
Se	*S. droebachiensis*	test height	0.1899 (17)		*0.6886*[3](10)	-0.9616 (3)	-0.0266 (11)
		test width	0.2925 (17)		0.5637 (10)	-0.8081 (3)	-0.2612 (11)
		dry weight	0.3343 (17)		*0.7417*[3](10)	-0.9836 (3)	-0.0987 (11)
	M. truncata	Shell length	-0.1128 (24)	0.3933 (19)		0.4065 (7)	
		Shell width	0.0796 (24)	0.4179 (19)		0.2508 (7)	
		Shell height	-	0.3630 (13)		-0.3987 (6)	
		dry weight	-0.1341 (24)	-		0.2268 (7)	

... /cont'd

Table 7. Cont'd

Metal	Species	Measurement	Station (n) 3	2	7	1	5
Hg	*S. droebachiensis*	test height	-0.0236 (17)		*0.6805*[3] (10)	-0.9120 (3)	0.1373 (11)
		test width	-0.0931 (17)		*0.8084*[3] (10)	*-0.9975*[3] (3)	0.2002 (11)
		dry weight	-0.1215 (17)		*0.6361*[3] (10)	-0.8683 (3)	0.0993 (11)
	M. truncata	Shell length	0.0593 (22)	0.1144 (19)		0.0673 (7)	
		Shell width	0.1374	0.1128 (19)		-	
		Shell height	-	-		-0.7274 (6)	
		dry weight	0.0999	0.0654 (19)		-0.1860 (7)	

[1] correlations performed on $\log_{10}$ transformed metal concentrations and body measurements.
[2] values below the level of detection were treated as absolute numbers.
[3] significant at the .05 level of probability.

Table 8. Summary of analysis of variance for trace metal concentrations relative to station location for *Mya truncata* and *Strongylocentrotus droebachiensis* from Strathcona Sound, N.W.T. - August, 1979.

Trace Element	*Mya truncata* Stations (1, 2, 3, 4)				*Strongylocentrotus droebachiensis* Stations (1, 3, 5, 7)			
	df[1]	F[1]	df[2]	F[2]	df[1]	F[1]	df[2]	F[2]
Pb	3, 49	4.3660[3]	3, 38	5.6682[3]	3, 37	44.9675[3]	3, 37	44.3856[3]
Zn	3, 49	69.0803[3]	3, 49	69.0780[3]	3, 37	36.1619[3]	3, 37	36.1620[3]
Cd	3, 49	9.5968[3]	3, 49	9.5968[3]	3, 37	3.9964[3]	3, 32	2.5930[3]
As	3, 48	5.2154[3]	3, 48	5.2154[3]	3, 37	1.0311	3, 37	1.0311
Se	3, 48	2.3617	3, 48	2.3617	3, 37	0.1229	3, 37	0.1230
Hg	3, 46	5.2423[3]	3, 45	5.2898[3]	3, 37	0.5637	3, 37	0.5740

[1] values below the limit of detection treated as absolute.
[2] values below the limit of detection treated as missing.
[3] significant at 0.01 level of probability.

Table 9. Comparison of least significant difference (LSD) and difference between means (D) for mean metal concentration (µg/g dry wt) in soft tissues of individual *Mya truncata* from Strathcona Sound, N.W.T. - August, 1979.

Metal (mean concentration)			Station (n)			
			3	2	4	1
Pb	LSD[1]	2.86	2.28 (24)	1.00 (20)	6.96 (2)	1.42 (7)
	D[1]	3.82				
Zn	LSD[1]	81.1	388 (24)	118 (20)	228 (2)	124 (7)
	D[1]	108				
Cd	LSD[1]	1.11	2.67 (24)	3.30 (20)	1.72 (2)	4.55 (7)
	D[1]	1.48				
As	LSD[1]	14.0	25.2 (24)	13.6 (19)	10.3 (2)	10.9 (7)
	D[1]	18.5				
Hg	LSD[1]	0.017	0.05 (22)	0.03 (19)	0.02 (2)	0.03 (7)
	D[1]	0.023				

[1] $P \leq 0.05$, values below the limit of detection treated as the absolute value of the detection limit.

Table 10. Summary of mean concentrations of trace metals in bivalve molluscs and gastropods from the vicinity of Station 3, Strathcona Sound, N.W.T., August, 1975.

Species	Group size	n	Metal Concentration (µg/g dry wt) ± Standard Deviation Pb	Zn	Cd	As	Hg	Fe	Cu
Mya truncata	3[1]	1[1]	1.19	105	1.84	-	-	1900	12.6
Astarte borealis	4	1	<0.10	83.3	21.0	12.5	0.02	183	867
	7	1	<0.10	88.0	15.5	13.7	<0.01	338	9.50
	9	1	0.33	88.0	20.5	12.6	0.02	288	9.20
	10	1	<0.10	113	15.0	11.6	0.04	288	10.3
Modiolaria nigra	4	1	2.94	88.4	3.72	-	-	930	26.7
Serripes groenlandicus	1	6	0.16 ± 0.04	77.6 ± 34.2	0.97 ± 0.62	6.48 ± 2.18	0.03	567 ± 390	7.60 ± 2.33
	2	1	0.37	70.9	1.25	6.00	<0.01	2595	6.80
	3	2	0.31	88.6 ± 12.5	0.56 ± 0.11	7.72 ± 0.40	0.05 ± 0.01	887 ± 361	10.5 ± 1.55
Cardium ciliatum	1	3	0.90 ± 0.95	51.3 ± 36.7	1.60 ± 0.98	4.90 ± 2.71	0.09 ± 0.06	544 ± 446	7.77 ± 3.67
	2	1	0.19	62.5	0.82	6.97	<0.01	800	10.7
Hiatella arctica	3	1	2.55	88.5	2.11	16.5	0.03	5030	10.6
	5	1	1.17	92.0	1.89	17.1	0.02	5800	11.5
Buccinum sp.	1	1	0.51	872	13.6	35.9	0.02	328	30.1
	2	1	0.72	589	15.2	15.2	0.06	380	26.1
	6	1	0.77	480	31.2	25.4	0.05	420	34.0
Buccinum hydrophanum	1	2	0.40	315 ± 4.95	19.8 ± 24.3	22.6 ± 0.91	0.05	251 ± 219	20.4 ± 5.09
Buccinum finmarkianum	1	1	<0.22	309	16.6	-	-	371	10.7
Sipho sp.	2	1	<0.25	582	14.1	-	<0.01	800	31.5
NBS Bovine Liver 1577									
Lab Value			0.30	125	0.27 ± 0.03	0.04	-	-	182 ± 6
Accepted Value			0.34 ± 0.08	130 ± 13	0.27 ± 0.04	0.055 ± 0.005	-	-	193 ± 10

[1]Analysis of one sample consisting of three organisms.

Table 11. Summary of mean concentrations of trace metals and selenium in molluscs collected from Strathcona Sound, N.W.T. during August, 1979.

Species	Component	Station	Metal Concentration (µg/g dry wt)[1] ± Standard Deviation											
			n	Pb	n	Zn	n	Cd	n	As	n	Se	n	Hg
Mya truncata	TS[2]	3	24	2.28 ± 3.34	24	388 ± 92.9	24	2.67 ± 0.85	24	25.2 ± 16.2	24	2.75 ± 0.45	22	0.05 ± 0.02
	TS	2	20	1.00 ± 0.70	20	118 ± 25.1	20	3.31 ± 1.00	19	13.6 ± 3.10	19	2.47 ± 0.27	19	0.04 ± 0.01
	TS	4	2	6.96 ± 1.17	2	228 ± 75.0	2	1.72 ± 0.40	2	10.3 ± 0.67	2	2.66 ± 0.09	2	0.02
	TS	1	7	1.42 ± 0.71	7	124 ± 15.0	7	4.55 ± 0.90	7	11.0 ± 2.98	7	2.50 ± 0.26	7	0.03 ± 0.01
	TS	5	1	2.39	1	163	1	0.82	1	33.1	1	2.33	1	0.01
Mya truncata	TSG(2)[3]	3	2	0.19	2	429 ± 37.5	2	2.32 ± 1.71	2	17.8 ± 7.92	2	2.63 ± 0.21	2	0.04 ± .004
	H(12)[4]	3	1	1.31	1	339	1	2.35	1	18.2	1	2.48	1	0.06
	TSG(2)	7	1	4.60	1	152	1	1.50	1	12.9	1	2.51	1	0.02
	TSG(3)	7	3	2.61 ± 0.43	3	178 ± 7.86	3	2.65 ± 0.21	3	16.0 ± 5.08	3	2.97 ± 0.36	3	0.02 ± .003
	TSG(4)	7	1	2.00	1	135	1	2.50	1	18.0	1	2.63	1	0.02
	H(7)	1	1	1.24	1	125	1	4.24	1	10.5	1	2.41	1	0.02
	TSG(2)	5	4	1.44 ± 1.26	4	150 ± 11.5	4	1.67 ± 0.35	4	32.1 ± 12.6	4	2.87 ± 0.08	4	0.01 ± 0.01
	TSG(3)	5	1	3.65	1	236	1	3.37	1	20.5	1	2.84	1	0.03
Serripes groenlandicus	TS	3	4	3.15 ± 3.87	4	175 ± 20.4	4	1.89 ± 0.56	4	10.8 ± 1.43	4	3.36 ± 0.21	4	0.14 ± 0.07
	TS	4	1	4.00	1	91.9	1	1.10	1	9.45	1	2.93	1	0.10
	TS	5	1	1.54	1	118	1	1.99	1	11.0	1	3.88	1	0.09
Cardium ciliatum	TS	3	3	1.27 ± 1.94	3	85.1± 10.3	3	3.78 ± 1.14	3	8.27 ± 0.55	3	3.88 ± 0.09	3	0.20 ± 0.05
Hiatella arctica	TSG(3)	4	1	10.5	1	112	1	2.24	1	12.3	1	4.87	1	0.04
	TSG(3)	5	1	0.08	1	78.5	1	1.56	1	11.6	1	3.87	1	0.04
	TSG(4)	5	5	0.82 ± 1.09	5	83.9 ± 10.6	5	1.64 ± 0.39	5	13.8 ± 1.74	5	3.95 ± 0.64	5	0.04 ± 0.01

[1] values below the level of detection were treated as absolute numbers.
[2] TS = total soft tissues - individuals.
[3] TSG = total soft tissues (group of n).
[4] H = homogenate (of n subsamples).

Table 12. Summary of mean concentrations of trace metals and selenium in miscellaneous invertebrates and fishes collected from Strathcona Sound, N.W.T. during August, 1979.

Species	Component	Station	Metal Concentration (µg/g dry wt) ± Standard Deviation											
			n	Pb	n	Zn	n	Cd	n	As	n	Sw	n	Hg
Leptasterias polaris	TI[2]	3	3	1.42 ± 0.55	3	64.8 ± 3.17	3	2.14 ± 0.66	3	3.59 ± 0.78	3	2.48 ± 0.19	3	0.21 ± 0.04
	TI	7	1	0.52	1	55.9	1	1.68	1	3.56	1	2.74	1	0.10
Sea Cucumber	TI	1	3	0.33 ± 0.05	3	52.1 ± 2.53	3	4.89 ± 0.88	3	4.89 ± 0.55	3	2.97 ± 0.42	3	0.04
Myoxocephalus quadricornis	M[3]	3	1	0.47	1	49.3	1	0.08	1	40.2	1	2.21	1	1.22
	M	2	2	0.09 ± 0.04	2	116 ± 38.3	2	0.22 ± 0.09	2	10.4 ± 8.02	2	2.47 ± 0.09	2	0.45 ± 0.45
	M	6	2	1.13 ± 1.44	2	72.3 ± 34.7	2	0.68 ± 0.54	2	9.77 ± 6.55	2	2.80 ± 0.27	2	0.60 ± 0.45
	M	8	5	0.23 ± 0.16	6	70.1 ± 22.0	6	0.15 ± 0.04	6	14.1 ± 3.31	6	2.30 ± 0.45	6	0.47 ± 0.22
	M	1	1	0.16	1	74.5	1	0.13	1	8.39	1	2.53	1	0.18
	M	5	4	0.60 ± 0.72	4	67.6 ± 26.3	4	0.15 ± 0.08	4	12.3 ± 10.1	4	2.19 ± 0.28	4	0.56 ± 0.21
Myoxocephalus quadricornis	L[4]	3	1	0.13	1	89.1	1	4.35	1	36.7	1	3.26	1	0.26
	L	2	-	-	-	-	-	-	1	18.4	1	5.91	1	0.34
	L	6	1	0.86	1	97.6	1	0.68	2	16.3 ± 15.6	2	3.56 ± 1.70	2	0.27 ± 0.34
	L	8	4	0.23 ± 0.27	4	120 ± 20.7	4	6.05 ± 2.14	6	14.5 ± 6.91	6	8.19 ± 6.93	6	0.14 ± 0.08
	L	1	-	-	-	-	-	-	1	5.72	1	4.57	1	0.08
	L	5	4	0.45 ± 0.15	4	66.6 ± 17.4	4	1.53 ± 1.19	3	15.9 ± 17.8	3	3.16 ± 0.24	4	0.09 ± 0.08
Myoxocephalus scorpioides	M	3	1	0.22	1	82.7	1	0.18	1	12.6	1	2.11	1	0.16
	M	2	1	0.45	1	34.3	1	0.24	1	12.6	1	1.62	1	1.01
Myoxocephalus scorpioides	L	3	-	-	-	-	-	-	1	11.9	1	3.26	1	0.09
	L	2	-	0.98	-	127	1	2.61	1	19.2	1	3.55	1	0.21

[1] values below the level of detection were treated as absolute numbers.
[2] TI = total organism - individual.
[3] M = muscle.
[4] L - liver.

Table 13. Summary of water quality in Twin Lakes Creek.

Year		n	Constituent µg/L (total) ± Standard Deviation Pb	Zn	Cd	As	Hg	Fe	Cu
1974	creek mouth	3[1]	< 1.0	223 ± 111	< 0.2			11.7 ± 9.5	< 1.0
1975	creek mouth	5[1]	< 1.0	236 ± 113	< 0.7	< 0.5		6.2 ± 4.4	1.4 ± 0.5
1976	below diversion dam	3[1]	< 1.0	4.1 ± 0.7	< 0.1	0.2 ± 0.2		603 ± 311	-
		3	1.6 ± 0.9	5.8 ± 1.2	0.2 ± 0.1	0.8 ± 0.2		2230 ± 585	-
	upstream of mill	1	< 1.0	159	0.4	0.6		1490	6.4
	downstream of mill	2[1]	< 1.0	109 ± 53.7	0.2 ± 0.1	0.2 ± 0.2		475 ± 544	1.6
		3	1.1 ± 0.2	141 ± 44.1	0.5 ± 0.4	0.5 ± 0.3		1380 ± 516	3.7 ± 0.9
	creek mouth	3[1]	< 1.0	47 ± 8	0.9 ± 1	< 0.6			2.0 ± 0.5
		4	< 1.0	63 ± 23	0.4 ± 0.2	0.2 ± 0.1			2.0
1977[2]	decant structure	5	34.0 ± 36	62 ± 15	< 5	< 10	< 0.2	310 ± 154	< 10
	creek mouth	15	52.0 ± 43	341 ± 149	< 5	< 10	< 0.2	533 ± 242	39
1978[2]	decant structure	31	60.0 ± 37	51 ± 57	< 5	-	< 0.2	374 ± 355[3]	< 10
	creek mouth	3	56.0 ± 35	147 ± 49	< 5	< 10	< 0.2	494 ± 183	8
1979[2]	decant structure	10	45.0 ± 32	53 ± 31	5		< 0.2	-	5
	creek mouth	8	19.0 ± 14	583 ± 184	< 5			-	< 5
1980[2]	decant structure	14	< 20	68 ± 26	< 20			222 ± 216[4]	33 ± 10
	creek mouth	11	< 20	2500 ± 1210	< 20			2797[5]	< 20
Maximum Average Concentrations of tailings pond decant stipulated in Current Water Licence N5L3-0159			100	200	5	25	2.0		100

[1] $\mu g l^{-1}$ dissolved metal - this study.
[2] Based upon results reported in Nanisivik Mines Limited, Annual Reports to the Northwest Territories Water Board.
[3] n = 3.
[4] n = 1.
[5] n = 10.

Table 14. Open ocean concentrations of trace metals compared with concentrations in Strathcona Sound, N.W.T. and two Greenland fjords.

Location	Depth (m)	Metal Concentration µg/L				Reference[4]
		Pb	Zn	Cd	Cu	
Open Ocean[1]		0.03	4.9	0.1	0.5	Brewer (1975)
Open Ocean (N.E. Atlantic)[2]			3.0	0.04	0.26	Preston et al. (1972)
Wadden Sea, Netherlands[2]		0.2	6.0	0.1	2.5	Duinker et al. (1979)
North-east Pacific[1]	0.2	-	0.08	0.005	-	Bruland et al. (1978 a,b)
Strathcona Sound, N.W.T. (1974)[2]	5	2.0	6.2	<0.2	1.0	This study
Agfardlikavsâ[2] (1973)	2	13	77	-	71	Bondam & Asmund (1974)
	20	19	57	-	40	
February, 1974 Station 1	2	176	353	2	-	Asmund (1980)
	20	165	625	2	-	
Qaumarujuk[2] (1973)	2	7	51	-	14	Bondam & Asmund (1974)
	50	6.5	56	-	12	
North-east Pacific coast						
Alice Arm	subsurface	1.20[1,3] 0.190[2,3]				Stukas and Wong (1981)
Dixon Entrance	subsurface	0.015[1,3] 0.012[2,3]				
English Bay	subsurface	0.17[1,3] 0.10[2,3]				
Saanich Inlet	subsurface	0.032[1,3] 0.026[2,3]				
Pacific Coast						
La Jolla, Calif.	0.1	0.036[1,3]				Patterson et al. (1976)
Straits of San Juan de Fuca, Wash.	0.1	0.024[1,3]				
New Zealand	surface				0.0021[1,3]	Boyle and Edmond (1975)

[1] Total metal.
[2] Dissolved metal.
[3] Values measured in $ngkg^{-1}$ and converted to µg/L.
[4] Improvements in sampling techniques and analytical methods render comparisons to pre 1975 data hazardous.

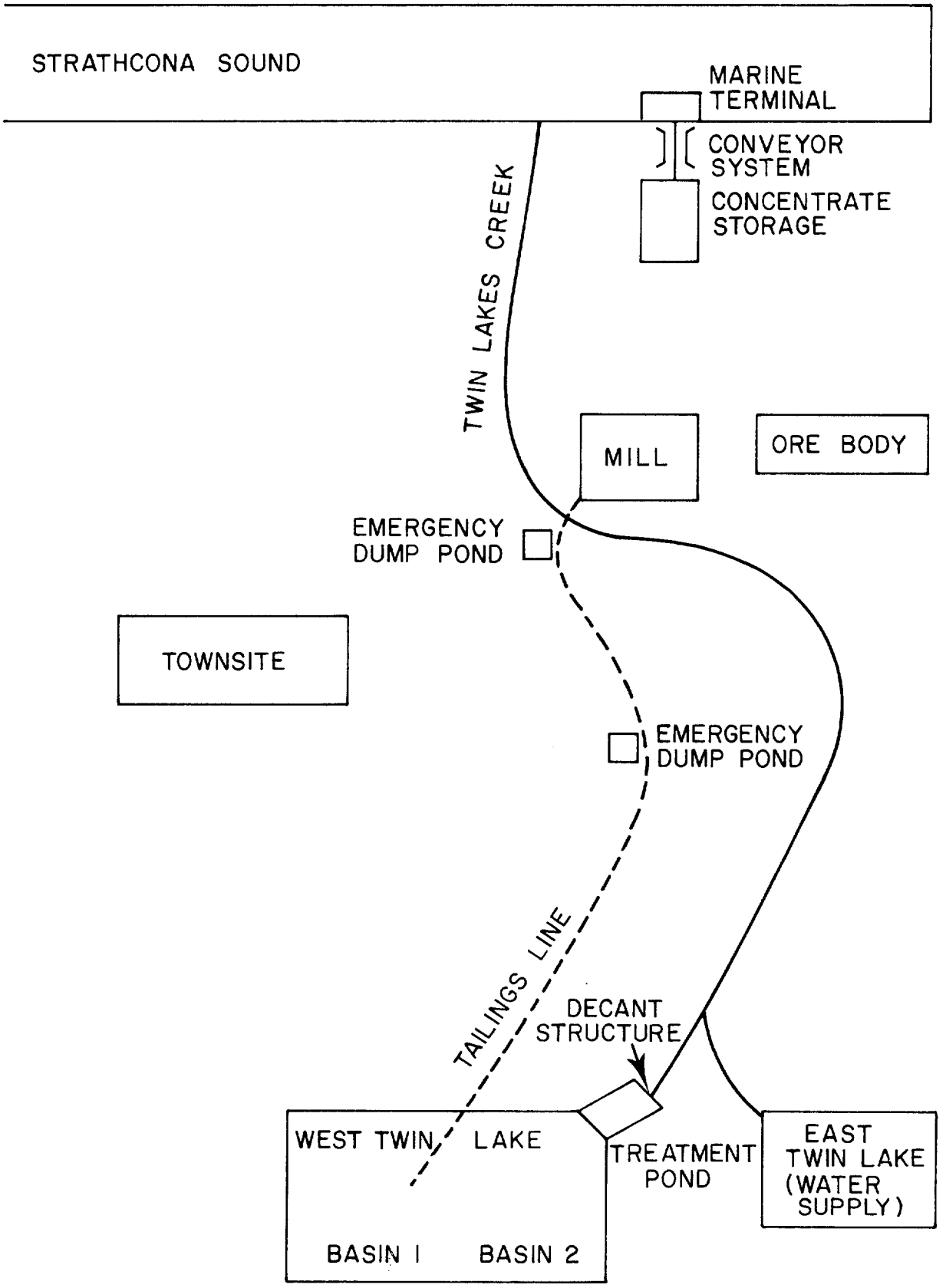

Figure 1. Schematic drawing of Nanisivik Mine tailings disposal system.

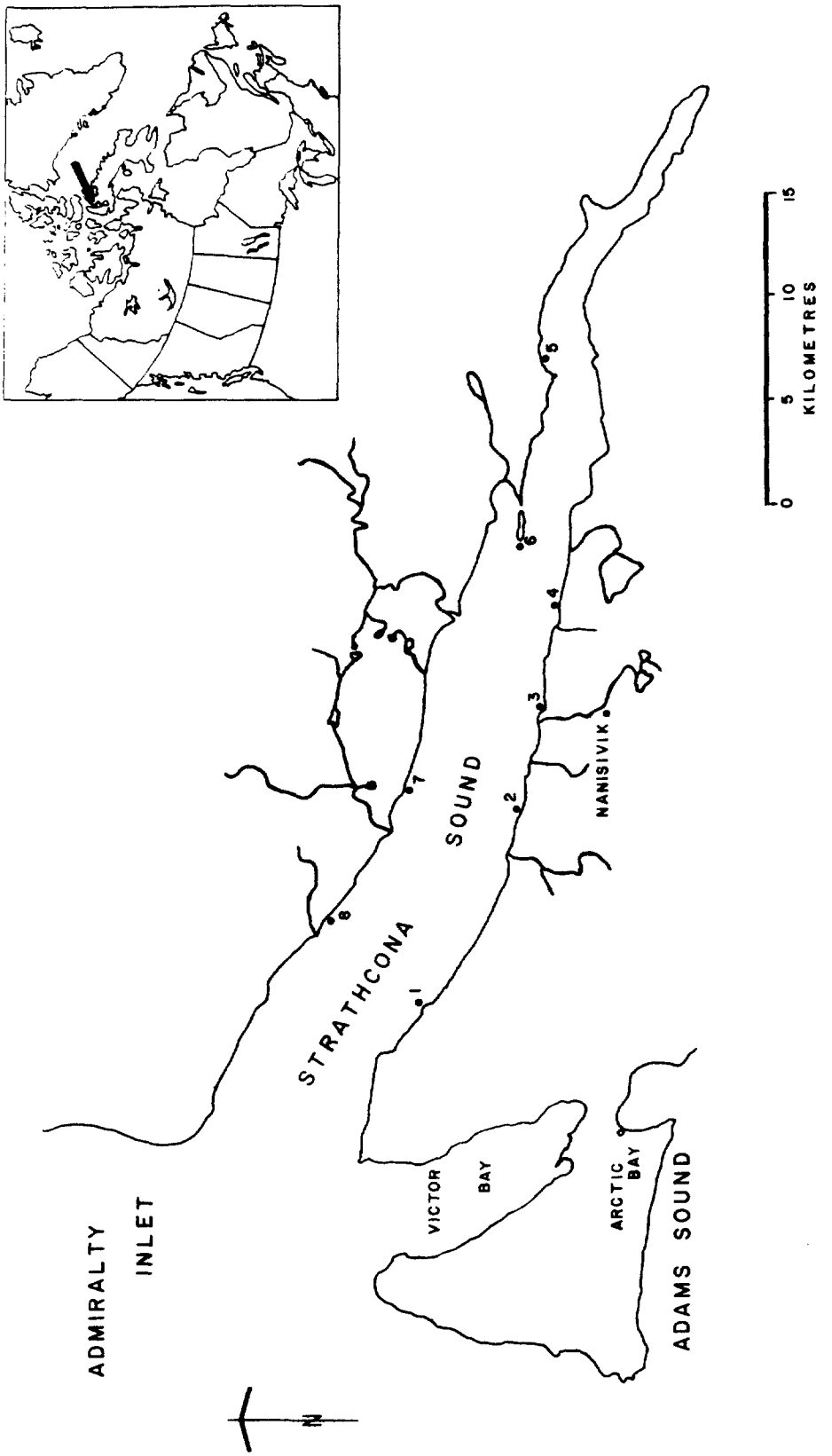

Figure 2. Location map and sampling stations associated with the 1979 monitoring programme.

Appendix I. Summary of analyses of NBS standard samples analysed in connection with trace metal determinations for the 1979 Nanisivik monitoring programme.

NBS Sample		Metal Concentration (µg/g dry wt) Pb	Zn	Cd	As	Se
Oyster SRM 1566	No. of Replicates	14	16	16	9	10
	Certified Value	0.48 ± 0.04	852 ± 14	3.5 ± 0.04	13.4 ± 1.9	2.1 ± 0.5
	Mean Obtained	0.49 ± 0.08	869 ± 30	3.39 ± 0.21	12.5 ± 0.65	1.89 ± 0.24
Bovine Liver SRM 1577	No. of Replicates	9	14	14	28	28
	Certified Value	0.34 ± 0.08	130 ± 13	0.27 ± 0.04	0.055 ± 0.005	1.1 ± 0.1
	Mean Obtained	0.34 ± 0.08	132 ± 8	0.27 ± 0.04	0.07 ± 0.02	1.08 ± 0.09
Tuna RM 50 (not certified)	No. of Replicates	10	10		32	33
	Expected Value	0.46	13.6 ± 1		3.3 ± 0.4	3.4 ± 0.4
	Mean Obtained	0.58 ± 0.16	15.8 ± 2.8		2.97 ± 0.49	3.66 ± 0.16

Appendix II. Methodologies employed for the analysis of cadmium, lead, zinc, arsenic, mercury and selenium in sediments, seaweed, invertebrate and fish tissues from Strathcona Sound, NWT.

(a) METALS IN SEDIMENTS

Sediments were digested with HNO_3, HF, $HClO_4$ and made to volume. Aliquots were extracted for lead as a metal chelate into methyl isobutyl ketone (MIBK). Other elements were analysed by appropriate dilution using atomic absorption spectrometry.

Weighed samples of 0.5-1.0 g dried, sieved sediment were placed into 100 mL Teflon beakers to which 2.5 mL concentrated nitric acid was added. The beakers were covered with watch glasses and heated gently until effervescence ceased. Fifteen mL of hydrofluoric acid was added and the beaker gently heated (overnight) at 200°C until volatilization of all silicates was complete. Two mL of concentrated HNO_3 was added to dissolve the residue and 1 mL of perchloric acid added and gently heated until perchloric acid fumes were visible and organic matter had been destroyed. Samples were gently heated to dryness, 2.5 mL HCl added and gently heated to dissolve the residue. This process was then repeated with an additional 2.5 mL conc. HCl. Volume was made up to 50 mL and transferred to an acid washed polyethylene screw cap bottle.

Four hundred g of citric acid monohydrate were dissolved in 100 mL distilled water to which 400 mL of reagent grade ammonium hydroxide were slowly added. The mixture was allowed to cool, the pH adjusted to 8.5 with ammonium hydroxide and made up to 1 L. Extraction was performed with 0.1% dithizone in chloroform until the extract remained green, and then extracted with chloroform to remove excess dithizone and filtered.

Twenty-five mL aliquots of the digest were transferred to a clean beaker and 5.0 mL pH 8.5 citrate buffer, 1.0 mL hydroxylamine hydrochloride added. Ammonium hydroxide was added dropwise while stirring to adjust the pH to 8.5. The sample was transferred to a 125 mL separatory funnel with a distilled water rinse. Two mL of freshly prepared ammonium pyrolidine dithiocarbamate (APDC) (prepared by dissolving 1.0 g APDC in water, diluting to 100 mL and filtering through 0.45μ Millipore filter) were added, mixed, and allowed to stand two minutes. To this 5.0 mL of water saturated MIBK was added and shaken for 1.5 minutes. The layers were allowed to separate and then transferred to a clean polyethylene centrifuge tube and centrifuged for 5 minutes at a #4 setting. The organic layer was aspirated into an air acetylene flame of an AAS set at the appropriate settings for solvent aspiration.

(b) METALS IN SEAWEED, INVERTEBRATES AND FISHES

Cadmium, Zinc, Lead

Approximately 1 g of dry material or 10 - 25 g of wet tissue (depending on amount of sample available) was taken to dryness on a hot plate with 10 mL concentrated nitric acid and 1 mL 25% K_2SO_4 solution as an ash aid (Menden et al. 1977). The samples were ashed in a muffle furnace for 10 - 12 h at 450°C. The ash was dissolved with heat in 1 mL concentrated nitric acid and 1 mL concentrated hydrochloric acid. The solutions were filtered and made to volume with deionized water. Standards, blanks, and NBS reference material were taken through the entire procedure.

Cadmium and zinc were analyzed directly by flame atomic absorption spectroscopy using their respective resonance line and a nearby non-absorbing line to correct for background intereference. Quantitation was against suitable standards.

An aliquot of the sample digest was extracted with a small volume of 0.5% w/v DDDC in butyl acetate and analyzed for lead by flame atomic absorption using the 283.3 nm line.

Arsenic and Selenium

Approximately 0.2 g of dry material or 2.5 g of wet tissue was dissolved with heat in 10 mL concentrated nitric acid. Five mL of concentrated sulfuric acid and 2 mL of concentrated perchloric acid were added and the solution heated until SO_3 fumes. Three 1 mL aliquots of H_2O_2 were added with heating. The solution was cooled and brought to volume with 30% HCl. Standards, blanks, and NBS reference material were taken through the entire procedure with the samples. An aliquot of solutions was mixed with a constant flow of 1% sodium borohydride and air in a 2:1:2 ratio. The gaseous phase was passed through a heated quartz cell (constructed with a quartz window and inlet tube at the same end) mounted in the light path of an atomic absorption spectrophotometer (Vijan and Wood 1974). Electrodeless discharge lamps were used and the arsenic and selenium determined at 193.7 nm and 196 nm respectively.

Mercury

The wet tissues were analyzed using the procedure of Hendzel and Jamieson (1976).

The dry sample material was analyzed according to the method of Knechtel and Fraser (1979) with slight modifications. A 0.5 g sample was weighed with ≈50 mg vanadium pentoxide into a graduated 50 mL digestion tube. Five mL of concentrated HNO_3 was added and the mixture was heated in a hot block at 160°C for 15 - 20 minutes. The solution was cooled and 4 mL of concentrated H_2SO_4 was added slowly. The samples were then placed back into the block and digested overnight at 160°C. Standard, blanks, and check samples were prepared in exactly the same way. The following morning, the samples were cooled, made to volume, and analyzed as described for the wet tissues.

Appendix III. Interlaboratory comparison of lead determinations on six check samples. (µg/g dry weight)

Sample No.	Industry Services Lab Mean S.D.	Toxicology Lab Mean S.D.
M-1-8	1.25 ± 0.76	2.43 ± 0.35
M-3-29	12.4 ± 2.3	13.8 ± 1.5
SU-3-16	47.3 ± 9.4	57.3 ± 4.9
SU-7-8	1.33 ± 1.30	1.4 ± 0.26
SW-4-2	5.36 ± 1.45	7.1 ± 0.70
SW-7-2	2.45 ± 1.40	2.2 ± 0.27

Appendix IV. Range of trace metal concentrations reported for seaweeds from various parts of the world.

Location	Species	Metal Concentration (μg/g dry wt) Pb	Zn	Cd	As	Reference
Canada (Atlantic Coast)	*F. vesiculosus* T[1]	-	49	-	58	Young and Langille (1958)
Canada (Strathcona Sound, 5 stn)	*F. distichus* T[1]	0.5 - 1.4	22 - 170	0.7 - 1.8	21 - 32	Bohn (1979)
Greenland (Qaumarujuk Fjord)	*F. vesiculosus* N[2]	5.6	6.8	<0.1	-	Møller and Pedersen (1972)
	F. vesiculosus O[3]	8.0	122	<0.1	-	Møller and Pedersen (1972)
	F. vesiculosus O[4]	3.0 - 137.5	24.5 - 277	0.7 - 2.2	-	Ministeriet for Grønland (1975)
	F. vesiculosus O[4]	12.0 - 127.8	57.1 - 365.8	0.8 - 4.0	-	Ministeriet for Grønland (1976)
	F. vesiculosus O[4]	10.9 - 209.5	47.4 - 504.4	0.8 - 2.1	-	Ministeriet for Grønland (1977)
Denmark (Kattegat)	*F. vesiculosus* T[1]	-	61.3 - 245.1	1.8 - 3.3	-	National Env. Prot. Agency Dk (1978)
Denmark (Belt Sea)	*F. vesiculosus* T[1]	<1	110 - 120	0.8 - 1.0	-	National Env. Prot. Agency Dk (1978)
Denmark (Limfjorden)	*F. vesiculosus* T[1]	<5	14 - 280	<4	-	National Env. Prot. Agency Dk (1978)
Denmark (3 stn)	*F. vesiculosus* N[2]	15.5 - 27.4	100 - 203	1.9 - 2.7	-	Phillips (1979)
Sweden (6 stn)	*F. vesiculosus* N[2]	14.0 - 21.3	73 - 270	1.9 - 3.9	-	Phillips (1979)
Wales (Cardigan Bay, 4 stn)	*F. vesiculosus* T[1]	-	317	-	-	Ireland (1973)
England (Bristol Channel)	*F. vesiculosus*	-	88.4 - 262	3.82 - 19.5	-	Fuge and James (1974)
Scotland	*F. vesiculosus*	0.5 - 4.3	60 - 124	0.9 - 2.1	-	Preston et al. (1972)
Canada (Atlantic coast)	*Laminaria digitata*	-	64	-	50	Young and Langille (1958)

[1]T = total plant.
[2]N = growing tips.
[3]O = old growth.
[4]O = old growth, ppm wet wt.

Appendix V. Ranges of trace metal concentrations reported for molluscs from various parts of the world.

Location	Species	Metal Concentration (µg/g dry wt) Pb	Zn	Cd	Reference
Greenland (Qaumarujuk)	*Mytilus edulis*[1]	2.3	8	<0.1	Møller and Pedersen (1972)
	M. edulis[1]	9.5 - 78.6	0.8 - 70.7	<0.5 - 1.2	Ministeriet for Grønland (1975)
	M. edulis[1]	5.3 - 67.6	5.1 - 84.2	<0.3 - 2.1	Ministeriet for Grønland (1976)
	M. edulis[1]	14.8 - 71.4	0.8 - 73.8	0.3 - 1.2	Ministeriet for Grønland (1977)
Denmark (8 locations)	*M. edulis*	20 - 125	81 - 211	0.8 - 3.3	Phillips (1979)
Sweden (9 locations)	*M. edulis*	34 - 202	52 - 361	0.6 - 7.6	Phillips (1979)
Canada (Burrard Inlet)	*M. edulis*	< 2 - 8	155 - 254	-	Popham et al. (1980)
Australia (Port Phillips Bay)	*M. edulis*[1]	-	19.3 - 60.1	0.20 - 0.61	Phillips (1976a)
Denmark (Øresund)	*Astarte borealis*	26.1	175	18.6	National Agency of Environmental Protection - Denmark (1978)
Denmark (Øresund)	*Buccinum undatum*	1.6 - 19.3	36 - 228	1.2 - 36.1	National Agency of Environmental Protection - Denmark (1978)
Denmark (Lillebaelt)	*Mya truncata* (incl. shell)	5.7	77	0.12	National Agency of Environmental Protection - Denmark (1978)
	Bivalve Molluscs - (mean concentration)	5.0	100	2.0	Bryan (1976)
Irish Sea (Port Erin)	*M. edulis*	9.1	91	5.1	Segar et al. (1971)

[1] µg/g wet weight.

Printed in Canada by
Supply and Services Canada
Printing Office
for exclusive distribution by
Fisheries and Oceans
Freshwater Institute
Winnipeg, Manitoba
Canada