96-80

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LONG RANGE ATMOSPHERIC TRANSPORT OF HEAVY METALS, PARTICULARLY MERCURY, IN CANADA: SOURCES, FATE AND EFFECTS

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ABSTRACT

This report makes available a series of diagrams and tables that were prepared as Overheads. The Overheads were selected to present examples of the available information relevant to questions surrounding the significance of long range atmospheric transport, deposition, trends and effects of heavy metals in Canada. Most of the available information in Canada concerns mercury and thus nearly all of the diagrams concern this metal(loid). Many scientists now consider mercury to be a pollutant of global concern and a major international conference is held biennially on the topic. However, it must always be remembered that mercury occurs naturally. There are many areas of Canada where natural concentrations of mercury in various media are much higher than in other parts of the country. An ongoing debate continues about the relative importance of natural mercury versus atmospherically deposited mercury from anthropogenic sources. Some information on other metals such as lead, arsenic, nickel, copper and zinc is included but this is mainly in the vicinity of smelters. Brief notes on the overheads are provided.

INTRODUCTION

Many of the overheads which follow have been compiled from the many more presented by various scientists who attended two Workshops held to discuss the Heavy Metals Protocol now proposed under the United Nations Economic Commission for Europe (UNECE-HM). These Workshops were held in 1995 in March in Ottawa and in Toronto in September 1995. Other diagrams have been extracted from the many reprints that were sent to me over the last twenty months of reviews of the science related to the UNECE-HM protocol. These reviews and workshops were held as cooperative efforts under the four Resource Departments (Environment Canada, Fisheries and Oceans Canada, Natural Resources Canada, and Agricultural and Agrifood Canada) Memorandum of Understanding. Everyone involved has been very generous in supplying me with these diagrams and reprints and especially those individuals who provided me with, as yet, unpublished data.

The drawings have been deliberately simplified by me. My objective was to remove as much extraneous lines or data in Tables as possible. Also, for example, I could include an infinite number of aquatic sediment metal maps for Canada to show natural ranges in concentrations but settled on only one for Hg as a perfect example. Similarly, there are a very large number of publications on sediment cores but since most show the same features, I have focused on some of the available Canadian Federal data and mostly on cores that have been age dated by radionuclides. Most of the examples are for Hg because this is the metal(loid) most studied today in terms of long range atmospheric transport. Formerly it was lead, but with the removal of lead from gasoline in Canada and the United States, the present interest in Pb is usually only to record its continuing downward trend.

In essence, this series of overheads has become a presentation of the type given as a Plenary Lecture at an international conference, where the audience comes from many disciplines and each individual only knows a small part of the total story, be it in great detail. I presented an earlier selection of these as part of just such an Invited Plenary Lecture at the 10th International Conference on Heavy Metals in the Environment held in Hamburg, Germany in September 1995. I was asked to present a more complete selection to the Department of Environment Science and Technology Committee at the Atmospheric Environment Service, Toronto, Ontario in November 1995 and as an Invited Plenary Session Lecture at the Environmental Monitoring and Assessment Network Conference in Halifax, Nova Scotia in January, 1996. Other presentations have been made to individual senior managers in Environment Canada. Copies of the overheads have been provided on request to the North American Commission on Environmental Cooperation (NACEC) in Montreal and to Environment Canada, Atlantic Region in Sackville. Photocopies such as those which follow have been provided to several individuals who have asked for them after presentations and to the Mining Association of Canada. Over the last year, the deck continued to expand but at this stage, there are only rare additions.

This collection is meant to be a balanced view. By balanced, the commentators, including those from industry, meant that the presentation included the viewpoints of both those who advocate the dominance of anthropogenic sources, at least for Hg, as well as those who consider natural sources of metals as the more important. The balanced view also means including data on major reductions in atmospheric emissions, recent improvements in terms of ecosystem contamination, and information on the relative importance of different Canadian versus American and European sources of metals to the atmosphere. Due to the nature and format of this report, subsequent editions will be continuously added to as new and relevant data becomes available.

NOTES ON THE OVERHEADS

The Overheads were prepared by the Graphics Art Group at the National Water Research Institute. They are brightly coloured so as to clearly show the content and have been positively commented on by many viewers. The Graphic Arts Group redid the Overheads in black and white for this report. The overheads are meant to be virtually self-explanatory but brief notes follow. Where locations are not obvious, they are mentioned in the notes below.

Mercury Concentrations in Aboriginal Peoples and Wildlife In Canada

1. Human standards. There is an excellent correlation between Hg in blood and hair. (Source Dr. B. Wheatley, HC.)

2. In humans, Hg is present as methyl-Hg. Note that 1060 measurements were over 100 ng/g (ppb). (Source Dr. B. Wheatley, HC.)

3. Similar results to Overhead 2 but these are the highest values for individuals instead of number of tests. (Source Dr. B. Wheatley, HC.)

4. Note high percent (55.4%) of Inuit women of child bearing age whose blood Hg is in the range of increasing risk. Mercury is considered to have more serious effects on the foetus and newly born. (Source Dr. B. Wheatley, HC.)

5. If belugas were human, several would be in the at risk level of over 100 ng/g Hg in blood. (Source Dr. R. Wagemann, FWI, DFO.)

6. Range of Hg in young otters. The lower concentrations in older animals has been hypothesised to be due to the fact that high Hg causes earlier death, possibly due to behavioural changes rather than toxicity. (Source Dr. R.D. Evans, Trent University, EMAN Report.)

7. The correlation between Hg in brain tissue and fur (hair) for male and female otters. As in humans and polar bears, Hg in hair is very closely correlated with Hg in blood. However, in humans, Hg in the brain and it's results as been a major concern since Minimata. Otter hair be used to monitor Hg exposure of fish eating mammals. Otters fed food with 2 ppm Hg died after about 9 months. (Source G. Mierle, OMEE Tech. Bull. AqSS-7.)

8. Mercury in loons (blood) from Alaska to Atlantic Canada. The high levels in Atlantic Canada (Kejimkujik Park) are under investigation. (Source N. Burgess, CWS, DOE, Atlantic Region.)

9. There is a correlation between Hg in fish eaten by loons and the Hg in the loons' blood. Reproductive effects on loons are suspected above 4 ug/ml Hg. (Source Dr. A.M. Scheuhammer, CWS, DOE, EMAN Report.)

10. Landlocked char in Amituk Lake (Overheads 44, 45 and 46) can be very old and exceed the 0.5 ppm Hg guideline. (Source Dr. L. Lockhart, FWI, DFO.)

11. Mercury in northern pike in Ontario based on the Ontario sport fish data base complied over 20 years. (Source Dr. G. Mierle, OMEE STB Tech. Bull. AqSS-6.)

12. Mercury in walleye in Ontario based on the Ontario sport fish data base compiled over 20 years. (Source Dr. G. Mierle, OMEE STB Tech. Bull. AqSS-6.)

13. Mercury in perch in Ontario. Wildlife uses different sizes of fish than humans who mainly use sport fish (Overheads 11 and 12). For example, loons and otters usually eat smaller fish such as perch. Many of the larger perch are in the 0.1 to 0.3 ppm concentration range. At 0.3 to 0.4 ppm Hg in fish, loons exhibited abnormal nesting behaviour and all chicks died before fledging. (Source Dr. G. Mierle, OMEE STB Tech. Bull. AqSS-7.)

14. Relationship between Hg and colour (DOC; humic material) in a small Ontario stream. Humic substances have a high affinity for Hg. (Source Dr. G. Mierle, OMEE STB Tech. Bull. AqSS-6.)

15. Because humic material is associated with wetlands, a similar relationship to that in Overhead 14 exists between Hg export and area of wetlands. Basins are complex and response to a uniform atmospheric load can be quite different and depends on many factors, e.g., dissolved organic carbon in the water column, planktonic species in the lake, natural concentrations, etc. These factors add to the variations seen in surface enrichment in lake sediments and different concentrations in fish from even adjacent lakes. Ninety-nine percent of Hg deposited is not in a methylated form while 90% or greater in fish is. Local factors and processes can strongly affect methylation rates and thus Hg bioaccumulation in fish. (Source Dr. G. Mierle, OMEE STB Tech. Bull. AqSS-6.)

Spatial and Temporal Mercury and Other Metal Trends in Canada

16. The concept of cultural (anthropogenic) enrichment of metals at the surface of lake sediment cores due to deposition from the atmosphere. Alternative view proposed by NRCan is that the enrichment is due to diagenesis - natural processes that accumulate the metals at the surface. (Source Dr. L. Lockhart, FWI, DFO.)

17. Enrichments of Hg in the surface of sediment cores is less in the northwest than north-south central Canada. (Source Dr. L. Lockhart, FWI, DFO and Dr. M. Lucotte, Univ. Quebec, Montreal.)

18. Shows natural and anthropogenic fluxes of mercury to lake sediments. Based on use of Pb-210 to account for focusing in lakes. Note the relatively higher natural mercury and lower anthropogenic fluxes in the northwest of Canada. (Source Dr. L. Lockhart, FWI, DFO.)

19. Shows enrichments in surface of lake sediments on background of range of natural Hg concentrations in over 161,000 lake sediments in Canada. Almost 90% of natural lakes have higher natural concentrations than Amituk Lake but the surface enrichment at Amituk reduces that to some 40%. The same applies to varying degrees to other lakes. The lake least affected is Kusawa (K) Lake in the Yukon. Amituk (A) is in the high Arctic. The other lakes are in a west to east sweep from Wisconsin (W), through southern Ontario (LT) to Quebec (T). Lake Ontario (O) (see Overhead 24) and Clay Lake (C) (see Overhead 25) are special cases. (Source Painter *et al*, 1994; various other reprints.)

20. It has been proposed that some diagenetic process, as opposed to increased atmospheric deposition of Hg caused by anthropogenic emissions, may cause the increases in Hg in the surface of some lake sediment cores. One process proposed is redox changes with depth which can alter the distribution of Fe and Mn and result in sub-surface peak concentrations for these metals as seen for Ya Ya Lake in the NWT. Note that the Hg and Pb in this core do not have significant surface enrichments in spite of the Mn, and to a lesser extent Fe, sub-surface peaks. (Source Dr. L. Lockhart, FWI, DFO.)

21. As above for Overhead 20, another proposed diagenetic process is the decomposition of organic matter with related parallel increases in both organic content (or loss on ignition - LOI) and Hg towards sediment core surfaces. In this core from Lake 375 at the Experimental Lakes Area (ELA) in northwestern Manitoba, there is, if any, trend in organic matter a slight decrease as the Hg increases in the recent surface layers. Note that this core is also described in the mass balance calculations shown in Overheads 42 and 43. (Source Dr. L. Lockhart, FWI, DFO.)

22. Shows natural burial in lake sediments of airborne input of Cesium from bomb testing. (Source Dr. L. Lockhart, FWI, DFO.)

23. Shows burial of airborne input of Pb in lake sediment cores in Lake Ontario. Core taken at exact same location in the east basin at three times. Considered due to reduction of Pb in gasoline. (Source A. Mudroch, NWRI, DOE.)

24. Shows burial of Pb and Hg in dated sediment cores from Lakes Ontario and Michigan. Pb reduction due to removal of Pb in gasoline; Hg due to closure or process changes at chlor-alkali plants or in the case of Michigan due to industrial changes. (Source SOLEC Report.)

25. Shows burial of Hg in a sediment core from Clay Lake which is located downstream from a former chlor-alkali plant (see Overheads 54 and 55). Core taken at the same location at different times. (Source Dr. L. Lockhart, FWI, DOE.)

26. Many lakes in Canada have trout exceeding the health consumption guideline for Hg of 0.5 ppm. (Source FWI, DFO.)

27. In four lakes from the geographic extremes of central-western Canada, no significant change in Hg concentrations were detected in pike between 1970 and 1993. Hg deposition in the area of most of the lakes is low (around 3 $ug/m^2/year$) by comparison to other regions of Canada and Europe. (Source Dr. R. Hecky, NWRI.)

28. Mercury concentration decreases in biota in Clay Lake (see Overhead 25) following chlor-alkali plant Hg release reductions beginning in 1970. (Source English-Wabigoon Mercury Report, Canada-Ontario, 1984.)

29. Mercury in beluga whales in the western Arctic is higher than in the east and thought to be related to higher natural Hg sources in northwest Canada as in Overhead 41 below. There is an apparent increase in Hg in whales and seals in both the east and west Arctic with time. However, both of these relationships are tenuous because of the problems of so few samples and complications arising from concentration/age relationships. (Source Dr. R. Wagemann, FWI, DFO.)

30. Annual trend in Hg in Innuit is thought to be related to hunting seasons. (Source Dr. B. Wheatley, HC.)

31. Overall long-term trend of blood Hg in first Nations is down. (Source Dr. B. Wheatley, HC.)

<u>Global, Regional and Local Sources of Mercury and Some Other Metals</u>

32. Mercury in air over the north and south Atlantic Oceans is higher in the northern hemisphere and may be related to more land with more industry or more natural sources.

33. Shows some earlier estimates of natural Hg fluxes based on a Greenland ice core (Weiss) and ice and snow samples from central Europe (Jaworowski) which are much larger than recent estimates. The earlier values are still being given along with the much lower calculations in recent OECD and WHO reports. (Source GSC, NRCan.)

34. This is the global mass balance model for Hg accepted by most of the world's experts from a Workshop funded by the U.S.A. Electric Power Research Institute (EPRI). Shows the present anthropogenic component in the atmosphere to be somewhat more than half the total. (Source EPRI Report.)

35. Shows estimates of Hg emissions from different global geographic areas. (Source Dr. H. Martin, formerly AES, DOE.)

36. Main source areas of annual emissions of sulphur dioxide are in northeastern North America and northern Europe and western Russia. Because many of the sources of heavy metals - coal and oil fired power stations, smelters, and incinerators - are also the main sources of sulphur dioxide, the main source areas for metals are likely to be quite similar. Note the location of the Arctic air mass in January - "Arctic Haze". (Source Dr. H. Martin, formerly AES, DOE.)

37. The source of arsenic measured in deposition at Alert has been back tracked using meteorological models to northwestern Europe and northern Russia. (Source Dr. W. Schroeder, AES, DOE.)

38. Circum-polar ratios of present-day total versus historical-geological mercury fluxes based on calculations on 51 lake sediment cores. Highest values greater than 3.5 are in south central and central Arctic Canada and in southern Scandinavia. Lower values are in the western Canadian Arctic, Quebec and northern Scandinavia. Lowest values are in Alaska and northern Russia. (Source Dr. D. Landers, U.S. EPA, Corvallis, U.S.A.).

39. Three dimensional model to fit North American total Hg flux ratios in lake sediments. The map shows contours bounding space of the data points in the stereographic coordinated space. (Source Dr. D. Landers, U.S. EPA, Corvallis, U.S.A.)

40. The main pathways of atmospheric metals into Canada are up the southeast coast and from Eurasia over the pole. (Source Dr. H. Martin, formerly AES, DOE.)

41. Higher natural Hg fluxes to lakes in the northwest is related to higher natural Hg in the local bedrock and surficial deposits. Note high Hg in stream sediments northeast of the Tintina Trench in the MacKenzie Mountains/Selwyn Basin area. There are many such maps for most metals and all reveal anomalous metal rich areas on a global scale. Coverage of Canada is presently about one third. The Hg map for the Yukon is a particularly good example. (Source Painter *et al.*, 1994.)

42. Mercury in a dated (by radionuclides) lake sediment core from lake 375 in the Experimental Lakes Area (ELA) which is about 40 km east of Kenora in northwestern Ontario near the Manitoba border. Present anthropogenic loadings are considered to be two to three times the natural geological and atmospheric loadings. (Source Dr. L. Lockhart, FWI, DFO.)

43. Calculated Hg mass balance for the lake from which the core in Overhead 42 above was taken. The present mass balance calculation of the loading, 20.2 ug/m^2/year, is close to that estimated from the lake sediment core (Overhead 42), 21 ug/m^2/year. (Source Dr. L. Lockhart, FWI, DFO.)

44. Mercury in environmental compartments at Amituk Lake, located some 60 km east-northeast of Resolute on Cornwallis Island in the Arctic Islands. Surface sediment enriched about four times. Historic (deeper) sediment is close to the mean concentrations in the relatively uniform limestone/dolomite in the drainage basin. (Source R. Semkin, NWRI, DOE.)

45. Mercury budget at Amituk separated into natural and anthropogenic components on basis of Ca to Hg ratios in bedrock and other media. The results indicate that the atmospheric component is just over four times the natural component. The match between the independent core estimate (Overhead 46 below) with the present day conditions, implies that the atmospheric component is almost entirely anthropogenic. This is also supported by the Ca/Hg content of the snowpack which shows that the local geological component (dust) in the snowpack is insignificant in terms of the total content. (Source R. Semkin, NWRI, DOE.)

46. Sediment core from Amituk lake. Note four times increase in concentration at the surface of Amituk Lake sediment versus geological component at depth. (Source Dr. L. Lockhart, FWI, DFO.)

47. The location of Atmospheric Environment Service's two major atmospheric chemistry monitoring stations in southern Ontario. (Source Dr. H. Martin, formerly AES, DOE.)

48. Lead deposition in precipitation decreased south to north, from U.S.A. into Canada.

49. Decline of Pb (and As) in precipitation with time at Point Petrie. See Overhead 47 for location of Point Petrie. Reductions in Pb deposition are primarily due to removing Pb from gasoline. (Source Dr. W. Schroeder, AES, DOE.)

50. When Hg is high in precipitation at Egbert, the sources are to the south and east in the U.S.A., when low north and west in Canada. See Overhead 47 for location of Egbert and Overhead 51 for main source area in U.S.A. (Source Dr. W. Schroeder, AES, DOE.)

51. Modelled total wet deposition of Hg based on 1989 emissions in the U.S.A.

52. Measurements made by the Mercury Deposition Network. Multiplied up to a year, they appear to be approaching the modelled numbers of Overhead 51 above. (Source Dr. S. Vermette, Buffalo State College, EMAN paper.)

53. Total Hg inputs in southern Ontario are higher than northwestern Ontario. Deposition in southern Sweden has declined in recent years - see Overheads 56 and 57 below. (Source Dr. J. Rudd, FWI, DFO.)

Point Sources of Mercury and Some Other Metal Emissions: Chlor-alkali Plants and Smelters

54. Former distribution in Canada of chlor-alkali plants using Hg cells, a source of Hg to the atmosphere directly and indirectly via effluents to rivers and lakes. Elimination of these effluents and emissions has been a major environmental success for Canada. Several such plants still operate in the U.S.A., in Europe and around the world. (Source P. Paine, EPS, DOE Report.)

55. Number of chlor-alkali plants operating in Canada peaked in early 1970s. (Source P. Paine, EPS, DOE Report.)

56. In Sweden, Hg cell chlor-alkali plants were the major internal source of Hg to the atmosphere. Peak was in mid-sixties. By the late 1980s, Hg deposition in Sweden was considered to be due to general emissions from coal fired power stations, smelters and incinerators to the south in Europe. However, after reunification of Germany in 1990, the very large Hg cell chlor-alkali plants built in the 1930s in the former East Germany were closed and since then Hg in precipitation in southern Sweden is said to have dropped dramatically. (Source Dr. A. Inverfeldt, Swedish Environmental Research Institute, EMAN Report.)

57. Mercury in sediment cores from two lakes in southern Sweden appears to record the recent decline in Hg loading noted above (Overhead 56). (Source Munthe *et al.*, 1995.)

58. Emission estimates for Pb, Cd and Hg from various sources in Canada, U.S.A. and Europe for 1988. (Dorion Report, EPS, DOE.)

59. Shows local deposition of Ni around Sudbury smelters in 1973. The area of primary deposition seems to be less than 100 km. (Source R. Semkin, NWRI, DOE.)

60. As above for Cu. Ratios of metals show sequences of deposition with distance. (Source R. Semkin, NWRI, DOE.)

61. Similar Cu pattern in 1991 in lichens. Area of primary deposition seems to be about 50 km. (Source Dr. K. Puckett, AES, DOE.)

62. Zinc in lake sediments around the Rouyn-Noranda smelter in early 1970s.

63. Nickle distribution in sediment cores from the Sudbury area in 1979/80 and in 1993. (Source Dr. J. Nriagu, Michigan State University.)

64. Zinc distribution in sediment cores collected in 1979 in the Flin Flon area. (Source NWRI.)

65. Pb, Hg and Ni in two lake sediment cores from northern Finland. The Pb profile implies long range atmospheric transport and deposition with surface increases due to anthropogenic sources of Pb. The same applies to the similar Hg profiles. Alternatively, the surface

increases in Ni near the Russian border, as opposed to western Lapland, imply local atmospheric Ni inputs from the Kola Peninsula Ni smelter complexes. (Source Dr. J. Mannio, Finish Environmental Agency, Helsinki.)

66. Zones of primary copper deposition around smelters in Scandinavia and Russia. (Source Nordic Council of Minister Report.)

67. Potential zones of primary deposition of metals around Canada's smelters. This does not mean that some proportion of the emitted metals do not become transported over much longer distances. This would be especially the case for metals emitted as very fine particulates, as aerosols and in gaseous form (Hg, Cd, As).

68. Voluntary reductions in Pb, Cd and Hg emissions from smelters between 1988 (or later) and 1995. Note that annual Hg emissions from the mining and smelting industry in Canada now total only 4.4 tonnes, an 83% reduction from the base year which is 1988 or later. This can be related to Overhead 60 for other Canadian sources in 1988. The 2000 data are projections. (Source Mining Association of Canada, ARET 1996 Report.)

Consistencies

69. The range of the science and the volume of data above is perhaps best viewed in terms of apparent consistencies while there remain active debates between scientists over individual aspects. Arguments can be made about individual items, such as natural Hg levels; the causes of Hg distribution in lake sediment cores; the role of basin features in bioaccumulation of methyl-Hg in fish, birds, mammals and humans; or the significance of Hg concentrations in the blood of birds, mammals and humans, etc.

Recommendations

70. Recommendations from the EMAN Mercury Workshop held at York University and attended by many of the scientific Hg experts in north America. (Source EMAN Report.)

ABBREVIATIONS

AES	Atmospheric Environment Service, DOE
CWS	Canadian Wildlife Service, DOE
DFO	Fisheries and Oceans Canada
DOE	Environment Canada
EPA	United States Environmental Protection Agency
EPS	Environmental Protection Service, DOE
FWI	Freshwater Institute, DFO
GSC	Geological Survey of Canada, NRCan

HC	Health Canada
NRCan	Natural Resources Canada
NWRI	National Water Research Institute, DOE
OMEE	Ontario Ministry of Environment and Energy

REPORTS AND PAPERS NOTED ABOVE

1. **ARET REPORT**. Voluntary Emissions Reduction. The Mining Industry and the Accelerated Reduction/Elimination of Toxics Program. Pub. Mining Association of Canada, 350 Sparks Street, Ottawa, 1996.

2. **DORION REPORT**. C.C. Dorion and Associates, 310 Jewett Street, Fredericton. Background Information Paper for a Heavy Metals Protocol under the UNECE Convention on Long Range Transboundary Air Pollution. Vol. No. 1, Feb. 1996.

3. **EMAN REPORT**. Proceedings 1995 Canadian Mercury Network Workshop. Environmental Monitoring and Assessment Network Occasional Paper Series Report No. 6, EMCO Office, Canada Centre for Inland Waters, Burlington, Ontario.

4. **EPRI REPORT**. Mercury Atmospheric Processes: A Synthesis Report. Expert Panel on Mercury Atmospheric Processes, Workshop Proceedings, U.S.A. Electric Power Research Institute Report EPRI/TR-104214, Sept. 1994.

5. **EPS REPORT**. Compliance with Chlor-Alkali Mercury Regulations, 1976-1989: Status Report. EPS 1/HA/2, Nov. 1994. ISBN 0-662-22715-8.

6. **IPCS REPORTS**. Environmental Health Criteria, Mercury. World Health Organisation, 1976, p. 42 and 1989, p.13.

7. **MUNTHE, J.**, Hultberg, H., Lee, Y.-H., Parkman, H., Inverfeldt, A. and Renberg, I. 1995. Trends of mercury and methylmercury in deposition, runoff water and sediments in relation to experimental manipulations and acidification. Water Air and Soil Pollution 85: 743-748.

8. **NORDIC COUNCIL OF MINISTERS REPORT**. Atmospheric Heavy Metal Deposition in Northern Europe 1990. Nord 1992: 12. The Nordic Council, Box 19506, S-10432 Stockholm. ISBN 9291200158.

9. **OECD REPORT**. Organisation for Economic Cooperation and Development. Risk Reduction Monograph No. 4. Mercury, 1994, p. 37 and 38.

10. **PAINTER, S.**, Cameron, E.M., Allan, R. and Rouse, J. 1994. Reconnaissance geochemistry and its environmental significance. Jour. of Geochemical Exploration 51(3): 213-246.

11. **SOLEC REPORT**. U.S.-Canada, State of the Lakes Environment Report, DOE, Ontario Region, Downsview, Toronto.

MEDICAL SERVICES BRANCH
MERCURY PROGRAM

HUMAN STANDARDS

BLOOD	< 20	ppb	Normal acceptable range
	20 - 100	ppb	Increasing risk
	> 100	ppb	At risk
HAIR	< 6	ppm	Normal acceptable range
	6 - 30	ppm	Increasing risk
	> 30	ppm	At risk

Exposure of Canadian Aboriginal peoples to Methylmercury cumulative results 1970 - 1992 - by region and level

Region	No. of Communities	Total Tests	ppb 20-99	ppb >100	Highest result	Year
Atlantic	23	710	15	-	99	1978
Quebec	52	23621	8376	689	649	1975
Ontario	106	20296	3714	286	660	1971
Manitoba	69	13897	2296	36	262	1989
Saskatchewan	74	2505	252	5	124	1978
Alberta	38	1505	52	2	105	1977
British Columbia	88	4620	315	3	146	1978
Northwest Territories	59	3826	1514	39	363	1971
Yukon	18	862	7	-	67	1977
Total	527	71842	16541	1060		

EXPOSURE OF CANADIAN ABORIGINAL PEOPLES TO METHYLMERCURY

INDIVIDUAL RESULTS 1972 - 1992

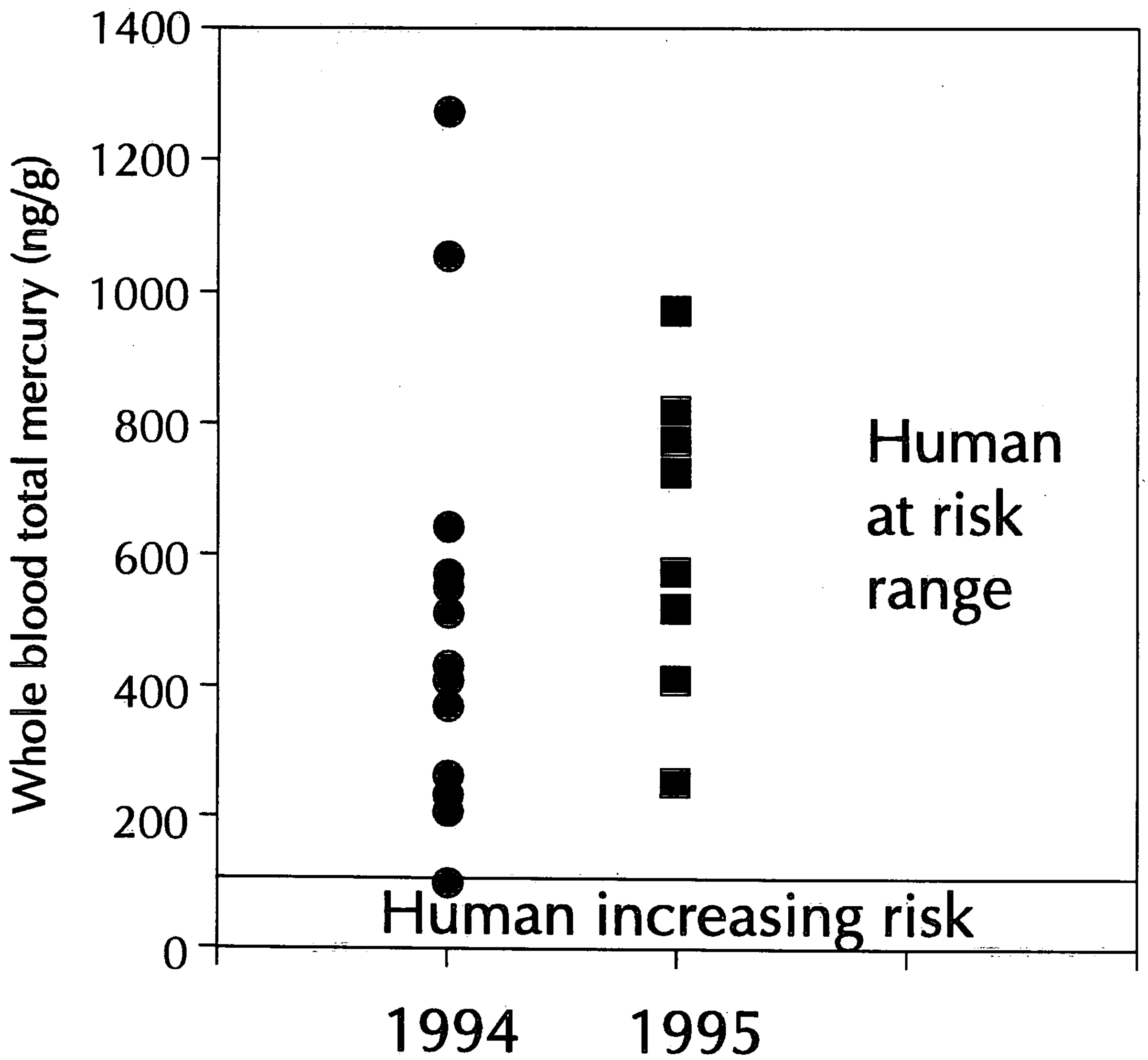
• 0 - 19ppb	29724	77.0%
• 20 - 99ppb	8239	21.4%
• 100 - 199ppb	541	1.4%
• OVER 200ppb	67	0.2%
• TOTAL	38571	100%

N.W.T. women between 15 and 45 years old MeHg levels (1974 - 1989)

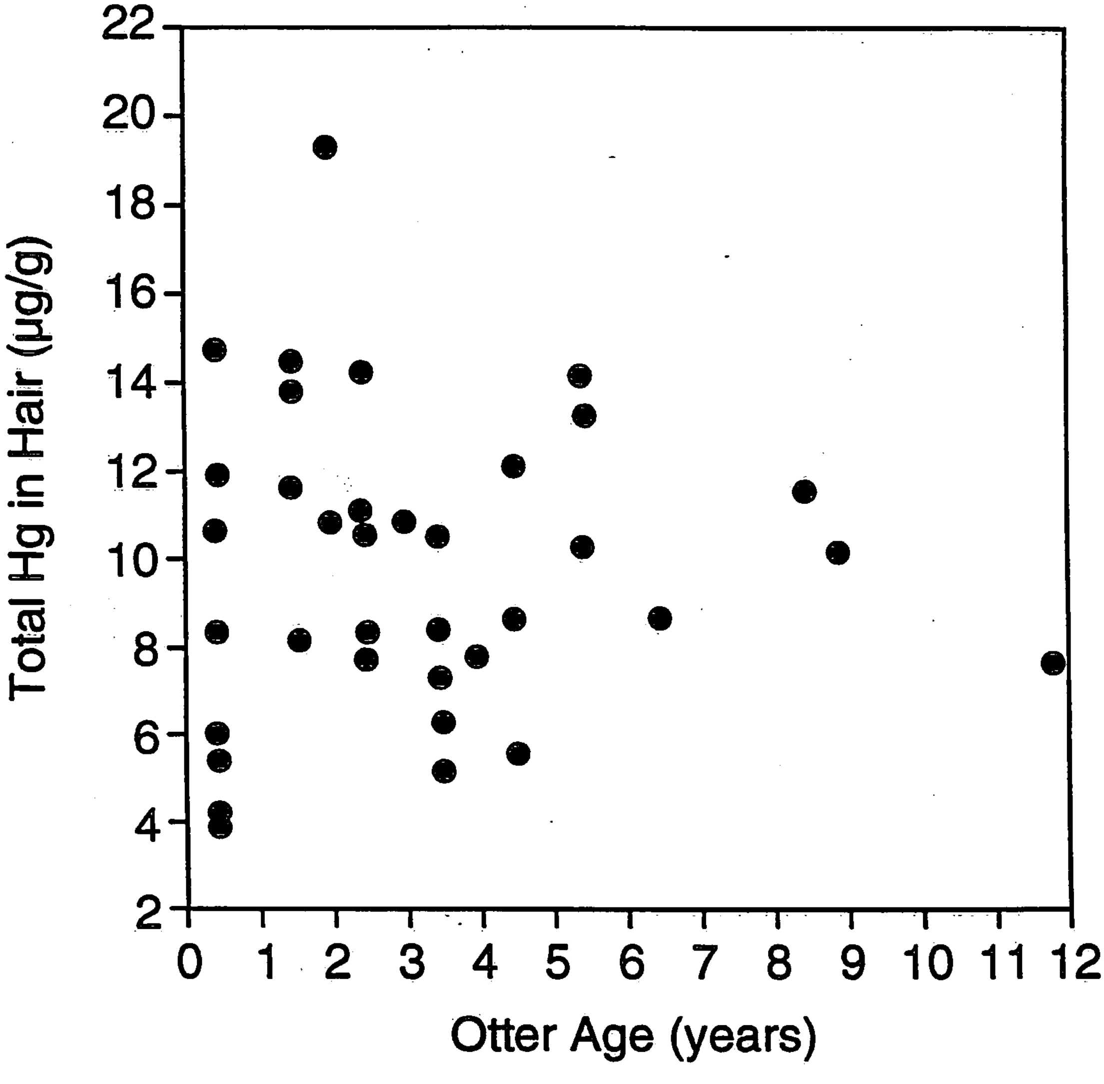
MeHg level (ppb)	DENE # of individuals	DENE Percent	INUIT # of individuals	INUIT Percent
More than 100	0	0	6	1
20 to 100	37	15.2	337	55 .4
TOTAL	244	100	608	100

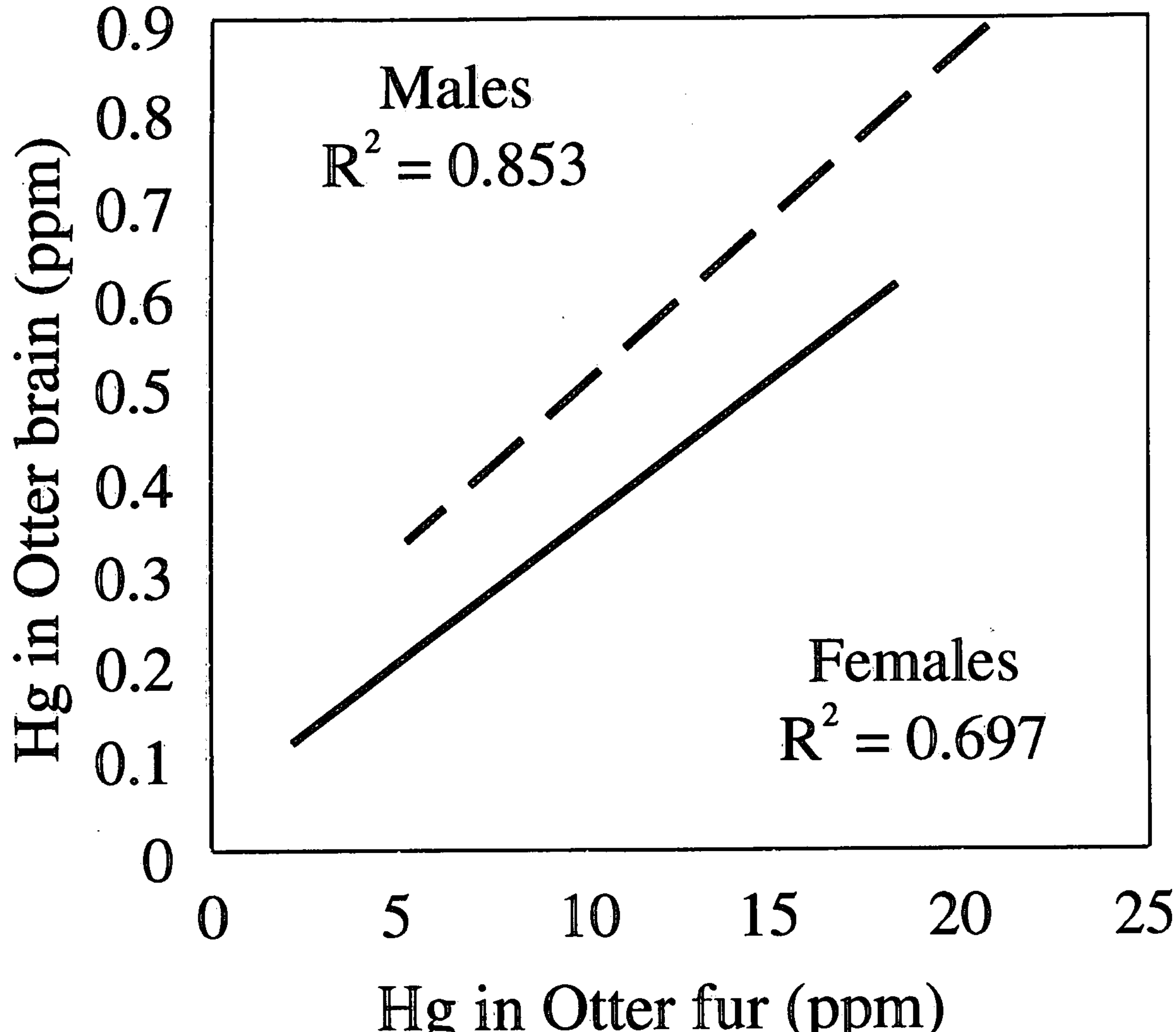
Each individual woman appears in only one category

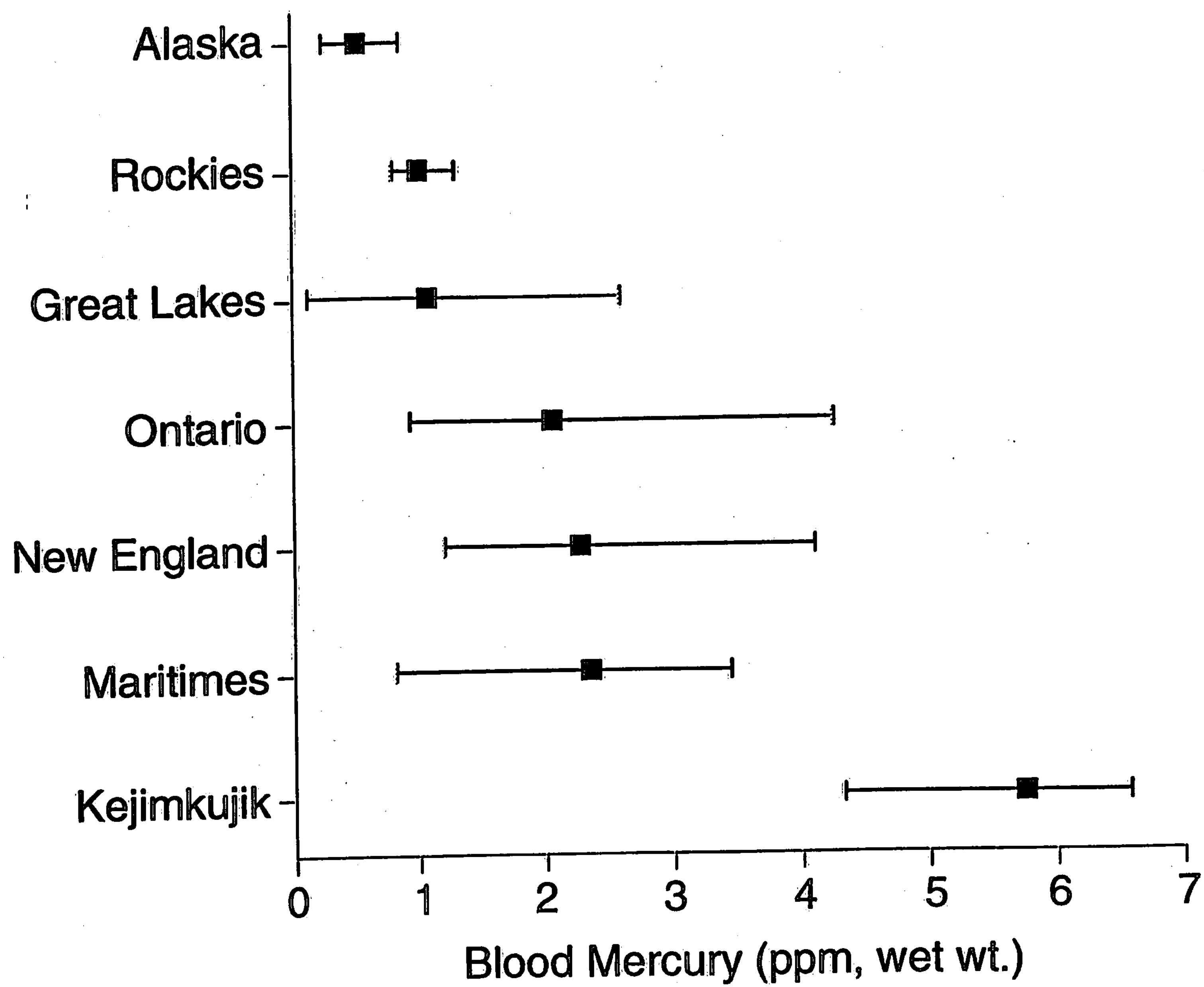
Beluga whale blood mercury
Mackenzie Delta, 1994 and 1995
(C. Hyatt, 1996)



HG IN OTTERS IN THREE TOWNSHIPS IN SOUTH CENTRAL ONTARIO

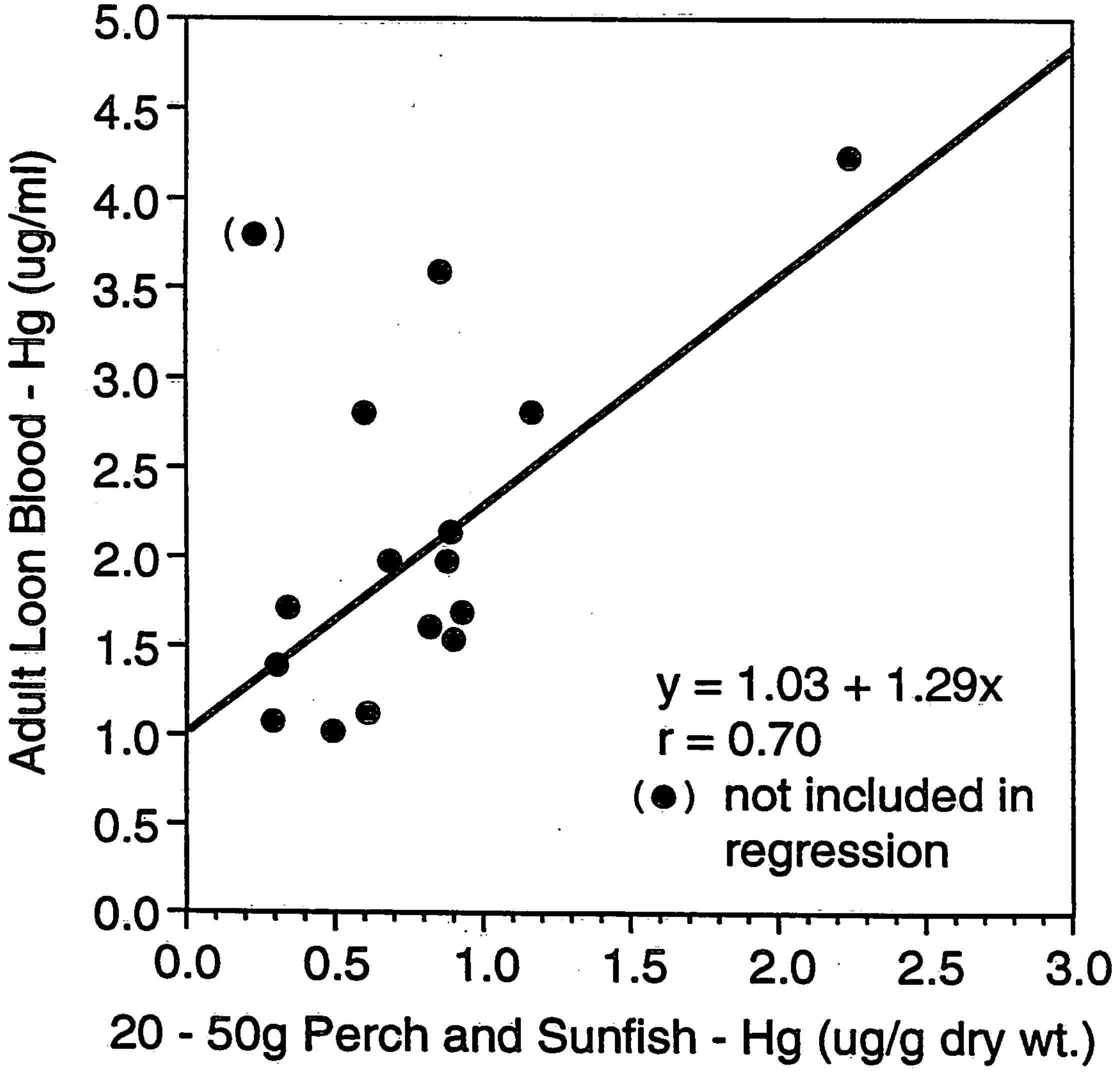


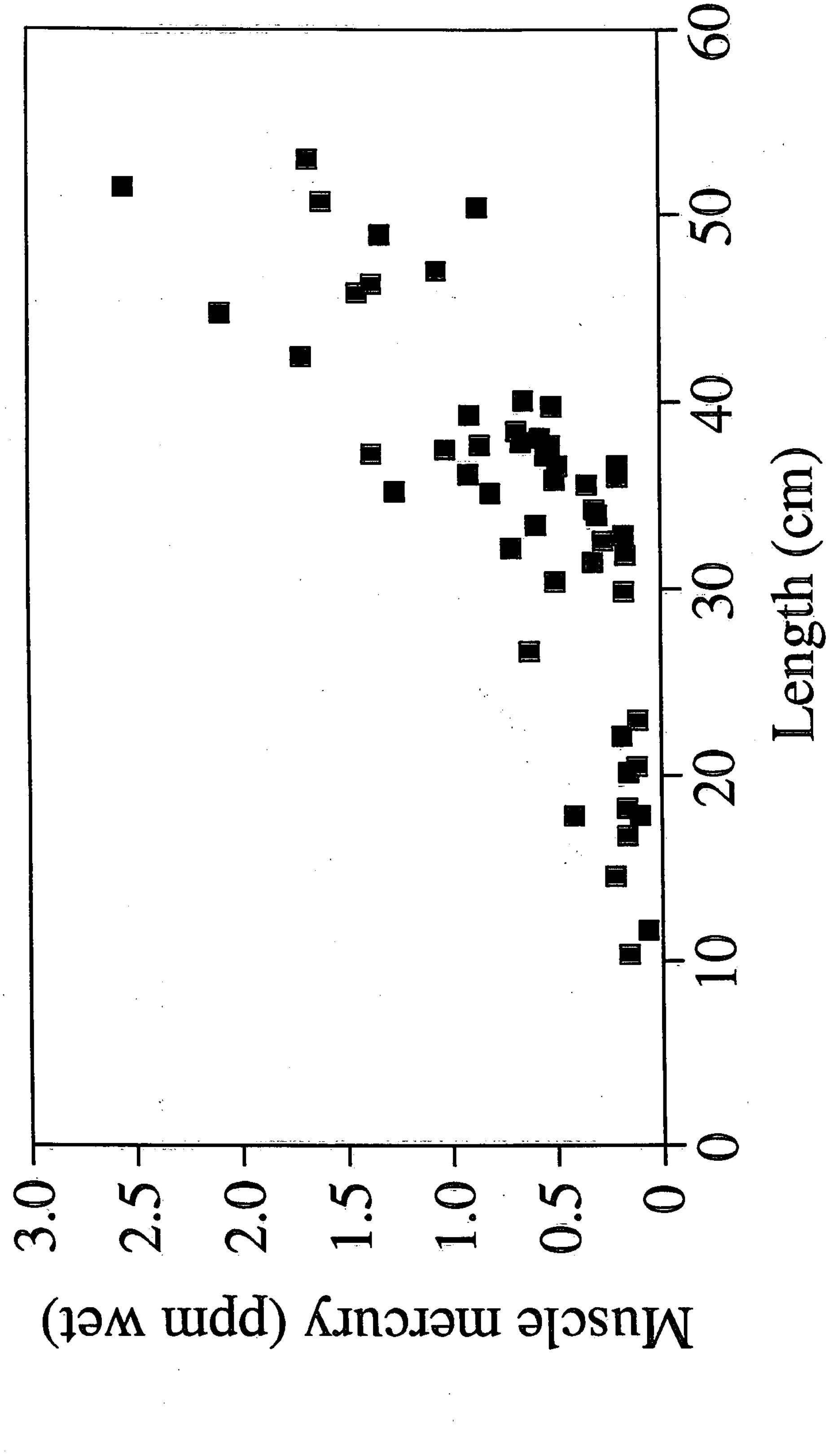

Males
R2 = 0.853
Females
R2 = 0.697
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
20
25
Hg in Otter brain (ppm)
Hg in Otter fur (ppm)



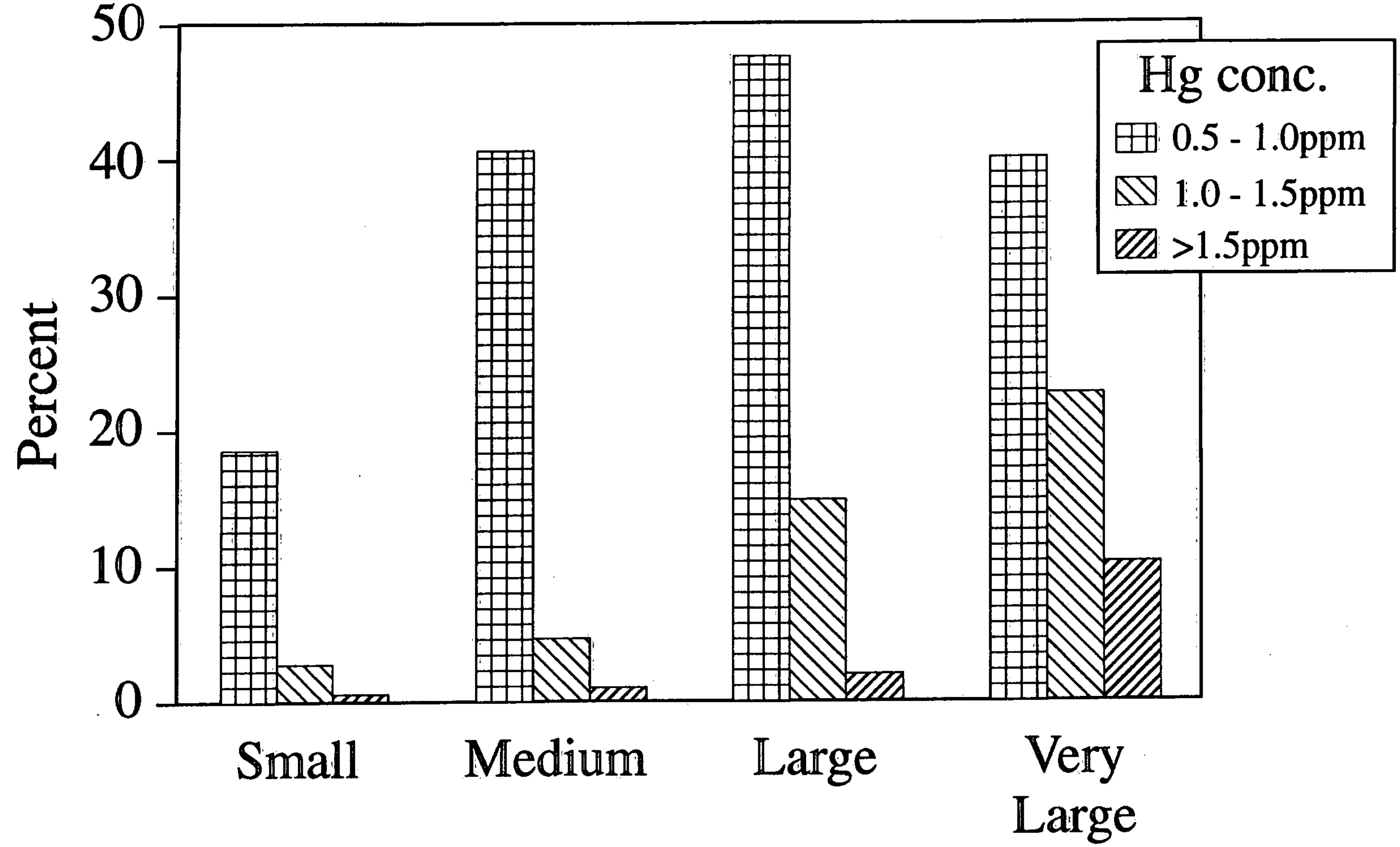
Mercury in North American adult loons
(Mean and range)

LOON BLOOD Hg AND FISH Hg IN CENTRAL ONTARIO LAKES

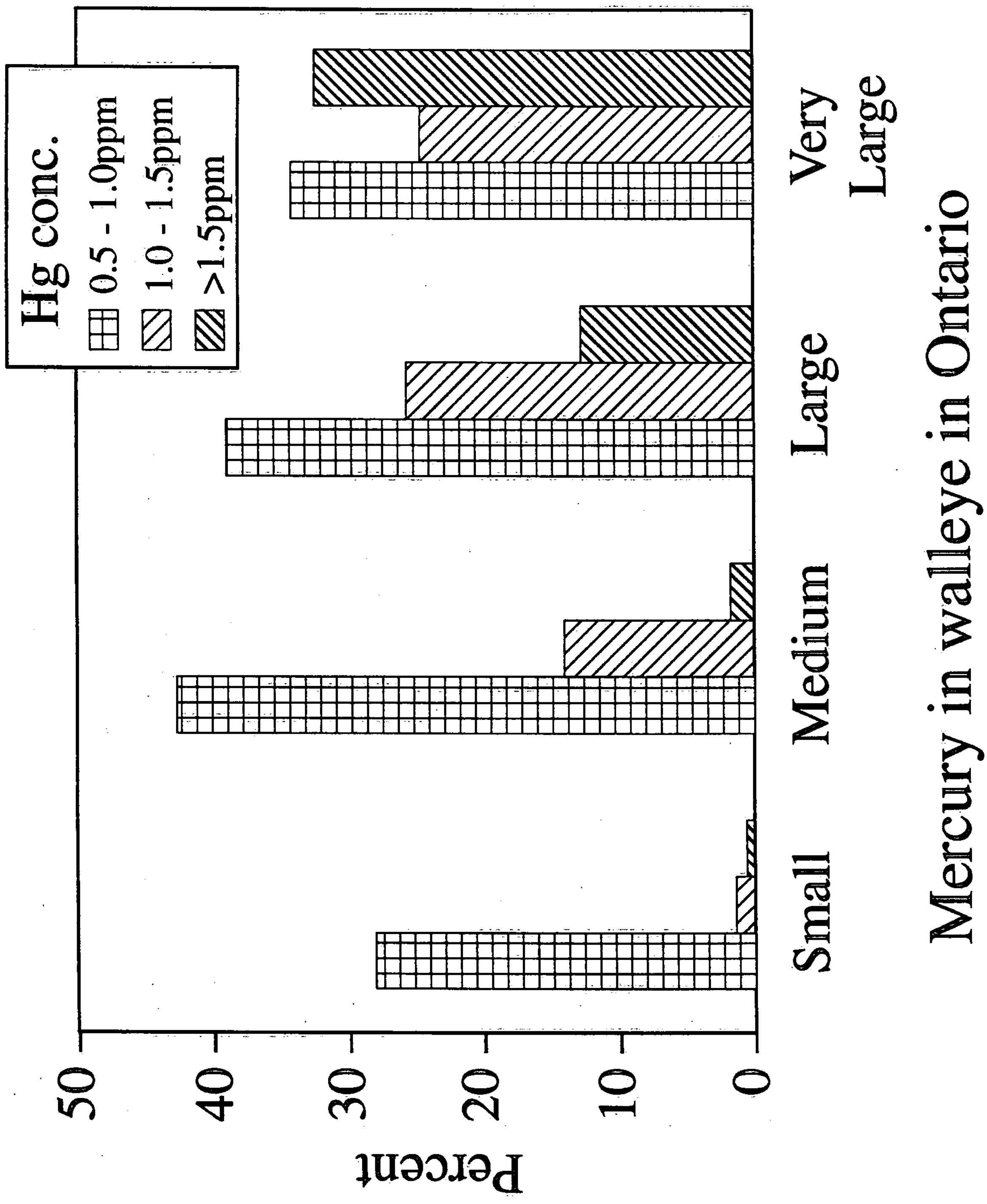


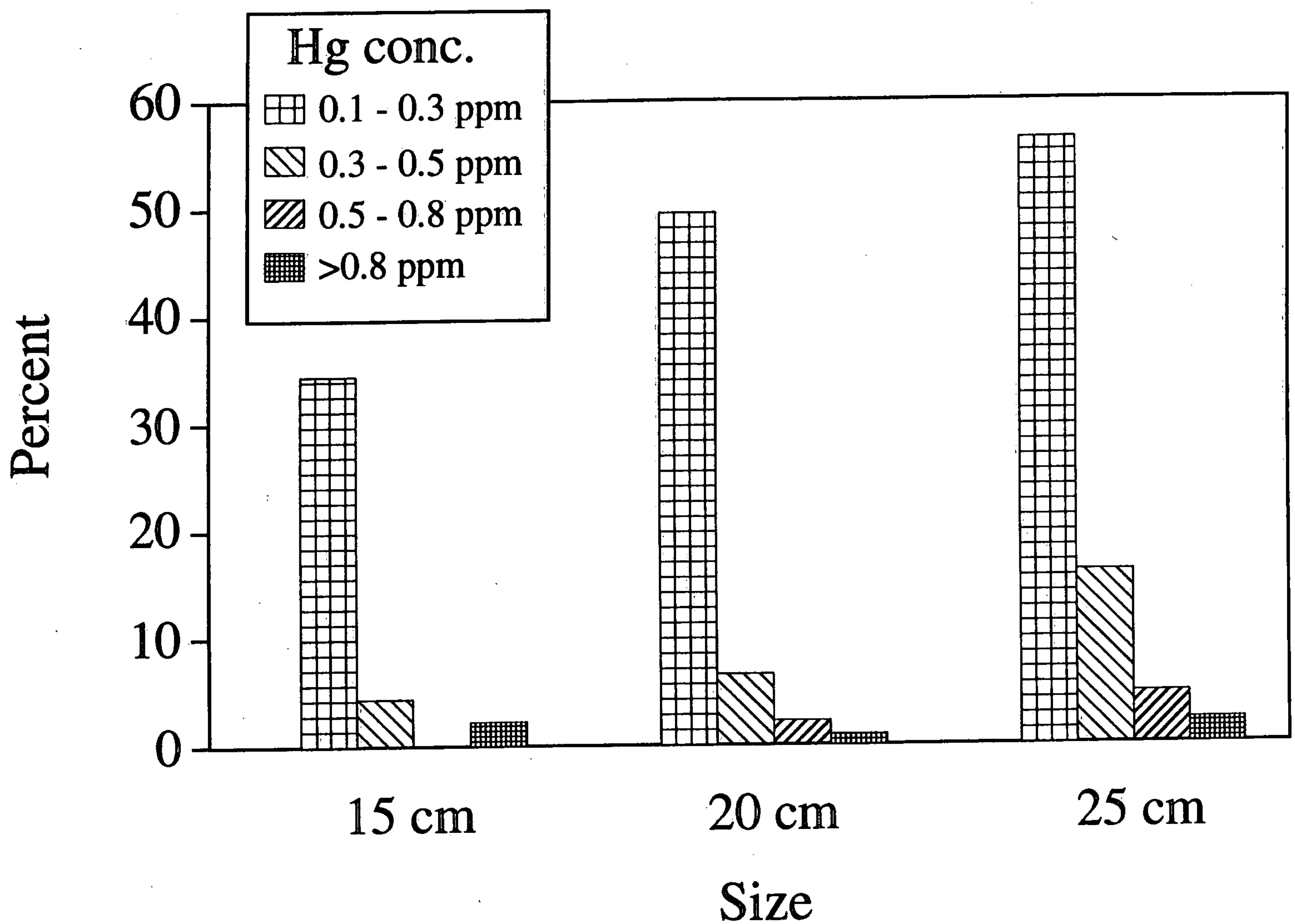


Mercury in land locked arctic char
from Amituk Lake, Cornwallis Island, N.W.T.

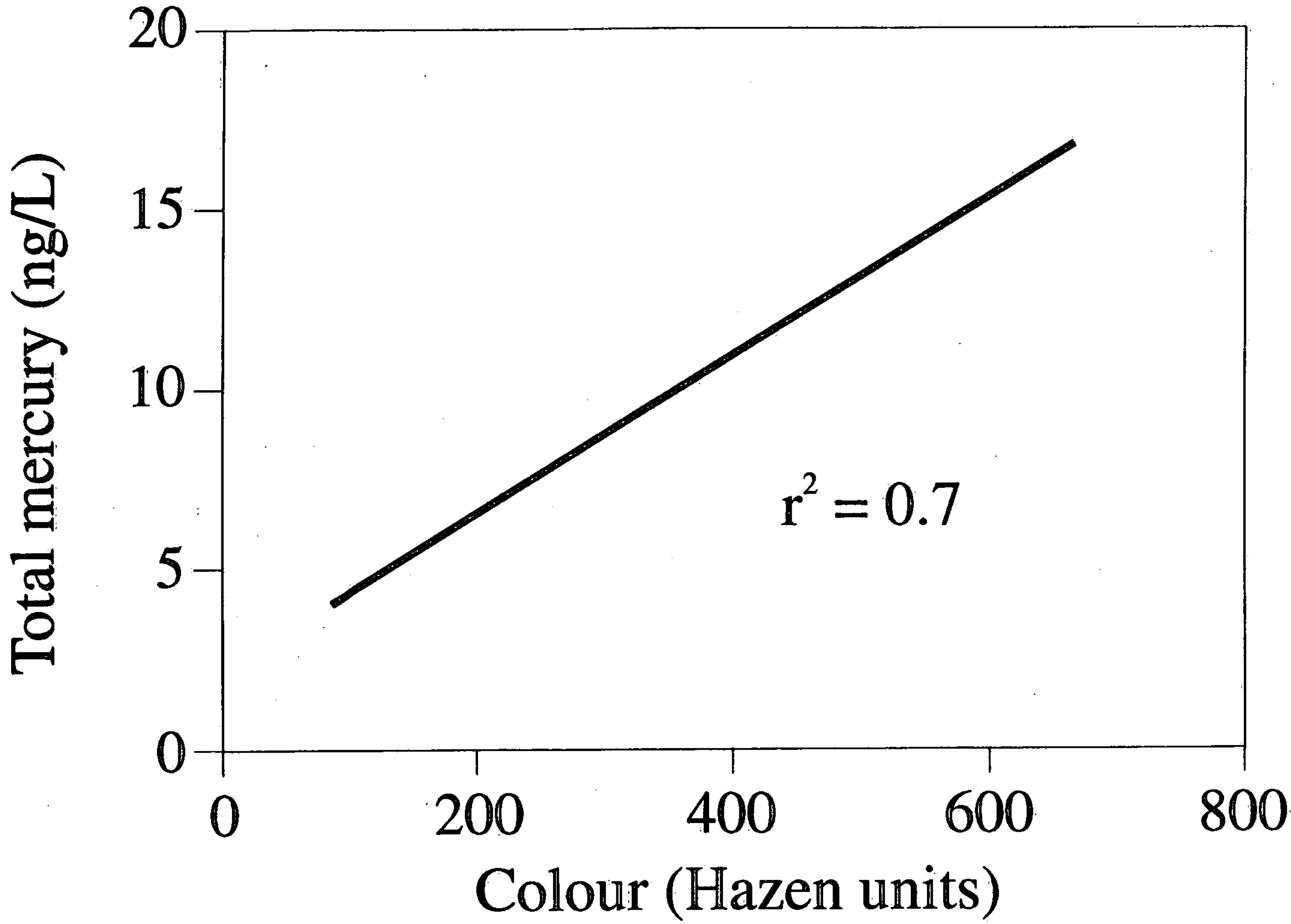


Mercury in Northern Pike in Ontario


Hg conc.
0.5 - 1.0ppm
1.0 - 1.5ppm
>1.5ppm
Percent
0
10
20
30
40
50
Small
Medium
Large
Very Large
Mercury in walleye in Ontario

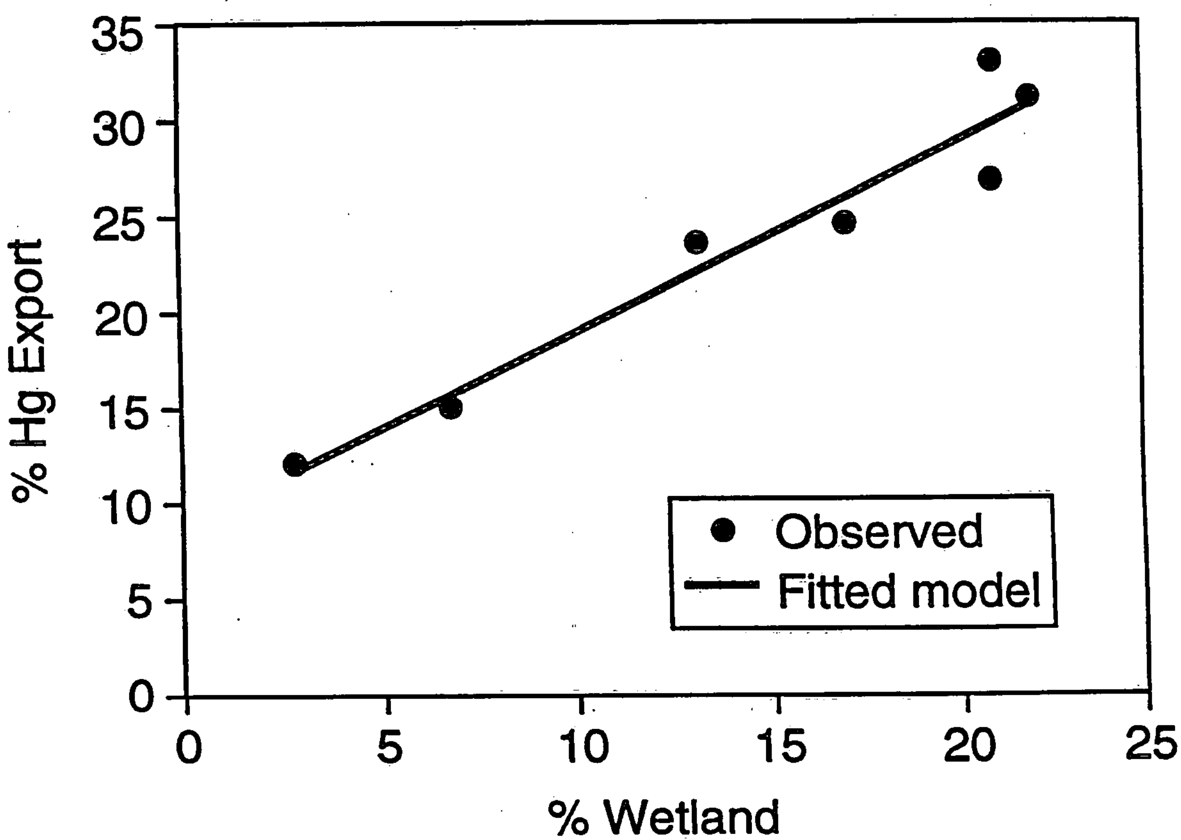


Hg in Perch in Ontario



Correlation of mercury to colour in a small Ontario stream over a two year period.

RELATIONSHIP OF HG EXPORT TO WETLANDS IN SEVEN WATERSHEDS IN ONTARIO



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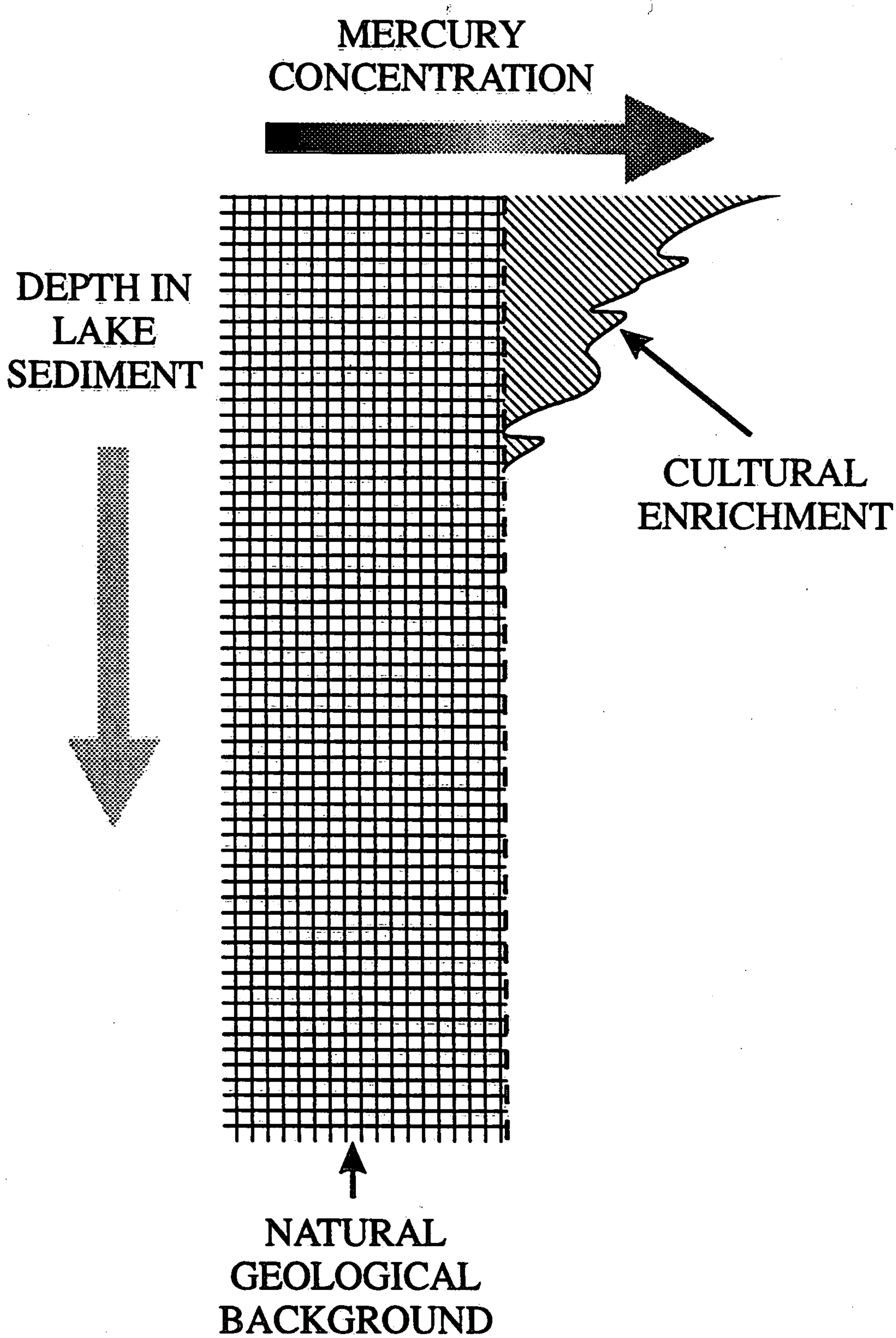
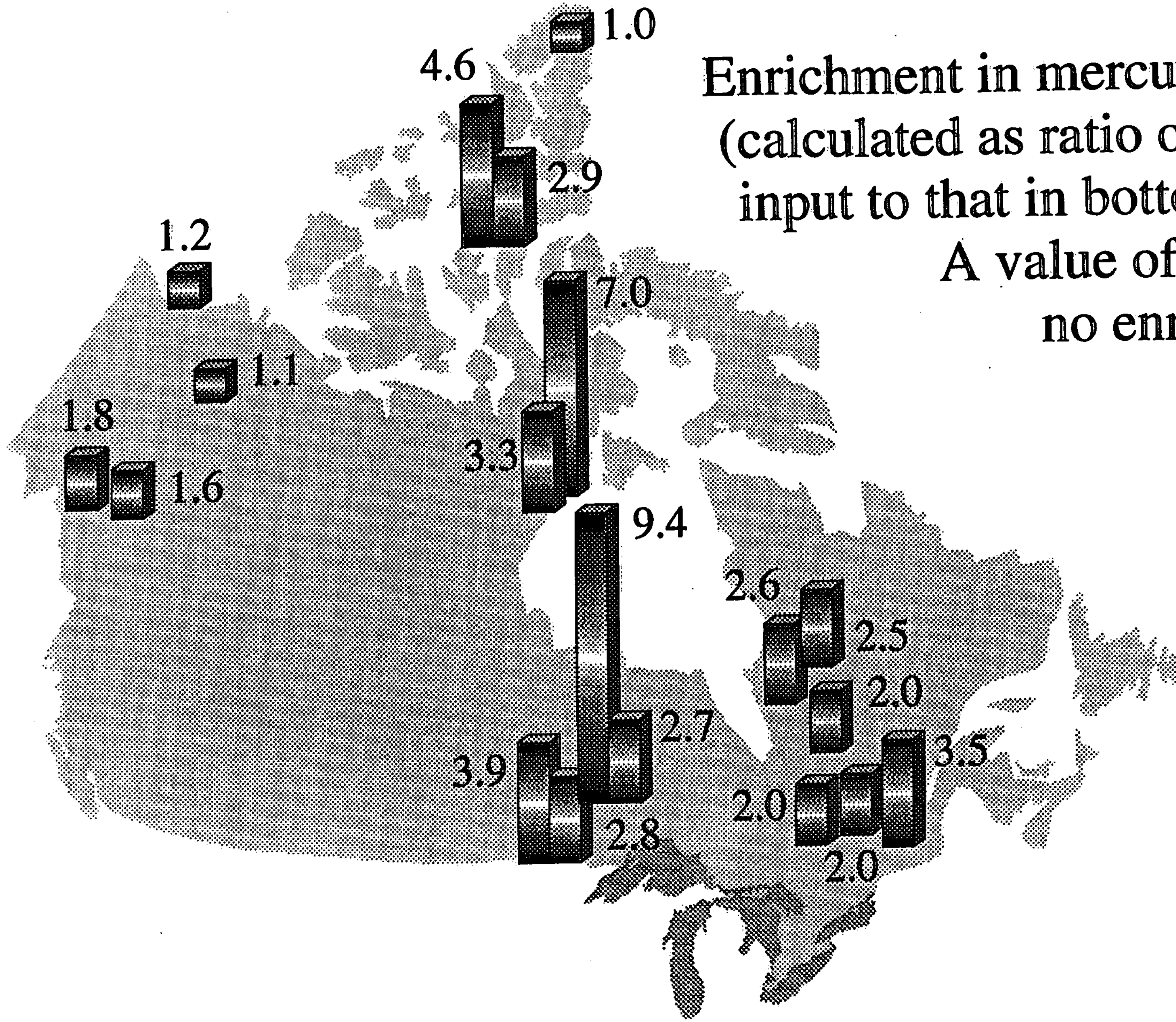
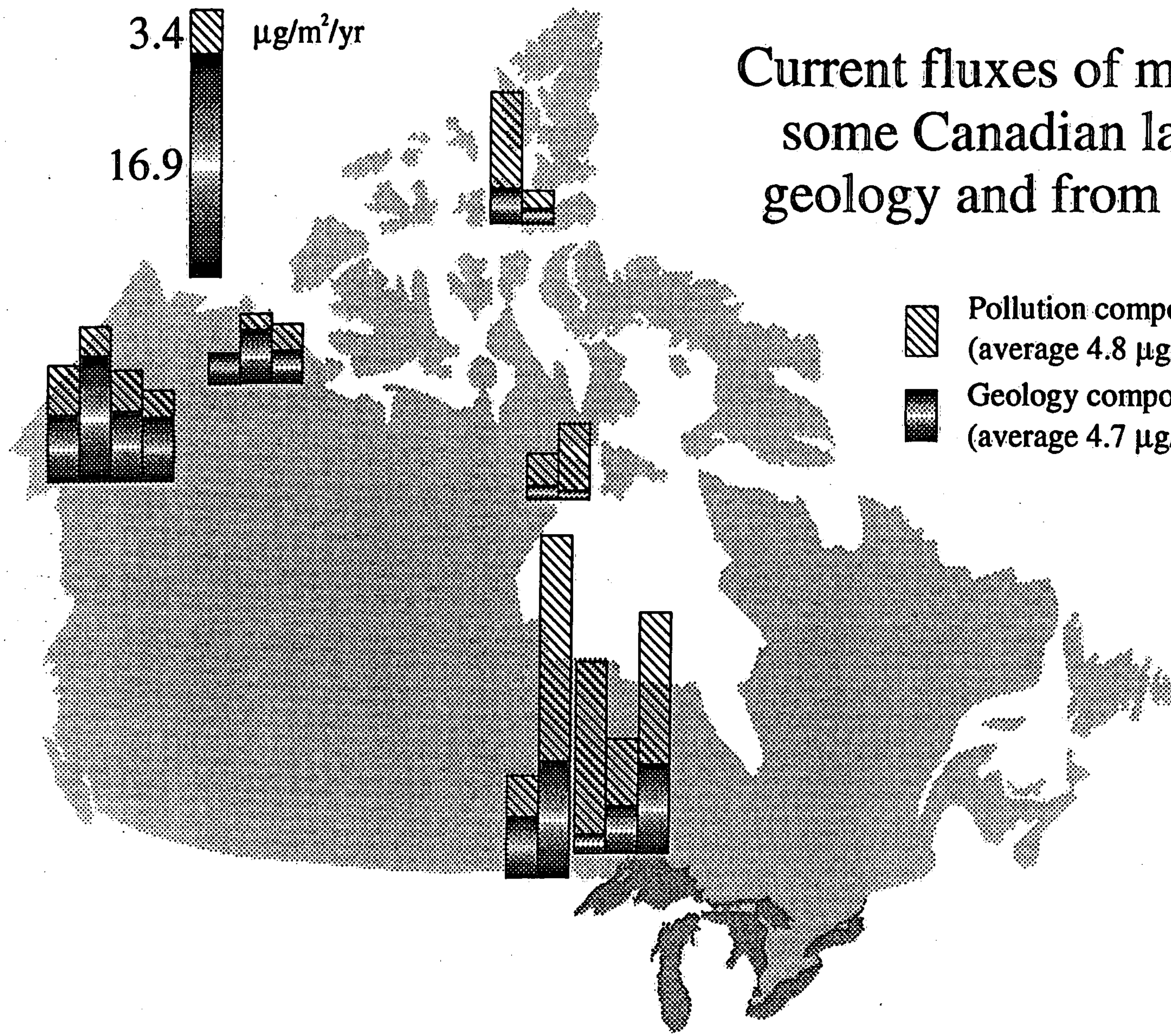
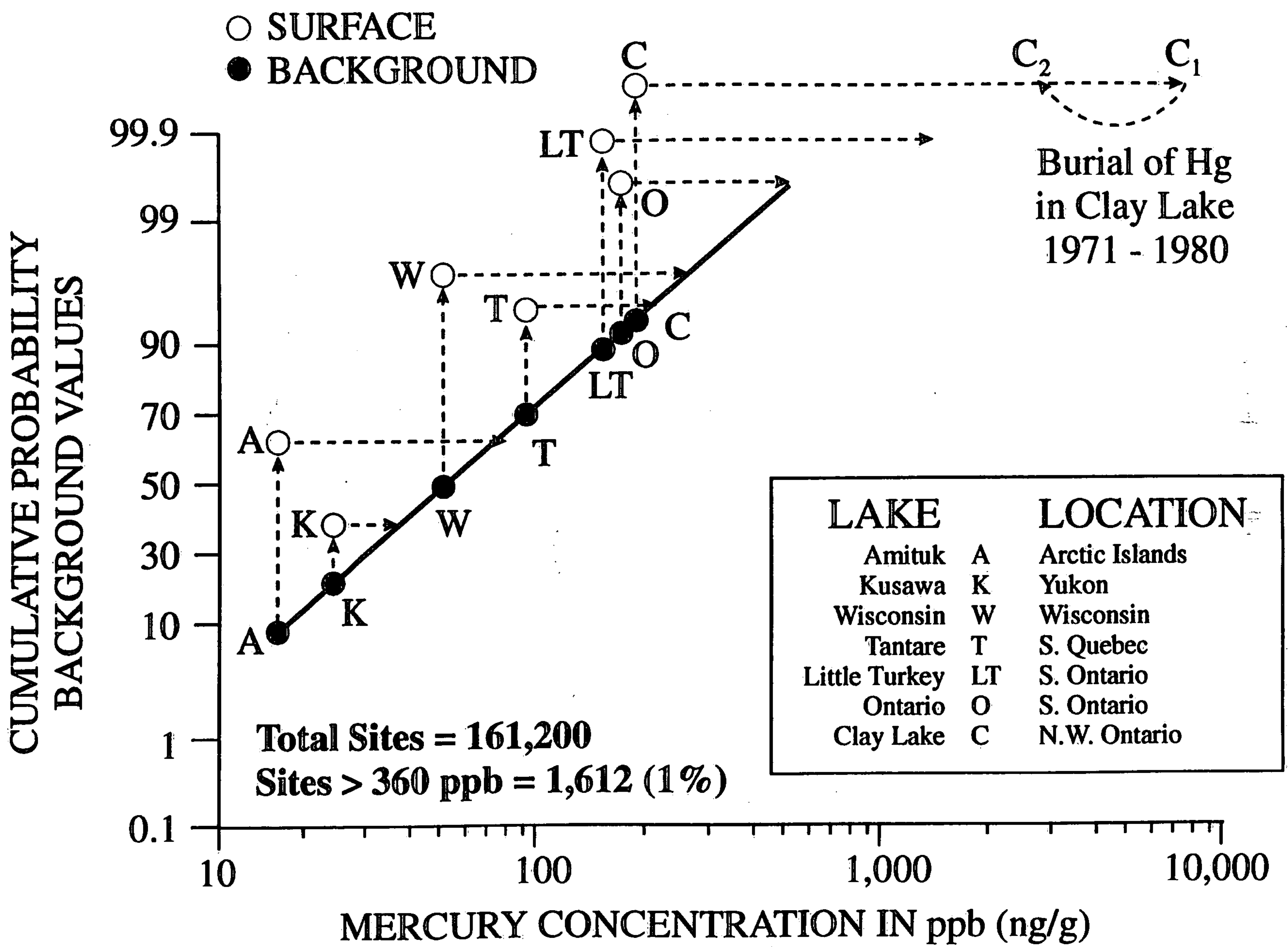

MERCURY
CONCENTRATION
DEPTH IN
LAKE
SEDIMENT
CULTURAL
ENRICHMENT
NATURAL
GEOLOGICAL
BACKGROUND

Enrichment in mercury inputs
(calculated as ratio of current
input to that in bottom slice)
A value of 1 means
no enrichment.

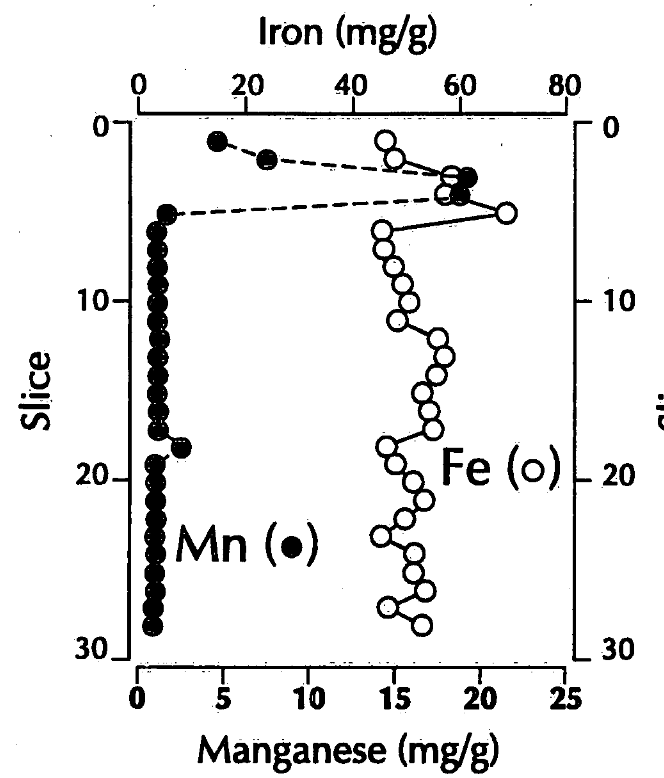


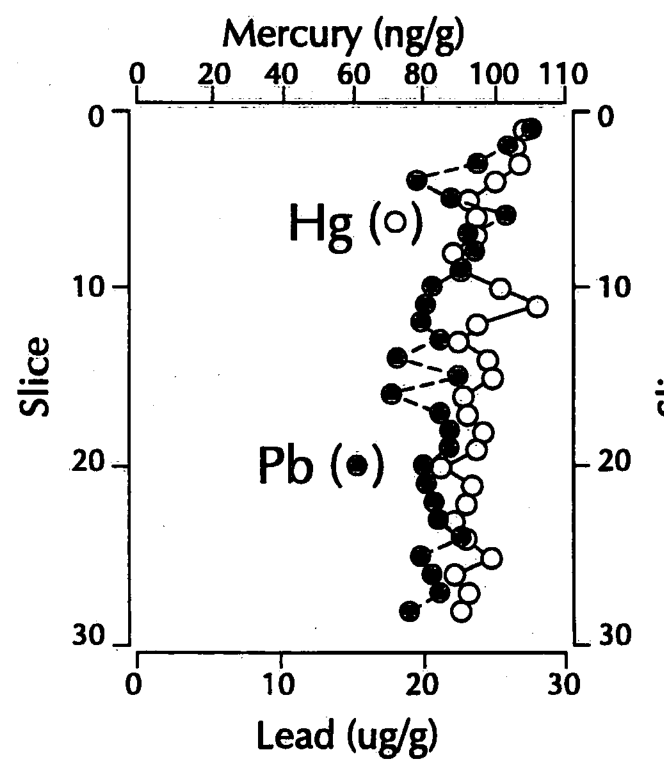
Current fluxes of mercury to some Canadian lakes from geology and from pollution



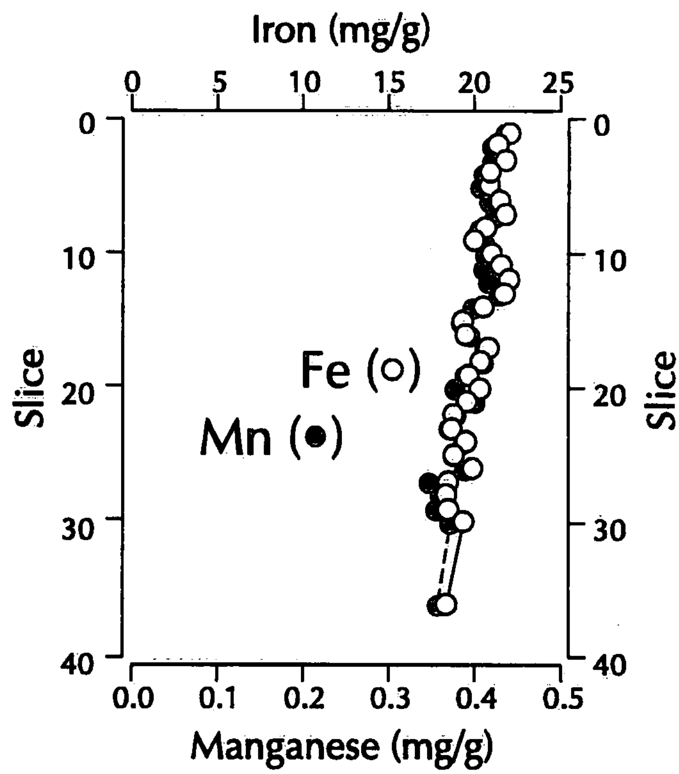

○ SURFACE
● BACKGROUND
CUMULATIVE PROBABILITY BACKGROUND VALUES
99.9
99
90
70
50
30
10
1
0.1
10
100
1,000
10,000
MERCURY CONCENTRATION IN ppb (ng/g)
A
K
W
T
LT
O
C
C_2
C_1
Burial of Hg in Clay Lake 1971 - 1980
Total Sites = 161,200
Sites > 360 ppb = 1,612 (1%)
LAKE
LOCATION
Amituk A Arctic Islands
Kusawa K Yukon
Wisconsin W Wisconsin
Tantare T S. Quebec
Little Turkey LT S. Ontario
Ontario O S. Ontario
Clay Lake C N.W. Ontario

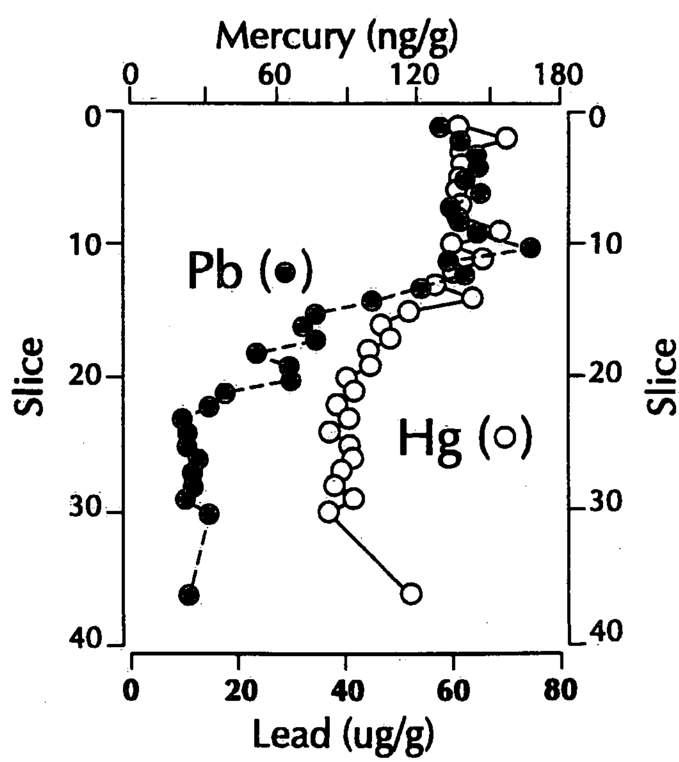
YaYa Lake
Mackenzie Delta, Core 1, 1995



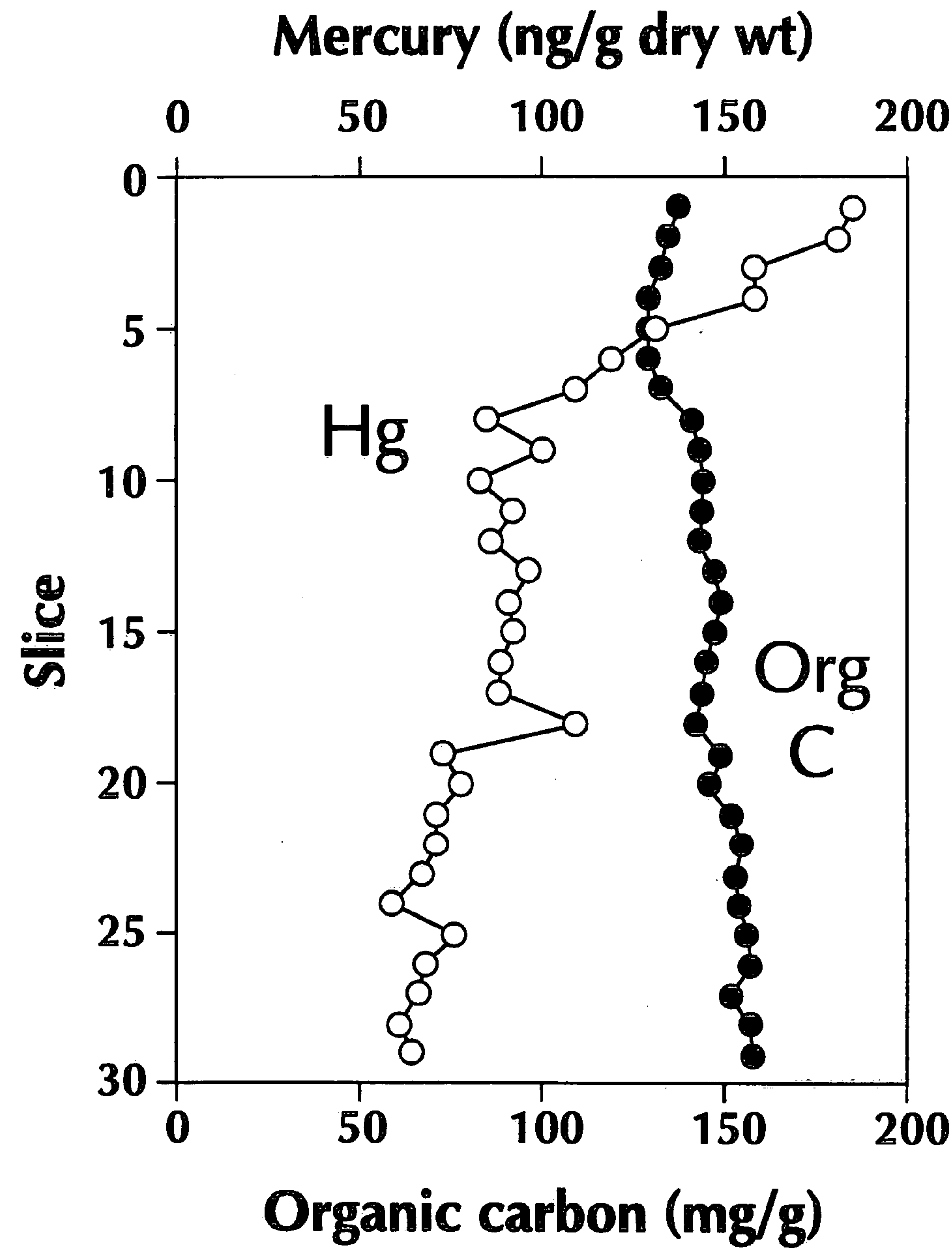


ELA Lake 382,
Box core 1, March, 1988

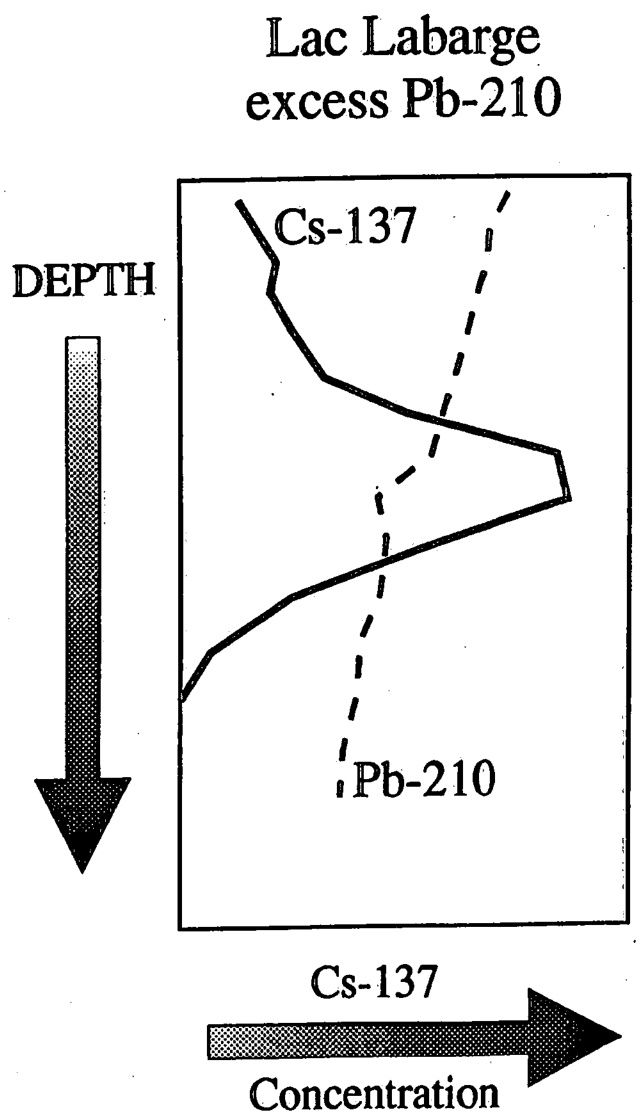


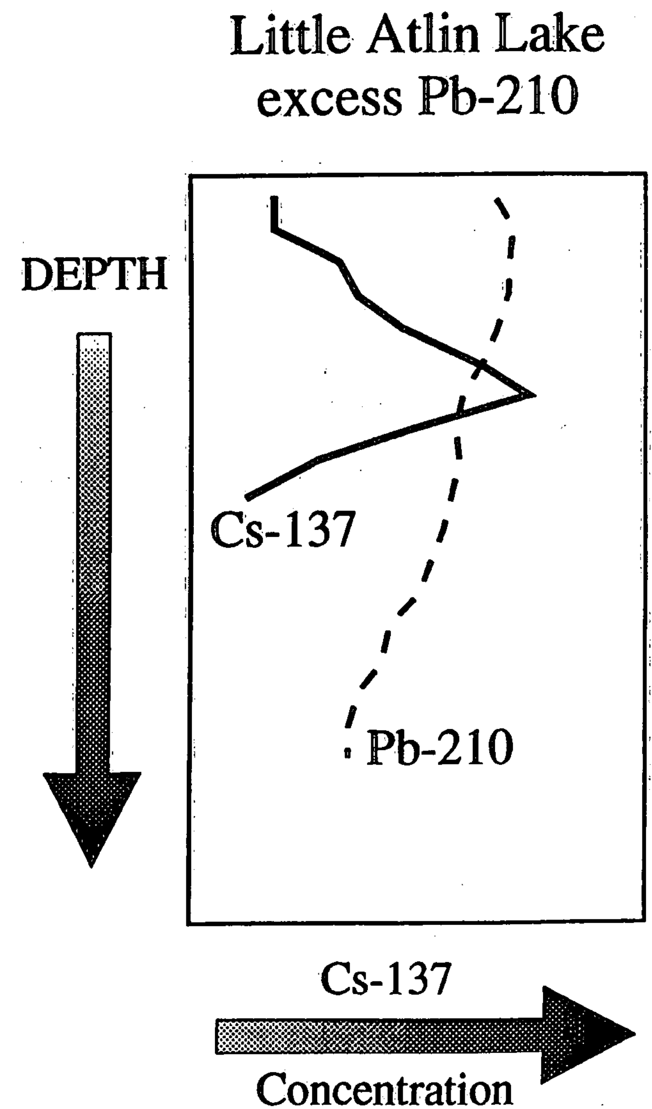


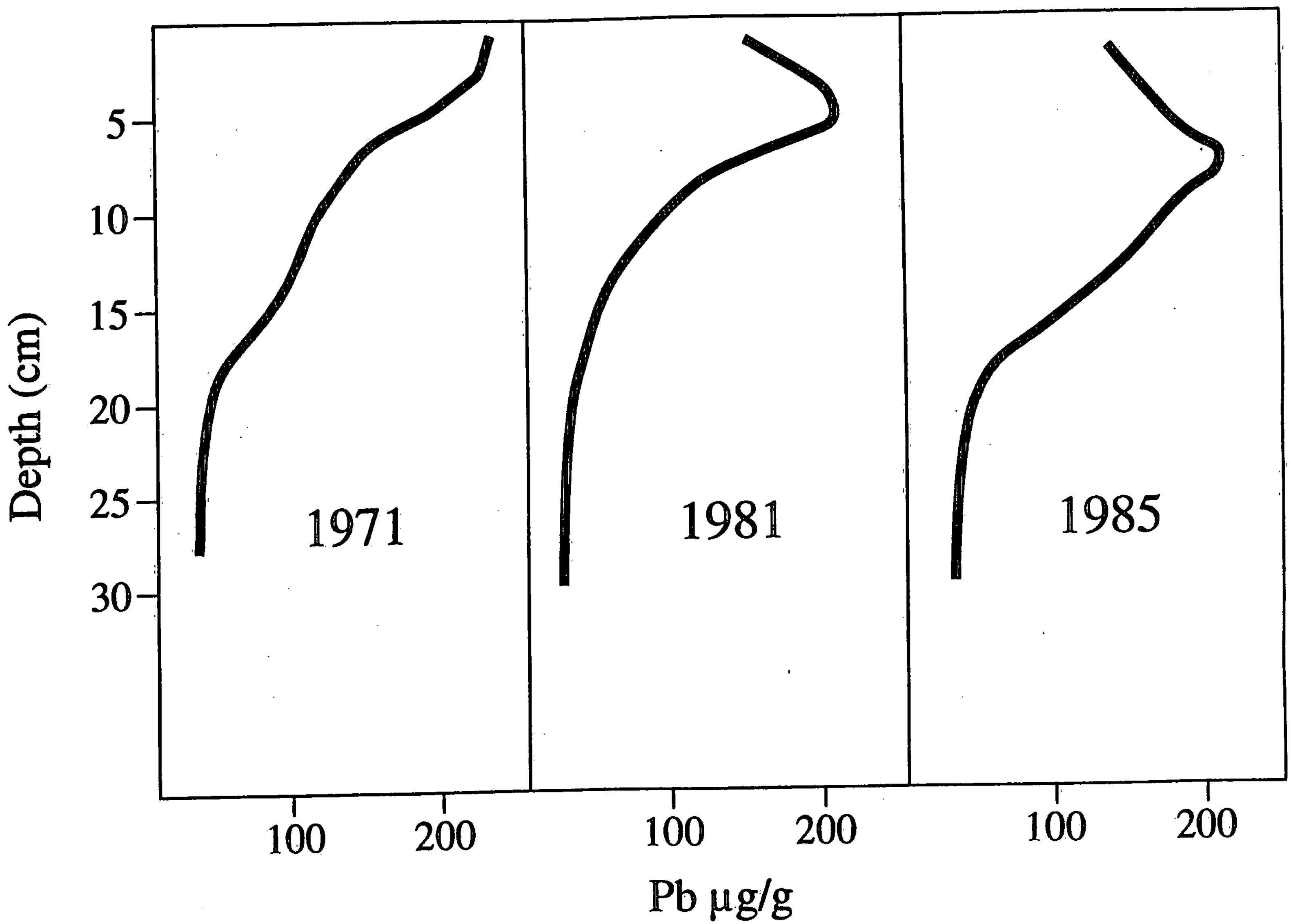
Mercury and organic carbon, Lake 375 Box Core A



Pb-210 and Cs-137 Profiles in Selected Yukon Lakes



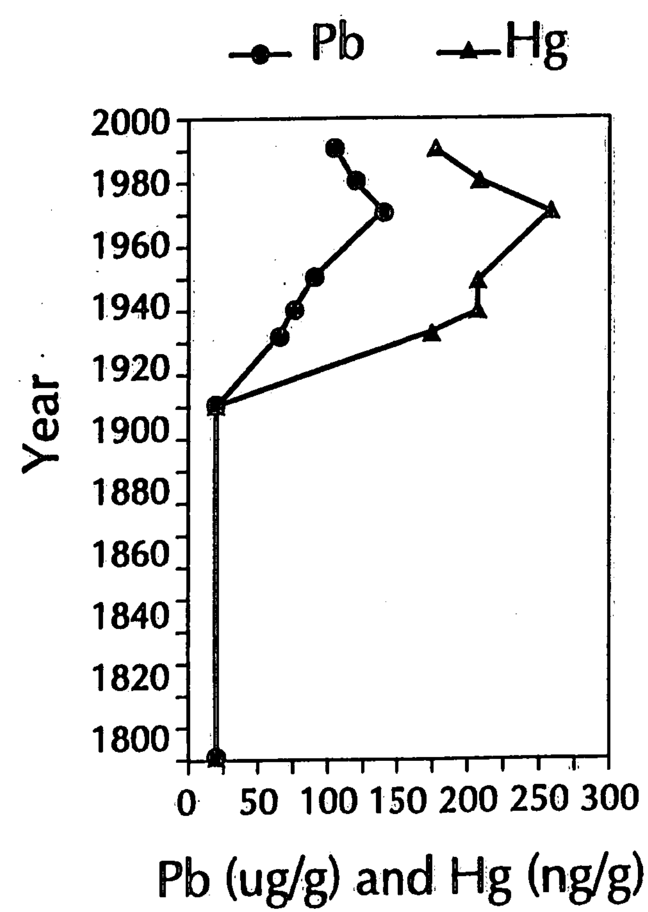




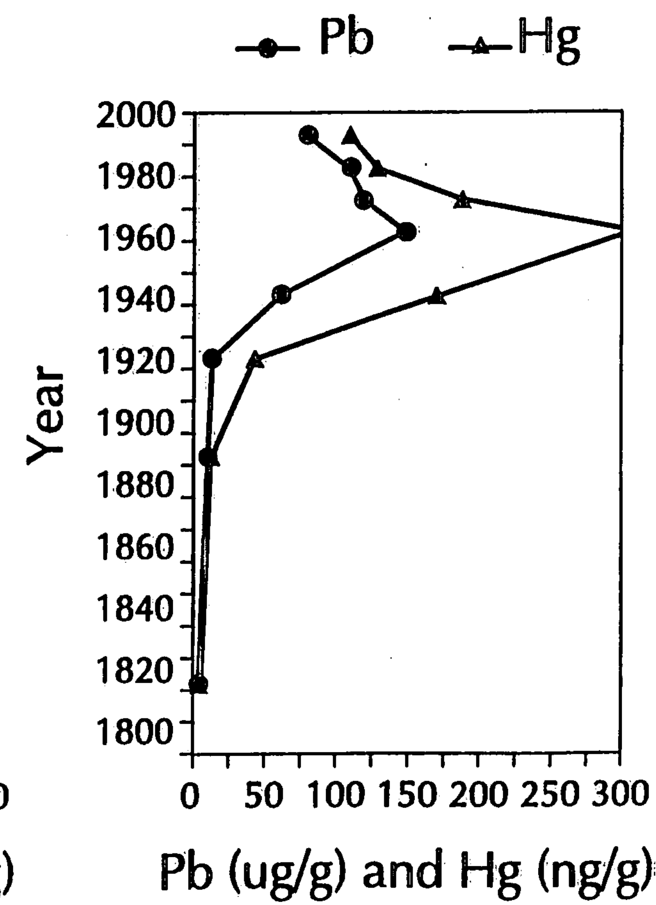
BURIAL OF LEAD (µg/g)
IN LAKE ONTARIO EAST BASIN

LEAD AND MERCURY IN LAKE MICHIGAN AND LAKE ONTARIO BOTTOM SEDIMENTS

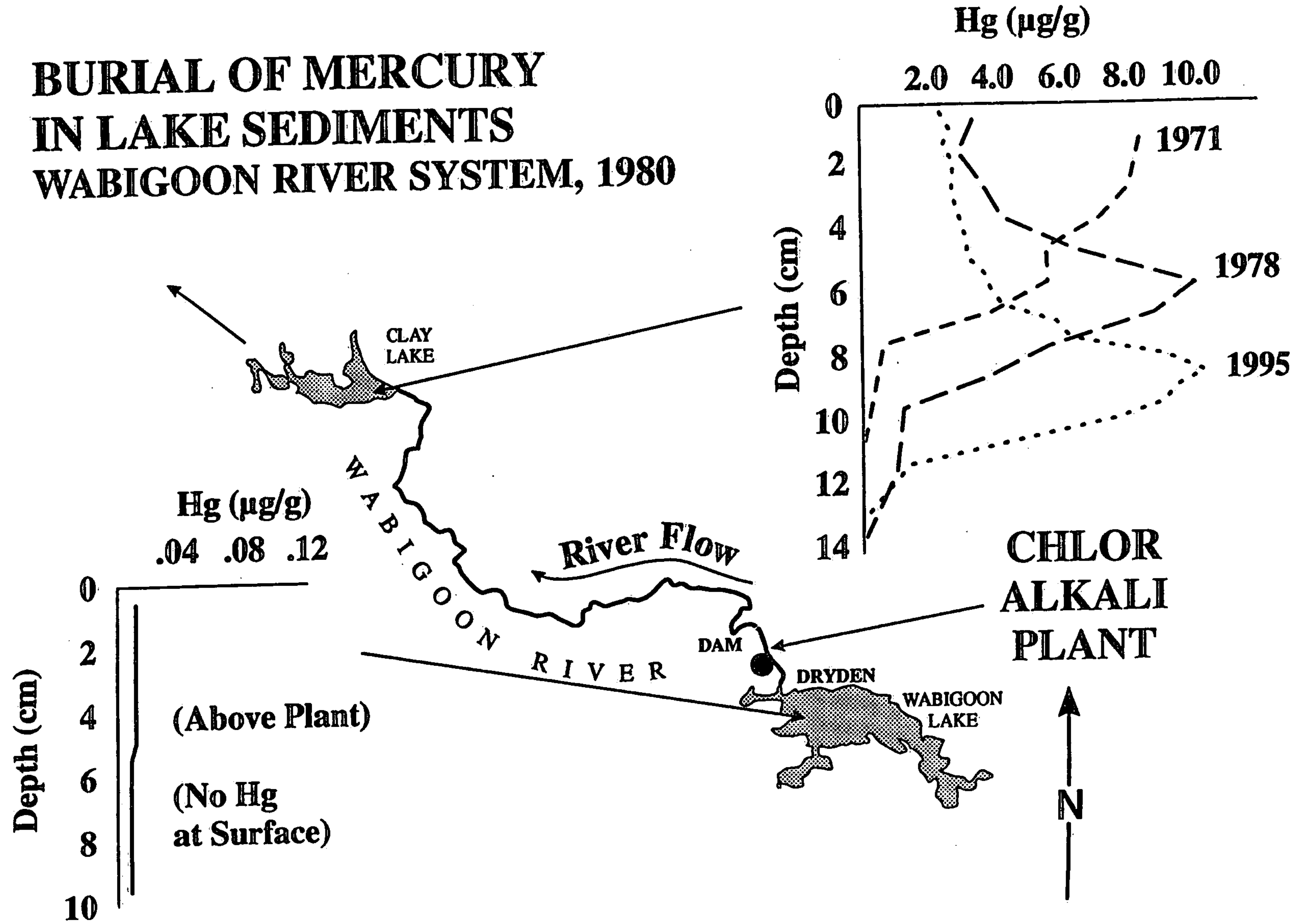
LAKE MICHIGAN



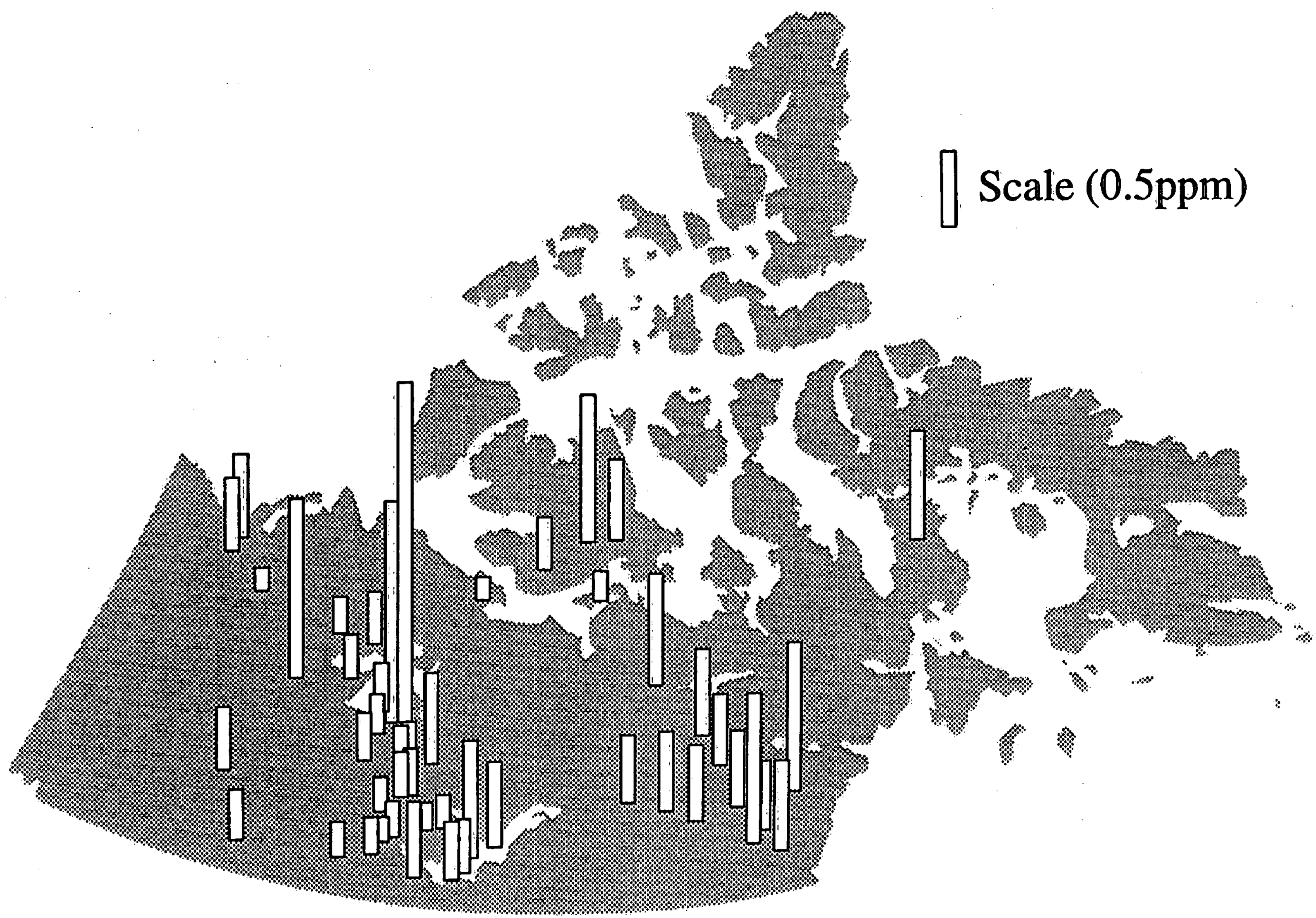
LAKE ONTARIO



BURIAL OF MERCURY IN LAKE SEDIMENTS
WABIGOON RIVER SYSTEM, 1980

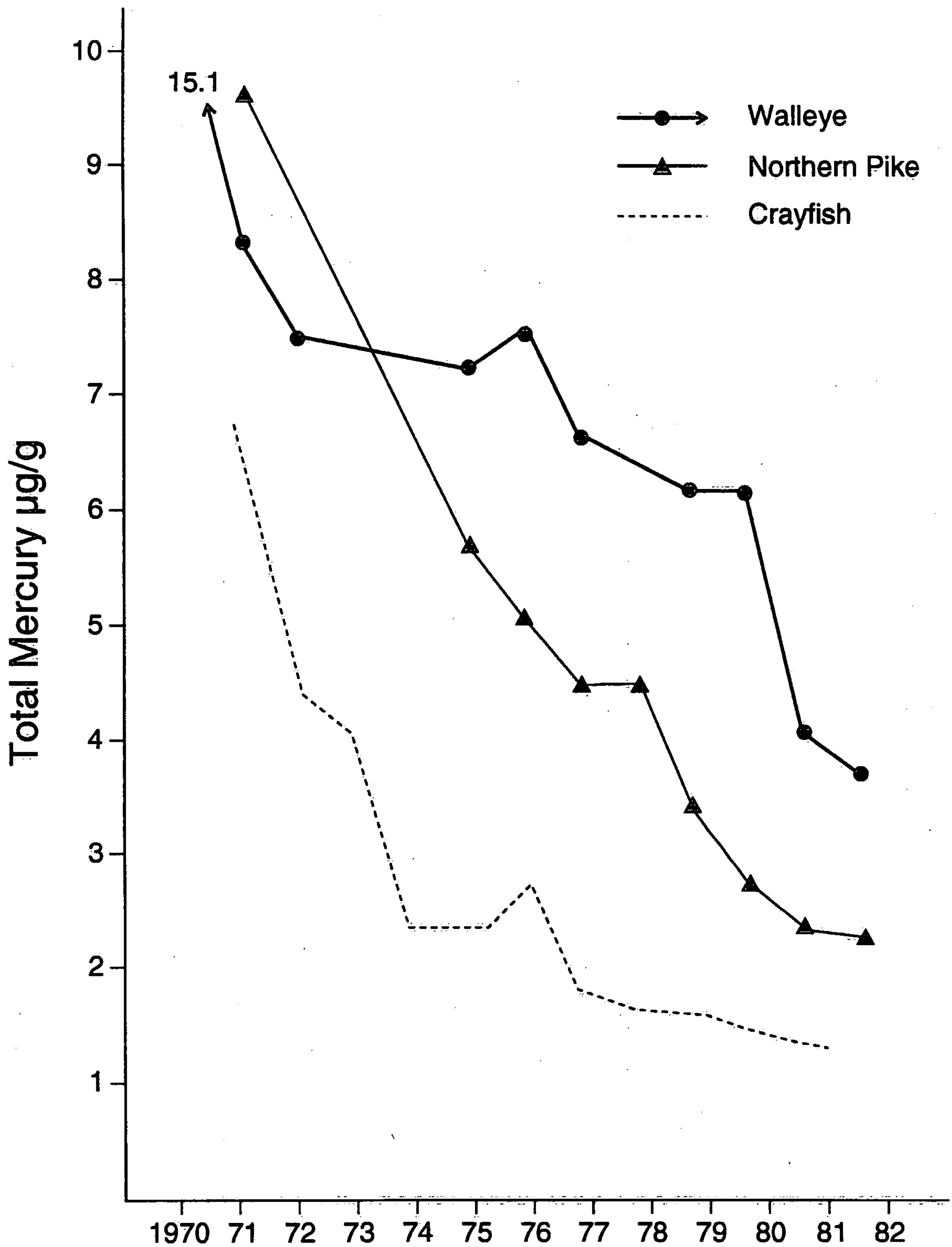


Mercury in lake trout in NWT lakes

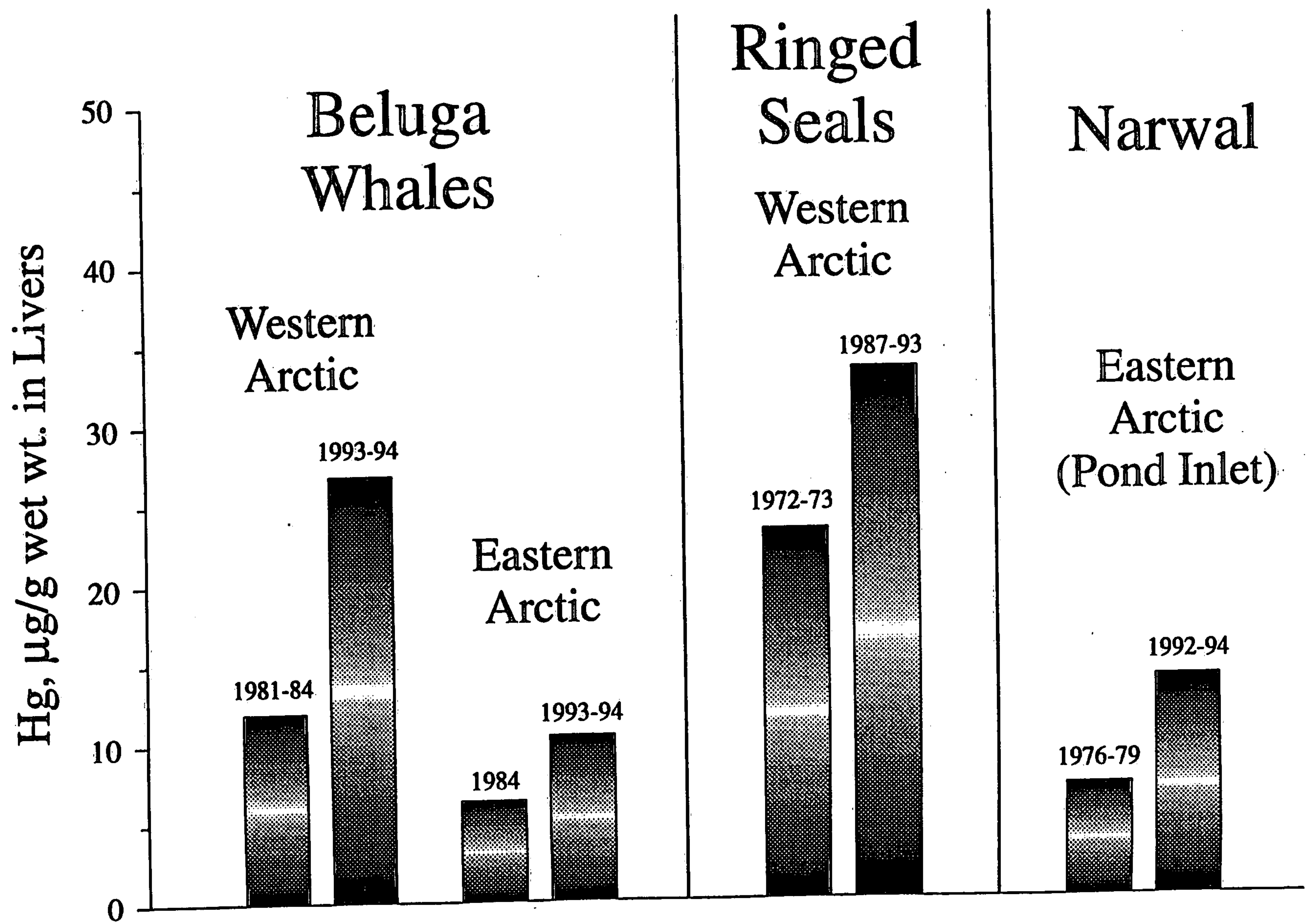


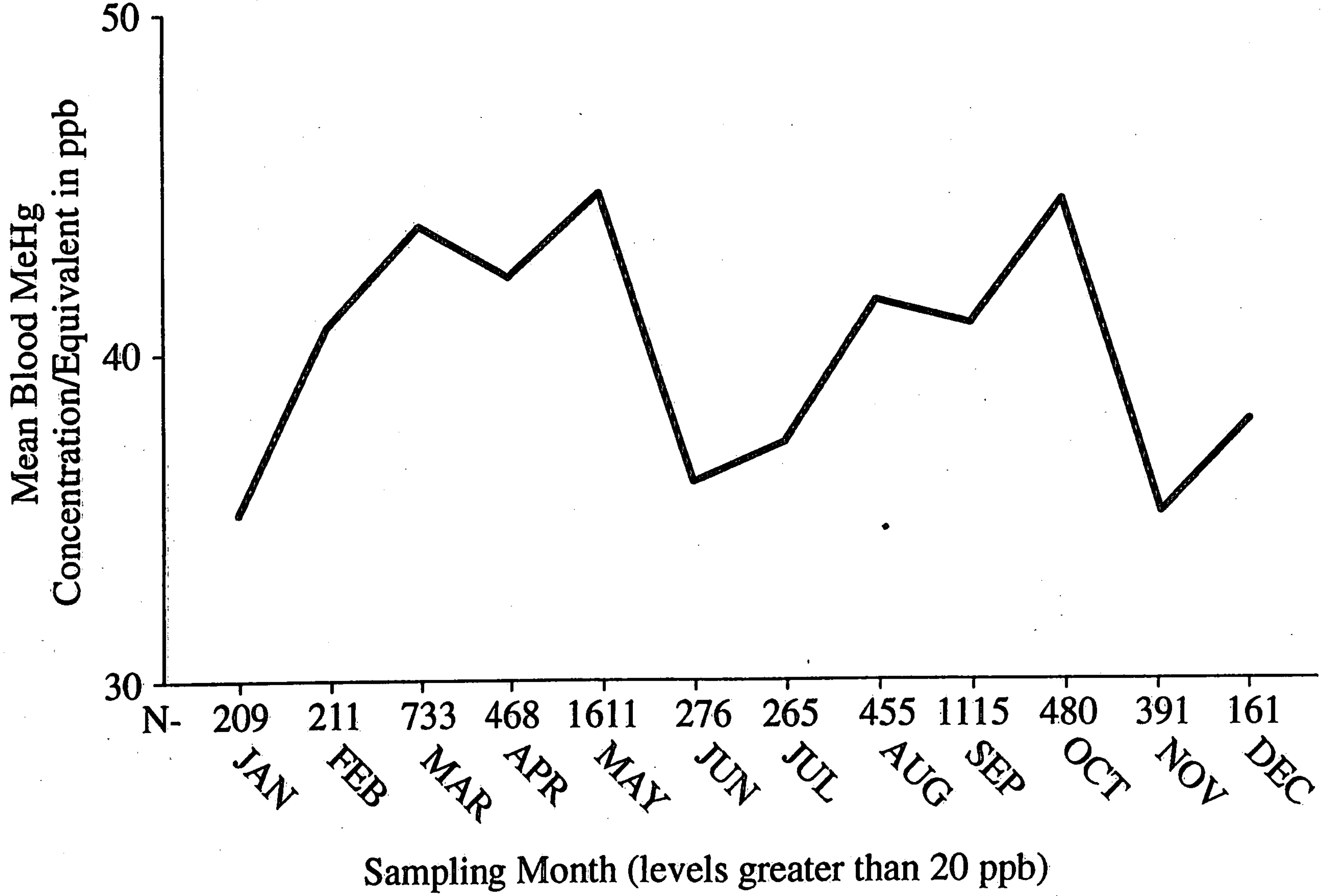
Northern Pike Mercury Concentrations at Geographic Extremes of Central/Western Canada

COMPASS	LAKE	LAT.	LOG.	CONC. INITIAL (mg/kg)	CONC. LAST (mg/kg)	RECORD LENGTH (years)
North	Mackenzie Delta	69 15	134 08	0.50	0.46	15
East	Whitewater	50 48	89 10	0.64	0.67	17
South	Dog Paw	49 23	93 53	0.58	0.56	21
West	Graham	56 35	114 33	0.08	0.11	14

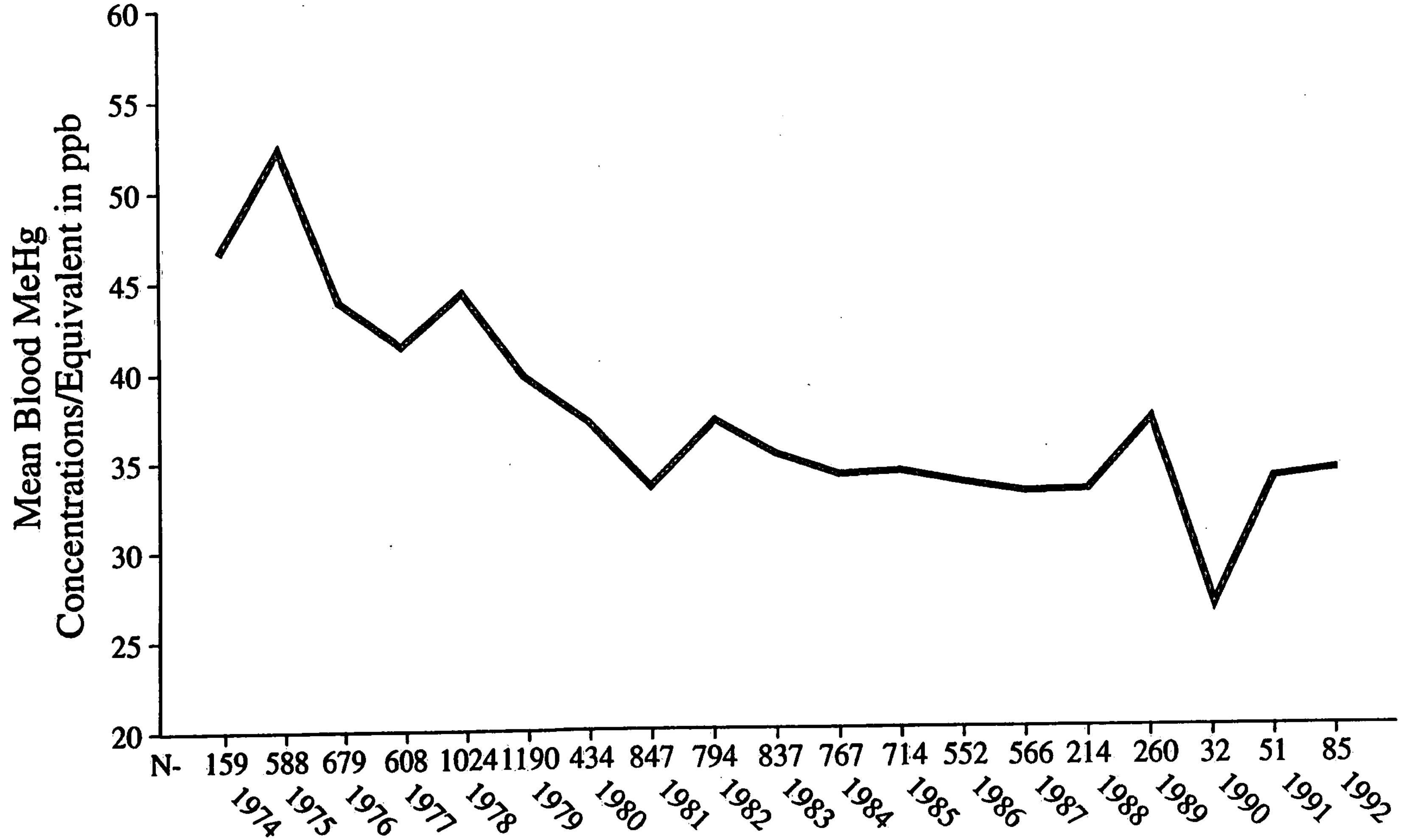


Mercury concentrations 60 cm northern pike, 50 cm walleye and crayfish from Clay Lake, 1970-82.


Hg, µg/g wet wt. in Livers
0
10
20
30
40
50
Beluga Whales
Western Arctic
1981-84
1993-94
Eastern Arctic
1984
1993-94
Ringed Seals
Western Arctic
1972-73
1987-93
Narwal
Eastern Arctic (Pond Inlet)
1976-79
1992-94

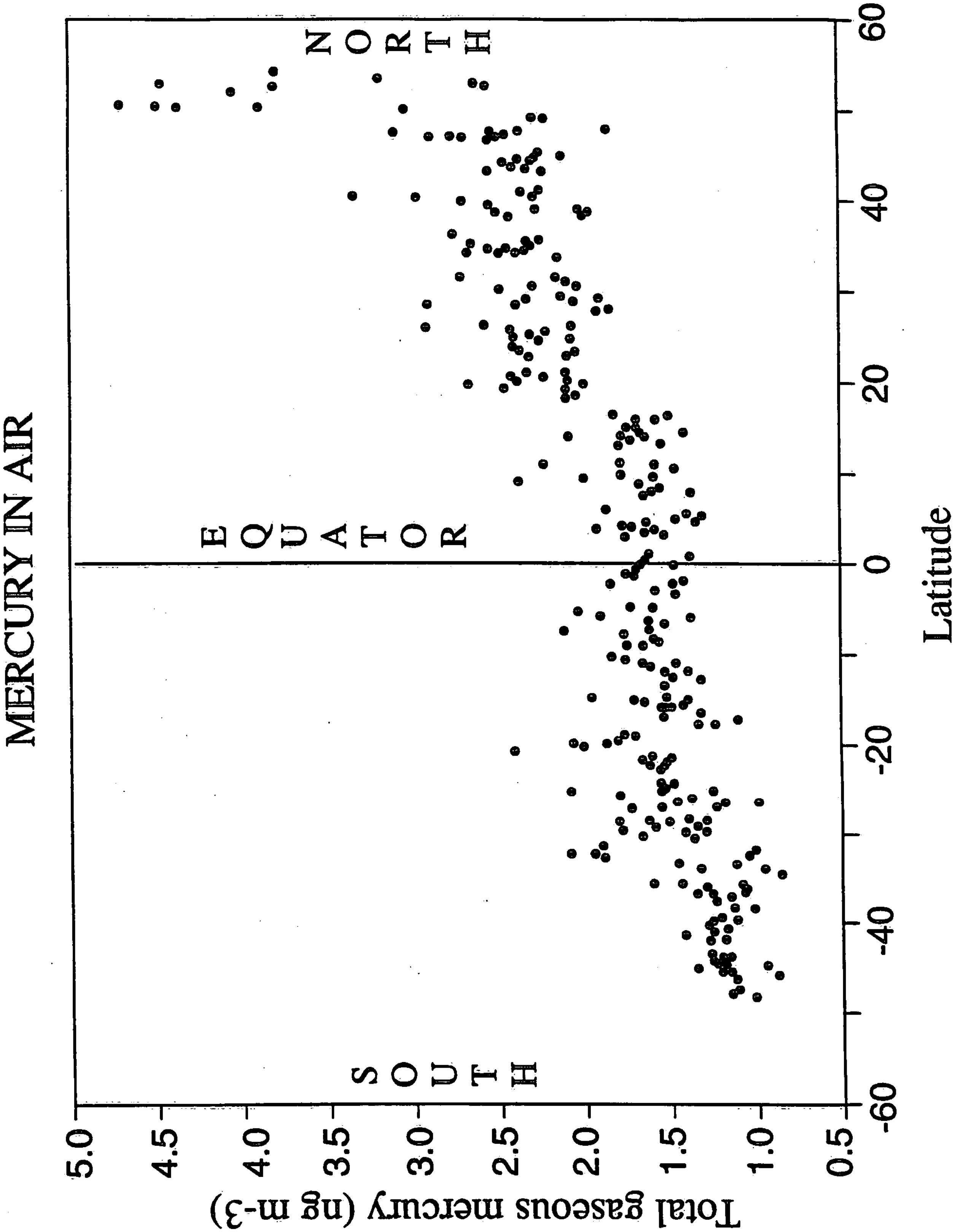


ANNUAL PATTERN OF EXPOSURE TO MeHg
IN N.W.T. COMMUNITIES (1973-1987)

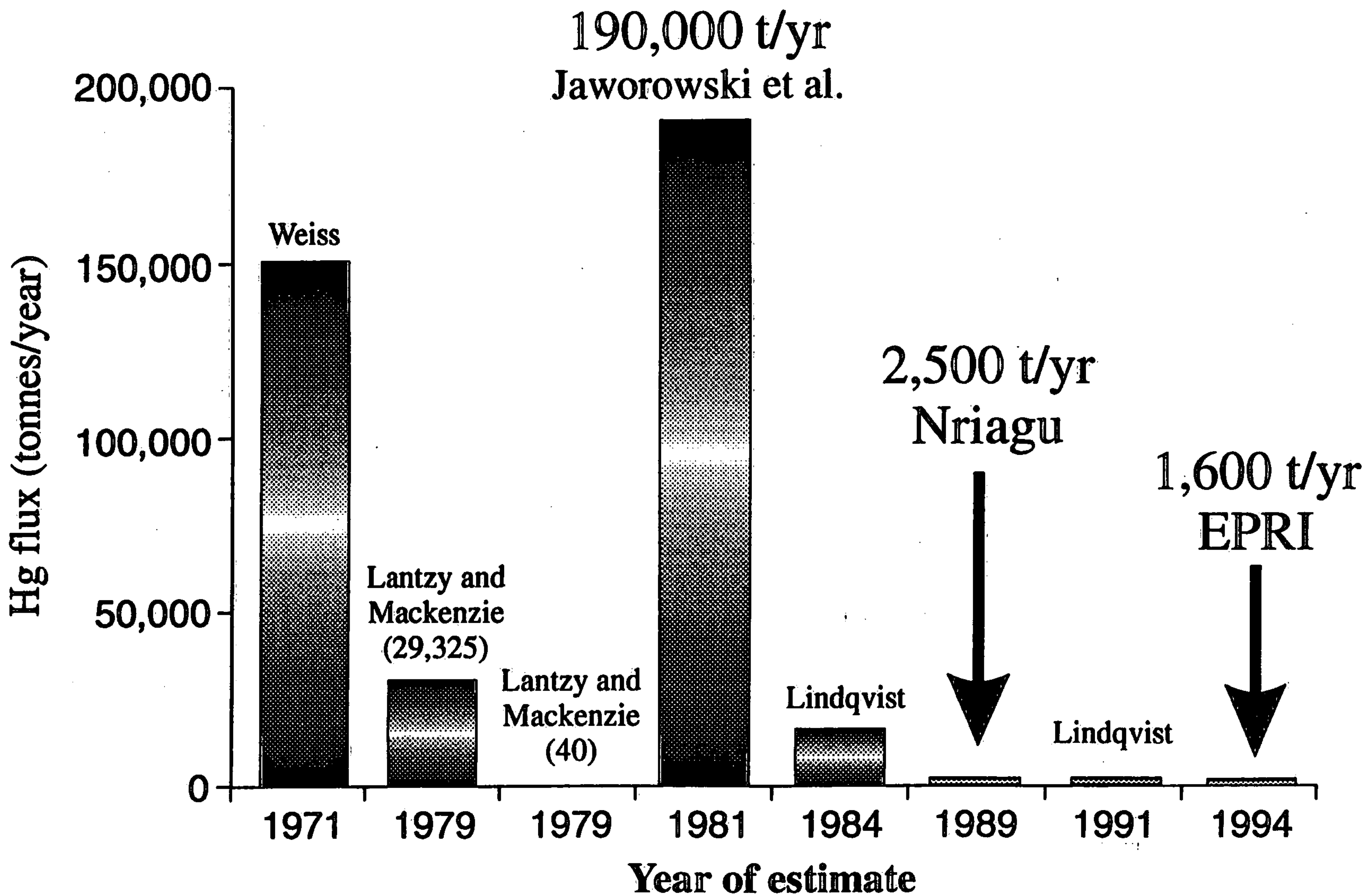


Communities with 10 or more sampling years (levels greater than 20 ppb)

TREND IN FIRST NATIONS MEAN METHYLMERCURY LEVELS 1974-1992

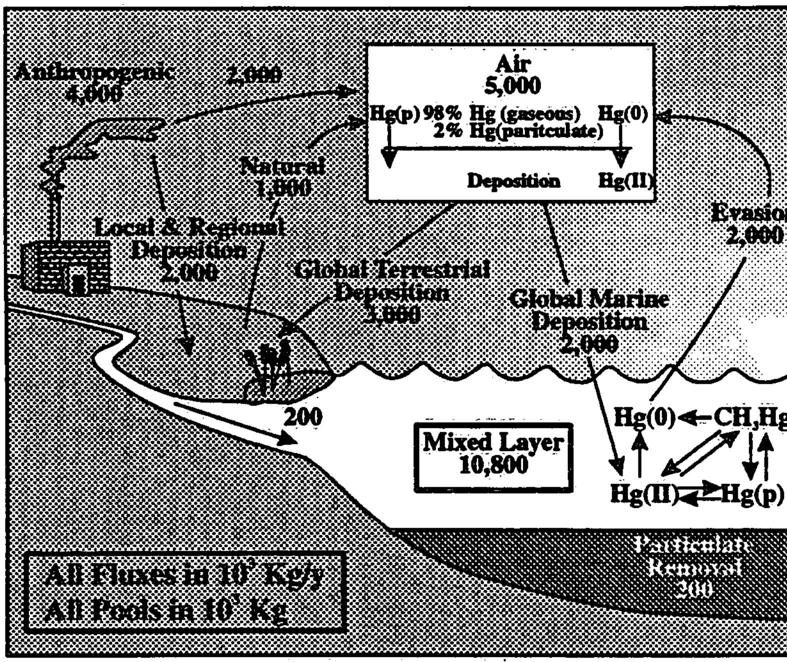

MERCURY IN AIR
NORTH
EQUATOR
SOUTH
Latitude
Total gaseous mercury (ng m-3)
-60
-40
-20
0
20
40
60
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0

Variation in estimates of the natural global mercury flux

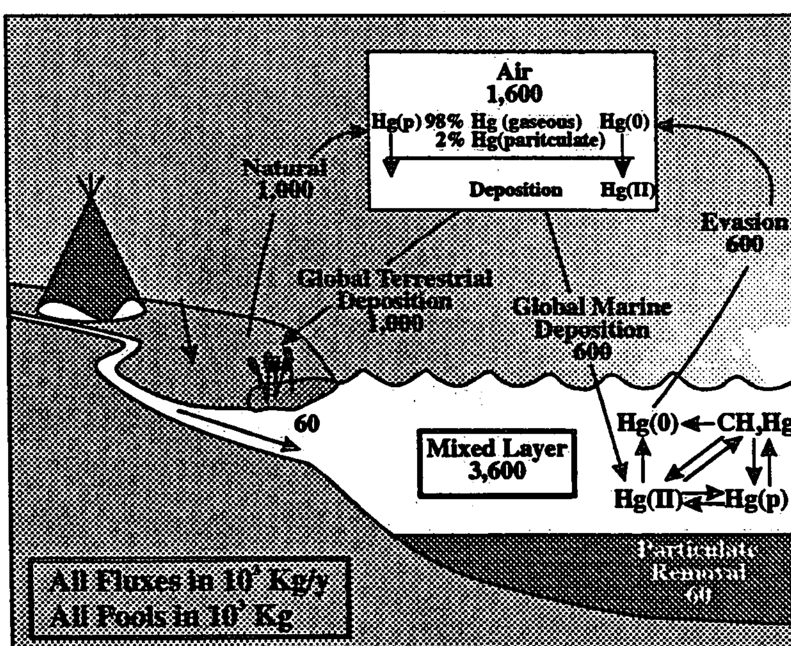


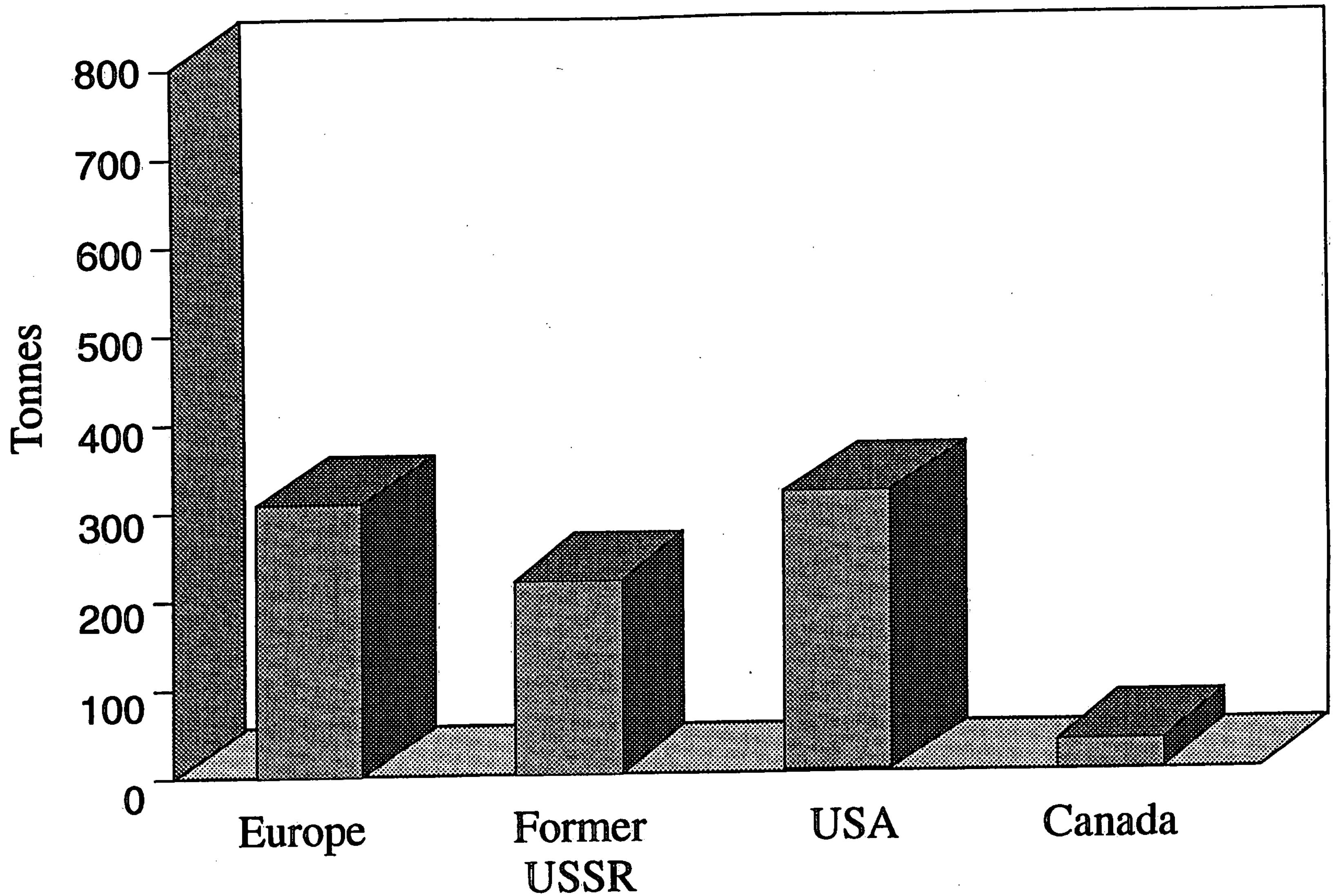
a chief source of uncertainty is the volcanic Hg flux
e.g. 10,000 to 18,000 t/yr from terrestrial volcanoes alone

CURRENT MERCURY BUDGETS AND FLUXES

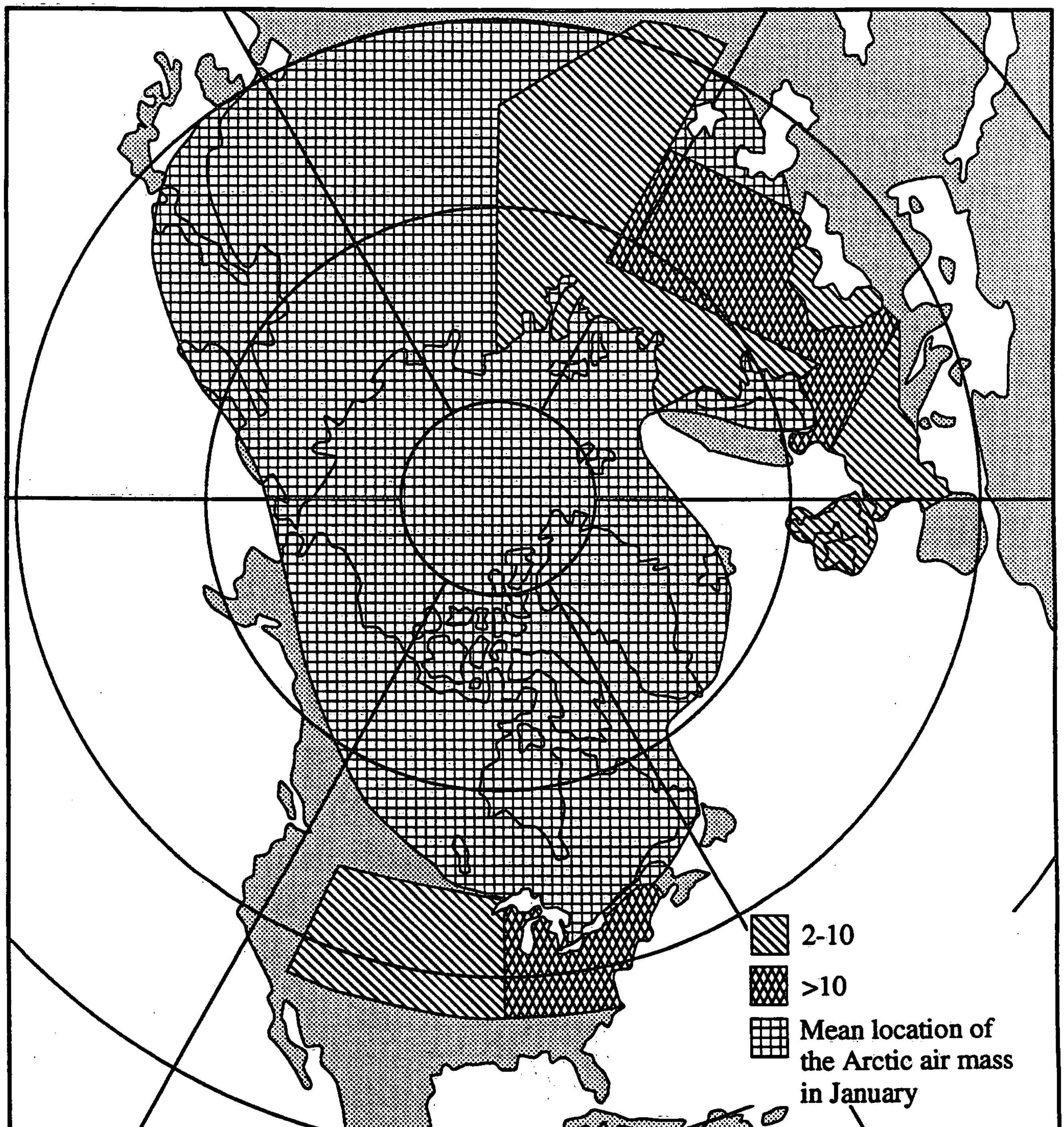


PRE-INDUSTRIAL MERCURY BUDGETS AND FLUXES

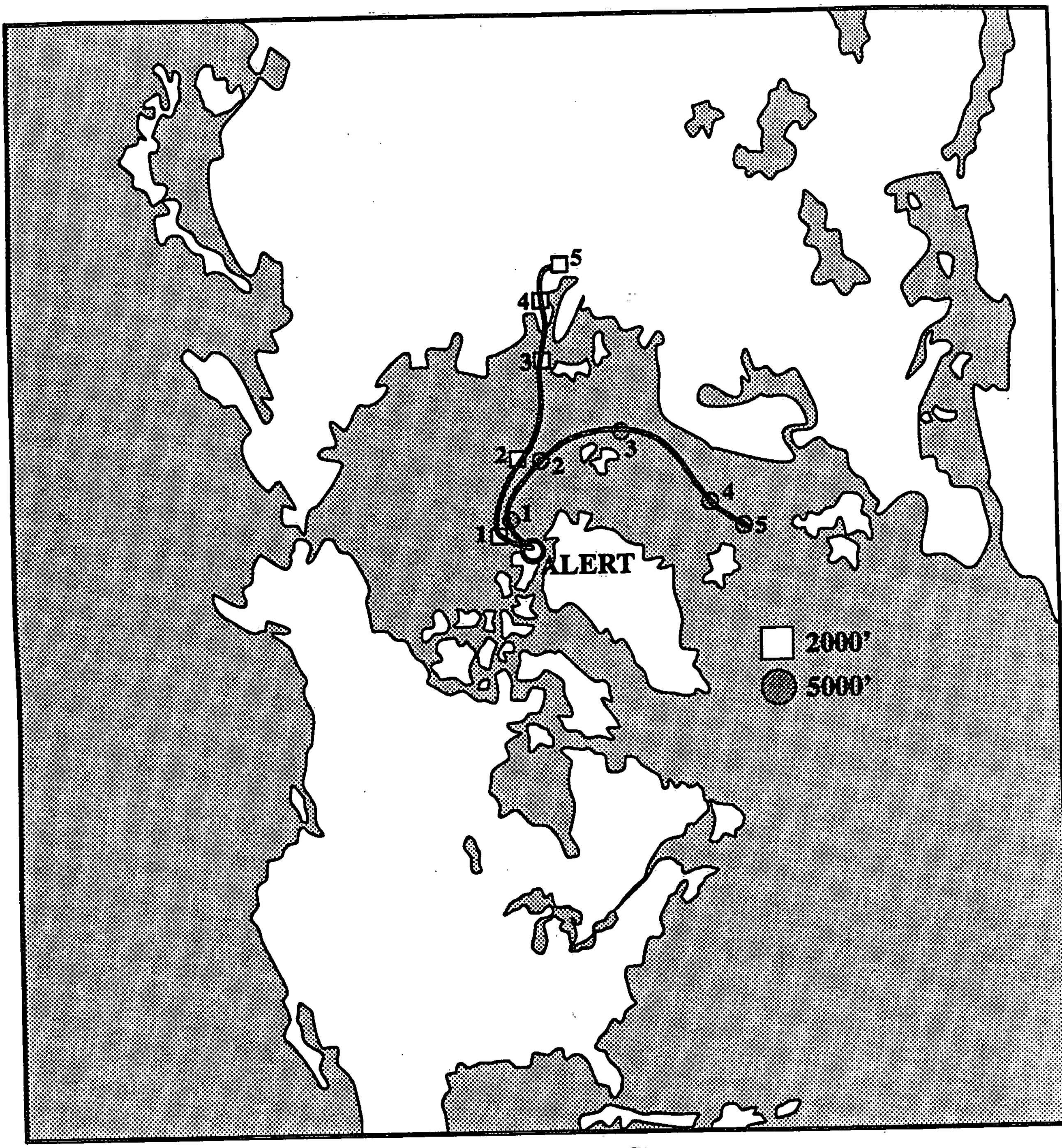




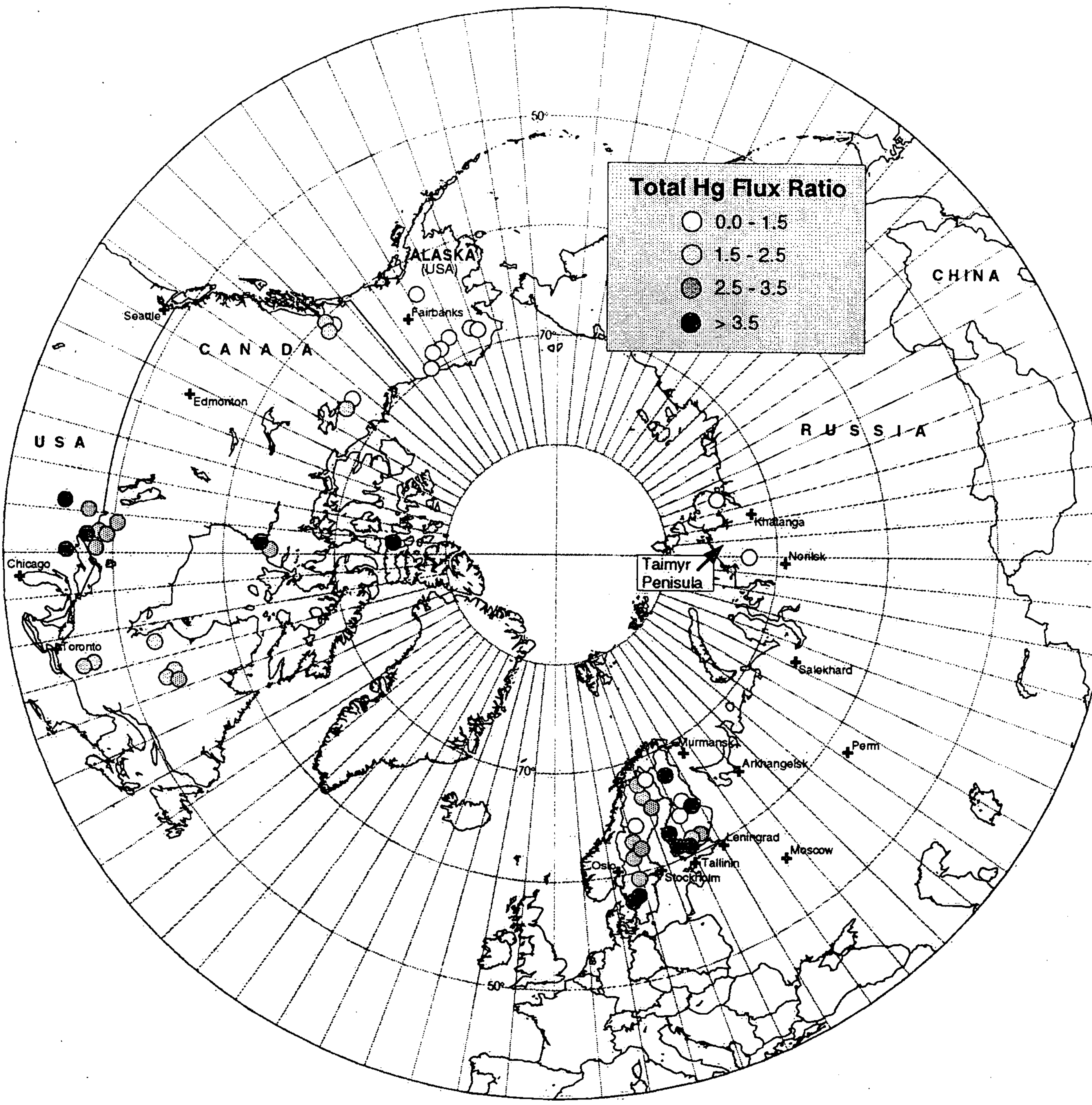
Atmospheric emissions of mercury from several regions



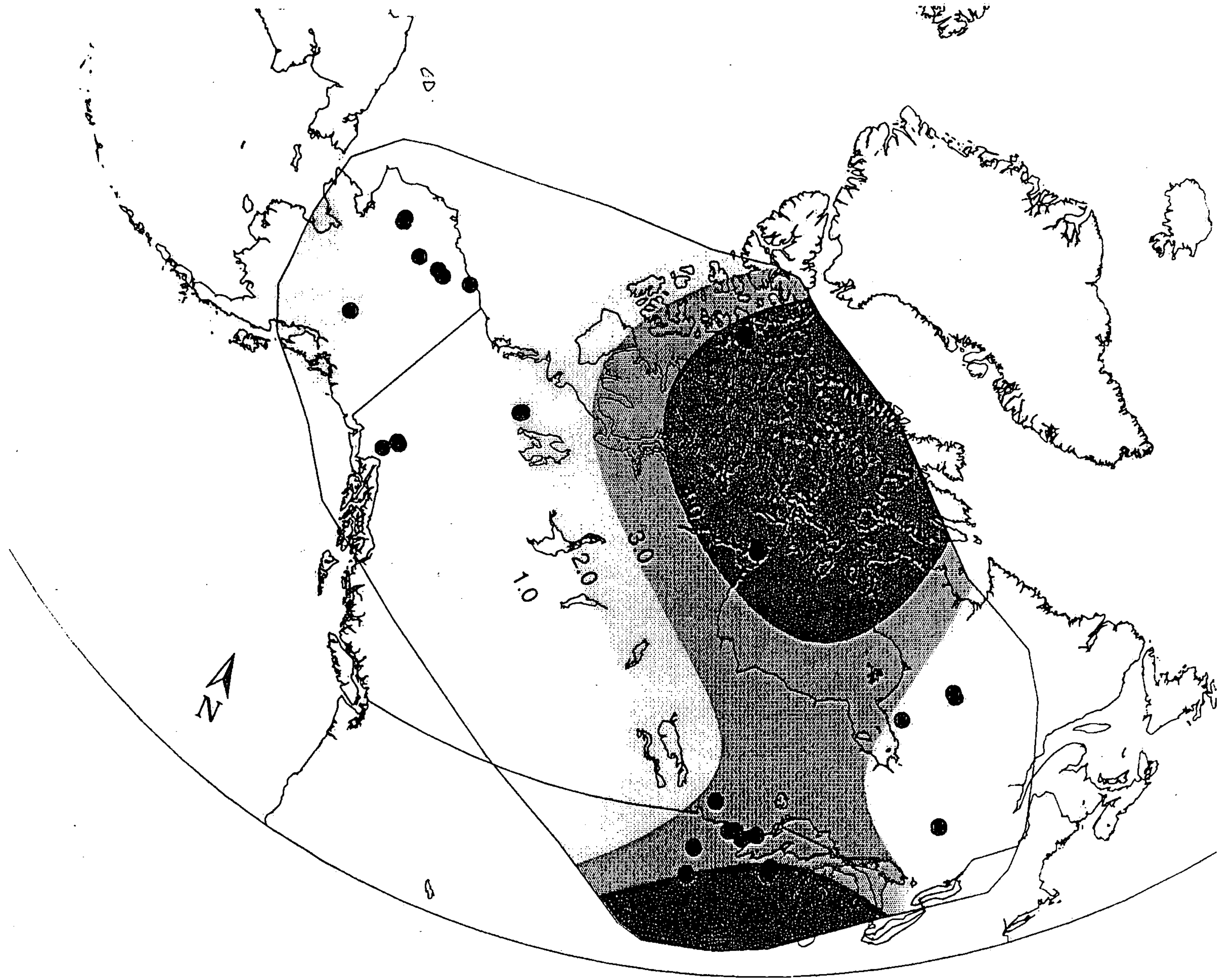
Annual emissions of sulphur dioxide (millions of tonnes) in the regions of the northern hemisphere that have the greatest influence on the Arctic air mass



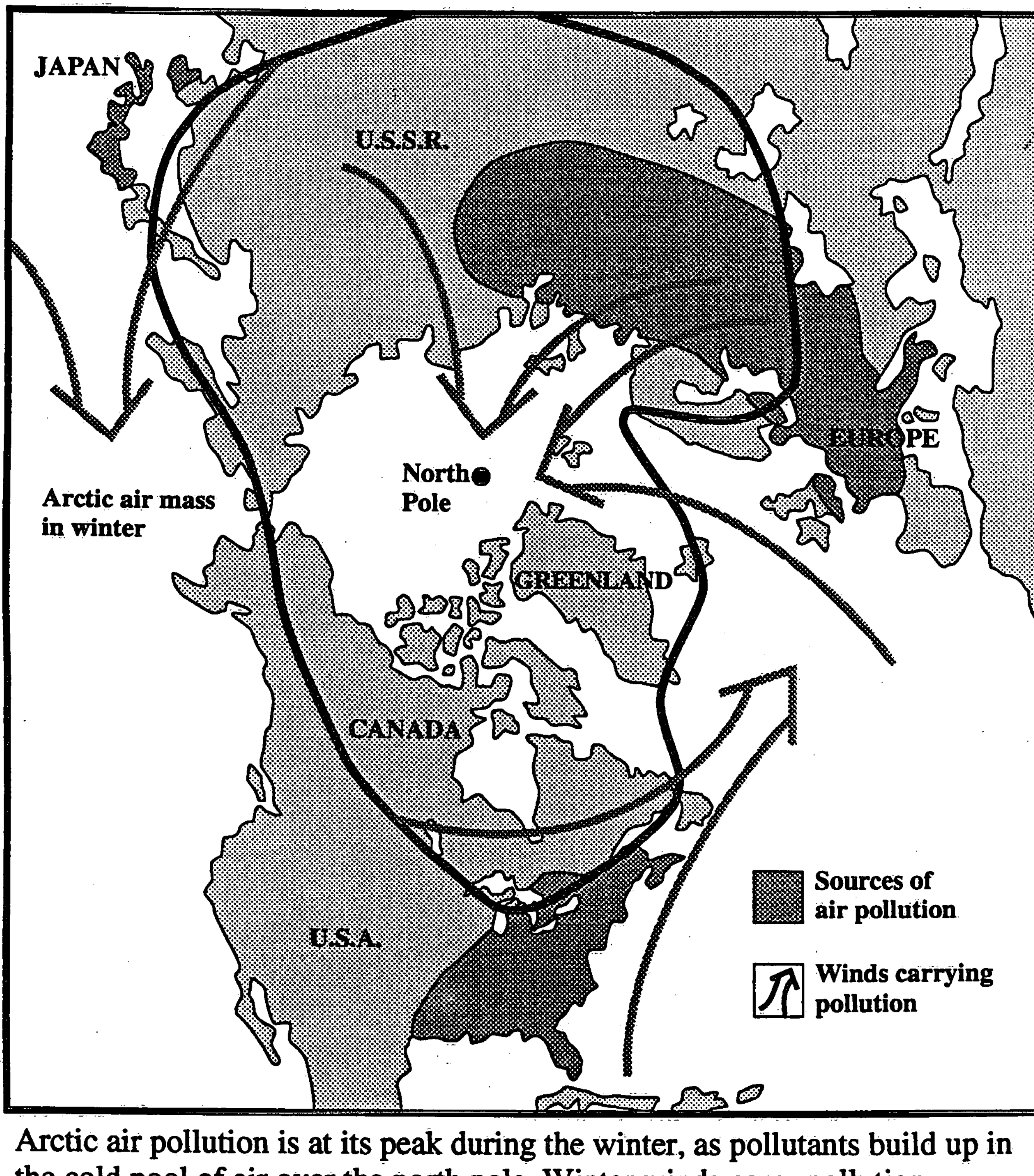
ARSENIC
5 Day Back-Trajectories
January 23, 1992



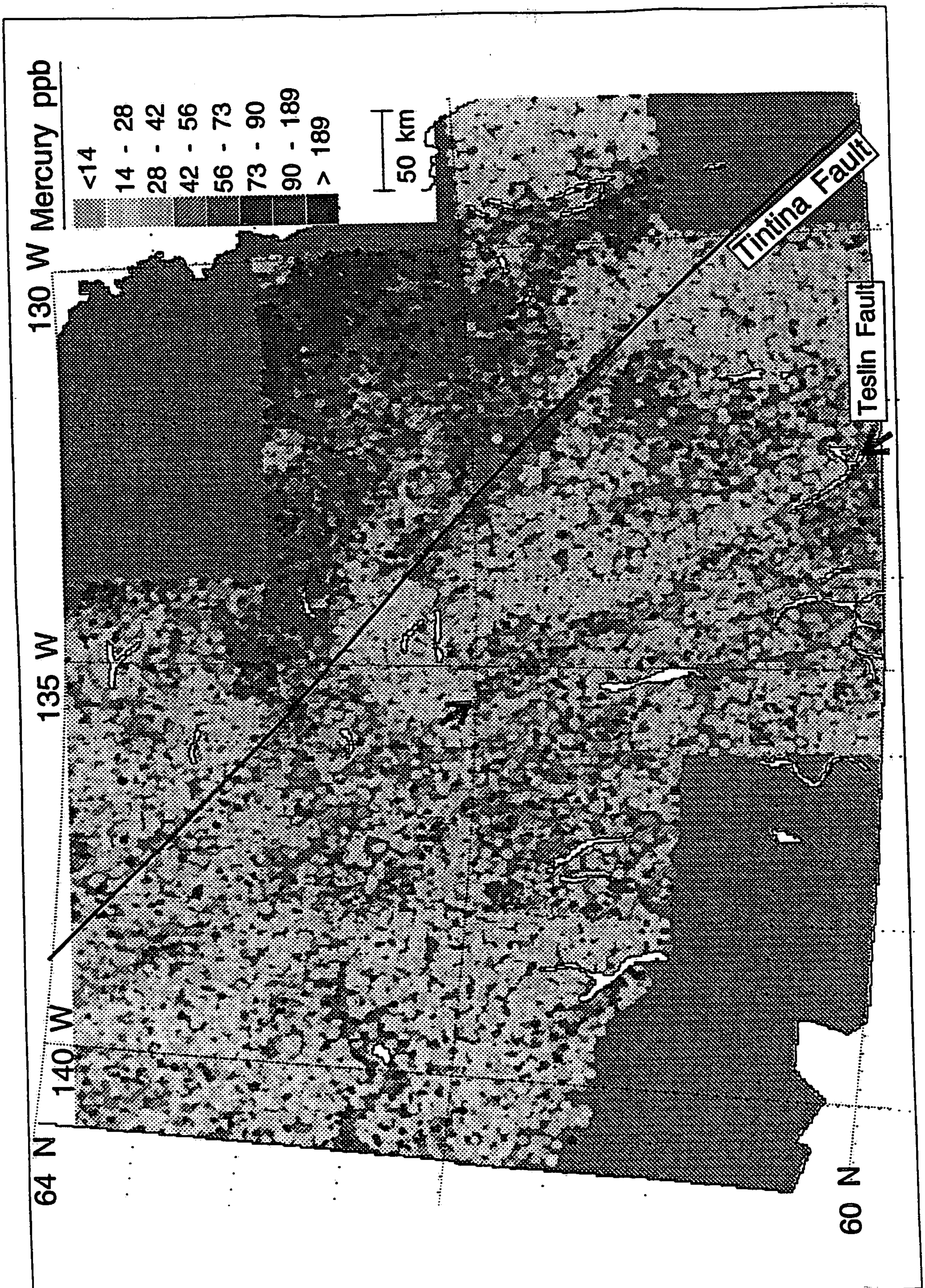
Ratio of geological to present day mercury flux in circumpolar lake sediments



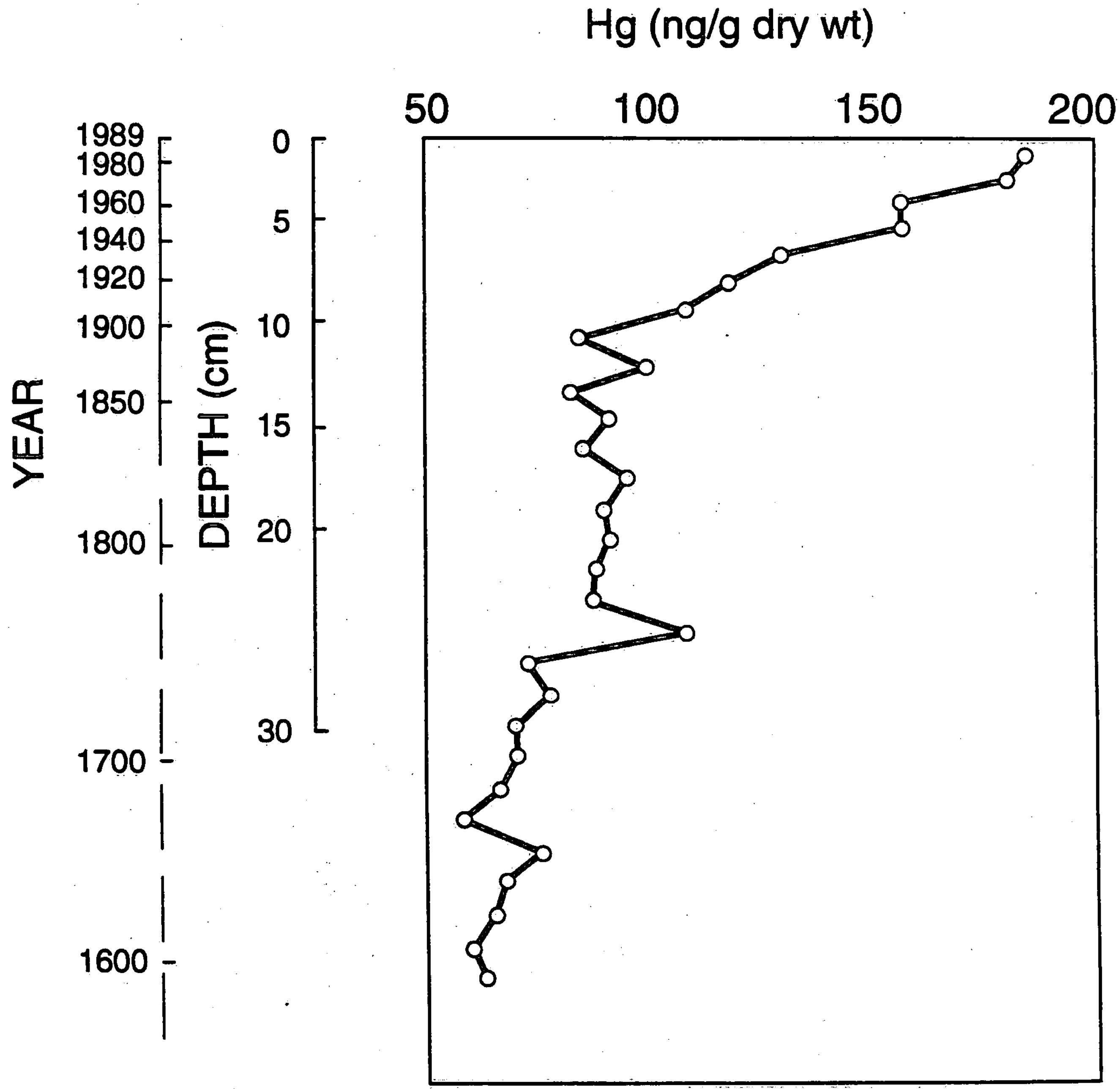
Mercury flux ratios model



Arctic air pollution is at its peak during the winter, as pollutants build up in the cold pool of air over the north pole. Winter winds carry pollution primarily from the U.S.S.R. and Europe, with lesser amounts from North America, China and Japan.


Mercury ppb
<14
14 - 28
28 - 42
42 - 56
56 - 73
73 - 90
90 - 189
> 189
50 km
130 W
135 W
140 W
64 N
60 N
Tintina Fault
Teslin Fault

MERCURY IN LAKE 375 (ELA) SEDIMENT



Core and loading estimates of inputs
Lake 375, ELA

Lake area = 18.9 ha
Watershed area = 231 ha

Precip to lake surface @ 31 mg/ha/yr
18.9 ha x 31 mg/ha/yr = 586 mg/yr

Runoff into lake @ 14 mg/ha/yr
231 ha x 14 mg/ha/yr = 3234 mg/yr

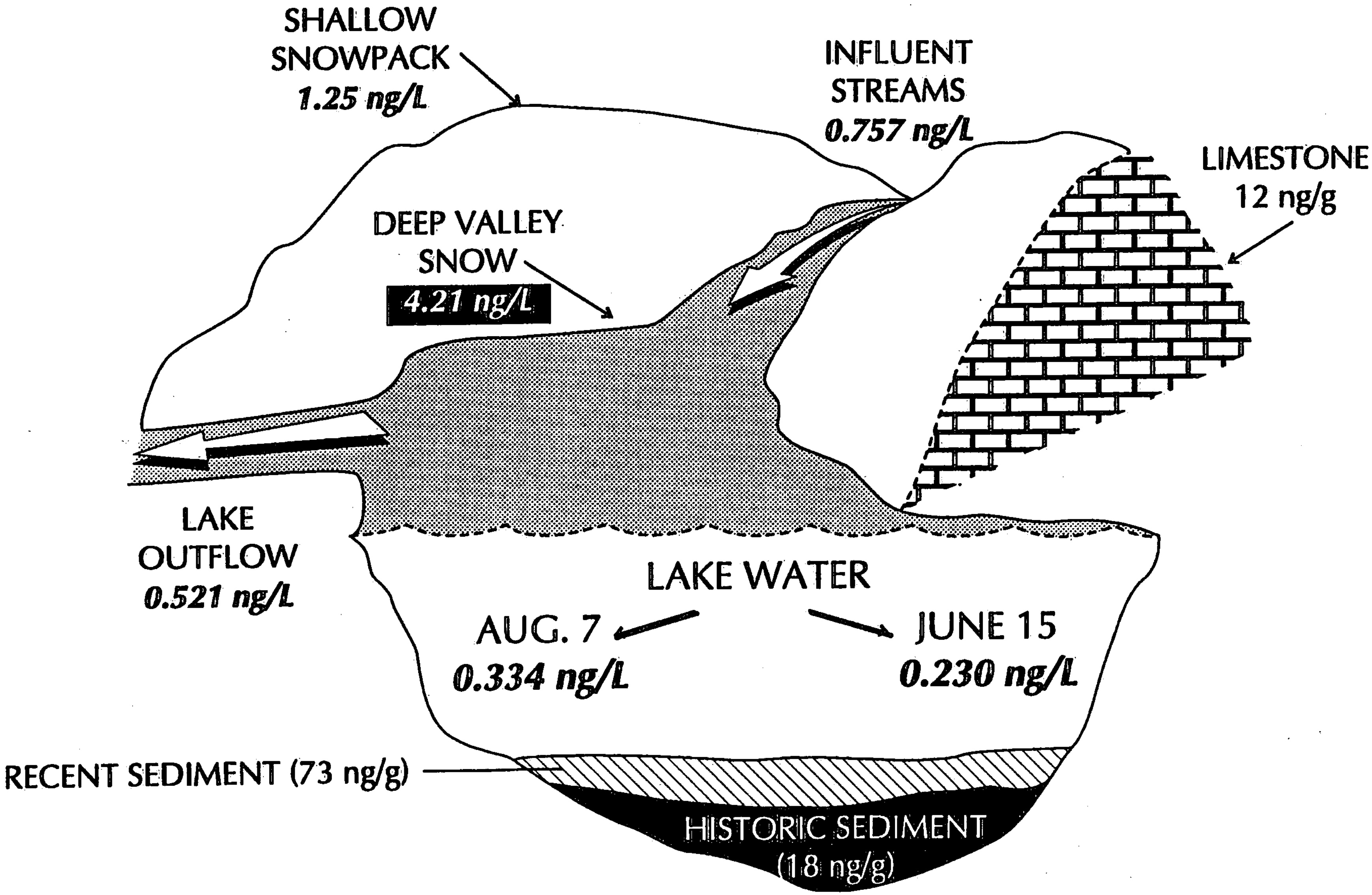
Total input to lake = 3820 mg/yr

Lake area = 18.9 ha

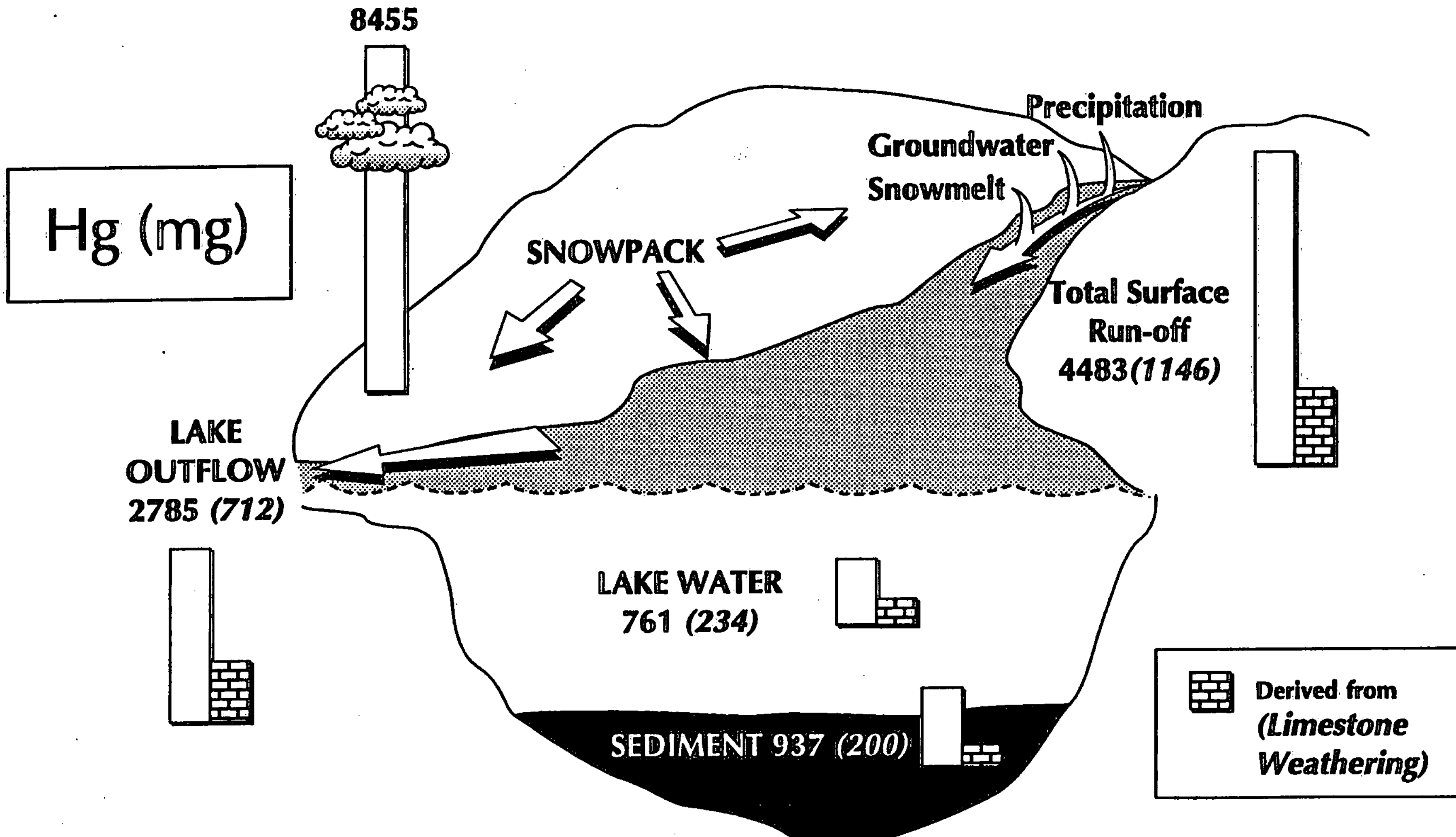
Loading = 3820 mg/yr / 18.9
= 202 mg/ha/yr
= 20.2 µg/m2/yr

Core estimate (Lockhart et al., Wat. Sci. Technol., 1994) = 21 $\mu g/m^2/yr$

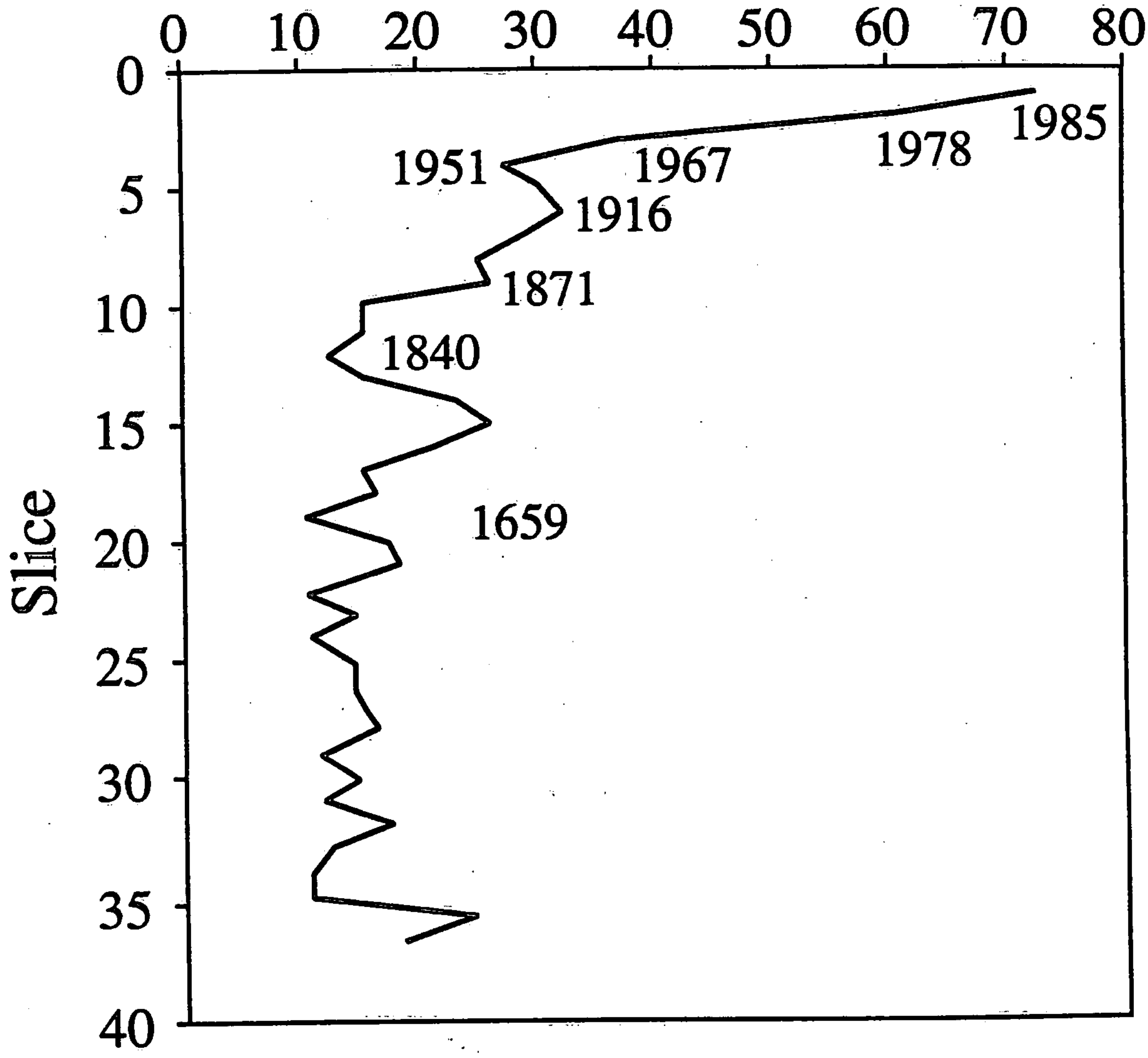
TOTAL Hg CONCENTRATIONS IN AMITUK LAKE, 1994



TOTAL MERCURY BUDGET - AMITUK LAKE
June 16 - August 24, 1994

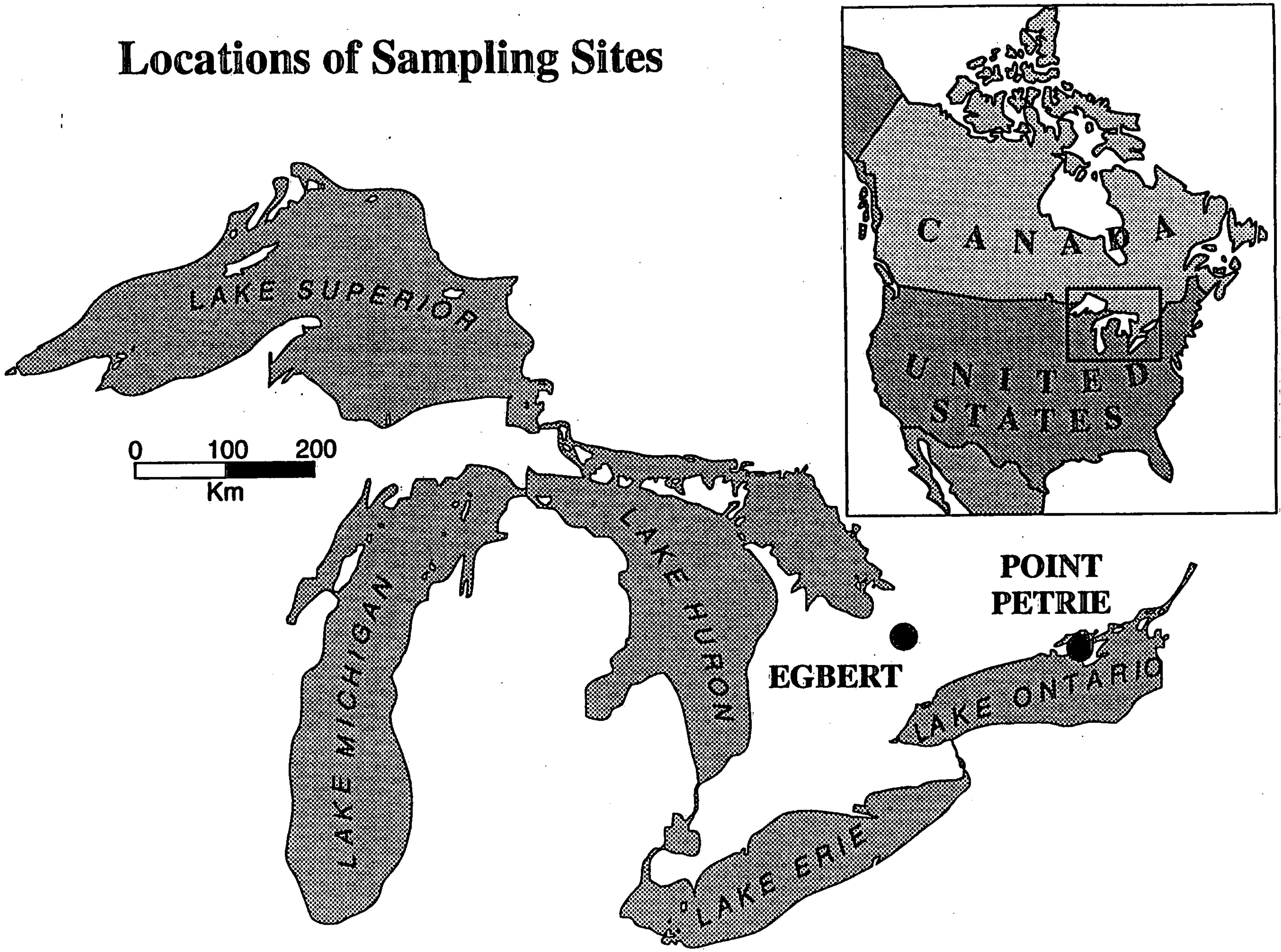


Amituk L., Cornwallis Is., KB core A, Mercury (ng/g)

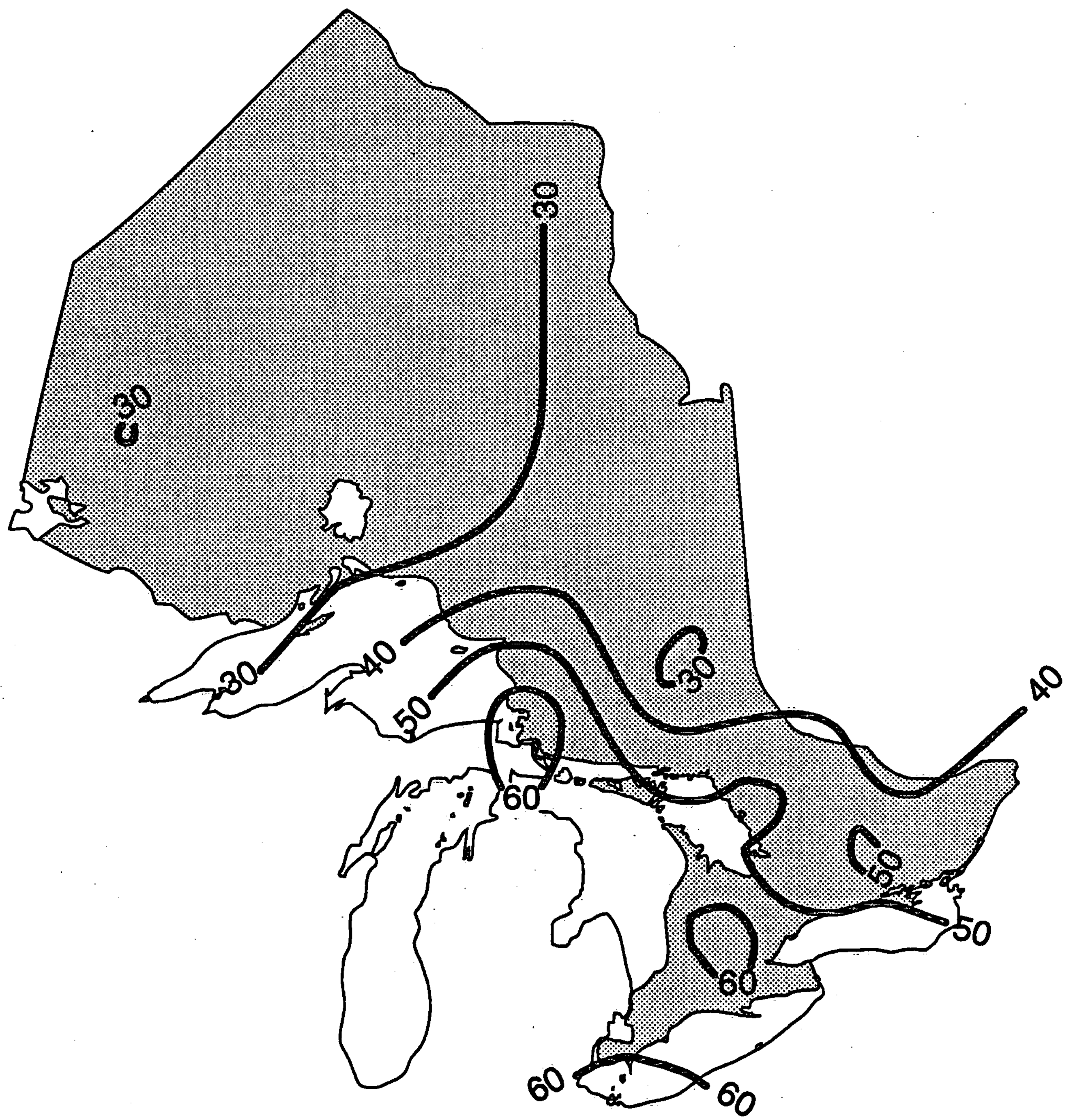


Dates earlier than about 1850 are extrapolations based on sedimentation rates established from recent slices

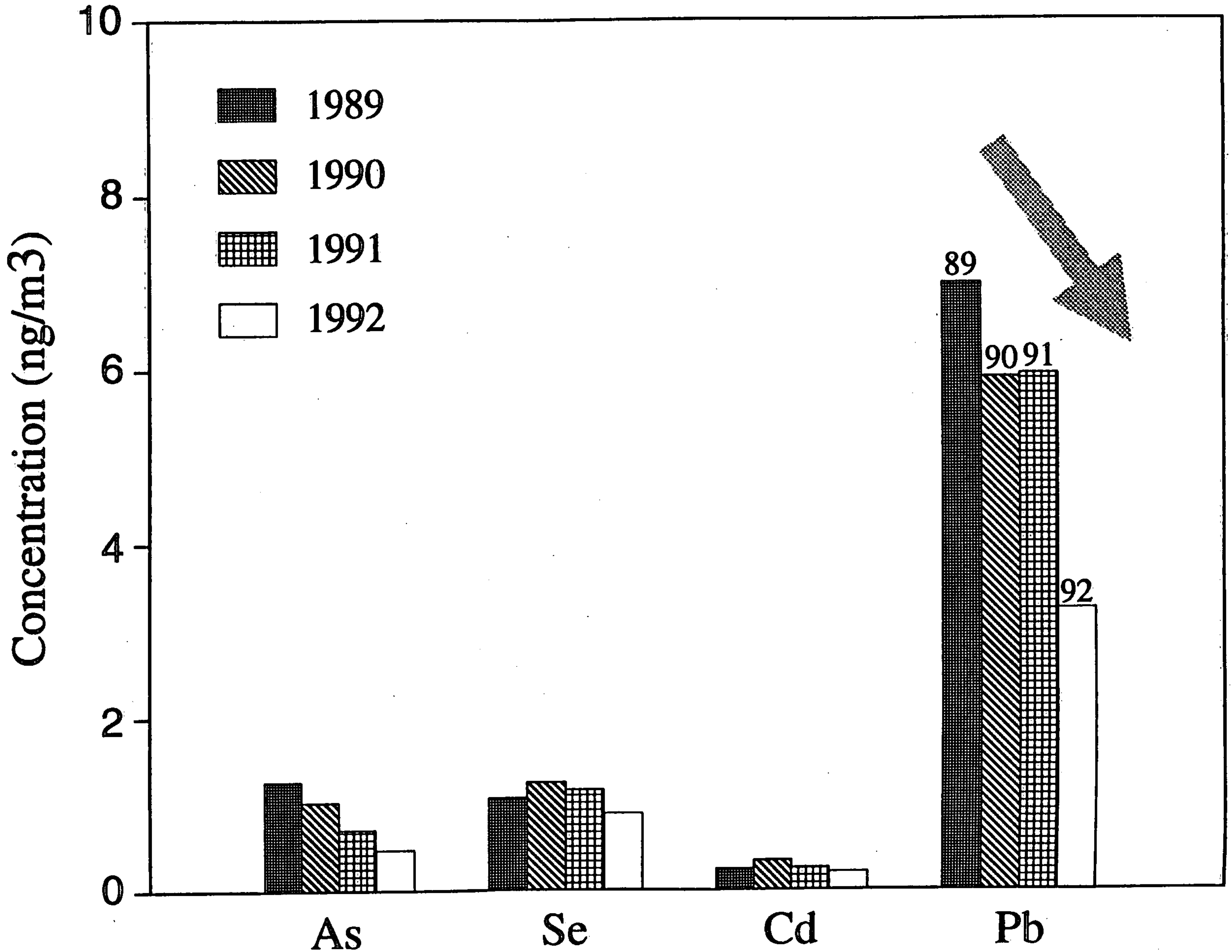
Locations of Sampling Sites

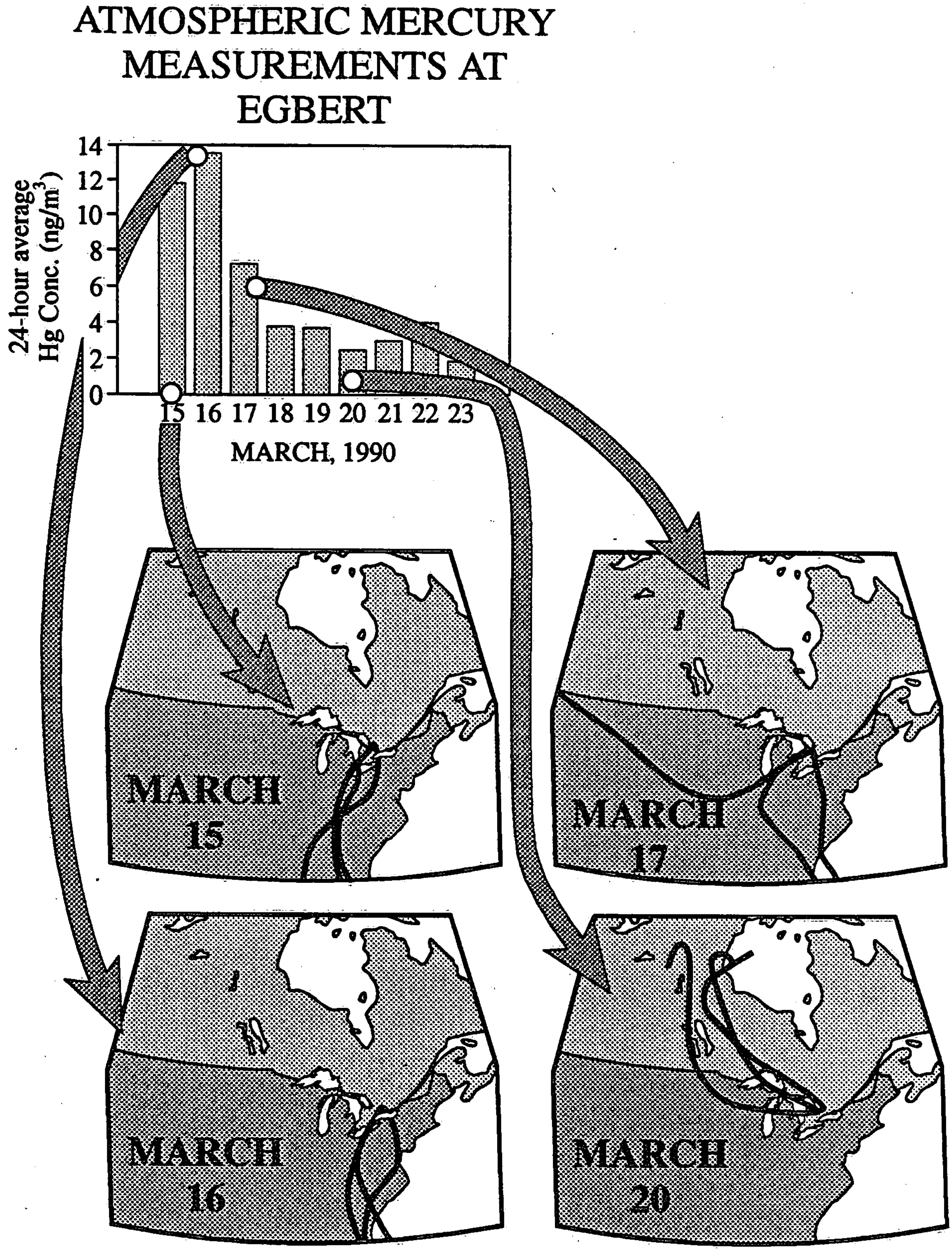


LEAD WET DEPOSITION (g/ha/yr) in Ontario 1981-1988



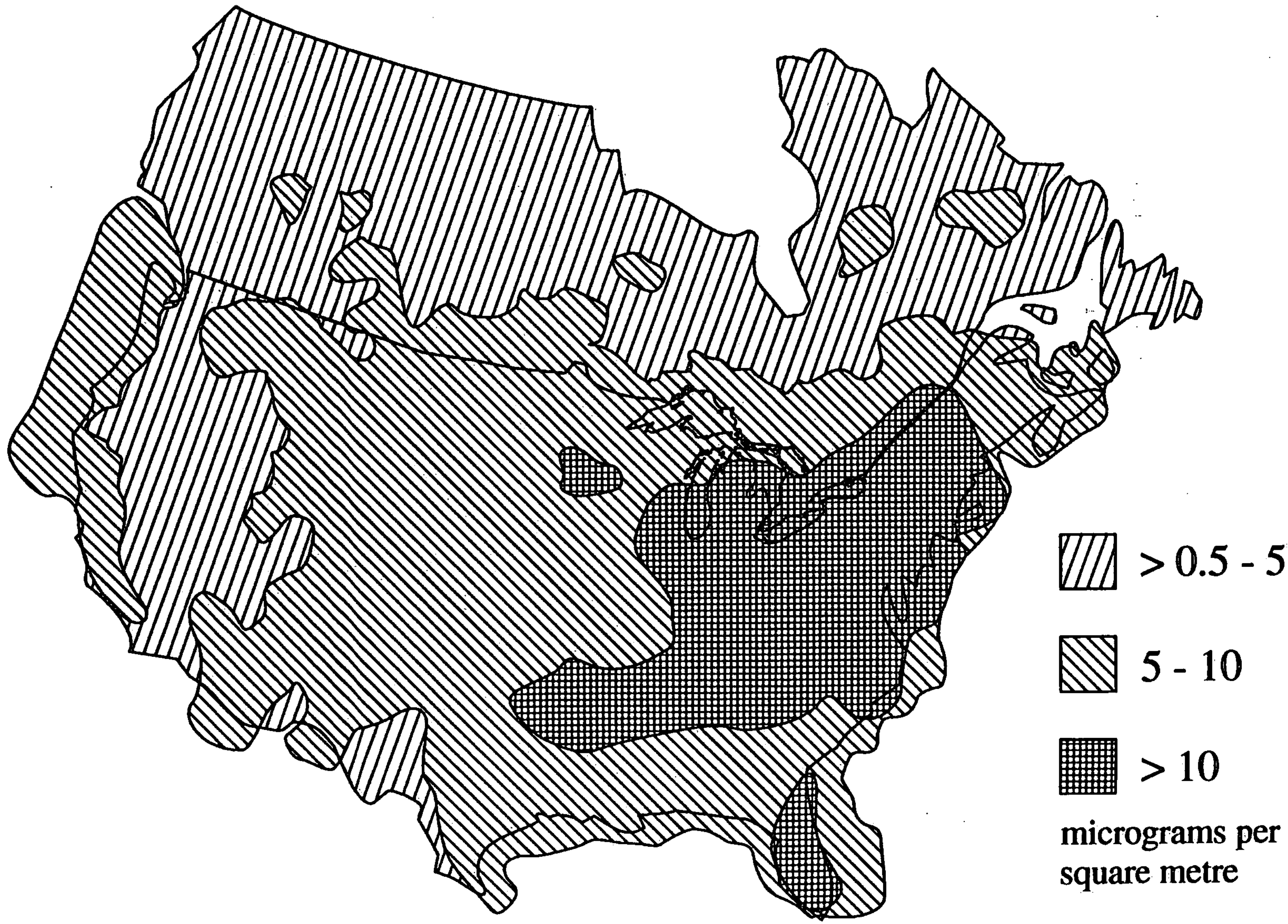
As, Se, Cd and Pb concentrations at Point Petrie for 1989-1992



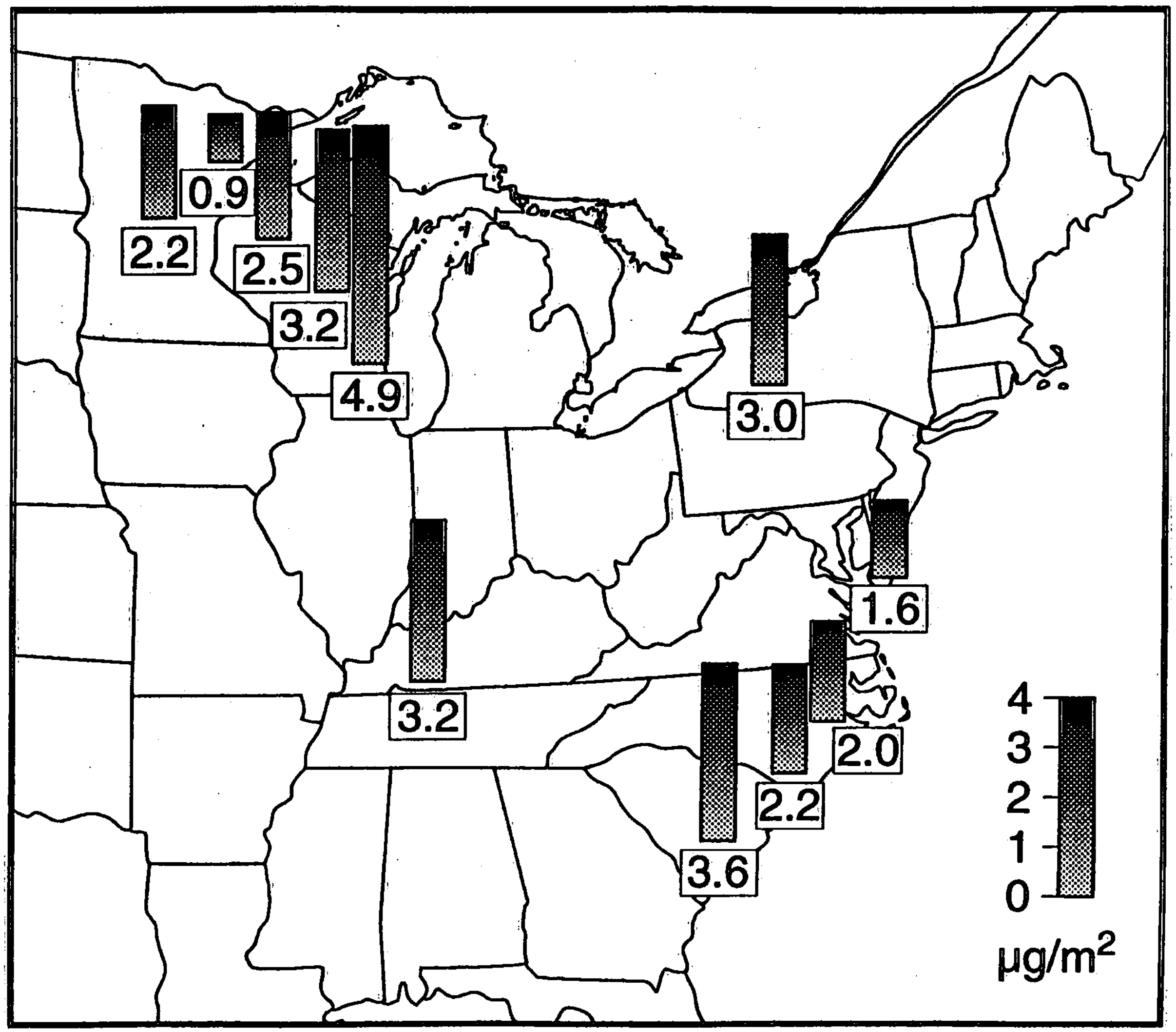


5 DAY BACK TRACK TRAJECTORIES

TOTAL Hg WET DEPOSITION
BASE EMISSIONS SCENARIO



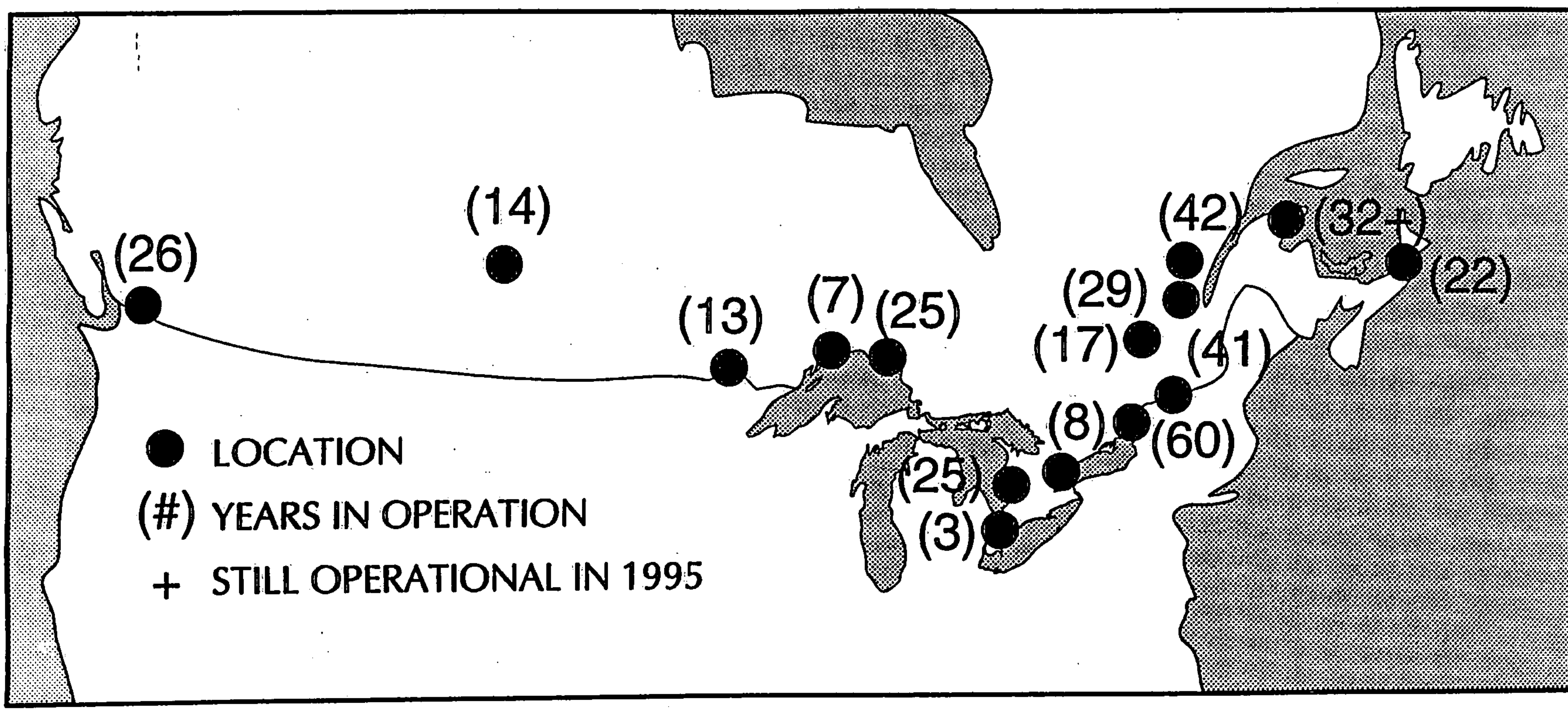
Hg DEPOSITION
JUNE 20 - AUGUST 15, 1995



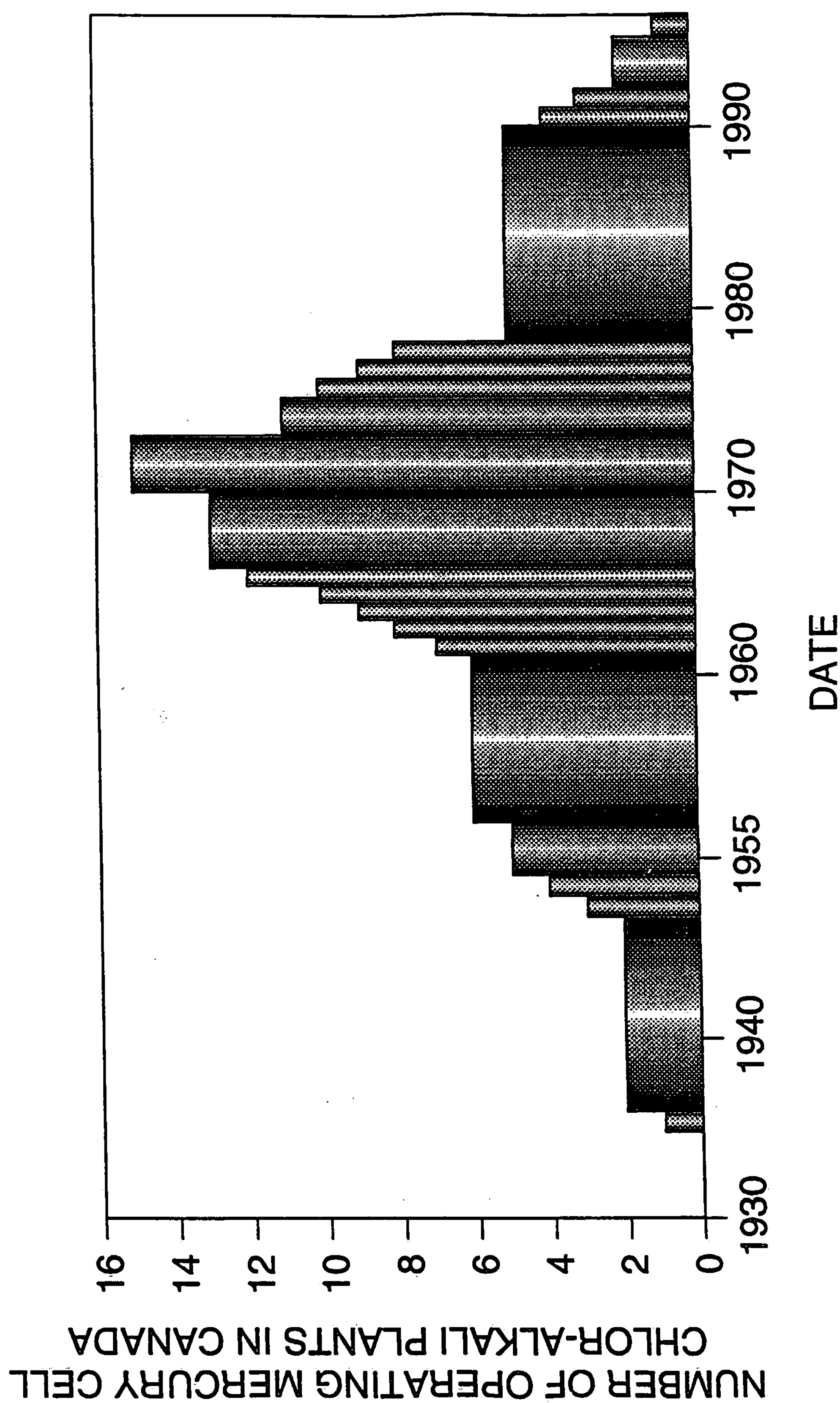
Total mercury annual inputs at the Experimental Lakes Area, and at other sites in Scandinavia and North America.

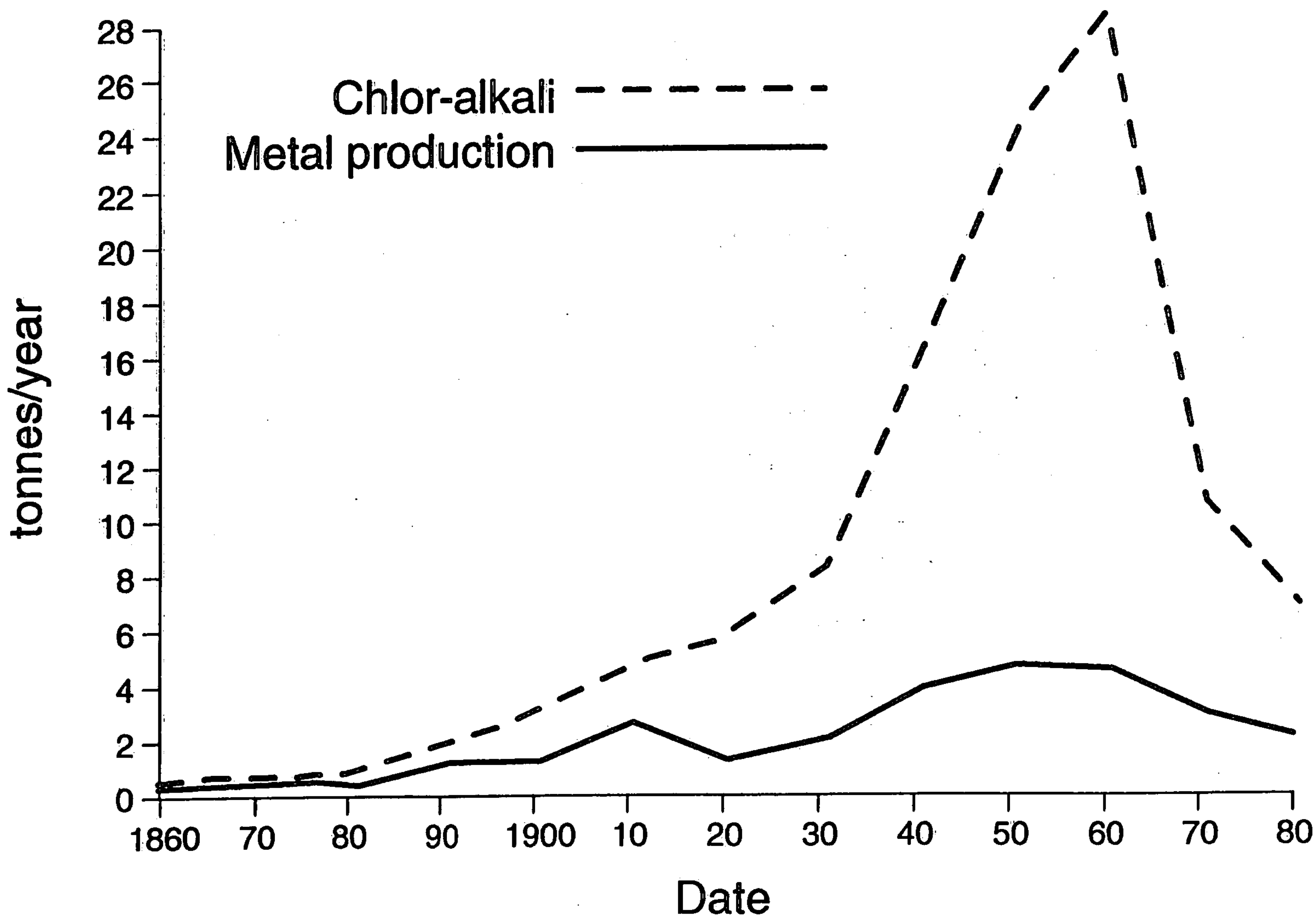
Values in parentheses are range of concentrations (when available) references.

Location	Total Mercury Input ($mg\ ha^{-1}\ yr^{-1}$)
Southern Norway	350
Southern Sweden	100-350
Western Sweden	97-270
Denmark	170
Dorset (S. Ontario)	102
Eastern Sweden	100
Central Norway	70
Northern Norway	50
Southern Finland	38
ELA (N.W. Ontario)	30

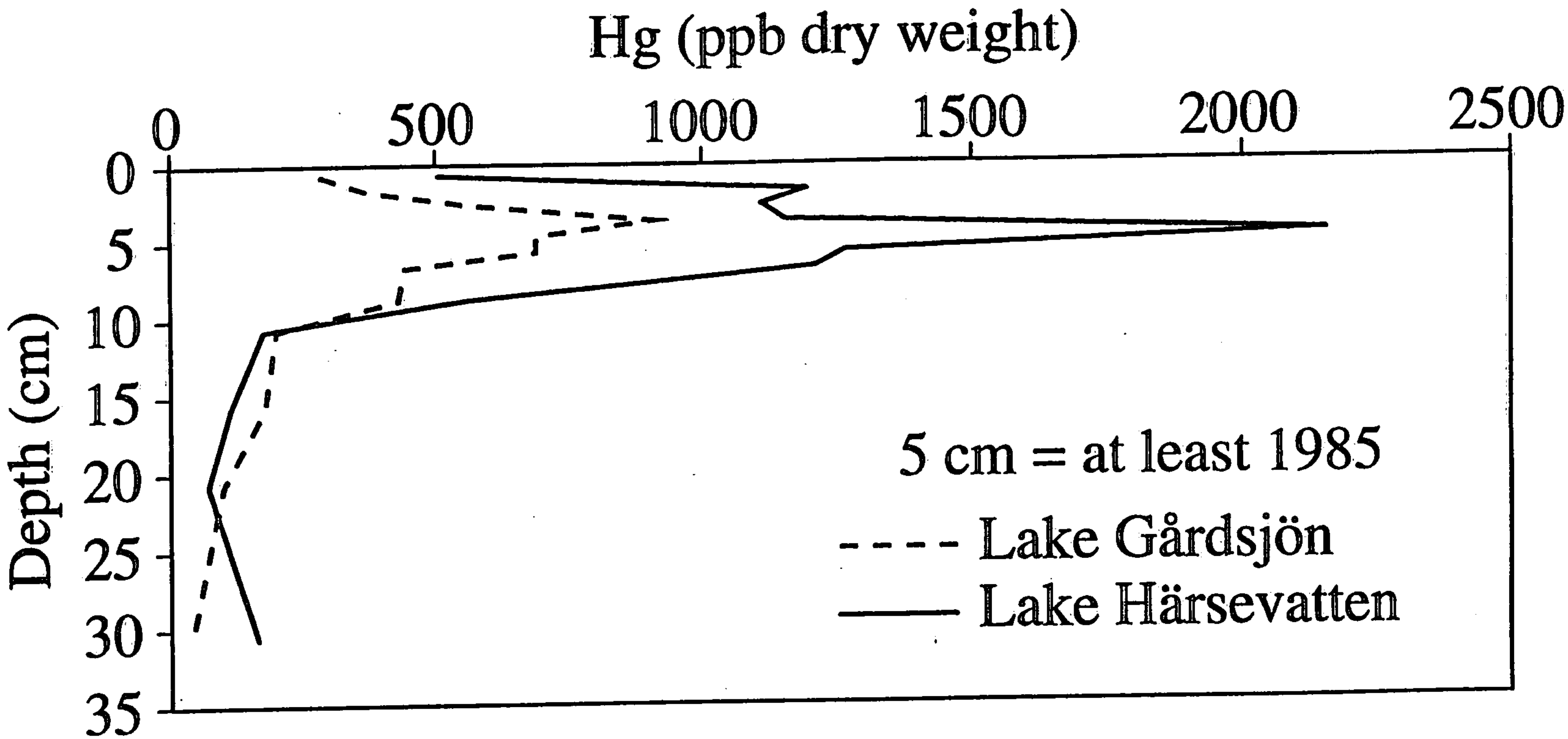


LOCATION IN CANADA OF THE 15
CHLOR-ALKALI PLANTS WHICH USED MERCURY CELLS


NUMBER OF OPERATING MERCURY CELL
CHLOR-ALKALI PLANTS IN CANADA
16
14
12
10
8
6
4
2
0
1930
1940
1955
1960
1970
1980
1990
DATE



Some emissions of Hg to the atmosphere in Sweden, 1860-1980



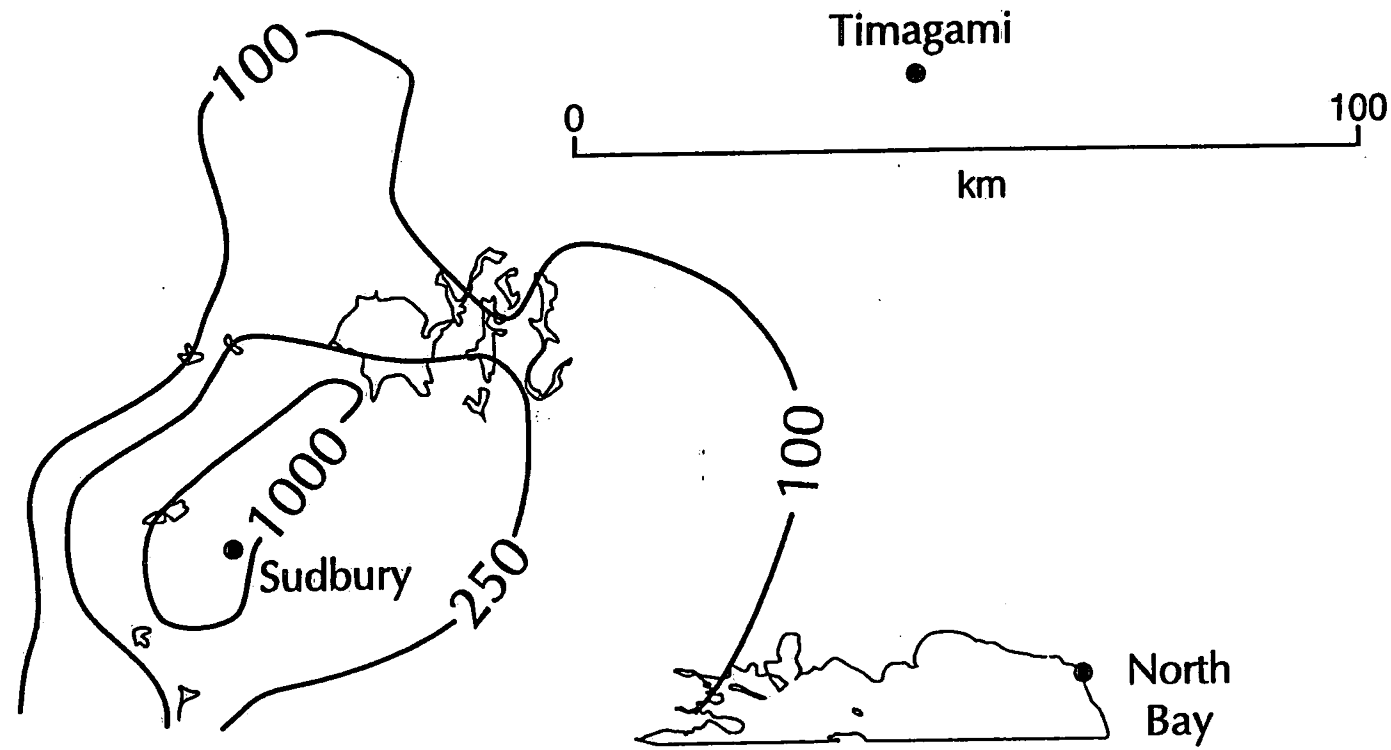
Hg in lake sediment cores from Lake Gårdsjön and Lake Härsevatten, Sweden

Pb, Cd and Hg Emissions in Canada

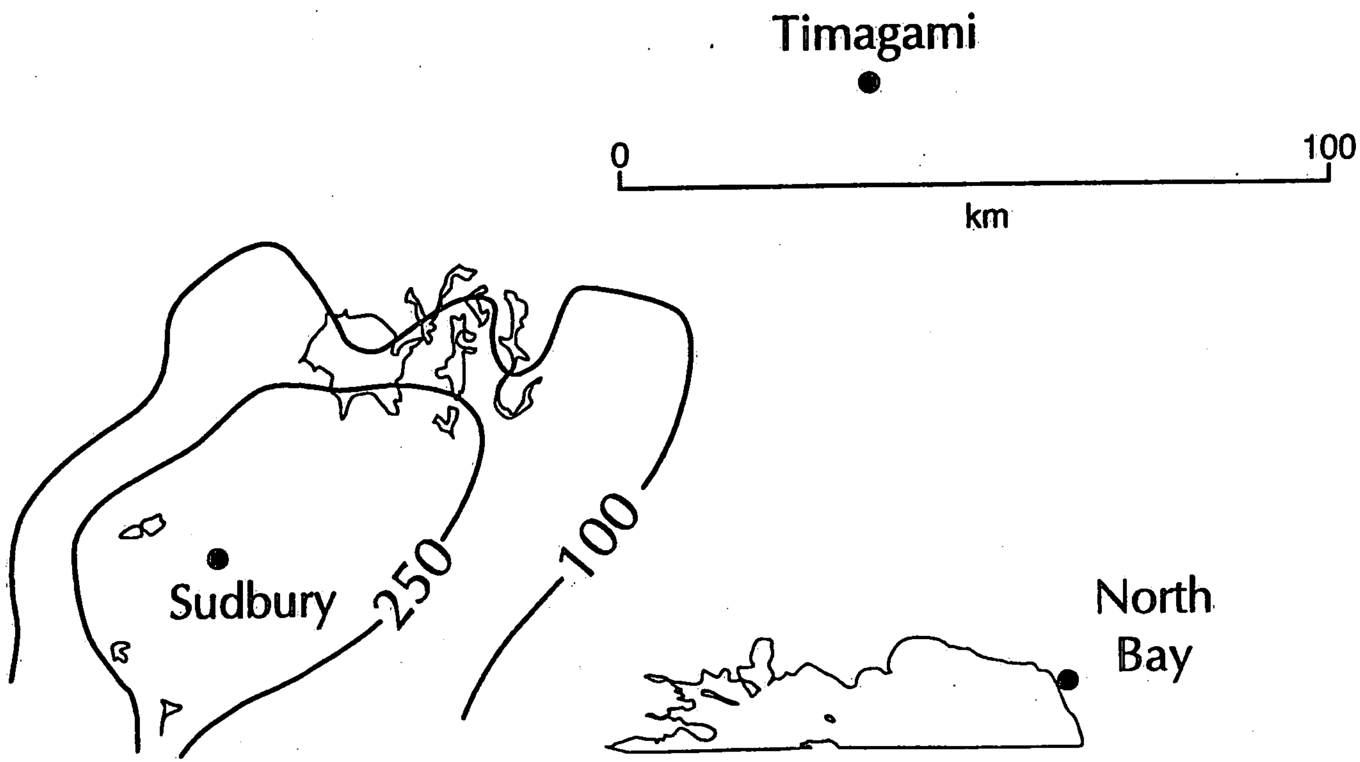
(1988 Data)

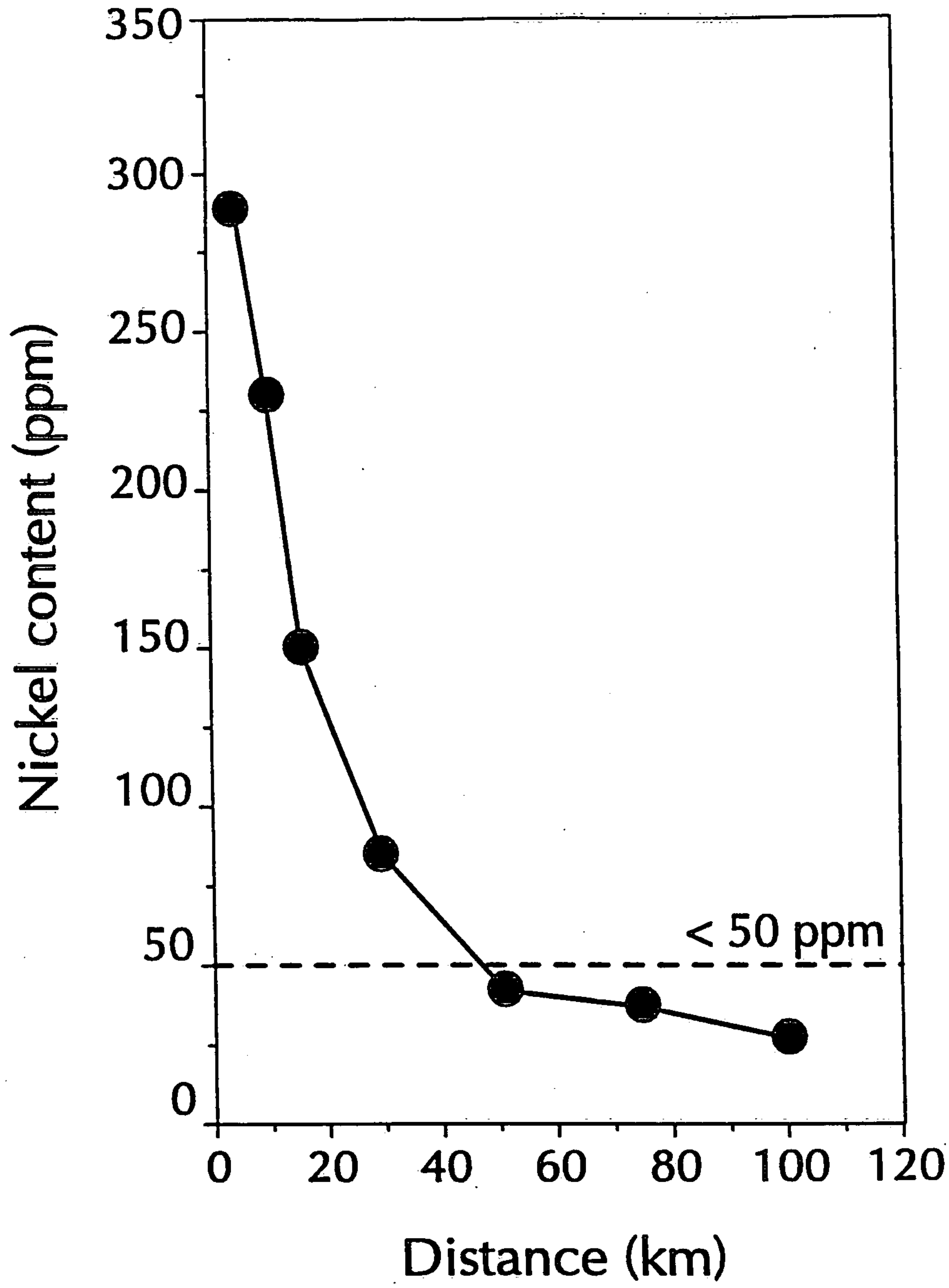
Source	Pb	Cd	Hg
	(to nearest tonne)		
Primary Non-Ferrous Metal Industry	920	40	30 *
Secondary Iron and Steel Industry	56	(<5)	(<1)
Fossil Fuel Combustion Power Production	39	33	4
Municipal Waste Incineration	(<15)	7	3
Other	60	6	2
CANADA TOTAL	1,875	86	39
USA TOTAL	4,908	192	301
EUROPE TOTAL	24,688	436	551

DISTRIBUTION OF Ni ppm IN BOTTOM SEDIMENTS OF LAKES, 1973



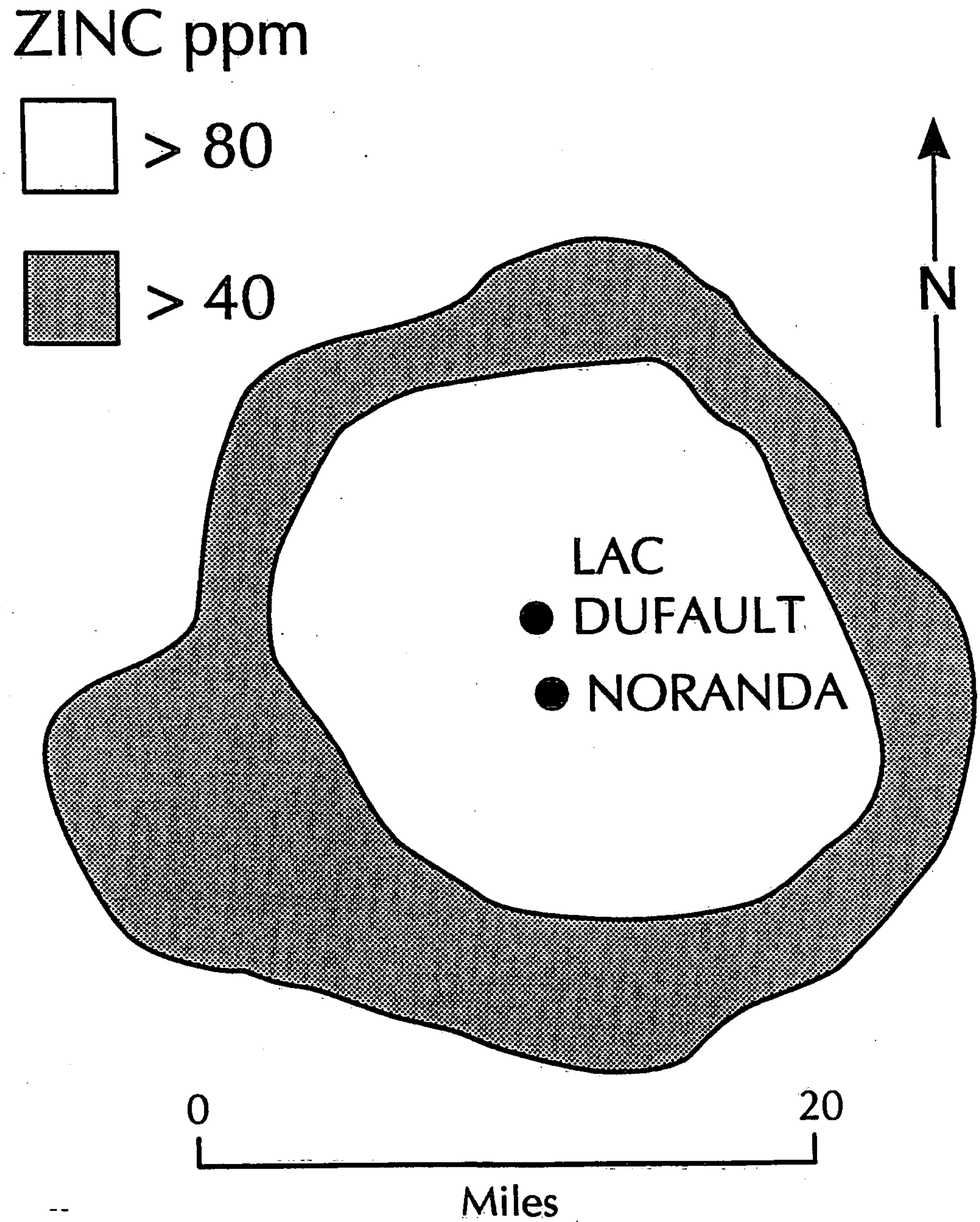
DISTRIBUTION OF Cu ppm IN BOTTOM SEDIMENTS OF LAKES, 1973



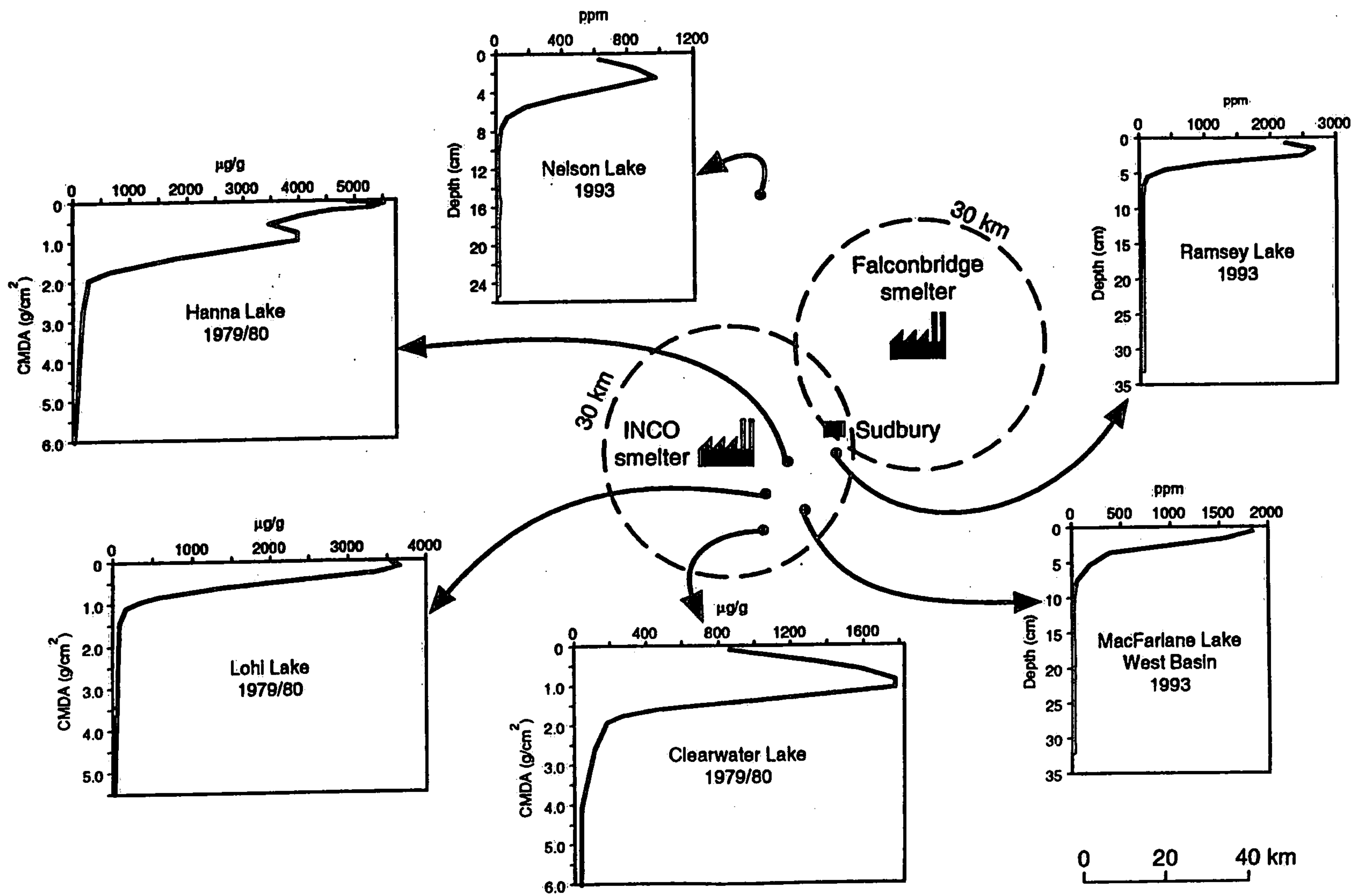


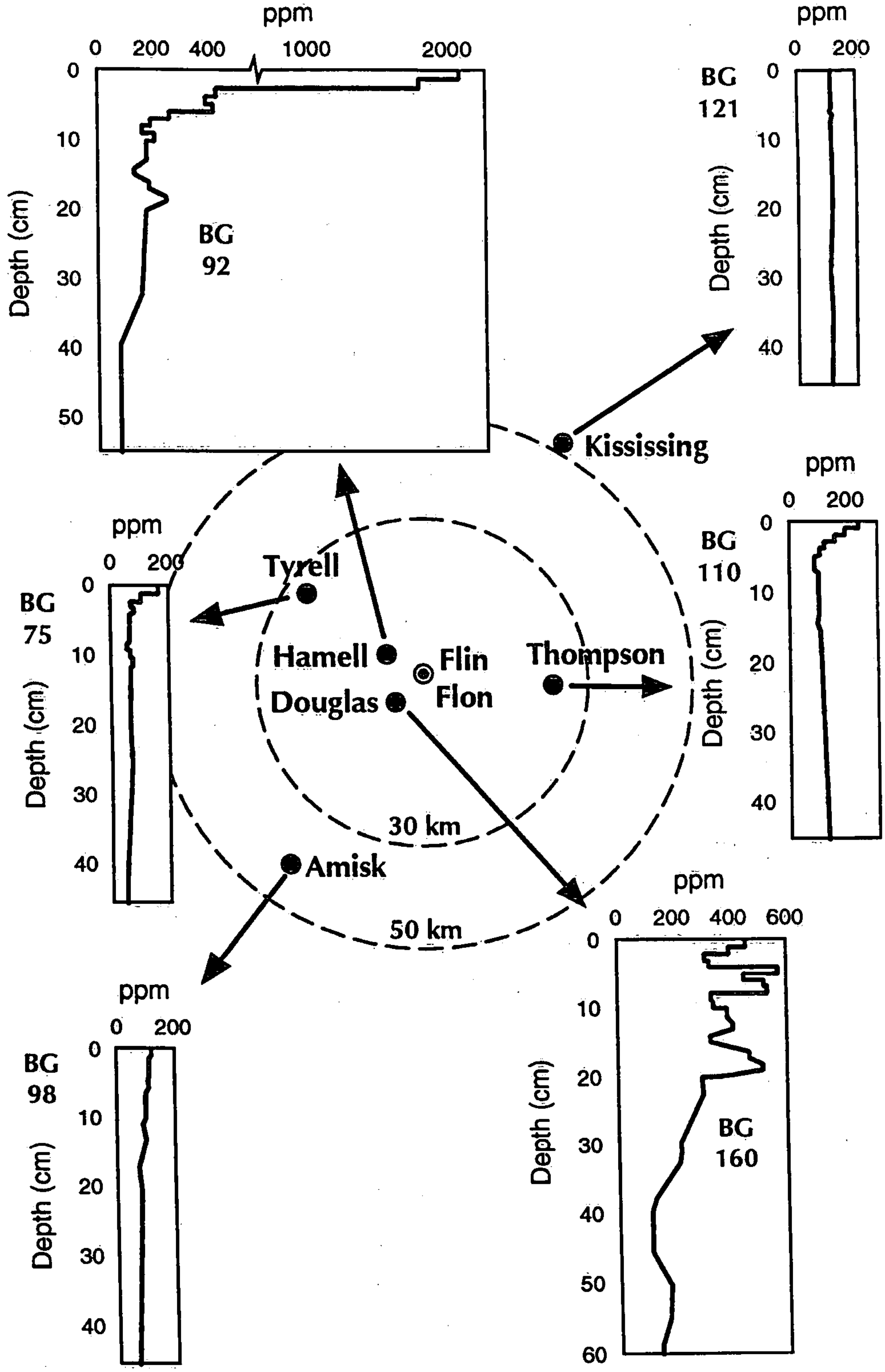
Changes in nickel concentration in foliose lichen Stereocaulon collected along a transect northwest of the Copper Cliff smelter in 1991

ROLLING-MEAN ZINC CONCENTRATIONS IN SURFACE LAKE SEDIMENTS IN VICINITY OF NORANDA, QUEBEC, 1973



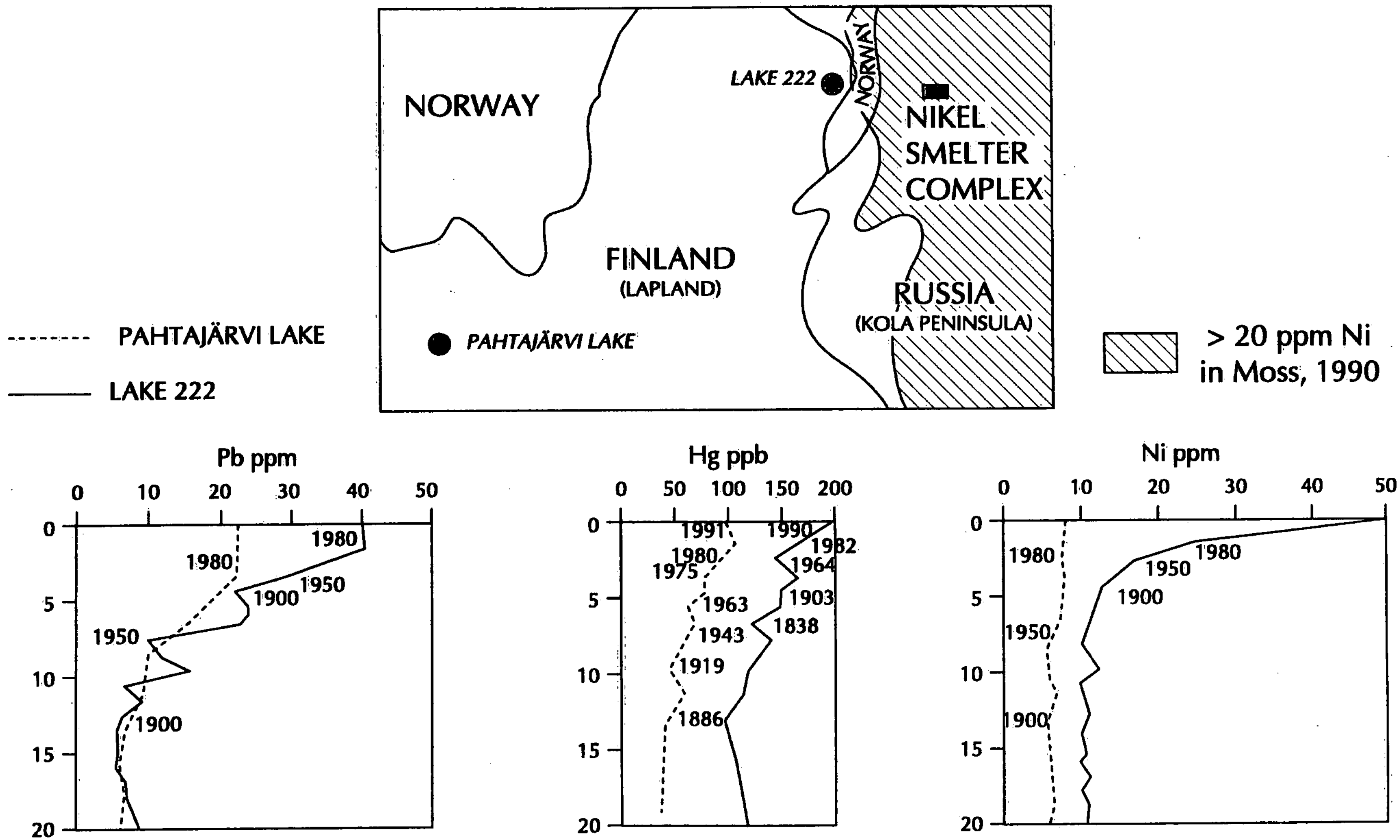
NICKEL DISTRIBUTION IN LAKE SEDIMENT CORES, SUDBURY AREA



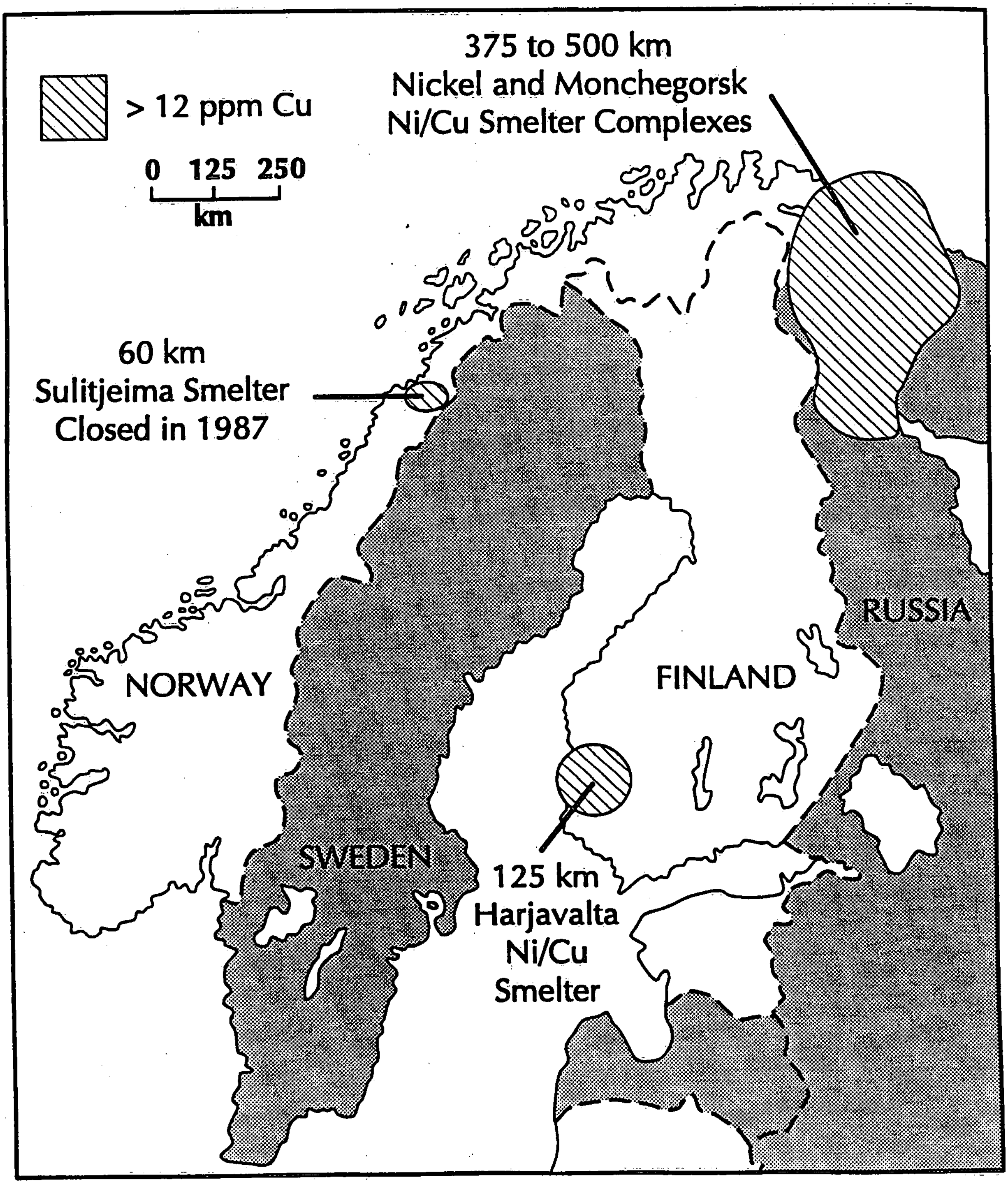


ZINC DISTRIBUTION IN LAKE SEDIMENT CORES, FLIN FLON AREA 1976

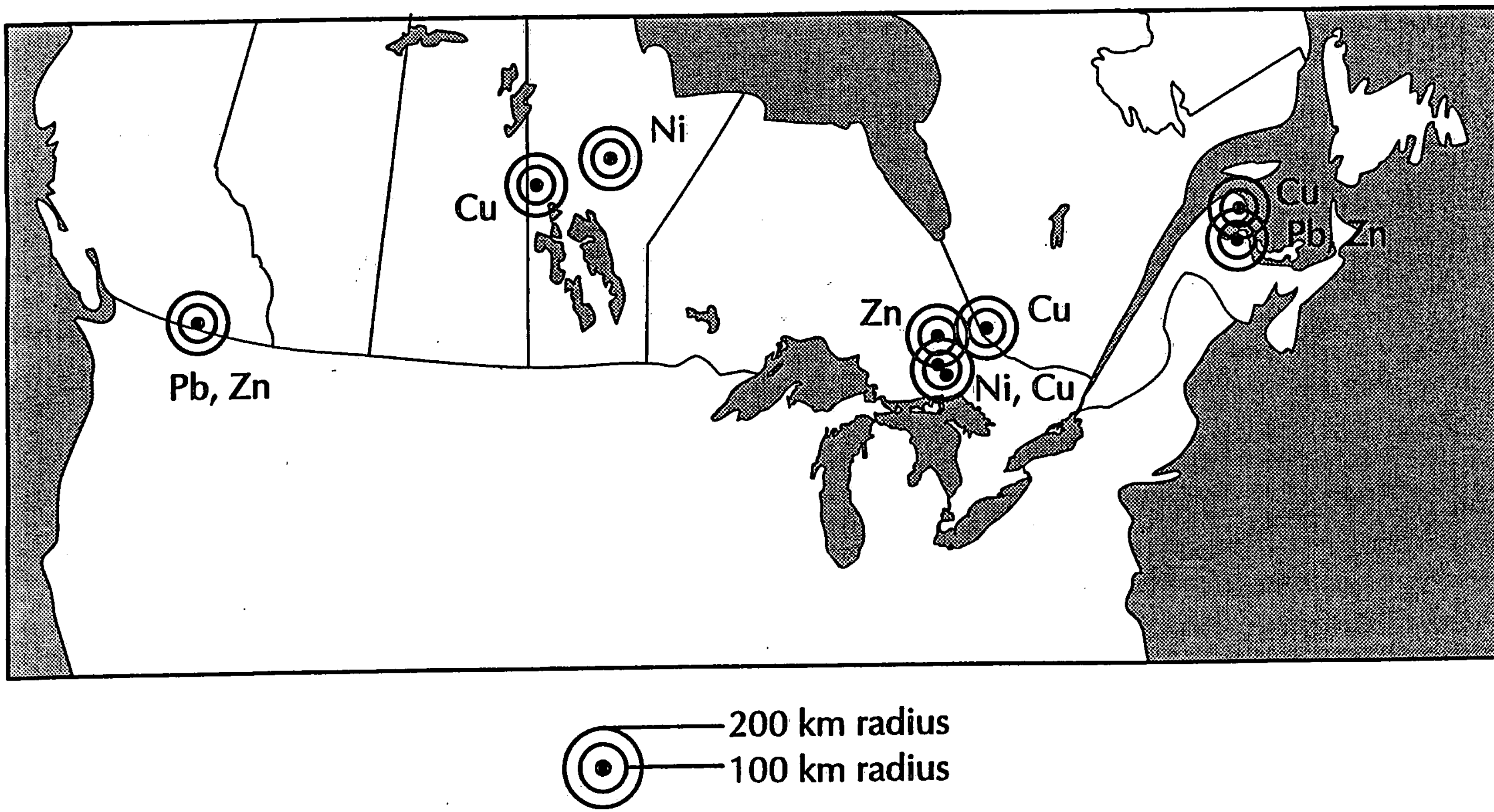
Pb, Hg AND Ni IN LAKE SEDIMENT CORES FROM FINNISH LAPLAND

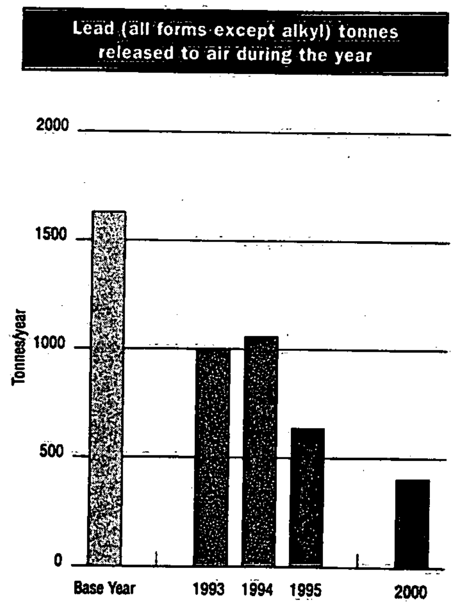


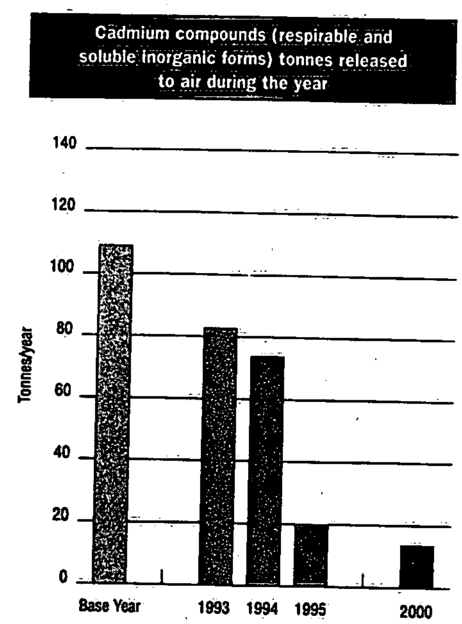
COPPER IN MOSS, 1990

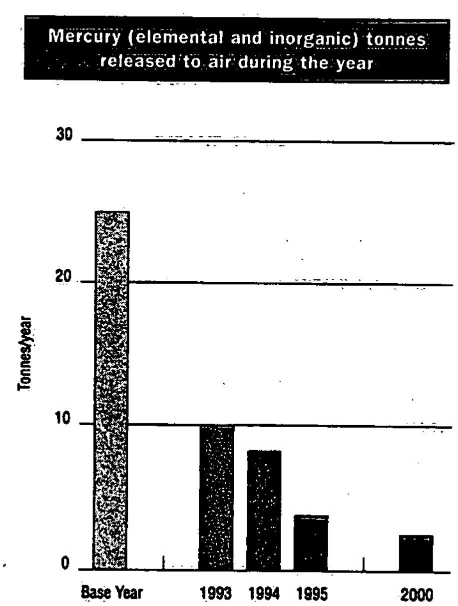


POTENTIAL ZONES OF PRIMARY METAL DEPOSITION AROUND CANADIAN BASE METAL SMELTERS









ANNUAL TOTAL LEAD, CADMIUM AND MERCURY RELEASES TO THE ATMOSPHERE FROM CANADIAN MINING AND SMELTING OPERATIONS

CONSISTENCIES

1. In the recent past, mercury in sediment cores and in other media is always going up or stays the same - never goes down - except where pollution sources have been reduced - e.g. Clay Lake, southern Sweden.

2. The measured deposition rates for mercury are similar to the deposition rates calculated from lake sediment cores.

3. In the western Arctic as opposed to east, the geology is mercury rich and the natural component in sediment cores is highest as well as the accumulation of mercury in seal and whale livers - but increases at both locations continue.

4. The dates of the start of increases in mercury in various media is similar and matches industrialization and not any sudden change in nature.

5. When the large chloralkali plants in former east Germany were closed in 1990, mercury in deposition in southern Sweden began to decrease.

6. When mercury is buried in lake sediments e.g. Clay Lake or the sediments self cleanse e.g. Lake St. Clair, the mercury in local biota decreases.

7. Watersheds are complex and lakes of different types in different geological settings react to mercury increases and decreases in complex ways just as before to acid precipitation and before that to phosphorus loads - but there is a link, be it complex, between mercury loads and concentrations in biota.

RECOMMENDATIONS

1. REGIONAL AND GLOBAL MERCURY MONITORING NETWORKS FOR ATMOSPHERIC DEPOSITION NEED TO BE ESTABLISHED
   - join the mercury deposition network
   - need more work on sediment core processes
   - need to get better estimates of natural atmospheric loads
   - need to get evasion/deposition rates at remote sites
   - need to assess long term effects of soil degassing in relation to climate change, agriculture and forestry
2. PREDICTIVE MODELS NEED TO BE DEVELOPED FOR BIOACCUMULATION AND EFFECTS FOR BOTH NATURAL AND ANTHROPOGENIC HOTSPOTS
   - need to fill in the aquatic sediments mercury map of Canada
   - need to document mercury concentrations in soils
3. MORE RESEARCH ON EFFECTS IS NEEDED
   - the biological response to natural and anthropogenic loads needs to be defined - biological effects monitoring should be linked to deposition monitoring
   - the role of LRTAP mercury to total mercury risk should be determined
   - the WHO guidelines for humans may need to be reassessed - the old, unborn and very young may be most at risk
4. A FEW STUDY AREAS NEED TO BE SELECTED FOR CONCENTRATED, LONG TERM, MULTIDISCIPLINARY SCIENTIFIC EFFORTS
   - the mechanisms of mercury release and recycling should be determined
   - the controls on bioaccumulation of mercury in fish need to be determined
5. THERE IS A NEED FOR NATIONAL LEADERSHIP TO ESTABLISH THESE ACTIVITIES

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