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A history of total mercury in edible muscle of fish from lakes in northern Canada

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Abstract

Subsistence fishing has been an important source of food for Native People in northern Canada since prehistoric time. Measurements of the levels of mercury in edible muscle of northern fish have been undertaken for over three decades in efforts to evaluate the risks of consuming northern fish. This report summarizes the data obtained from 7974 fish of 25 species from sites distributed from the Yukon to Labrador. The most abundant species were lake trout, lake whitefish, arctic char, walleye, northern pike and burbot. The question being asked was essentially "Are the fish safe to eat?" The results were used to support decisions on fishing and consumption of fish. They were sorted in several ways, into concentration ranges corresponding to human consumption guidelines, into political jurisdictions and into types of bedrock geology. Overall walleye, northern pike

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and lake trout, usually exceeded the subsistence consumption guideline of 0.2 μg g^{-1} total mercury and often exceeded the higher guideline of 0.5 μg g^{-1} total mercury for commercial sales of fish. Mercury in burbot, another facultative predator, was often lower but several still exceeding a guideline. Arctic char collections were mostly from anadromous populations and these had very low levels of mercury, presumably reflecting marine food sources. Lake whitefish were among the cleanest fish examined with 69 of 81 collections falling in the lowest range. Most collections were from sites in sedimentary rock. However a few sites were in metamorphic, intrusive or volcanic rocks and these, taken together, tended to have a higher proportion of sites in the higher ranges of mercury. These results indicate a widespread problem with mercury in subsistence fisheries for predator species of fish with the problem being most problematic for Nunavut.

Keywords: Canadian Arctic; Mercury; Fish; Arctic; Muscle; Consumption; Spatial trends; Temporal trends

1. Introduction

For approximately three decades samples of fish and marine mammals from northern Canada have been analyzed to determine levels of mercury in edible portions. Interest in these levels has been high because of observations that blood and hair of indigenous people from isolated communities in northern Canada have relatively high levels of mercury in comparison with other Canadians (Health and Welfare Canada, 1979, 1984; Wheatley and Paradis, 1995). Canada allows a maximum of 0.5 μg g^{-1} total mercury (wet weight) in fish for commercial sale. In addition, in recognition of the fact that families who fish for subsistence often consume more fish than the average for the Canadian population as a whole, a lower level of 0.2 μg g^{-1} total mercury (wet weight) has been recommended for subsistence consumers (Health and Welfare Canada, 1979).

Several studies of mercury in northern fish have been conducted, usually with the objective of describing the levels in fish from a particular location of interest (e.g. Trout Lake, NT, Swiripa et al., 1993; Hay and Slave rivers, NT, Grey et al., 1995). Some of the accumulated results from these studies have been summarized in government reports (e.g. Desai-Greenaway and Price, 1976; Sherbin, 1979; Muir et al., 1986; Northern Contaminants Program, 1997, 2003), but few of the results have appeared in the open literature. By comparison with northern freshwater fish, arctic marine fish have received little attention. Information on levels of mercury, other elements and synthetic organic compounds in arctic marine fish was summarized by Muir et al. (1986). The primary purpose of this report is to catalogue the data available in a publicly accessible format and to compare them with human consumption guidelines. Most of the collections reported were obtained to evaluate the fish as food for people. Investigations aimed at developing a more complete understanding of the levels found in the fish in a subset of the lakes are described by Evans et al. (2005). Many of the data originate from the 1970s or 1980s and they were applied at the time to decisions regarding existing or potential commercial fishing operations or subsistence consumption. A number of consumption advisories have been issued for individual lakes with information on quantities of fish of different species can be eaten safely.

In addition, the data permit some examination for temporal and spatial trends. The data are of high quality in terms of chemical measurements but are highly erratic in terms of sample numbers and sample frequency. The data have been listed in tables sorted into concentrations found in different political and geological regions. They have also been plotted on maps in which they are superimposed on political boundaries of northern Canadian territories and on geological boundaries describing types of bedrock at collection locations.

In spite of the isolated locations of most northern lakes, investigators have consistently found instances in which levels of mercury in fish and marine mammals exceed the guidelines used to regulate human consumption of fish. This is particularly the case with predator species (e.g. lake trout (*Salvelinus namaycush*), northern pike (*Esox lucius*), walleye (*Stizostedion vitreum vitreum*)). The conclusion sometimes drawn has been that the levels of mercury found must represent natural conditions because local sources of anthropogenic mercury do not exist (e.g.

Shilts and Coker, 1995). We have no rigorous way to partition the mercury in fish into amounts contributed by potential sources, although recent developments in the analyses of the numerous isotopes of mercury may offer potential to do this. The contributions of local geological settings to mercury in fish have not been explored adequately (e.g. Rasmussen, 1994). The collections presented here were obtained from a wide geographic range of settings in four different types of bedrock, although most were from areas of sedimentary rock. Surface rocks and sediments are more difficult to evaluate than bedrock because northern Canada was glaciated until a few thousand years ago and surface materials have been moved.

When a local source of contamination with mercury does exist, it is clear that it can have a dramatic effect on the levels of mercury in the fish. For example, fish from Giauque Lake have very high levels of mercury as a result of the operations of a gold mine where mercury was used for a time to extract gold. Mine tailings leaked into the lake (Moore et al., 1978; Moore and Sutherland, 1980; Lockhart et al., 2000) and have been the subject of recent cleanup operations.

Over the past decades we have become aware that mercury is dispersed widely through the air and that the amount of mercury in the air has been increasing (Slemr and Langer, 1992). This awareness of hemispheric or planetary dispersal of mercury has opened a third possibility in addition to local geology and local polluting activities, namely atmospheric fallout of mercury derived from sources outside the watersheds. Air samples from northern Canada consistently contain measurable quantities of mercury (e.g. Schroeder et al., 1998). Samples of snow taken from sea ice across a range of arctic coastal communities also contained measurable amounts of mercury (Lu et al., 2001). However, the presence of mercury in the air or snow is not definitive evidence that its sources are anthropogenic since there is natural cycling of mercury between the air and the surface. Human activities have contributed significantly to the amounts of mercury circulating in air (e.g. Nriagu and Pacyna, 1988). The fate of atmospheric mercury is still under study, but processes are becoming understood by which gaseous mercury (Hg^0) in air can be oxidized to species that are deposited with snow, notably at polar sunrise, and which may then become biologically available (Scott, 2001; Lindberg et al., 2002). Recent studies (Kirk and St. Louis, 2004; Steffen et al., 2005) suggest that two thirds or more of the Hg (II) species deposited during Mercury Depletion Events (MDEs) is reduced back to Hg (0) and subsequently released back into atmosphere. However, Stern and Macdonald (2005) reported a transient rise in *C. hyperboreus* CH_3Hg concentration during peak snow melt in the Chukchi Sea which seems to point to the mercury accumulated in snow during MDEs.

2. Methods

2.1. Fish samples

This work summarizes data from a number of independent studies. Some fish were obtained by experimental netting to assess lakes for their potential to yield fish of high quality. Some were obtained as sub-samples from commercial catches. Some were obtained in research studies or fish stock surveys. Generally fish were obtained by gill-netting but sometimes angling or trap-netting was used. In most instances a section of dorsal muscle was sealed in a plastic bag, frozen and sent to the Freshwater Institute in Winnipeg for analysis but occasionally fish were supplied whole for subsequent sub-sampling in the laboratory. The level of mercury in muscle usually correlated statistically with length and age. Measurements of the length and weight of most of the fish were taken but we have ages for fewer than half of them. Many of these fish were taken to test their suitability as food for people; hence the size range was typically restricted to those most desired for subsistence human food.

Table 1 lists the freshwater locations where fish were obtained. A web site established by Natural Resources Canada lists geographical names in Canada and supplies a unique five-letter code for each named location (http://geonames.nrcan.gc.ca/index_e.php). These five-letter codes have been included in Table 1 as unambiguous descriptors of each named location. Some lakes have not been assigned official names and they do not appear in the list by Natural Resources Canada. However, they often have unofficial names recognized locally. In those instances the name lacks official recognition and is described as 'local' in Table 1. With large geographic features like rivers or large lakes or the ocean, a single five-letter code may apply to a huge area. In those instances, when the intent of

Table 1
Locations where samples of fish were obtained for determinations of mercury

Location/Lake	Prov/Terr	NRCan no.	Latitude north (dec deg)	Longitude west (dec deg)	Type of bedrock
à Jacques	NT	LALVS	66.17	127.40	Sedimentary
Aishihik	YT	KAABF	61.43	137.25	Sedimentary
Amituk (local)	NT		75.48	93.82	Sedimentary
Atlin	YT	KAAGK	60.00	133.83	Intrusive
Aubry	NT	LABPX	67.40	126.45	Sedimentary
Baker	NU	OABNQ	64.17	95.50	Sedimentary
Baker Foreland (local)	NU		62.92	90.82	Sedimentary
Bandy	NT	LACAN	65.27	126.50	Sedimentary
Basler	NT	LACFW	63.95	115.97	Sedimentary
Belot	NT	LACPG	66.88	126.27	Sedimentary
Bennett	YT	KAAMN	60.08	134.86	Volcanic
Bonanza Creek	YT	KAARL	64.05	139.42	Sedimentary
Bovie	NT	LADMZ	60.17	122.93	Sedimentary
Buchanan	NU	OACUG	79.47	87.67	Sedimentary
Burnt	NT	LAEAB	67.43	128.17	Sedimentary
Byron Bay	NU	OACYI	68.92	108.50	Sedimentary
Cambridge Bay	NU	OADAE	69.05	105.12	Sedimentary
Campbell	NT	LAEHM	68.22	133.45	Sedimentary
Canyon	YT	KABAE	61.13	137.01	Intrusive
Carcajou	NT	LAEMC	67.28	128.67	Sedimentary
Chesterfield Inlet	NU	OADJS	63.34	90.70	Sedimentary
Cli	NT	LAFBS	61.98	123.30	Sedimentary
Coal	YT	KABHQ	60.49	135.16	Sedimentary
Colville	NT	LAFGR	67.17	126.00	Sedimentary
Corbett Inlet	NU	OADUO	62.47	92.33	Sedimentary
Cumberland Sound	NU	OAEAQ	65.17	65.50	Sedimentary
Dease Strait	NU	OAEFG	68.83	107.50	Sedimentary
Deep	NT	LAGCI	61.21	120.91	Sedimentary
Dubawnt	NU	OAUHG	63.13	101.47	Metamorphic
Ekali (local)	NT		61.29	120.58	Sedimentary
Ekalluk River	NU	OAFAC	69.40	106.30	Sedimentary
Ellice River	NU	OAFCR	68.03	103.97	Intrusive
Faber	NT	LAHUR	63.93	117.25	Intrusive
Ferguson	NU	OAFOH	69.42	105.25	Sedimentary
Ferguson River	NU	OAFOJ	62.05	93.33	Intrusive
Fire	YT	KACCK	61.20	130.55	Sedimentary
Firth River	YT	KACCS	69.55	139.53	Sedimentary
Foggy Bay	NU	OAFTW	68.28	104.78	Sedimentary
Fork	NT	LAIJT	60.88	111.08	Intrusive
Fox	YT	KACHF	61.23	135.47	Volcanic
Francis	YT	KACHP	63.43	135.66	Sedimentary
Gargan (local)	NT		61.25	120.37	Sedimentary
Garry	NU	OAGDS	65.97	100.30	Metamorphic
Giauque	NT	LAJAD	63.18	113.85	Sedimentary
Gordon	NT	LAJHI	63.08	113.18	Sedimentary
Gore Bay	NU	OAGKM	66.32	84.40	Metamorphic
Grainger River	NT	LAJJQ	61.13	123.07	Sedimentary
Gray	NT	LAJMM	61.87	108.25	Metamorphic
Great Bear	NT	LAJMV	65.83	120.75	Sedimentary
Great Slave all	NT	LAJNH	61.50	114.00	Sedimentary
Great Slave 1E	NT	LAJNH	61.00	116.00	Sedimentary
Great Slave AR1W	NT	LAJNH	61.00	116.00	Sedimentary

Table 1 (*continued*)

Location/Lake	Prov/Terr	NRCan no.	Latitude north (dec deg)	Longitude west (dec deg)	Type of bedrock
Great Slave AR2	NT	LAJNH	61.50	113.50	Sedimentary
Great Slave AR3	NT	LAJNH	61.00	113.83	Sedimentary
Great Slave AR4	NT	LAJNH	62.00	112.00	Sedimentary
Great Slave AR5	NT	LAJNH	62.17	114.50	Sedimentary
Great Slave Fort Resolution	NT	LAJNH	61.17	113.67	Sedimentary
Great Slave Bog Narrows	NT	LAJNH	61.17	113.67	Sedimentary
Great Slave Lutsel K'e	NT	LCABE	62.41	110.74	Sedimentary
Great Slave Resolution Bay	NT	LAUDB	61.10	113.87	Sedimentary
Great Slave Windy Bay	NT	LBAFI	61.35	115.95	Sedimentary
Hall	NU	OAGTT	68.68	82.28	Sedimentary
Hall Beach	NU	OAGTH	68.79	81.24	Sedimentary
Hanson	YT	KACSN	64.01	135.35	Sedimentary
Hay River (at Vale Island)	NT	LAZHH	60.85	115.77	Sedimentary
Hawk (local)	NU		63.65	90.65	Sedimentary
Hazen	NU	OAHAW	81.80	71.02	Sedimentary
Hidden	NT	LAKLY	66.00	117.85	Intrusive
Hjalmar	NT	LAKOK	61.55	109.42	Sedimentary
Hopedale	NFLD	AAKDE	55.47	60.22	Sedimentary
Hottah	NT	LAKVB	65.07	118.50	Volcanic
Hudson Bay southeast	NU		55.53	77.54	Sedimentary
Island (local name)	NT		66.90	126.58	Sedimentary
Itsi Lakes	YT	KADCR	62.83	130.20	Sedimentary
Jayko River	NU	OASGL	69.57	103.35	Sedimentary
Kagloryuak River	NT	LAMGB	70.28	111.50	Sedimentary
Kakisa	NT	LAMHA	60.93	117.72	Sedimentary
Kam	NT	LAMHZ	62.42	114.40	Volcanic
Kaminak	NU	OAIND	62.17	95.00	Intrusive
Kaminuriak (Qamanirjuaq)	NU	OAINF	62.95	95.77	Metamorphic
Kangiqsujuaq (sea run)	QU	EJNER	61.60	71.96	Volcanic
Kangiqsujuaq (land locked)	QU	EJNER	61.60	71.96	Volcanic
Kangirsuk	QU	EKQQU	60.02	70.03	Volcanic
Kelly	NT	LAMQE	65.39	126.25	Sedimentary
Klondike River	YT	KADJR	64.05	139.44	Sedimentary
Kloo	YT	KADJT	60.95	137.86	Metamorphic
Kluane	YT	KADKD	61.25	138.72	Metamorphic
Koksoak River	QU	EFVTB	57.53	68.17	Metamorphic
Kugaluk River	NT	LANJD	69.13	130.97	Sedimentary
Kusawa	YT	KADLN	60.35	136.37	Intrusive
Kuujjua River	NT	LANLF	71.26	116.80	Intrusive
Kuuk River	NT	LANLG	70.57	112.63	Sedimentary
Laberge	YT	KADLW	61.18	135.20	Sedimentary
Lake 100	NT		69.32	138.87	Sedimentary
Lauchlan River (Byron Bay)	NU	OAJPC	68.95	108.53	Sedimentary
Leland	NT	LANVQ	60.00	110.98	Intrusive
Liard River at Upper Liard	YT	KAGZA	60.05	128.90	Sedimentary
Liard River (NT)	NT	KADQD	61.85	121.30	Sedimentary
Little Atlin	YT	KADRG	60.25	133.96	Sedimentary
Little Doctor	NT	LAOBU	61.88	123.27	Sedimentary
Little Salmon	YT	KADSW	62.18	134.67	Sedimentary
Loche	NT	LAODT	65.32	125.67	Sedimentary
Loon	NT	LAOHX	66.62	128.72	Sedimentary
Mackenzie Delta	NT	LAOPQ	69.25	134.13	Sedimentary

(continued on next page)

Table 1 (*continued*)

Location/Lake	Prov/Terr	NRCan no.	Latitude north (dec deg)	Longitude west (dec deg)	Type of bedrock
Mackenzie River at Arctic Red River	NT	LABKG	69.44	133.74	Sedimentary
Mackenzie River at Delta	NT	LAOQD	69.25	134.13	Sedimentary
Mackenzie River at Horseshoe Bend	NT	LAKUA	68.22	134.27	Sedimentary
Mackenzie River at Fort Good Hope	NT	LAIKL	66.26	128.63	Sedimentary
Mackenzie River at Little Chicago	NT	LAOBK	67.20	130.25	Sedimentary
Mackenzie River at Ramparts	NT	LATTO	66.22	128.87	Sedimentary
Mackenzie River at Canyon Creek	NT	LAEKQ	65.21	126.54	Sedimentary
Mackenzie River at Oscar Creek	NT	LARUO	65.43	127.45	Sedimentary
Mackenzie River at Stewart Creek	NT	LAWUL	65.20	126.65	Sedimentary
Mackenzie River at Fort Simpson	NT	LAOQD	61.87	121.38	Sedimentary
Maguire	NT	LAOSC	63.22	113.90	Sedimentary
Maguse	NU	OAKFN	61.62	95.17	Sedimentary
Mahony	NT	LAOSI	65.50	125.33	Sedimentary
Makkovik	NFLD	AANQV	54.83	59.63	Intrusive
Manuel	NT	LAOWT	66.97	128.90	Sedimentary
Margaret Lake	YT	KADZG	65.35	134.50	Sedimentary
Marian River	NT	LAOYE	63.07	116.35	Intrusive
Marsh	YT	KADZU	60.45	134.30	Sedimentary
Mattberry	NT	LAPCU	64.08	115.90	Sedimentary
Mayo	YT	KAEBE	63.75	135.03	Sedimentary
McCrea	NT	LAPGB	63.55	112.58	Intrusive
McEwan (local name)	NT		60.82	119.95	Sedimentary
McGill	NT	LAPHE	61.30	121.01	Sedimentary
Mirror	NT	LAPUT	64.85	126.92	Sedimentary
Muskeg River	NT	LAQHC	60.32	123.35	Sedimentary
Nahanni River	NT	LCAVJ	61.60	125.68	Sedimentary
Nain	NFLD	AAPBP	56.53	61.68	Sedimentary
Naloagyuk River (local name)	NT		70.22	112.22	Sedimentary
Nares	YT	KAENW	60.16	134.66	Sedimentary
Nettilling	NU	OALOQ	66.48	70.33	Intrusive
Nonacho	NT	LARBC	61.98	109.47	Sedimentary
Old Crow Flats	YT	KAEVH	68.17	140.17	Sedimentary
Old Crow River	YT	KAEVL	67.58	139.80	Sedimentary
P&N Lake (local name)	NU		63.65	90.65	Sedimentary
Pangnirtung Fiord	NU	OAMLM	66.12	65.63	Intrusive
Parker	NT	LASBW	64.27	115.27	Volcanic
Paulatuk	NT	LASFJ	69.35	124.07	Sedimentary
Peel River (McPherson)	NT	LAIKT	67.44	134.88	Sedimentary
Peter	NU	OAMTR	63.13	92.80	Metamorphic
Pistol Bay	NU	OAMYM	62.42	92.68	Sedimentary
Pitz	NU	OAMZF	63.95	96.53	Sedimentary
Porcupine River	YT	KAFEG	67.58	139.83	Sedimentary
Povirnituq	QU	EPWSV	60.03	77.28	Sedimentary
Quaqtaq	QU	EJNEV	61.03	69.62	Metamorphic
Quartzite	NU	OANOR	62.37	94.53	Volcanic
Quiet	YT	KAFHP	61.08	133.08	Intrusive
Rae Lakes	NT	LATSB	64.08	117.28	Intrusive
Rankin Inlet	NU	OANSI	62.82	92.08	Sedimentary
Reade (local)	NT		60.90	119.92	Sedimentary
Resolute Lake	NU	OANXC	74.68	94.95	Sedimentary
Rorey	NT	LAULX	66.92	128.40	Sedimentary
Ross	NT	LAUMV	62.68	113.25	Sedimentary
Sandy Point	NU	OAOKN	61.73	92.25	Sedimentary
Sanguez (local)	NT		61.25	120.47	Sedimentary

Table 1 (*continued*)

Location/Lake	Prov/Terr	NRCan no.	Latitude north (dec deg)	Longitude west (dec deg)	Type of bedrock
Saputing	NU	OAOLK	70.70	85.42	Metamorphic
Saturday Night (local)	NU		63.65	90.65	Sedimentary
Schultz	NU	OAOPD	64.75	97.50	Sedimentary
Schwatka	YT	KAFTH	60.68	135.03	Sedimentary
Sekulmun	YT	KAFVA	61.43	137.55	Sedimentary
Sibbeston	NT	LAVSR	61.75	122.75	Sedimentary
Simpson	YT	KAFZA	60.73	129.24	Sedimentary
Slave River	NT	LAWBJ	61.30	113.65	Sedimentary
Slemon	NT	LAWBV	63.22	116.03	Sedimentary
Small (I)	NU		61.83	93.67	Volcanic
Sophia	NT	OAPJA	75.10	93.60	Sedimentary
South MacMillan River	YT	KAGED	63.05	133.30	Sedimentary
South Nahanni River	NT	LAWLJ	61.05	123.35	Sedimentary
Sparks	NT	LAWMY	61.20	109.67	Sedimentary
Sparrow	NT	LAWND	62.62	113.63	Sedimentary
Ste Therese	NT	LAWTZ	64.63	121.58	Sedimentary
Steep Bank Bay	NU	OAPQE	63.58	91.63	Sedimentary
Stony Point	NU	OAPSJ	63.85	92.80	Sedimentary
Surrey	NU	OAPXJ	69.67	107.22	Sedimentary
Surrey Riv/Palikyuak River	NU		69.45	107.22	Sedimentary
Sylvia Grinell River	NU	OAQAF	63.73	68.57	Sedimentary
Tagatui	NT	LAXJA	64.96	125.23	Sedimentary
Tagish	YT	KAGMK	60.15	134.39	Sedimentary
Tagniuknitak	NU		69.25	102.08	Sedimentary
Taltson River	NT	LAXLO	61.40	112.75	Intrusive
Tasiujaq	QU	EJLMJ	58.70	69.93	Sedimentary
Tathlina	NT	LAXOY	60.55	117.53	Sedimentary
Tatlmain	YT	KAGOH	62.62	135.98	Sedimentary
Tessikakjuak	NU	OAQIZ	64.30	76.77	Volcanic
Teslin	YT	JBAYC	60.23	132.92	Volcanic
Thekulthili	NT	LAXVY	61.00	110.10	Sedimentary
Thirty Mile	NU	OAQKL	63.60	96.50	Intrusive
Thirty Mile River	NU		69.17	107.07	Sedimentary
Thistlethwaite	NT	LAXWX	63.17	113.57	Sedimentary
Thompson	NT	LAXYB	62.62	113.50	Sedimentary
Travaillant	NT	LAYJY	67.70	131.78	Sedimentary
Tree River	NU	OAQTN	67.68	111.88	Sedimentary
Trout	NT	LAYNI	60.58	121.32	Sedimentary
Tsetso	NT	LAYOK	61.85	123.02	Sedimentary
Tulemalu	NU	OAOXO	62.97	99.42	Intrusive
Tunago	NT	LAYSN	66.32	125.83	Sedimentary
Turton	NT	LAYVL	65.81	126.95	Sedimentary
Wagenitz	NT	LAZMD	63.05	113.87	Sedimentary
Watson	YT	KAHDI	60.10	128.82	Sedimentary
Wellington Bay	NU	OARSH	69.33	106.58	Sedimentary
Willow	NT	LBADP	62.17	119.13	Sedimentary
Wilson River	NU	OARZP	62.32	93.05	Sedimentary
Yathkyed	NU	OASDE	62.67	97.97	Metamorphic
Yaya (local)	NT		69.20	134.63	Sedimentary
Yeltea	NT	LBAMQ	66.92	129.37	Sedimentary
Yukon River (Takhini)	YT	KALHD	60.45	136.13	Intrusive

Province/Territory codes are: YT, Yukon Territory; NT, Northwest Territory; NU, Nunavut; QU, Quebec; NFLD, Newfoundland (Labrador). The 5-letter code following Prov/Terr is from the Natural Resources Canada database on geographic names in Canada. When no NRCan code is given, the name is known locally but has not been recognized formally.

the original source was clear, sites were identified by their local names with latitude and longitude coordinates from the original source.

2.2. Mercury determination

Most of the samples reported here were analyzed in the laboratories of the Freshwater Institute, Department of Fisheries and Oceans, in Winnipeg, Manitoba using minor modifications of methods described previously (Armstrong and Uthe, 1971; Hendzel and Jamieson, 1976). A small portion of dorsal muscle (0.2–1 g) adjacent to the dorsal fin was used for analysis. Tissue was thawed partially and external surfaces were cut away to yield the analytical sample. This was digested with a sulphuric/nitric acid mixture at 80–90 °C for 2 h; potassium permanganate solution was added and the digest was allowed to stand for several more hours. This procedure oxidized any organic mercury to inorganic mercury; other organic material was mineralised. Hydrogen peroxide was then added to the digest to decompose excess permanganate. The samples were analyzed for total mercury by Cold Vapour Atomic Absorption Spectroscopy (CVAAS) at the 253.7 nm mercury line which requires mercury to be in the elemental state. This was accomplished by the addition of a reductant, stannous chloride or sulphate. In some instances analyses were performed by other laboratories; the original sources usually explain what laboratory and methods performed the analyses.

The Freshwater Institute laboratories quality control procedures include the analyses of known analytical standards and certified reference tissue samples. Laboratory staff have participated in numerous internal and external quality assurance programs for many years including those of the Northern Contaminants Program (Canada) and the National Oceanographic and Atmospheric Administration, USA. Staff at the laboratory have organized and conducted interlaboratory calibrations (Wagemann and Armstrong, 1988). With the exception of one period of several weeks while the roof of the laboratory building was replaced, quality control results were within accepted ranges.

2.3. Data storage and analysis

The data produced by Freshwater Institute laboratories after 1971 are stored in several electronic databases. These files contain information on mercury in muscle of about 8400 fish from northern Canadian sites. Several other databases on mercury in fish exist, notably those associated with hydroelectricity developments in northern Manitoba and Quebec, with sports fisheries in individual provinces and with mercury in human foods. Those data were not examined because the intent here was to examine results from fish from the Yukon Territory, the Northwest Territory and Nunavut. Raw data from 500 additional northern fish were available from government reports and those data were entered into a separate database and then combined with data from the Freshwater Institute. The Yukon Contaminants Database was used for data on Yukon fish not already included in any of the other databases. Data were retrieved from each database with the restriction that positive values were recorded both for mercury in muscle and for length for each individual fish. When duplicate samples of the same fish were analyzed, the mean of the duplicates was taken as the final result. Data were then read into SAS software for statistical calculations.

Data have been tabulated in several ways. The arithmetic means of concentrations of mercury in muscle and of fish lengths were calculated for each species and collection using PROC MEANS of SAS. The arithmetic mean is the statistic used by human health agencies to calculate amounts suitable for consumption and it is appropriate for that purpose. Data on fish from Giauque Lake were excluded from calculations because of the known local source of mercury there and the unusually high levels in the fish.

The fish varied relatively little in length but even with the restricted ranges mercury in muscle usually correlated positively with fish length. An effort was made to adjust mercury levels to a constant length by calculating the regression equation for (natural log) mercury on length using PROC REG of SAS for each sample of fish of the 6 major species. The equations obtained were solved for an arbitrary length approximating the mean for all the fish of a given species from all locations. The length-adjusted means were also tabulated and used to compare mercury levels among different sites.

Some of the sites were sampled on two or more occasions over approximately 30 years. For comparisons of results from a single site sampled on different occasions, an analysis of covariance by PROC GLM of

SAS software was used taking length as a covariate. The slopes of regressions of ln(mercury) on length were compared initially by including a mercury*-length interaction term. If that interaction term was not significant at $p=0.05$, then the slopes of the regressions were taken to be parallel. In that instance, the analysis was run again without the interaction term and that result was used to determine whether the length-adjusted mercury levels from samples taken at different times were different. In several instances, there were three or more different sampling times, and in those cases, if the effect of year of sampling was significant, the differences among pairs of sampling times were identified using the LSMEANS option of PROC GLM. In instances where the interaction between length and year was significant at $p=0.05$, indicating that slopes of the regression lines were not parallel, no conclusion was reached regarding differences.

Geological maps were prepared from data published on the compact disc "Geological Map of Canada, Map/carte (ver 1.0; Jan. 97)". Maps were displayed using MapInfo software. Each collection site was characterized by its geographic coordinates and by its most recent length-adjusted mean of mercury levels in each species. The software plotted the points at the appropriate coordinates and placed a color-coded dot at each location. The colors were selected based on the following ranges in concentrations of mercury: <0.2 μg g^{-1}, green dot; 0.2–0.499 μg g^{-1}, yellow dot; >0.5 μg g^{-1}, red dot. The software was used also to categorize each lake location by its bedrock type. Lakes or other collection sites were identified as single points of latitude and longitude. MapInfo software associated each point with the polygon of rock type that contained that point. A large geographic feature like a big lake or river might cover more than one rock type but it would be represented by the type of rock present at the single point.

3. Results and discussion

The species of greatest interest as components of subsistence human food, and the species for which

Table 2
Species obtained and number of samples of each with information on body length and mercury in muscle in the same individual

Species	*N*	Length (mm), arithmetic mean ± S.D.	Concentration of mercury in muscle (μg g^{-1}) wet weight, arithmetic mean ± S.D.
Arctic char	741	504 ± 191	0.115 ± 0.237
Arctic grayling	109	331 ± 98	0.053 ± 0.045
Atlantic salmon	24	550 ± 158	0.049 ± 0.035
Broad whitefish	202	483 ± 42	0.054 ± 0.032
Brook trout	22	317 ± 106	0.106 ± 0.050
Burbot	315	601 ± 121	0.210 ± 0.135
Chinook salmon	1	786	0.090
Chum salmon	8	610 ± 41	0.067 ± 0.012
Cisco	135	282 ± 78	0.108 ± 0.094
Dolly varden	1	450	0.004
Fourhorn sculpin	3	228 ± 19	0.209 ± 0.094
Greenland turbot	5	363 ± 36	0.106 ± 0.026
Inconnu	211	661 ± 134	0.153 ± 0.105
Lake trout	1855	556 ± 110	0.384 ± 0.351
Lake whitefish	1917	429 ± 63	0.111 ± 0.096
Least cisco	3	194 ± 14	0.038 ± 0.002
Longnose sucker	81	428 ± 70	0.108 ± 0.084
Northern pike	1169	613 ± 119	0.378 ± 0.298
Pacific herring	25	300 ± 15	0.031 ± 0.021
Round whitefish	41	353 ± 94	0.090 ± 0.193
Sculpin (unspecified)	25	286 ± 21	0.137 ± 0.037
Sucker (unspecified)	22	429 ± 53	0.212 ± 0.101
Walleye	868	438 ± 69	0.470 ± 0.349
White sucker	96	444 ± 51	0.099 ± 0.081
Whitefish (unspecified)	95	384 ± 43	0.105 ± 0.072

Table 3
Arithmetic mean concentrations of total mercury (μg g^{-1}) in dorsal muscle of northern fish, arithmetic mean length (mm), number of samples in parentheses, and antilog of length adjusted geometric mean concentration of mercury in muscle

Location	Lake trout	Lake whitefish	Northern pike	Walleye	Arctic char	Burbot	Other species[1]
à Jacques 1994		0.16, 454 (2)	0.44, 660 (17) [0.34]	0.98, 515 (11) [0.78]			
à Jacques 1995		0.30, 416 (18) [0.27] na	0.59 654 (13) [0.54] ↑	1.00, 493 (20) [0.61] in			
Aishihik 1977	0.26, 514 (3) [0.25]	0.07, 408 (5) [0.09]					0.21, 653 (2) H
Aishihik 1991	0.09, 523 (10) [0.09] in	0.04, 451 (10) [0.04] ↔	0.13, 637 (9) [0.10]				
Amituk, 1989					0.83, 390 (27) [1.60]		
Amituk 1992					0.57, 297 (27) [1.78] ↔		
Arctic Red River, 2000							0.04, 473 (10) K 0.15, 856 (10) B
Atlin, 1977	0.11, 416 (6) [0.13]						
Atlin, 1993	0.26, 793 (4) [0.14]						
Atlin, 1998	0.20, 499 (11) [0.15] in						
Aubry, 1999	0.25, 577 (88) [0.23]	0.05, 507 (14) [0.02]				0.11, 558 (8) [0.11]	
Baker, 1995	0.37, 644 (5) [0.18]]				0.05, 601 (6) [0.04]		
Baker Foreland, 1989					0.05, 618 (5) [0.01]		
Bandy, 2000			0.32, 591 (19) [0.43]				0.23, 325 (19) A
Basler, 1981	0.70, 604 (10) [0.22]						
Basler, 1982	0.34, 601 (15) [0.22] ↔		0.45, 719 (5) [0.33]				
Basler, 1983	0.22, 576 (6) [0.17] ↔		0.42, 748 (5) [0.08] ↔				
Beaufort Sea, 1981							0.03, 300 (25) R
Belot, 1993	0.14, 621 (19) [0.11]						
Belot, 1999	0.21, 618 (54) [0.17] ↑					0.13, 517 (6) [0.18]	
Bennett, 1977	0.18, 599 (5) [0.16]	0.06, 462 (5) [0.04]					0.02, 254 (1) H 0.06, 399 (4) I
Bonanza Creek, 1977							0.14, 231 (1) H
Bovie, 1988		0.15, 513 (5) [0.18]		0.18, 362 (5) [0.13]			
Buchanan, 1991					0.04, 520 (19) [0.03]		
Burnt, 1989		0.03, 447 (2)					
Byron Bay, 1984					0.05, 724 (4) [0.04]		
Byron Bay, 1988					0.04, 711 (5) [0.05] ↔		
Byron Bay, 1989					0.03, 674 (5) [0.03]* ↔		
Byron Bay, 1990					0.03, 607 (5) [0.06] ↔		
Cambridge Bay, 1977					0.06, 538 (5) [0.08]		
Cambridge Bay, 1992					0.04, 688 (10) [0.04] ↓		
Cambridge Bay, 1993					0.06, 756 (5) [0.08]* ↔		
Campbell, 1992							0.07, 454 (8) K
Canyon, 1991	0.16, 415 (6) [0.17]						
Carcajou 1978	0.56, 528 (2)	0.15, 480 (5) [0.05]	0.44, 660 (1)				
Chesterfield Inlet, 1977					0.02, 588 (5) [0.01]		
Chesterfield Inlet, 1984					0.04, 563 (6) [0.03] ↑		
Chesterfield Inlet, 1989					0.04, 591 (5) [0.04] ↔		
Chesterfield Inlet, 1992					0.05, 597 (10) [0.02] ↔		
Chesterfield Inlet, 1993					0.04, 618 (5) [0.05] ↔		
Chesterfield Inlet, 1994					0.04, 618 (5) [0.02] ↔		
Cli, 1983	0.39, 477 (5) [0.15]						
Cli, 1996	0.88, 485 (49) [0.95] ↑	0.09, 502 (36) [0.06]				0.89, 500 (1)	
Cli, 1999	0.39, 440 (4) [0.21] ↔	0.05, 450 (5) [0.05] ↔	0.35, 660 (5) [0.28]				
Coal, 1995	0.10, 375 (4) [0.66]						
Coal, 1999	0.06, 332 (12) [0.21] ↔						
Colville, 1993	0.31, 562 (10) [0.27]	0.02, 455 (24) [0.02]					
Colville, 1999	0.20, 512 (238) [0.21] ↔	0.04, 447 (30) [0.02] ↔	0.24, 630 (7) [0.23]			0.12, 595 (18) [0.11]	
Corbett Inlet					0.06, 645 (5) [0.03]		
Cumberland Sound							0.11, 363 (5) W
Dease Strait, 1977	0.30, 511 (7) [0.37]				0.04, 525 (10) [0.03]		

Deep, 2000		0.25, 444 (28) [0.24]	0.67, 584 (6) [0.74]	1.11, 448 (4) [1.10]			0.26, 155 (1) A
Dubawnt, 1971	0.42, 520 (28) [0.42]	0.11, 554 (3) [0.26]					
Ekali, 1996		0.08, 470 (20) [0.05]	0.30, 578 (7) [0.31]	0.26, 410 (14) [0.29]			0.12, 338 (20) A
Ekalluk River, 1990					0.03, 617 (5) [0.06]		
Ellice River, 1977	0.13, 525 (4) [0.10]	0.05, 468 (24) [0.04]			0.42, 513 (3) [0.18]		
Ellice River, 1984					0.05, 651 (6) [0.04] ↓		
Ellice River, 1988					0.03, 624 (5) [0.02] ↓		
Ellice River, 1989					0.04, 593 (4) [0.03] ↔		
Ellice River, 1990					0.03, 606 (5) [0.03] ↔		
Ellice River, 1993					0.08, 670 (5) [0.05] ↑		
Ellice River, 1994					0.04, 651 (5) [0.02] ↓		
Faber, 2000	0.35, 539 (10) [0.36]	0.10, 481 (10) [0.11]					
Ferguson, 1971	1.04, 513 (10) [1.11]	0.13, 406 (1)					
Ferguson River, 1992					0.04, 663 (5) [0.01]		
Ferguson River, 1994					0.04, 618 (5) [0.004] ↑		
Firth River, 1977							0.05, 334 (5) H
Foggy Bay, 1993					0.08, 640 (5) [0.07]		
Fork, 1992			0.26, 314 (5) [0.81]				
Fox, 1977		0.19, 401 (7) [0.18]				0.48, 604 (1)	0.09, 359 (1) S
Fox, 1992	0.51, 530 (5) [0.41]	0.28, 455 (1) na				0.56, 661 (3) [0.34]	
Fox, 1993	0.36, 407 (12) [0.30] ↔	0.22, 419 (9) [0.22] ↔	0.51, 718 (6) [0.28]			0.30, 488 (4) [0.14] ↔	
Fox, 1998	0.40, 400 (2)						
Francis, 1977	0.13, 495 (3) [0.11]						0.11, 411 (2) I
Fire, 1997	0.15, 549 (7) [0.13]					0.03, 340 (1)	0.004, 450 (1) Z 0.025, 334 (7) H
Gargan, 1996		0.10, 482 (20) [0.06]	0.59, 668 (2)				
Garry, 1976	0.76, 533 (8) [0.73]						
Giauque, 1977	3.80, 571 (31) [2.55]	1.13, 480 (1) na	1.75, 584 (27) [1.58]				1.37, 498 (9) I 1.22, 467 (35) S
Giauque, 1982	2.79, 550 (2)↔						
Giauque, 1983	2.29, 443 (7) [2.85] ↔						
Giauque, 1992	2.31, 532 (30) [2.36] ↓	0.87, 506 (30) [0.58]					0.91, 474 (19) I in 0.40, 420 (14) S ↓
Gordon, 1981		0.03, 334 (5) [0.04]					
Gore Bay, 1993					0.02, 634 (5) [0.02]		
Grainger River, 1977			0.37, 616 (25) [0.33]	0.46, 468 (15) [0.39]			
Gray, 1986	0.53, 501 (12) [0.62]	0.18, 465 (15) [0.15]	0.77, 643 (3) [0.56]				
Great Bear, 1978	0.10, 565 (5) [0.10]						0.02, 304 (25) A
Great Bear, 1979	0.20, 618 (25) [0.13] ↑		0.36, 728 (25) [0.30]				
Great Slave, Bog Narrows, 2001	0.18, 550 (4) [0.20]						
Great Slave, Fort Resolution, 1999			0.24, 719 (10) [0.17]			0.10, 616 (5) [0.10]	
Great Slave, Fort Resolution, 2000	0.23, 655 (10) [0.14]		0.21, 654 (10) [0.21]↔			0.12, 673 (5) [0.13] ↔	
Great Slave, Fort Resolution, 2001	0.24, 594 (6) [0.21] ↔		0.30, 731 (10) [0.18]↔			0.20, 677 (6) [0.18] ↑	
Great Slave, Lutsel K'e, 1995	0.12, 665 (8) [0.09]	0.07, 566 (5) [0.09]					
Great Slave, Lutsel K'e, 1999	0.14, 704 (10) [0.13] ↔		0.20, 706 (10) [0.13]			0.08, 565 (6) [0.08]	
Great Slave, Lutsel K'e, 2000	0.26, 614 (10) [0.15] ↑		0.22, 730 (10) [0.15]↔			0.12, 479 (10) [0.26] ↑	
Great Slave, Lutsel K'e, 2001	0.15, 592 (10) [0.14] ↓		0.19, 665 (10) [0.18]↔			0.12, 534 (10) [0.12]↔	
Great Slave, Windy Bay, 1995						0.09, 597 (5) [0.10]	
Great Slave, Windy Bay, 2000	0.11, 601 (9) [0.10]						
Great Slave Area 1E, 1989	0.20, 641 (5) [0.20]						
Great Slave Area 1E, 1990	0.22, 546 (5) [0.21] ↔		0.33, 474 (5) [0.29]	0.50, 397 (5) [0.35]			
Great Slave All, 1975		0.06 ± 404 (86) [0.06]				0.16, 610 (1) na	
Great Slave All, 1976		0.07, 397 (29) [0.05]↔	0.14, 610 (5) [0.14]				0.05, 396 (7) G
Great Slave All, 1977		0.04, 403 (66) [0.05] ↓	0.21, 592 (47) [0.19]↑	0.28, 428 (35) [0.27]		0.16, 660 (1) na	0.07, 674 (18) B 0.03, 326 (14) S 0.06, 435 (3) G

(continued on next page)

Table 3 (*continued*)

Location	Lake trout	Lake whitefish	Northern pike	Walleye	Arctic char	Burbot	Other species[1]
Great Slave All, 1978		0.07, 418 (26) [0.07] ↑	0.07, 418 (26) [0.07] ↑	0.28, 591 (25) [0.27]			0.04, 396 (25) H 0.10, 643 (9) B ↑
Great Slave All, 1979	0.11, 573 (24) [0.11]						
Great Slave All, 1988				0.33, 413 (6) [0.25]	0.03, 643 (5) [0.02]		0.11, 530 (5) B ↔
Great Slave All, 1989		0.14, 450 (14) [0.07] ↔					
Great Slave All, 1992			0.32, 688 (5) [0.33] ↔				0.07, 481 (5) B ↔
Great Slave All, 1993				0.22, 470 (5) [0.20]			
Great Slave All, 1994						0.17, 642 (5) [0.19]	
Great Slave All, 1996						0.16, 514 (5) [0.16] ↔	
Great Slave All, 1997				0.16, 473 (6) [0.14]			
Great Slave All, 1998				0.25, 362 (6) [0.13] in			
Great Slave AR1W, 1988	0.19, 654 (10) [0.14]						
Great Slave AR1W, 1989	0.08, 515 (5) [0.05] ↔		0.29, 616 (5) [0.26]				
Great Slave AR1W, 1990	0.15, 648 (3) [0.09] ↔		0.36, 676 (5) [0.33] ↔	0.35, 459 (5) [0.38]*			
Great Slave AR2, 1988		0.04, 416 (5) [0.05]					
Great Slave AR2, 1989	0.13, 592 (5) [0.13]*		0.33, 510 (4) [0.36]				
Great Slave AR2, 1990	0.06, 505 (5) [0.05]		0.29, 475 (5) [0.56]* ↔	0.43, 620 (1)			
Great Slave AR2, 1992	0.23, 677 (6) [0.09] in		0.36, 623 (6) [0.31] ↔			0.15, 538 (6) [0.15]	
Great Slave AR3, 1988		0.04, 408 (5) [0.02]					
Great Slave AR3, 1989	0.19, 626 (5) [0.18]		0.31, 612 (5) [0.28]	0.25, 414 (5) [0.27]			0.14, 360 (5) G
Great Slave, AR3, 1990			0.33, 555 (2)	0.31, 495 (5) [0.05] ↔			
Great Slave AR4, 1989	0.10, 597 (5) [0.09]		0.31, 689 (5) [0.36]	0.21, 471 (5) [0.19]			
Great Slave AR4, 1990	0.12, 580 (5) [0.09] ↔		0.43, 540 (5) [0.60] in	0.21, 453 (5) [0.19] ↔			
Great Slave AR5, 1988	0.12, 569 (10) [0.10]	0.03, 407 (10) [0.01]	0.27, 621 (10) [0.23]	0.37, 512 (10) [0.19]			0.03, 479 (7) B
Great Slave AR5, 1989	0.13, 521 (5) [0.14]		0.20, 457 (5) [0.17] ↔	0.11, 370 (5) [0.13] ↔			
Great Slave AR5, 1990	0.18, 625 (5) [0.11]		0.20, 655 (5) [0.23] ↔	0.24, 473 (5) [0.18] ↔			
Great Slave AR5, 1992	0.17, 688 (6) [0.21] in		0.45, 640 (6) [0.36] ↑				
Great Slave, Resolution Bay, 1996			0.25, 705 (5) [0.23]	0.18, 423 (5) [0.15]		0.08, 580 (5) [0.08]	0.11, 793 (5) B
Hall, 1977	0.47, 683 (2)						
Hall, 1978	0.73, 668 (23) [0.45]				0.04, 642 (25) [0.02]		
Hall Beach, 1992					0.05, 698 (5) [0.05]		
Hanson			0.13, 556 (4) [0.16]				
Hay River, 1984		0.03, 392 (15) [0.03]	0.26, 590 (15) [0.26]	0.23, 406 (13) [0.21]			
Hay River, 1989		0.06, 397 (10) [0.08] ↑	0.32, 604 (21) [0.31] ↑	0.22, 380 (35) [0.25] ↔			
Hay River, 1990		0.08, 381 (30) [0.07] ↑					
Hay River, 1992		0.05, 389 (30) [0.05] ↓	0.30, 633 (30) [0.27] ↔	0.20, 387 (30) [0.16] ↔			
Hawk 1988	0.24, 495 (9) [0.19]						
Hazen, 1990					0.18, 404 (45) [0.26]		
Hidden, 1978	0.32, 462 (6) [0.38]	0.30, 515 (2)				0.17, 500 (2)	0.09, 285 (2) A
Hjalmar 1986	0.76, 675 (11) [0.39]	0.11, 491 (15) [0.05]	0.72, 685 (5) [0.39]				
Hopedale					0.03, 406 (7) [0.04]		
Hottah 1972	0.24, 588 (5) [0.21]	0.04, 501 (5) [0.05]	0.27, 738 (2)				
Hudson Bay, 1992							0.21, 228 (3) Q
Island, 1989		0.34, 580 (1)					
Itsi, 2001	0.09, 503 (5) [0.18]						
Jayko River, 1979	0.52, 836 (3) [0.36]				0.08, 728 (5) [0.03]		
Jayko River, 1984					0.07, 655 (6) [0.06] ↔		
Jayko River, 1989					0.08, 652 (5) [0.06] ↔		
Jayko River, 1990					0.06, 554 (5) [0.11] ↔		
Jayko River, 1993					0.12, 680 (5) [0.07] ↔		
Jayko River, 1994					0.06, 623 (5) [0.08] ↓		
Kagloryuak River, 1989					0.06, 345 (4) [0.05]		
Kakisa, 1977			0.25, 572 (16) [0.27]	0.25, 438 (25) [0.25]			
Kakisa, 1978			0.34, 652 (9) [0.35] ↑				

Kakisa, 1981			0.26, 538 (6) [0.29] ↔	0.25, 285 (28) [0.24] ↔			
Kakisa, 1988				0.38, 406 (5) [0.78] ↑			
Kakisa, 1989				0.42, 397 (5) [0.44] ↔			
Kakisa, 1990				0.30, 357 (5) [0.34] ↔			
Kakisa, 1992				0.45, 416 (6) [0.55] ↑			
Kakisa, 1997			0.35, 400 (6) [0.79] ↑				
Kakisa, 1998			0.24, 415 (6) [0.31] ↓	0.32, 327 (6) [0.08] ↓			
Kam, 1976							0.11, 368 (13) A
Kaminak, 1971	0.99, 436 (5) [1.27]						
Kaminak, 1995/96	0.95, 596 (10) [0.79] ↔						
Kaminuriak 1971	0.74, 495 (12) [0.91]	0.14, 457 (1)					
Kaminuriak 1972	0.65, 646 (59) [0.32] ↓						
Kaminuriak 1975	0.47, 617 (6) [0.33] ↔	0.12, 510 (1)			0.02, 640 (1)		
Kangiqsujuaq 1998 (landlocked)					0.14, 500 (7) [0.14]		
Kangiqsujuaq 1998 (sea run)					0.04, 548 (3) [0.03]		
Kangirsuk 1998					0.03, 460 (15) [0.02]		
Keller (Stephens 95)	0.41 (15)	0.06 (15)	0.45 (1)				
Kelly, 1998	0.48, 598 (30) [0.41]	0.17, 495 (78) [0.15]	0.55, 673 (13) [0.43]			0.38, 598 (5) [0.36]	0.40, 760 (4) B
Klondike River, 1977							0.09, 378 (1) H
Kloo, 1990	0.53, 561 (4) [0.46]	0.11, 320 (5) [0.12]	0.20, 658 (5) [0.19]			0.16, 398 (1)	
Kluane, 1977	0.08, 410 (2)	0.2, 294 (1)					
Koksoak River, 1993/1994	0.37, 541 (8) [0.37]		0.53, 772 (3) [0.43]			0.23, 444 (2)	0.05, 550 (24) C
							0.11, 317 (22) D
							0.14, 286 (25) E
							0.23, 405 (15) F
							0.17, 376 (28) Y
Kugaluk River 1989							0.03, 447 (10) K
Kuujjua River, 1992					0.05, 603 (6) [0.04]		
usawa 1992	0.35, 490 (11) [0.41]	0.09, 374 (6) [0.14]					0.10, 375 (7) I
							0.04, 174 (3) S
Kusawa, 1993		0.11, 386 (8) [0.08] ↔					
Kusawa, 1999	0.57, 515 (14) [0.57] ↑						
Kuujjua River, 1992					0.05, 603 (6) [0.04]		
Kuuk River, 1987					0.05, 634 (6) [0.03]		
Laberge, 1977		0.26, 277 (12) [0.57]				0.45, 603 (2)	
Laberge, 1992	0.38, 512 (6) [0.23]	0.09, 306 (30) [0.12]	0.10, 549 (2)			0.37, 560 (10) [0.32]	0.04, 203 (7) A
							0.04, 194 (3) X
							0.23, 429 (3) I
							0.04, 285 (3) S
Laberge, 1993	0.44, 483 (13) [0.51] ↔						
Laberge, 1996	0.33, 489 (14) [0.35] ↔						
Laberge, 1998	0.61, 700 (7) [0.37] ↔	0.12, 335 (5) [0.19]					
Lake 100, 1988							0.02, 381 (4) K
Lauchlan River (Byron Bay), 1993					0.02, 719 (5) [0.03]		
Leland, 1989		0.11, 432 (10) [0.10]	0.34, 532 (22) [0.44]	0.46, 488 (9) [0.41]			
Leland, 1990		0.13, 445 (21) [0.11] ↔	0.35, 583 (19) [0.35] ↔	0.46, 476 (20) [0.41]			
Leland, 1992		0.10, 440 (10) [0.10] ↔	0.37, 588 (10) [0.40] ↔	0.40 476 (10) [0.29] in			
Liard River, YT,1977							0.07, 300 (4) H
Liard River, NT, 1977		0.05, 364 (8) [0.06]					0.09, 456 (25) G
Little Atlin, 1977		0.15, 434 (10) [0.13]	0.77, 525 (1)				
Little Doctor, 1996	0.39, 547 (10) [0.40]	0.13, 407 (18) [0.13]	0.74, 695 (9) [0.56]	0.75, 474 (18) [0.63]			0.19, 491 (6) F
Little Salmon River, 1977	0.22, 504 (1)	0.08, 464 (5) [0.09]	0.16, 547 (1)				
Loche, 1978		0.17, 444 (5) [0.10]	0.51, 688 (5) [0.58]				
Loon, 1997	0.37, 600 (6) [0.35]		0.51, 648 (14) [0.47]				

(continued on next page)

Table 3 (*continued*)

Location	Lake trout	Lake whitefish	Northern pike	Walleye	Arctic char	Burbot	Other species[1]
Mackenzie Delta, 1971		0.11, 422 (5) [0.09]	0.09, 427 (9) [0.11]				0.02, 448 (2) K na 0.06, 355 (1) B na 0.07, 412 (6) I
Mackenzie Delta, 1981		0.07, 446 (6) [0.05] ↔					0.03, 486 (5) K 0.09, 680 (6) B
Mackenzie Delta, 1989		0.05, 470 (5) [0.01] ↔				0.27, 625 (4) [0.21]	
Mackenzie Delta, 1992		0.07, 516 (11) [0.05] ↔	0.47, 667 (11) [0.45] ↑				0.17, 538 (5) B ↑
Mackenzie River at Horseshoe Bend, 1992							0.06, 487 (12) K
Mackenzie River at Canyon Creek, 1997			0.16, 524 (8) [0.19]			0.45, 590 (1)	0.06, 411 (4) H 0.08, 438 (20) B
Mackenzie River at Fort Good Hope, 1985		0.11, 360 (7) [0.11]	0.26, 693 (1)			0.27, 663 (16) [0.22]	0.10, 650 (2) B
Mackenzie River at Little Chicago, 1995		0.07, 360 (1)				0.24, 650 (1)	0.06, 483 (54) K 0.195, 647 (16) B
Mackenzie River at Oscar Creek, 1997			0.15, 520 (2)	0.23, 410 (2)		0.12, 515 (1)	0.14, 400 (1) H 0.12, 419 (5) I
Mackenzie River at Ramparts, 1995						0.22, 659 (3) [0.22]	0.06, 491 (83) K 0.19, 742 (43) B
Mackenzie River at Ramparts, 2000						0.35, 713 (36) [0.44] ↑	
Mackenzie River at Stewart Creek, 1997			0.24, 620 (1)	0.12, 235 (1)		0.14, 628 (3)	0.06, 392 (13) H 0.10, 425 (5) I
Maguire, 1977	0.46, 479 (34) [0.68]	0.28, 550 (2)	0.49, 593 (4) [0.42]				
Maguse, 1995	0.73, 543 (13) [1.16]						
Mahony, 1996	0.37, 672 (20) [0.17]	0.13, 510 (20) [0.14]	0.26, 660 (20) [0.19]				
Makkovik, 1998					0.03, 533 (13) [0.03]		
Makkovik, 1999					0.03, 424 (9) [0.06] in		
Manuel, 1978		0.11, 523 (5) [0.06]	0.34, 574 (4) [0.46]				
Manuel, 1989		0.03, 434 (4) [0.02] ↓					
Manuel, 1993		0.15, 530 (10) [0.04] ↑				0.20, 615 (2) na	
Manuel, 1995		0.14, 524 (14) [0.14] ↔	0.46, 651 (10) [0.43] ↔			0.27, 655 (7) [0.17]	
Manuel, 1997	0.30, 484 (17) [0.44]	0.06, 473 (10) [0.08] ↓	0.39, 633 (17) [0.39] ↔			0.24, 626 (12) [0.19]	
Manuel, 1998	0.28, 494 (2) na	0.12, 506 (7) [0.08] ↑	0.54, 654 (11) [0.40] ↔			0.28, 627 (9) [0.28] in	
Margaret Lake, 1977			0.20, 383 (3) [0.04]				
Marian River, 1979			0.44, 644 (23) [0.37]				
Marsh, 1977	0.15, 422 (5) [0.34]	0.02, 357 (1)				0.17, 348 (5) [0.09]	
Mattberry, 1981	0.40, 549 (11) [0.36]						
Mayo, 1977	0.46, 802 (1) na	0.05, 368 (5) [0.11]	0.30, 656 (3) [0.19]				0.06, 399 (4) S
Mayo, 1990	0.11, 430 (5) [0.11]	0.06, 422 (5) [0.06] ↔	0.11, 568 (5) [0.15] ↔			0.11, 380 (2)	
McCrae, 1977	0.59, 482 (17) [0.69]	0.30, 560 (1)	0.49, 600 (8) [0.50]				0.53, 550 (1) S 0.24, 443 (4) I
McEwan, 2000		0.09, 450 (30) [0.08]	0.33, 569 (15) [0.35]	0.36, 429 (17) [0.30]		0.09, 479 (7) [0.13]	0.09, 198 (35) A
McGill, 2000		0.15, 392 (29) [0.12]	0.71, 577 (28) [0.74]	1.13, 480 (22) [0.99]		0.10, 40 (1)	0.21, 471 (17) G
Mirror, 2000	0.61, 460 (63) [1.32]	0.35, 457 (107) [0.42]				0.40, 470 (1)	
Muskeg River, 1977				0.51, 435 (25) [0.46]			
Nahanni River						0.02, 850 (1)	0.04, 295 (12) H 0.03, 305 (3) I
Nain, 1998					0.03, 513 (11) [0.03]		
Nain, 1999					0.03, 488 (10) [0.03] ↔		
Naloagyuk River, 1989					0.04, 501 (5) [0.05]		
Nares, 1996	0.34, 530 (1)		0.26, 870 (3) [0.13]				0.07, 405 (2) H 0.05, 420 (1) F 0.07, 500 (3) Y
Nettilling, 1990					0.08, 561 (5) [0.09]		
Nonacho, 1975	1.06, 598 (8) [0.84]	0.19, 473 (4) [0.16]					
Nonacho, 1986	0.54, 546 (51) [0.51] ↓	0.16, 506 (20) [0.08] ↔	0.39, 588 (20) [0.42]				

Old Crow Flats, 1977			0.06, 365 (6) [0.02]				
Old Crow River, 1998							0.07, 610 (8) J
P&N	0.33, 494 (9) [0.40]				0.09, 368 (15) [0.07]		
Pangnirtung Fiord, 1990					0.03, 449 (13) [0.04]		
Pangnirtung Fiord 1992					0.04, 544 (10) [0.03] ↔		
Parker, 1974	1.57, 838 (2)						
Paulatuk, 1984					0.04, 547 (6) [0.04]		
Peel River at Fort McPherson, 1999							0.08, 516 (10) K
							0.32, 780 (10) B
Peter, 1993	1.04, 811 (5) [0.30]						
Pistol Bay, 1988					0.03, 700 (6) [0.05]		
Pitz, 1976	0.45, 653 (3) [0.60]						
Porcupine River at Old Crow, 1977		0.14, 384 (2)	0.39, 524 (6) [0.40]				0.09, 341 (5) H
							0.09, 786 (1) V
							0.97, 684 (1) B
Puvirnituq					0.04, 525 (11) [0.05]		
Quaqtaq Derek					0.07, 484 (14) [0.06]		
Quartzite, 1971	0.43, 365 (5) [0.95]	0.22, 324 (2)					
Quiet, 1992	0.30, 537 (5) [0.24]						0.14 ± 0.02 (2)H
Quiet, 1999	0.30, 553 (9) [0.30] ↔						0.20 ± 0.06 (5) A
Rae Lakes, 2000	0.46, 554 (10) [0.45]	0.08, 474 (10) [0.09]					
Rankin Inlet, 1984					0.06, 563 (6) [0.04]		
Rankin Inlet, 1992					0.03, 534 (10) [0.03] ↔		
Rankin Inlet, 1993					0.11, 573 (5) [0.08] ↑		
Reade, 2000		0.15, 427 (30) [0.15]	0.43, 584 (45) [0.43]			0.09, 589 (2)	
Resolute Lake, 1997					0.20, 32.8 (10) [No]		
Resolute Lake, 1999					0.17, 39.6 (10) [No] ↓		
Resolute Lake, 2000					0.16, 39.1 (18) [No] ↔		
Resolute Lake, 2001					0.16, 39.3 (17) [No] ↔		
Resolute Lake, 2002					0.14, 37.1 (10) [No] ↔		
Rorey, 1978	0.49, 522 (3) [0.53]	0.04, 370 (1)					
Rorey, 1997	0.46, 537 (47) [0.48] ↔						
Ross, 1973	0.27, 579 (18) [0.25]						
Sandy Point, 1992					0.05, 634 (5) [0.01]		
Sandy Point, 1993					0.06, 542 (5) [0.06] ↔		
Sanguez, 1996		0.15, 493 (20) [0.12]	0.70, 683 (20) [0.57]	0.54, 440 (20) [0.54]			0.16, 267 (12) A
Saputing, 1979					0.05, 733 (5) [0.03]		
Saturday Night, 1988	0.22, 404 (15) [0.19]						
Schultz, 1976	0.55, 533 (7) [0.34]						
Schwatka, 1977			0.13, 570 (5) [0.19]				0.07, 394 (5) I
Sekulmun, 1991	0.46, 672 (10) [0.24]	0.09, 443 (10) [0.07]	0.19, 658 (6) [0.16]			0.30, 490 (1)	
Sibbeston, 1997		0.07, 422 (143) [0.07]	0.17, 671 (2)	0.33, 468 (5) [0.31]			0.14, 506 (7) G
Simpson, 1977	0.52, 495 (5) [0.60]	0.13, 483 (5) [0.14]					
Slave River, 1988			0.33, 574 (13) [0.34]	0.31, 408 (35) [0.25]			
Slave River, 1989			0.35, 550 (20) [0.35] ↔	0.36, 397 (35) [0.36] ↑			0.11, 724 (11) B
Slave River, 1990		0.08, 382 (30) [0.09]	0.34, 568 (30) [0.35] ↔	0.36, 436 (29) [0.32] ↔			
Slave River, 1992		0.04, 376 (34) [0.05] ↓	0.37, 615 (28) [0.40] ↔	0.46, 428 (30) [0.42] ↑			
Slave River, 1996				0.19, 458 (1)			0.11, 827 (3) B
Slave River, 2001						0.15, 600 (10) [0.15]	
Slemon, 1983	0.28, 568 (5) [0.21]						
Small (I), 1976	0.59, 659 (4) [0.22]						
Sophia, 1989					0.20, 637 (3) [0.13]		
South MacMillan River, 1977							0.08, 229 (4) H
South Nahanni River, 1977							0.11, 419 (7) G

(continued on next page)

Table 3 (*continued*)

Location	Lake trout	Lake whitefish	Northern pike	Walleye	Arctic char	Burbot	Other species[1]
Sparks, 1981	0.29, 620 (15) [0.17]						
Sparrow, 1983	0.26, 634 (7) [0.22]		0.25, 725 (3) [0.31]				
Ste Therese, 1975				1.00, 484 (16) [0.81]			
Ste Therese, 1980	1.25, 848 (12) [0.76]		1.45, 840 (9) [1.15]	1.40, 505 (12) [1.21] ↑			
Ste Therese, 1992	0.95, 633 (4) [0.67] ↔	0.13, 463 (23) [0.09]	0.82, 748 (11) [0.44] ↓	1.34, 465 (30) [1.11] ↔			0.23, 497 (7) I
Steep Bank Bay, 1992			0.21, 394 (5) [0.38]				
Stony Point, 1988					0.03, 636 (5) [0.01]		
Surrey, 1984					0.04, 654 (5) [0.02]		
Surrey River, 1989					0.04, 680 (5) [0.16]		
Surrey River, 1990					0.03, 618 (5) [0.04] ↔		
Surrey River, 1993					0.04, 753 (5) [0.04] ↔		
Sylvia Grinell River, 1992					0.08, 302 (5) [0.18]		
Tagatui, 1996		0.04, 337 (20) [0.06]	0.17, 634 (16) [0.15]				
Tagish, 1977		0.07, 380 (3) [0.06]				0.10, 383 (3) [	
Tagniuknitak, 1994					0.06, 630 (5) [0.03]		
Taltson River, 1982			0.46, 661 (5) [0.42]				
Tasiujaq, 1998					0.04, 506 (15) [0.04]		
Tathlina, 1981			0.40, 619 (4) [0.30]	0.36, 395 (8) [0.72]			
Tathlina, 1990				0.43, 397 (10) [0.52] ↔			
Tathlina, 1993				0.59, 388 (5) [0.80] ↑			
Tathlina, 1994				0.67, 433 (5) [0.65] ↔			
Tathlina, 1998			0.21, 448 (6) [0.32] ↔	0.33, 357 (6) [1.35] ↔			
Tatlmain, 1977		0.09, 297 (3) [0.24]					
Tatlmain, 1991	0.50, 745 (9) [0.36]						
Teslin, 1977		0.13, 303 (3) [*]				0.29, 405 (4) [*]	
Tessikakjuak, 1977					0.01, 379 (5) [0.002]		
Thekulthili, 1981	0.31, 605 (15) [0.22]						
Thirty Mile, 1988					0.04, 722 (5) [0.02]		
Thirty Mile, 1989					0.05, 631 (5) [0.06] ↔		
Thirty Mile, 1990					0.02, 636 (5) [0.03] ↓		
Thirty Mile, 1994					0.08, 632 (5) [0.14] ↑		
Thirty Mile River, 1993					0.02, 738 (5) [0.07]		
Thistlethwaite, 1977	0.35, 567 (16) [0.29]	0.06, 447 (10) [0.03]	0.23, 586 (8) [0.16]				0.03, 388 (4) I
							0.18, 429 (9) S
Thistlethwaite, 1982	0.32, 495 (4) [0.70] ↔						
Thompson, 1978		0.20, 377 (33) [0.11]	1.69, 535 (16) [1.42]				
Travaillant, 1992							0.02, 484 (4) K
Tree River, 1977	0.09, 607 (3) [0.07]	0.04, 416 (4) [0.05]			0.02, 660 (8) [0.01]		
Trout, 1977	0.29, 604 (25) [0.31]		0.27, 813 (3) [0.06]	0.83, 591 (7) [0.74]			0.03, 435 (25) G
Trout, 1982	0.30, 553 (5) [0.32] ↔						
Trout, 1990	0.18, 539 (3) [0.20] ↓	0.02, 310 (3) [0.08]	0.10, 629 (2)	0.13, 474 (20) [0.11]		0.09, 655 (3) [0.04]	0.05, 467 (6) I
Trout, 1991	0.24, 533 (9) [0.25] ↔	0.03, 363 (4) [0.04] ↔				0.12, 676 (10) [0.08] ↔	0.06, 475 (10) I
Tsetso, 1997		0.08, 421 (102) [0.07]	0.39, 763 (3) [0.32]	0.49, 493 (99) [0.41]			
Tulemalu, 1971	0.50, 543 (9) [0.49]						
Tunago, 1978	0.08, 400 (1)		0.38, 568 (2)				0.14, 420 (1) A
Turton, 1996	0.60, 566 (55) [0.57]	0.11, 419 (12) [0.11]					
Wagenitz, 1977	0.31, 547 (15) [0.31]	0.06, 445 (15) [0.04]	0.28, 669 (10) [0.17]				0.10, 505 (2) I
							0.08, 470 (1) S

Watson, 1997	0.15, 515 (2)						0.10, 381 (4) Y
Watson, 1998		0.09, 399 (12) [0.10]					
Wellington Bay, 1984					0.06, 692 (5) [0.08]		
Wellington Bay, 1988					0.03, 616 (5) [0.03] ↓		
Wellington Bay, 1989					0.04, 600 (4) [0.05] ↔		
Willow, 1999	0.38, 614 (32) [0.39]	0.09, 405 (167) [0.09]	0.28, 634 (30) [0.22]			0.26, 611 (7) [0.21]	0.15. 443 (3) I
Wilson River, 1988					0.03, 624 (5) [0.01]		
Wilson River, 1993					0.07, 584 (5) [0.08] ↔		
Yathkyed, 1971	0.48, 501 (14) [0.61]	0.12, 508 (1)					
Yaya, 1995	0.21, 581 (28) [0.17]						0.17, 656 (30) B
Yeltea		0.14, 467 (3) [0.09]				0.24, 670 (1)	
Yukon River (Takhini), 1977		0.12, 362 (5) [0.16]				0.24, 736 (4) [0.11]	0.22, 309 (1) H 0.16, 417 (5) I 0.09, 338 (5) S

The latter was calculated from the natural logarithms of concentrations of mercury using the “Robust regression” procedure of NCSS software, which removes any statistical outliers. The figure in square brackets is the antilog of the length-adjusted mean calculated from the equation of log Hg against length and solved for a length of 555 mm for lake trout, 430 mm for lake whitefish, 622 mm for northern pike, 438 mm for walleye, 507 mm for arctic char and 604 mm for burbot. In those instances where the same species has been sampled more than once from a single location, the arrows indicate apparent changes, ↑ increase, ↓ decrease, ↔ no change. In statistical interaction between year and lnHg in PROC GLM of SAS, no test for change conducted. In cases where temporal differences were observed and samples were obtained on more than two occasions, the series of arrows indicate change from the previous mean. For example, levels of mercury in lake trout from Cli Lake were higher in 1996 than in 1983, but did not change between 1996 and 1999. When an entry is followed by “na”, no comparison could be made, usually because of low numbers of samples. When an entry is followed by “in” there was significant statistical interaction between lnHg and year and comparisons among years were not made.

[1] Other species.

A	Cisco	*Coregonus artedii*
B	Inconnu	*Stenodus leucichthys*
C	Salmon, unspecified	
D	Brook trout	*Salvelinus fontinalis*
E	Sculpin, unspecified	
F	Sucker, unspecified	*Catostomus* spp.
G	White sucker	*Catostomus commersoni*
H	Arctic grayling	*Thymallus arcticus*
I	Longnose sucker	*Catostomus castostomus*
J	Chum salmon	*Oncorhynchus keta*
K	Broad whitefish	*Coregonus nasus*
L	Greenland shark	*Somniosus microcephalus*
M	Arctic cod	*Boreogadus saida*
N	Greenland cod	*Gadus ogac*
O	Fish doctor	*Gymnelis viridis*
P	Arctic flounder	*Liopsetta glacialis*
Q	Fourhorn sculpin	*Myoxocephalus quadricornis*
R	Pacific herring	*Clupea harengus pallasii*
S	Round whitefish	*Prosopium cylindraceum*
T	Coho salmon	*Oncorhynchus kisutch*
U	Sockeye salmon	*Oncorhynchus nerka*
V	Chinook salmon	*Oncorhynchus tshawytscha*
W	Greenland turbot	*Reinhardtius hippoglossoides*
X	Least cisco	*Coregonus sardinella*
Y	Whitefish, unspecified	*Coregonus* spp.
Z	Dolly varden	*Salvelinus malma*

*in, interaction between age and year significant, year means not compared
*na, not included in analysis for year to year differences usually because $n=1$

we have the most samples, are lake trout, lake whitefish, arctic char, northern pike, walleye and burbot. The numbers of these and other species, their average lengths, and their mean levels of mercury are shown in Table 2. Walleye ($n=868$) had the highest average level of mercury in muscle averaging 0.47 ± 0.35 μg g^{-1} followed by lake trout ($n=1855$, mean mercury 0.38 ± 0.35 μg g^{-1}), and northern pike ($n=1169$, mean mercury 0.38 ± 0.30 μg g^{-1}). Levels in burbot were somewhat lower with a mean of 0.210 ± 0.135 μg g^{-1}. Lake whitefish ($n=1917$) and arctic char ($n=741$) had lower levels, averaging 0.111 μg g^{-1} and 0.115 μg g^{-1}, respectively. Smaller numbers of other species were also available, mostly with means below consumption guidelines. Since some of the samples were taken from the same site but during different years, the possibility of temporal change prompted examination of those sites in an attempt to discern any trend. The interest in trends derives largely from observations of air samples, snow samples and lake sediment records that indicate inputs of mercury from the atmosphere. Sediment samples have indicated that inputs of mercury have increased, especially in the eastern Arctic. The question these observations raise is whether the atmospheric inputs have resulted in increased mercury in the fish.

3.1. Temporal variation at locations sampled on more than one occasion

Table 3 lists the mean levels of mercury in muscle with values sorted into collection sites and years of collection for the 6 major species. In those instances where temporal comparisons were possible, the entries in Table 3 are followed by an arrow symbol. The arrow pointing up "↑" means higher values in an entry as compared with the previous entry for that species and location. The horizontal arrow "↔" means that entry failed to differ from the previous one and the arrow pointing down "↓" means that the more recent entry had a lower value. Some comparisons could not be shown in this way; for example, when several samples were available from a site, the differences shown by the arrow symbols apply to two collections only. In some instances, the statistical interaction term between year and length was significant and comparisons of mean levels of mercury were not made. Also, means were ignored if they represented fewer than three fish.

Table 3 lists 167 instances in which two mean values for mercury have been compared. Of these, 34 indicate higher levels of mercury, 111 indicate no change, and 22 indicate lower levels. Overall, there appears to be no consistent regional trend of increasing or decreasing levels over time, although individual lakes sometimes show striking differences between two samples taken at different times. For example, the levels in lake trout from Lac Belot were convincingly higher in 1999 than in 1993 and those in the same species in Nonacho Lake were convincingly lower in 1986 than in 1975. Lacking further data, it is difficult to determine whether these differences represent natural variation or points on trends. If they do represent trends, then the direction must vary from place to place. More likely, if any consistent, regional trend in the levels of mercury in these northern lakes exists, it is too subtle to be discriminated from sampling variation with the data available.

3.1.1. Lac à Jacques temporal data

Samples from this lake differed by 1 year only. Mercury in northern pike in 1995 was statistically higher than in 1994. We could not test for year to year differences in lake whitefish because the sample in 1994 had only 2 individuals. Similarly, we could not test the walleye for differences because of the statistical interaction between year and mercury.

3.1.2. Aishihik Lake temporal data

Aishihik Lake, Yukon Territory, was sampled by Atkins-Baker in 1977 and again by the Yukon Government in 1990–1991. The arithmetic mean of mercury in muscle from the three lake trout in 1977 was 0.26 ± 0.31 μg g^{-1} for fish of average length 514 mm. That could not be compared with the 10 lake trout sampled by the Yukon Government in 1990–1991 for which the arithmetic mean level in muscle was 0.09 μg g^{-1} for fish of almost the same size. Because of a significant interaction term, further analysis was not done. The small number of samples (3) in 1977 would preclude definitive comparison in any event. The collections included 5 lake whitefish in 1977 and 10 in 1991. The analysis of covariance indicated that the samples on these occasions failed to differ statistically in slopes or means. This lake is regulated by a dam used to produce hydroelectricity but in spite of this the levels of mercury in the fish were lower than overall species means (Table 2).

3.1.3. Amituk Lake temporal data

We obtained samples of relatively small arctic char from Amituk Lake in 1989 and again in 1992. The levels of mercury were very high in both collections in spite of the small size of these fish. The high levels probably indicate a landlocked population feeding mostly in freshwater. The mean concentration of mercury in 1989 was 0.83 ± 0.55 μg g^{-1} for 27 fish of average length 390 mm. Three years later in 1992 the mean for mercury was 0.57 ± 0.60 for 27 μg g^{-1} for 27 fish that were considerably smaller at 297 mm. There was no statistical difference between these means.

3.1.4. Atlin Lake temporal data

Atlin Lake was sampled for lake trout on three occasions in 1977, 1993 and 1998. The arithmetic means on the three occasions were 0.113, 0.259 and 0.203 μg g^{-1}, respectively. The fish in 1993 were much longer (793 mm) than those in 1977 (416 mm) or 1998 (499 mm). The interaction between ln mercury and year was significant and no conclusion about possible changes was drawn.

3.1.5. Basler Lake temporal data

Lake trout were obtained from Basler Lake three times in consecutive years in 1981, 1982 and 1983 with arithmetic means of 0.700, 0.344 and 0.215 μg g^{-1}, respectively. The analysis of covariance with SAS indicated that the interaction term was not significant and also that the effect of year of sampling was not significant. Similarly, 5 northern pike were obtained in each of 1982 and 1983 and these also failed to differ.

3.1.6. Lac Belot temporal data

Lac Belot represents one of the more useful cases available to test for temporal changes because of good numbers of lake trout obtained (19 in 1993 and 54 in 1999). The arithmetic mean levels of mercury of 0.135 ± 0.049 and 0.212 ± 0.075 μg g^{-1} in 1993 and 1999, respectively and the fish lengths were almost exactly the same. The slopes of the two regressions did not differ and the effect of year was highly significant ($F = 26.05$, $p < 0.0001$). The length-adjusted least square means calculated by SAS were -0.905 (antilog 0.124 μg g^{-1}) in 1993 and -0.702 (antilog 0.199 μg g^{-1}) in 1999. The levels of mercury in lake trout from this lake were significantly higher in 1999 than in 1993.

3.1.7. Byron Bay temporal data

Small numbers of Arctic char were taken from Byron Bay in 1984 ($n = 4$), 1988 ($n = 5$), 1989 ($n = 5$) and 1990 ($n = 5$), all with low levels of mercury. The analysis indicated no differences in levels of mercury.

3.1.8. Cambridge Bay temporal data

The interaction term between length and year for these arctic char fell just short of statistical significance and so the analysis was carried on without no interaction. The effect of year of sampling was significant ($p = 0.02$). The pattern suggested not a consistent trend but rather erratic year to year variation. Mercury was higher in 1977 ($n = 5$) than in 1992 ($n = 10$). However, the sample 1 year later in 1993 ($n = 5$) differed from neither that in 1997 nor 1992.

3.1.9. Chesterfield Inlet temporal data

The analysis of the 6 small collections of arctic char from Chesterfield Inlet over the period from 1977 to 1994 indicated that the effect of year of sampling was significant. Mercury levels in the first sample in 1977 were lower than those in the remaining years, but those latter samples did not differ from each other.

3.1.10. Cli Lake temporal data

Cli Lake was sampled in 1983 ($n = 5$), in 1996 ($n = 49$) and again in 2000 ($n = 4$). The mean levels of mercury in muscle were 0.390 ± 0.094 μg g^{-1} in 1983, 0.876 ± 0.791 μg g^{-1} in 1996 and 0.388 ± 0.097 μg g^{-1} in 2000. The statistical analysis indicated that the slopes of the three regression lines did not differ, and that the effect of sampling year was significant. The least square means for each year were -0.411 (antilog 0.388) in 1983, -0.170 (antilog 0.676) in 1996 and -0.337 (antilog 0.460) in 2000. The value for the large sample in 1996 differed from both the earlier and the later samples. However, the small samples in 1983 and 2000 did not differ from each other.

3.1.11. Coal Lake temporal data

The two samples of lake trout from Coal Lake were comprised of small fish with mean lengths of 375 mm in 1995 and 332 mm in 1999. The analysis indicated no effect of year of sampling.

3.1.12. Colville Lake temporal data

We obtained a sample of 10 lake trout from Colville Lake in 1993 and a large sample of 238 fish in 1999. The slopes of the two regressions failed to differ and the analysis of covariance indicated that the means also failed to differ. The least square mean in 1993 was −0.662 (antilog 0.218 μg g^{-1}) and that in 1999 was −0.760 (antilog 0.174 μg g^{-1}). Perhaps the major value of these samples is the large sample of 238 fish in 1999; this should be useful for comparison with future samples.

3.1.13. Ellice River temporal data

Arctic char from Ellice River were obtained 7 times between 1977 and 1994 and all had very low levels of mercury. There was no significant interaction term and the effect of year of sampling was highly significant. However, the least squares means indicated every possible effect, increase, decrease and no change. There was an apparent decrease in levels between 1977 and 1984 and then another decline between 1984 and 1988. There were no further differences until 1993 when there was an increase, which was followed by a decrease in 1994. The net result was that the levels in 1994 did not differ from those in 1977.

3.1.14. Ferguson River temporal data

Arctic char from the Ferguson River in 1994 had low levels of mercury but showed an apparent increase from 2 years earlier in 1992. The fish taken in 1994 had about the same mean level of mercury (Table 3) but were considerably shorter in length. When adjusted for length, the mean in 1994 was −3.062 (antilog 0.047 μg g^{-1}) as compared with −3.808 (antilog 0.022) in 1992.

3.1.15. Fox Lake temporal data

Lake trout were obtained from Fox Lake in 1992 ($n=5$) and 1993 ($n=12$). An additional sample of two fish in 1998 was not used for temporal comparison. There was no interaction between length and year, and no difference detected between the 2 years.

Similarly, levels of mercury in lake whitefish were unchanged between 1977 and 1993 and those of burbot were unchanged between 1992 and 1993.

3.1.16. Giauque Lake temporal data

This lake has been contaminated with mercury from the operations of the former Discovery gold mine. The fish from this lake contain the highest levels of mercury recorded from northern Canadian lakes to date. The results from this lake were excluded from the calculations of species means shown in Table 2. Good numbers of samples were available from 1977 to 1992 with smaller collections in 1982 and 1983. The analysis indicated that means differed. Inspection of the least squares means indicated that the levels remained little changed until the period between 1983 and 1992 when they dropped significantly. The value for 1982 was of little consequence because it was based on two samples only. There was no difference among the means for 1977 (0.418, antilog 2.62 μg g^{-1}), 1982 (0.429, antilog 2.68 μg g^{-1}) and 1983 (0.508, antilog 3.22 μg g^{-1}). The mean for 1992 was lower at 0.299, (antilog 1.99 μg g^{-1}). This apparent drop in the late 1980s probably does not imply any regional change but rather local events within the drainage. Mine tailings have been leaking into the lake since mining ceased and recent efforts have been made to clean them up.

3.1.17. Great Bear Lake temporal data

Great Bear Lake has received surprisingly little attention in spite of its size and importance. We have data from 5 lake trout in 1978 and 25 in 1979. The statistical analysis indicated that there was a difference in the means for the 2 years. The least squares mean was −2.347 (antilog 0.096 μg g^{-1}) in 1978 and −1.784 (antilog 0.168 μg g^{-1}) in 1979. It seems likely that such a large apparent change in a single year is an artifact of the small number of samples in 1978 rather than a genuine increase in levels.

3.1.18. Great Slave Lake temporal data

Great Slave Lake was sampled at several different locations and on several occasions. The locations are presented separately.

3.1.19. Great Slave Lake, Fort Resolution area, temporal data

Lake trout, lake whitefish and burbot were obtained from the Fort Resolution area of Great Slave Lake on more than one occasion between 1999 and 2001. The only change indicated was in burbot for which the small sample in 2001 had higher levels than in 2000.

3.1.20. Great Slave Lake, Lutsel K'e area, temporal data

Great Slave Lake was sampled on 4 occasions near Lutsel K'e (1995, 1999, 2000, 2001) for a total sample of 38 lake trout. The slopes of the four regression equations did not differ, but the means did ($p=0.0004$). The least squares means were used to locate the differences and these suggested an increase between 1999 and 2000 followed by a decrease between 2000 and 2001. This seems an unlikely pattern and suggests year to year variation rather than a consistent trend. Three collections of northern pike were available from this area in 1999, 2000 and 2001. No changes were indicated. However, burbot collected in 2000 and 2001 had higher levels than in 1999.

3.1.21. Great Slave Lake, Area 1E, temporal data

Five lake trout were taken from Area 1E of Great Slave Lake in each of 1989 and 1990. The slopes were homogeneous and the means did not differ.

3.1.22. Great Slave Lake, Area 1W, temporal data

Similarly, 18 fish were sampled from Great Slave Lake Area 1W over the period 1988 ($n=10$), 1989 ($n=5$) and 1990 ($n=3$). The means did not differ.

3.1.23. Great Slave Lake, Area 2, temporal data

Sixteen lake trout were obtained from Great Slave Lake Area 2 in 1989 ($n=5$), 1990 ($n=5$) and 1992 ($n=6$). For this area, the slopes of the regression equations were not the same and no conclusion was drawn with regard to temporal change. The arithmetic means formed an erratic sequence; the mean for 1989 was 0.132 ± 0.013 μg g^{-1}, that for 1990 was 0.062 ± 0.013 μg g^{-1} and for 1992, 0.233 ± 0.133 μg g^{-1}. The pattern shown by the levels of mercury was similar to that shown by the sizes of the fish, the mean length in 1989 being 592 mm as compared with 505 mm in 1990 and 677 mm in 1992.

3.1.24. Great Slave Lake, Area 4, temporal data

Area 4 of Great Slave Lake was sampled twice for lake trout, in 1989 and 1990, with the result that means did not differ.

3.1.25. Great Slave Lake, Area 5, temporal data

This area furnished 26 lake trout over the years 1988, 1989, 1990 and 1992. The slopes of the regressions of mercury on length were significantly different and no statistically supportable conclusion was drawn with regard to temporal change. The LSMEANS length-adjusted means were 0.098 in 1988, 0.133 in 1989, 0.116 in 1990 and 0.211 in 1992.

3.1.26. Hall Lake temporal data

Hall Lake was sampled twice, in 1977 and 1978 but the sample in 1977 consisted of two fish only and so no temporal comparison was made.

3.1.27. Hay River temporal data

Four good samples of lake whitefish were available from Hay River: 1984, 1989, 1990 and 1992. The slopes of the regressions did not differ and the effect of year of sampling was highly significant. The first sample taken in 1984 had the lowest values for mercury in muscle. The two samples in 1989 and 1990 had higher levels of mercury and the final sample in 1992 fell back towards the levels in 1984 but remained significantly higher than in 1984. Northern pike also showed an increase between 1984 and 1989 followed by a non-significant apparent decline in 1993 with the result that levels in 1984 and 1992 did not differ. Levels in walleye failed to show any significant differences over the three sampling occasions in 1984, 1989 and 1992.

3.1.28. Jayko River temporal data

Arctic char were obtained in small numbers from the Jayko River on six occasions over the period from 1979 to 1994. Slopes were homogeneous and the effect of year of sampling was significant. Inspection of least squares means indicated no difference between 1979 and 1994 although there were several small pair differences (1979 vs. 1993; 1984 vs. 1993; 1994 vs. 1994).

3.1.29. Kakisa Lake temporal data

This lake was sampled on nine occasions from 1977 to 1999 but not all species were obtained on each occasion. Northern pike were obtained five times and the statistical analysis suggested differences among the occasions. The pattern suggested an increase in mercury in the late 1970s followed by a recent decline with the result that levels in 1999 were about the same as they were in 1978. Walleye were obtained in good numbers in 1977 and 1978 and then in small numbers on five subsequent occasions. The slopes failed to differ statistically ($p = 0.06$) and there were significant differences among years. Pair comparisons of least squares means suggested that mercury increased on some occasions, remained unchanged on others and then decreased over the final interval. The final sample was unusual in that the slope of the regression of mercury against length was negative so that adjusting the level for length in these small fish produced a low value for the larger fish.

3.1.30. Kaminak Lake temporal data

This lake had very high levels in the relatively small lake trout taken in 1971 (arithmetic mean 0.99 μg g^{-1}) and they remained high and statistically unchanged in the larger fish taken in the mid-1990s (arithmetic mean 0.95 μg g^{-1}). Shilts and Coker (1995) reported that a commercial fishery on this lake was closed in 1972 because of the high levels of mercury in the fish and moved to nearby Kaminuriak Lake.

3.1.31. Kaminuriak Lake temporal data

Lake trout were obtained from Kaminuriak Lake three times in the 1970s, 12 fish in 1972, 59 fish in 1973, and 6 fish in 1975. All the mercury values were high although not perhaps quite as high as in Kaminak Lake. The slopes of the regressions did not differ, but there were significant differences in the means ($p < 0.0001$). The least squares (geometric) means for the three collections were: 0.109 ± 0.105 S.E. (antilog 1.12 μg g^{-1}) in 1972, -0.852 ± 0.045 S.E. (antilog 0.43 μg g^{-1}) in 1973, and -0.376 ± 0.0604 (antilog 0.42 μg g^{-1}) in 1975. Statistically, the 1972 mean was higher than either those from 1973 or 1975 but the later two did not differ from each other.

3.1.32. Kusawa Lake temporal data

Lake trout from Kusawa Lake in southern Yukon were sampled in 1992 (11 fish) and in 1999 (14 fish). The analysis revealed no interaction between length and year but different means. The least squares mean in 1992 was -0.524 ± 0.0407 S.E. (antilog 0.200 μg g^{-1}) and that in 1999 was -0.324 ± 0.0361 S.E. (antilog 0.475 μg g^{-1}) indicating an unusually large increase in mercury over the interval from 1992 to 1999. Such a large difference will likely prompt additional future sampling. Lake whitefish samples were obtained in 1992 and 1993 but there was no difference between them.

3.1.33. Lake Laberge temporal data

We have data on 40 lake trout from Lake Laberge on four occasions from 1992, 1993, 1996 and 1998. The slopes of the regressions did not differ, and the effect of sampling year fell just short of significance. The least squares means varied erratically: 1992 LSMEAN = -1.108 (antilog 0.33 μg g^{-1}), 1993 LSMEAN = -0.772 (antilog 0.46 μg g^{-1}), 1996 LSMEAN = -0.068 (antilog 0.34 μg g^{-1}), 1998 LSMEAN = -0.419 (antilog 0.39 μg g^{-1}). These data suggest not a consistent trend in either direction.

3.1.34. Leland Lake temporal data

Lake whitefish and northern pike were sampled from Leland Lake in 1989, 1990 and 1992. There were no differences among the years with regard to levels of mercury. With walleye, the slopes of the regressions were not homogeneous and no comparisons among annual means were made.

3.1.35. Mackenzie Delta temporal data

Small numbers of lake whitefish were taken from the Mackenzie Delta and were obtained on four occasions, 1971, 1981, 1989 and 1992. There were no differences among the different years with respect to levels of mercury.

3.1.36. Mackenzie River at Ramparts temporal data

Three burbot were obtained from the Ramparts in 1995 and an additional 36 were obtained in 2000. Comparing these two catches, bearing in mind the small numbers of samples in 1995 ($n = 3$), the values were statistically higher in 2000.

3.1.37. Manuel Lake temporal data

Manuel Lake has been sampled on several occasions. The two samples of lake trout in 1997 and 1998 could not be compared because two fish only were obtained in 1998. However, reasonable numbers of lake whitefish were obtained on most occasions from 1978 to 1998 and results for mercury were consistently low. There were no interaction effects and the effect of year of sampling was highly significant. The pattern of differences indicated increases during some intervals, decreases in others and one instance of no change. Northern pike were also obtained on several occasions, but no differences in means were indicated. Means for burbot were quite similar although they were not tested rigorously for differences because of a significant interaction effect.

3.1.38. Mayo Lake temporal data

The sample from a single large lake trout ($n=1$) obtained from Mayo Lake in 1977 could not be compared with those in 1990. However, comparisons were made using the small numbers of lake whitefish and northern pike and there was no indication that levels of mercury had changed.

3.1.39. Nain temporal data

Levels of mercury in arctic char from Nain in 1998 and 1999 did not differ.

3.1.40. Nonacho Lake temporal data

Lake trout and lake whitefish were obtained from Nonacho Lake in 1975 ($n=8$) and 1986 ($n=51$) in sufficient numbers to make sound temporal comparisons. The adjusted level of mercury in 1986 was considerably lower (LSMEAN $=-0.689$, antilog 0.50 $\mu g\ g^{-1}$) than it was in 1975 (LSMEAN $=-0.119$, antilog 0.89 $\mu g\ g^{-1}$). The lake trout in 1986 were shorter than those in 1975 but the difference in length did not account for all of the decline in levels of mercury. Levels in lake whitefish in this lake were unchanged.

3.1.41. Quiet Lake temporal data

Mercury in samples of lake trout taken in 1992 and 1999 were unchanged over the interval.

3.1.42. Rankin Inlet temporal data

Three samples of arctic char were obtained in 1984, 1992 and 1993. There was no statistical difference between the levels in 1984 and 1992 but the samples in 1993 had more mercury than in 1992 although not more than in 1984.

3.1.43. Resolute Lake temporal data

Levels of mercury in these very small arctic char were measured on five occasions over the period from 1997 to 2002. The levels were all relatively high for char, especially considering the sizes (averages 30–40 mm) suggesting that these fish were confined to freshwater. The statistical treatment indicated that levels fell between 1997 and 1999 and remained unchanged after that. These fish were the smallest of all the char collected. Extrapolation to larger sizes typical of other catches was not successful but comparison within the size range was valid.

3.1.44. Rorey Lake temporal data

A very small sample of lake trout ($n=3$) was available from 1978 for comparison with a larger sample in 1997 ($n=47$). Means and sizes were comparable on these occasions and no change was detected statistically over the interval.

3.1.45. Sandy Point temporal data

The two samples of lake trout taken 1 year apart in 1992 and 1993 did not differ statistically.

3.1.46. Slave River temporal data

Good numbers of lake whitefish were obtained in 1990 and 1992; the comparison indicated that levels were lower in the later sample. Four good samples of northern pike over the years from 1988 to 1992 showed no changes in levels of mercury. Good numbers of walleye were obtained four times over the period from 1988 to 1992 and levels increased over two of the intervals and remained unchanged for the third. (The single walleye obtained in 1996 was ignored.) Two catches of inconnu were obtained in 1989 and 1996; the inconnu taken in 1996 were considerably larger and comparison of the length-adjusted values indicated that the levels in the fish from 1996 were lower.

3.1.47. Lac Ste. Therese temporal data

This lake had unusually high levels of mercury in lake trout, northern pike and walleye on all sampling occasions. The levels in lake trout were about the same in 1992 as they were in 1980 while levels in northern pike declined slightly. Levels in walleye were higher in 1980 than in 1975 and then unchanged in 1992. This lake was the subject of study by Stephens (1995) who had some additional data from 1993. The unadjusted mean levels in 1993 were: lake trout, 1.34 ($n=2$); lake whitefish, 0.273 ($n=15$), northern pike, 0.735 ($n=4$); walleye 1.49 ($n=30$). The levels of mercury in fish from this lake have remained unusually high for at least 18 years and the reasons for these high levels remain obscure.

3.1.48. Surrey River temporal data

The arctic char from this location in 1989, 1990 and 1993 showed no indication of a change in levels of mercury.

3.1.49. Tathlina Lake temporal data

Two samples of northern pike in 1981 and 1998 showed no difference in age-adjusted means. The effect of year of sampling was significant for walleye, however, which were sampled five times from 1981 to 1998. There were higher levels of mercury in 1993 than in 1981 but by 1998 the difference between 1981 and 1998 was not significant.

3.1.50. Thirty Mile Lake temporal data

Four samples of arctic char were analyzed from 1988 to 1994 and there were some differences among levels in different years. Statistically, the levels were higher in 1990 than in 1989 but were lower again by 1994. The decrease did not compensate for the earlier increase and levels in 1994 remained above those of 1988.

3.1.51. Trout Lake temporal data

Lake trout from this lake, taken over the interval from 1977 to 1991, showed no overall effect of year of sampling ($p=0.08$) although some individual pair comparisons from the LSMEANS option showed differences, notably a drop in levels between 1982 and 1990. The small number of whitefish from Trout Lake was not different between 1990 and 1991.

3.1.52. Wellington Bay temporal data

The effect of year of sampling fell short of statistical significance for the arctic char from Wellington Bay.

3.1.53. Wilson River temporal data

Levels of mercury in the char from Wilson River in 1993 were not statistically different from those in 1988.

3.2. Spatial variation in levels of mercury

3.2.1. Spatial variation, lake trout

The data in Table 3 summarize the information on 1855 lake trout for which both length and mercury were recorded (excluding those from Giauque Lake). The length-adjusted mean level of mercury was calculated for each location using the robust regression option of NCSS software. This software removes statistical outliers from the calculation and produces a regression equation. In a few instances, the robust regression could not be used because of internal correlations within the data and in those instances, bivariate regression was used. When the regression equations were obtained, they were solved for the same length of fish, 555 mm in the case of lake trout, to produce an estimated length-adjusted mean. When only one or two fish were available, no regression was calculated and no length-adjusted mean was obtained; the arithmetic mean was used instead. The length-adjusted means are shown in square brackets in Table 3. Since the temporal analysis suggested that levels of mercury may have changed in about one third of cases, the different collections from a location were not pooled. Rather, the most recent length-adjusted mean for each location was used to make spatial comparison.

Mercury levels are usually adjusted for length to facilitate comparisons among lakes where the sizes of the fish differ (e.g. McMurtry et al., 1989; Wren et al., 1991). Without adjustment, variation is present due to differing sizes of fish. However, with data like those presented here where sample sizes were often small and the size classes within a catch were restricted, variation can be introduced due to statistical extrapolations to the chosen length. In the case of the 94 lakes with lake trout reported here, the average of the most recent unadjusted means in Table 3 was 0.375 ± 0.252 and the average of the adjusted means for the same catches was 0.358 ± 0.275. The relative standard deviation was actually increased slightly from 67.2% in the unadjusted means to 76.8% in the adjusted means. The advantages of adjusting mercury levels for fish length, while helpful in most instances, appear to have been marginal for these data.

The adjusted mean levels of mercury in lake trout are listed sorted by political units in northern Canada in Table 4. The range of adjusted means was from 0.07 μg g^{-1} to 1.32 μg g^{-1}, a range similar to that reported for the same species in lakes in Ontario (0.05–1.16 μg g^{-1}; McMurtry et al., 1989). Most lake trout were observed from the 49 sampling locations across the Northwest Territory. Several of these were different fishing areas of a single large lake, Great Slave Lake. We obtained data from 22 sites in the Yukon, 22 in Nunavut and from 1 in northern Quebec. The adjusted mean levels in lake trout ranged from 0.26 μg g^{-1} in the Yukon to 0.47 μg g^{-1} in Nunavut (Table 4). The levels in lake trout from Nunavut appeared to be slightly higher than the others; the statistical test for effect of territory of collection using PROC GLM and natural logarithms of adjusted means was significant at a probability of 8% ($p=0.077$). When pair comparisons were made using LSMEANS, the levels in Nunavut were higher than those from the Yukon ($p=0.01$) and apparently higher than those from the Northwest Territory ($p=0.067$).

The adjusted mean levels in lake trout are shown graphically in Fig. 1 with points superimposed on a map of bedrock geology of northern Canada. The red dots represent collections where means exceed the guideline for sale of commercial fish; yellow dots represent means that exceed the guideline for subsistence consumption. Green dots represent means below 0.2 μg g^{-1}.

Table 4
Numbers of length-adjusted means of levels of mercury in muscle found in each geographic region together with the averages of the means (± S.D.) (Giauque Lake excluded)

Species	Geographic region	Number of sites and mean ± S.D. in low range (green) (<0.2 μg g^{-1})	Number of sites and mean ± S.D in medium range (yellow) (between 0.2 and 0.5 μg g^{-1})	Number of sites and mean ± S.D in high range (red) (>0.5 μg g^{-1})	Total	Mean for all collections in geographic area ± S.D.
Lake trout	YT	10 (0.13 ± 0.03)	10 (0.32 ± 0.08)	2 (0.59)	22	0.26 ± 0.15
Lake trout	NT	14 (0.13 ± 0.04)	25 (0.29 ± 0.09)	10 (0.79 ± 0.36)	49	0.35 ± 0.29
Lake trout	NU	5 (0.15 ± 0.06)	10 (0.37 ± 0.08)	7 (0.85 ± 0.23)	22	0.47 ± 0.31
Lake trout	QU	0	1 (0.37)	0	1	0.37
Total		29	46	19	94	
Lake whitefish	YT	16 (0.10 ± 0.05)	3 (0.22 ± 0.02)	0	19	0.12 ± 0.06
Lake whitefish	NT	47 (0.08 ± 0.04)	7 (0.31 ± 0.06)	0	54	0.11 ± 0.09
Lake whitefish	NU	6 (0.09 ± 0.04)	2 (0.24)	0	8	0.13 ± 0.08
Total		69	12	0	81	
Arctic char	NT	6 (0.04 ± 0.01)	0	0	6	0.07 ± 0.04
Arctic char	NU	38 (0.05 ± 0.04)	1 (0.26)	1 (1.78)	40	0.10 ± 0.28
Arctic char	QU	6 (0.06 ± 0.04)	0	0	6	0.06 ± 0.04
Arctic char	NFLD	3 (0.04 ± 0.02)	0	0	3	0.04 ± 0.02
Total		53	1	1	55	
Walleye	NT	11 (0.14 ± 0.04)	11 (0.35 ± 0.07)	7 (0.92 ± 0.30)	29	0.41 ± 0.34
Northern pike	YT	11 (0.13 ± 0.06)	2 (0.34 ± 0.08)	1 (0.77)	14	0.20 ± 0.19
Northern pike	NT	10 (0.16 ± 0.03)	38 (0.35 ± 0.07)	11 (0.69 ± 0.26)	59	0.38 ± 0.21
Northern pike	NU	0	1 (0.38)	0	1	0.49 ± 0.15
Northern pike	QU	0	1 (0.43)	0	1	0.43
Total		21	42	12	75	
Burbot	YT	6 (0.12 ± 0.03)	3 (0.30 ± 0.02)	0	9	0.18 ± 0.10
Burbot	NT	18 (0.12 ± 0.04)	10 (0.31 ± 0.10)	1 (0.89)	29	0.21 ± 0.17
Burbot	QU	0	1(0.23)	0	1	0.23
Total		24	14	1	39	

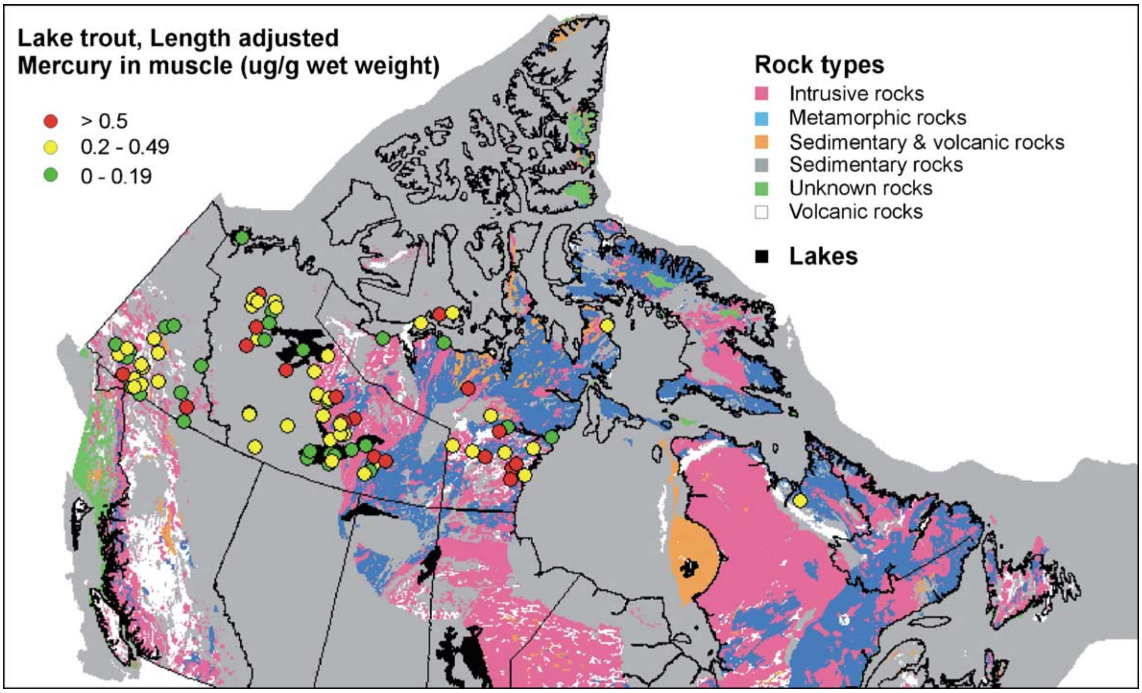

Fig. 1. Ranges of mercury in muscle of lake trout (μg g^{-1} wet weight). Green dots, mercury in the range below 0.2 μg g^{-1}; yellow dots, mercury in the range between 0.2 and 0.5 μg g^{-1}; red dots, mercury greater than 0.5 μg g^{-1}.

An unanswered question about mercury in fish concerns the importance of local within-basin geological sources. The map in Fig. 1 has been superimposed on a geological map of the types of bedrock. The numbers of adjusted means falling in each range of concentrations are shown in Table 4 together with the value of each. Overall, about two-thirds (66 of 94) of the values for lake trout fell into yellow or red range categories. The Yukon had 2 of 22 sites in the range plotted as red, the Northwest Territory 10 of 49 sites, and Nunavut 7 of 22 sites. Within each concentration range, the average of the adjusted means tended to be highest in the samples from Nunavut. With regard to mercury in lake trout, the problem appears to be more serious in Nunavut than in the Yukon or the Northwest Territory.

There are significant geological differences between the Northwest Territory and Nunavut. Given the possibility of some regional differences in levels of mercury between these two territories, a testable hypothesis was that different geological settings might contribute to an explanation. The background geological map incorporated in Figs. 1–6 shows that the locations from which lake trout were obtained were situated in four types of bedrock: sedimentary rocks (e.g. sandstone), intrusive rocks (e.g. granite), metamorphic rocks (e.g. slate), and volcanic rocks (e.g. basalt). A summary of the numbers of sites and the mean levels of mercury in lake trout from collections from each type of bedrock is shown in Table 5. Most of the collections of lake trout were from locations situated in sedimentary rock (68 of 94 sites). Statistically there were no differences in levels of mercury found in lake trout from lakes in the four types of bedrock. Based on totals for lake trout, we might expect about one third of the sites to fall in the “green” category of <0.2 μg g^{-1} but the sites in metamorphic rock had only 1 of 9 sites in this low range. A large occurrence of metamorphic rock (blue color, Fig. 1) extends from northern Saskatchewan to northeastern Baffin Island with smaller pockets throughout. While our collections are sparse in those areas, there are almost no green dots in the blue areas of the map (Fig. 1). If an association with metamorphic rock were confirmed, it would predict that many lakes in the large area of blue color in Fig. 1 would have fish with high levels of mercury.

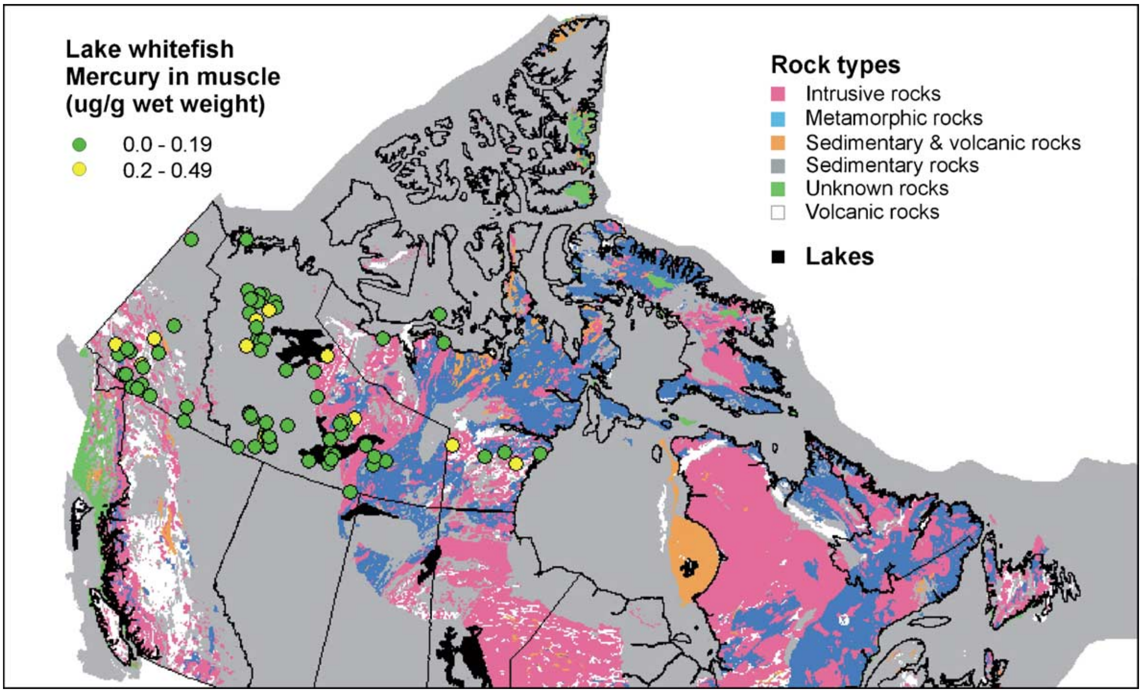

Fig. 2. Ranges of mercury in muscle of lake whitefish (μg g^{-1} wet weight). Green dots, mercury in the range below 0.2 μg g^{-1}; yellow dots, mercury in the range between 0.2 and 0.5 μg g^{-1}; red dots, mercury greater than 0.5 μg g^{-1}.

A possible alternative or additional explanation might be that inputs of atmospheric mercury may be higher in the Eastern Arctic than in the Western Arctic. The evidence from sediment cores suggests this type of regional difference in recent inputs of mercury (Lockhart et al., 2000).

The study by McMurtry et al. (1989) examined a number of lake variables in a search for features that might explain the levels of mercury found in lake trout. Dissolved organic carbon in the water was the most promising of these with a correlation to mercury levels of 0.6 ($p = 0.0001$). This or other limnological features (pH, hardness, iron, etc.) may explain the variation in levels in these northern lakes as well but data on the physical, chemical and biological attributes of these lakes are very limited. For example, Loseto et al. (2004) have shown that mercury is methylated in high arctic wetlands but the extent of wetlands in the drainages of most of the lakes listed here has not been established. Fish may grow at different rates in different lakes or the food chain may be more highly contaminated in one lake than in another. Stafford and Haines (2001) argued that the mercury content in fish is responsive to the mercury content of the food than to growth rate. The position in the food chain as indicated by stable isotopes of nitrogen offers strong evidence for the food as the dominant pathway for the accumulation of mercury in a wide array of freshwater and marine organisms (Kidd et al., 1995; Atwell et al., 1998).

3.2.2. Mercury in muscle of lake whitefish

Muscle of lake whitefish had lower levels of mercury than muscle of lake trout. This difference is expected based on feeding habits. Kidd et al. (1995) found that lake whitefish represented a lower trophic level than lake trout in lakes in Northwestern Ontario, and presumably the same applies further north. The arithmetic mean for 1917 fish was only 0.11 μg g^{-1}, well below the guidelines for human consumption (Table 2). With this species the length used for adjustment of levels of mercury was 430 mm. All but 12 of the 81 sites had adjusted mean values below 0.2 μg g^{-1} (Table 4). The averages for the three territories were very similar, 0.11 μg g^{-1} for NT, 0.12 μg g^{-1}

Table 5
Numbers of length-adjusted means of levels of mercury in muscle found in concentration range within each type of bedrock with averages of the means and standard deviations in parentheses (Giauque Lake excluded)

Species	Bedrock type	Total sites in rock type	Sites with mean Hg <0.2 μg g^{-1}	Sites with mean Hg between 0.2 and 0.5 μg g^{-1}	Sites with mean Hg >0.5 μg g^{-1}
Lake trout	Sedimentary	68 (0.32 ± 0.25)	24 (0.14 ± 0.04)	33 (0.30 ± 0.09)	11 (0.77 ± 0.28)
Lake trout	Metamorphic	9 (0.44 ± 0.20)	1 (0.08)	5 (0.38 ± 0.07)	3 (0.65 ± 0.07)
Lake trout	Intrusive	11 (0.41 ± 0.22)	3 (0.14 ± 0.04)	5 (0.40 ± 0.08)	3 (0.68 ± 0.11)
Lake trout	Volcanic	6 (0.59 ± 0.56)	1 (0.16)	3 (0.28 ± 0.11)	2 (1.26 ± 0.44)
Totals		94 (0.36 ± 0.27)	29 (0.14 ± 0.04)	46 (0.32 ± 0.09)	19 (0.79 ± 0.29)
Lake whitefish	Sedimentary	63 (0.10 ± 0.08)	57 (0.08 ± 0.04)	6 (0.29 ± 0.07)	0
Lake whitefish	Metamorphic	6 (0.16 ± 0.06)	4 (0.13 ± 0.02)	2 (0.23 ± 0.04)	0
Lake whitefish	Intrusive	7 (0.16 ± 0.10)	5 (0.10 ± 0.04)	2 (0.30)	0
Lake whitefish	Volcanic	5 (0.13 ± 0.09)	3 (0.07 ± 0.05)	2 (0.22)	0
Totals		81 (0.11 ± 0.08)	69 (0.08 ± 0.04)	12 (0.27 ± 0.06)	0
Arctic char	Sedimentary	40 (0.10 ± 0.27)	38 (0.06 ± 0.04)	1 (0.26)	1 (1.78)
Arctic char	Metamorphic	4 (0.03 ± 0.02)	4 (0.03 ± 0.02)	0	0
Arctic char	Intrusive	7 (0.06 ± 0.05)	7 (0.06 ± 0.05)	0	0
Arctic char	Volcanic	4 (0.05 ± 0.06)	4 (0.05 ± 0.06)	0	0
Totals		55 (0.09 ± 0.24)	53 (0.05 ± 0.04)	1 (0.26)	1
Walleye	Sedimentary	28 (0.41 ± 0.35)	11 (0.14 ± 0.04)	10 (0.36 ± 0.07)	7 (0.92 ± 0.30)
Walleye	Intrusive	1 (0.29)	0	1 (0.29)	0
Totals		29 (0.41 ± 0.34)	11 (0.14 ± 0.04)	11 (0.35 ± 0.07)	7 (0.92 ± 0.30)
Northern pike	Sedimentary	65 (0.34 ± 0.21)	20 (0.14 ± 0.05)	36 (0.35 ± 0.07)	9 (0.72 ± 0.08)
Northern pike	Metamorphic	3 (0.39 ± 0.19)	1 (0.19)	1 (0.43)	1 (0.56)
Northern pike	Intrusive	5 (0.50 ± 0.18)	0	3 (0.40 ± 0.03)	2 (0.66 ± 0.22)
Northern pike	Volcanic	2 (0.28)	0	2 (0.28 ± 0.01)	0
Totals		75 (0.35 ± 0.21)	21 (0.14 ± 0.05)	42 (0.35 ± 0.07)	12 (0.70 ± 0.25)
Burbot	Sedimentary	33 (0.21 ± 0.16)	20 (0.12 ± 0.04)	12 (0.31 ± 0.09)	1 (0.89)
Burbot	Metamorphic	2 (0.20 ± 0.05)	1 (0.16)	1 (0.23)	0
Burbot	Intrusive	2 (0.14 ± 0.04)	2 (0.14)	0	0
Burbot	Volcanic	2 (0.22 ± 0.11)	1 (0.14)	1 (0.29)	0
Totals		39 (0.20 ± 0.15)	24 (0.12 ± 0.04)	14 (0.30 ± 0.08)	1 (0.89)

for YT and 0.13 μg g^{-1} for NU (Table 4). There was no indication of differences among territories.

Fig. 2 shows the geographic distribution of adjusted mean levels of mercury in lake whitefish using the same color display conventions as with lake trout. In contrast to Fig. 1, most of the dots in Fig. 2 are green, showing that adjusted mean levels in whitefish from all jurisdictions fell mostly below the guideline of 0.2 μg g^{-1} for subsistence consumption. Three of the 19 sites in the Yukon exceeded the lower guideline for consumption of 0.2 μg g^{-1} and these did so by only a small amount since the mean for them was 0.22 μg g^{-1}. Within the Northwest Territory, 7 of 54 sites exceeded 0.2 μg g^{-1} and in Nunavut 2 of 8 sites did so. The sites reported from the Northwest Territory include several areas of Great Slave Lake, a very large lake with distinct fishing zones and low levels of mercury in the fish. The 8 locations in Nunavut included two with adjusted mean levels over 0.2 μg g^{-1}, namely Lakes Quartzite and Dubawnt, but these figures were based on 2 and 3 fish, respectively. The other 6 sites in Nunavut had mean levels below 0.2 μg g^{-1}.

Most of the lakes where whitefish were obtained were situated in sedimentary rock. Table 5 lists the numbers and adjusted mean values for whitefish from lakes in each type of rock. For example, the 63 adjusted means from lakes in sedimentary rock included only 6 or about 10% that exceeded the guideline of 0.2 μg g^{-1}. The proportions of lakes exceeding a guideline appeared to be higher in the other kinds of rocks (2 of 6 in metamorphic rocks, 2 of 7 in intrusive rocks and 2 of 5 in volcanic rocks) but the number of lakes in these settings was small. Taking the non-sedimentary rocks together, about one third of the lakes had whitefish over the lower guideline.

3.2.3. Mercury in muscle of arctic char

Mercury in muscle of arctic char is reported for 741 individuals from 55 locations (Northwest Territory, 6; Nunavut, 40; Quebec 6; Newfoundland/Labrador, 3). One collection of char was recorded from Great Slave Lake in 1988; this is well outside the range of arctic char shown in Scott and Crossman (1973) and it is not certain whether this represents an error or unusual migrants. (Mercury in char from nearby Lac La Marte was reported also by Desai-Greenaway and Price, 1976.) The levels of mercury in char were almost always very low in comparison with their taxonomic relatives, lake trout, probably because anadromous char feed partially at sea. The few instances in which char had higher values were from populations believed to live exclusively in freshwater. One set of samples from Kangiqsujuaq was identified as sea run and another as landlocked; the mean for the sea run group was 0.04 μg g^{-1} while for the landlocked group it was 0.14 μg g^{-1}. A similar difference between anadromous and landlocked char has been noted in Greenland (Riget et al., 2004). The overall arithmetic average of all the char was only 0.115 μg g^{-1} (Table 2), about one third the value for lake trout. The average of the length-adjusted means was even lower at 0.087 ± 0.237 μg g^{-1}. The results are sorted by territory in Table 4. The adjusted value for Amituk Lake (1.78 μg g^{-1}) was outside the range of all the other char and probably represents a statistical artifact. The average lengths of the char in the two samples from Amituk Lake were 390 mm and 297 mm, well below the length of 507 mm used for adjustment. The robust regression equations used to adjust for length had positive slopes and gave good descriptions of the data (R-squared = 0.71 and 0.80). The range of original lengths (303–532 mm in 1989 and 107–516 mm in 1992) overlapped the length of 507 mm used as a standard. When adjusted to a length of 507 mm, the results were probably high because the regression equations were derived largely from considerably smaller fish. The adjusted values obtained were 2–3 times higher than the arithmetic means (Table 3). A similar but more extreme circumstance applied to the much smaller char from Resolute Lake (fish length 29–48 mm) and that result was so unusual that it was rejected for Table 3. Instead, the most recent arithmetic mean was used. The average of the adjusted means for each territory were: NT, 0.042; NU, 0.101; QU, 0.057; NFLD 0.043. The high value for Nunavut represents bias due to the presumed artifact in the adjusted mean from Amituk Lake. When the average for Nunavut was recalculated without Amituk Lake, the average of adjusted means there dropped to 0.058 μg g^{-1}.

Arctic char can be anadromous or exclusively freshwater and it appears that their migratory habits determine to a large extent their levels of mercury. A value of about 0.1 μg g^{-1} separated the char into two groups, probably representing anadromous populations with means below 0.1 μg $g^{-1}$and landlocked populations with means over 0.1 μg g^{-1}. The levels in landlocked char are discussed more fully by Muir et al. (2005).

Char from 6 locations in the Northwest Territory all had mean values below 0.2 μg g^{-1} (green dots, Fig. 3). Most char collections were from Nunavut with 40 sites represented. The map in Fig. 3 shows only one red point, Amituk Lake on Cornwallis Island where the mercury levels were high with or without adjustment for fish size. Presumably these char are confined to freshwater. The yellow dot further north is Lake Hazen where the fish are also landlocked. With this lake the extrapolation from the average length of 404 mm to 507 mm appears within reason and the adjustment for length moved the value from just under the guideline of 0.2 to somewhat over it. All the sites in Quebec and Labrador fell below 0.2 μg g^{-1}.

Lake trout and arctic char are of the same genus *Salvelinus* and samples of both species were obtained from P&N Lake, near Saqvaqjuac near the west coast of Hudson Bay. The char, presumably anadromous, had a mean mercury level of 0.085 μg g^{-1} (n = 15) while the non-migratory lake trout had a mean almost four times higher at 0.33 μg g^{-1} (n = 9).

Table 5 lists the numbers of means found in each type of bedrock. The migratory habits of anadromous char probably make this type of comparison irrele-

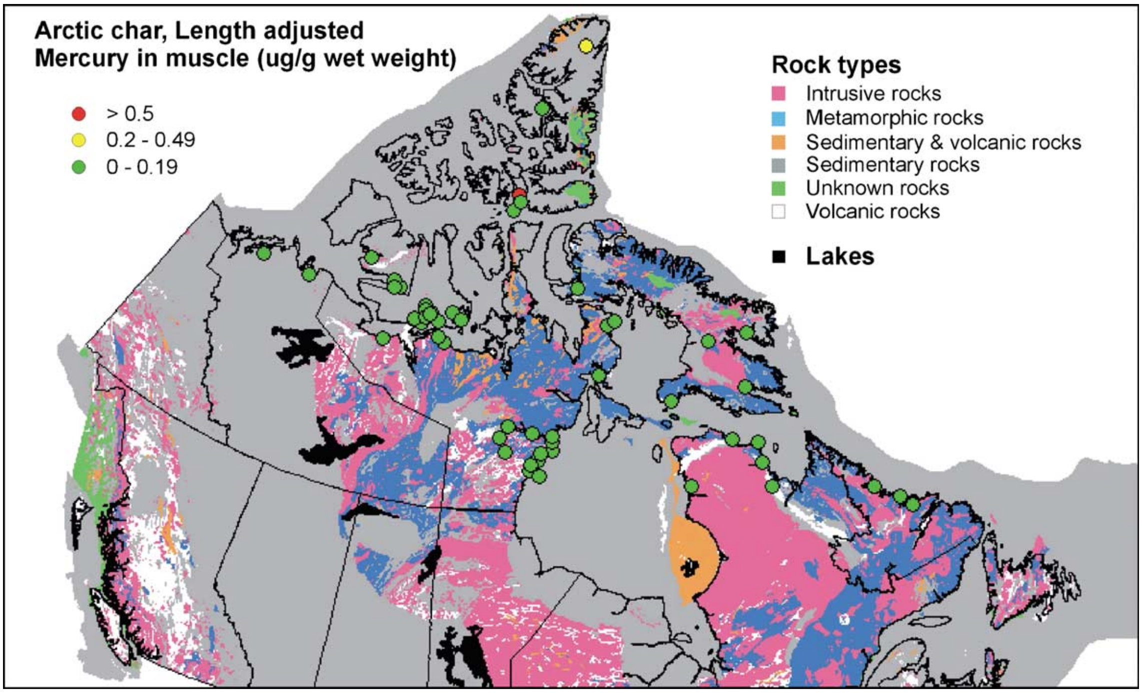

Fig. 3. Ranges of mercury in muscle of arctic char (μg g^{-1} wet weight). Green dots, mercury in the range below 0.2 μg g^{-1}; yellow dots, mercury in the range between 0.2 and 0.5 μg g^{-1}; red dots, mercury greater than 0.5 μg g^{-1}.

vant. Anadromous char, obtaining much of their annual caloric intake at sea, would be expected to assimilate mercury as a marine species and not necessarily to reflect conditions in their freshwater habitat. The geological sorting should be relevant for landlocked char, however, there were a small number of them.

3.2.4. Mercury in muscle of walleye (pickerel)

The geographic distribution of walleye (pickerel) in northern Canada is restricted to a broad band roughly described by the Mackenzie River drainage (Scott and Crossman, 1973). Samples of walleye were obtained from 868 individual fish from 29 locations all within the Northwest Territories. The arithmetic average level of mercury in walleye was 0.470 ± 0.349 μg g^{-1}, the highest for any species (Table 2). After adjustment to a length of 438 mm the average of the 29 means fell to 0.41 μg g^{-1}. Wren et al. (1991) reported levels of mercury in 79 lakes in Ontario and used a standard length of 410 mm. They found a range lake means from 0.23 to 2.22 μg g^{-1} with a mean of 0.65 μg g^{-1}. Our values are slightly lower than the Ontario values, although the length of fish reported here was slightly longer. The range of adjusted walleye mean values here was 0.05 to 1.35 μg g^{-1} with an average of 0.406 μg g^{-1}. Kidd et al. (1995) reported levels of mercury and $\delta^{15}N$ in walleye from northwestern Ontario. The mean levels of mercury in five lakes ranged from 0.37 to 1.22 μg g^{-1} and the $\delta^{15}N$ values ranged from 9.3 to 10.6. Based on the $\delta^{15}N$ values, the levels of mercury in walleye should be similar to or a little lower than those in lake trout.

Since all the samples were from the Northwest Territory, no spatial comparison could be made by political units. The locations of the source lakes and grouping of the means within concentration ranges are shown on the map in Fig. 4. With the exception of Great Slave Lake, most of the map points are red or yellow. Nineteen of 29 locations had mean levels in the mid-range (yellow) or high range (red). Human health agencies have issued a number of consumption advisories for walleye as a result of these data. Furthermore, all the walleye sites were located in sedimentary rock except for Leland Lake which is

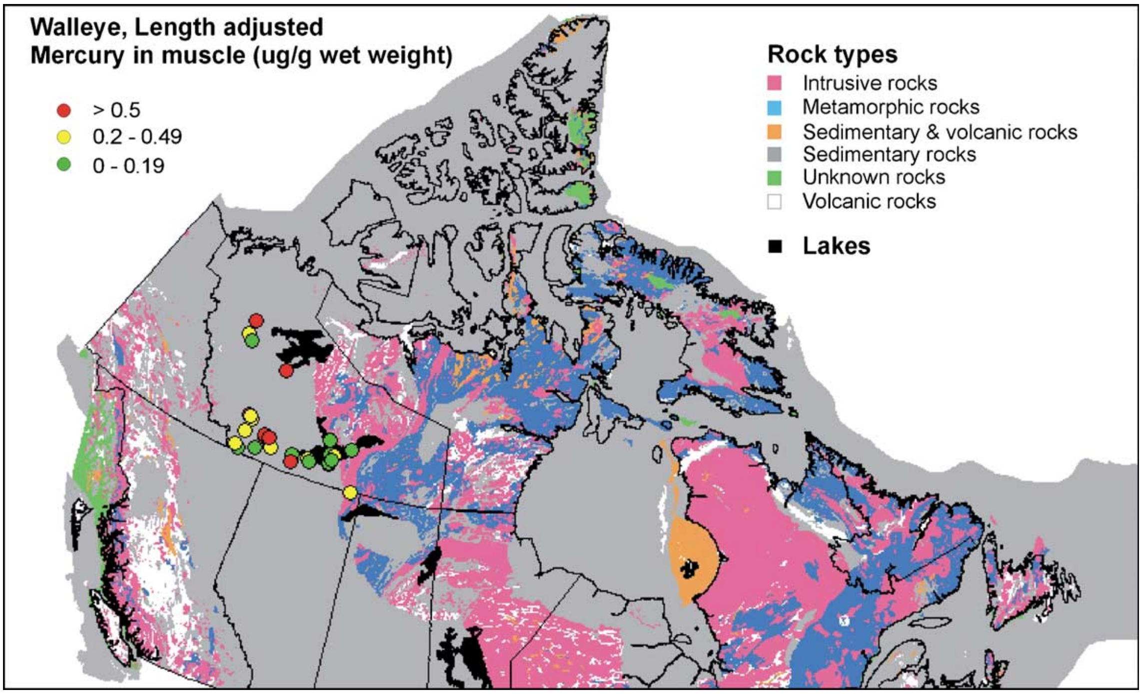

Fig. 4. Ranges of mercury in muscle of walleye (μg g^{-1} wet weight). Green dots, mercury in the range below 0.2 μg g^{-1}; yellow dots, mercury in the range between 0.2 and 0.5 μg g^{-1}; red dots, mercury greater than 0.5 μg g^{-1}.

in intrusive rock (Table 5). Leland Lake walleye had an adjusted mean mercury content of 0.29 μg g^{-1}, a value in the middle of the range. Consequently the data on mercury in walleye offer no insight into possible associations between mercury levels and types of bedrock.

3.2.5. Mercury in muscle of northern pike

Northern pike (jackfish), another predatory species, are widely distributed throughout the mainland of Canada including northern Canada, extending to several arctic drainage basins. The predatory habits of this species were evident in the δ^{15}N values reported by Kidd et al. (1995) for lakes in northwestern Ontario; values were very similar to walleye. The data in Table 3 include 1169 northern pike from 75 locations, mostly in the Northwest Territory but including a few locations from the other regions: Yukon, 14; Northwest Territory, 59; Nunavut, 1; Quebec, 1 (Table 4). Northern pike occur widely in the mainland portion of Nunavut, but surprisingly, they are virtually absent from the data present here. The geographic pattern of means was similar to that found for lake trout with the highest values in Nunavut, although only two collections were from there. As with the other species, the levels of mercury found are plotted as colored dots on the map in Fig. 5.

Northern pike from 12 locations had adjusted mean levels of mercury over 0.5 μg g^{-1} and these extended over most of the range (Fig. 5). Forty-two sites had mean levels of mercury over the subsistence recommendation of 0.2 μg g^{-1} but below 0.5 μg g^{-1} (yellow points in Fig. 5). The remaining 21 sites, largely in the Yukon, had mean mercury levels of less than 0.2 μg g^{-1} (green in Fig. 5). The sites in different Territories are summarized in Table 4.

As with other species sedimentary rock predominated at collection sites for northern pike. Sixty-five of the 75 sites were in sedimentary rock; the average of these 65 means was 0.34 ± 0.21 μg g^{-1} (Table 5). Three sites were in metamorphic rock (0.39 ± 0.19 μg g^{-1}), five were in intrusive rock (0.50 ± 0.18 μg g^{-1}) and two were in volcanic rock (0.28 μg g^{-1}). Twenty of 65 sites in sedimentary rock, about one third, had mean values below the recommended maximum for subsistence fishing of 0.2 μg g^{-1}. Considering the

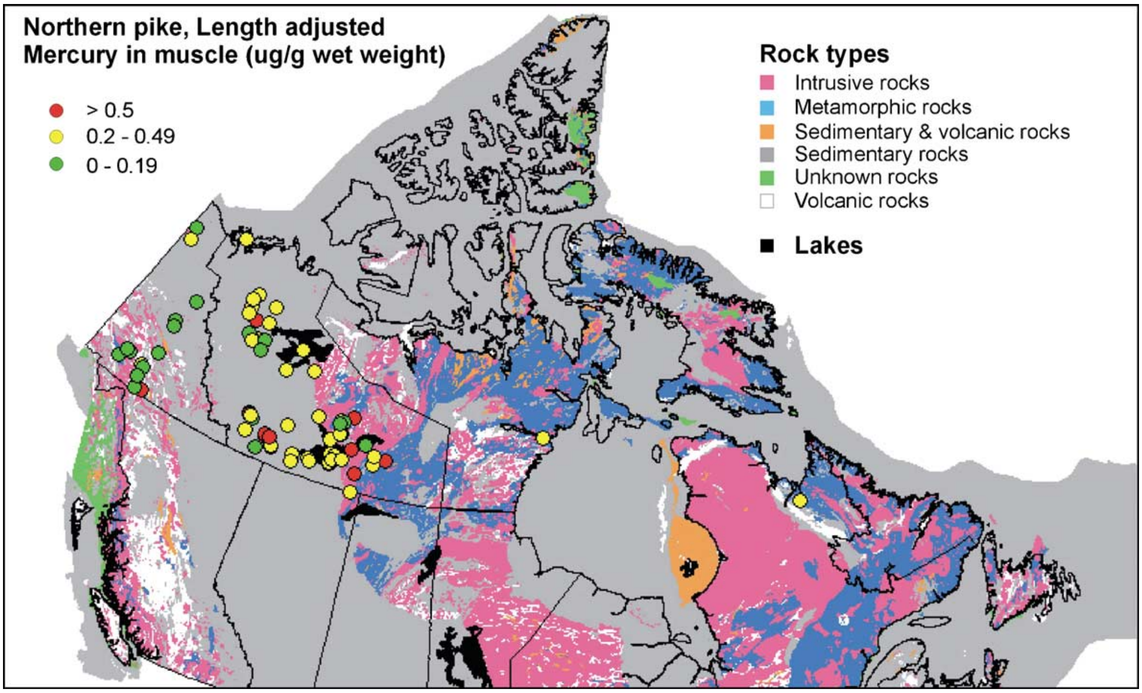

Fig. 5. Ranges of mercury in muscle of northern pike (μg g^{-1} wet weight). Green dots, mercury in the range below 0.2 μg g^{-1}; yellow dots, mercury in the range between 0.2 and 0.5 μg g^{-1}; red dots, mercury greater than 0.5 μg g^{-1}.

other types of bedrock, only 1 of the 10 sites had a mean value below 0.2 μg g^{-1}. Two out of three sites in metamorphic rock exceeded 0.2 μg g^{-1}; five out of five sites in intrusive rock and two out of two sites in volcanic rock exceeded this recommendation. The proportions of sites in the higher ranges (yellow and red in Fig. 5) tended to be higher in the non-sedimentary rocks than in sedimentary rocks.

3.2.6. Mercury in muscle of burbot (Lota lota)

Burbot (loche, mariah) are distributed widely in Canada, extending throughout most of the mainland part of northern Canada (Scott and Crossman, 1973). However, they are not as highly prized for human consumption as some other species and so they are not well represented in our collections. Burbot liver used to be consumed before imported fats were readily available because the liver can contain very high proportions of fat. We might expect burbot to contain relatively high levels of mercury, similar to the other predators, lake trout, walleye and northern pike, based on their $\delta^{15}N$ values (Kidd et al., 1995). The data describe mercury in 315 burbot from 39 locations. The number of samples obtained from a site ranges up to 39 but several locations are represented by a single fish only (Table 2). Generally the means for burbot, whether sorted by territory (Table 4) or by bedrock type (Table 5) tended to be a little lower than those for the other predators. We have no data on burbot from Nunavut (Table 4) even though they are present throughout most of the mainland area. As shown on the map in Fig. 6, one location only had a mean concentration of mercury in muscle over 0.5 μg g^{-1}, namely Cli Lake which was represented by a single fish in 1996. Over half the sites (24 of 39) had low levels of mercury, less than 0.2 μg g^{-1}.

Thirty-three of the 39 sites where burbot were obtained were situated in sedimentary rock and the average for the means of mercury levels was 0.21 ± 0.16 μg g^{-1} (Table 5). Two lakes only were located in metamorphic rock, Kloo Lake in the Yukon with one fish (Hg = 0.16) and the site in the Koksoak River, Quebec, with two fish (Hg = 0.23). Two sites (Hidden Lake (NT, 2 fish) and the Yukon River at Takhini (YT, 4 fish)) were in intrusive rock and these averaged 0.14 μg g^{-1}. The two lakes in volcanic rock

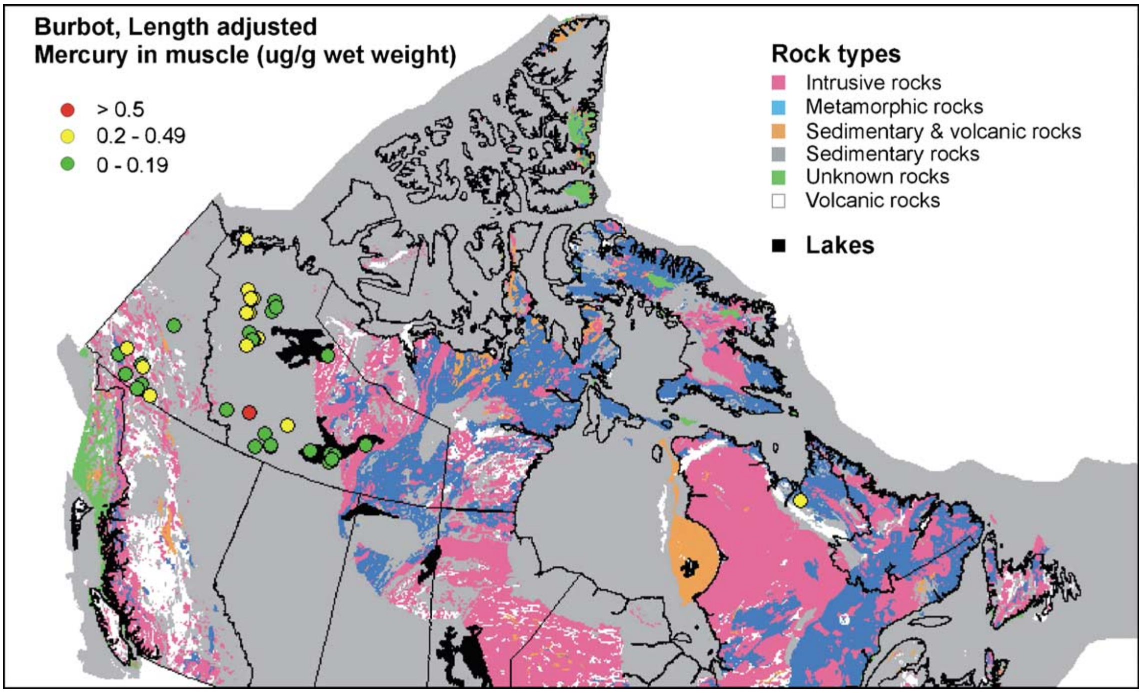

Fig. 6. Ranges of mercury in muscle of burbot (μg g^{-1} wet weight). Green dots, mercury in the range below 0.2 μg g^{-1}; yellow dots, mercury in the range between 0.2 and 0.5 μg g^{-1}; red dots, mercury greater than 0.5 μg g^{-1}.

(Fox, 4 fish in 1993 and Teslin, 4 fish in 1977) averaged 0.22 μg g^{-1}. There was no obvious suggestion that the 6 sites in non-sedimentary rock had a higher proportion of values over a recommended limit than sites in sedimentary rock.

3.2.7. Mercury in muscle of other species

The data include information on more restricted numbers of several other species that are not as widely used for human consumption. Some samples were not identified unambiguously to species. For example, some were identified as "sucker" or "whitefish" and these are shown with the common name followed by "unspecified". Means and sample numbers for the different locations are included in Table 2. Species are identified by code letters in Table 3. With the exception of fish from Giauque Lake, all of the arithmetic averages tabulated for these species fell below the guideline of 0.5 μg g^{-1} for commercial fish and most fell below the guideline for subsistence consumption as well. Longnose sucker, sucker unspecified and fourhorn sculpin exceeded the lower guideline. A sample of three greenland sharks from Pangnirtung had an average of 0.97 μg g^{-1} but these were excluded from the table because biological data were missing. A number of these species were extremely low in mercury, namely Pacific herring, dolly varden ($n = 1$), arctic grayling, (Atlantic) salmon, broad whitefish, chum salmon and least cisco, all with levels under 0.1 μg g^{-1}. Arctic cod had among the lowest levels but these were not tabulated because of missing biological data. The 3 fourhorn sculpins from southeastern Hudson Bay had a mean of 0.209 μg g^{-1}. Other values in that range have been obtained for fourhorn sculpins (250 mm length, 0.1 to 0.55 μg g^{-1}) in James Bay (Schetagne and Verdun, 1999). These values may have been influenced by the escape of mercury from hydroelectric facilities there.

Most collections of inconnu had values below the consumption recommendation of 0.2 μg g^{-1}. However, a few collections did exceed the guideline, notably the samples from Kelly Lake, from the Peel River near Fort McPherson (Snowshoe and Stephenson, 2001), and a single remarkable fish from the Porcupine River in the Yukon in 1977 with a value of 0.97 μg g^{-1}. Round whitefish, represented by 41 fish, had the low average of 0.09 μg g^{-1} although McCrea Lake had a high value of 0.53 μg g^{-1} for this species. All of the species of salmon had very low means, the highest being 0.09 for a single chinook salmon from the Porcupine River, YT, in 1977.

The average for the 81 longnose suckers was 0.108 μg g^{-1} and that for white suckers was 0.099 μg g^{-1}, consistent with the feeding habits of these species (Table 2). The unspecified sucker species had a higher average of 0.212 μg g^{-1}; this group consisted of 15 individuals from the Koksoak River, Quebec, for which the mean was 0.231 μg g^{-1}, well over the recommendation for subsistence consumption.

4. Summary

Mercury was found at measurable levels in muscle of fish of all species sampled from all locations sampled. Some of the lowest values were in fish that feed in the sea rather than in freshwater locations where they were caught (e.g. migratory salmon, char, herring). However, feeding in the sea is not a guarantee of low values because a few fourhorn sculpins had levels over 0.2 μg g^{-1}. Three greenland sharks had values over the higher guideline of 0.5 μg g^{-1} although biological data on them were not available and they were excluded from the tables. Results have been presented showing arithmetic means since these are the values used to evaluate the suitability of fish for human consumption. The results have been presented also as length-adjusted means for the 6 major species since these means offer some advantages, at least in principle, for comparing among different sites when the fish are of different sizes.

Temporal differences within sites were examined statistically and a number of differences were identified. Most of the comparisons involved collections not separated by many years. Sometimes differences indicated that values in more recent collections were higher than earlier ones, and sometimes they were lower. Mostly differences were too small to be identified with statistical confidence. There was no indication of any consistent regional trend to higher or lower levels of mercury in the fish. Some of the comparisons could be points on a regional trend but it will take future data to discriminate any trends from normal sampling variation from year to year.

Overall, excluding the very high values from Giauque Lake, the presence of mercury in muscle in excess of 0.5 μg g^{-1} in freshwater fish is largely restricted to predator species like lake trout, northern pike and walleye and burbot with some high values from landlocked char. These predator species are distributed widely throughout northern Canada and are widely available to people fishing there. Levels within all three concentration ranges (<0.2; 0.2–0.5; >0.5 μg g^{-1}) were found throughout northern Canada (Figs. 1–6). Less than one third of lake trout had length-adjusted values for mercury less than 0.2 μg g^{-1}. The problem with mercury in lake trout was somewhat more severe within Nunavut where only 5 of 22 means fell in the low range. About one third of northern pike length-adjusted means were in the range for unrestricted consumption; catches of this species were almost all from the Yukon and Northwest Territory. Most of the catches from the Yukon had length-adjusted means in the lowest range whereas most from the Northwest Territory were in one or the other of the higher ranges. Some 54 of 75 collections exceeded the lower recommended level. Walleye had some of the highest values recorded with 18 of locations having length-adjusted means in the two higher ranges. All the walleye were from the Northwest Territory. Burbot were generally less contaminated than the other predator species, with more than half the length-adjusted means (24 of 39) falling below the consumption guidelines. Lake whitefish displayed the opposite pattern with 69 of 81 collections having length-adjusted means below 0.2 μg g^{-1}. The situation with anadromous arctic char was similar to whitefish with 53 of 55 collections in the lowest concentration range. Most of the char samples were from anadromous populations and almost certainly the low levels found were the result of feeding at sea and the few high values were from landlocked populations.

A strong local source of mercury at Giauque Lake has resulted in all species accumulating high levels. A few other lakes have high levels of mercury in several species, although the reasons for this are not established (e.g. Parker, McCrea, Ste. Therese).

We have very limited information on marine fish but these appear to have relatively low levels of mercury, except for greenland sharks. These sharks probably occupy a trophic position similar to seals and toothed whales; they live a very long time and eat fish. At least two species from southeastern Hudson Bay or James Bay appear to have high levels of mercury also; it has been suggested that this may be the result of the export of mercury from hydroelectric impoundments draining into James Bay. The Pacific herring and all species of salmon taken in Arctic drainages had very low levels of mercury, again presumably reflecting marine food chains.

The geological maps presented as backgrounds in Figs. 1–6 allow preliminary examination of regional bedrock geology as a potential contributor to the variation of mercury in fish. The apparently higher values of mercury in Nunavut in lake trout may reflect the fact that much more of the mainland portion of Nunavut is in areas of metamorphic and intrusive bedrock. Limited data only are available on the measured levels of mercury in lake and stream sediments (e.g. Painter et al., 1994). While these limited data give good coverage for a few locations, only a small proportion of northern Canada was covered and few of our collection sites occur in the areas described. Numerous types of geological descriptors and sub-descriptors are available in georeferenced format (e.g. ages of rocks, fault lines, etc.) for Canada and the one selected for this initial analysis was bedrock type. This is a relatively simple descriptor which includes a few rock types only. Nonetheless it did suggest that higher levels in predators like lake trout and northern pike may occur with increasing frequency in non-sedimentary rocks. The nature of the associations with rock type might be described better as a hypothesis for future testing than as a firm conclusion.

The use of geological maps at a higher scale of resolution might help to test this potential association. For example, Kaminak Lake is placed in the intrusive rock category by the mapping software, but the more detailed description by Shilts and Coker (1995) is much more complex. Any association between mercury in fish and rock type is likely to be complex. The reasons for any such association between mercury in fish and geological settings are speculative and may involve limnological variables associated with bedrock, not just the bedrock type. Preliminary efforts at explaining the variation in mercury levels in fish from a subset of these sites based on limnological and biological variables have been reported by Evans et al. (2005).

Also, as mentioned above, an association between mercury in fish and bedrock type may reflect regional differences not only in bedrock types but also in fluxes of atmospheric mercury. Lockhart et al. (1998) suggested that recent inputs of mercury to lake sediment cores was greater in lakes from the eastern mainland area of northern Canada than to the western part or to the high arctic islands. This coincides approximately with areas of metamorphic and intrusive rocks. Based on the sediment profiles, a flux of mercury of the order of 2 μg m^{-2} $year^{-1}$ from the atmosphere might be hypothesized. One might hypothesize that external mercury is processed differently in lakes with different geological settings. It has been established through experiments at the Experimental Lakes Area on northwestern Ontario that mercury appears in the fish quickly after it is added to the water column of a lake (J. Rudd, personal communication). However, future work will be required to establish whether atmospheric mercury is sufficient to make a measurable change in the levels in the fish.

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