5 Impacts of mercury on the environment

5.1 Overview

Build-up of mercury in food webs

337. A very important factor in the impacts of mercury to the environment is its ability to build up in the organisms and up along the food chain. Although all forms of mercury can accumulate to some degree, methylmercury is absorbed and accumulates to a greater extent than other forms. Inorganic mercury can also be absorbed, but is generally taken up at a slower rate and with lower efficiency than is methylmercury (US EPA, 1997). The biomagnification of methylmercury has a most significant influence on the impact on animals and humans. Fish appear to bind methylmercury strongly, nearly 100 percent of mercury that bioaccumulates in predator fish is methylmercury. Most of the methylmercury in fish tissue is covalently bound to protein sulfhydryl groups. This binding results in a long half-life for elimination (about two years; Wiener and Spry, 1996). As a consequence, there is a selective enrichment of methylmercury (relative to inorganic mercury) as one moves from one trophic level to the next higher trophic level.

Bioaccumulation and biomagnification

The term **bioaccumulation** refers to the net accumulation over time of metals within an organism from both biotic (other organisms) and abiotic (soil, air, and water) sources.
The term **biomagnification** refers to the progressive build up of some heavy metals (and some other persistent substances) by successive trophic levels – meaning that it relates to the concentration ratio in a tissue of a predator organism as compared to that in its prey (AMAP, 1998).

338. In contrast to other mercury compounds the elimination of methylmercury from fish is very slow (US EPA, 1997). Given steady environmental concentrations, mercury concentrations in individuals of a given fish species tend to increase with age as a result of the slow elimination of methylmercury and increased intake due to changes in trophic position that often occur as fish grow to larger sizes (i.e., the increased fish-eating and the consumption of larger prey items). Therefore, older fish typically have higher mercury concentrations in the tissues than younger fish of the same species.

339. The mercury concentrations are lowest in the smaller, non-predatory fish and can increase many-fold on the way up the food chain (AMAP, 1998). Apart from the concentration in food, other factors affect the bioaccumulation of mercury. Of most importance are the rates of methylation and demethylation (see section 2.3) by mercury methylating bacteria (e.g., sulphate reducers). When all of these factors are combined, the net methylation rate can strongly influence the amount of methylmercury that is produced and available for accumulation and retention by aquatic organisms. As described in section 2.3, several parameters in the aquatic environment influence the methylation of mercury and thereby its biomagnification. While much is generally known about mercury bioaccumulation and biomagnification, the process is extremely complex and involves complicated biogeochemical cycling and ecological interactions. As a result, although accumulation/magnification can be observed, the extent of mercury biomagnification in fish is not easily predicted across different sites.

340. At the top levels of the aquatic food web are fish-eating species, such as humans, seabirds, seals and otters. The larger wildlife species (such as eagles, seals) prey on fish that are also predators, such as trout and salmon, whereas smaller fish-eating wildlife (such as kingfishers) tend to feed on the smaller

forage fish. In a study of fur-bearing animals in Wisconsin, the species with the highest tissue levels of mercury were otter and mink, which are top mammalian predators in the aquatic food chain. Top avian predators of aquatic food chains include raptors such as the osprey and bald eagle (US EPA, 1997). Thus, mercury is transferred and accumulated through several food web levels (US EPA, 1997). Aquatic food webs tend to have more levels than terrestrial webs, where wildlife predators rarely feed on each other, and therefore the aquatic biomagnification typically reaches higher values.

Mercury compounds toxic to wildlife

341. Methylmercury is a central nervous system toxin, and the kidneys are the organs most vulnerable to damage from inorganic mercury. Severe neurological effects were already seen in animals in the notorious case from Minamata, Japan, prior to the recognition of the human poisonings, where birds experienced severe difficulty in flying, and exhibited other grossly abnormal behaviour. Significant effects on reproduction are also attributed to mercury, and methylmercury poses a particular risk to the developing fetus since it readily crosses the placental barrier and can damage the developing nervous system.

342. In birds, adverse effects of mercury on reproduction can occur at egg concentrations as low as 0.05 to 2.0 mg/kg (wet weight). Eggs of certain Canadian species are already in this range, and concentrations in the eggs of several other Canadian species continue to increase and are approaching these levels.

343. The levels of mercury in Arctic ringed seals and beluga whales have increased by 2 to 4 times over the last 25 years in some areas of the Canadian Arctic and Greenland (Muir *et al.*, 2001; Wagemann *et al.*, 1996). In warmer waters as well, predatory marine mammals may also be at risk. In a study of Hong Kong's population of hump-backed dolphins, mercury was identified as a particular health hazard, even more than other heavy metals.

Vulnerable ecosystems

344. Recent evidence suggests that mercury is responsible for a reduction of micro-biological activity vital to the terrestrial food chain in soils over large parts of Europe – and potentially in many other places in the world with similar soil characteristics. Preliminary critical limits to prevent ecological effects due to mercury in organic soils have been set at 0.07-0.3 mg/kg for the total mercury content in soil. (Pirrone *et al.*, 2001)

345. On the global scale, the Arctic region has been in focus recently because of the long-range transport of mercury. However, impacts from mercury are by no means restricted to the Arctic region of the world. The same food web characteristics - and a similar dependence on a mercury contaminated food source - are found in specific ecosystems and human communities in many countries of the world, particularly in places where a fish diet is predominant.

346. Rising water levels associated with global climate change may also have implications for the methylation of mercury and its accumulation in fish. For example, there are indications of increased formation of methylmercury in small, warm lakes and in many newly flooded areas.

347. This chapter is not intended to provide a comprehensive synthesis of the literature on mercury exposure, effects and risks to ecological receptors. Rather it represents a summary of selected reviews of the topic, as well as data and comments submitted during the drafting process.

348. Different parts of the descriptive text in this chapter were based on Pirrone *et al.* (2001), US EPA (1997), the Canadian government submission of information to UNEP (sub42gov) and the submission from the Nordic Council of Ministers (sub84gov).

5.2 Eco-toxicological effect levels

349. Over the years numerous scientific papers, reports and reviews have been published on mercury and methylmercury toxicity and ecotoxicity. The reader is referred to the comprehensive coverage in the WHO IPCS Monographs on Mercury (WHO/IPCS, 1991), Methylmercury (WHO/IPCS, 1990) and Mercury - Environmental Aspects (WHO/IPCS, 1989) for detailed information. In this text a broader perspective is adopted in combination with some of the data from the recent decade as compiled in reviews (US EPA, 1997; Pirrone *et al*., 2001; the Canadian submission to UNEP (sub42govatt1); and others).

350. This section will primarily focus on the mercury concentrations and doses resulting in effects in individual organisms. The data are mostly laboratory results or from epidemiological studies. Despite a number of field investigations of the potential effects of mercury on free-living aquatic and terrestrial wildlife, the effects of mercury at higher levels of biological organization (e.g., ecosystem, community, population) are not well understood, as indicated in the review by US EPA (1997).

351. Mercury exposure may result in severe neurological effects, and this was seen in Minamata, Japan, from about 1950-1952 (prior to the recognition of human poisonings), where birds experienced severe difficulties in flying, and exhibited other grossly abnormal behaviour (US EPA, 1997). Signs of neurological disease including convulsions, fits, highly erratic movements (mad running, sudden jumping, bumping into objects) were observed among domestic animals, especially cats whose diets were high in seafood.

5.2.1 Mammals

352. The bulk of data on mammals have been generated through laboratory experiments on mice, rats and other typical laboratory animals, for the evaluation of risk for humans. These findings are not evaluated in this text, where wildlife species are the main focus.

353. Laboratory studies under controlled conditions have been used to assess the effects of methylmercury (from a fish diet) on mink and otter (and several avian species). According to the US EPA (1997), effects can occur at a dose of 0.18 mg/kg body weight per day or 1.1 mg/kg methylmercury in diet (LOAEL established by US EPA for mink from Wobeser *et al.*, 1976). Death may occur in species at 0.1-0.5 mg/kg body weight per day or 1.0-5.0 mg/kg in the diet. Smaller animals (for example, minks, monkeys) are generally more susceptible to mercury poisoning than are larger animals (for example, mule deer or harp seals).

354. The US EPA has developed methylmercury wildlife criteria for two mammal species in the USA (mink and otter) relying on an aquatic diet (US EPA, 1997). The wildlife criteria are based on a methylmercury level in water (from which the animals get their food) that is thought not to harm the species. The criteria were calculated from effect concentrations (LOEL and NOEL) and bioaccumulation factors.

355. The derived Mammalian Wildlife Criteria for methylmercury were 57 picograms per litre (pg/l) for mink and 42 pg/l for river otter. The US EPA noted that the criteria reflect effect levels that are just over two orders of magnitude higher than those forming the basis for their human reference dose, and that the wildlife criteria do not cover more subtle effects like those observed in humans recently (US EPA, 1997).

356. It should be mentioned that methylmercury is rarely measured in water, and that concentrations in the Wildlife Criteria are extraordinarily difficult to measure. Recent total mercury concentrations in unpolluted (only diffuse load) surface water are reported in the range of 0.1 to 5 ng/l. A number of studies have shown that methylmercury typically amounts to 1-10 percent of total mercury in water. Assuming a mercury concentration of 1 ng/l in the water, methylmercury will range from 10-100 pg/l and it will thus not be uncommon to exceed the Wildlife Criteria.

357. Lethal or harmful effects in marine and terrestrial mammals are reported in AMAP (1998) when mercury concentrations exceed 25 to 60 mg/kg wet weight in kidneys and liver. Methylmercury is a central nervous system toxin and the kidneys are the organs most vulnerable to damage from inorganic mercury. Significant effects on reproduction are attributed to mercury, but in particular methylmercury poses a risk to the developing fetus since it readily crosses the placental barrier (AMAP, 1998).

5.2.2 Birds

358. Eggshell thinning in birds was observed in the 1950's and 1960's as some of the first environmental consequences of the spreading of mercury (and other environmental toxins); in this case methylmercury was used as seed dressing, and severe poisoning of wildlife was observed in Scandinavia and North America. The populations of pheasants and other seed-eating birds, as well as birds of prey (e.g. hawks and eagles), were drastically reduced and in some areas nearly disappeared (Ramel, 1974). Therefore birds, feathers and eggs have been used since then for monitoring the effects of mercury, and a number of effect values are available.

359. Acutely poisoned birds usually have whole body residues of mercury in excess of 20 mg/kg wet weight (US EPA, 1997).

360. Burger and Gochfeld (1997) quote a number of studies relating concentrations of mercury in eggs to a variety of effects in birds, particularly reduced hatchability, chick survival and other reproductive failures. The effect concentrations range from 0.05-5.5 mg/kg wet weight in eggs with the majority around 0.5-1.0 mg/kg wet weight, see table 5.1. It should be noted that effect levels vary among species, depending on their feeding preferences, for example, and that extrapolation to other species should be done with caution.

Table 5.1 Summary of acute and other adverse mercury effect levels in birds.

Level	Concentration	Reference
Acute effects level		
Whole body residue	20 mg/kg wet weight	US EPA, 1997
Other adverse effect levels		
Eggs	0.5-2.0 mg/kg wet weight	Canadian submission, sub42gov
Eggs	0.05-5.5 mg/kg wet weight	Burger and Gochfeld, 1997
Feathers (laboratory data)	5-65 mg/kg dry weight	Burger and Gochfeld, 1997
Fish diet	0.3-0.4 mg/kg wet weight (in fish)	Scheuhammer *et al*., 1998 in Pirrone *et al*., 2001.
Fish diet (field studies)	0.2 - 0.4 mg/kg wet weight	Various sources quoted in Canadian submission, sub42gov (see text below).
Fish diet (laboratory data)	> 0.5 mg/kg wet weight	Sources quoted in Canadian submission, sub42gov (see text below).

361. In particular, the ability of birds to demethylate methylmercury (which may be related to their dietary preference – fish diet versus vegetable diet) has important implications for avian risk assessment since most tests have been conducted on non-fish-eating species. In addition, the confounding effects of co-exposure to selenium on methylmercury toxicity should be mentioned, as selenium has been shown in laboratory studies to elicit protective and in some cases antagonistic effects on mallards depending on the life stage (US EPA, 1997).

362. Sensitivity to mercury toxicity is species specific, making it difficult to predict toxic thresholds for mercury in eggs of seabirds. Nevertheless, laboratory studies on other bird species indicate that adverse effects of mercury on reproduction can occur at egg concentrations as low as 0.5 to 2.0 mg/kg wet wt. (Burgess and Braune, 2001). The eggs of Leach's Storm-Petrel are already in this range of mercury concentrations, and concentrations in the eggs of several other Canadian species continue to increase and are approaching these levels.

363. Concentrations of mercury in feathers associated with adverse effects are reported in the range 5-65 mg/kg dry weight (Burger and Gochfeld, 1997), see table 5.1.

364. In controlled feeding studies concentrations of mercury down to 0.5 mg/kg wet weight in the diet have been shown to produce reproductive and behavioural effects. Field studies on free-living common loons indicate negative impacts when mercury in prey fish reaches 0.2 - 0.4 mg/kg wet weight (Barr, 1986; Nocera and Taylor, 1998; Scheuhammer, 1995).

365. It has been suggested (though not proven) that methylmercury may cause immuno-toxicological effects and increased prevalence of chronic diseases in great white herons (Spalding *et al.*, 1994). This is consistent with immunotoxic findings of methylmercury in laboratory mammals, and may be a particularly important consequence of methylmercury exposure to wildlife populations, which frequently encounter infectious diseases (USA, comm-24-gov). For reviews on immunotoxicological and histopathological effects of methylmercury on wild birds, see Wolfe *et al.* (1998) and Spalding *et al.* (2000).

366. Wildlife criteria for birds were established by the US EPA for kingfisher, loon, osprey and bald eagle, and range from 33 to 100 pg methylmercury/l water, see table 5.2. The US EPA noted that the criteria reflect effect levels that are just over two orders of magnitude higher than those forming the basis for the human reference dose, and that the wildlife criteria do not cover more subtle effects like those recently observed for humans (US EPA, 1997).

Table 5.2 Wildlife Criteria for methylmercury in water (US EPA, 1997).

Organism	Wildlife Criterion (pg/l) *
Kingfisher	33
Loon	82
Osprey	82
Bald eagle	100

Note: * 1 pg (picogram) is 10^{-12} g.

5.2.3 Fish

367. While toxic levels in adult fish are believed to occur at levels well above those typically encountered in the environment (except in grossly polluted systems), recent evidence suggests that mercury exposure to early life stages in some fish can affect growth, development and hormonal status at levels within a factor of 10 of levels encountered in "pristine" lakes (i.e., lakes where there are no known mercury point sources; US EPA, 1997*(Volume VI)*; Friedman *et al.*, 1996; Wiener and Spry, 1996). Furthermore, Wiener and Spry (1996) concluded that while direct waterborne exposure to methylmercury is generally not a serious concern to adult fish, effects from indirect exposure via dietary uptake and maternal transfer of methylmercury to eggs and developing embryos occur at 1 percent of levels affecting adult fish, and may be a concern (i.e., embryo mortality in lake trout eggs at 0.07 - 0.10 µg/g w.w. versus toxicity in adults at 10-30 µg/g). Although not conclusive, they further suggest that the reproductive success of some walleye populations may be impaired by existing levels of mercury exposure (USA, comm-24-gov).

368. Mercury concentrations and biomagnification in fish have been assessed extensively due to the risks of mercury to humans through fish in the diet. In general, acute toxicity (96 hour LC_{50}) ranges from 33-400 µg/l for freshwater fish, with seawater fish being less sensitive (WHO/IPCS, 1989).

5.2.4 Micro-organisms

369. Mercury is toxic to micro-organisms and has long been used to inhibit the growth of bacteria in laboratory experiments (WHO/IPCS, 1990). Effects of inorganic mercury have been reported at concentrations of 5 µg/l in cultures of micro-organisms, and of organic mercury compounds at concentrations

at least 10 times lower (WHO/IPCS, 1991). As mentioned, organic mercury compounds have been used as fungicidal seed dressings.

370. Investigations in temperate forest soils have shown that adverse effects on microbial processes can be expected at concentrations corresponding to the present level increased by a factor of about 3. (Rundgren *et al.*, 1992 ; Tyler, 1992, in Pirrone *et al.*, 2001). Recent research indicates, however, that impacts may already be evident in soils over large parts of Europe (Johansson *et al.*, 2001; Johansson, 2001) – and potentially in many other places in the world with similar soil characteristics.

371. Recently, preliminary critical limits to prevent ecological effects from mercury in organic soils have been set to 0.07–0.3 mg/kg for the total mercury content in soil. The limits were developed by an international expert group on effect-based critical limits for heavy metals, working within the framework of the UN ECE Convention on Long-Range Transboundary Air Pollution (Curlic *et al.*, 2000; quote from Pirrone *et al.*, 2001). The bioavailability of mercury in soil has a strong influence on its toxicity. This means that mainly the water-dissolved fraction of the mercury present is the determining factor for its toxicity in soil environments.

5.2.5 Other species

372. Aquatic plants are affected by mercury in the water at concentrations approaching 1 mg/l for inorganic mercury, but at much lower concentrations of organic mercury (WHO/IPCS, 1991). High concentrations of inorganic mercury affect macroalgae by reducing the germination (AMAP, 1998).

373. Aquatic invertebrates vary greatly in their susceptibility to mercury. Generally, larval stages are more sensitive than adults. In 48-hour exposures, 50 percent mortality in larvae often occur at concentrations around 10 µg/l, which typically is 100 times lower than in adults. Oyster larvae are even more sensitive to mercury (WHO/IPCS, 1989). Toxicity is also affected by temperature, salinity, dissolved oxygen, and water hardness (Boening, 2000).

374. For other classes of animals (e.g. reptiles, amphibians), little data exist from which to draw conclusions regarding risk levels. Several species (e.g. alligator, snapping turtle) are expected to experience significant methylmercury exposure due to their piscivorous feeding habits. Some data on residues in alligators are available, but corresponding effect levels are lacking (USA, comm-24-gov).

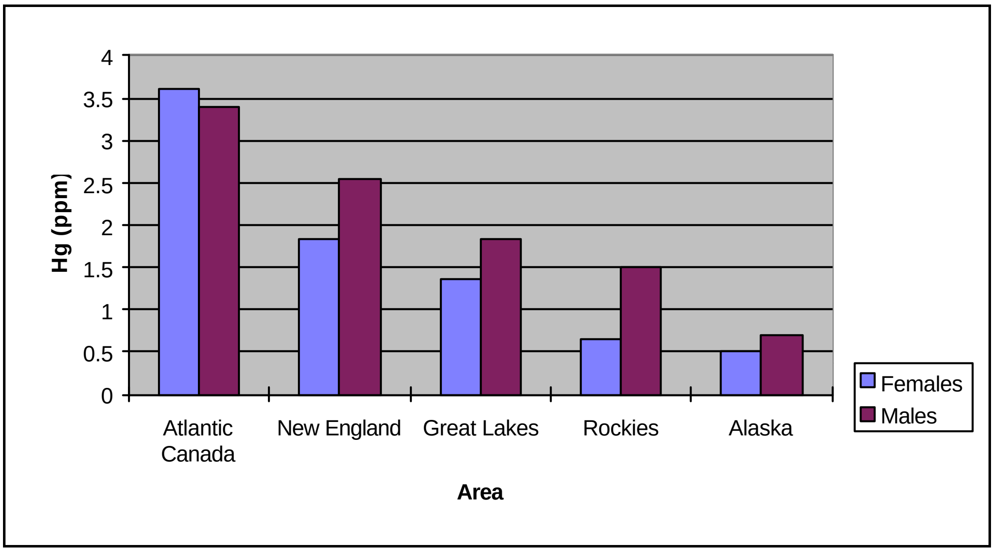
375. There is very limited information on toxicity in the terrestrial environment, apart from the mammals, birds and the recent micro-organism data. Terrestrial plants are fairly insensitive to the toxic effects of mercury compounds. Mercury is, however, accumulated in higher plants, especially in perennials (Boening, 2000). The primary effect observed in plants is associated with root tips (Boening, 2000).

5.3 Ecosystems at risk and vulnerable species

376. This section describes the increased risks to ecosystems and to various species due to the specific properties of mercury and the environment. On the global scale, the Arctic region has been in focus recently because of mercury's particular tendency to long-range transport. It is important to acknowledge, however, that impacts of mercury are by no means restricted to the Arctic region. The same food web characteristics and similar dependence on a mercury contaminated food source are found in specific ecosystems and human communities in many countries around the world, particularly where a fish diet is predominant. Consequently, fish-eating birds and mammals are more highly exposed to mercury than any other known denizens of the aquatic ecosystem (Pirrone *et al.*, 2001).

377. In the absence of a specific local mercury source, the pattern of mercury deposition over a country or continent strongly influences which eco-regions and eco-systems are more highly exposed.

378. For example, in Canada and the Northern USA the mercury levels in loons decreases from east to west (Canadian submission, sub42gov), see figure 5.1.



Source: Burgess, 1998; Evers *et al*., 1998 in the Canadian submission sub42gov.
(ppm = mg/kg)

Figure 5.1 Mean mercury levels in loon blood in Canada and the Northern USA from East to West (Canadian submission, sub42gov)

5.3.1 Aquatic food webs

Marine environment

379. The top marine predators are especially vulnerable to mercury exposure for reasons previously discussed. The levels of mercury in Arctic ringed seals and beluga whales have increased 2- to 4-fold over the last 25 years in some areas of the Canadian Arctic and Greenland (Muir *et al*., 2001; Wagemann *et al*., 1996). However, it is not yet fully understood how much of the mercury found in the biological environment is derived from natural sources versus human activity.

380. In warmer waters as well, predatory marine mammals may be exposed to mercury levels that are health threatening. In a study of Hong Kong's population of hump-backed dolphins, mercury was identified as a particular health hazard, even more than other heavy metals (Parsons, 1998).

381. Recent knowledge points to the sub-surface parts of the oceans, which are low in oxygen, as a source of conversion of mercury to methylmercury, fueling the latter's bioconcentration in fish and food web. Concentrations of methylmercury in fish species increased 4-fold from a depth of less than 200 m to more than 300 m, with no further increases, however, even down to about 1200 m (Monteiro *et al.*, 1999).

Freshwater environments

382. In their recent report, the US EPA (1997) presented a number of characteristics of the freshwater ecosystems that are most at risk from airborne releases of mercury:

- They are located in areas where atmospheric deposition of mercury is high;
- They include surface waters already affected by acid deposition;
- They possess characteristics other than low pH that result in high levels of bioaccumulation; and/or
- They include sensitive species.

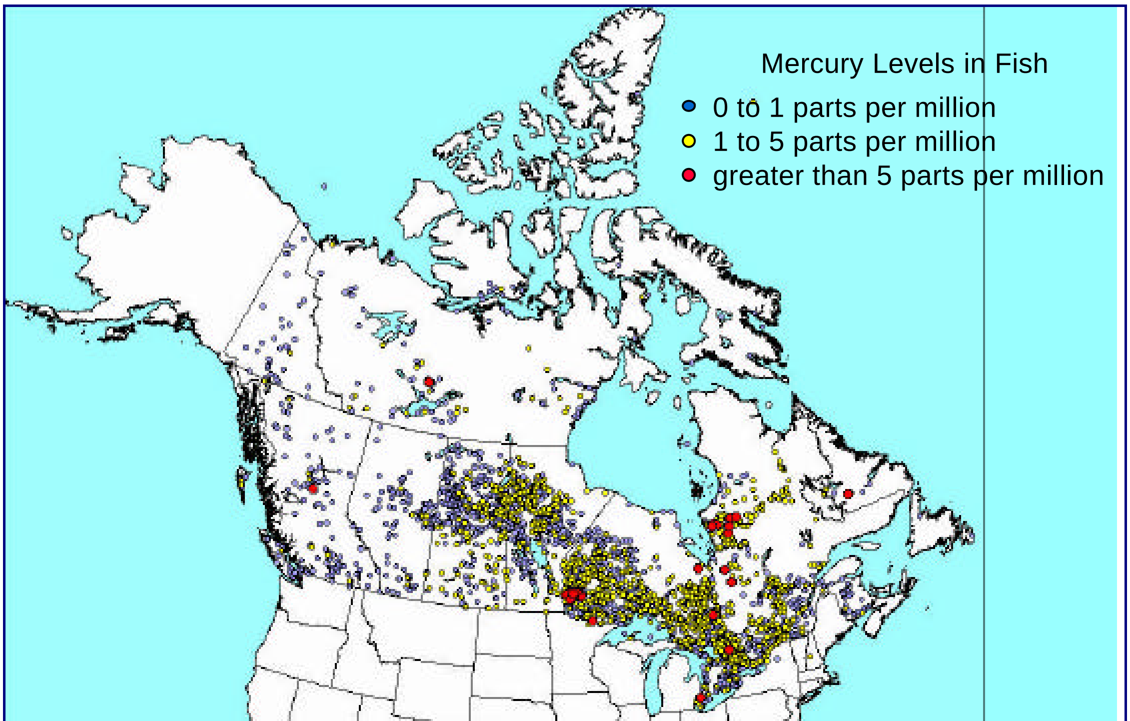
383. It could be added, for other parts of the world, that freshwater bodies subject to local direct releases of mercury are also at risk.

384. The Canadian environmental authorities likewise recognise that "fish-eating species in regions with higher mercury deposition, and in areas that favour methylation such as partially acidified water-

sheds, watersheds with large wetlands high in dissolved organic carbon, and reservoirs, are expected to be most at risk from increased dietary mercury exposure” (Canadian submission, sub42govatt1).

385. Surveys have shown that approximately 30 percent of Ontario lakes sampled contained small fish (<250 g) with mercury concentrations averaging more than 0.3 ppm, the level suggested as the dietary threshold for severe reproductive impairment in fish-eating birds (loons) (Scheuhammer and Blancher, 1994, in Canada submission, sub42gov).

386. The map in figure 5.2 (subject to updates, with additional data for Atlantic Canada forthcoming) indicates, by range, the mercury concentrations in freshwater fish from 3,200 different locations in Canada.



The Canadian National Database for Mercury Levels in Freshwater Fish has information for over 3200 locations. Many areas have naturally high levels of mercury due to local geology or other factors. Areas without coloured dots have not been sampled for mercury.

Source: Draft Status and Trends Report, Environment Canada, 2001.

Figure 5.2 Mercury levels in freshwater fish in Canada (Canadian submission, sub42gov).

Climate changes

387. Other factors remaining constant, mercury contamination of fish tends to be higher in small lakes than in large lakes. This may be explained by small lakes being warmer, increasing the methylation of mercury. This relationship may have further important implications for the methylation of mercury and its accumulation in fish in the context of long-term climate change (Canadian Dept. of Fisheries and Oceans, 1998).

388. Also, rising water levels and newly flooded areas, which might occur as a result of climate change, could possibly influence the rate at which mercury is released and methylated, as such events have been shown to be a source of increased mercury release and methylmercury formation (Canadian submission, sub32gov, and Canadian comments, comm-20-gov).

5.3.2 The terrestrial food web

389. Historically, the use of organic mercury compounds for agricultural seed dressing has resulted in mercury exposures of seed-eaters, particularly birds and rodents (Fimreite, 1970; Johnels *et al.*, 1979, in Pirrone *et al.*, 2001). Where the use of mercury-coated seeds continues, some impact on the terrestrial environment is expected.

390. Until recently, inorganic mercury was not considered a major source of effects in the soil compartment because it is bound to the soil particles and is not very bioavailable to plants or organisms. In fact, the uptake of gaseous elemental mercury through leaves is much more efficient than the uptake of soil mercury (Hg(II)) in roots, and the main exposure of plants may therefore be through the air.

391. New studies from both the field and laboratory have shown that a mercury-related reduction of microbiological activity in soils is likely taking place in southern Sweden (Bringmark and Bringmark 2001a; 2001b; Palmborg *et al.*, 2001; all in Pirrone *et al.*, 2001). The findings in Sweden and in other countries show that the microbiological activity in the topsoil appears to be very sensitive to the mercury burden, and that significant impacts may already be taking place in forest soils over large parts of Europe – and potentially in many other places in the world with similar soil characteristics (Johansson *et al.*, 2001; Johansson, 2001; all in the submission from the Nordic Council of Ministers (sub84gov).

392. The microbiological activity in soil is vital to the processing of carbon and nutrients in the soil, and the health of the microbiological community has a great effect on the living conditions of trees and soil organisms, which form the basis for the terrestrial food chain.

5.3.3 Arctic region

393. The Arctic region is affected by long-range transported mercury. In the Arctic sediments mercury shows increasing concentrations, and there is some evidence that the concentration in some marine mammals has increased by a factor of 2- to 4-fold over the last 25 years in some areas of the Canadian Arctic and Greenland (Muir *et al.*, 2001; Wagemann *et al.*, 1996; both in Canadian submission, sub42gov). To what extent that is due to increased mercury levels, or to increases in the fraction of the total mercury that is bio-available - a possible outcome of the current warming trend and increased biotic activity in the Arctic - is a subject of current discussion in AMAP (Canadian comments, comm-20-gov). The Arctic marine food web is often in the spotlight regarding the risk to ecosystems and the impact on human populations from mercury. In the Arctic, the aquatic food web is very long, with three levels of predators (including humans) at the top, and therefore high concentrations of biomagnified mercury occur there.

394. A wealth of information is available on concentrations and trends for mercury, particularly from AMAP, which published a comprehensive assessment report in 1998, with another assessment report due in 2002/2003. However, it remains uncertain whether mercury poses a health threat to the most highly exposed groups of Arctic marine mammals.

395. Accumulation and exposure of top predators also occurs in subarctic and temperate regions where the biomagnification is seen most clearly in aquatic environments (US EPA, 1997). The animals considered at most risk of adverse effects from mercury are again the species depending on a diet of fish (e.g. otters, seals, eagles) or a diet of the fish-eating species (e.g. bears).

396. For comparison, figure 5.3 shows mercury concentration levels found in different tissue types from Arctic fish, birds and mammals. Note that concentrations are presented on a logarithmic scale, meaning that large differences in concentrations between trophic levels visually appear small. The figure was developed in AMAP (1998).

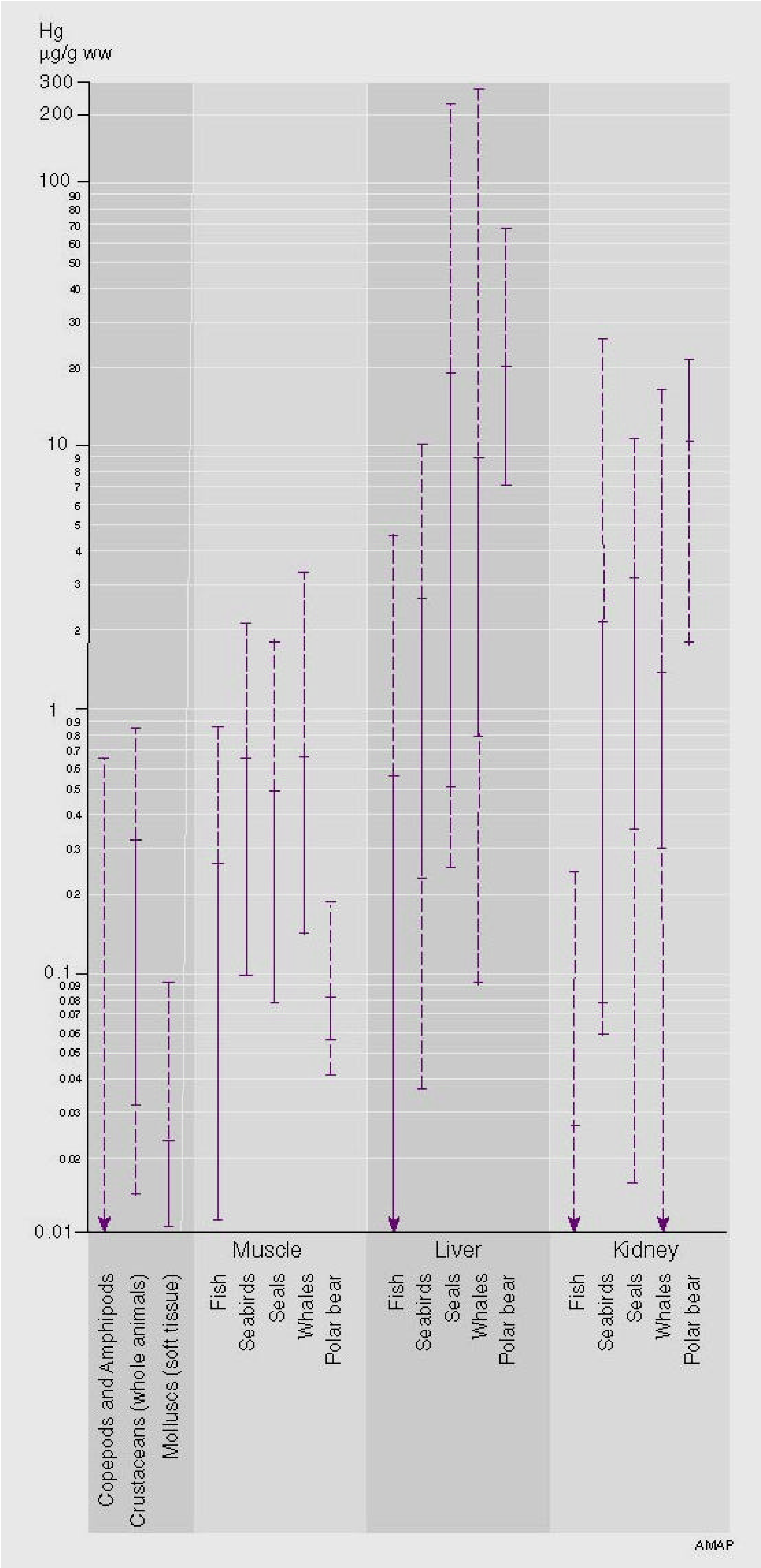


Figure 5.3 *Summary of ranges of mercury concentrations found in Arctic marine organisms (means). Solid parts of the lines indicate ranges for Greenland data from Dietz et al. (2000), where the analytical data have been critically evaluated. The figure with concentration levels was originally produced in AMAP (1998), and is shown here courtesy of AMAP.*

5.3.4 Tropical issues

397. Large quantities of mercury are released to the waters of the Amazon and to the air of vast gold mining areas where mercury is used for amalgamation of the precious metal. This leads to impacts far beyond the local area, as seen in the Pantanal floodplain wetland in western Brazil, and parts of Bolivia and Paraguay (Leady and Gottgens, 2001). Post gold-rush mercury deposition was more than 1.5 times higher than the deposition rate at the Acurizal reference site, confirming a regional mercury effect due to gold mining. Post gold-rush (1980) mercury accumulation in Acurizal was also 2.1 times the rate reported for a global reference during that time period, suggesting an additional basin-wide effect over such reference sites. The authors estimated that only 2-8 percent of the total mercury released from gold mining was secured in sediments. The remainder of the mercury was lost to the atmosphere, downstream areas or stored in biota.

398. Other sources of intermediate increases in mercury mobilisation in tropical rain forests include slash-and-burn clearing of land for agriculture use or for mining operations. These activities permit mercury already present in the soil to be more exposed to mobilising mechanisms.

399. Biologically, there is a general difference between tropical and temperate ecosystems that may make tropical systems more vulnerable. In tropical ecosystems, more species are sustained and the niche of each species becomes smaller. In both ecosystems the top predators are the vulnerable species, but there are relatively fewer of each species in the tropics and this will magnify the effect of loss of individuals (Burger, 1997).

5.3.5 Reservoirs and wetlands

400. Reservoirs and wetlands are often mentioned as sources of methylmercury due to the methylation of inorganic mercury in the sediment (Canadian submission, sub42govatt1).

401. According to the Canadian submission (sub42gov), the "creation of reservoirs is an important source of mercury contamination of fish in Canada", because the mercury present in newly flooded land becomes more available, and then more toxic due to the increased rate of conversion to methylmercury. Most fish caught in new reservoirs have mercury concentrations that exceed the consumption limit of 0.2 mg/kg wet weight recommended by Health Canada for people who frequently consume fish (Canadian submission, sub42gov).

402. In an investigation of mercury in feathers of birds from a number of tropical locations, Burger (1997) reported that although fish-eating birds generally had the highest mercury content, a similar content was found in Cattle Egrets from the Aswan dam area, although this species is an insect-eating bird. The author suggested that this may have been caused by more methylmercury in the food web due to a recent flood in the area initiating the methylation process.

403. An experiment in a wetland and pond at the Experimental Lakes Area in Northwestern Ontario demonstrated that natural wetlands are important sites of mercury methylation, and that flooding of wetlands increases methylation rates by a factor of more than 30 (Canadian submission, sub42gov). Increased concentrations of methylmercury were found in water, the food chain and eventually fish. Monitoring of boreal reservoirs indicates that concentrations of methylmercury in fish may return to normal 10 to 50 years after flooding.

5.3.6 Birds of prey and fish-eating birds

404. It is through fish consumption that mercury exposure in fish-eating birds occurs. Fish-eating birds in regions with high mercury in fish may be at risk of reproductive and behavioural affects (Scheuhammer, 1995, in Pirrone *et al.*, 2001).

405. The use of seabirds as biomonitors of marine environmental quality is widely recognised. Environment Canada (2001) stated that because of their widespread foraging habits and long lifespan, sea-

birds integrate mercury exposure over large geographic areas, and may be an excellent bioindicator of trends in long-range atmospheric transport of mercury. With birds the use of non-invasive monitoring strategies, such as collection of feathers and eggs, can be used.

406. The levels of mercury in Canadian Arctic seabird eggs have increased 2- to 3-fold over the last 20 years (Braune *et al.*, 1999), similar to the increases reported in Arctic ringed seals and beluga whales over the same period. In a detailed survey of Canadian conditions, Burgess and Braune (2001) stated already at the time of the investigation that the mercury content in eggs indicated a reproductive risk:

> "Egg mercury levels were highest in Leach's Storm-Petrel and showed the greatest increase over time. Levels and increases over time were similar for Atlantic Puffins, Thick-billed Murres/Brünnich's Guillemots and Northern Fulmars. All these species occupy Arctic or North Atlantic waters year-round and forage offshore. In contrast, mercury levels in Double-crested Cormorant and Black-legged Kittiwake eggs did not increase over time. These species overwinter further south in the Atlantic Ocean. The levels indicate a potential threat to reproduction in some seabird species that will increase if trends continue".

407. Also, the concentrations in feathers have pointed to increasing levels of mercury, geographical distributions, and differences in food preference.

408. Monteiro and Furness (1997) have recently shown that feathers from fish-eating birds, which catch fish from the deeper mesopelagic layer, accumulate higher concentrations of mercury than birds feeding on fish from the upper parts of the water column. Based on comparison with feathers from pre-1931 museum samples, they have shown that the accumulation has also increased by 65-397 percent.

409. In a companion study, Monteiro *et al.* (1999) reported a similar relationship between bird populations in the Portuguese Atlantic islands and mainland colonies. The egg mercury concentrations were typically 1-5 mg/kg dry weight, depending on geographical location and species. These birds from rather isolated locations had egg mercury concentrations well above the lowest adverse effect level of 0.5 mg/kg dry weight proposed by Burger and Gochfeld (1997). Mercury levels in feathers were also higher than the adverse effect level of 5 mg/kg dry weight. Comparing to the adverse effect levels, Burger and Gochfeld (1997) mentioned that the birds of prey and fish-eaters most vulnerable include: hawks and eagles, gulls and skuas, herons and egrets, penguins, albatrosses, ducks, shorebirds, terns, puffins and alcids.

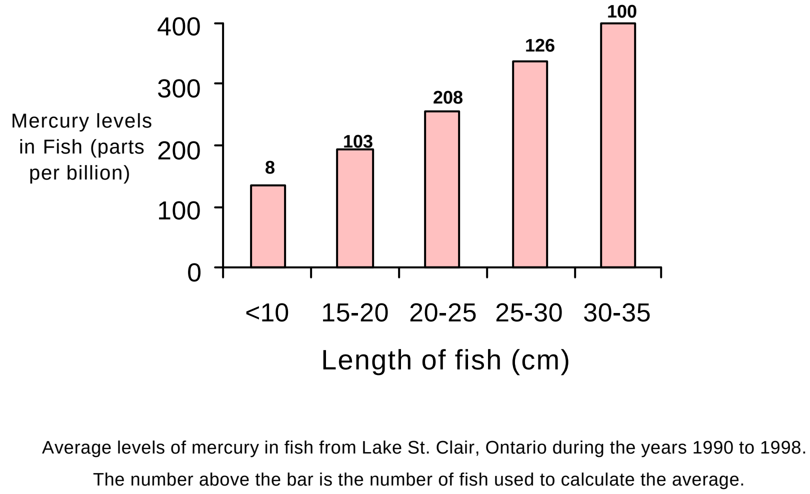
5.3.7 Canadian experience

410. The information in two recent reviews of the Canadian environment (Muir *et al.,* 1999; Braune *et al.,* 1999) provided a very detailed picture of the status and trends for mercury and other contaminants. The following section is built on these references.

411. Polar bears, ringed seals and beluga whales from western Arctic Canada had elevated mercury levels, apparently due to differences in sedimentary geology compared to the eastern Arctic. Belugas in contaminated environments (St. Lawrence estuary) had higher kidney and liver mercury content than belugas from five Arctic locations. Due to the lack of dose/response data for Arctic animals, the data cannot be directly interpreted with respect to impact, but rates of accumulation of mercury are higher (1.5-2.5 times) in recent samples of ringed seals and belugas than they were 10-20 years previously. This is in contrast to cadmium, which in the same period remains unchanged.

412. Levels of mercury in muscle of most species of Canadian Arctic freshwater fish cross the US EPA (1997) threshold (between 0.077 and 0.30 ppm for trophic level three fish) for protection of fish-eating birds and mammals. A number of lakes in the Northwest Territories and Northern Quebec have fish populations with levels exceeding the human consumption guidelines. The higher mercury levels are typically associated with larger, older fish.

413. Figure 5.4 shows average mercury levels in fish from Lake St. Clair, Ontario in southern Canada. Again, higher mercury levels are associated with larger, older fish.



Source:Environment Canada, 2001

Figure 5.4 An example of observed fish mercury concentrations as compared to fish size.

414. Methylmercury is hardly released from fish at all, and methylmercury accounts for approximately 90 percent of the mercury in fish. In comparison with the terrestrial environment, virtually all mercury in the kidneys of caribou is of the less toxic inorganic form.

5.3.8 Ecological risk assessments

415. Numerous ecological risk assessments have been conducted in various places around the world. Table 5.3 contains examples of risk assessment and criteria development efforts.

Table 5.3 Examples of risk assessment and criteria development efforts, as aggregated by USA (comm-24-gov).

Study	**Finding**	**Reference**
1997 US EPA Mercury Study Report to Congress	0.077-0.3 ppm methylmercury is the estimated threshold in forage fish for protection of piscivorous wildlife. Suggests that it is probable that individuals of some highly exposed wildlife subpopulations are experiencing adverse toxic effects due to airborne mercury emissions	US EPA, 1997
1999 East Fork Popular Creek Risk Assessment	Moderate risks to mink (24% probability of at least a 15% mortality) Moderate risks to kingfisher (50% probability of at least a 12-28% decline in fecundity)	Moore *et al.*, 1999
2000 Everglades Risk Assessment	25% - 59% probability of exceeding methylmercury NOAEL for Wood Stork, Great Egret, Great Blue Heron	Rumbold *et al.*, 2000
Environment Canada Tissue Guidelines	< 0.033 ppm methylmercury in fish tissue recommended for wildlife protection	Caux *et al.*, 2000

416. Epidemiological studies that attempt to associate mercury exposure with effects measured in natural field settings offer another important line of evidence. While these studies are usually insufficient to conclusively establish causal relationships between stressor and response, they nonetheless add significantly to the evaluation of methylmercury impacts on wildlife populations. Field data contain important strengths such as reduced uncertainty associated with extrapolating effects between the laboratory and the field. This uncertainty is particularly important for methylmercury because several ecological risk assessments tend to be sensitive to relatively small amounts of uncertainty (i.e., a factor of 2 or 3 has important implications for the findings). Selected reviews of field epidemiological studies are found in US EPA (1997) for loons, bald eagles and other species in addition to Wolfe *et al.* (1998).

Local variations in ecosystem sensitivity

417. It is important to note the complex biogeochemistry of mercury with respect to a given food chain and in specific environments. The sensitivity of local ecosystems varies depending on natural conditions and anthropogenic influence. This also implies that the "critical loading" – the input of mercury that leads to enhanced mercury contamination and serious concerns for human health and the environment – varies according to local conditions. In some environments, fairly heavy mercury loads have only a limited effect on living matter, as either mercury is not efficiently bioaccumulated throughout the particular configuration of the local food chain, or the mercury is not easily methylated (Canadian comments, comm-20-gov). In other cases, ecosystems may be particularly sensitive to mercury loading. A good example is the Arctic region, where food chain characteristics seem to mediate biomagnification to very high levels, resulting in a high exposure of humans and other species at the highest trophic levels (see section 4.4.3). Another example may be the high sensitivity of the micro-flora in terrestrial environments of organic forest soils reported in Sweden (as described in section 5.3.2 above).

5.4 Mercury concentrations in environmental media

418. Large amounts of data on mercury concentrations in various environmental media (air, water, soil, sediments) and biota (plants, animals and other living organisms) have been referenced in submissions to this assessment, as well as in the literature. For further detail, the reader is invited to consult, inter alia:

- Reports and data of the French Institute for Marine Research, available on their website http://www.ifremer.fr/envlit/surveillance/index.htm;
- Reports and data of the Arctic Monitoring and Assessment Programme (AMAP), available on their website http://www.amap.no/;
- Chapter 3 of Volume III of the US EPA Mercury Study Report to Congress (US EPA, 1997), available at http://www.epa.gov/airprogm/oar/mercury.html.

419. It would be very important to investigate and review all such available data, which would likely add to our understanding of the impact of mercury as a global pollutant, and could provide a baseline for monitoring. However, this has not been possible within the time and resource constraints imposed on UNEP's global mercury assessment process. Therefore, the information submitted from different parts of the world on mercury concentrations in fish (see section 4.5) serves as an indicator illustrating the omnipresence of mercury in the global environment.