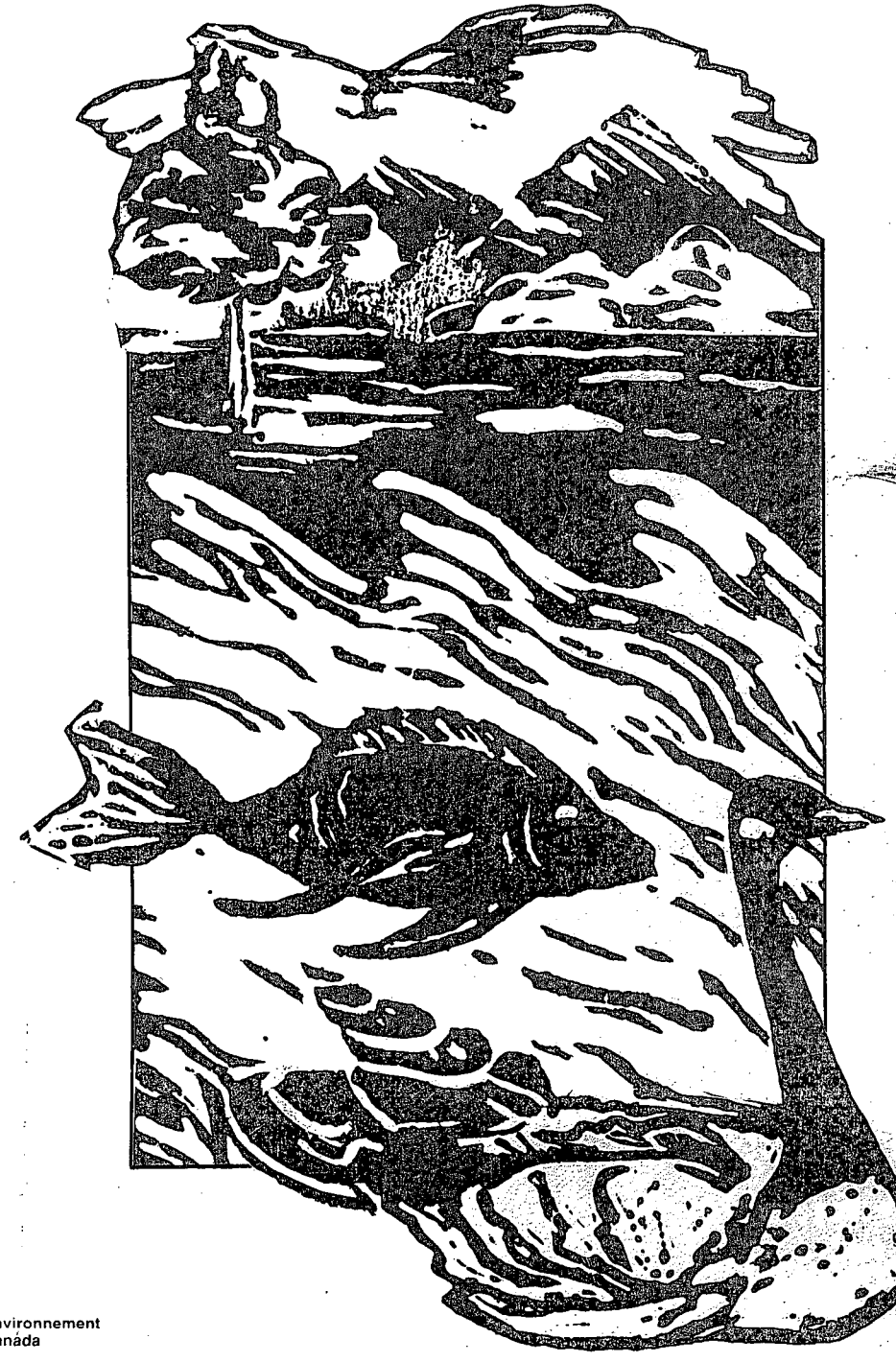
SUMMARY REPORT

B. Kay

MERCURY



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PACIFIC & YUKON REGION

DEPARTMENT OF THE ENVIRONMENT
ENVIRONMENTAL PROTECTION SERVICE
PACIFIC AND YUKON REGION

CHEMICALS IN THE ENVIRONMENT
PACIFIC AND YUKON REGION

I. MERCURY

By

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1. INTRODUCTION

This report is one in a series entitled "Chemicals in the Environment - Pacific and Yukon Region" prepared by the Environmental Protection Service. The objective of these reports is to provide the technical guidance necessary for: a) the interpretation of environmental quality data on specific chemicals, and b) the assessment of potential impacts resulting from the release of these chemicals into the environment.

The series will focus on both naturally occurring and man-made compounds whose release to the environment is of concern due to their persistence, toxicity and/or bioaccumulative abilities.

These reports discuss highlights of existing environmental quality data for B.C. and Yukon and provide information on environmental dynamics, potential impacts on the environment, and pertinent legislation and guidelines controlling both releases to the receiving environment and environmental quality.

This report is adapted from Garrett, C.L. et al, "Mercury in the British Columbia and Yukon Environments", Environmental Protection Service, Pacific Region Program Report 80-4 (1980). For additional information refer to this document.

2. USES AND SOURCES OF RELEASE

Mercury is a heavy silvery-white element which occurs naturally in the environment. Its application is extensive and diverse in industry. The major use has been as a cathode for the electrolytic production of chlorine and caustic soda in chlor-alkali plants. Other applications include usage in electrical equipment, scientific instruments, paints, pesticides, dental amalgams, gold recovery procedures, drywall compounds, pharmaceuticals and chemical manufacturing. Releases to the environment have been documented at chlor-alkali plants, mines, smelters, fossil fuel combustion facilities, laboratories, hospitals, dental offices, and municipal waste disposal facilities.

3. ENVIRONMENTAL DYNAMICS

The accumulation of high concentrations of mercury in the bottom sediments results from the sedimentation (coagulation and flocculation) of suspended particulate matter in areas receiving large amounts of mercury from urban or natural sources (1, 2, 3, 4).

Inorganic and organic forms of mercury can be converted to the toxic methylated form by microorganisms in the sediments. Therefore, environmental conditions which promote microbial activity (warm temperatures and high nutrient and organic content) can also be expected to result in increased mercury methylation. In sediments with low mercury concentrations, or under high pH conditions, the formation of volatile dimethylmercury is favoured. At high sediment mercury concentrations, or under low pH conditions, monomethylmercury predominates. At pH levels of less than 5.6 dimethylmercury is unstable and is converted to monomethylmercury. Dimethylmercury is primarily released to the atmosphere, while the more stable monomethylmercury remains in the aqueous environment and becomes available for accumulation in the tissues of aquatic organisms (4).

Methylation can occur under aerobic and anaerobic conditions but usually proceeds more efficiently in aerobic environments. Under anoxic conditions the rate of methylation would be considerably reduced (4, 5, 6, 7, 8). The production of hydrogen sulphide (H_2S) by anaerobic bacteria in the sediments would result in the formation of the stable compound mercuric sulphide which is not readily methylated (4, 10). In addition, methylmercury may react with H_2S to produce the volatile dimethylmercury product which would result in less methylmercury becoming available for uptake by fish and shellfish (11).

The anaerobic conditions and the abundance of natural sulfates often found in marine and estuarine environments results in a slower rate of methylation than occurs in freshwater systems. In addition, it has been shown that the methylation rate decreases with increasing salinity (12) and decreasing temperature (13).

Although it is widely accepted that methylation processes do occur in the bottom sediments, many researchers have noted surprisingly low concentrations of methylmercury in sediment samples (14, 15). These findings have been attributed, in part, to the fact that methylmercury can be biologically transformed to methane and elemental mercury by microorganisms in the sediments. Although there is currently little information on the prevalence of these 'demethylating' organisms in the aquatic environment, it has been suggested that they may serve an important function in providing some degree of control over the amount of methylmercury in the bottom sediments (16, 17).

The dredging of bottom sediments from contaminated areas, and the ultimate disposal of these sediments on land or in ocean dump sites, is of concern due to potential environmental impacts. Dredging of contaminated sediments can result in a temporary increase in dissolved levels of mercury and other metals in overlying waters, although, most studies have shown that the levels of most metals rapidly return to normal (18). However, methylation occurs more rapidly when sediments are kept in suspension (9)

and, for this reason, attempts should be made to minimize disturbance during dredging activities.

The exposure of sediments to air during tidal changes or dredging also increases the rate of methylation. In addition, when dredge spoils are deposited in nearshore areas or in settling ponds, significant amounts of mercury may be released back to the environment in association with the suspended organic matter and fine particulates in drainage water (9).

Researchers have suggested certain precautions to minimize mercury release during dredging and redeposition of contaminated sediments. These include: the treatment of drainage water from dredge spoils with lime or aluminum sulfate in order to precipitate mercury prior to the release of drainage water back to the environment; the selection of deep-water anaerobic, sulfide-rich areas as ocean dump sites; and, covering the most contaminated sediment with those of lesser contamination at the disposal site (9, 12, 18).

4. ENVIRONMENTAL LEVELS

4.1 Aquatic Systems

4.1.1 Water.

General

High concentrations of mercury are rarely found in natural waters due to its low solubility, high affinity for organic matter, and the volatility of some mercury compounds. Mercury rapidly adsorbs onto suspended particulate matter in the water column and is ultimately deposited in the bottom sediments by the forces of sedimentation. Consequently, even in areas of known contamination, surface waters may contain very low concentrations of mercury, often below the limits of detection.

Mercury levels in seawater vary with the area and the depth at which the samples were collected, but are generally less than 0.126 ug/l with a median value of approximately 0.015 ug/l (19). Some researchers, however, estimate that unpolluted ocean waters contain 0.005 to 0.006 ug/l mercury and attribute all higher estimates to analytical problems (20).

Dissolved mercury levels in the Irish Sea ranged from 0.01 to 0.05 ug/l but concentrations of more than 200 ug/l were detected in the vicinity of three chlor-alkali plants and a sewage sludge disposal area (21).

The natural level of mercury in freshwater systems varies with the degree of local mineralization, but in most uncontaminated areas surface water concentrations are less or close to the limits of detection (typically 0.05 ug/l) (22).

British Columbia

Guidelines for freshwater quality set by the Inland Waters Directorate recommend that total mercury levels do not exceed 0.1 ug/l in water systems containing fish species used for human consumption and 0.2 ug/l in other systems (22).

Freshwater systems in B.C. generally meet this objective. Elevated mercury levels were, however, periodically detected in certain freshwater systems including: Stoney Creek and the Columbia River near a smelter/fertilizer complex at Trail; the St. Mary River and various creeks near a mining operation at Kimberley; Pinchi Lake in the vicinity of extensive mercury mineralization and the past site of a mercury mine; and the industrialized lower portion of the Fraser River. Certain freshwater systems in the Yukon Territory may also contain elevated levels of mercury, including: South McQuesten River; Keno Ladue River system; Tank Creek; Tagish Lake; and Rose Creek. Further verification is required as existing information is very limited. Potential sources of mercury to these water systems include natural mineralization and mining activity (23).

Information on mercury levels in marine waters off B.C. is limited. In most areas sampled mean concentrations were below or near the detection limit of 0.05 ug/l. Somewhat higher mercury levels were occasionally detected in Kitimat Arm (up to 0.4 ug/l), Ucluelet Inlet (up to 0.16 ug/l), Bamfield Inlet (up to 0.34 ug/l), and Quatsino Sound (up to 0.14 ug/l) (23). However, due to problems associated with past determinations of low mercury levels in water, the accuracy of this data is uncertain.

Although there are currently no Canadian guidelines for marine water quality, the U.S. Environmental Protection Agency has set guidelines of 0.1 ug/l (over a 24 hour period) and 3.7 ug/l (maximum) total recoverable mercury (24).

4.1.2 Sediments.

General

The concentration and mobility of mercury in sediments is determined by a number of factors including grain size, organic matter content, oxidation conditions, and the presence of microorganisms. The highest mercury concentrations are associated with the finer sediments and with high organic matter content (1, 25, 26, 27, 28).

Mercury concentrations in sediments can vary greatly as a result of natural mineralization and it is often difficult to establish natural background levels, especially in areas of industrialization. Mercury concentrations in freshwater sediments in non-industrialized and non-mineralized areas are generally below 100 ug/kg, with slightly higher concentrations being found in some marine sediments (29). While sediment concentrations of less than 100 ug/kg (0.1 mg/kg) are not usually considered to indicate enrichment due to man's activities, the interpretation of higher mercury values is very difficult. Concentrations above 100 ug/kg may indicate naturally high background levels, contamination as a result of

industrial or other man-related releases, or may result through a combination of both factors. Sediment concentrations in excess of 1000 ug/kg (1.0 mg/kg) warrant further investigation as they are often associated with elevated tissue levels in aquatic organisms. Levels of several milligrams per kilogram have been detected in bottom sediments in the vicinity of mercury emission sources such as chlor-alkali and sewage treatment plants (1, 25, 28, 30, 31).

British Columbia

Mercury concentrations of greater than 1000 ug/kg (1.0 mg/kg) have been identified in bottom sediments from the following areas of B.C. (20):

Location	Concentration (mg/kg)
a) Marine	
Howe Sound	
- in the vicinity of a mercury cell chlor-alkali plant	< 0.010 to 20
Victoria Harbour	0.078 to 3.98
Powell River	
- off a pulp and paper mill	< 0.020 to 21.0
Point Grey	0.975 to 1.4
Sturgeon Bank	0.010 to 1.5
b) Freshwater	
Port Clements	
- on mining property containing high order Hg anomalies	1.3 to 26.0
Pinchi Lake	
- area of extensive mineralization and past site of a mercury mine	2.0 to 117.0
Columbia River at Trail	
- near a smelter/fertilizer complex	0.26 to 2.52

Water systems in B.C. containing mean sediment mercury concentrations in the 100-1000 ug/kg (0.1-1.0 mg/kg) range include: various lakes in the Kamloops area, a region of known mineralization; Port Alberni, in the vicinity of a pulp and paper mill which used mercury-based slimicides from 1959 to 1970; Alice Arm and Observatory Inlet, where several mines and a smelter once operated; Roberts Bank, which receives discharges and surface runoff from a coal superport and is also affected by the potential contamination sources that have been identified for Sturgeon Bank; the heavily industrialized False Creek area; the Coal Harbour portion of Burrard Inlet; Tezzeron Lake which is located in the Pinchi Lake Fault Zone; and various lakes in the fruit producing Okanagan Region.

Mean mercury concentrations in the 100-1000 ug/kg (0.1-1.0 mg/kg) range were detected in the bottom sediments of several water systems in the Yukon Territory including: Rose Creek, near a mining operation: Francis Lake; Dezadeash River; Schwatka Lake; Marsh Lake; Bennett Lake, Tagish Lake, near an abandoned gold mine; Teslin River; Teslin Lake; and Simpson Lake. Areas of natural mineralization are present throughout Yukon and elevated mercury concentrations are attributed primarily to natural sources. Man-related sources of mercury release in Yukon are limited primarily to mining activity.

4.1.3 Aquatic Organisms.

4.1.3.1 Uptake. Mercury can accumulate to significant concentrations in some species of aquatic organisms. The rate of mercury accumulation in aquatic organisms depends on a variety of factors including trophic level, feeding habits, general biology, sex, age, and availability of food (32, 33, 34, 35, 36, 37, 38, 39). Non-migratory, predatory, bottom-feeding species and filter-feeding bivalves are considered to be the most reliable indicators of local levels of contamination (40, 41).

Sediment mercury levels alone do not necessarily influence the level of contamination in local aquatic organisms. Water and sediment characteristics such as low pH, low salinity, low dissolved oxygen, low

alkalinity, warm temperature, low organic matter content, low Se content, the presence of microorganisms, elevated mercury concentration and readily available chemical forms play important roles in increasing the rate of accumulation in aquatic biota (31, 42, 43, 44, 45, 46, 47, 48, 49).

Almost all of the mercury detected in aquatic organisms in their natural environment is in the form of methylmercury (50, 51, 52). The highest concentrations of mercury are detected in the liver and kidney but they are slowly eliminated from these organs and subsequently accumulate in the muscle (9, 53). Particularly high accumulations are also found in the hepatopancreas of shellfish (54).

4.1.3.2 Levels.

General

Under the appropriate environmental conditions, all forms of mercury entering the marine and freshwater environments can be converted to the toxic methylmercury state by naturally occurring microorganisms, and so become biologically available to aquatic life. Biomagnification through the food chain may occur and, as a result, organisms at the higher trophic levels often accumulate mercury to concentrations several orders of magnitude greater than the concentrations in the ambient waters (32, 33, 55, 56). Positive correlations between mercury concentration and both weight and length of several aquatic species have been noted by many researchers (34, 37, 39, 57, 58).

Regional background concentrations in aquatic organisms from unpolluted areas vary depending on the degree of local natural mineralization, however, natural levels in most species of fish are normally less than 0.20 mg/kg (59).

Mercury contaminated effluent and aerial discharges from industrial facilities such as chemical manufacturers, chlor-alkali plants and pulp and paper mills have resulted in the accumulation of unacceptably high levels of mercury in localized populations of aquatic organisms throughout the world (60, 61).

Health and Welfare Canada has established a guideline of 0.50 mg/kg (wet weight) for mercury content in fish and shellfish intended for human consumption.

British Columbia

Mean concentrations were below 0.5 mg/kg in invertebrates from almost all areas. The highest concentrations were detected in Howe Sound in the early 1970's (up to 13.4 mg/kg) in the vicinity of a mercury cell chlor-alkali plant. Howe Sound was closed to fishing at this time but has since been reopened due to significantly decreased residue levels. Crabs from the Fraser River estuary also contained somewhat elevated mercury levels (up to 0.74 mg/kg) as did freshwater clams from Pinchi Lake (up to 1.46 mg/kg) (23).

No information was available on mercury concentrations in aquatic invertebrates from the Yukon Territory (23).

Halibut over 60 lbs in weight often contain > 0.5 mg/kg mercury. However, as the average weight of halibut collected off the coast of B.C. is approximately 30 lbs, most would contain lower mercury levels. Groundfish species and sharks contain > 0.5 mg/kg mercury due to natural enrichment. However, the highest concentrations were detected in the early 1970's in groundfish and dogfish from the vicinity of the mercury-cell chlor-alkali plant on Howe Sound. Discharges from the plant and mercury levels in Howe Sound biota have now decreased significantly (23).

Mercury levels in salmon and pelagic ocean species were low (< 0.5 mg/kg). Concentrations in freshwater fish from B.C. were also low except in Pinchi Lake and in some coarse fish from the industrialized Lower Fraser River. Mercury levels in certain species (most notably squawfish) from the Columbia River near Trail are also somewhat elevated (23).

4.1.3.3 Toxicity. Acute toxic values of mercury compounds in invertebrates and fish are listed in Table 1.

The various life stages in the development of aquatic organisms exhibit different degrees of sensitivity to mercury compounds with embry-

embryonic, larval, and juvenile stages generally being more susceptible than adult organisms (62, 63, 64).

In laboratory experiments a wide range of behavioural and physiological effects have been attributed to exposure to various mercurial compounds at concentrations well below established acutely lethal levels. The severity of the observed effects is dependent upon the form and concentration at which mercury is administered and the length of exposure.

Inorganic and organic mercury compounds at concentrations in the micrograms per litre range, disrupt reproductive mechanisms by decreasing the hatchability of eggs and lowering the survival rate of larval and juvenile stages of several organisms (63, 64, 65, 66, 67). Other sublethal effects of mercurial compounds include: inhibition of limb regeneration and pigmentation in fiddler crabs at 0.5 and 0.1 mg/l methylmercury (68), respectively; the disruption of immune responses and a lowered resistance to disease in blue gouramis at 0.009 mg/l methylmercury (69); depressed olfactory processes and impairment of metabolic processes in rainbow trout at 0.100 mg/l mercuric chloride (70, 71); and increased incidence of spinal deformities in fathead minnows (67). Mercurials exert toxic effects on the secondary lamellae in the gills resulting in extensive structural damage to the gill apparatus, impaired osmoregulation, respiratory disturbances and, in many cases, death by asphyxiation (44, 50, 72, 73).

One of the most important factors contributing to the toxic action of mercurials is the long retention time of these compounds in the tissues. Studies on northern pike from a mercury contaminated environment suggest that, even after a recuperatory period of one year, the ability of the fish to cope with disease, predation, and sub-optimal environmental conditions was still impaired (74, 75).

Very low concentrations (ng/l to ug/l range) of mercury in water have been found to decrease growth, reproduction and survival of plankton and diatoms. Lowering the survival rate of these primary producers would decrease the availability of food for higher organisms and increase their susceptibility to the toxic effects of mercury, thereby disrupting local ecosystems.

TABLE 1 ACUTE TOXICITY OF MERCURIAL COMPOUNDS TO AQUATIC ORGANISMS

i) Invertebrates

COMPOUND	SPECIES	EXPOSURE TIME*	LC_{50} (mg/l)	REFERENCE
Mercuric chloride	Crayfish	96	1.0	76
	Grass shrimp	120	0.2	77
	Grass shrimp - larvae	48	0.0056	64
	Brine shrimp - larvae	3	1000	78
	Barnacle - larvae	3	0.2	78
	Fiddler crab - larvae	11 days 8 days 24	0.000018 0.0018 0.18	79
	American oyster - embryo	48	0.0056	79
n-amyl mercuric chloride	Brine shrimp - larvae	3	1.0	78
	Barnacle - larvae	3	0.01	78
Mercuric acetate	American oyster	50 days	0.100	80

TABLE 1 ACUTE TOXICITY OF MERCURIAL COMPOUNDS TO AQUATIC ORGANISMS (continued)

ii) Fish

COMPOUND	SPECIES	EXPOSURE TIME*	LC_{50} (mg/l)	REFERENCE
Mercuric chloride	Rainbow trout - fingerlings	96	0.22-0.40	70
		48	0.30-0.65	70
		24	0.90	50
	Rainbow trout - adults	14 days	0.014	81
		96	0.016	81
		24	0.036	81
	Eel	24	1.0	82
Methylmercuric chloride	Blue gourami	96	0.09	69
	Brook trout - juvenile	96	0.075	62
	Rainbow trout - fry	96	0.024	50
		48	0.045	50
		24	0.084	50
	Rainbow trout - fingerlings	96	0.042	50
		48	0.066	50
		24	0.125	50
Phenylmercuric acetate	Rainbow Trout	24	0.025	70

*Hours except as noted

4.2 Terrestrial Systems

4.2.1 Atmosphere.

General

Mercury released to the atmosphere can adhere to particulate matter and be distributed over great distances by air currents, ultimately being deposited by precipitation and dry deposition mechanisms (83, 84). Elevated concentrations of mercury, sometimes detected in water systems in areas where there are no obvious sources of mercury release, are often attributed to the atmospheric transport of mercury.

Mercury enters the atmosphere through the natural erosion and degassing of the earth's surface (volcanic activity, etc.) and as a result of a variety of man's activities. The concentration of total airborne mercury in areas free of obvious sources of contamination is in the range of 1-10 ng/m^3 (84) but levels several orders of magnitude higher have been detected near sources of natural and industrial mercury releases, such as chlor-alkali plants, sewage treatment plants, municipal incinerators, smelters and coal-fired power plants.

For example, air samples collected at a sewage treatment plant in Washington, D.C., contained concentrations of greater than 60 ng/m^3 and decreased to a concentration of approximately 1 ng/m^3 at a distance of approximately 9.65 km.

British Columbia

Information on mercury concentrations in the atmosphere of B.C. is very limited (23).

Monitoring of mercury levels in stack gases and ambient air at a chlor-alkali plant near Squamish, B.C., in the early 1970's, indicated that the plant was a major source of atmospheric mercury release to the Howe Sound area. Elevated atmospheric concentrations were consistently detected in the ambient air. Concentrations of up to 6030 ng/m^3 were detected in

1970 but monitoring programs conducted between 1971 and 1977, subsequent to improvements of the ventilation system, indicated a general reduction in atmospheric levels.

Other significant point sources of mercury release to the atmosphere in British Columbia include smelters and municipal incinerators.

4.2.2 Soil and Vegetation .

General

The mercury content of various rock types ranges from a few micrograms per kilogram (ug/kg) to several thousand milligrams per kilogram (mg/kg), however, rocks from most regions contain less than 1.0 mg/kg. Concentrations are usually below 0.2 mg/kg in unmineralized areas (85) with mean levels in the earth's crust being estimated at 0.05 to 0.08 mg/kg (86).

With the exception of regions of natural mineralization and areas receiving contributions from industrial or agricultural sources, mercury levels in soil do not normally exceed 0.15 mg/kg (87). Background concentrations in California soils ranged between 0.02 and 0.04 mg/kg but levels in soil around mercury deposits ranged from 10 - 100 mg/kg (85). Analysis of various Canadian soils indicated that mean mercury levels were 0.08 mg/kg in areas removed from mineralization while a concentration of 14 mg/kg was detected in a sample collected from a mercuriferous region (88).

Mercury levels in terrestrial vegetation removed from both anthropogenic contamination and mineral deposits, are usually less than 0.50 mg/kg (89). Much higher concentrations (several mg/kg) (90, 91, 92) are often detected in the vicinity of industrial activity and natural mineralization. The exposure to mercury in the soil and in the atmosphere can result in uptake and translocation within plants. Under some conditions, significant amounts of mercury may enter edible portions (93, 94, 95).

Mosses and fungi often contain higher levels of mercury than do grasses and other vascular plants (95, 96. 97).

British Columbia

Data on rocks from British Columbia mining properties, mineral claims and areas of mineralization indicate that the highest mercury values were present in rock samples collected in the vicinity of the Pinchi Lake Fault Zone, Kamloops, Port Clements, Bridge River, and Yalakom River areas (23). Mercury contents of over 1 000 mg/kg were common at these locations, and rock samples from a mineral claim near Kamloops contained up to 32 000 mg/kg. Significant enrichment was also detected in rocks from Pb-Zn base metal deposits throughout British Columbia and Yukon.

No background data for mercury levels in rocks from unmineralized areas of B.C. has been obtained.

Soils collected from various regions in British Columbia indicate that normal background concentrations from unmineralized areas were between 0.01 and 0.05 mg/kg (23). Mercury levels in soils from the vicinity of gold, molybdenum, and base metal deposits normally range from 0.05 to 0.25 mg/kg and rarely exceed 2.0 mg/kg. Concentrations of over 10 mg/kg, however, were commonly detected in soils from anomalous areas in the Pinchi Lake Fault Zone and other mercuriferous regions in British Columbia including Kimberley and the Port Clements area on the Queen Charlotte Islands.

Surface soil horizons sampled in various agricultural areas of B.C. contained mean mercury concentrations below 0.15 mg/kg in all areas.

In 1971 surface soils from the immediate vicinity of a chlor-alkali plant at Squamish contained concentrations of up to 12.3 mg/kg. Mercury levels were elevated in soils collected up to 16 km from the plant. However, by 1977 concentrations of mercury in soils had decreased to background within 2 km of the plant.

All of the information on mercury in B.C. vegetation was based on samples collected from mining properties and mineralized areas. Mercury concentrations in these samples were higher than would typically be found in vegetation in this province.

Vegetation from almost every location sampled contained between 0.10 and 1.00 mg/kg mercury (dry weight). Concentrations exceeding

1.00 mg/kg were common in vegetation from mining properties and from the vicinity of the now defunct Pinchi Lake mercury mine.

No information was available for vegetation from Yukon.

4.2.3 Wildlife.

4.2.3.1 Birds.

General

Mercury levels in birds are largely dependent upon the proportion of animal food in the diet (34). Fish-eating birds occupy the highest levels of the food chain and contain the most significant levels of mercury contamination with the highest concentrations being found in the liver tissue. Levels of mercury in invertebrate feeders are generally somewhat lower (98, 99, 100, 101, 102).

It has been reported that liver/kidney composites of birds normally contain less than 1.0 mg/kg mercury. Concentrations in excess of this level indicate exposure to either natural or industrial contamination.

Mercury discharges from pulp mills, chlor-alkali plants and other industrial facilities are often implicated as a cause of elevated mercury levels in aquatic birds (103).

British Columbia

Mercury concentrations of over 1.0 mg/kg were consistently found in the livers of pelagic species (including guillemots, murrelets, auklets and puffins) from coastal areas of British Columbia (23). Mercury contamination was especially evident in birds collected near Victoria and other southern Vancouver Island and Lower Mainland coastal locations. A concentration of 30.0 mg/kg was detected in the liver of a heron from Victoria.

Particularly high mercury concentrations have been detected in fish-eating raptorial species, such as bald eagles, and also in predatory

birds, such as hawks and owls, that do not utilize fish as a food source. A bald eagle collected near Campbell River on Vancouver Island in 1973 contained a surprisingly high mercury concentration of 19.3 mg/kg in liver tissue.

Falconiformes from Victoria also contained elevated concentrations of mercury with liver concentrations of over 6.0 mg/kg being detected in some species. Mercury concentrations in excess of 1.0 mg/kg have been detected in the liver of many species of raptors from British Columbia.

Elevated mercury concentrations were also detected in the liver of heron from Powell River in 1976 (63.45 mg/kg), the liver of a western grebe from Creston in 1969 (3.29 mg/kg), and several species of fish-eating birds from Pinchi Lake in the early 1970's (up to 17.4 mg/kg in the liver).

Gallinaceous species and Passeriformes from B.C. generally contained very low levels of mercury with the exception of a few individuals collected in the Alberni Valley, Westham Island, Vernon and Victoria.

There is very little information relating to present levels of mercury in birds of British Columbia, with most of the existing data having been collected in the 1960's and early 1970s. Elevated mercury concentrations detected in the tissues of birds sampled during this period would reflect the widespread agricultural and industrial application of mercury-containing products including slimicides and other fungicides. The curtailment of the use of such compounds in the early 1970's would be expected to result in decreases in tissue mercury concentrations. Consequently, much of the data discussed here may not provide an accurate representation of current levels of contamination in British Columbia avian populations (23).

4.2.3.2 Mammals.

General

Marine mammals occupy an important place at the highest trophic level of the food chain and serve as useful indicators of contamination in the aquatic ecosystem.

Particularly high levels of mercury detected in the tissues of seals (especially in the liver) have led to suggestions that these mammals may retain mercury in their tissues to an even greater degree than do other marine mammals (104). For example, ringed seals and bearded seals from Inuvik, Northwest Territories contained mercury concentrations of up to 184.0 mg/kg and 420.0 mg/kg, respectively, in liver tissues. The maximum concentrations in muscle were much lower, 2.12 mg/kg in ringed seals and 88.7 mg/kg in bearded seals (105).

High concentrations of mercury have also been detected in other species of marine mammals including porpoises, dolphins, and whales and also in other fish-eating mammalian species such as otter and mink.

Herbivorous species do not usually concentrate large amounts of mercury in their tissues, with the exception of individuals exposed to mercury through the ingestion of vegetation from highly mineralized areas or in regions of past agricultural application of mercurial compounds (106, 107).

British Columbia

There is very little available information on mercury concentrations in marine mammals from coastal British Columbia and Yukon, but it is apparent that elevated levels of mercury do exist in the livers of some species (23).

High mercury levels were detected in the liver tissue of seals collected from southern Vancouver Island (and the Washington coast) (1.6-151.0 mg/kg); Triangle Island (2.2 mg/kg); Herschel Island in Yukon (0.2-19.6 mg/kg); and a walrus from Herschel Island (9.8 mg/kg). Mean mercury levels in muscle tissue were much lower (< 0.5 mg/kg).

No information was available on mercury concentrations in the tissues of mink and otter from B.C. and Yukon but levels in the tissues of other species of terrestrial mammals were very low. The highest concentrations were detected in the livers of predatory species, 0.64 mg/kg in a wolf from Cowichan River and 0.37 mg/kg in a cougar from Saanich. Levels in herbivorous species including deer, moose, caribou, beaver, marmot, and

chipmunk in B.C. and moose in Yukon, were generally below or close to the analytical limits of detection.

4.2.3.3 Toxicity. The first indications of hazards to wildlife species associated with the use and release of mercury compounds, occurred in the 1960's when Swedish researchers attributed the death and reproductive failures of large numbers of seed-eating and predatory birds to the widespread use of mercurial seed treatments.

Experiments by numerous researchers have confirmed the toxicity of alkyl mercury compounds to avian and mammalian species. Adverse effects induced by the dietary administration of methylmercury to mallards and pheasants included decreased egg production, decreased hatchability, small eggs, and shell-less eggs (108, 109, 110, 111). The administration of mercury in the diet of juvenile starlings resulted in kidney damage (112). Inorganic mercury appears to be relatively non-toxic to birds, however, as acute exposure to dietary levels of up to 200 mg/kg did not significantly affect reproductive processes (113).

A study on the effects of mercury on red-tailed hawks indicates that the lethal level of mercury in liver tissue is approximately 20 mg/kg.

The high concentrations of mercury in tissues of marine mammals, have not been linked to any obvious pathological effects. It has been suggested that seals, and possibly other marine mammals, may possess enzyme systems capable of demethylating methylmercury (114).

Selenium, which is a toxicant itself at certain concentrations, appears to have a protective effect against mercury intoxication. It has been suggested that the high correlations between mercury and selenium noted in the livers of marine mammals may be an important factor in the ability of these species to tolerate high body burdens of mercury.

Certain other species, such as mink, do not exhibit the ability to tolerate the large body burdens of mercury that are apparent in many species of marine mammals. It is uncertain whether this disparity is due to differences in selenium content of respective food sources or to dissimilarities in the mecnanisms of selenium accumulation (115).

A dietary dosage of 5 mg/kg methylmercury per day was lethal to mink within approximately one month. Symptoms of poisoning including incoordination, convulsions, and weight loss, became evident twenty-four days after the initiation of treatment. In contrast, a daily intake of 10 mg/kg mercuric chloride for five months appeared to be non-toxic.

Some researchers suggest that the presence of more than 5 mg/kg mercury in mink brain and muscle tissue, combined with observations of the appropriate clinical symptoms and pathological aberrations, indicate mercury poisoning. It has been speculated that elevated mercury concentrations in fish from some water systems may be causing decreased survival in populations of otter and mink frequenting these waterways by affecting their behaviour and reproductive mechanisms (116, 117).

Little information is available on the toxicity of mercury to other wildlife species.

5.0 REGULATIONS AND GUIDELINES

The current regulations and guidelines pertaining to mercury levels in the aquatic environment are as follows.

5.1 Water Quality

At present there are no Canadian water quality criteria or guidelines for acceptable concentrations of mercury in marine waters. However, the U.S. Environmental Protection Agency water quality guidelines for the protection of marine life specify that levels of total recoverable mercury should not exceed 0.10 ug/l over a 24 hour period or 3.7 ug/l at any time (24).

The Canadian Inland Waters Directorate has proposed the following objectives for total mercury in freshwaters systems (22).

In water systems containing species used for human consumption	0.1 ug/l
In other water systems	0.2 ug/l

The 1978 Canada/U.S. Great Lakes Water Quality Agreement specifies that the mercury level in filtered water from the Great Lakes must not exceed 0.2 ug/l.

The U.S. EPA criteria for the protection of freshwater aquatic organisms specify that mercury levels should not exceed 0.2 ug/l as a 24-hour average or 4.1 ug/l at any time (24).

5.2 Human Health

Health and Welfare Canada Health Protection Branch has established a guideline of 0.50 mg/kg (wet weight) as an acceptable level of mercury in fish and shellfish intended for human consumption. However, the recommended maximum weekly consumption of fish varies depending on the mercury content of the fish.

SAFE WEEKLY CONSUMPTION LEVELS OF FISH[1] (118)	
MERCURY LEVEL IN FISH	SAFE FISH CONSUMPTION PER WEEK
1.0 ppm	0.46 lb (0.21 kg)
0.5 ppm	0.92 lb (0.42 kg)
0.4 ppm	1.15 lb (0.52 kg)
0.3 ppm	1.54 lb (0.70 kg)
0.2 ppm	2.31 lb (1.05 kg)
0.1 ppm	4.62 lb (2.10 kg)

[1]Based on 70 kg man and assuming 20 ppb to be maximum acceptable blood level or a maximum weekly intake of approximately 0.20 mg methylmercury

5.3 Ocean Disposal

Regulations under the federal Ocean Dumping Control Act specify that materials disposed of at sea must contain no more than 0.75 mg/kg mercury in the solid phase and 1.5 mg/kg in the liquid phase.

Provincial criteria for the disposal of dredged material in both Ontario and Quebec stipulate a maximum concentration of 0.3 mg/kg mercury.

5.4 Industrial Effluents and Emissions

The level of mercury to both marine and fresh waters, and in atmospheric emissions, is regulated under both federal and provincial legislation. For example, the federal Fisheries Act and the Clean Air Act, as well as the B.C. Waste Management Act, regulate mercury levels in effluents and atmospheric emissions from chlor-alkali plants.

REFERENCES

1. Cranston, R.E. and D.E. Buckley, "Mercury Pathways in a River and Estuary", Environ. Sci. Technol., 6, (3), 274-278 (1972).

2. Edzwald, J.K., J.B. Upchurch, and C.R. O'Melia, "Coagulation in Estuaries", Environ. Sci. Technol., 8 (1), 58-63 (1974).

3. Airey, D. and P.D. Jones, "Mercury in the River Mersey, its Estuary and Tributaries During 1973 and 1974", Wat. Res., 16; 565-577 (1982).

4. Rae, J.E. and S.R. Aston, "The Role of Suspended Solids in the Estuarine Geochemistry of Mercury", Wat. Res., 16; 649-654 (1982).

5. Fagerstrom, T. and A. Jernelov, "Some Aspects of the Quantitative Ecology of Mercury", Water Res., 6, 1193-1202 (1972).

6. Bisogni, J.J., Jr. and A.W. Lawrence, "Kinetics of Mercury Methylation in Aerobic and Anaerobic Aquatic Environments", J. Water Pollut. Control Fed., 47 (1), 135-152, (1975).

7. Gillespie, D.C., "Mobilization of Mercury from Sediments into Guppies (Poecilia reticulata)", J. Fish Res. Board Can., 29 (7), 1035-1041, (1972).

8. Jernelov, A., "Mercury and Food Chains", In: Environmental Mercury Contamination, R. Hartung and B.D. Dinman, Eds., Ann Arbor Science Publishers Inc., Ann Arbor, Mich., pp. 174-177 (1972).

9. Jernelov, A. and H. Lann, "Studies in Sweden on the Feasibility of Some Methods for Restoration of Mercury-contaminated Bodies of Water", Environ. Sci. Technol., 7 (8), 712-718, (1973).

10. Gillespie, D.C. and D.P. Scott, "Mobilization of Mercuric Sulphide from Sediment into Fish Under Aerobic Conditions", J. Fish. Res. Board Can., 28, 1807-1808, (1971).

11. Rowland, I.R., M.J. Davies, and P. Grasso, "Volatilization of Methylmercuric Chloride by Hydrogen Sulphide", Nature, 265, 718-719, (1977).

12. Blum, J.E. and R. Bartha, "Effect of Salinity on Methylation of Mercury", Bull. Environ. Cont. Toxicol., 25; 404-408 (1980).

13. Wright, D.R. and R.D. Hamilton, "Release of Methyl Mercury from Sediments: Effects of Mercury Concentration, Low Temperature, and Nutrient Addition", Can. J. Fish. Aquat. Sci., 39; 1459-1466 (1982).

14. Andren, A.W. and R.C. Harris, "Methylmercury in Estuarine Sediments", Nature, 245, 256-257, (1973).

15. Batti, R., R. Magnaval and E. Lanzola, "Methylmercury in River Sediments", Chemosphere, 1, 13-14, (1975).

16. Spangler, W.J., J.L. Spigarelli, J.M. Rose, and H.M. Miller, "Methylmercury: Bacteria Degradation in Lake Sediments", Science, 180, 192-193, (1973).

17. Billen, G., C. Jairis and R. Wallast, "A Bacteria Methylmercury Mineralizing Activity in River Sediments", Water Res., 8, 219-225, (1974).

18. Lindberg, S.E. and R.C. Harris, "Release of Mercury and Organics from Resuspended Near-Shore Sediments", J. Water Pollut. Control Fed., 49(12), 2479-2487 (1977).

19. Fitzgerald, W.F., "Distribution of Mercury in Natural Waters". In: The Biogeochemistry of Mercury in the Environment. J.O. Nriagu, Ed., Elsevier/North Holland, New York, p.161 (1979).

20. Matsunaga, K., S. Konishi and M. Nishimura, "Possible Errors Caused prior to Measurement of Mercury in Natural Waters with Special Reference to Seawater", Environ. Sci. Technol., 13, 63-65 (1979).

21. Gardner, D. and J.P. Riley, "Distribution of Dissolved Mercury in the Irish Sea", Nature, 241, 526-527, (1973).

22. Reeder, S.W., A. Demayo and M.C. Taylor, "Guidelines for Surface Water Quality; Vol. 1 Inorganic Chemical Substances - Mercury", Inland Waters Directorate, Water Quality Branch, Ottawa (1979).

23. Garrett, C.L., L.A. MacLeod and H. Sneddon, "Mercury in the British Columbia and Yukon Environments - A Summary of Data to January 1, 1979", Environmental Protection Service, Pacific Region, Regional Program Report 80-4 (1980).

24. Environmental Protection Agency, "Ambient Water Quality Criteria for Mercury," EPA-440/5-80-058 (1980).

25. Applequist, M.D., A. Katz and K.K. Turekian, "Distribution of Mercury in the Sediments of New Haven, (Conn.) Harbour", Environ. Sci. Technol., 6 (13), 1123-1124, (1972).

26. Colwell, R.R., G.S. Sayler, J.D. Nelson, Jr., and A. Justice, "Microbial Mobilization of Mercury in the Aquatic Environment" In: Environmental Biogeochemistry, Vol. II, Metals Transfer and Ecological Mass Balances, J.O. Nriagu, Ed., Ann Arbor Science Publishers Inc., Ann Arbor, Mich. pp. 473-487 (1976).

27. Cranston, R.E., "Accumulation and Distribution of Total Mercury in Estuarine Sediments," Estuarine Coastal Mar. Sci., 4, 695-700 (1976).

28. MacDonald, R.W. and C.S. Wong, "The Distribution of Mercury in Howe Sound Sediments", Pacific Marine Sciences Report 77-22, (1977).

29. Travers, I., "Mercury in the Sediments of the Saint John River Basin", Environmental Protection Service, Report EPS 5-AR-76-10 (1976).

30. Thompson, J.A.J. and F.T. McComas, "Distribution of Mercury in the Sediments and Waters of Howe Sound, British Columbia", Fish. Res. Board Can., Technical Report No. 396, (1973).

31. Fujiki, M. and S. Tajima, "The Pollution of Minimata Bay and the Neighbouring Sea by Factory Waste Water Containing Mercury", Proceedings of International Symposium of Environmental Chemistry and Toxicology, Japan, pp. 217-229, (1973).

32. Klemmer, H.W., C.S. Unninayer, and W.I. Okuko, "Mercury Content of Biota in Coastal Waters in Hawaii", Bull. Environ. Contam. Toxicol., 15 (4), 454-457, (1976).

33. Hannerz, L., "Experimental Investigations on the Accumulation of Mercury in Water Organisms", Inst. Freshwater Research, Drottningholm, Sweden, pp. 120-176, (1968).

34. Fimreite, N., W.N. Holsworth, J.A. Keith, P.A. Pearce, and I.M. Gruchy, "Mercury in Fish and Fish-eating Birds Near Sites of Industrial Contamination in Canada," Can. Field-Nat., 85, 211-220, (1971).

35. Gardner, D., "Mercury in Fish and Waters of the Irish Sea and Other United Kingdom Fishing Grounds", Nature, 272, 49-51, (1978).

36. Bache, C.A., W.H. Gutenmann, and D.J. Lisk, "Residues of Total Mercury and Methylmercuric Salts in Lake Trout as a Function of Age", Science, 172, 951-952, (1971).

37. Hall, A.S., F.M. Teeny, and E.J. Gauglitz, Jr., "Mercury in Fish and Shellfish of the Northeast Pacific: II. Sablefish, Anoplopoma fimbria", Fish. Bull., 74 (4), 791-797, (1976).

38. Grieg, R.A., D. Weuzloff, C. Shelpuk, and A. Adams, "Mercury Concentrations in Three Species of Fish from North Atlantic Offshore Waters", Arch. of Environ. Contam. Toxicol., 5, 315-323, (1977).

39. MacCrimmon, H.R., C.D. Wren, and B.L. Gots, "Mercury Uptake by Lake Trout Relative to Age, Growth, and Diet in Tadenac Lake with Comparative Data from Other PreCambrian Shield Lakes", Can. J. Fish. Aquat. Sci., 40; 114-120 (1983).

40. Phillips, D.J.H., "The Use of Biological Indicator Organisms to Monitor Trace Metal Pollution in Marine Estuarine Environments - A Review", Environ. Pollut., 13, 281-317, (1977).

41. Smith, A.L., R.H. Green, and A. Lutz, "Uptake of Mercury by Freshwater Clams (Family Unionidae)", J. Fish. Res. Board Can., 32, 1297-1303, (1975).

42. Johnels, A.G., T. Westermark, W. Berg, P.I. Persson, and B. Sjostrand, "Pike (Esox lucius L.) and Some Other Aquatic Organisms in Sweden as Indicators of Mercury Contamination in the Environment", Oikos, 18, 323-333, Copenhagen (1967).

43. Armstrong, F.A.J. and A.L. Hamilton, "Pathways of Mercury in a Polluted Northwestern Ontario Lake", In: Trace Metals and Metal Organic Interactions in Natural Waters, Ann Arbor Science Publishers, Ann Arbor, Mich., pp. 131-156, (1973).

44. Amend, D.F., W.T. Yasutake and R. Morgan, "Some Factors Influencing Susceptibility of Rainbow Trout to the Acute Toxicity of an Ethyl Mercury Phosphate Formulation (Timsan)", Trans. Am. Fish. Soc., 3, 419-425, (1969).

45. Brouzes, R.J.P., R.A.N. McLean and G.H. Tomlinson, "The Link Between pH of Natural Waters and the Mercury Content of Fish", Center de recherches, Research Report, Senneville, Quebec, 34 p., (1977).

46. Tsai, S., G.M. Boush and F. Matsumura, "Importance of Water pH in Accumulation of Inorganic Mercury in Fish", Bull. Environ. Contam. Toxicol., 13 (2), 188-193, (1975).

47. Akielaszek, J.J. and T.A. Haines, "Mercury in the Muscle Tissue of Fish from Three Northern Maine Lakes", Bull. Environ. Cont. Toxicol., 27; 201-208 (1981).

48. Rodgers, D.W. and F.W.H. Beamish, "Water Quality Modifies Uptake of Waterborne Methylmercury by Rainbow Trout", Can. J. Fish. Aquat. Sci., 40; 824-828 (1983).

49. Turner, M.A. and A.L. Swick, "The English-Wabigoon System: IV. Interaction between Mercury and Selenium Accumulated from Waterborne and Dietary Sources by Northern Pike", Can. J. Aquat. Sci., 40; 2241-2250 (1983).

50. Wobeser, G., "Acute Toxicity of Methyl Mercury Chloride and Mercuric Chloride for Rainbow Trout (Salmo gairdneri) Fry and Fingerlings", J. Fish. Res. Board Can., 32, 2005-2013, (1975).

51. Suzuki, T., T. Miyama and C. Toyama, "The Chemical Form and Bodily Distribution of Mercury in Marine Fish", Bull. Environ. Contam. Toxicol., 10 (6), 347-355, (1973).

52. Bull, K.R., A.F. Dearsley and M.H. Inskip, "Growth and Mercury Content of Roach, Perch and Pike Living in Sewage Effluent", Environ. Poll., 25; 229-240 (1981).

53. Julshamm, K., O. Ringdal, and O.R. Braekkan, "Mercury Concentration in Liver and Muscle of Cod as an Evidence of Migration Between Waters with Different Levels of Mercury", Bull. Environ. Cont. Toxicol., 79; 544-549 (1982).

54. Guarino, A.M., J.B. Anderson, J.B. Pritchard and D.P. Rall, "Tissue Distribution of [^{14}C] Methylmercury in the Lobster, Homarus americanus", J. Toxicol. Environ. Health, 2, 13-24, (1976).

55. Koli, A.K., W.R. Williams, E.B. McClary, E.L. Wright, and T.M. Burrell "Mercury Levels in Freshwater Fish of the State of South Carolina", Bull. Environ. Contam. Toxicol., 17 (1), 82-89 (1977).

56. Rucker, R.R. and D.F. Amend, "Absorption and Retention of Organic Mercurials by Rainbow Trout and Chinook and Sockeye Salmon", Prog. Fish - Cult., pp. 197-201, (October, 1969).

57. Harbo, R.M., and I.K. Birtwell, "Mercury Contamination of Some Marine Organisms from Howe Sound, British Columbia", Dept. of Fisheries and the Environment, Fisheries and Marine Service, Tech. Report No. 763, 49 p., (1978).

58. Barber, R.T. and P.J. Whaling, "Mercury in Marlin and Sailfish", Mar. Poll. Bull., 14(10); 395-396 (1983).

59. Lofroth, G., "Methylmercury - A Review of Health Hazards and Side Effects Associated with the Emission of Mercury Compounds into Natural Systems", Ecolog. Research Committee, Bull. 4, 2nd Edition, Swedish Natural Research Council, (1970).

60. Kiorboe, T., F. Mohlenberg, and H.U. Riisgard, "Mercury Levels in Fish, Invertebrates and Sediment in a Recently Polluted Area", Mar. Poll. Bull., 14(1); 21-24 (1983).

61. Riisgard, H.U., "Mercury Pollution in the Waters Around Harboore Tange and Limfjord, Denmark", Mar. Poll. Bull., 15(4); 129-133 (1984).

62. McKim, J.M., G.F. Olson, G.W. Holcombe, and E.P. Hunt, "Long Term Effects of Methylmercuric Chloride on Three Generations of Brook Trout (Salvelinus fontinalis): Toxicity, Accumulation, Distribution and Elimination", J. Fish. Res. Board Can., 33, 2726-2739, (1976).

63. Akiyama, A., "Acute Toxicity of Two Organic Mercury Compounds to the Teleost, Oryzias latipes, in Different Stages of Development", Bull. Jpn. Soc. Sci. Fish., 36 (6), 563-570, (1970).

64. Shealy, M.H., Jr. and P.A. Sandifer, "Effect of Mercury and Survival and Development of the Larval Grass Shrimp, Palaemonetes vulgaris", Mar. Biol., 33, 7-16, (1975).

65. Kihlstrom, J.E., and L. Hulth, "The Effect of Phenylmercuric Acetate Upon the Frequency of Hatching of Eggs from the Zebrafish", Bull. Environ. Contam. Toxicol., 7 (2/3), 111-114, (1972).

66. Heisinger, J.F. and W. Green, "Mercuric Chloride Uptake by Eggs of the Ricefish and Resulting Teratogenic Effects", Bull. Environ. Contam. Toxicol., 14 (6), 665-674, (1975).

67. Snarski, V.M. and G.F. Olson, "Chronic Toxicity and Bioaccumulation of Mercuric Chloride in the Fathead Minnow", Aquat. Toxicol., 2; 143-156 (1982).

68. Weis, J.S., "Limb Regeneration in Fiddler Crabs: Species Differences and Effects of Methylmercury", Biol. Bull., 152, 263-274, (1977).

69. Roales, R.R., and A. Perlmutter, "The Effects of Sublethal Doses of Methylmercury and Copper Applied Singly and Jointly, on the Immune Response of the Blue Gourami (Trichogaster trichoterus) to Viral and Bacterial Antigens", Arch. Environ. Contam. Toxicol., 325-331, (1977).

70. MacLeod, J.C. and E. Pessah, "Temperature Effects on Mercury Accumulation, Toxicity and Metabolic Rate in Rainbow Trout (Salmo gairdneri)", J. Fish. Res. Board Can., 30, 485-492, (1973).

71. Hara, T.J., Y.M.C. Law, and S. MacDonald, "Effects of Mercury and Copper on the Olfactory Response in Rainbow Trout, Salmo gairdneri", J. Fish. Res. Bd. Can., 33; 1568-1573, (1976).

72. Renfro, J.L., B. Schmidt-Nielsen, D. Miller, D. Benos, and J. Allen, "Methylmercury and Inorganic Mercury: Uptake, Distribution, and Effect on Osmoregulation Mechanisms in Fishes", In: Pollution and Physiology of Marine Organisms, F.J. Vernberg and W.B. Vernberg, Eds., Academic Press, New York, pp. 101-122, (1974).

73. Lindahl, P.E., and C.E.B. Hell, "Effects of Short-term Exposure of Leuciscus rutilus L. (Pisces) to Phenyl-mercuric Hydroxide", Oikos, 21, 267-275, (1970).

74. Pentreath, R.J., "The Accumulation of Inorganic Mercury from Seawater by the Plaice, Pleuronectes platessa L.", J. Exp. Mar. Biol. Ecol., 24, 103-119, (1976).

75. Lockhart, W.L., J.F. Uthe, A.R. Kenny, and P.M. Mehrle, "Methylmercury in Northern Pike (Esox lucius): Distribution, Elimination, and Some Biochemical Characteristics of Contaminated Fish", J. Fish. Res. Board Can., 29, 1519-1523, (1972).

76. Doyle, M., S. Koepp, and J. Klaunig, "Acute Toxicological Response of the Crayfish (Orconectes limosus) to Mercury", Bull. Environ. Contam. Toxicol., 16; 422-424, (1976).

77. Barthalmus, G.T., "Behavioural Effects of Mercury on Grass Shrimp", Mar. Pollut. Bull., 8 (4), 87-90, (1977).

78. Corner, E.D.S., and F.H. Rigler, "The Modes of Action of Toxic Agents; III. Mercuric Chloride and N-amyl- Mercuric Chloride on Crustaceans", J. Mar. Biol. Assoc., U.K., 37, 85-96, (1958).

79. DeCoursey, P.J., and W.B. Vernberg, "Effect of Mercury on Survival, Metabolism and Behaviour of Larval, Uca pugilator (Brachyura)", Oikos, 23, 241-247, (1972).

80. Cunningham, P.A. and M.R. Tripp, "Accumulation and Depuration of Mercury in the American Oyster, Crassostrea virginica", Mar. Biol., 20, 14-19, (1973).

81. Calamari, D. and R. Marchetti, "The Toxicity of Mixtures of Metals and Surfactants to Rainbow Trout (Salmo gairdneri Rich.)", Water Res., 7, 1453-1464, (1973).

82. Noel-Lambot, E., and J.M. Bouquegneau, "Comparative Study of Toxicity, Uptake and Distribution of Cadmium and Mercury in the Sea Water Adapted Eel Anguilla anguilla", Bull. Environ. Contam. Toxicol., 18 (4), 418-424, (1977).

83. Matheson, D.H., "The Atmospheric Transport of Mercury - A Review and Appraisal of the Current Literature", Inland Waters Directorate, CCIW, (1977).

84. Johnson, D.L. and R.S. Braman, "Distribution of Atmospheric Mercury Species Near the Ground", Environ. Sci. Technol., 8 (12), 1003-1009, (1974).

85. U.S. Dept. of the Interior, "Mercury in the Environment", Geological Survey, Professional Paper 713, pp. 1-5, (1970).

86. Vostal, J., "Transport and Transformation of Mercury in Nature and Possible Routes of Exposure", In: Mercury in the Environment, L. Friberg, and D. Vostal, Eds., CRC Press, Cleveland, pp. 15-27, (1974).

87. Jonasson, I.R. and R.W. Boyle, "Geochemistry of Mercury", In: Mercury in Man's Environment, Symposium, Ottawa, (February 1971).

88. McKeague, J.A. and B. Kloosterman, "Mercury in Horizons of Some Soil Profiles in Canada", Can. J. Soil Sci., 54, 503-509, (1974).

89. Shacklette, H.T., "Mercury Content of Plants", In: Mercury in the Environment, Geological Survey Professional Paper 713, pp. 32-34, (1970).

90. Norvick, S., "A New Pollution Problem", Environment, 11 (4); 2-9 (1969).

91. John, M.K., "Mercury Uptake from the Soil by Various Plant Species, Bull. Environ. Contam. Toxicol., 8 (2); 77-80 (1972).

92. Lodenius, M. and E. Tulisalo, "Environmental Mercury Contamination Around a Chlor-Alkali Plant", Bull. Environ. Cont. Toxicol., 32; 439-444 (1984).

93. Weaver, R.W., J.R. Melton, D. Wang, and R.L. Duble, "Uptake of Arsenic and Mercury from Soil by Bermudagrass", Environ. Poll., 33; 133-142 (1984).

94. Suckcharoen, S., "Mercury Contamination of Terrestrial Vegetation near a Caustic Soda Factory in Thailand", Bull. Environ. Cont. Toxicol., 24; 463-466 (1980).

95. Huckabee, J.W., F. Sanz Diaz, S.A. Janzen, and J. Solomon, "Distribution of Mercury in Vegetation at Almaden, Spain", Environ. Poll., 30; 211-224 (1983).

96. Byrne, A.R., V. Raunick and L. Kate, "Trace Elemental Concentrations", Sci. Total Environ., 6; 65-78, (1975).

97. Yeaple, D.S., "Mercury in Bryophytes (MOSS)," Nature, 235; 229-230, (1972).

98. Vermeer, K., "A Survey of Mercury Residues in Aquatic Bird Eggs in the Canadian Prairie Provinces", Thirty-sixth North American Wildlife Conference, pp. 138-149, (1971).

99. Vermeer, K., "Spotted Sandpipers as Possible Indicators of Mercury Contamination of Rivers", The Blue Jay, pp. 59-60, (June 1971).

100. Vermeer, K., and F.A.J. Armstrong, "Mercury in Canadian Prairie Ducks", J. Wildl. Manage., 36 (1), 179-182, (1972).

101. Barrett, R.T., J.U. Skaare, G. Norheim, W. Vader, and A. Froslie, "Persistent Organochlorines and Mercury in Eggs of Norwegian Seabirds 1983", Environ. Poll., 39; 79-93 (1985).

102. Heinz, G.H., T.C. Erdman, S.D. Haseltine, and C. Stafford, "Contaminant Levels in Colonial Waterbirds from Green Bay and Lake Michigan, 1975-80", Environ. Mon. Assess., 5; 223-236 (1985).

103. Study Group on Mercury Hazards, "Hazards of Mercury", Special Report to the Secretary's Pesticide Advisory Committee, Dept. of Health, Education and Welfare, November 1970, Environ. Res., 4, 1-69, (1971).

104. Kim, K., R.C. Chu, and G.P. Barron, "Mercury in Tissues and Lice of Northern Fur Seals", Bull. Environ. Contam. Toxicol., 11 (3), 281-284, (1974).

105. Freeman, H.C., and D.A. Horne, "Mercury in Canadian Seals", Bull. Environ. Contam. and Toxicol., 10 (3), 172-180, (1973).

106. Wren, C., H. MacCrimmon, R. Frank, and P. Suda, "Total and Methylmercury Levels in Wild Mammals from the PreCambrian Shield Area of South Central Ontario, Canada", Bull. Environ. Cont. Toxicol., 25; 100-105 (1980).

107. Jenkins, J.H., A.H. Davis, W.J. Bigler, and G.L. Hoff, "Mercury and Cesium-137 in Urban Gray Squirrels", Bull. Environ. Cont. Toxicol., 25; 321-324 (1980).

108. Fimreite, N., "Effects of Dietary Methylmercury on Ring-necked Pheasants", Can. Wildlife Service, Occasional Paper No. 9, (1971).

109. Heinz, G., "Effects of Low Dietary Levels of Methylmercury on Mallard Reproduction", Bull. Environ. Contam. Toxicol., 11 (4), 386-392.

110. Heinz, G., "Methylmercury: Second-year Feeding Effects on Mallard Reproduction and Duckling Behaviour", J. Wildl. Manage., 40 (1), 82-90, (1976).

111. Adams, W.J. and H.H. Prince, "Mercury Levels in the Tissues of Ring-necked Pheasants Fed Two Mercurial Fungicides", Bull. Environ. Contam. Toxicol., 15 (3), 316-323, (1976).

112. Nicholson, J.K. and D. Osborn, "Kidney Lesions in Juvenile Starlings Fed on a Mercury-Contaminated Synthetic Diet", Environ. Poll., 33; 195-206 (1984).

113. Scott, M.L, J.R. Zimmermann, S. Marinskey, P.A. Mullenhoff, G.L. Rumsey, and R.W. Rice, "Effects of PCB's, DDT, and Mercury Compounds Upon Egg Production, Hatchability, and Shell Quality in Chickens and Japanese Quail", Poultry Science, 54, 350-368, (1975).

114. Gaskin, D.E., G.J.D., Smith, P.W. Arnold, M.V. Louisy, R. Frank, M. Holdrinet, and J.W. McWade, "Mercury, DDT, Dieldrin and PCB in Two Species of Odontoceti (Cetacea) from St. Lucia, Lesser Antilles", J. Fish. Res. Board Can., 31, 1235-1239, (1974).

115. Jernelov, A., A. Johansson, L. Sorenson, and A. Svenson, "Methylmercury Degradation in Mink", Toxicology, 6, 315-321, (1976).

116. Cumbie, P.M., "Mercury Levels in Georgia Otter, Mink and Freshwater Fish", Bull. Environ. Contam. Toxicol., 14 (2), 193-196, (1975).

117. Wobeser, G., and M. Swift, "Mercury Poisoning in a Wild Mink", J. Wildl. Dis., 12, 335-340, (1976).

118. Wheatley, B., "Methylmercury in Canada: Exposure of Indian and Inuit Residents to Methylmercury in the Canadian Environment", Medical Services Branch, Department of National Health and Welfare, Ottawa (Dec. 1979).