Spring 2004 ISSUE # 25

FUNDY ISSUES

Contaminant Concerns:

Heavy Metals and the Bay of Fundy

Mainly a Matter of Metals

Compared to some coastal areas in the world, most of the northern Gulf of Maine is almost pristine and unpolluted. Nevertheless, we who dwell upon these shores shouldn't be complacent or smug about this. It is largely attributable to the low population, few large urban areas and low level of industrialization in the region. In spite of this, some contamination is widespread and pollution is present in a few localized areas. This distinction between "contamination" and "pollution" largely hinges on the difference between the detection of elevated levels of a noxious chemical in the environment *i.e.* contamination, and the occurrence of measurable biological or ecological effects resulting from its presence *i.e.* pollution. The Gulf of Maine Council on the Marine Environment in its Action Plan for 2001-2006 identified mercury, nitrogen and sewage as the priority contaminants in the region requiring research and remedial action. The Bay of Fundy's rapid tidal circulation ensures that problems of nitrogen enrichment and sewage contamination are largely confined to localized areas. However, heavy metals, particularly mercury, are of concern across much of the region. This Fundy Issue examines the nature, distribution, sources and ecological effects of the heavy metals present in the Bay of Fundy.

What are Heavy Metals?

Metals form almost two thirds of the chemical elements listed in the period table. However, which elements are considered metals is still a matter of some debate. Typically, elemental metals have luster (reflected light glow), are solid at room temperature, can lose electrons to form a positive ion, and readily conduct heat and electricity. However, the precise boundary of the metal category is fuzzy, as shown by the use of the terms metalloids, semi metals and transition metals for elements that can behave like metals or non-metals depending on the conditions. The metals belonging in the category "heavy metals" are also awkward to pin down. There are about 40 heavy metals, although again, the exact number depends on the definition used. One definition, based on specific gravity, excludes metals that another definition includes, based on atomic number. There are so many different definitions that the term lacks precise chemical meaning. Many chemists simply assert cryptically that a heavy metal is "a metal that behaves in a heavy metal manner". Some heavy metals that are typically monitored in environmental surveys are listed in the accompanying table.

Aluminum	Al	Manganese	Mn
Antimony	Sb	**Mercury**	**Hg**
Arsenic	**As**	Molybdenum	Mo
Barium	Ba	**Nickel**	**Ni**
Beryllium	Be	Selenium	Se
Cadmium	**Cd**	Silver	Ag
Chromium	**Cr**	Strontium	Sr
Cobalt	Co	Thalium	Tl
Copper	**Cu**	Tin	Sn
Iron	Fe	Titanium	Ti
Lead	**Pb**	Vanadium	V
Lithium	Li	Zinc	Zn
Magnesium	Mg		

"Heavy metals" that are often measured in environmental surveys.

Those in bold are the most common heavy metal pollutants, according to the United Nations Environmental Programme (UNEP).

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Migrating Metals

Heavy metals are widely distributed in the Earth's crust. Most have a rather patchy distribution worldwide, with scattered pockets of higher concentrations. Whether local rocks are igneous (of volcanic origin), sedimentary (formed in layers by sedimentation) or metamorphic (transformed by intense heat and pressure) influences the types and amounts of heavy metals they contain. Heavy metals weathered from natural rock formations spread widely in the environment, occurring in particulate or dissolved form in soils, rivers, lakes, seawater and sea floor sediments. Volcanoes also release heavy metals into the atmosphere.

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During the last two centuries, heavy metals released by human activities have superimposed new patterns of metal distribution on those naturally occurring. The mining industry depends on the ability to find and extract the scattered natural concentrations of commercially valuable heavy metals, such as iron, nickel or lead. During mining, transport, refining and manufacturing, heavy metals are released into the environment, typically in wastewater or from smokestacks. The way that the many products made from these metals are used may also release toxic metals into the environment. For example, lead was once added to gasoline to enhance the performance of automobile engines and this volatile, highly toxic metal was widely dispersed with the exhaust gases. Heavy metals have long been a component of some agricultural pesticides that are sprayed on croplands and eventually find their way into rivers, lakes and coastal waters. Metals are used in many common household products. For example, mercury is used in electrical components such as switches, batteries and fluorescent lights. Its use in thermometers is now being phased out in North America. Other heavy metals are used in products such as automobiles, household appliances, dental amalgams, paints, photographic papers and photo chemicals, to name but a few. After use, these products are often discarded in landfills. Their subsequent breakup and corrosion releases metals into the environment. In short, people extract toxic heavy metals from localized areas of high natural concentration, often buried safely underground, and then scatter them over the Earth's surface, where they are more readily available to plants and animals.

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Human activities sometimes indirectly increase the amounts of heavy metals released into the environment by natural processes. For example, in Southwestern Nova Scotia acid rain has made lakes and rivers much more acidic, enabling their waters to dissolve heavy metals more readily from soil, sediment and rock. Also, when lands are submerged behind hydroelectric dams, decomposing plants rapidly release volatile organic mercury that they had slowly absorbed from the soil. Past industrial activities often contaminated bottom sediments of lakes, rivers and coastal areas with heavy metals that are now being released by natural processes. Only by detailed, long-term monitoring of metal concentrations in different parts of the environment is it possible to distinguish between natural heavy metal contamination and that arising from human activities.

Mutating Metals

Another challenge in measuring and studying metals in the environment is that they may be present in the air, water or soil in several chemical forms and can change from one to another depending on conditions. They may exist as a single element in ionic form or be combined with other chemicals in compounds such as salts or oxides. Their chemical form in aquatic habitats can vary with acidity (pH), temperature, presence of oxygen, other chemicals, organic matter or suspended particles. Bacterial activity or chemical processes may attach a small organic methyl molecule (comprised of carbon and hydrogen, the building blocks of life) to some metals. This "methylation" creates organo-metallic compounds such as organotins and methylmercury. These hybrid molecules are particularly toxic to animals and plants because their "organic" disguise enables them to be easily absorbed, while their metallic part disrupts critical physiological processes.

The different chemical forms that metals assume in the environment are sometimes difficult to separate and measure. Thus, pollution studies often don't distinguish between the forms but simply measure the total amount of metal present. Some metal molecules are attracted to the surface of small particles in the air or water and are transported wherever the particles go. Airborne in smoke, metals may be transported for hundreds or thousands of kilometres before settling or being carried to the ground by rain. Similarly, metals adsorbed on fine silt and organic particles may be carried many kilometres by rivers or coastal currents. When the water slows, such as in an estuary, the particles and their burden of toxic metal settle out and accumulate in the bottom mud. Moreover, metals dissolved in rivers may, if suddenly mixed with salty estuarine water, become insoluble, form precipitates and settle to the bottom. This is why estuaries downstream from long-established industries often have thick accumulations of metal-bearing bottom sediments that steadily release toxic metals back into the water. This happened in Quebec's Saguenay Fjord, where an aluminum smelter and chlor -alkali plant contaminated bottom sediments with mercury. Three decades after the plant closed, the bottom sediments are still releasing mercury and the area's shrimp fishery remains shut down because of worrisome levels of the metal in the catch.

Clearly, metals are everywhere in the environment in one form or another, sometimes naturally occurring and sometimes introduced by humans. Monitoring studies typically find a variety of different metals, mostly in trace amounts, but sometimes in higher concentrations. The presence of a metal doesn't necessarily indicate an environmental problem. However, it is a matter of concern when the amounts detected approach or exceed the concentrations that can harm organisms, including humans. Determining the concentrations at which toxic chemicals harm plants and animals is one important goal of toxicology, a broad and complex scientific discipline. Through detailed, long-term laboratory and field studies, researchers estimate the concentrations of heavy metals that just begin to cause detectable adverse effects on test organisms. Government agencies responsible for protecting the environment, living resources and human health then use these findings, usually adding an appropriate safety margin, to issue guidelines for the maximum safe concentrations of a metal in various parts of the environment, such as water, sediment, soil, air or animal tissue.

Helpful or Harmful?

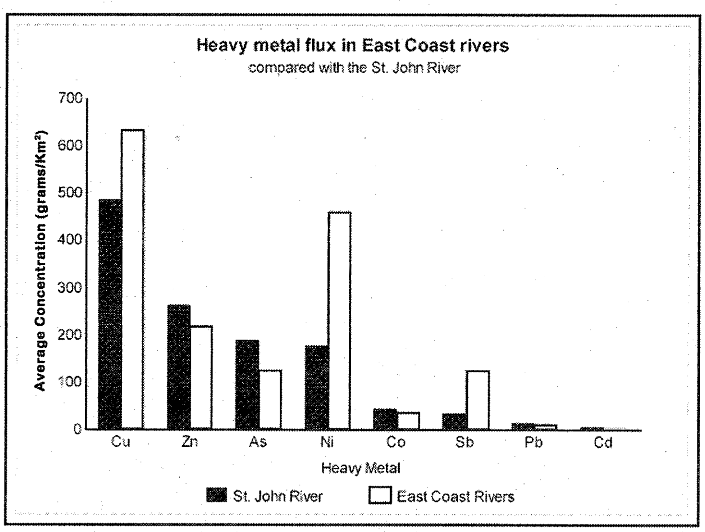
The labels on bottles of vitamins and mineral supplements typically list such metals as chromium, copper, iron, magnesium, manganese, molybdenum, potassium, selenium and zinc. Small amounts are essential in our diet because they are key components of biologically important molecules such as enzymes, haemoglobin and other biochemical compounds that are essential to life. However, if ingested in much larger amounts they can disrupt physiological processes and even kill organisms. Some heavy metals, such as cadmium, mercury, lead and tin, may serve no particular biological function and can be toxic at relatively low concentrations, particularly in their disguised organic form. The guidelines for harmful concentrations of some of these metals are not far above their natural background levels in some areas, so even modest inputs from human activities may raise levels enough to cause concern.

Metals can be absorbed by organisms from the surrounding water or ingested with their food. Once absorbed, metals tend to accumulate in certain tissues and organs rather than distributing uniformly through the body. Most are excreted only slowly and thus they may accumulate in the body. Heavy metals can have numerous harmful effects on organisms. They often accumulate in the nervous system and brain, causing lesions, behavioural disturbances and diverse neurological problems. They may also impair growth, development and reproduction, cause malformations of the body, damage organs or disrupt the immune system. Developing fetuses and growing young are particularly sensitive to low levels of many metals The adverse biological effects are varied, insidious, complex and potentially fatal. Thus, researchers and those responsible for protecting the environment and human health carefully monitor the distributions and concentrations of several metals in the air, soil and water throughout the Maritimes.

Metals in the Maritimes

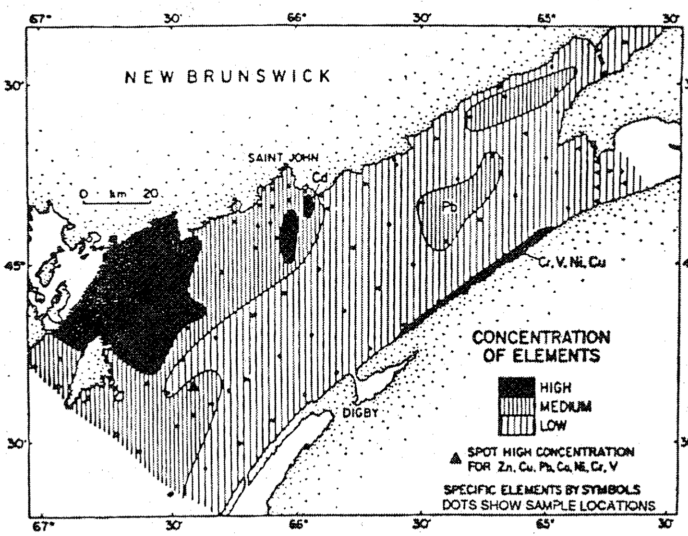
Over the years there have been several attempts to paint a broad geographic picture of the distribution of heavy metals across the Maritimes, including the Bay of Fundy. Different studies have focused on metals present in air, water, sediments, soils, plants and animals. Particular attention has been paid to measuring heavy metals in river water, because this is an important route by which they are flushed from large areas of land and carried into the sea. Rivers also often receive inputs of metals from any industrial, forestry and agricultural operations present in the watershed.

Phil Yeats and John Dalziel, from DFO's Bedford Institute of Oceanography, measured the concentrations of 30 different metals in 29 rivers in New Brunswick and Nova Scotia flowing into the Bay of Fundy or onto the Scotian Shelf. Between 1992 and 1996 they measured the metals dissolved in the water as well as adsorbed on small, suspended particles. Their results provide a comprehensive overview of heavy metals in rivers throughout the region and reveal significant differences between rivers. However, measuring the quantity of metal present in the river water doesn't tell us much about the "metal flux", or the rate at which the contaminant is being carried into the ocean. This depends on how big the river is and how much water it discharges over a period of time. The size of the land area, or watershed, drained by the river is also an important consideration. The river flow, and hence the amount of metal carried into the sea, may also vary with season and from year to year. Attempts have been made to calculate the quantities of metals being carried by rivers into our coastal waters. Herb Windom of the University of Georgia measured the concentrations of eight different metals in some of the larger rivers along the eastern seaboard. He then calculated the amount of each metal that was being transported each



The amounts of various heavy metals carried into the Bay of Fundy each year from each square kilometre of watershed, compared with the average for major East Coast rivers.

— based on data from Windom, H. 1996. Riverine Contributions to Heavy Metal Inputs to the Northeast Shelf Ecosystem. Pp 313-325 In: K. Sherman, N.A. Jaworski and T.J. Smayda (eds). The Northeast Shelf Ecosystem. Assessment, Sustainability and Management. Blackwell Science, Cambridge Mass.



General distribution of several heavy metals in the bottom sediments in the Bay of Fundy.

— From D.H. Loring, 1982. Can. J. Earth Sci. 19(5):930-944

year from each square kilometre of watershed drained by the river. The St. John River, draining a watershed of 39,900 square kilometres and with an average flow of 1,000 cubic metres per second, is one of the larger rivers in this study. The quantities of metals carried by the St. John River compared to the average for other East Coast rivers are shown in the accompanying graph. Most metals are close to the average, with large amounts of copper and relatively little lead or cadmium. A glaring and unexplained difference is the relatively small amount of nickel transported by the St. John River.

Doug Loring, a sediment geochemist previously with the Bedford Institute of Oceanography, measured heavy metal concentrations in seafloor sediments in coastal areas of the Maritimes, including the Bay of Fundy. In the late 1970s, he measured 15 different metals in the surface sediments at sites located throughout the Bay. Mostly, the concentrations were close to natural background levels. The variations in the quantities of metals in different parts of the Bay were largely associated with differences in the nature and size of sediment particles present. Generally metal concentration were lower in the coarser, sandier sediments of the central and eastern parts of the Bay and higher in the finer sediments around the Passamaquoddy Bay region of Southwestern New Brunswick. The abundance of metals in different areas was also related to the presence of bedrock of differing geologic origins in coastal formations around the Bay. Elevated concentrations of chromium, vanadium and nickel in the sediments along the Nova Scotia coast and near Grand Manan Island probably result from the weathering of volcanic rocks with high metal content.

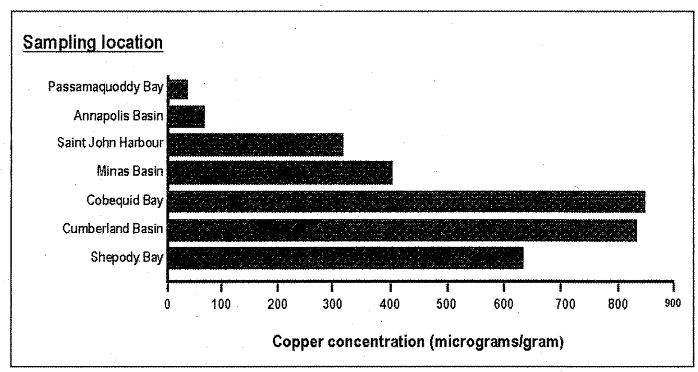
Other scientists have studied at the distribution of heavy metals on the land around the Bay. In the mid 1990s, Wilfred Pilgrim of the New Brunswick Department of the Environment and Bill Schroeder of Environment Canada measured several metals in urban and rural areas of New Brunswick. They collected samples of rain, fallen snow, soil and garden vegetables from several parts of the province and analyzed them for nine different metals. Not surprisingly, the levels of most metals were higher in rain and snow collected near urban centres such as Saint John than in remote rural regions. Smokestacks, such as those of the oil-fired power stations near the city, release significant amounts of some metals, particularly vanadium, into the atmosphere. The amounts of most heavy metals in garden soils were also much higher around urban than rural areas. Nevertheless, even in urban centres the quantities of metals in the soil were below the threshold levels established by the Canadian Council of Ministers of the Environment (CCME) for contaminated sites requiring cleanup (remediation). However, some metals were higher than the average background or natural concentrations in soils in Canada. Lead levels were sufficiently high in urban gardens that the researchers recommended that "home grown vegetables should continue to be thoroughly cleaned and washed before consumption". Cadmium and copper were higher in rain and snow in rural areas of Northern New Brunswick than around Saint John, a likely result of atmospheric transport from a copper smelter in southeastern Quebec.

"the tissues of lobsters from Minas Basin, Cobequid Bay, Cumberland Basin and Shepody Bay located in the Upper Bay of Fundy, all had much higher levels of copper than ones from other areas of the Bay, greater even than lobsters collected in Saint John Harbour!"

Another way of monitoring heavy metal distribution in the Maritimes involves measuring them in the tissues of animals. This is a more useful measure, since it indicates the amount of the metal that is actually available to living organisms and can accumulate in their bodies, with possibly harmful consequences. Large amounts of metal in sediment may be little concern if it is in a form that is unavailable to animals or plants and thus can't harm them. Some organisms can slowly absorb and accumulate metals until the concentrations in their fat, muscles or organs is much higher than in the surrounding environment. More importantly, since humans eat fish and other seafood, measuring metals in the tissues of such animals shows the amount that humans might acquire through their diet.

Scallops and lobsters are important fisheries in the Bay of Fundy, so metals and other contaminants have often been measured in these invertebrates. In the 1980s, scientists from the Biological Laboratory at St. Andrews, New Brunswick measured copper, zinc, cadmium and lead in different tissues of scallops collected around the Maritimes. Some samples came from the Bay of Fundy (Passamaquoddy Bay, near St. Andrews and Digby), while others were from Georges and Browns banks, offshore of the Gulf of Maine. The concentration of copper was high in scallops from Passamaqoddy Bay, but scallops from most of Fundy generally had metal levels comparable to those from uncontaminated areas. Unexpectedly, scallops on offshore Georges and Browns banks, located far from any industrial source, had much more cadmium than Fundy scallops. The researchers speculated that this was probably coming from natural sources, although its exact origin was unclear.

Phil Yeats and Chiu Chou, marine chemists from the Bedford Institute of Oceanography, have recently measured copper in the tissues of lobsters collected around the Maritimes, including the Bay of Fundy. Surprisingly, the tissues of lobsters from Minas Basin, Cobequid Bay, Cumberland Basin and Shepody Bay in the Upper Bay



The concentration of copper in the digestive glands of lobsters collected in the Upper Bay of Fundy is much higher than in those from other areas of the Bay, including Saint John Harbour.

— based on data from C.L. Chou, L.A. Paon, J.D. Moffatt and B. Zwicker, 2000. Bull. Envir. Contam. Toxicol. 65:470-477.

of Fundy, all had much higher levels of copper than ones from other areas of the Bay, greater even than lobsters collected in Saint John Harbour! The levels were as much as 30 to 100 times higher than reported for lobsters from industrialized areas. Where is this copper coming from? The few urban centres around the Upper Bay are comparatively small and there are relatively few heavy industries in the region releasing pollutants. However, the rivers flowing into the upper Bay drain a landscape dominated by exposed sedimentary rock formations dating from the carboniferous era. The rivers there have a higher copper content than rivers along Nova Scotia's southwestern coast, where the land surface is mostly derived from igneous (volcanic) rocks. Lobsters can actively accumulate copper from the surrounding water. However, the copper concentration of over 800 ug/g in lobsters from the upper Bay is unusually high. Because there are as yet no Health Canada guidelines for copper levels in fishery products, the possible implications for human health are uncertain. The researchers recommend additional studies to confirm the source of the copper and to determine if there are any adverse biological effects on lobsters and humans.

"Fish from coastal waters appear to have much lower concentrations of mercury than their freshwater counterparts. In some estuaries, fish had mercury levels a quarter to a tenth that in fish in nearby lakes."

Fish are an important food for birds of prey, such as eagles, ospreys and loons, as well as some marine and terrestrial mammals, including humans. In fact, consumption of fish is the major way that heavy metals, such as mercury, are transferred from the environment to people. Typically, as much as 95% of the mercury present in fish is biologically active methylmercury It is not surprising, therefore, that attention has been paid to monitoring heavy metals, particularly mercury, in fish in rivers, lakes and coastal waters throughout the Maritimes. Health Canada has set 0.5 ppm as the upper threshold level for mercury in fish and fish products intended for human consumption. Higher levels trigger an advisory to limit the consumption of fish from the contaminated area. Eight species of fish from various parts of the St. John River system all had elevated levels of mercury, in some cases as much as five times greater than the Health Canada guidelines. It is generally assumed that this comes from both natural sources and inputs from human activities, although the relative contribution of each is unknown. Striped bass from the Annapolis and Shubenacadie rivers on the Nova Scotia side of the Bay have mercury levels up to 3 or 4 times above the Health Canada guidelines. Because there are no obvious local industrial or other human sources in these regions it is generally assumed that this mercury is coming from natural geological sources and from long-range atmospheric transport. Fish from coastal waters appear to have much lower concentrations of mercury than their freshwater counterparts. In some estuaries, fish had mercury levels a quarter to a tenth that in fish in nearby lakes. The reason for this is not immediately clear, but may result from differences in the habitat, greater dilution of contaminants in seawater or differences in the food. Marine fish, such as herring, caught in weirs along the New Brunswick coast typically have a mercury content of about 5-15 parts per billion (note the billion), almost 1000 times lower than the Health Canada guideline.

"Gulfwatch monitoring indicates that in most of the Bay of Fundy heavy metal concentrations in mussels are near natural levels".

Scientists have also measured metal concentrations in other types of animals, not because humans may consume them, but because they provide a convenient way of monitoring contaminants in their environment. Studies have particularly focused on mussels, seabirds and marine mammals. The long running "Gulfwatch" mussel monitoring program is described more fully in Fundy Issues #12 *"Gulfwatch: Putting a Little Mussel into Gulf of Maine Marine Monitoring"*. At intervals of 1 to 3 years, mussels collected from 58 sites around the Gulf of Maine and Bay of Fundy are analyzed for many different contaminants, including several heavy metals. Bivalve molluscs are particularly useful for monitoring contaminants in their environment because they accumulate and concentrate in their tissues chemicals present in food particles or dissolved in the large amounts of water that they filter. The fact that mussels are attached permanently to rocks means that any contaminants that they accumulate must have come from the water, plankton or sediment present at that specific location. With free ranging animals, such as fish, one is never sure where they picked up any contaminants they contain. Over a decade of Gulfwatch sampling has provided a valuable series of snapshots of the distribution of chemicals throughout the Gulf of Maine and has also produced a baseline for monitoring if these levels are rising or falling. Silver, lead, chromium, mercury and zinc levels are much higher in mussels from the southern areas of the Gulf. The very much greater population densities and levels of industrialization there almost certainly account for this. In the Bay of Fundy, mussels from a few sites have heavy metal concentrations higher than the average for northern areas of the Gulf. For example, mussels from Saint John Harbour have elevated levels of iron, aluminum, chromium and nickel, presumably arising from the industrial sources described below. Mussels from sites at Broad Cove and Argyle, along the Nova Scotia side of the Bay, have above average levels of metals such as iron, cadmium, nickel, chromium, mercury and lead. Since there are no industrial sources nearby, it is assumed that these arise from the weathering of local metal-bearing rocks or from the activities of fishing boats in these ports. Except for these anomalies, Gulfwatch monitoring indicates that in most of the Bay of Fundy heavy metal concentrations in mussels are near natural levels.

Contaminants in the tissues of seabirds and marine mammals, such as seals and porpoises, are of interest because these are predators near the top of the food chain. As such, they tend to accumulate contaminants from the organisms that they eat. For some chemicals, they demonstrate a process of "biomagnification" by showing concentrations even higher than their prey. Thus, they can provide a general picture of the types and amounts of contaminants present in their food and in the wider ecosystem. Dave Gaskin, formerly a scientist at the University of Guelph, and his students measured contaminants, including heavy metals, in the flesh of porpoises and seals from the Bay of Fundy for over thirty years. Both harbour porpoises and harbour seals eat fish and frequent coastal waters and are thus exposed to contaminants coming from land-based sources. The initial studies done in the 1970s showed that the level of most metals in the tissues were comparable to those in similar species worldwide. Only mercury was significantly higher in animals from the Bay of Fundy. Similar studies in the 1990s revealed that although levels of copper, cadmium and zinc in porpoises had not changed significantly, the amount of mercury had declined from that measured two decades earlier.

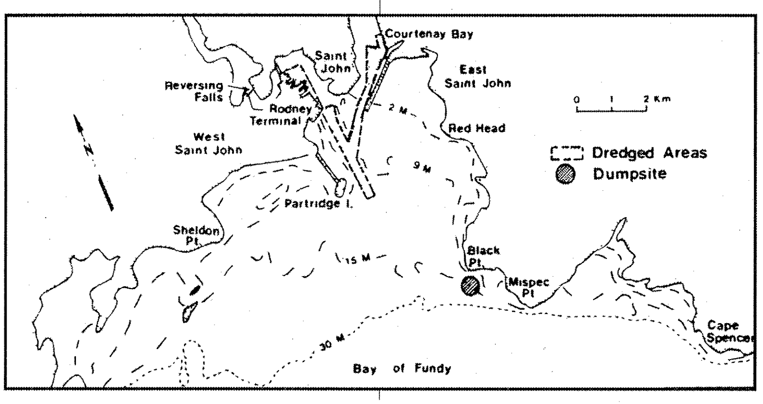
Scientists with the Canadian Wildlife Service (CWS) routinely use seabirds to monitor the presence of contaminants in the marine environment. In the early 1990s, measurements were made of cadmium, lead, mercury and 18 other metals in the tissues of seabirds collected at several sites in Atlantic Canada, including the Bay of Fundy. The concentrations of most metals were comparable to those found in similar species worldwide. However, the highest concentration of mercury was measured in the livers of double-crested cormorants collected in Saint John Harbour. Elevated levels of lead were also recorded in the bone tissue of herring gulls from three Bay of Fundy colonies. An earlier CWS study had shown that the highest cadmium levels occurred in storm petrels and that levels in Bay of Fundy birds were comparable to the elevated levels present in Gulf of St. Lawrence birds. A microscopic examination of tissues and cells of the contaminated birds revealed no evidence of any apparent damage, leading the researchers to conclude that these seabirds may be able to tolerate low-levels of metals in their tissues without ill effect.

Heavy Metal Hotspots

Large industrialized seaports are often flagged as hotspots for elevated concentrations of heavy metals in water and sediment. This is not surprising, given the high population density, concentration of polluting industries and constant vessel traffic. Saint John, now the only major seaport on the Bay of Fundy, has been the focus of many pollution studies. There are numerous sources of heavy metals in and around the port and even farther afield. The harbour area is in the estuary of the St. John River. The river valley has long been productive agricultural land and much of the remainder of the watershed has a 200-year history of forestry. Both agricultural and forestry activities have contributed to erosion and inputs to the river of heavy metals from the soils as well as from some types of pesticides. The river also collects runoff bearing the products of atmospheric pollution deposited across the entire watershed. On its way to the sea, the river cuts through two geological formations containing heavy metals such as copper, lead, zinc, nickel, tin, antimony and molybdenum. In addition, mining operations for coal, potash and antimony within the watershed may contribute other metals.

However, the largest input of heavy metals undoubtedly occurs in the neighbourhood of Saint John, particularly around the port area. Untreated sewage has been flowing into the river for centuries from one of the oldest municipal sewage systems in North America. About 16.3 million litres a day, or almost half of the total sewage from the city, flows untreated into the harbour through 55 of the 135 municipal outfalls. Although much progress is being made in upgrading and building treatment facilities, it may be years before the process is complete.

The city is also the most heavily industrialized area in the province. Around the harbour are clustered a pulp and paper mill, a paper making plant, textile plants, food processing plants, an oil refinery and oil storage depots, a brewery, a sugar refinery, assorted manufacturing plants, a drydock with ship building and repair facilities, and freighter and cruise ship terminals. In addition, a fossil fuel electrical generating station on Courteney Bay uses seawater as a coolant. In the early 1990s a consulting firm collected water samples from most of the industrial and municipal outfalls flowing into the harbour and analyzed them for several heavy metals. Most samples had significant concentrations of copper (2-170 ppm) and zinc (6-220 ppm), but low levels (less than 2 ppm) of most other metals measured. In addition, the paper plant released significant amounts of aluminum (710 ppm), while the power station effluent had high levels of iron (1100 ppm) and vanadium (2000 ppm). In samples taken from municipal sewage outfalls, the heavy metal concentrations were low, all below 1 ppm. The total amount of each heavy metal that each industry adds to the estuary depends on the volume of water it uses and discharges each year, but the overall input is significant.



Saint John Harbour, showing location of dredged areas and Black Point Dumpsite.

— From Washburn and Gillis Associates Ltd. 1993. Saint John Harbour Environmental Quality Study. Washburn and Gillis Associates Ltd. Fredericton , NB.

In view of this, it is surprising that, with the exception of a few localized hotspots, the levels of metals in the water and sediments in much of the estuary are generally low and not much greater than those elsewhere in the Bay of Fundy. The concentrations of metals are lower than in most other major ports on the eastern seaboard. Only mercury is consistently present in concentrations above background levels. As for hotspots, there are slightly elevated levels of several metals in sediments just below the reversing falls, near the main port area in Courteney Bay and at the mouth of Little River, all areas near large industrial outfalls. The concentration of metals in the bottom sediment decreases seaward from the inner harbour. A number of factors are responsible for the relatively low levels of metals within the St. John Estuary. Firstly, the estuary is extremely well flushed, both by the large flow of the St. John River and the very high tides sweeping in and out. Secondly, most heavy metals are probably quickly adsorbed onto suspended fine-grained sediment and organic particles that are carried seaward by the currents. Thirdly, the Harbour's shipping channels are continually filling in with sediments and have to be dredged frequently. Every year, almost a million cubic metres of sediment, along with any adsorbed heavy metals, are removed from the area, particularly from around the wharves and shipping channels.

Dumpsite Details

The dredged sediment, or spoil, is transported by barge to a designated dumpsite off nearby Black Point. The strong currents sweeping over the area are supposed to disperse much of the sediment into the wider Bay. The site has been used for dumping harbour spoil for more than half a century. Environment Canada regulations forbid the dumping of sediments excessively contaminated with some heavy metals. For example, there can be no more than 0.75 ppm of mercury, 0.6 ppm of cadmium, or 160 ppm of zinc in the spoil. Sediments with higher concentrations must be disposed of on land. Although the sediments from some areas of the Harbour have elevated levels of mercury and other metals, the amounts are within these limits for ocean disposal.

Over the years, studies have revealed "relatively high" concentrations of some metals in the bottom sediments around the dumpsite. In 1992, Environment Canada and DFO scientists launched a three-year Black Point Disposal Site Monitoring Program as part of a broader Canadian "Green Plan Ocean Disposal Action Plan". The project's objectives were to ascertain if there were any physical, chemical or biological changes caused by the dumping and to determine the extent of the seafloor that may have been affected. The decades of dumping had created a shoal up to 10 meters high about a kilometre around the site's marker buoy. The strong currents had dispersed the finer sediments, leaving mostly coarser materials. Only 15-20 percent of the material dumped during the previous three and a half decades still remained at the site. Seafloor sediments collected around the dumpsite were analyzed for arsenic, cadmium, copper, lead, zinc and mercury. Concentrations were slightly elevated within a two-kilometre radius, but were near background levels beyond this. The researchers concluded that the quantities present posed no real threat to the ecosystem. Nevertheless, they carried out additional tests to see if the sediments were toxic to marine organisms. Shrimp-like amphipod crustaceans survived exposure to the sediments for several days. More sensitive test involving bacteria and sea urchin embryos indicated significant effects of exposure to the sediments. However, this was attributed to low oxygen in the sediments rather than heavy metal poisoning. A survey of the bottom communities at the dumpsite revealed that the animals present were similar but their abundance was lower compared to areas farther away. This probably results from disturbance and smothering by frequent sediment dumping rather than the toxicity of the sediments. The researchers concluded that "disposal activities did not seem to have resulted in major changes in the benthic communities in the vicinity of the disposed spoil". Thus, there is no reason to cease using the dumpsite, although inputs of coarse material should be limited to avoid growth of the shoal.

"The Passamaquoddy Bay - Grand Manan area of Southwestern New Brunswick appears to be a 'sink', or region of deposition, for finer sediments transported from elsewhere, along with their attached heavy metals."

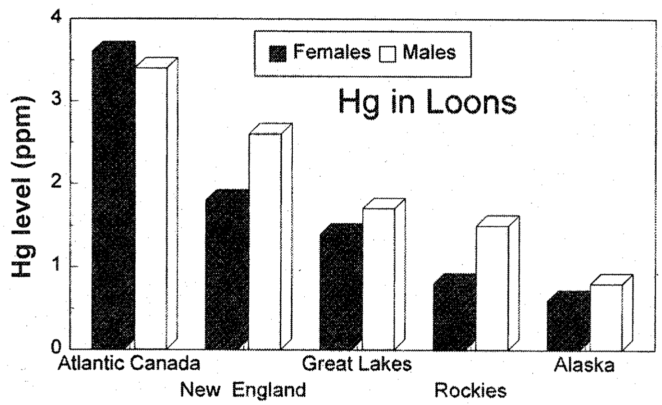
Problem in Passamaquoddy

The elevated metal concentrations in Saint John Harbour and at the Black Point disposal site were not wholly unexpected. However, the finding of elevated heavy metals in the water and sediments around Grand Manan Island and in Passamaquoddy Bay, 100 kilometres to the southwest, was more of a surprise. It's an area that is noted for small picturesque fishing communities and tourism. Smokestacks and industrial outfalls are noticeably absent from the coastline. Nevertheless, a 1972 study found that in the St. Croix River estuary, which includes Passamaquoddy Bay, the amounts of cadmium and lead in suspended particulate matter were comparable to "moderately polluted estuaries". Some metals, such as chromium, vanadium and nickel, are naturally occurring in the sediments of coastal areas of Southwestern New Brunswick, being derived from metal-bearing rocks. The St. Croix River may also have carried metals from upstream pulp and paper mills and other industries. However, it seems that many of the heavy metals are coming from even further afield. As noted earlier, the finer contaminated sediments from Saint John Harbour and the Black Point dumpsite are carried by the St. John River and tidal currents out into the Bay of Fundy. The water in the Bay generally circulates in a counterclockwise direction, entering along the Nova Scotia coast and departing along the New Brunswick shore. This latter southwestward current carries with it the finer sediments from the Saint John river plume, depositing some along the way but even more as it slows in passing through Passamaquoddy Bay. In the 1980s, elevated levels of mercury had been noted in the coastal sediments between Point Lepreau, near Saint John, and Passamaquoddy Bay. The Passamaquoddy Bay - Grand Manan area of Southwestern New Brunswick appears to be a "sink", or region of deposition, for finer sediments transported from elsewhere, along with their attached heavy metals. Scientists from the University of Guelph found elevated levels of lead and vanadium in suspended particulate matter in the Passamaquoddy region, especially in the smaller organic particles that are food for the teeming planktonic copepods. The copepods too had significant levels of both metals in their bodies. The copepods are an important food for young herring, seabirds such as red-necked phalaropes, and mammals such as the endangered northern right whale. Thus, there is justifiable concern about the potential long-term effects of this metal contamination on marine animals right up the food chain.

"Mercury is a heavy metal that is pervasively present in elevated amounts in much of the Maritimes, including the Bay of Fundy."

The Mercury Menace

Mercury is a heavy metal that is pervasively present in elevated amounts in much of the Maritimes, including the Bay of Fundy. This has attracted the attention of many researchers because of concerns about the possible effects on wildlife populations and on human health. The public was first sensitized to the threat of mercury in the environment during the 1950s by the catastrophic effects on human health resulting from industrial mercury pollution in Japan's Minimata Bay. In the 1970s, this wake-up call was reinforced in Canada after mercury from pulp mills and mine tailings had for two decades contaminated the English and Wabigoon rivers in northwest Ontario. This resulted in mercury contamination of game fish as well as elevated levels and health effects in the native peoples who ate



Loons in Atlantic Canada have higher levels of mercury in their blood than those in other parts of North America.

— From N.M. Burgess, D.C. Evers and J.D. Kaplan.1998. Pages 96-100. In: Mercury in Atlantic Canada: A Progress Report. Environment Canada - Atlantic Region.

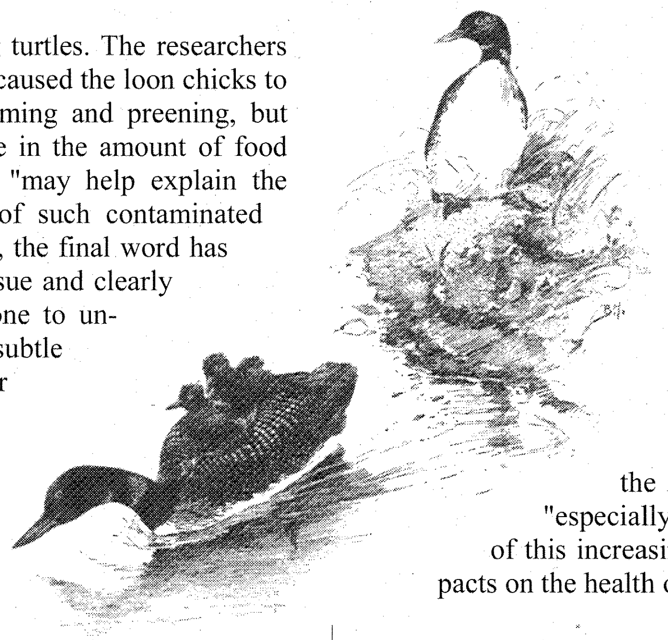
them. Public concern about mercury in the Fundy region was triggered in the late 1990s when scientists from the Canadian Wildlife Service reported that loons in and around Kejimkujik National Park in Southwestern Nova Scotia had the highest levels of mercury found in these birds anywhere in North America. This catalyzed studies to find out where it was coming from, how it was getting into the loons and if it was affecting their health and survival. Many of the studies were part of a comprehensive, long-term Environment Canada initiative known as the Long Range Transport of Air Pollutants (LRTAP) Program.

The Maritimes are directly downwind from the most industrialized centres in North America. Plumes from smokestacks in Chicago, Sarnia, Hamilton, Toronto and Pittsburgh are carried by prevailing winds across the Gulf of Maine, Bay of Fundy and southwestern Maritimes. Such "long range atmospheric transport" is the way that most of the mercury is introduced into the region's environment. However, local bedrock also contributes some mercury and recent studies show that "acid rain", also carried in by the prevailing air movements, makes the lakes and streams more acid, causing even more mercury to be leached from rocks and soils. Compounding the problem, the lakes and rivers in Southwestern Nova Scotia typically have high levels of dissolved organic matter because they often drain from the numerous peat bogs and marshes. This abundance of organic matter results in more of the mercury being converted into highly toxic methylmercury.

Loons are fish eating predators, so efforts to follow the trail of the mercury focused initially on the fish populations, particularly yellow perch which make up 85% of a loon's diet in the summer. Earlier studies had already indicated that game fish in many rivers in the Maritimes, such as the St. John River and its tributaries, have elevated levels of mercury. The perch, as well as several other fish, in Lakes in Kejimkujik Park also had elevated mercury levels. The amounts of mercury in the fish varied from lake to lake and tended to be higher in lakes that were more acid, had more organic carbon in the water, were darker in colour (a result of dissolved organic matter and humic acids) and had higher levels of mercury in the water.

There was concern that the high levels of mercury might be the cause of the loon's low reproductive success. Laboratory studies had shown that small amounts of mercury alter the breeding behaviour of loons and reduce their reproductive success. A field study of loons living downstream from an industrial source of mercury in Ontario revealed that nesting and reproduction were reduced when fish prey contained 0.3-0.4 ppm mercury. Even more ominously, no young loons were produced when the fish contained more than 0.4 ppm mercury. Since the perch in some Keji Lakes had levels of mercury close to and above this, the CWS researchers predicted that "mercury risks to common loon reproduction are anticipated at Kejimkujik". However, confirming this has not been easy, since loon reproduction can be impaired by many other factors, such as disturbance from human activity around lakes, predation, fluctuating lake levels and scarcity of suitable food.

The researchers conducted a number of studies to determine the reproductive success of Keji's loons in relation to the mercury levels in the blood. Higher levels of mercury in the birds tended to result in lower rates of nesting and reduced egg laying. On average, loon pairs with blood mercury less than 2.5 ppm had 1 chick, while those with more than 6 ppm mercury averaged only 0.2 young. Surprisingly, the mercury had little effect on the survival of chicks that had hatched. Other studies looked at the effects of mercury on the behaviour of the adults and their chicks. This involved watching them closely for long periods and noting how frequently they performed, and how much time they spent in doing, certain behaviours. The amount of time that the chicks spent feeding and begging for food was not altered by elevated mercury levels. However, chicks with more mercury in their blood spent much less time riding on the backs of the swimming adults and more time preening. This back-riding not only conserves the chick's energy and keeps them warmer but also reduces their exposure to predatory fish and snapping turtles. The researchers hypothesized that the mercury caused the loon chicks to expend more energy in swimming and preening, but with no compensating increase in the amount of food they consumed. Their results "may help explain the chronically low productivity of such contaminated sites as Kejimkujik". However, the final word has not yet been written on this issue and clearly more research needs to be done to unravel the complexities of the subtle effects of mercury and other heavy metals on loons and other wildlife. Nevertheless, we already know enough about the damaging effects of these contaminants on wildlife and on human health to raise alarms and redouble our efforts to reduce the inputs and lower the concentrations already present in the environment.



the health risk to loons, to other wildlife and ultimately to humans. To this end, the Collaborative Mercury Research Network (COMERN) was formed in Canada in 2001 to "integrate Canadian research efforts toward a better understanding of processes ruling mercury exchanges and accumulations in wide-scale ecosystems in the northern part of the American continent" and to "especially aim at identifying the causes of this increasing contamination and its impacts on the health of [human] communities".

Managing Metals

Little can be done to reduce inputs of metals from natural sources, such as bedrock formations and volcanic activity, so reducing concentrations in the environment will depend on curbing the excessive amounts released by human activities. There is still some uncertainty about the relative proportions of metal contamination that man and nature are ultimately responsible for. It is essential, therefore, to continue monitoring the trends in metal inputs from industrial and other human sources and track the metals as they disperse in the environment. We need to better understand how the different metals behave in coastal environments, how and under what conditions they change from one form to another, and how they distribute themselves in air, water, soil and sediments. Most importantly, we need to learn more about how they are taken up by organisms and disrupt their important biological processes, such as behaviour, development, growth, and reproduction. Demonstrating the link between mercury in the smoke from steel mills in Hamilton or from coal-fired electrical generating stations in Pittsburgh and elevated mercury in loon blood and reduced nesting in these birds, may convince regulators and industry leaders that reducing emissions reduces

"Little can be done to reduce inputs of metals from natural sources, such as bedrock formations and volcanic activity, so reducing concentrations in the environment will depend on curbing the excessive amounts released by human activities."

Metals and other airborne contaminants move quickly over large distances, unconstrained by political boundaries. Thus, monitoring their transport and deposition must involve coordinated regional, national and international efforts. A network of air monitoring sites, such as those at Kejimkujik National Park in Nova Scotia and Huntsman Marine Science Centre in New Brunswick, keeps tabs on seasonal and year to year fluctuations in mercury levels across the country. This, in turn, is linked to a North American monitoring network. Similarly, the GulfWatch Monitoring Program routinely monitors the trends in concentration of water-borne contaminants, including 10 heavy metals, in coastal areas of the Gulf of Maine and Bay of Fundy. Gulfwatch is part of an even larger Mussel Watch, funded by the National Oceanographic and Atmospheric Administration, which monitors contaminants in coastal waters all around the U.S. This is further linked to a worldwide array of mussel watch programs in several other countries.

Controlling emissions and reducing heavy metals in the environment also requires international cooperation. To this end, Canada and 34 other nations in 1998 signed the Protocol on Heavy Metals, part of a United Nations sponsored Convention on Long-range Transboundary Air Pollution. The Protocol, which went into effect in December 2003, requires participants to monitor their national emissions of lead, cadmium and mercury and actively work towards reducing the amounts released by using the best available technology.

Appreciable progress is being made in curbing human inputs of metals into the environment. In recent decades emissions from industrial smokestack and outfalls have been steadily reduced, partly as a result of stringent regulations, but also because many industries increasingly recognize that it is not only the socially responsible, but often the most economically sound, thing to do. Heightened awareness of the environmental and human health impacts of heavy metals has encouraged manufacturers to seek new ways to reduce or eliminate them from their products or manufacturing processes. The removal of lead from gasoline and paints, the elimination of mercury from pesticides and electrical devices and thermometers, and the digital camera boom, which removes the need for silver and other toxic chemicals for manufacturing and developing film, are just a few examples of advances being made. Also, in many parts of Canada, laws regulating waste disposal and promoting recycling have diverted heavy metal-containing products, such as batteries, electrical equipment and appliances from landfills and fostered the recovery and reuse of their valuable contents.

But we shouldn't be complacent - there is still much to be done to reduce the risk from various toxic metals to Fundy's ecosystem. Renewed efforts in research, monitoring, assessment, education, regulation, recycling and industrial innovation will go a long way towards making the region's environment safer for us, the loons and the other wildlife that we share it with.

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Collaborative Mercury Research Network (COMERN) website. www.unites.uqam.ca/comern/