

COAL AND MERCURY IN ALASKA

AN ENVIRONMENTAL RESEARCH AND POSITION PAPER

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TABLE OF CONTENTS

Executive Summary	1
Introduction.....	2
Coal exploration.....	2
Mercury content.....	3
Where does the mercury come from?	4
Human activities	5
Alaska.....	6
Mercury transport and cycling	8
Types of mercury	8
Fate and transport of mercury.....	9
Travel through air.....	9
Travel by ocean.....	10
Travel by rivers and migratory animals	11
Can mercury be controlled?	12
When mercury reaches Alaska	14
Polar sunrise	14
Mercury in snow and lichen	14
Cycling in streams and lakes.....	15
What do bacteria have to do with it?	17
Bioaccumulation and Biomagnification	18
Mercury in fish and wildlife.....	21
Arctic wildlife	21
Marine Mammals	22
Marine Fish in Alaska.....	23
Freshwater Fish in Alaska	23

Fish Consumption	26
Impacts	31
Health Impacts on People.....	31
Health of Wildlife and Fish.....	33
Impacts on Markets.....	34
Summary.....	37
References	38
Appendix A: Units and conversions.....	47
Appendix B: Atmospheric Chemistry.....	48
Appendix C: Methylation and Demethylation	50
Appendix D: Biochemical Mechanisms of Toxicity.....	51

Executive Summary

The pristine nature of Alaska drives multi-million dollar industries in sport-fishing, commercial fishing, mountain climbing, winter sports, tourism, and the arts. The recent boom in mineral exploitation may reduce the viability of these ecosystem-dependent economic resources through direct impacts and tarnishing the "Wild Alaska" image. Burning coal, in-state or after export to Asia, has a particularly strong potential to impact the health of Alaskans and the health of their ecosystem-based industries by increasing mercury concentrations in Arctic air and water.

In 2006, Alaska and Wyoming were the only two states that did not limit how much fish could be eaten because of mercury toxicity; by 2009 Alaska had issued state advisories for both marine and freshwater fish. The mercury did not come from Alaskan industry. In the Eastern US the source of mercury is nearby US coal-fired power plants, which are now installing mercury capture equipment, and in the Western US mercury comes from Asian emissions that travel on air currents in the spring. But Alaska is unique: it receives mercury directly from Asia on air currents and receives "global pool" mercury from around the Northern Hemisphere that preferentially deposits in the Arctic.

When mercury in the atmosphere falls onto Alaska soil and sediment, it can change to a form that is taken up by fish, wildlife and people: methylmercury. Effects are just beginning to be observed, and there is speculation that Alaska's vast wetlands, coasts, and forests are environments that contribute to mercury methylation and consequently high concentrations of mercury in some fish. Northern pike and lake trout in some remote regions of Alaska have mercury loads high enough to be of some concern.

Ironically, while mercury in fish in the contiguous states is declining due to mercury controls on local sources, mercury in Alaska is expected to increase. The amount deposited is likely to increase as the global pool grows, and recently-thawed permafrost may provide ideal environments for methylating.. Burning coal in Alaska directly contributes to mercury in air, water, and soil; mining and export of Alaska coal indirectly contributes to future mercury loads.

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Introduction

As of 2005, there was an estimated 5,526 billion tons in the northern, central, and southcentral regions of Alaska (Figure 1).¹ Alaska has all four grades of coal: anthracite, bituminous, sub-bituminous, and lignite.² Anthracite, with the highest heating value, is used in steel production. Bituminous, sub-bituminous, and lignite have progressively less heating value.³ The coal at the North Slope is primarily bituminous and lignite, while the others are primarily sub-bituminous and lignite grades.

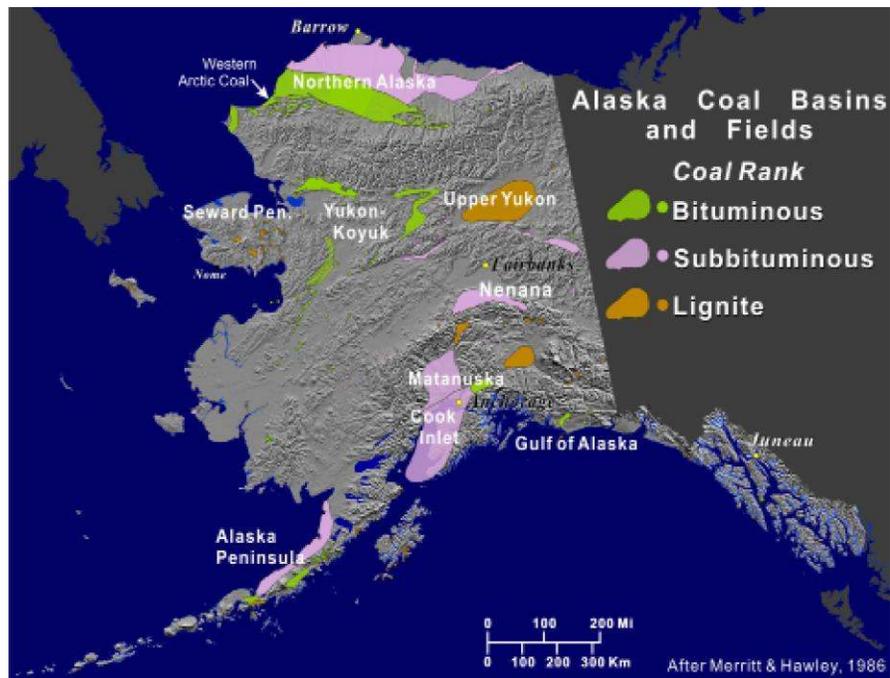


FIGURE 1. COAL FIELDS IN ALASKA. Anthracite contains the highest heating value while lignite contains the lowest. From http://energy-alaska.wikidot.com/local--files/overview-of-alaska-s-coal-basins/coal_165.jpg

COAL EXPLORATION

Although the Usibelli mine near Healy is the only operating coal mine in the state of Alaska, exploration is actively occurring throughout the state:

- Usibelli is actively exploring at the Wishbone Hill location near Palmer.⁴

¹ Flores et al 2005

² Alaska Business Monthly Nov 1 2001; Flores et al 2005

³ Heating values for coal types are: anthracite 12,000-14,000 Btu/lb; bituminous 11,000-14,000 Btu/lb; sub-bituminous 8,000-12,000 Btu/lb.

⁴ ADNR surface coal exploration renewal permit 01-86-795 issued July 7, 2010; Chickaloon Village Traditional Council media advisory June 9, 2010

- PacRim Coal LLC, a Delaware-based corporation owned by Texans, holds leases to over 20,000 acres on the west side of Cook Inlet and is in the advanced exploration stage to develop a strip mine at the Chuitna coalfields, which hold an estimated 1 billion tons of sub-bituminous coal.⁵
- The Alaska Mental Health Trust Authority (AMHTA) holds 22,000 acres near Chickaloon that it may offer for coal leases. Hobbs Industries has applied for coal exploration on 180 acres and Australia-based Black Range Minerals has secured leases to 1,450 acres nearby.

MERCURY CONTENT

Coal often contains mercury, and 75 tons of mercury are delivered to US power plants every year with coal.⁶ Of this, up to 50 tons per year go into the atmosphere, and the remainder is captured on pollution control equipment and put in landfills.

Coal in Alaska is low in mercury (<0.5 mg/kg), but some samples from the Herendeen Bay coal fields on the Alaska Peninsula range from 3-63 mg/kg,⁷ higher than average.⁸ When coal is burned, some mercury in it becomes a gas and travels⁹ while some attaches to particles and falls out close by. Because the Arctic is a "sink" for gaseous contaminants from the Northern Hemisphere, because Alaska is downwind of spring air currents from Asia, and because Pacific ocean currents pick up mercury from Asia and transport it, some mercury in coal exported from Alaska will likely return by air and ocean cycles.

Regulators and legislators need to weigh the potential risks and deficits of coal export and coal-fueled industry in addition to the immediate benefits as they consider the course of economic development in Alaska.

⁵ Spence, H. 2007

⁶ http://www.epa.gov/mercury/control_emissions/index.htm accessed January 2009

⁷ <http://energy.er.usgs.gov/coalqual.htm>

⁸ US EPA 2005. The normal range is 0.02-0.3 mg/kg.

⁹ http://www.epa.gov/mercury/control_emissions/index.htm; Rackley et al 2004

Where does the mercury come from?

Unlike most metals, which are transported by erosion or leaching and impact areas near the source, mercury primarily travels through the atmosphere, allowing a point source to impact both local areas and points around the globe.

NATURAL SOURCES

Mercury is an element – it has always been present on Earth. About half the mercury depositing in the western US is from natural sources, including Asian natural sources.¹⁰ Natural mercury comes from the oceans, volcanoes, geothermal water, rock, soil, plants, and forests. Its mobility determines a lot about its chemical character and behavior. Mercury in highly consolidated material, such as rock – or a coal seam – is less likely to be exposed to air and water that could mobilize it, unless there is a geologic event. Massive volcanic eruptions, such as Krakatau or Mount St. Helens provide significant but short-term inputs of mercury into the atmosphere.¹¹ Forest fires can also release bursts of mercury.¹² Fire leaves the land susceptible to erosion, so mercury that was tied up in soils may be carried by water into watersheds where it is more likely to become bioavailable.¹³

Most natural sources – oceans, soil, and vegetation – both absorb and emit mercury. Overall, vegetation as "litterfall" probably retains more mercury than plants emit.¹⁴ Mercury in consolidated rock, including ore, is not generally of concern as it does not leach out easily. However, erosion of rock can generate small particles that are carried by mud and water. Rivers, although not sources of mercury, can transport erosional material and mercury that settles into stream and river sediment can cycle into bioavailable forms.

¹⁰ In the spring, Asian natural land emissions may account for up to 13% of the mercury that arrives in Oregon (Strode et al 2008)

¹¹ Hutchison and Atwood 2003; Schuster et al 2002

¹² Globally, wildfires may release between 200-1000 tons of mercury per year (Freidli and Radke 2002).

¹³ Mercury may deposit in environments where methylation can occur, and nutrients released in erosion may enhance this (Jewett and Duffy 2007).

¹⁴ Grasslands and forests each emit in the range of 800-2300 tons of mercury per year, but "litterfall" vegetation probably retains 2400-6000 tons of mercury per year, making vegetation a likely absorber of mercury overall (Xin et al 2007). Litterfall is leaves, twigs and other material that accumulates on soil surfaces.

HUMAN ACTIVITIES

The vast majority of atmospheric mercury comes from coal combustion, incinerators, gold processing and industrial boilers.¹⁵ Industrial processes only emit mercury and do not absorb it, so mercury in the atmosphere worldwide has increased since industrialization. According to ice core data, human activities have

TABLE 1. MERCURY RELEASES OF ARCTIC NATIONS (adapted from Rackley et al 2004)

Country	Release to air (tons/yr)
Iceland	na
Finland	0.6
Norway	0.7
Sweden	0.7
Denmark	1.5
Canada	8.8
Russian Federation	43
USA	120
Total	175
% contribution from US	69%

contributed 70% of the mercury emitted to the atmosphere in the past 100 years.¹⁶

Since the 1990's, emissions from Europe and North America have been declining, although Russia and the US still contribute the vast majority of mercury released from Arctic nations (Table 1). Asian emissions are increasing rapidly and Asia (China, Korea, Japan) is now the largest source of atmospheric emissions on the planet. While North America and Europe each contribute about 10% of the total global anthropogenic emissions, Asia contributes over half.

Coal combustion is the single highest contributor in the US¹⁷ (Table 2). However, not all the mercury that deposits in the US came from the US. Human activities in North America contribute about 25% of the mercury deposited;¹⁸ mercury originating in Asia deposits just as much.¹⁹ Up to 95% of all the mercury deposited west of the Mississippi originates from non-US sources,²⁰ including Asian industrial emissions and from seasonal biomass (crop and forest) burning in Asia.²¹

¹⁵ AMAP 1997. For information on mercury from gold processing: Federal Register 75 (81) April 28, 2010 ; "Mercury, the Donlin Creek Mine Project and what it means for the Kuskokwim River" fact sheet (2010) by the Northern Alaska Environmental Center, the Center for Science in Public Participation, and Ground Truth Trekking; Jones and Miller 2005

¹⁶ Schuster et al 2002

¹⁷ EPRI 2006; US EPA 1997b; Rackley et al 2004.

¹⁸ Seigneur et al 2004

¹⁹ Seigneur 2004 estimates about 21% of North American mercury comes from Asia; Jaffe and Strode 2008 estimate 16% of all North American mercury is from Asian anthropogenic sources (7% of the mercury in the Northeast US to about 20% of the mercury in Alaska). Strode et al 2008 estimate 16% of the mercury in the US comes from Asian anthropogenic sources and 11% from Asian natural sources for a total of 27% total US mercury originating in Asia.

TABLE 2. SOURCES OF MERCURY TO THE ENVIRONMENT IN THE US (adapted from Rackley et al 2004).

Source	Release to air (tons/yr)	Release to soil (tons/yr)	Release to water (tons/yr)
Coal combustion	48	36	na
Coal, other uses	10	na	na
Gold mining, processing	12	2653	50
Medical waste incinerators	10	na	na
All other US sources	30	241	1
Total	120	2930	51
% contribution from coal	48%	1%	na

na=not analyzed

ALASKA

Forest fires are the main source in Alaska, releasing about 29 tons of mercury each year.²² In 2004 and 2005, there was a five-fold increase in forest fires in interior Alaska compared to the 1990's.²³ If this increase is part of a pattern of climate change, it can be expected to continue. A "mercury belt" of rock containing naturally high mercury is found across 190,000 km² within the Yukon-Kuskokwim area, but to date it has not been associated with coal deposits.²⁴ Mercury instead is found as native mercury, cinnabar (HgS), or as a gold-arsenic antimony-mercury complex.²⁵ Sources outside Alaska include Asia, which contribute about 20%; wildfires in Siberia in the summer, and European emissions in winter.²⁶

Alaskan industry only releases 71 lbs of mercury per year to air in 2008.²⁷ However, this could change should industrial activity increase. There have been proposals to increase coal-fired power plants in Alaska. A proposal for one in the Matanuska Valley was defeated, but the Healy "Clean Coal Plant" (HCCP) may be re-

²⁰ EPRI 2006; Strode et al 2008

²¹ Jaffe and Strode 2008; Weiss-Penzias et al 2007; Liang et al 2004; Bey et al 2003

²² Weiss-Penzias et al 2007

²³ <http://www.dnr.state.ak.us/forestry/firestats/index.htm>

²⁴ Historically the area was mined specifically for its mercury, producing about 1400 US tons (Gray et al 2000; also Miller et al).

²⁵ Ore at the proposed Donlin Creek mine is in Au-As-Sb-Hg complexes, mostly as microscopic cinnabar inside sulfide veins (AMEC 2009).

²⁶ Liang et al 2004, based on correlations between CO and Hg.

²⁷ The sources include both point and fugitive source emissions, and are: Aurora Energy LLC (13 lbs from point sources), Delong Mountain Transportation Facility Port Site (1 lb each from point and fugitive sources), Golden Valley Electric Associates Inc. Healy Power Plant (5 lbs from point sources), Helca Greens Creek Mining Co. (5 lbs from point sources), Pogo Mine (1 lb from point sources), Red Dog Operations (8 lbs from fugitive and 2 lbs from point sources), Tesoro Alaska-Kenai Refinery (17 lbs from point sources), U.S. Army Fort Wainwright (3 pounds from point sources), and U.S. Air Force Eielson Air Force Base (15 lbs from point sources). U.S. EPA, Toxic Release Inventory, Releases: Facility Report for mercury and mercury compounds, 2008 report, available at <http://www.epa.gov/tri/> (last visited June 18, 2010).

started.²⁸ The HCCP was mothballed when the state-of-the-art sulfur and nitrogen oxide controls did not function; since then, less costly and more effective sulfur and nitrogen air pollution controls have been commonplace in power plants around the country. The HCCP has no mercury pollution control devices.

Current gold mines release little to no mercury to air; what is reported as "release to land" in the Toxic Release Inventory is mercury bound up in waste rock with little chance for significant release to air or water (Table 3). However, gold mines in Alaska's mercury belt could be developed. The ore in this area must be heated during processing, and heating releases mercury; the proposed Donlin mine alone is predicted to release 20-40 tons of mercury from ore.²⁹ Air pollution controls are likely to capture 99% or more,³⁰ but proposed federal guidelines would allow the release of over 3000 lbs per year legally.³¹ While this is significantly less than forest fires, it represents emissions from a single mine, and presumes mercury controls will work properly.

TABLE 3. SOME INDUSTRIAL EMISSION RELEASES OF MERCURY IN ALASKA. Comparison of mercury releases to air, soil, and water from coal-fired power plants and a gold mine. The gold ore is not located with mercury. From the US EPA Toxic Release Inventory.

Facility	Fugitive Air Emissions (lbs)	Point Source Air Emissions (lbs)	Discharges to Surface Water (lbs)	Land Disposal (lbs)
Healy Power Plant, 2006	0	23	0	0
Healy Power Plant, 2007	0	5	0	0
Healy Power Plant, 2008	0	5	0	0
Aurora Power Plant, 2006	0	28	0	16
Aurora Power Plant, 2007	0	13	0	0
Aurora Power Plant, 2008	0	13	0	0
Pogo Mine, 2006	0.05	0.5	0.01	1879
Pogo Mine, 2007	<0.05	0.5	<0.01	4682
Pogo Mine, 2008	<0.05	0.8	<0.01	6551

²⁸ http://www.frontiersman.com/articles/2010/01/01/local_news/doc4b3d1462b83a0653474152.txt;

www.ktva.com/alaskanews/ci_15760436

²⁹ Breithaupt 2009

³⁰ Barrick Gold claims on its website that it can remove 99.5% of emissions from a particular thermal processing unit called a "roaster" (<http://www.barrick.com/CorporateResponsibility/KeyTopics/MercuryManagement/default.aspx>); they have made similar statements in the Kuskokwim region, although the Donlin mine would not have a roaster.

³¹ US EPA 2010; "Mercury, the Donlin Creek Mine Project and what it means for the Kuskokwim River" fact sheet (2010) by the Northern Alaska Environmental Center, the Center for Science in Public Participation, and Ground Truth Trekking

Mercury transport and cycling

Alaska has few of the classic mercury emitters – coal plants and incinerators – yet may be more at risk for increasing mercury than any other state because of long range atmospheric transport from sources around the world. Mercury is more mobile than most metals: it can move back and forth between soil, water, air, and life forms, it can move between organic (carbon-based) and inorganic forms and it can travel around the world. Sunlight, saltwater, and soil bacteria can all be involved in transforming mercury from one form to another.

TYPES OF MERCURY

Mercury comes in inorganic and organic forms. It acts differently and has different toxicity depending on the form it is in. Mercury continually transforms and cycles.³² A stable molecule in air may react with sunlight to become a reactive mercury molecule, precipitate into a bubbling stream, which then enters a wetland where mercury converts to the methylmercury fish can take up. Or a mercury molecule in a stream may become an atmospheric molecule and travel.

Inorganic mercury is very stable in the elemental (Hg^0) form. We are familiar with elemental liquid mercury (as in a thermometer) but if you break a thermometer, the liquid can become a gas, referred to as "gaseous elemental mercury" or GEM.³³

The ionic form (Hg^{2+}) is not stable and is referred to as "reactive gaseous mercury" (RGM) because it reacts quickly with other ions, molecules, or organic matter (soil). When Hg^{2+} attaches to dust, it is called particulate mercury (PHg). Hg^{2+} may also bind to sulfide (HgS) to make a solid, in which case it is referred to by the molecule or ore name (e.g. mercury sulfide is the same as cinnabar).

Mercury becomes dangerous when it becomes "organic". "Organic" means mercury has attached to some carbon-based molecule that animals can absorb, usually dimethylmercury ($\text{CH}_3\text{-Hg-CH}_3$) or methylmercury ($\text{CH}_3\text{-Hg}^+$, abbreviated MeHg). In this way, mercury enters the food chain.

³² Hutchison and Atwood 2003

³³ Liquid elemental mercury is not found at power plants or incinerators. Elemental liquid mercury is not particularly dangerous unless ingested in large amounts or if the fumes are inhaled; fumes are very toxic.

FATE AND TRANSPORT OF MERCURY

Natural sources release only GEM, not RGM or PHg, but anthropogenic activities release all three. This is important because each species has different life spans and ability to travel. Mercury released from the coal combustion stack is about 50-60% GEM, 30% RGM, and 10% particulate.³⁴ Generally mercury travels furthest in the GEM form, precipitates in the RGM form, and once precipitated may move into watersheds and become "organic" and available to fish and aquatic organisms.

- PHg is the heaviest, and deposits close to the source. While this impacts the Eastern US, where there is a high density of coal-fired power plants, it does not affect most of Alaska. PHg could be expected near the Healy plant, which released 10-12 kg of mercury in 2005 and 2006, and the Fairbanks Aurora plant, which released 14 kg in 2004 and 4 kg in 2005.³⁵
- RGM survives for 5-14 days and moves hundreds of miles from where it was formed.³⁶ Eventually RGM will precipitate in dust ("dry deposition") or with salt air, cloud water vapor, rain, or snow and precipitate with moisture ("wet deposition").³⁷
- As GEM, mercury can circulate for 6-18 months in the atmosphere, moving globally; nearly all (95-98%) of mercury in the world's atmosphere is GEM.³⁸ Most mercury emitted from industry is GEM; it lives for a long time, travels far from the original coal plant, becomes part of the global mercury pool. This is the form that most impacts Alaska.

TRAVEL THROUGH AIR

Mercury travel in air depends on the form of mercury and altitude. GEM emissions follow a pressure bar at low altitudes northwest along the coast of China, into Siberia, and across to the Aleutians, Kuskokwim, and Norton Sound.³⁹ RGM travels eastward from Asia along latitudes. Asian emissions are high in spring and summer, when burning rice straw, deforestation, and Siberian wildfires contribute to the anthropogenic load, at the same time that weather patterns shift to bring air masses east.⁴⁰ More information on the atmospheric chemistry of mercury is in Appendix B.

³⁴ Weiss-Penzias et al 2007

³⁵ <http://www.epa.gov/triexplorer>

³⁶ <http://www.ec.gc.ca/MERCURY/EH/EN/eh-t.cfm>

³⁷ Carpi 1997

³⁸ Xin et al 2007; <http://www.ec.gc.ca/MERCURY/EH/EN/eh-t.cfm>

³⁹ Bey et al 2003; Liang et al 2004; Jaffe and Strode 2008; Strode et al 2008

⁴⁰ Jaffe and Strode 2008; Liang et al 2004; Bey et al 2003

While some mercury reaches Alaska on winds, most arrives by way of "global distillation". This refers to a slow northward migration: as point sources in low latitudes release mercury, warm temperatures allow it to vaporize and enter the air currents. As temperatures cool or the mercury reacts with rain, clouds, snow, ozone, and fog, it precipitates.⁴¹ Warming air may release it again. In this way, mercury "hops" north – vaporizing as temperatures warm and precipitating with cool or wet conditions.⁴² Asia is an important source to the global pool,⁴³ contributing about 54% of the total global anthropogenic emissions, primarily from coal combustion.⁴⁴ About 150-300 tons arrives in the Arctic each year⁴⁵ by way of "global distillation" and direct transport on air currents.⁴⁶

Research on “spheroidal carbon particles” (SCPs) supports the theory that most of Alaska's mercury is from the "global pool". Burning fossil fuels produces SCPs. Metals and SCPs attach to fine particles in the atmosphere and travel up to 2000 km. In most of the US, declines were observed in SCPs at lakes in National Parks when particle scrubbers were installed in industrial plants and the ban on leaded gasoline took effect. This indicates that the metal contaminants were from local sources. In Alaska, SCPs were very low, indicating a lack of air-borne regional contaminant sources.⁴⁷

TRAVEL BY OCEAN

Most of the mercury in the ocean originated from deposition of mercury traveling in the atmosphere. One third of the total global mercury may cycle between oceans and the atmosphere,⁴⁸ and about 20-30% of oceanic emissions originated from anthropogenic sources.⁴⁹ The "Aleutian low" weather system likely causes atmospheric mercury to be pulled down towards the ocean where GEM oxidizes and enters the ocean.

⁴¹ Carpi 1997

⁴² Hutchison and Atwood 2003; Selin et al 2007

⁴³ It is difficult to estimate the total amount of mercury in the global pool. Hutchison and Atwood estimate between 6,000-10,800 tons at any one time. The US EPA (1997, Volume I) estimates 5500 tons. This number is also stated in the Canadian government website <http://www.ec.gc.ca/MERCURY/EH/EN/eh-t.cfm>, with about 5000 tons of GEM, 365 tons of RGM, and about 2 tons of PHg.

⁴⁴ The 54% contribution does not include natural emissions from the Asian landmass. Of mercury deposited in the US, natural land emissions from Asia may contribute 11% on top of the 7-20% that comes from anthropogenic emissions from Asia (Jaffe and Strode 2008).

⁴⁵ Focus North 2005

⁴⁶ AMAP 1997; WACAP 2005; Fitzgerald et al 2005

⁴⁷ Landers et al 2008, Chapter 4

⁴⁸ US EPA 1997a

⁴⁹ US EPA 1997a; <http://www.ec.gc.ca/MERCURY/EH/EN/eh-t.cfm>

Further west, Pacific currents pick up mercury deposited near Asian coasts and carry it to the US and Alaska in a matter of weeks; at the surface of the ocean, mercury concentrations increase with latitude.⁵⁰

In addition to a simple transport function, oceans provide a place for mercury methylation. Most RGM that deposits from the atmosphere into the ocean is expected to attach to particles. These particles sink. At specific depths, the combination of carbon in the particles and low oxygen in the water allow methylating bacteria to survive, and they may methylate the mercury in the particles.⁵¹ It is speculated that this may be the source of much of the mercury found in ocean fish.

TRAVEL BY RIVERS AND MIGRATORY ANIMALS

Mercury bound to soil is washed into rivers through flooding, erosion, rain, and melting events. Some precipitates in ponds, lakes, and reservoirs where there is less turbulence. Russian rivers emptying into the Arctic are considered to be the second highest source of mercury to the Arctic.⁵² Rivers draining the Kuskokwim mercury belt contain mercury from erosion of cinnabar (HgS) rock. Although HgS is quite stable and does not dissolve easily, a small percent is likely to dissolve and in river sediment, under the right conditions, methylmercury may form and enter the food chain. Predicting whether mercury will become bio-available is complex.⁵³

Migrating animals can move mercury into and out of Alaska. When salmon die and decompose, the nutrients and contaminants in their carcasses enter aquatic and terrestrial ecosystems.⁵⁴ Using a conservative estimate of 0.035 mg/kg MeHg per salmon, Jewett and Duffy (2007) calculated that migrating sockeye salmon could carry a total mass of about 21 kg of MeHg from the ocean into the Bristol Bay watersheds. However, outmigrating smolt may carry some mercury out of the nearby Wood River system, including mercury that has accumulated in sediment from local sources.⁵⁵ Migrating birds that pick up mercury outside Alaska also may transport it to Alaskan lakes.⁵⁶

⁵⁰ Sunderland et al 2009

⁵¹ ibid

⁵² Focus North 2005

⁵³ Gray et al 2000; Jewett and Duffy 2007

⁵⁴ Kline et al 1993; Ewald et al 1998; Sarica et al 2004

⁵⁵ Baker et al 2009

⁵⁶ Rothschild and Duffy 2005

Can mercury be controlled?

Mercury emissions from point sources can be controlled. How much mercury is emitted from a power-plant stack is affected by elements in the coal, by boiler type, and by air pollution control devices (APCD).⁵⁷ Because most APCD are designed to control nitrogen and sulfur emissions, a plant may have pollution controls and still remove virtually no mercury.⁵⁸ Correctly designed APCD reduce the amount of mercury in US power plant emissions, but if coal-fired power plant capacity is expanding in Asia, India, Russia, and Eastern Europe, gains made by the US may be overshadowed and mercury deposits to Alaska could continue to increase despite US regulations.

Mercury-specific control technologies such as activated carbon have reduced mercury emissions on municipal waste combustion plants (down 88% from the 57 tons emitted in 1990) and medical waste incinerators (down 95% from the 50 tons emitted in 1990). Between 1990 and 1999, industrial emissions of mercury in the US dropped⁵⁹ by 44% from 220 tons down to 115 tons per year.⁶⁰

However, success in incinerators does not translate directly to success in removing mercury from coal-fired power plant exhaust. Incinerator gases contain high mercury and chlorine concentrations, and move the gases through constricted ducts. Chlorine reacts with mercury to make it easier to remove, and the small ducts and high mercury content decrease the cost of activated carbon per pound of mercury removed. Coal plants contain low mercury and chlorine concentrations, and use bigger ducting because they are much larger than incinerator plants, raising the cost of design and decreasing efficiency.⁶¹

Mercury pollution stack controls need to be designed for the type of coal burned, and even then it is possible for a plant to have pollution control equipment and still remove virtually no mercury. This has to do with what form the mercury is in when it reaches the APCD. No method will capture gaseous elemental mercury. If the elemental mercury (Hg^0) can be oxidized to the ionic form (Hg^{2+}) then it will attach to particles and can be removed with particle filters (referred to as particulate matter, PM, controls). Plants with only PM controls

⁵⁷ Quick 2005; US EPA 1993

⁵⁸ This is particularly true for gold processing, in which mercury release is much different than at power plants and incinerators. At gold processing facilities, mercury is released at several points; mining companies are still developing controls to keep mercury out of the air. See US EPA 2010 for details of mercury control at gold mines.

⁵⁹ Note that these figures do not include mercury emissions from gold mines, which can be significant and remain unregulated.

⁶⁰ http://www.epa.gov/mercury/control_emissions/emissions.htm

⁶¹ http://www.epa.gov/mercury/control_emissions/technology.htm

could remove up to 90% of the mercury, but might remove none if mercury does not oxidize. Chlorine will oxidize Hg⁰, as will selective catalytic reducers (SCRs). Fabric filters (a type of PM control) were most effective at removing mercury, but only 14% of US plants use them. About 72% of plants in the US use only less effective electrostatic precipitators (ESP) as PM controls, and Chinese plants are beginning to use ESPs. Plants combining PM and scrubbers can remove up to 98% of the mercury, but again might remove none of it.⁶² The difference has to do primarily with chlorine content.

With bituminous coal, a combination of SCR, PM, and wet scrubbers together had high mercury removal. However, if arsenic is also present in the coal, the SCR may become clogged, and if the combustion process includes re-injecting fly ash, the SCR will be clogged by arsenic even faster, particularly if ESP or fabric filters are also in use.⁶³ Using different technology, 95% of mercury may be removed from plants burning bituminous coal by a combination of spray dry absorbent and fabric filters.

A fabric filter alone will remove up to 75% of the mercury when a plant burns sub-bituminous coal, but using a spray dry absorbent and a fabric filter together reduces removal to 25%. Therefore if a plant uses different types of coal, the mercury removal efficiency will fluctuate.

No matter what controls are utilized, gaseous elemental mercury, the kind that contributes to the global pool of mercury, is not captured. With industrial expansion increasing around the world, the global pool of mercury will likely continue to increase for some time.

⁶² US EPA 2005

⁶³ US EPA 1993; http://www.epa.gov/hg/control_emissions/tech_exist.htm

When mercury reaches Alaska

Mercury reaches Alaska by atmospheric transport, oceans, rivers, or migrating animals. The vast majority remains and has the potential to become bioavailable.⁶⁴

POLAR SUNRISE

Gaseous mercury is transported to Alaska year-round, and accumulates over the pole in winter.⁶⁵ Spring brings the return of the sun for short periods – polar sunrise. As the sun shows above the horizon, salt air molecules in combination with sunlight react to oxidize the stable gas mercury to reactive gas mercury, and daily "pulses" of precipitating mercury can be recognized.⁶⁶ This is observed most dramatically near the coast. Most RGM deposited during polar sunrise remains in the snow, and moves into tundra when snow melts.⁶⁷

MERCURY IN SNOW AND LICHEN

At snowmelt, mercury may move into lichen, soil, watersheds, rivers, and lakes. Total mercury and methylmercury concentrations jump noticeably in snow at Barrow between January and May. In snow, mercury binds to particles and is not likely to re-emit to the atmosphere.⁶⁸ Methylmercury is not made in the snow, but may be transported in from the ocean and deposited.⁶⁹

The MeHg measured in snow in National Parks in Alaska, inland from Barrow, was usually low (Figure 2).⁷⁰ Just beneath the snow is lichen, and MeHg measured in lichen in Alaskan National Parks was also low.⁷¹

⁶⁴ Of atmospheric deposition onto uplands, 90-95% stays; when mercury deposits on wetlands, 85-90% stays in the wetland; and of mercury entering lakes, only 60-70% stays in the lake (Mae Gustin synopsis of the METAALICUS study; University of Nevada, Reno Biogeochemistry class 2004). The METAALICUS study can be accessed at <http://www.umanitoba.ca/institutes/fisheries/METAALICUS1.html>

⁶⁵ Selin et al 2007; Lindberg et al 2002

⁶⁶ <http://www.ec.gc.ca/MERCURY/EH/EN/eh-t.cfm>; Lindberg et al 2002

⁶⁷ Lindberg et al 2002

⁶⁸ Particulate mercury does not travel to Alaska, and the SCP-type particles that form during coal combustion were not observed at Alaska lakes. (Landers et al 2008, Chapter 4)

⁶⁹ The bacteria that methylate mercury probably do not live in the snow. It may come from ocean upwelling where dimethylmercury forms, and decomposes to methylmercury as it is transported inland (Betts 2001).

⁷⁰ Betts 2001, Landers et al 2008, Chapter 4

⁷¹ MeHg in snow was usually below the detection limit of 0.04 ng/L, except one lake in Denali with 700 ng/L total mercury and 0.6 ng/L MeHg. Lichen at Noatak, Gates of the Arctic, and Denali parks had 20 – 30 ng/g dry weight concentrations. (Landers et al 2008, Chapter 4)

There is no historical data on lichen mercury concentrations in Alaska.⁷² Monitoring lichen in coming years could show both the effects of local efforts to reduce mercury concentrations from industry, and whether global mercury is increasing in the area.

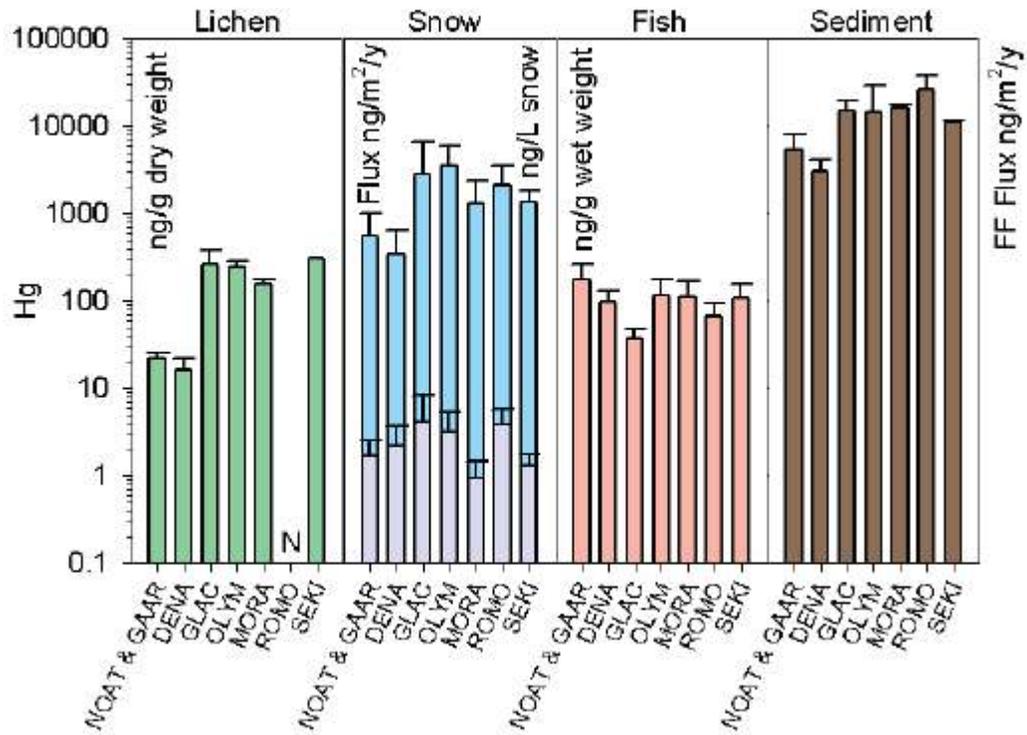


FIGURE 2. MERCURY IN SEDIMENT, LICHEN, SNOW AND FISH. From Landers et al 2008 Figure 4-33.

CYCLING IN STREAMS AND LAKES

Once atmospheric mercury has deposited, the landscape has a lot to do with whether the mercury will become available to fish or not. Of the many forms mercury can take, only methylmercury is significantly bioavailable.

- If mercury (atmospheric or geologic) deposits in fast-running rivers, it is unlikely to become bioavailable because the bacteria that make methylmercury don't live in oxygenated water.

⁷² ibid

- Mercury depositing in wetlands, lakes and estuaries with high organic carbon and low oxygen are environments where methylating bacteria tend to be found – a higher percent of mercury entering the system may methylate and move into aquatic life. Some forest soils also promote these conditions.
- Dry terrestrial locations like meadows, sand, and dry mountains are less likely to have the conditions that support methylating bacteria, so terrestrial plants (and the animals that eat them) tend to be low in mercury.
- Disturbances in streams – such as ice scouring, flooding, or biological activity like building redds or outmigration of smolt – can mobilize mercury to wetlands and estuaries where it can go through cycles of emission and precipitation, and potentially enter the global pool or be methylated at the ocean oxycline.

What drops out of the atmosphere needs to enter an environment where it methylates before it becomes bioavailable. Therefore, the amount of atmospheric or geologic contribution of total mercury to a system is much less important than the concentration of methylmercury, particularly in sediments. Sediment cores in Alaskan lakes have shown consistent increase in mercury.⁷³

Mercury that accumulates in sediment is also unlikely to build to high concentrations,⁷⁴ although recent measurements have found that sediment mercury has increased with accumulation of algal-derived organic matter, particularly in the high Canadian Arctic as climates have grown warmer.⁷⁵

Lakes in Alaska National Parks receive less atmospheric mercury than in National Parks in the western United States, but nonetheless there has been a constant enrichment of mercury in Alaska lake sediments. Unlike the western US lakes, the mercury in lakes in Alaska's national parks

"results entirely from an increase in anthropogenic global background of mercury, rather than regional sources".⁷⁶

The amount deposited, no matter what the source, is not directly related to the amount of mercury that eventually ends up in fish, but rather fish concentrations are closely tied to whether the mercury methylates.

⁷³ Landers et al 2008 Executive Summary pg E-11

⁷⁴ Compeau and Bartha 1987

⁷⁵ Carrie et al 2010

⁷⁶ Landers et al 2008 Chapter 4

Despite the low total atmospheric mercury input, fish in Alaskan parks had high mercury ("Freshwater Fish" section) while Colorado parks with higher mercury deposition had low mercury in fish. This emphasizes the importance of local cycling and food web dynamics as well as bioaccumulation in older fish.⁷⁷ "Demethylation" can also occur. Long hours of sunlight help to break up MeHg, so that some lakes are essentially "self-cleansing".⁷⁸ However, lakes receiving more mercury input and/or sediment that blocks sunlight (as may occur with erosion and melting related to warming trends) may not be able to break down the MeHg, potentially resulting in greater methylmercury accumulation in fish.⁷⁹

In Alaska, there may be a cycle of rapid precipitation of atmospheric mercury at polar sunrise followed by MeHg formation in the vast calm lakes, tundra, and coastal wetlands, followed then by some degree of destruction of MeHg by the long hours of sunlight. Variations on this theme will be highly dependent on local site environments, such as proximity to the ocean, amount of sediment and oxygen in the water body, and many others.

WHAT DO BACTERIA HAVE TO DO WITH IT?

Water soluble mercury molecules like HgCl_2 can cross the cell membranes of bacteria.⁸⁰ Because mercury is toxic to the bacteria, they transform HgCl_2 to elemental Hg^0 (essentially GEM) so it will volatilize out of the cell (Figure 3).⁸¹ Some bacteria, particularly "sulfate-reducing bacteria", take mercury they encounter and attach a methyl group to it to make the methyl mercury (MeHg) that can be taken up by animals.⁸² How much MeHg is produced becomes a function of the growth of methylating bacteria, and becomes very complex (Appendix C).⁸³ Once MeHg is released and diffuses into water, it will partition into muscle when ingested and enter the food chain.

⁷⁷ See also Chetelat et al 2008 and Chetelat and Amyot 2009 for a discussion of the role of *Daphnia* and copepods

⁷⁸ Hammerschmidt and Fitzgerald 2006

⁷⁹ Rozell 2006

⁸⁰ Hutchison and Atwood 2003

⁸¹ Sams, CE. Methylmercury contamination: impacts on aquatic systems and terrestrial species, and insights for abatement. Available at stream.fs.fed.us/afsc/pdfs/Sams.pdf; Morel et al 1998

⁸² Macalady et al 2000; Compeau and Bartha 1987; Sams, CE at stream.fs.fed.us/afsc/pdfs/Sams.pdf. MeHg is shorthand for a mercury salt that has had a methyl group added to it: HgCl_2 becomes CH_3HgCl , $\text{Hg}(\text{OH})_2$ becomes CH_3HgOH , and so forth.

⁸³ Hammerschmidt et al 2006; St Louis et al 2004; Driscoll et al 1998; Sams, CE at stream.fs.fed.us/afsc/pdfs/Sams.pdf

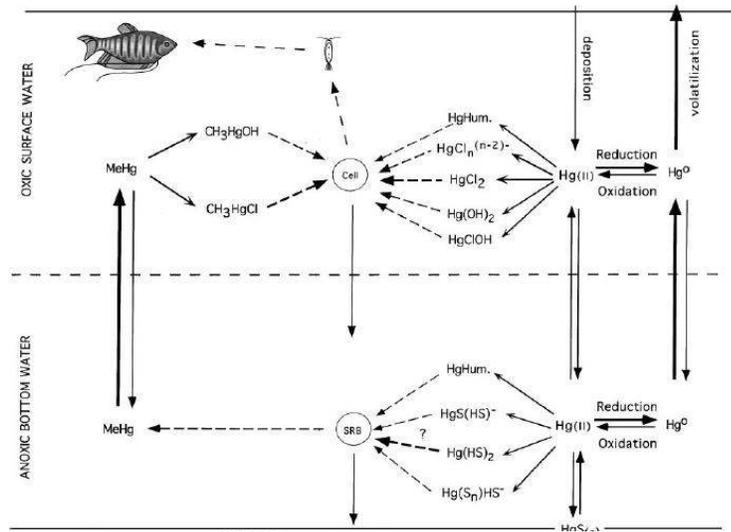


FIGURE 3. AQUATIC MERCURY CYCLING. The small "cell" and "SRB" circles represent bacteria that transform mercury. Arrows show the transformation between inorganic and organic forms of mercury (Morel et al 1998).

Bioaccumulation and Biomagnification

When polar sunrise converts GEM to RGM in the spring, it deposits to underlying land and water shortly before the burst of spring growth in phytoplankton and plants. Similarly mercury that has deposited over the winter on ice floes or in snow will release into the ocean, ponds, lakes, tundra, and river systems as snow and ice melt, again bringing a "pulse" of mercury into the environment in what has been referred to as "a bad time for the Arctic ecosystem".⁸⁴ The reason for this statement is that once MeHg is released out of bacteria and diffuses back into the aquatic environment, it will partition into muscle when ingested by stream or lake animals. Newly deposited mercury is taken up nearly four times as quickly by biota as mercury that has been in a system for some time.⁸⁵ This means that mercury freshly dropped from the atmosphere is taken up faster than mercury sequestered in stream sediments.

Methylmercury is absorbed by a plant or animal is excreted slowly. In higher organisms, it will be re-absorbed by the liver, increasing the amount of time it remains in the body.⁸⁶ A single older animal will have more mercury than a single younger animal – this is referred to as bioaccumulation. Bioaccumulation may have limits: one study found that mercury increased in lake trout until they reached 15 years old, and then decreased;⁸⁷ another found that age and mercury concentrations correlated in Arctic char and grayling but not in rainbow trout and pike,⁸⁸ however, other studies did find a correlation with age and mercury in rainbow trout⁸⁹ and with size and mercury in northern pike.⁹⁰

Another kind of accumulation – with increasing concentrations and consequences - is referred to as biomagnification (Figure 4). This refers to the way mercury transfers from a prey animal to a predator, and becomes part of the predator. In biomagnification, the size of the animal does not dictate the amount of mercury in it, but rather the amount of mercury is dependent on how long the food chain is. For instance, reindeer are large, but eat only plants; in a study of five ranges in Alaska, lichen ranged from 37-47 ng/g total

⁸⁴ Betts 2001

⁸⁵ Scott 2001; Hintelmann et al 2002

⁸⁶ Hutchison and Atwood 2003; Hodgson and Levi 1997 Chapter 5

⁸⁷ Landers et al 2008 Executive Summary (mercury as wet weight)

⁸⁸ Baker et al 2009 (mercury as wet weight)

⁸⁹ Landers et al 2008, Appendix 5B (mercury as wet weight)

⁹⁰ US Fish and Wildlife Service, <http://alaska.fws.gov/fisheries/contaminants/>

mercury, and the reindeer that fed on the lichen ranged from 15-83 ng/g total mercury, which is not very much.⁹¹ Fish are considered safe at 300-1000 ng/g total mercury wet weight.⁹²

Marine food chains are much longer, allowing mercury to concentrate in predators. If mercury in water is taken up by zooplankton, and the zooplankton is eaten by fish fry, the mercury in the zooplankton is transferred to the fry, not broken down. The longer the food chain, the more chance for mercury accumulation, say from zooplankton to fish fry to juvenile fish to adult fish to black bear to a gull scavenging on a dead bear. Phytoplankton may have 300,000 times more mercury than surrounding water, and the bioconcentration factor in fish may be 10,000 up to 3 million.⁹³ Animals with the highest mercury content include pilot whales, dolphins, otter, mink, osprey, and eagles;⁹⁴ all top predators or scavengers of top predators that have died. Because marine food chains are long, the primary exposure of people to mercury will be through eating wildlife that accumulated mercury, particularly marine mammals and fish.⁹⁵

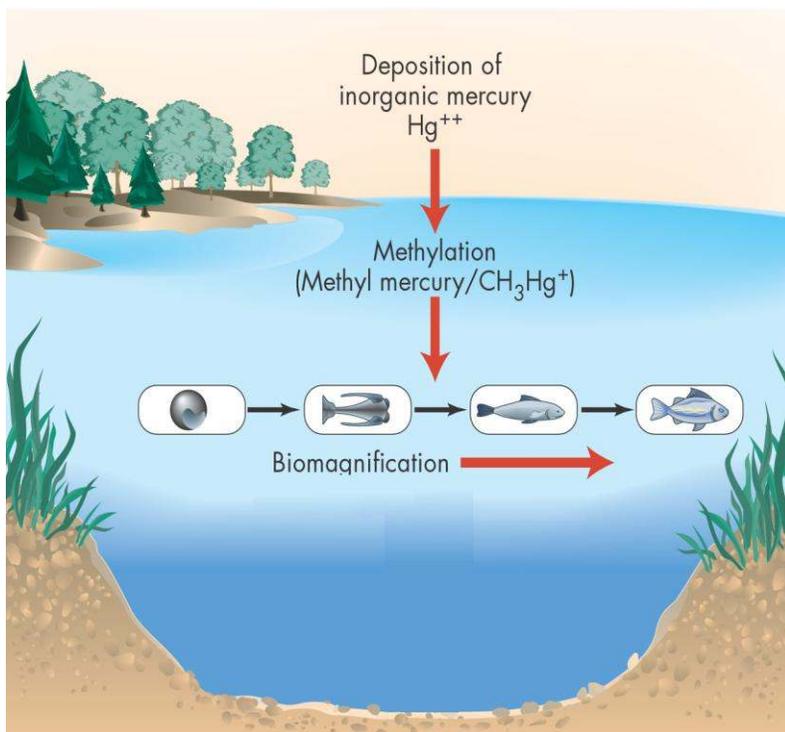


FIGURE 4. BIOMAGNIFICATION. Biomagnification is the process of mercury increasing in concentration through the food chain, so that it increases with every trophic level.

⁹¹ Lokken et al 2008

⁹² The US FDA considers 1,000 ng/g to be safe in fish; the US EPA considers fish safe at 300 ng/g; the World Health Organization uses 500 ng/g.

⁹³ IPCS 1990; EPRI 2004

⁹⁴ <http://www.chem.unep.ch/MERCURY/Report/Key-findings.htm>; Endo et al 2003

⁹⁵ Endo et al 2003; Mahaffey et al 2004

Mercury in fish and wildlife

How much mercury is in an animal or fish is controlled by

- global influences (how much mercury gets to an area where wildlife may be exposed)
- local influences (seasonal changes, mercury cycling, local sources)
- wildlife ecology (what they eat, where, and how old an animal is)

Global atmospheric transport is the original source of most of the mercury in Alaska. Seasons and weather control if mercury will remain in one location. The location where mercury lands controls whether mercury will re-emit to the atmosphere (and not be available to local biota), stay attached to soil particles (in a form not available to biota), or enter into cycling that makes it bio-available.

Fish and wildlife located where microbial cycling occurs, or who eat at the top of a long food chain, are the ones most susceptible to building up mercury in their bodies. It is important to discriminate why different animals accumulate or do not accumulate mercury.

- Plant-eating fish, birds, and wildlife are likely to have little mercury in them, no matter how big or how old they are, because plants don't accumulate much mercury.
- Marine fish and mammals may have mercury if they are old or at the top of the food chain.
- Freshwater fish will likely only concentrate mercury if they live where microbes methylate mercury and are at the top of the food chain.

ARCTIC WILDLIFE

Herbivores, even large ones such as caribou are not likely to have high mercury concentrations, because they eat plants. Reindeer and moose in Alaska have low mercury.⁹⁶ Reindeer in Norway, Sweden, and Canada had higher mercury concentrations than Alaska reindeer, but were still well within levels safe for consumption.⁹⁷

Land-based birds such as ptarmigan (plant-eaters) have low levels of mercury in all areas tested across the Arctic.⁹⁸ But birds that eat fish such as guillemots and scavengers like seagulls had much higher

⁹⁶ Reindeer hair contained 15-83 ng/g (Lokken et al). Moose had 2-26 ng/g in meat, 7-33 ng/g in liver (Landers et al 2008 Chapter 5).

⁹⁷ Total mercury in kidneys was 500-4000 ng/g in Yukon herds (MeHg less than detection limit of 100 ng/g wet weight); livers were 200-900 ng/g in Northwest Territories herds; livers from reindeer in Sweden and Norway were 200 ng/g (Muir et al 1996).

⁹⁸ For rock and willow ptarmigan in the Yukon, Norway, Sweden, and Russia, muscle was 20-40 ng/g (wet weight), kidney was 50-300 ng/g (dry weight), and liver was 20-400 ng/g (dry weight); livers of rock ptarmigan in Alaska had less than 20 ng/g (dry weight) (AMAP 1998).

concentrations, much higher than is "safe" for consumption and some with mercury in eggs high enough to impact reproduction.⁹⁹

MARINE MAMMALS

Like birds and mammals, whales that eat plants (baleen whales) generally have less mercury than those that eat fish or other meat. A study in the North Pacific observed low concentrations of mercury in baleen whales and high concentrations in carnivores like dolphin, belugas, and pilot whales.¹⁰⁰ Killer whales that eat fish will have lower levels of mercury than those that eat seals; seals that eat clams will have lower levels than those that eat fish.¹⁰¹ Some specific examples include:

- Walrus on St. Lawrence Island have high concentrations of mercury.¹⁰²
- Beluga in Canada had mercury concentrations twice the Health Canada consumption guidelines; ringed seals had high concentrations in the liver but not in muscle.¹⁰³
- Polar bears, the top Arctic predator, had very high concentrations.¹⁰⁴

It is thought that the health of marine mammals themselves are not impacted until concentrations reach about 60,000 ng/g,¹⁰⁵ but the meat far exceeds US FDA guidelines set for fish consumption. Unlike levels of lead, which are decreasing in Arctic animals, levels of mercury have increased in some species, such as ringed seals and beluga whales from Canada and Greenland, with levels doubling or even quadrupling in only 25 years.

⁹⁹ Black-legged kittiwakes (*Rissa tridactyla*), which skim food from the surface of the ocean, had mean total mercury of 16,500 ng/g; northern fulmars (*Fulmaris glacialis*), which eat like kittiwakes but also scavenge had 80,000 ng/g; thick-billed murrelets (*Uria lomvia*) and black guillemots (*Cephus grylle*) which feed on fish and amphipods had 44,800 and 106,000 ng/g respectively; and glaucous gulls (*Larus hyperboreus*) (scavengers) had 1,180,000 ng/g (Muir et al 1996); <http://www.chem.unep.ch/MERCURY/Report/Key-findings.htm>

¹⁰⁰ Belugas had 10-540 ng/g while striped dolphin had 63,000 ng/g and false killer whales had 81,000 ng/g (Endo et al 2003). Another study found the baleen bowhead, fin, and minke whales had 300 ng/g, 546 ng/g, and 452 ng/g mercury in liver, while the carnivorous marine mammals white-beaked dolphin, harbor porpoise, narwhals, belugas, and pilot whale livers had 831 ng/g, 8200 ng/g, 11,000 ng/g, 42,000 ng/g, and 280,000 ng/g respectively. The pilot whales with the very high total mercury in liver had 35,000 ng/g MeHg. This is considered less than the amount likely to cause health effects to the whale, but is much too high for consumption (AMAP 1998 Chapter 7).

¹⁰¹ Dehn et al 2005; Dehn et al 2006

¹⁰² 900-1700 ng/g (AMAP 1998)

¹⁰³ Canada sets risk level at 500 ng/g total mercury in fish. Belugas averaged 1,340 ng/g in muscle, muktuk 780 ng/g, and liver 2,200 – 32,100 ng/g (wet weight). The mercury in muscle was all MeHg but less than 12% in the liver was MeHg. Ringed seals had 4,100 – 59,300 ng/g total mercury in liver, with MeHg as about 800 ng/g (2-9% of total mercury) and muscle about 450 ng/g MeHg (Muir et al 1996).

¹⁰⁴ up to 53,000 ng/g total mercury

¹⁰⁵ Warburton and Seagars 1993

MARINE FISH IN ALASKA

Mercury has been found in every fish tested in the western US,¹⁰⁶ including Alaska. Studies of freshwater, marine and anadromous fish have shown consistently low levels in marine fish in Alaska.¹⁰⁷ Salmon and other ocean fish are less susceptible to the sediment/biota mercury cycling, and salmon throughout Southwest Alaska had low mercury.¹⁰⁸ However, coastal estuaries are environments that can promote methylation, and a new study found methylation occurring at intermediate depths in the Pacific Ocean, suggesting this may be the source of mercury for some ocean fish.¹⁰⁹ Large halibut from the Northeast Pacific approach a level of concern, near 300 ng/g.¹¹⁰ Mercury concentrations have remained the same in halibut from southeast Alaska over the past 30 years, but decreased in sablefish.¹¹¹

FRESHWATER FISH IN ALASKA

The study done of contaminants in western US National Parks concluded that the amount of mercury that arrived at a location through atmospheric deposition did not correlate with the amount of mercury in fish. The actual amount of mercury found in water or sediment may be less influential than whether the environment promotes mercury cycling. Fast-running, well-oxygenated rivers should not have mercury cycling, but calm pools and slow, shallow streams and ponds may provide ideal environments for methylating bacteria, and streams may receive water from wetlands in which methylating bacteria reside. Methylation, fish age and fish trophic positions are key factors in freshwater fish mercury concentrations.

Environments that promote methylation: Mercury is methylated primarily by sulfate-reducing bacteria. Therefore, mercury reaching an environment that these bacteria thrive in will likely be methylated and move into the food chain. The bacteria require sulfate – found in low levels in all waters but highest in oceans and

¹⁰⁶ Peterson et al 2007

¹⁰⁷ Jewett and Duffy 2007

¹⁰⁸ Gray et al 2000

¹⁰⁹ Sunderland et al 2009

¹¹⁰ Jewett and Duffy 2007

¹¹¹ Halibut in Southeast Alaska had mean concentrations of 260 (40-1300 ng/g) in the 1970's and 220 (40 – 880 ng/g) recently; sablefish had a mean of 280 (60-770 ng/g) to 80 (range 10-210 ng/g) (Jewett and Duffy 2007 from information collected by ADEC 2007 and Hall et al 1967.)

Mercury was measured as wet weight. Original references are Alaska Department of Environmental Conservation 2007

http://www.dec.state.ak.us/eh/vet/heavy_metals.htm and Hall et al 1967.

brackish waters – an organic carbon source, and a pH greater than 4.5.¹¹² Wetlands and waters draining forests may have tannic and humic acids in them that will lower the pH, but the pH will not go below 4.5. These systems also often have high dissolved organic carbon from water moving through layers of organic material. This is particularly true of areas with permafrost – as temperatures warm, snowmelt and rain moving down hill slopes and downgradient are restricted to the upper, organic rich layer of the soil horizon and is kept from the lower layers that may contain sand and gravel and allow water to flow vertically into deeper aquifers not connected to surface ponds, streams and lakes.¹¹³ Estuaries also provide excellent habitat for sulfate-reducing bacteria, as they have high concentrations of sulfate and neutral to alkaline pH; the limiting factor will be the availability of dissolved organic carbon.¹¹⁴

Environments that restrict demethylation also allow mercury to accumulate. Methylmercury molecules can be broken apart by UV light – of which vast quantities are received by sediments in shallow Arctic ponds and lakes in Arctic summer. Sediment, algae, and high concentrations of dissolved organic carbon can block UV light and limit Demethylation.

Local sources. Former mercury mines leach mercury from old tailings piles and local regions may be naturally elevated in cinnabar (HgS), but mercury in the water column near these sites was low enough that there was no risk to aquatic life or to anyone drinking it.¹¹⁵ Stream sediment samples had high concentrations of total mercury. The mobile forms of mercury, Hg²⁺ and MeHg, were less than 5% and 1% of the total, respectively in sediment,¹¹⁶ yet Arctic grayling and Dolly Varden had mercury concentrations up to 620 ng/g wet weight, twice as high as in large, old halibut; fish from "control" areas were quite low in mercury.¹¹⁷ All fish were within levels considered safe by the US FDA (1000 ng/g wet weight), but dollies and grayling would not be considered safe by the US EPA (300 ng/g wet weight).

¹¹² Personal experience through experimentation; also see Zamzow 2007 for a full discussion on sulfate-reducing bacteria

¹¹³ Petrone et al 2007

¹¹⁴ Zamzow 2006

¹¹⁵ Gray et al 2000. Water samples contained 0.5-2.5 ug/L, mostly as mercury attached to particles; dissolved mercury in water was 0.05 ug/L. According to Alaska statutes 18 AAC 70 updated 2003, water is safe for human health consumption at 2 ug/L, and safe for freshwater aquatic life at 1.4 ug/L (acute exposure) or 0.77 ug/L (chronic 4 day exposure). These are also the guidelines set by the US EPA.

¹¹⁶ *ibid.* Total mercury was as high as 5500 ug/g, but Hg²⁺ and MeHg were only 5% and 1% of the total.

¹¹⁷ *ibid.* The highest concentrations in muscle were 620 ng/g in Dolly Varden and 420 ng/g in Arctic grayling, which is considered unsafe by the US EPA but safe by the US FDA. The livers of these fish had 920 ng/g and 1300 ng/g total mercury, respectively. Control fish had 200 ng/g, and salmon (chum, coho, and kings) had less than 100 ng/g.

Age. In US National Parks, the mercury concentrations in brook trout (*Salvelinus fontinalis*) correlated well with fish age. However lake trout (*Salvelinus namaycush*) did not. There may be a variety of reasons for this. They were captured in different locations (brook trout only in Lower 48 parks and lake trout only in Alaskan parks), they may occupy different trophic positions (lake trout may be piscivorous and certainly ate snails; brook trout were presumed to eat insects and plankton) and the lake trout captured were considerably older.¹¹⁸ Trout from Burial Lake in Noatak National Park had mercury concentrations of 70 to over 400 ng/g (average 219 ng/g), higher than trout in Olympic National Park, Washington or Sequoia/Kings Canyon Park, California.¹¹⁹

Trophic position. Trophic position was found to be important in mercury content of arctic char in 18 lakes across the Canadian arctic.¹²⁰ Trophic position may also explain high mercury levels in some Alaskan freshwater fish. Arctic grayling and whitefish in the Yukon and Kuskokwim rivers had low mercury (Table 4) when tested in areas not near mercury mines.¹²¹ However, northern pike – a predatory fish that eats young salmon – had high levels, and tissue samples often exceeded the US FDA 1000 ng/g guideline.¹²² Pike had mean total mercury concentrations of 1500 ng/g (Yukon) and 630 ng/g (Kuskokwim), mostly in the MeHg form.¹²³ Nearly half the pike from the Nowitna National Wildlife Refuge had 1000-2900 ng/g.¹²⁴ In a study that examined 15 data sets of mercury and pike in Alaska, 11 of 15 showed pike with mean mercury concentrations above the 300 ng/g EPA level of concern, and 8 data sets had mean mercury concentrations in pike above 500 ng/g.¹²⁵ This was likely due to the predatory nature of the fish.

Because of all the factors involved in mercury cycling (fish age, sediment type, oxygen levels, nutrients, sulfate, etc) predictions are difficult. Whether a fish will have high concentrations of mercury is not directly related to the mercury concentration in water, soil, snow, or plants.¹²⁶ Studies are only just beginning to understand the correlations between physical and microbial factors. It is clear that two factors are important: deposition of mercury and a landscape that promotes methylation. Measured mercury in lake sediments

¹¹⁸ Landers et al 2008 Chapter 3.4.7 and Appendix 5A and 5B

¹¹⁹ Landers et al 2008 Chapter 4 and 5

¹²⁰ Gantner et al 2009

¹²¹ Jewett et al 2003. Grayling from the Yukon had 260 ng/g; grayling from the Kuskokwim had 80 ng/g; whitefish had 30 ng/g.

¹²² Jewett and Duffy 2007

¹²³ Jewett et al 2003

¹²⁴ Snyder-Conn et al 1992

¹²⁵ Data is summarized in Arnold and Middaugh 2004

¹²⁶ Bloom 1992; Landers et al 2008 Chapter 4 and 5; Wiener et al 2006

highlights the importance of global contributions to Alaska, which are expected to increase. And Alaskan estuaries, forests and tundra are being impacted fastest by global warming, with potential to increase methylation rates. Even remote regions are likely at risk.

TABLE 4: MERCURY IN YUKON AND KUSKOKWIM IN RIVER FISH, 2000. Concentrations of total mercury, with methylmercury in parentheses. Units are mg/kg wet weight. (Jewett et al 2003)

Species	Tissue	Yukon River	Kuskokwim River
Total Mercury			
Northern pike	muscle	1.5 (0.3) n=6	0.6 (0.4) n=15
	liver	1.7 (0.9) n=6	0.5 (0.6) n=15
Arctic grayling	muscle	0.3 (0.03) n=4	0.08 (0.02) n=6
Whitefish	muscle		0.03 (0.01) n=6
	liver		0.06 (0.02) n=6
Methylmercury			
Northern pike	muscle	1.6 (0.3) n=6	0.6 (0.4) n=15
	liver	1.2 (0.6) n=6	0.3 (0.2) n=15
Arctic grayling	muscle	0.2 (0.04) n=4	0.08 (0.01) n=6
Whitefish	muscle		0.03 (0.01) n=6
	liver		0.03 (0.02) n=6

FISH CONSUMPTION

How safe a fish is to eat depends on the concentration of mercury found in specific fish in specific regions, fish age, how many meals of fish a person eats each month, whether the person is a pregnant woman or an infant, and which recommendations are followed.

Tolerable Daily Intake. "Safe" amounts are often calculated as the amount of mercury a person can take in every day, and accounts for a person's body weight and expressed as "tolerable daily intake" (TDI).¹²⁷ The TDI is often correlated with the amount of mercury circulating in blood or being excreted through hair. All mercury is presumed to be consumed as "wet weight".

¹²⁷ The following bullets are from Verbrugge 2007

- The World Health Organization (WHO) TDI for children and women who may have children is 0.22 ug of mercury per kilogram of body weight per day (0.22 ug/kg body wt/day). This corresponds to a hair value of 2.2 mg/kg and a blood value of 0.0087 mg/L.
- The World Health Organization established a TDI of 0.5 ug/kg body wt/day for everyone else (corresponding hair mercury of 5 mg/kg and blood mercury of 0.020 mg/L).
- Recommendations from Health Canada are essentially the same as WHO.
- The US Agency for Toxic Substances and Disease Registry uses 0.3 ug/kg body wt/day.
- The EPA safe consumption level is 0.1 ug/kg body wt/day, corresponding to 1.2 mg/kg of hair mercury and 0.0058 mg/kg blood mercury.
- The US Food and Drug Administration (FDA) test fish, not people, and needed to determine a "safe" level of mercury that fish could contain. The FDA accepts 1 mg of mercury per kg of fish as safe (1000 ng/g). They assumed the same daily intake as the WHO, but presumed that most people weighed 70 kg and ate ½ pound of fish per week in order to make their calculation.
- The Alaskan Department of Health and Human Services, on recommendation from the Alaska Scientific Advisory Committee for Fish Consumption, recommends 0.4 ug/kg body wt/day for consumption of Alaska-caught fish.

Fish Advisories. Each state puts out fish advisories for specific lakes and rivers, or statewide, usually based on US EPA and US FDA guidelines. The State of Alaska developed guidelines based on the low mercury found in the majority of fish in Alaska, the benefits of fish consumption both nutritionally and culturally, and the risks of alternatives such as store-bought foods high in sodium and sugar.

Alaska issued advisories for some marine fish such as large halibut or lingcod in 2007. They did not issue freshwater fish advisories at the time, with the argument that most of the population consumed salmon, cod, small halibut, and pollock, which were not high in mercury, and that there was not enough data from enough freshwater regions to balance the risks and benefits of consuming specific fish. Researchers from the University of Alaska, Fairbanks did have suggestions for consumption guidelines (Figure 5).¹²⁸

¹²⁸ Jewett and Duffy 2007

According to ADFG, 60% of rural harvest was fish, and about 45% of the subsistence salmon was from the

Yukon-Kuskokwim watershed.¹²⁹ The take of species varied between communities and with swings in the abundance of commercially-caught fish. On average, rural Alaskans consume 9-21 ounces of subsistence foods per *day*,¹³⁰ or 4-11 pounds per week.

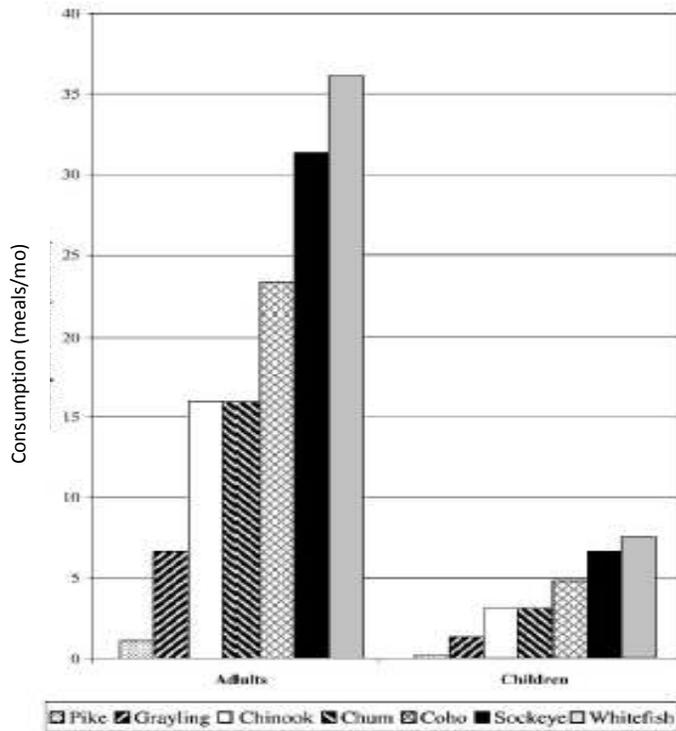


FIGURE 5. ESTIMATED CONSUMPTION LIMITS FOR FISH. The graph shows the number of meals per month researchers estimate could be safely consumed in the Yukon-Kuskokwim region given consumption of 100% individual fish species. (Jewett et al 2003). As of 2009, the State of Alaska had issued fish advisories only for pike.

In 2009 the Alaska Department of Health and Human Services issued the first freshwater fish consumption advisories: for large northern pike on the Kuskokwim River and Lower Yukon, suggesting up to 8 meals of large fresh pike per month, based on results of a multi-year study by the US Fish and Wildlife Service (Table 5).¹³¹

¹²⁹ Important subsistence fish include whitefish (*Coregonus* spp.), lamprey (*Lamprata japonica*), sheefish (*Stendus leucichthys*), northern pike (*Esox lucius*), trout (*Onchorhynchus mykiss*), and Dolly Varden (*Salvelinus* spp.). Summarized in Jewett and Duffy 2007. Original references are Kuhnlein et al 1996; ADFG 2001; Krieg et al 2005; Brown et al 2005.

¹³⁰ Kuhnlein et al 1996

¹³¹ http://www.epi.hss.state.ak.us/eh/fish/YKD_Pike_Mercury_Poster.pdf

TABLE 5. ALASKA FISH CONSUMPTION ADVISORIES. Advisories are for women who can become pregnant, nursing mothers, and children 12 years and younger; unlimited consumption of Alaska-caught fish is recommended for everyone else. Based on 6 oz meals (mercury as wet weight) and assuming a TDI of 0.4 ug/kg body wt/day. From Verbrugge 2007.

Fish MeHg concentration (mg/kg, ww)	No. meals per month	Marine Species			Freshwater Species	
		Halibut	Lingcod	Other marine fish	Fresh Pike	Dried Pike
0-0.15	Unlimited	0-19.9 lbs	0-29.9 inches	Pacific cod Walleye pollock Black rockfish Pacific ocean perch King salmon Chum salmon Pink salmon Red salmon Silver salmon	No Kuskokwim or Lower Yukon pike should be eaten in unlimited amounts	
> 0.15 -0.32	4 per week or 16 per month	20-39.9 lbs	30-39.9 inches	Sablefish Rougheye rockfish	Kuskokwim < 2 ft	None from Kuskokwim or Lower Yukon
>0.32-0.40	3 per week or 12 per month	40-49.9 lbs				
>0.40 - 0.64	2 per week or 8 per month	50-89.9 lbs	40-44.9 inches	Yelloweye rockfish	Kuskokwim > 2 ft, All Lower Yukon	None from Kuskokwim or Lower Yukon
>0.64 - 1.23	1 per week or 4 per month	> 90 lbs	>45 inches	Salmon shark Spiny dogfish		Kuskokwim < 2 ft
>1.2 - 1.4	up to 3 per month					
>1.4-2.0	up to 2 per month					
<2.0 - 3.4	up to 1 per month					Kuskokwim > 2 ft, All Lower Yukon

The table above has different columns for fresh and dried pike because preparing fish for consumption may actually increase the mercury concentrations; the State of Alaska did consider this. Although 8 meals of fresh pike might be considered safe, only one meal per month of the same pike dried was recommended. Half-dried red salmon from the lower Kuskokwim had more than twice the concentration of mercury (120 ng/g) as raw red salmon (50 ng/g).¹³² Drying Arctic char (*Salvelinus alpinus*) increased the mercury 4-6 times above that in the raw fish¹³³ because as water is removed, mercury is concentrated per unit of weight, although the total mercury per fish does not change. Many villages depend on dried fish during winter.

Mercury is not the only element of concern. The Western Airborne Contaminants Assessment Project found high levels of lead, cadmium, copper, and zinc in Alaska park lakes as well. These can be associated with burning coal if there is a nearby source, but these metals do not tend to travel through long-range transport the way mercury does.¹³⁴

¹³² Rothschild and Duffy 2002

¹³³ Chan et al 1995

¹³⁴ Landers et al 2008 Chapter 4

Impacts

The impacts to Alaska will begin when coal mining begins, and continue indefinitely when exported coal is burned and releases mercury that is transported back to Alaska. Impacts could include direct effects on fish and wildlife through habitat destruction, on subsistence users when fish advisories are recommended, and on commercial set net fishermen if leased area is "taken" to allow for mining infrastructure. Indirectly there is the potential for impacts to commercial fish markets and tourism.

HEALTH IMPACTS ON PEOPLE

Potential health impacts to people could result from:

- destruction of fish and wildlife habitat in subsistence use areas
- changed migration patterns as wildlife avoid industrial mining areas
- reduction in harvest of fish where fish advisories are posted due to mercury levels
- reduction in harvest of traditional foods due to fear of mercury contamination
- mercury-related nerve and brain damage to children and adults

If coal mining disrupts subsistence use areas, it directly impacts users, who generally do not harvest outside traditional use areas.

Mercury contamination is not likely to be a result of mining, except where mining for mercury has occurred or in future gold processing mills, but rather a result of mercury released when coal is burned. It is known that global mercury levels are increasing, and this affects Alaskan fish. If people are afraid to harvest traditional foods, or do not understand which foods are most likely to pose a risk, they may turn to less nutritious store-bought foods. Rural Alaskans harvest 375 pounds of subsistence foods per person per year, providing about 35% of their diet. Replacing traditional foods with the high fat, high sugar foods common in rural stores may increase a person's risk of diabetes and other "western" diseases.

Mercury produces well-known direct impacts on exposed people. The body does remove it: the half-life of mercury in people ranges from 46 days in women who are breastfeeding to 90 days in children.¹³⁵ However, if people accumulate mercury faster than they eliminate it, effects may manifest:

¹³⁵ Young 2001; IPCS 1990

- Mental deficiency and symptoms similar to cerebral palsy occur.¹³⁶
- Enzymes and signal molecules (like hormones) don't work as well, which can lead to endocrine disruption and reproductive problems in both wildlife and people.
- Neurochemical (coordination, speech and vision, feeling in hands and feet, tremors, moods) systems can be damaged.¹³⁷
- Heart and lung damage can occur if mercury induces oxidative stress and free radicals are made¹³⁸ while enzymes that remove free radicals are suppressed.¹³⁹

The primary toxic effects are on children exposed in the womb. Mercury can cross the blood-brain barrier to reach the fetus, and then oxidize to inorganic mercury that binds to sulfhydryl groups on proteins, targeting fast-dividing cells such as nerve and brain cells. The result is neurological problems, including learning disorders.¹⁴⁰ It can even affect a baby's blood pressure,¹⁴¹ especially if they also had low birth weight.¹⁴² Exposure continues after the baby is born; mother's milk may contain up to 5% of the mercury in the mothers blood.¹⁴³

Hair and blood samples in Alaska show that

- Rural Alaskans absorbed more mercury than urban Alaskans.
- People that did not eat fish had lower blood mercury than those that did.¹⁴⁴
- Mothers in Barrow had less mercury in their blood than mothers from Bethel.¹⁴⁵

Although elevated, the levels found in rural Alaskans should not pose a health risk to adults,¹⁴⁶ but in infants these levels may not be safe.

¹³⁶ Hodgson and Levi 1997; Hutchison and Atwood 2003

¹³⁷ Weil et al 2005; Anthony et al 2003; Hodgson and Levi 1997

¹³⁸ Arnold and Middaugh 2004; Sorenson et al 1999; <http://www.chem.unep.ch/MERCURY/Report/Key-findings.htm> ; Yee and Choi 1996; Miller et al 1991

¹³⁹ Quig 1998

¹⁴⁰ Anthony et al 2003; Goyer and Clarkson 2003

¹⁴¹ Some infants with 1-10 ug/L mercury in blood had high blood pressure.

¹⁴² Sorenson et al 1999; AMAP 2002

¹⁴³ Jewett and Duffy 2007. The strongest correlations to neurodevelopment were seen when mercury in hair was over 10 ug/g (Clarkson 1997).

¹⁴⁴ 0.002 ug/L in blood of non-fish-eaters; fish-eaters had 0.02-0.04 ug/L

¹⁴⁵ Barrow mother's blood had 1.3 ug/L; Bethel 5.5 ug/L. Hightower and Moore 2003; AMAP 2002

HEALTH OF WILDLIFE AND FISH

Coal mines such as the proposed Chuitna mine have the potential to impact salmon streams and game harvest areas. The proposed Chuitna coal mine would be the first in Alaska to mine through a salmon stream and through 22 square miles of lush fish and game habitat. Discharged sediment from mining operations or runoff from stored coal piles could affect stream life by suffocating fish eggs, reducing fish life expectancy, increasing susceptibility to disease, and blocking sunlight so that phytoplankton growth is reduced, resulting in reduced food supply for fish and macroinvertebrates. Over 200 tons of coal dust could blow off storage piles every year, blackening beaches.¹⁴⁷

The indirect impacts of mining on fish and wildlife would occur when coal, burned in Alaska or exported around the Pacific Rim for combustion, releases mercury that returns to Alaska. The same biochemical mechanisms of toxicity that disrupt enzymes and hormones in humans also occur in wildlife (Appendix D).¹⁴⁸ As with humans, the half-life of mercury in fish is 2-3 months.¹⁴⁹ Accumulation of non-lethal concentrations of mercury in wildlife can damage the nervous system, reduce reproduction, increase juvenile mortality, affect vision and thinking, and have other indirect impacts that affect small mammal and bird populations.¹⁵⁰

- Small mammals that eat fish, such as mink and river otter, are likely to have higher concentrations of mercury than large animals that forage, if the fish themselves have mercury. When mink (*Mustela vison*) and otter (*Lutra canadensis*) eat fish with 1000 ng/g mercury, they may die.¹⁵¹
- Birds such as falcons (*Falco columbarius*), loons (*Gavia immer*) and terns (*Sterna hirundo*) that eat aquatic prey containing mercury may have elevated MeHg, which can lead to fewer eggs.¹⁵²
- Weight loss and impacts to nerves and reproduction have been observed in red-tailed hawks (*Phasianus colchicus*) and goshawks (*Buteo jamaicensis*), stemming from mercury-induced degradation of the protective sheath around the spinal cord and nerves.¹⁵³

¹⁴⁶ Up to 20 ug/L in blood is considered normal by Health Canada, with 20-100 ug/L considered increasing risk and over 100 ug/L as at risk.

AMAP 1998 Table 12-A7

¹⁴⁷ US EPA. 1990. Diamond Chuitna Coal Project Final EIS.

¹⁴⁸ Harris et al 2003

¹⁴⁹ Kramer and Neidhart 1974

¹⁵⁰ Halbrook et al 1994; Halbrook et al 1997; Wolfe et al 1998; Wiener et al 2002; Landers et al 2008 Executive Summary

¹⁵¹ Wiener et al 2002

¹⁵² Wiener et al 2002; Evers et al 2003; Fevold et al 2003

¹⁵³ AMAP 1998 Chapter 7

- Mercury in waterfowl and game birds in northern Canada was related to the food they ate. Birds that browsed or grazed had the least mercury, followed by omnivores and mollusk-eaters. The highest concentrations were found in fish-eating birds, some of which had mercury concentrations between 1000-2000 ng/g.¹⁵⁴

Models were run to determine potential impacts of persistent contaminants and mercury in Alaska lakes. Because natural systems like lakes are very complex, and actual contaminant loads from specific lakes were not used, the models are not good at identifying exactly what will happen. But results suggest that if fish had high levels of contaminants, mammals and birds preying on fish could experience double impacts: 1) fewer fish to prey on and 2) increased body burden of contaminants. Combined this could lead to fewer births.¹⁵⁵

Marine mammals are most at risk from health effects of mercury. In the 1960's and 1970's when ringed seals were found to have very high concentrations of mercury, there was a high rate of pups born prematurely (stillborn), resulting in a sharp population decline. This may have been due to high mercury in lakes and low selenium; selenium can bind mercury and keep it from being bioavailable.¹⁵⁶

Mercury in trout in Alaska parks increased with the age of the fish, up to 15 years of age, at which point it began to decrease for reasons that are not entirely clear.¹⁵⁷ In brook, rainbow, and cutthroat trout there were correlations between mercury concentrations and cells from the immune system,¹⁵⁸ indicating immune systems were affected. Mercury in trout in remote Alaska parks, and in pike, longnose sucker (*Catostomus catostomus*) and burbot (*Lota lota*) in the Yukon were high enough to pose some risk to fish-eating birds and mammals.¹⁵⁹

IMPACTS ON MARKETS

Coal mining could have a direct impact on commercial fisheries. The proposed Chuitna coal strip mine would seriously impact setnet fishermen that have fished the beaches for decades. In addition to potential

¹⁵⁴ Browsers had <30 – 60 ng/g; grazers <30 – 156 ng/g; omnivores 24-665 ng/g; molluscivores <20 – 455 ng/g; and piscivores 74-1930 ng/g.

There were some differences between whether the bird was found in Northeastern or in Northwestern Canada (Muir et al 1996)

¹⁵⁵ Landers et al 2008 Chapter 5

¹⁵⁶ Ringed seals in Finland had 50,000 ng/g in 1965, but only a maximum of 20,700 ng/g in 1983. AMAP 1998 Chapter 7

¹⁵⁷ Landers et al 2008 Executive Summary

¹⁵⁸ Macrophages are part of the immune system; they engulf and "eat" foreign material and old cells.

¹⁵⁹ Hinck et al 2006; Landers et al 2008 Chapter 4

impacts on the Chuitna River fish, the mining infrastructure would include a two-mile long trestle into Cook Inlet, with the pilings directly on setnet leased beach area and an artificial island, which would likely change the currents and siltation patterns. If approved, this would set a precedent for "taking" commercial fishing leases. A proposed 500,000 metric ton coal storage pile is predicted to blow 200 tons of coal dust onto the beaches annually.

Coal combustion could have an indirect impact on marketing and tourism by affecting the image of "wild Alaska". About 55,000 direct jobs and 84,000 total full time equivalent jobs were closely linked to the health of Alaskan ecosystems. These jobs produce almost \$2.6 billion of income for Alaska workers.

Commercial fisheries. Marketing of wild Alaska fish has resulted in a lucrative market for commercially-caught fish. In 2006, 50% of US seafood came from Alaskan waters, and the 4 billion pounds caught was worth \$1.4 billion to commercial fishermen. Regionally, the wholesale value of the salmon fishery in Bristol Bay was \$248 million, with the ex-vessel harvest value increasing 245% over 2002 value; this value is based in large part on the image of a wild sustainable fishery. In addition to the improved price for fish, the price of permits held by fishermen doubled and tripled, increasing the equity permits represent.¹⁶⁰ Cook Inlet generated \$104 million in ecosystem-based jobs in 2006, with commercial fishing contributing \$25 million in ex-vessel price.¹⁶¹

Alaska spent \$50 million on the Salmon Revitalization Strategy program to improve the competitiveness of Alaska's seafood, particularly salmon, in the market. The potential marketing impacts of increased mercury in wild Alaskan fish needs to be seriously considered, but predictive economic models have not been developed. Whether health effects are likely or not, the impression of contamination can disrupt markets. The market for Alaskan salmon decreased sharply when the Exxon Valdez Oil Spill occurred, resulting in wholesalers and retailers turning to farmed fish; this permanently changed the market share for all commercially-caught Alaska salmon. When dioxin was reported in Belgian dairy products, the Belgian food industry lost over €1.5 billion¹⁶² in one year alone. Findings of mad cow disease in the UK cost the British beef industry an estimated €820 million between 1996 and 2000, and caused the destruction of entire herds. The finding of mad cow disease in some US cattle in 2003 resulted in banning 90% of beef exports in 2003 and 2004, with

¹⁶⁰ McDowell Group 2008

¹⁶¹ Horton 2008

¹⁶² €1.5 billion was about \$2 billion in February 2009; €820 million was about \$1 billion; €3.4 billion was the equivalent of \$4.3 billion

some bans still in place in 2008, and an estimated loss of \$3-\$5 billion.¹⁶³ Mercury contamination in the Arctic is causing concern in Norway regarding public confidence in seafood exports, estimated at €3.4 billion.¹⁶⁴

Marketing the pristine nature of Alaska has also brought in millions of dollars from tourists and recreational fishermen. Sport fishing in Alaska generated \$637 million in sales and \$209 million in payroll when the total economic significance was examined in 1993,¹⁶⁵ and \$61 million to the Bristol Bay area alone in 2005.¹⁶⁶ Bristol Bay National Wildlife Refuge brought in \$5.2 million in payroll for people employed in recreation in 1997.¹⁶⁷ Tourists spent \$1.8 billion in 2002, generating over 37,000 full time equivalent jobs.¹⁶⁸ The arts brought in \$54 million, with over 1,000 employees.¹⁶⁹

Impacts to ecosystem-based economies from coal mining are expected to be place-based, but impacts from coal burning and consequential increase in mercury in Alaska could be much more extensive.

¹⁶³ In 2003, the US exported 1.1 million metric tons of beef (\$3.9 billion). When a single case of mad cow disease was found in a Holstein in Washington state, the four main importers of US beef all banned it (Japan imported 37% of US beef, S. Korea 24%, Mexico 20%, and Canada 10% for a total of 91% of US exports banned). Canada and Mexico resumed buying beef in 2004. Japan and South Korea agreed to limited imports in 2006, but both rejected several shipments. The total estimated impact was \$3.2-\$4.7 billion (Hanrahan and Becker 2006). South Korea maintained the ban into 2008; in June 2008 there were massive demonstrations in S. Korea against US beef when it was announced that import restrictions would be lifted (CNN news, <http://edition.cnn.com/2008/WORLD/asiapcf/06/01/skorea.usbeef/index.html>).

¹⁶⁴ Focus North 2005

¹⁶⁵ Haley et al 1999

¹⁶⁶ Duffield et al 2007

¹⁶⁷ ISER 1998

¹⁶⁸ ADCED 2004

¹⁶⁹ US Census Bureau 2002

Summary

Coal mining and coal combustion have the potential to degrade Alaskan habitat; subsistence opportunities; human, fish, and wildlife health; commercial fish markets; and tourism.

Coal mining is likely to directly degrade fish and wildlife habitat, as well as established commercial fishing uses. Coal combustion, both within and outside Alaska, results in an increase in the global pool of atmospheric mercury that is already impacting Alaskan fish, and may be the source for mercury that is being methylated in the North Pacific. While US and European emissions have declined over the last 20 years, Asian emissions have increased. Asia is the likely market for coal exported from Alaska. Yet Asia, particularly eastern China, now emits more mercury than any single nation, and may account for 20% of the mercury deposited in Alaska.

Alaskan ecosystems provide ideal conditions for methylation of the mercury which deposits, so that even low concentration of mercury in water and soil has resulted in fish with relatively high mercury levels. While some lakes are able to naturally cleanse themselves of methylmercury during the long sunlight hours in summer, lake sediments overall are becoming more concentrated in mercury, indicating the problems are likely to become worse. This may be in part due to effects of climate change and warmer temperatures that promote higher productivity and higher deposition of organic matter. Therefore coal combustion contributes directly to mercury inputs and indirectly exacerbates global warming and mercury methylation.

Mercury has reached unexpectedly high levels in some freshwater fish in some regions, such as northern pike in the Kuskokwim and Yukon Rivers. In addition to any actual impacts, the fear of impacts could change subsistence use patterns. Similarly, fear of mercury contamination has the potential to degrade the Alaska "wild image" and could result in declines in fishing and recreational economies.

Although Alaska has vast coal reserves, mining and export of coal for combustion will have a negative impact on Alaskan fish and wildlife, and potentially on the health of Alaska's people and ecosystem-based economies.

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Appendix A: Units and conversions

Units used in this paper are metric. For instance, 1 ton will refer to 1 metric ton=1000 kg.

Contaminants or elements are measured in units such as mg/kg (soil), ng/g (animal tissue), ug/L (water or blood). Units are mass to mass for solids and mass to volume for liquids, and the specific units used are chosen based on the contaminant concentration; very low concentrations are reported in ng/g or ug/L while higher concentrations are reported in mg/kg or mg/L.

Additionally, tissue concentrations of contaminants may be reported as "wet weight" or "dry weight". In order to compare one set of data to another, they both need to be in wet weight or both in dry weight or some reasonable conversion applied.

1 part per million = 1 mg/kg=1 mg/L=1 ug/g = 1000 ng/g

1 part per billion = 0.001 mg/kg =1 ug/kg=1 ng/g=1 ug/L

Appendix B: Atmospheric Chemistry

The terms RGM and GEM are used throughout the paper. RGM (reactive gaseous mercury) refers to the free ion Hg^{2+} and also to molecules like HgCl_2 that are water-soluble. GEM (gaseous elemental mercury) refers to the element Hg^0 in the gas form.

Oxidation-Reduction (Redox). Sunlight, ozone (in fog and clouds), or atmospheric radicals (above the ocean) cause GEM to become (oxidize to) RGM.¹⁷⁰ Stable GEM can react to become a molecule that precipitates (RGM). Similarly, RGM can become (be reduced to) GEM by sunlight and bacteria. This means reactive mercury in soil or water can be transformed into the stable species that can travel for years in the atmosphere.

Redox and Polar Sunrise. Gaseous mercury is transported to Alaska year-round, and accumulates over the pole in winter; it needs warm temperatures and air currents to move it, and oxidants like radical hydroxyl ions ($\text{ClO}\bullet$, $\text{BrO}\bullet$, $\text{OH}\bullet$, etc) to oxidize it to the RGM form that can precipitate.¹⁷¹ During winter, without sunlight, salt air halogens (Cl , Br , etc) accumulate; high levels of GEM and low levels of RGM are observed. Spring brings the return of the sun for short periods – polar sunrise. As the sun shows above the horizon, halogens rapidly become radicals which oxidize GEM, causing a sharp decrease in GEM and increase in RGM, and daily "pulses" can be recognized. This is observed most dramatically near the coast due to the influence of salt air halogens.

Redox affects Transport. At low altitudes (0-8 km above the Earth surface), GEM is transported long distances but RGM quickly reacts with other molecules, precipitates, and does not move far. At higher altitudes (8-12 km), RGM travels far because there is little to react with it.¹⁷² GEM at high altitudes is oxidized to RGM by ozone and travels. Mercury from a point source will move to Alaska as GEM at low altitudes and as RGM at high altitudes.

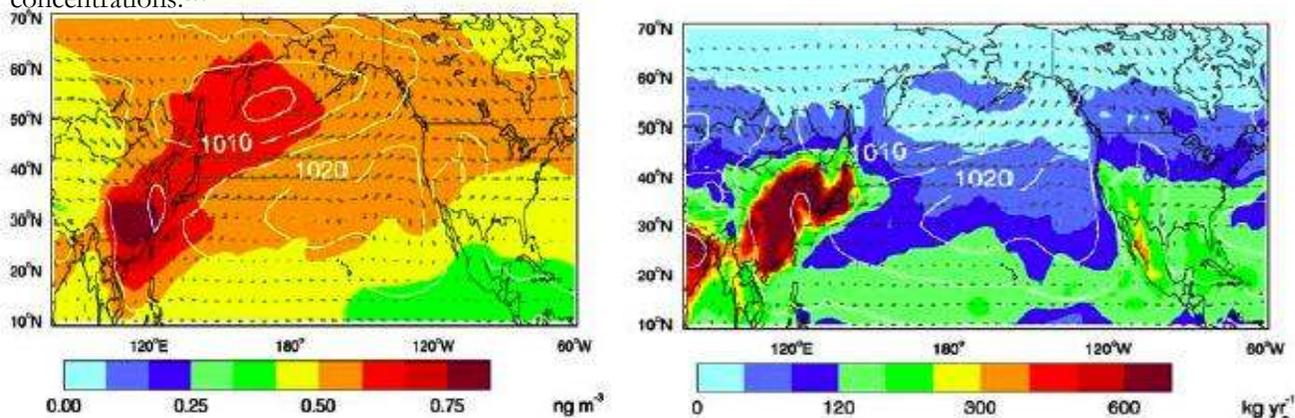
¹⁷⁰ Lindberg et al 2002; Carpi 1997

¹⁷¹ Morel et al 1998; Lindberg et al 2002

¹⁷² Strode et al 2008; Selin et al 2007

Rapid cycling. There is debate about how far RGM travels and how long it "lives". There is a question as to whether RGM that leaves coal stacks is immediately transformed to GEM, or is deposited and re-emitted.¹⁷³ When GEM deposits to dry soils, UV-A will cause it to re-emit, and if RGM deposits on dry soils, UV-B will reduce it to GEM and cause it to re-emit. But if RGM lands on wet soil, it does not re-emit right away.¹⁷⁴ There is evidence that much of the RGM that deposits quickly at polar sunrise in the Arctic may re-emit back to the atmosphere rapidly. Research is ongoing to determine if rapid cycling could be occurring in soils, lakes, vegetation, and oceans; if so, it could give the impression of mercury having a long residence time, when in fact it may be in constant flux.¹⁷⁵

Modeling direct transport. Carbon monoxide (CO) measurements reflect episodic lifting of pollution over central and eastern China ahead of eastward-moving cold fronts. This frontal lifting, followed by transport in the lower free troposphere (2-5 km above the Earth surface), is the principal process responsible for export of pollution from Asia.¹⁷⁶ In the Aleutians and Western Alaska, models indicate GEM concentration can be 0.30-0.35 ng/m³ in spring, which is high. The highest regional concentration in China near point sources is about 0.5 ng/m³. The same source provides about 0.25-0.30 ng/m³ to the Pacific Northwest. The mercury movement correlates very well with CO movement, so CO can be used to model predicted mercury concentrations.¹⁷⁷



TRANSPORT AND DEPOSITION FROM ASIA. (LEFT) GEM travels from Asia to Alaska but will not precipitate unless oxidized to RGM. Map shows concentrations of GEM at 700 hPa pressure, March-May 2004 (ng of GEM per cubic meter of air). GEM is also produced globally and moves northward to the Arctic. (RIGHT) The model indicates that when all mercury is accounted for (GEM, RGM, and PHg) most Asian mercury follows latitudinal lines. Concentration in kg/yr. Data and figures from Strode et al 2008.

¹⁷³ Abbott et al 2003

¹⁷⁴ Lamborg et al 2004

¹⁷⁵ Xin et al 2007; Xin and Gustin 2007; Gustin et al 2006

¹⁷⁶ Bey et al 2003; Liang et al 2004; Jaffe and Strode 2008

¹⁷⁷ Strode et al 2008

Appendix C: Methylation and Demethylation

Methylation

- The following promote growth of sulfate-reducing bacteria (SRB), a primary group of methylators.¹⁷⁸
 - Water with high concentrations of sulfate.
 - High levels of organic carbon. Due to correlations with organic carbon, MeHg may vary on a seasonal basis, being low when nutrients are low and higher when nutrients increase in spring and summer.¹⁷⁹ Water from snowmelt and rain, including storm runoff, is also more likely to pick up organic carbon when it is kept to the upper layers of the soil horizon due to underlying permafrost; water that percolates down to groundwater is less likely to carry organic carbon to surface water bodies.¹⁸⁰
 - Warm temperatures.
- The following limit SRB growth.
 - Oxygen. Methylation tends to occur near the oxycline in sediment or oceans, where the environment is changing from aerobic to anaerobic.¹⁸¹
 - Sulfide is toxic to SRB.
- The following compete with SRB to keep mercury from being available for methylation.
 - Sulfide and chloride, found in the ocean, bind mercury. In estuaries, tides may cause methylation rates to change over the course of a day.¹⁸²
 - Humic and fulvic acid organic material will bind mercury.
 - Selenium binds mercury.

Demethylation

- Bacteria can make enzymes that remove the methyl group and let inorganic mercury form again. SRBs, methanogens, and other anaerobes demethylate in freshwater; only SRBs demethylate in estuaries.¹⁸³
- Sunlight can remove the methyl group through photo-reduction.¹⁸⁴

¹⁷⁸ Compeau and Bartha 1987; Macalady et al 2000; Langer et al 2001; Stoichev et al 2004; Lambertson and Nilsson 2006; Wiener et al 2006

¹⁷⁹ Driscoll et al 1998

¹⁸⁰ Petrone et al 2007

¹⁸¹ Sunderland et al 2009; Langer et al 2001; Gagnon et al 1996. Figure is from Sunderland et al 2004.

¹⁸² Langer et al 2001

¹⁸³ Oremland et al 1995; Marvin-Dipasquale et al 2000; Martin-Doimeadios et al 2004

¹⁸⁴ Hutchison and Atwood 2003

Appendix D: Biochemical Mechanisms of Toxicity

Toxicity of mercury is primarily associated with its attraction to sulfur. Once organic mercury has crossed into a cell, it oxidizes to inorganic mercury that binds to sulfhydryl groups on proteins, targeting fast-dividing cells such as nerve and brain cells. The result is neurological problems, including learning disorders.¹⁸⁵

Due to the strong affinity of mercury for sulfur, MeHg will also bind to the detoxification molecule GSH, which contains sulfur, and inhibit the enzymes that control the activities of GSH.¹⁸⁶ When MeHg binds to sulfur-containing molecules such as GSH, glutathione, or the amino acid cysteine, the physical structure of the molecule changes and impacts the ability of the molecule to work. Many enzymes and molecules act by “fitting” into other molecules, and when the shape changes “lock and key” mechanisms are disrupted. For instance, when amino acid structure is changed, signal molecules like serotonin and dopamine may not be made or may not move as they should.¹⁸⁷ When mercury binds to cell receptors, it interferes with thyroid and steroid hormones, which can lead to reproductive problems in both wildlife and people.¹⁸⁸

The same processes that occur in humans – such as attachment of MeHg to sulfur-based molecules – also occur in wildlife, and MeHg cysteine and glutathione complexes have been found in cells and fish tissue.¹⁸⁹

¹⁸⁵ Anthony et al 2003; Goyer and Clarkson 2003

¹⁸⁶ Zalups and Lash 1996

¹⁸⁷ Quig 1998; Newland 2002; Ram and Sathyanesam 1985; Peroza et al 1998

¹⁸⁸ Aschner and Clarkson 1988; Lundholm 1991; Dansereau et al 1999; Halbrook et al 1994

¹⁸⁹ Harris et al 2003