Global Mercury Assessment 2018

Contents

Key Policy-Relevant Findings 3
1. Introduction 5
Background and mandate 5
Developing the 2018 Report 5
Scope and coverage 6
2. Recent Advances in Understanding the Global Mercury Cycle 7
Current understanding and questions 7
Revised global and oceanic total mercury budgets 8
3. Mercury Emissions to Air 11
Methods for compiling an inventory of mercury emissions 11
2015 global anthropogenic mercury emissions to air 13
Summary of results by region 13
Breakdown of results by sector 16
BOX: Comparing GMA global inventory estimates with national inventories 19
Comparing the 2010 and 2015 global inventory estimates 20
4. Levels of Mercury in Air 23
Spatial variability in the Southern and Northern Hemispheres 23
Regional variability in atmospheric mercury 25
Vertical profiles of mercury in the atmosphere and the distribution mercury plumes 27
5. Atmospheric Pathways, Transport, and Fate of Mercury 28
Emissions and different types of mercury 28
Atmospheric chemistry 29
Removal processes 29
Results from mercury modelling 30
Historical trends and future scenarios 34
6. Anthropogenic Releases of Mercury to Water 36
Methods for estimating global anthropogenic mercury releases 36
Global anthropogenic mercury releases in 2015 38
BOX: Artisanal and small-scale gold mining 38
Releases from selected sectors 41
7. Trends in Atmospheric Mercury and Mercury in Aquatic Biota 42
Recent advances in understanding mercury methylation and demethylation 42
The response of mercury levels in aquatic biota to changes in atmospheric mercury concentrations 43
Causes of the mismatch between atmospheric and aquatic mercury trends 50
The implications of mercury emission regulations on mercury levels in biota 51
8. Mercury Concentrations in Biota 53
Methylmercury in biota 53
Biomonitoring programs 55

Bioindicators for human health 56
Bioindicators for ecological health 59
Critical knowledge gaps 62
9. Mercury Levels and Trends in Human Populations Worldwide 64
Mercury and human health 64
Mercury exposure assessment using biomarkers 65
Mercury levels in humans 66
Remaining questions and prospects for action 72
Key Findings 74

Key Policy-Relevant Findings

The Global Mercury Assessment 2018 is the fourth such assessment undertaken by The United Nations Environment Programme (UN Environment), following earlier reports in 2002, 2008, and 2013. It is the second assessment produced by UN Environment in collaboration with the Arctic Monitoring and Assessment Programme (AMAP). The assessment is supported by a technical background document, the chapters of which have been prepared by teams of experts and peer-reviewed for scientific quality. This summary document presents the main findings of the technical document in plain language. Recognizing the relevance of the results of the Global Mercury Assessment 2018 for policy makers, this section presents key findings of highest policy relevance. The full list of key findings can be found at the end of the report.

- A new global inventory of mercury emissions to air from anthropogenic sources in 2015 quantifies emissions from 20 key sectors at about 2220 tonnes. Additional emissions of the order of tens to hundreds of tonnes per year may arise from smaller anthropogenic sources not currently detailed in the global inventory work.
- Estimated global anthropogenic emissions of mercury to the atmosphere for 2015 are approximately 20% higher than they were in updated estimates for 2010. Continuing action to reduce emissions has resulted in modest decreases in emissions in North America and the EU. Increased economic activity, notably in Asia, and the use and disposal of mercury-added products appears to have more than offset any efforts to reduce mercury emissions. However, different sectors contribute differently to the overall increase.
- Emissions patterns in 2015 are very similar to those in 2010. The majority of the 2015 emissions occur in Asia (49%; primarily East and South-east Asia) followed by South America (18%) and Sub-Saharan Africa (16%). Emissions associated with artisanal and small-scale gold mining account for almost 38% of the global total and are the major contributor to the emissions from South America and Sub-Saharan Africa. In other regions, emissions associated with energy production and industrial emissions predominate.
- Stationary combustion of fossil fuels and biomass is responsible for about 24% of the estimated global emissions, primarily from coal burning (21%). Main industrial sectors remain non-ferrous metal production (15% of the global inventory), cement production (11%) and ferrous metal

production (1.8%). Emissions from wastes from mercury-containing products comprise about 7.5% of the 2015 global inventory.

- Human activities have increased total atmospheric mercury concentrations by about 450% above natural levels. This increase includes the effects of mercury emitted from human sources in the past which is still circulating in the biosphere. The influence of climate change and legacy mercury complicates our ability to assess potential future changes.
- Artisanal and small-scale gold mining released about 1220 tonnes of mercury to soils and waters in 2015. Other global releases of anthropogenic mercury to aquatic environments were about 590 tonnes in 2015, compared with the estimate of 185 tonnes for 2010. The difference is largely due to new methods and more data. New sectors added to the 2015 inventory include releases with municipal wastewater, from coal washing, and from coal-fired power plants.
- Methylmercury production in the oceans and in some lakes is no longer limited by the input of inorganic mercury. Other factors such as climate change, biogeochemistry, and changes in soil processes are playing increasingly important roles.
- Reductions in emissions may take time to show up as reductions of mercury concentrations in biota. For some time to come, methylmercury will continue to be produced from the legacy mercury already present in aquatic systems.
- Mercury loads in aquatic foodwebs are at levels of concern for ecological and human health around the world.
- All people are exposed to some amount of mercury. For many communities worldwide, dietary consumption of fish, shellfish, marine mammals, and other foods is arguably the most important source of methylmercury exposure. Exposures to elemental and inorganic mercury mainly occur in occupational settings or via contact with products containing mercury. There remains high concern for vulnerable groups with high dietary or occupational exposure to mercury.

1. Introduction

Background and mandate

Global inventories for mercury emissions to air from human sources have been produced at approximately 5-year intervals since 1990 by scientific groups. The United Nations Environment Programme (UN Environment) produced its first Global Mercury Assessment in 2002 and subsequent reports in 2008 and 2013. These reports have provided the scientific basis for the negotiations that resulted in the Minimata Convention on Mercury, which was adopted in October 2013 and entered into force in August 2017.

This report constitutes the Global Mercury Assessment 2018 (GMA 2018). Its findings are supported by the Technical Background Report. GMA 2018 has been prepared in response to a request from the Governing Council of UN Environment (now the UN Environment Environmental Assembly) in 2013 to update the Global Mercury Assessment 2013 (GMA 2013) for delivery no later than 2019.

Developing the 2018 Report

As in 2008 and 2013, the Technical Background Report forms the basis for the statements made in this report and is fully referenced according to standard scientific practice. As such, it is the single reference for this GMA 2018 Report. It has again been prepared in co-operation with the Arctic Monitoring and Assessment Programme (AMAP) and uses national data and information submitted by several governments. Contributions have also been incorporated from the UN Environment's Global Mercury Partnership, in particular its partnership areas on mercury in artisanal and small-scale gold mining, and mercury air transport and fate; AMAP mercury expert group; UN Economic Commission for Europe Long-range Transboundary Air Pollution Convention groups; industry; and non-governmental organizations. Each section was prepared by a team of experts and then reviewed to ensure its scientific accuracy. The evaluation of information of mercury levels in humans is a new component of GMA 2018 and benefits from contributions from experts from the World Health Organization (WHO).

Scope and coverage

This update to GMA 2013 provides the most recent information available for the worldwide emissions to air, releases to water, and transport of mercury in atmospheric and aquatic environments. To the extent possible, the information comes from the published scientific literature, supplemented where necessary by other sources. Since GMA 2018 is intended as a basis for decision making, emphasis is given to anthropogenic emissions (mercury going into the atmosphere) and releases (mercury going into water and land), that is, those associated with human activities.

The report reflects progress made by the scientific community, national authorities and organisations in better understanding mercury cycling (Chapter 2), atmospheric mercury emissions (Chapter 3), mercury levels in air (Chapter 4), atmospheric transport and fate (Chapter 5), releases to water (chapter 6), and the cycling and methylation of mercury in the aquatic environment (Chapter 7). In addition to updating GMA 2013, new additional sections are included on observed levels of mercury in biota (Chapter 8) and observed levels and effects of mercury in humans (Chapter 9).

Technical Background Report chapters prepared by teams of experts were subject to peer and national review to ensure their scientific validity. This GMA 2018 Report is based on the content of the Technical Background Report and has been reviewed by the authors of the Technical Background Report. It was also circulated for national review.

2. Recent Advances in Understanding the Global Mercury Cycle

Mercury is emitted to the atmosphere and released into waters as a result of human activities, and from natural sources and processes such as volcanoes and rock weathering. Mercury in the air can be carried around the world, eventually being deposited onto soils, waters, or plants. From there, mercury can re-volatilize into the air again, or be transported further by water, or be taken into the food web. Eventually, mercury is removed from this global cycle through burial in deep ocean sediments, lake sediments, and subsurface soils. Only a minute fraction of the mercury present in the environment is methylmercury, the only form of mercury that biomagnifies in the food web. Methylmercury is produced from inorganic mercury, mainly in aquatic ecosystems through microbial action. An improved understanding of the global mercury cycle is important for predicting how regulatory efforts to reduce mercury emissions to air and releases to water and land will affect mercury concentrations in the environment, including biota and humans.

Current understanding and questions

GMA 2013 estimated that anthropogenic activities cumulatively had increased atmospheric mercury concentrations by 300-500% over the past century. Mercury in surface ocean waters less than 200 metres deep had approximately doubled in the same period. Deeper waters exhibited smaller increases because anthropogenic inputs take longer to reach the isolated water masses of the deep ocean. Substantial amounts of mercury were already naturally present in soils worldwide, so the addition of anthropogenic mercury has also made only a modest difference there. Mercury from historical human activities now in soils and oceans acts as a reservoir, maintaining atmospheric mercury concentrations at higher levels than would be the case only from current emissions.

Since GMA 2013 was completed, new studies of New World mining emissions from the 16th century onwards, and re-examination of mercury profiles in lake sediments and peat bogs, have shown that human influence on the global mercury cycle began well before the start of the Industrial Age. Previous assessments often used 1850 as the starting point for gauging human effects on mercury levels worldwide. There is not yet agreement on the earlier time that should be used instead, but it is clear that current atmospheric concentrations of mercury are several times higher than “natural” levels.

In the terrestrial system, soils globally are likely to contain more anthropogenic mercury than was estimated at that time. For the oceans, however, new models differ significantly in their conclusions. Because much of the risk of mercury contamination for humans and wildlife comes via marine food webs, it is important to improve the understanding of the role of anthropogenic mercury in the sea. The models differ primarily in their estimates of the mercury delivered to the ocean as a result of New World silver and gold mining between the 15th and late 19th centuries, and in their estimates of how much natural mercury was already present in the oceans.

The total amount of mercury currently in the environment reflects a mixture of sources: historical anthropogenic releases to air, land and oceans; historical natural inputs; and current anthropogenic and natural releases. The influence of historic silver mining on the oceanic mercury budget is particularly important in this regard. How much was emitted to air or released to water is the crucial question. Recently, a new historical study examined mercury importation and consumption during colonial silver mining in what are now Mexico, Peru, and Bolivia. Lake sediment profiles near the mining operations show substantial increases in mercury during the mining era. Outside this region, however, the global record in lake sediments, peat bogs, and glacier ice shows a negligible impact from colonial mining, suggesting a far more modest role for anthropogenic contamination in that period than was assumed in previous emissions inventories and models.

Revised global and oceanic total mercury budgets

With these new findings in mind, a recent model indicates that mining in those four centuries accounts for about two-thirds of all anthropogenic mercury currently in the oceans. This mercury entered the oceans prior to 1920. The remaining third of anthropogenic mercury inputs to oceans have come since then, mainly from coal combustion and other industrial activities. The results of this models are consistent with other estimates of the amount of anthropogenic mercury in the world's oceans. The new information has been used to create a revised total mercury budget for GMA 2018. Most of the changes from GMA 2013 are relatively small, though the emissions from soils and vegetation is notably lower than the previous average. Based on this revised global budget, the mercury budget in the world's oceans was updated as well.

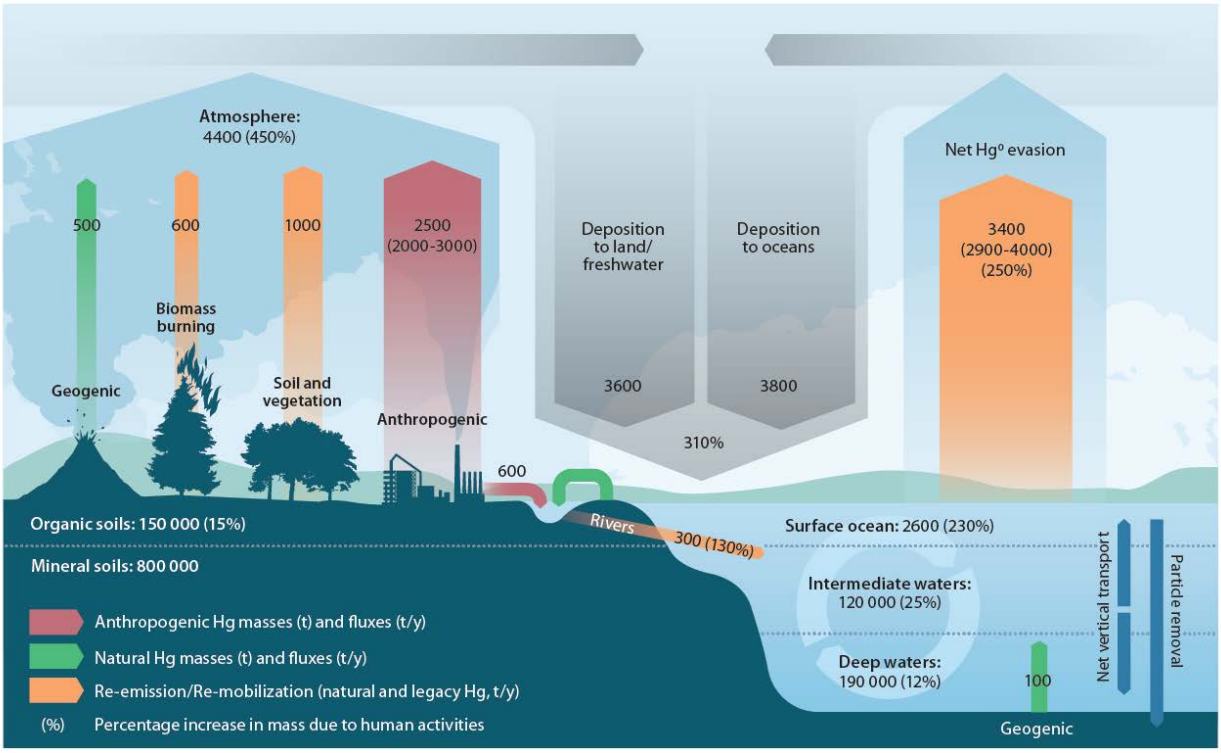


Fig. 2.1. An updated global Hg budget indicating the anthropogenic impact on the Hg cycle since the preanthropogenic period (prior to 1450 AD) (see text for explanation of its derivation. Natural Hg masses and fluxes in green; anthropogenic Hg in red; revolatilized or remobilized legacy Hg (both natural and anthropogenic) in red/green stripes. Ranges are given in brackets after the best estimate values; percentages in brackets represent the estimated increase in mass or flux due to human activities since the preanthropogenic period. Mass units in tonnes (t), fluxes in t/yr)

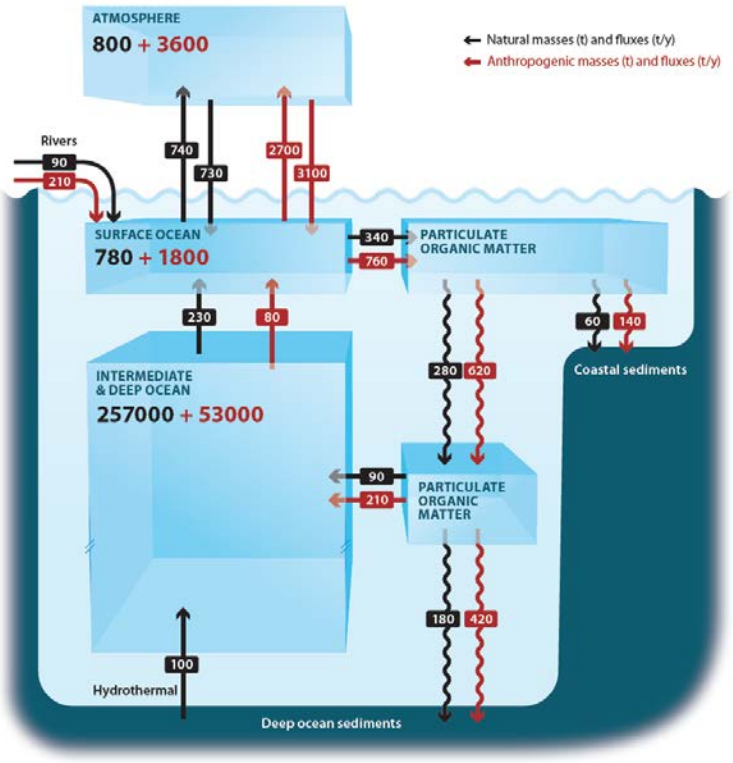


Figure 2.2. Natural and anthropogenic Hg fluxes and masses in the world's oceans. (Masses in tonnes (t), and fluxes in tonnes per year (t/yr)). Data adapted and revised from Zhang et al. 2014b, based on the revised global budget shown in Fig. 2.1 (see text)).

The uncertain role of historical mining on global anthropogenic mercury levels, combined with limited understanding of some basic oceanographic processes, makes it difficult to assess how quickly mercury levels in the ocean will respond to emission reductions. All the models predict that the marine response will be much slower than that of the atmosphere. Removal of anthropogenic mercury from the world's oceans will take many decades to centuries, varying substantially between different ocean basins. In the shorter term, mercury in seawater and marine food webs is likely to increase even at current levels of anthropogenic emissions and releases, simply because legacy mercury from soils will continue to be carried by rivers to the sea and to be re-volatilized into the air. Regardless of the timeline, however, emissions reductions are required to reverse the trend in oceanic anthropogenic mercury back towards natural levels.

3. Mercury Emissions to Air

Industrial activities to produce power and other commodities, together with a range of intentional uses of mercury in processes and products, result in anthropogenic emissions of mercury to the atmosphere. Stationary combustion of fossil fuels, especially coal, and high temperature processes involved in industrial activities such as metal smelting and cement production give rise to emissions as a by-product. The use of mercury-containing products such as lamps, batteries, and dental fillings also result in mercury emissions to air (and releases to water), largely during waste disposal. Mercury is also used in industrial processes such as chlor-alkali production. A further intentional use of mercury is in artisanal and small-scale gold mining where mercury is used to extract gold from gold-bearing sediments and rocks. Of these sources, stationary combustion of coal and artisanal gold mining are estimated to be responsible for almost 60% of emissions to air in 2015.

Mercury emissions to air have changed over time. Historically gold and silver mining have been major sources of mercury emissions and releases. With the advent of the industrial revolution (ca. 1850s) and the subsequent rise of fossil fuel economies, mercury emissions increased. Emissions remain high, estimated at around 2000-2500 tonnes per year during the first decades of the 21st century. These emissions give rise to global pollution, including long-range transport to remote regions, with associated concerns for impact on health of wildlife and human populations.

Methods for compiling an inventory of mercury emissions

As part of the work to prepare GMA 2018, a new global inventory of anthropogenic mercury emissions to air has been produced, for the target year 2015. This inventory addresses emissions from the source sectors and activities. These include three sectors not previously quantified: biomass combustion (for energy production), secondary steel production, and mercury emitted during production of vinyl chloride monomer, a raw material for plastics. Additional, though smaller, sectors have been identified that are not yet fully quantified in global emission inventory work.

The method employed to produce the 2015 global inventory of anthropogenic emissions to air is essentially the same as that used in the 2010 inventory reported in GMA 2013. The method applies a mass-balance approach to derive emissions estimates that considers:

- the amounts of fuels and raw materials used, or commodities produced (*activity data*);
- the associated mercury content of fuels and raw materials and the types of process involved (reflected in 'unabated' *emissions factors*); and
- technology applied to reduce (abate) emissions to air (through *technology profiles* that reflect the degree of application and the degree of effectiveness of air pollution controls)

The artisanal and small-scale gold mining and mercury-added product sectors employ variations on this approach. A variety of improvements have been made in the way this method has been applied, generally reflecting improvements in available information. The method used to spatially distribute the global inventory to point and distributed sources across the globe has also been upgraded as part of GMA 2018. These new developments allow national estimates to be mapped at a finer geographical resolution for use in modelling work.

Table3.1: Methodological improvements in GMA 2018

Sector	*Change(s) in methods or data*
Coal burning	Updated technology profiles Separation of coal burning by industry sector
Biomass burning	Quantified for the first time
Cement production	Separation of emissions from different steps in cement production
Primary iron and steel production	More details on the individual steps in production Separation of coal burning from other steps
Secondary steel production	Quantified for the first time
Copper, lead, and zinc production	Better data on mercury levels and emission rates Separation of coal burning from other steps
Aluminum production	Better data including new emission factors
Large-scale gold production	Better data on emission reductions in some countries
Oil refining	Minor adjustments to mercury content in oil from different countries
Vinyl chloride monomer production	Quantified for the first time
Waste disposal and incineration	Mercury assumed to be released continually More detailed assessment of emissions and technology
Crematoria emissions	Updated data on dental fillings and cremation rates
Artisanal and small-scale gold mining	Improved information globally, especially from South America Revised methodology on emission rates associated with different practices

2015 global anthropogenic mercury emissions to air

The global inventory of mercury emissions to the atmosphere from anthropogenic sources in 2015 is 2220 tonnes. Such emissions account for about 30% of mercury emitted annually to the atmosphere. A further 60% of current global mercury emissions to air result from environmental processes, much of which involves recycling of anthropogenic mercury previously deposited to soils and water. This legacy anthropogenic mercury is not a natural source. The remaining 10% comes from present-day natural sources such as volcanoes. This global inventory total for 2015 does not include sectors that cannot yet be reliably quantified and therefore are not yet addressed separately in the inventory work. For example, emissions from contaminated sites are estimated to be in the range of 80 tonnes, similar to what they were in 2010. This and other such sectors may add tens to a few hundred tonnes of mercury to the actual emission inventory total.

The 2015 inventory is consistent with the GMA 2013 statement that global emissions to air in the first part of the 21st century from principal anthropogenic sectors are of the order of 2000-2500 tonnes per year. Uncertainties associated with the 2015 inventory estimate of 2220 tonnes create an approximate range of 2000-2820 tonnes of anthropogenic emissions. The emissions total for 2015 is higher than it was for 2010, when the same methods are applied in both cases. The increase has several explanations. Some are associated with improved information. Others, such as emissions from some industrial sectors, appear to be largely due to increased economic activity in some regions, notably East Asia. Updated estimates of emissions for 2010 also incorporated final activity data for 2010 from key sources including the International Energy Agency. The resulting updated total inventory of 1815 tonnes for 2010 is somewhat lower than the 1880 tonne estimate presented in GMA 2013.

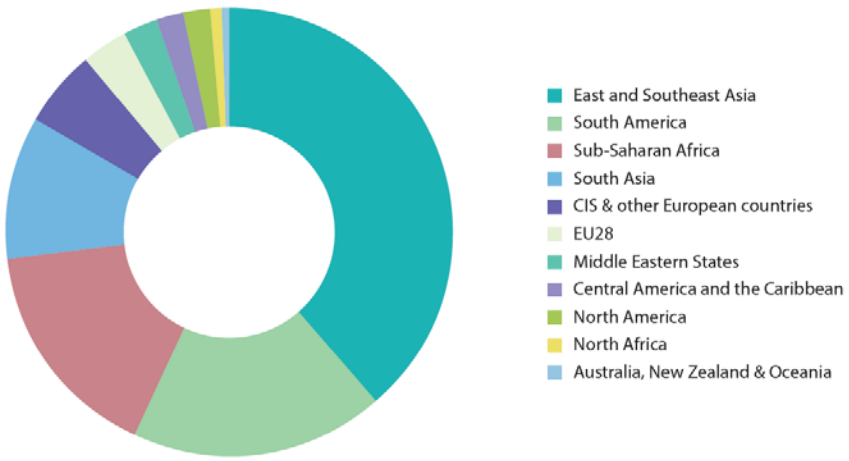
Summary of results by region

Regional (i.e., sub-continental) contributions to the global inventory in 2015 are very similar to those of 2010. The majority of emissions occurred in Asia (49%, of which 39% in East and South-east Asia), followed by South America (18%) and Sub-Saharan Africa (16%). The consistency in the regional distribution of emissions indicates that these patterns are robust and not influenced to any undue extent by changes in methodology or the addition of more sectors since GMA 2013. It is noteworthy that

artisanal and small-scale gold mining accounts for about 70% and not more than 80% of the emissions from South America and Sub-Saharan Africa, respectively.

If emissions associated with artisanal and small-scale gold mining are set aside, the East and South-east Asian region remains responsible for the largest share of emissions (47% of the remaining total), with South Asia responsible for a further 16%. Sub-Saharan Africa and the CIS and other European countries, between them, contribute a further 16% of emissions, with the non-ferrous metals industry as the main source. In the remaining regions of the world, coal combustion still accounts for the major part of the emissions in North America (almost 60%), the EU (over 50%) and Australia, New Zealand and Oceania (37%). In the Middle Eastern States and North Africa, the cement industry is the principle source of emissions (43% and 52% of the regional totals, respectively). Sources associated with wastes from mercury-containing products account for approximately 10-20% of emissions in most regions, somewhat higher in North Africa (27%) and lower in the EU, East and South-east Asian, South America, and Sub-Saharan Africa regions.

All percentage contributions need to be considered in relation to the total (absolute) amounts of mercury emitted in each sub-region.



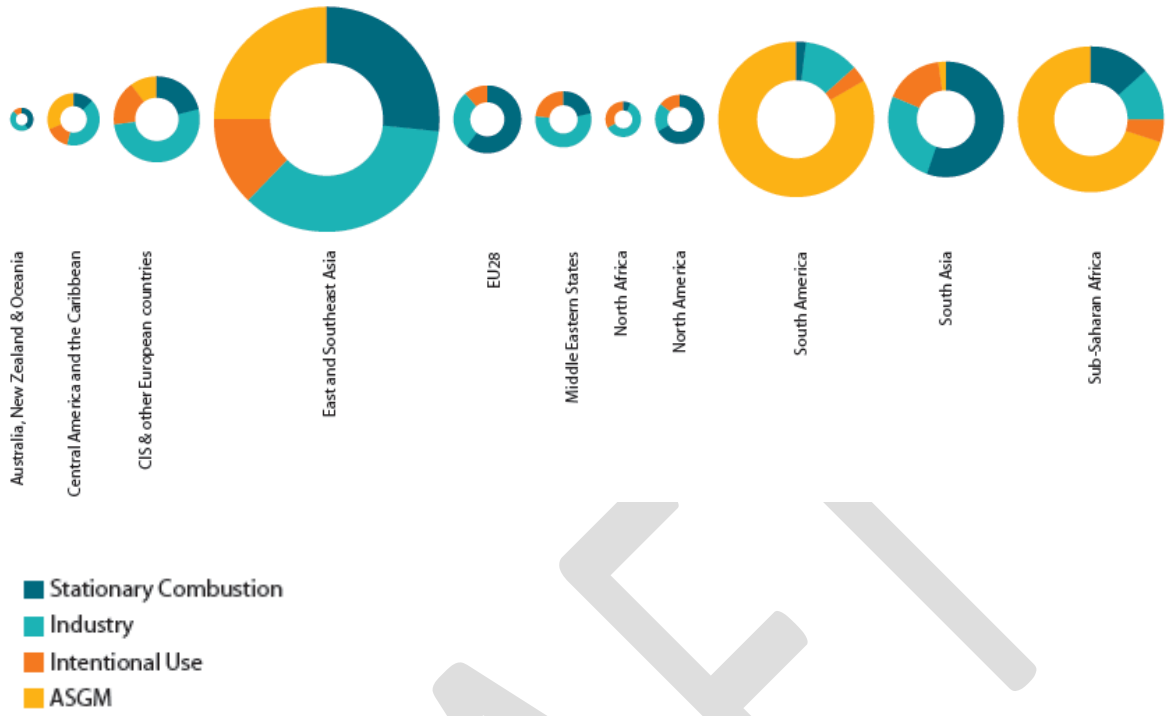


Figure 3.1: Regional breakdown of global emissions of mercury to air from anthropogenic sources in 2015.

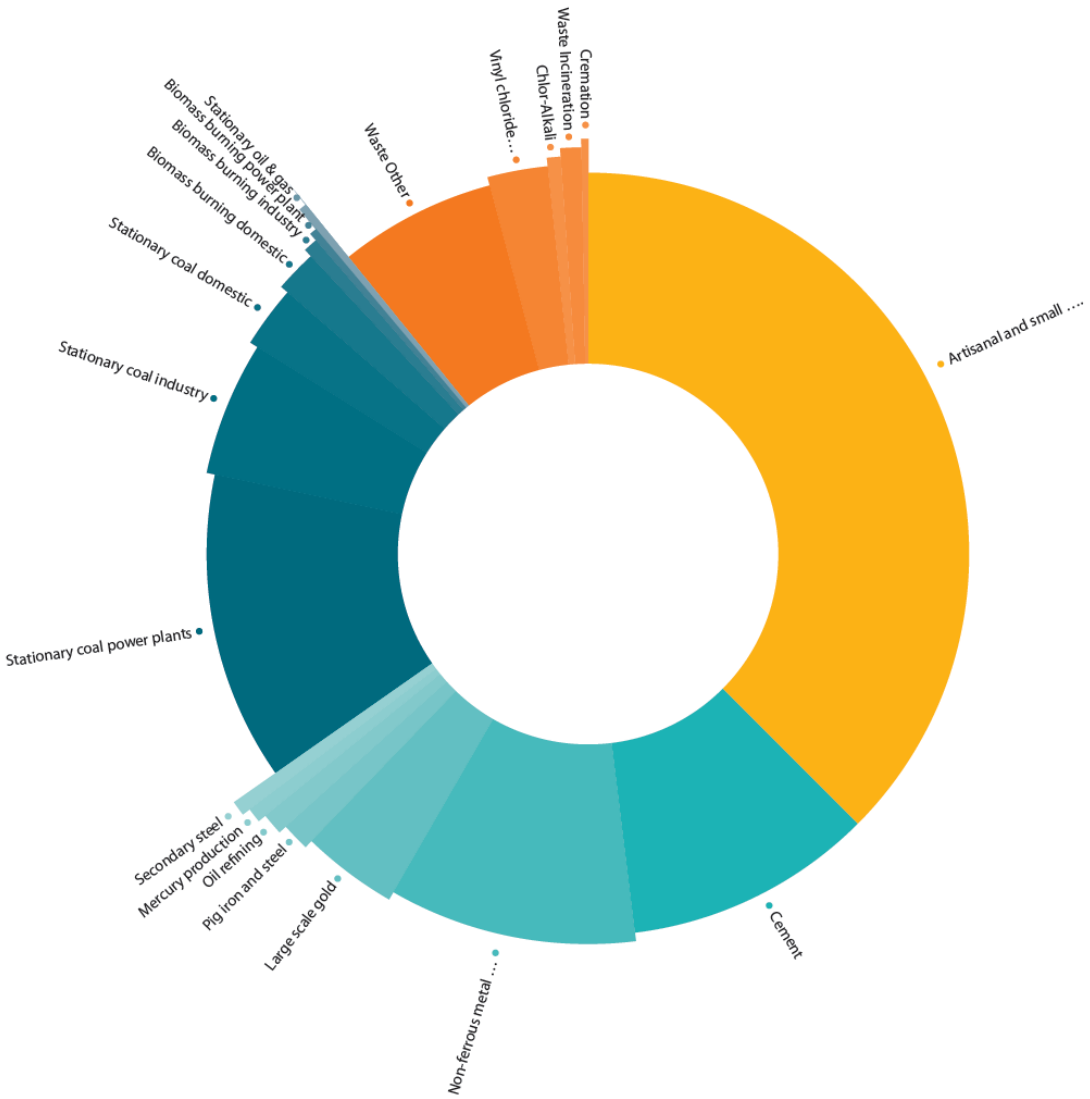
Table R1: Regional breakdown of global emissions of mercury to air from anthropogenic sources in 2015.

	Sector group				Regional total (and range), tonnes	% of global total
	Fuel combustion	Industry sectors	Intentional-use (including product waste)	ASGM		
Australia, New Zealand & Oceania	3.57	4.07	1.15	0.0	8.79 (6.93-13.7)	0.4
Central America and the Caribbean	5.69	19.1	6.71	14.3	45.8 (37.2-61.4)	2.1
CIS & other European countries	26.4	64.7	20.7	12.7	124 (105-170)	5.6
East and	229	307	109	214	859	38.6

Southeast Asia					(685-1430)	
EU28	46.5	22.0	8.64	0.0	77.2 (67.2-107)	3.5
Middle Eastern States	11.4	29.0	12.1	0.225	52.8 (40.7-93.8)	2.4
North Africa	1.36	12.6	6.89	0.0	20.9 (13.5-45.8)	0.9
North America	27.0	7.63	5.77	0.0	40.4 (33.8-59.6)	1.8
South America	8.25	47.3	13.5	340	409 (308-522)	18.4
South Asia	125	59.1	37.2	4.50	225 (190-296)	10.1
Sub-Saharan Africa	48.9	41.9	17.1	252	360 (276-445)	16.2
Global inventory	533	614	239	838	2220 (2000-2820)	100.0

Breakdown of results by sector

As with the regional breakdown, the breakdown of 2015 anthropogenic mercury emissions by sectors is very similar to that of 2010. The predominant source sector is artisanal and small-scale gold mining (about 38%) followed by stationary combustion of coal (about 21%). These are followed by emissions from non-ferrous metal production (about 15%) and cement production (about 11%). Emissions associated with disposal of mercury-containing product waste (8%), stationary combustion of other fuels including biomass (3%), ferrous-metal production (2%), and other sources (2%) make up the rest.



339

340 ***Figure 3.2: Proportions of global emissions of mercury to air from different anthropogenic source sectors in 2015.***

341

342

343

344

345

346 ***Table S1: Sectoral breakdown of global emissions of mercury to air from anthropogenic sources in 2015.***

Sector Code	Description	Sector emission (range), tonnes	Sector % of total
ASGM	Artisanal and small-scale gold mining	838 (675-1000)	37.7
BIO	Biomass burning (domestic, industrial and power plant)	51.9 (44.3-62.1)	2.33
CEM	Cement production (raw materials and fuel, excluding coal)	233 (117-782)	10.5
		See also BC–IND-CEM and HC-IND-CEM	
CREM	Cremation emissions	3.77 (3.51-4.02)	0.17
CSP	Chlor-alkali production (mercury process)	15.1 (12.2-18.3)	0.68
NFMP	Non-ferrous metal production (primary Al, Cu, Pb, Zn)	228 (154-338)	10.3
		See also BC–IND-NFM and HC-IND-NFM	
NFMP-AU	Large-scale gold production)	84.5 (72.3-97.4)	3.8
NFMP-HG	Mercury production)	13.8 (7.9-19.7)	0.62
OR	Oil refining	14.4 (11.5-17.2)	0.65
PISP	Pig iron and steel production (primary)	29.8 (19.1-76.0)	1.34
		See also BC–IND-PIP and HC-IND-PIP	
SC-DR-coal	Stationary combustion of coal (domestic/residential, transportation)	55.8 (36.7-69.4)	2.51
SC-DR-gas	Stationary combustion of gas (domestic/residential, transportation)	0.165 (0.13-0.22)	0.01
SC-DR-oil	Stationary combustion of oil (domestic/residential, transportation)	2.70 (2.33-3.21)	0.12
SC-IND-coal	Stationary combustion of coal (industrial)	126 (106-146)	5.67
SC-IND-gas	Stationary combustion of gas (industrial)	0.123 (0.10-0.15)	0.01
SC-IND-oil	Stationary combustion of oil (industrial)	1.40 (1.18-1.69)	0.06

SC-PP-coal	Stationary combustion of coal (power plants)	292 (255-346)	13.1
SC-PP-gas	Stationary combustion of gas (power plants)	0.349 (0.285-0.435)	0.02
SC-PP-oil	Stationary combustion of oil (power plants)	2.45 (2.17-2.84)	0.11
SSC	Secondary steel production	10.1 (7.65-18.1)	0.46
VCM	Vinyl-chloride monomer (mercury catalyst)	58.2 (28.0-88.8)	2.6
WASOTH	Waste (other waste)	147 (120-223)	6.6
WI	Waste incineration (controlled burning)	15.0 (8.9-32.3)	0.67
Total		***2220 (2000-2820)***	***100***

BOX: Comparing GMA global inventory estimates with national inventories

The target for the GMA 2018 air emissions inventory activity remains the production of a robust global inventory for the target year of 2015, for a defined set of sectors for which reliable global estimates can be produced. Although it presents emission estimates broken down by sector for each of some 200 countries, the applied methodology is directed at global/regional rather than national level application.

A major new development since GMA 2013 is that a large number of countries are engaged in preparing new national inventories or national emission/release estimates, many of these associated with the Minamata Initial Assessments (MIAs) or Minamata National Action Plans. This allows increased possibilities for comparing the global and nationally derived emissions estimates.

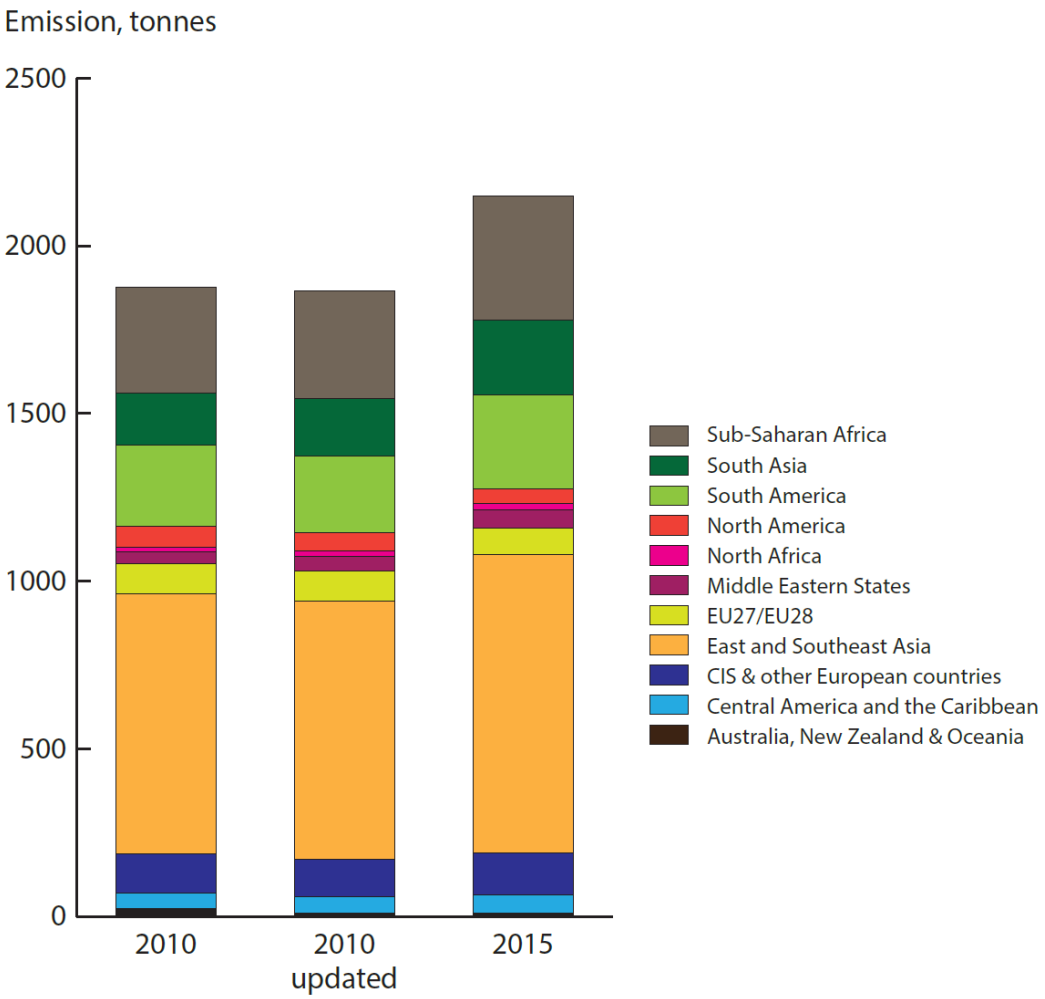
In general, the GMA inventory estimates of national emission totals agree fairly well with available nationally reported values, but there can be significant differences on the sector level. These differences are often associated with the way sectors are defined and emissions attributed to different sector categories and activities. They may also be due to methodological differences in the approach employed to estimate emissions, or use of different years of (activity) data. Preliminary comparisons with MIAs identified differences that can also be due to errors in national data collection for the MIAs; or,

regarding the GMA 2018 estimates, application of default emission factors and technology profiles not representative for that specific country, and a variety of other reasons.

Some national inventories include additional emissions that are not yet quantified in the GMA 2018 inventory, such as other chemical manufacturing processes; other mineral products (e.g., lime manufacturing), secondary non-ferrous metal production, oil and gas extraction, pulp and paper industry, and food industry, etc. These emission sources are currently difficult to quantify at the global scale, largely due to lack of comprehensive activity data as well as lack of emission factors for highly variable process technologies. However, for the few (generally developed) countries reporting emissions from 'other' sources the contribution is approximately 5-20% of the national inventory totals, which extrapolated globally could amount to additional emissions of the order of 10s to 100s of tonnes.

Comparing the 2010 and 2015 global inventory estimates

As a first step in trying to gain a reliable insight into whether apparent changes in emissions patterns between 2010 and 2015 represent real changes in emissions, an updated 2010 inventory was prepared using the same emission factors, abatement technology, and sources of data on activity levels as was used for the 2015 inventory, as well as inclusion of a retrospective emission estimate for most of the sectors newly introduced in the 2015 inventory. For some countries, activity data for 2010 were updated with respect to those applied in the original 2010 inventory presented in GMA 2013. This comparison was not possible before due to major changes in inventory methods from one assessment to the next. Those changes also make it impossible to make comparisons with inventories before the 2010 version.



384

385 ***Figure 3.3: Regional breakdown of global emissions of mercury to air from anthropogenic sources in 2015 in***
386 ***relation to 2010.***

387 Estimated global emissions of mercury to the atmosphere from anthropogenic source in 2015 are
388 approximately 20% higher than they were in 2010. Continuing action to reduce emissions has resulted in
389 modest decreases in emissions in some regions and some sectors, but increasing emissions are seen in
390 most other regions. Increased economic activity, as reflected in activity data, seems to be a major factor
391 in driving up emissions associated with certain industrial sectors in a number of regions. In this respect,
392 differences between 2010 and 2015 may also reflect recovery following the financial crisis in 2008 that
393 may have influenced global emissions in 2010. These factors appear to have more than offset any
394 (technological) efforts to reduce mercury emissions.

Mercury emissions to air have decreased between 2010 and 2015 in two of the eleven world regions: North America and the EU. In the case of North America in particular, shifts in fuel use (from coal to oil/gas) in the energy sector, combined with introduction of control measures that have high efficiency to reduce mercury emissions at major point sources appears to be a major factor. In all other regions, however, mercury emissions increased.

Higher emissions in 2015 than in 2010 were estimated for some large source sectors: cement production, coal combustion in power plants, non-ferrous metal production, primary iron and steel production, and waste associated with mercury-added products. The chlor-alkali industry is the only sector for which emissions are estimated to have decreased significantly between 2010 and 2015. The 6-tonne reduction in chlor-alkali emissions, however, is negligible compared with the 200-tonne increase from other sectors, not counting artisanal and small-scale gold mining. In that latter sector, estimated emissions for 2015 are 158 tonnes higher than in 2010, largely due to improved information about the use of mercury in that sector, especially in South America.

Row Labe	ASGM	BIO	CEM	CREM	CSP	NFMP	NFMP-AU	NFMP-HG	OR	PISP	SC-DR-coal	SC-DR-gas	SC-DR-oil	C-IND-coa	SC-IND-gas	SC-IND-oil	SC-PP-coal	SC-PP-gas	SC-PP-oil	SSC	VCM	WASOTH	WI	Grand Tota
Australia, New Zeal		1.6	7.4	-16.5		-1.9	1.3		-13.8	-10.4	-25.2	13.1	16.3	4.2	7.3	-38.8	-10.9	11.0	13.8	-11.2	#DIV/0!	46.2	46.2	0.2
Central A	18.4	11.0	9.3	-70.2	0.0	-22.1	100.1	1900.0	1.0	8.7		6.3	-1.0	438.6	8.5	-47.0	-19.1	6.2	-4.6	12.9	#DIV/0!	20.0	20.0	18.6
CIS & othe	5.6	14.1	27.8	40.9	-3.9	6.1	33.7	-57.3	5.8	2.4	-22.8	-7.6	-6.7	-28.7	-1.4	-26.1	-3.0	-4.8	-15.2	18.8	#DIV/0!	42.6	42.6	10.2
East and S	-12.4	-5.5	32.2	-33.2	0.0	158.0	-28.5	3.1	9.7	17.4	9.2	44.3	5.2	-5.5	33.6	-80.0	22.1	23.6	-18.5	-10.3	#DIV/0!	11.2	11.2	23.4
EU28		6.2	-14.0	-37.6	-66.2	-15.6	76.8		-3.3	2.7	-20.5	-17.9	-6.7	-8.6	-4.6	-36.8	-2.9	-31.0	-46.2	-7.2	#DIV/0!	-33.0	-33.0	-12.5
Middle Eastern Stat	-33.3	13.9	-20.5	0.0	2.9	47.8			14.2	19.3	-27.9	26.6	40.6	-19.5	16.4	1.3	4.9	26.8	1.6	36.9	#DIV/0!	51.4	51.4	14.5
North Africa		-2.7	4.8	-19.0	0.0	-53.4	316.2	-50.0	-14.2	-29.4		56.9	-0.6	-15.2	-13.9	-31.5	59.8	19.2	22.5	-4.1	#DIV/0!	66.7	66.7	15.8
North America		-1.4	23.0	-5.2	-83.3	-8.6	9.9		6.2	2.5	-51.5	1.6	-4.8	-19.0	7.8	-57.5	-23.0	27.0	-15.0	9.7	#DIV/0!	-44.7	-44.7	-21.8
South Am	91.6	6.1	19.8	-69.5	5.1	-5.0	7.9	0.0	-2.0	-8.4	69.1	10.7	5.0	11.8	-11.2	-40.8	66.5	27.5	21.4	0.8	#DIV/0!	1.5	1.5	67.6
South Asi	300.0	9.5	24.3	46.1	-74.0	12.7	-30.9		18.3	38.5	-8.8	15.9	5.0	25.4	-30.6	-13.9	38.0	-23.3	3.9	27.0	#DIV/0!	47.6	47.6	28.0
Sub-Sahar	8.6	10.1	62.0	-9.3	0.0	-32.4	11.0		-11.6	-13.6	58.5	400.0	26.5	6.9	129.0	0.0	-13.9	40.2	12.3	-12.3	#DIV/0!	164.3	164.3	9.1
Grand Tot	23.4	4.8	24.9	-23.3	-28.0	51.7	15.6	13.0	9.4	11.5	2.5	1.8	2.9	2.6	6.9	-54.1	9.0	9.4	-5.3	4.7	#DIV/0!	27.8	-2.9	22.8

Figure 3.4. Matrix, of % changes from 2010 to 2015 by region and sector.

4. Levels of Mercury in Air

There are several major global and regional mercury monitoring networks around the world. Although there are monitoring sites in both the northern and southern hemispheres, there are still large regions that lack any sites and hence any data, such as Africa, Latin America and the Caribbean, and Russia. Nonetheless, much can be said about mercury levels in the world's atmosphere.

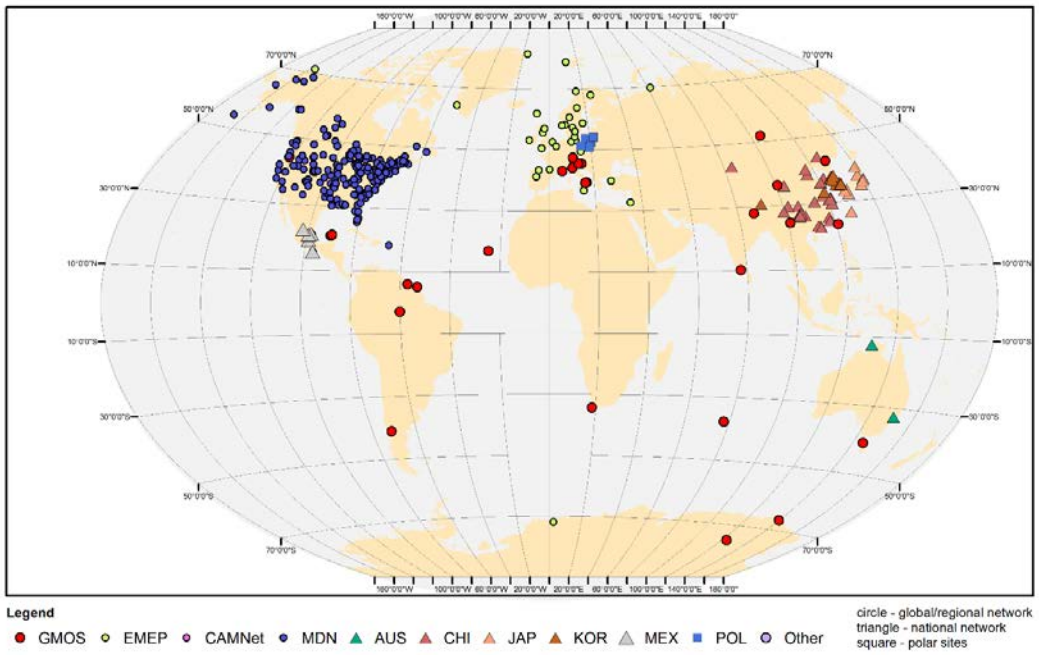


Figure 4.1. - Global map of monitoring networks

Spatial variability in the Southern and Northern Hemispheres

There is a clear gradient of mercury concentrations between the Northern and Southern hemispheres, confirming that the gradient observed is mostly driven by local and regional sources, which can be anthropogenic, natural, or a combination of both. Seasonal variations of gaseous elemental mercury concentrations have also been observed at all European sites in the Northern Hemisphere, with most of them showing higher concentrations during the winter and spring and lower concentrations in summer and autumn seasons. Measurements of gaseous elemental mercury show a downward trend over time

from the 13 northern sites, which continued to have significantly higher median concentrations than those recorded at the southern sites. Long term monitoring data exist from some of these sites. A downward temporal trend was observed at Mace Head, Ireland, from 1996 to 2015, while data from Cape Point, South Africa, show a slight increase from 2007 to 2014.

Seasonal trend analysis of total mercury in precipitation showed increasing concentrations and deposition during the spring and summer months. The dominant factor in determining the mercury wet deposition loading recorded at all the European sites was then generally related to the amounts of the collected precipitation. Mercury deposition measurements are scarce in tropical latitudes, though high wet mercury deposition measured at Sisal Station, Mexico, suggests that other tropical areas may be hotspots for mercury deposition as well. In remote areas particularly in the Southern Hemisphere, far from any local sources, atmospheric deposition has been recognized as the main source of mercury to the ocean.

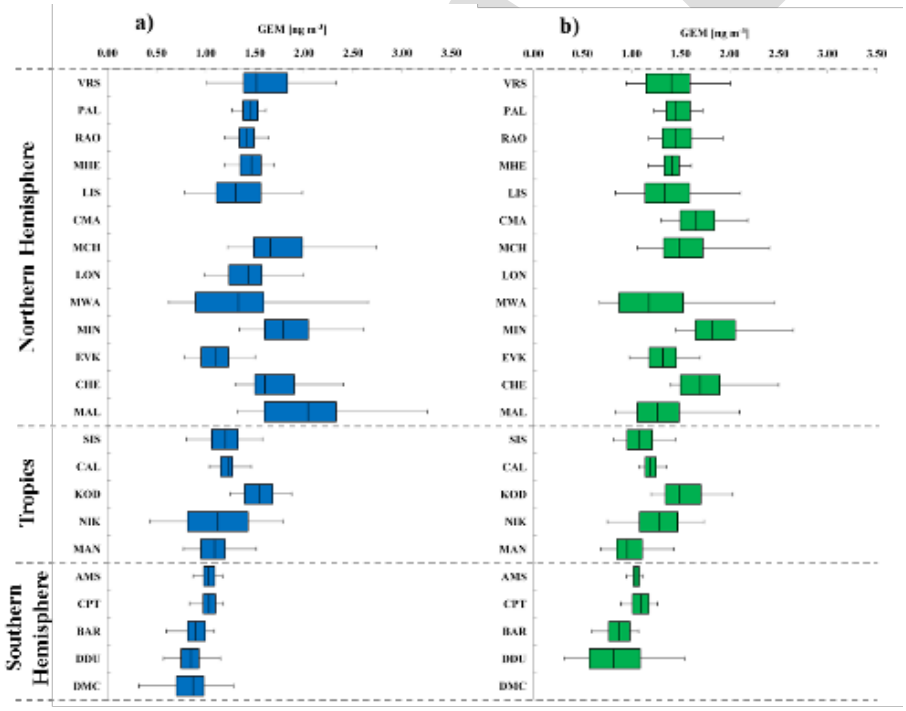


Figure 4.2: Box-and-whisker plots of gaseous elemental mercury yearly distribution at the GMOS stations for (a) 2013 and(b) 2014. The sites are organized according to their latitude from the northern to the southern locations. Each box includes median(midline), 25th and 75th percentiles (box edges), 5th and 95th percentiles (whiskers) (Sprovieri et al., 2016).

Regional variability in atmospheric mercury

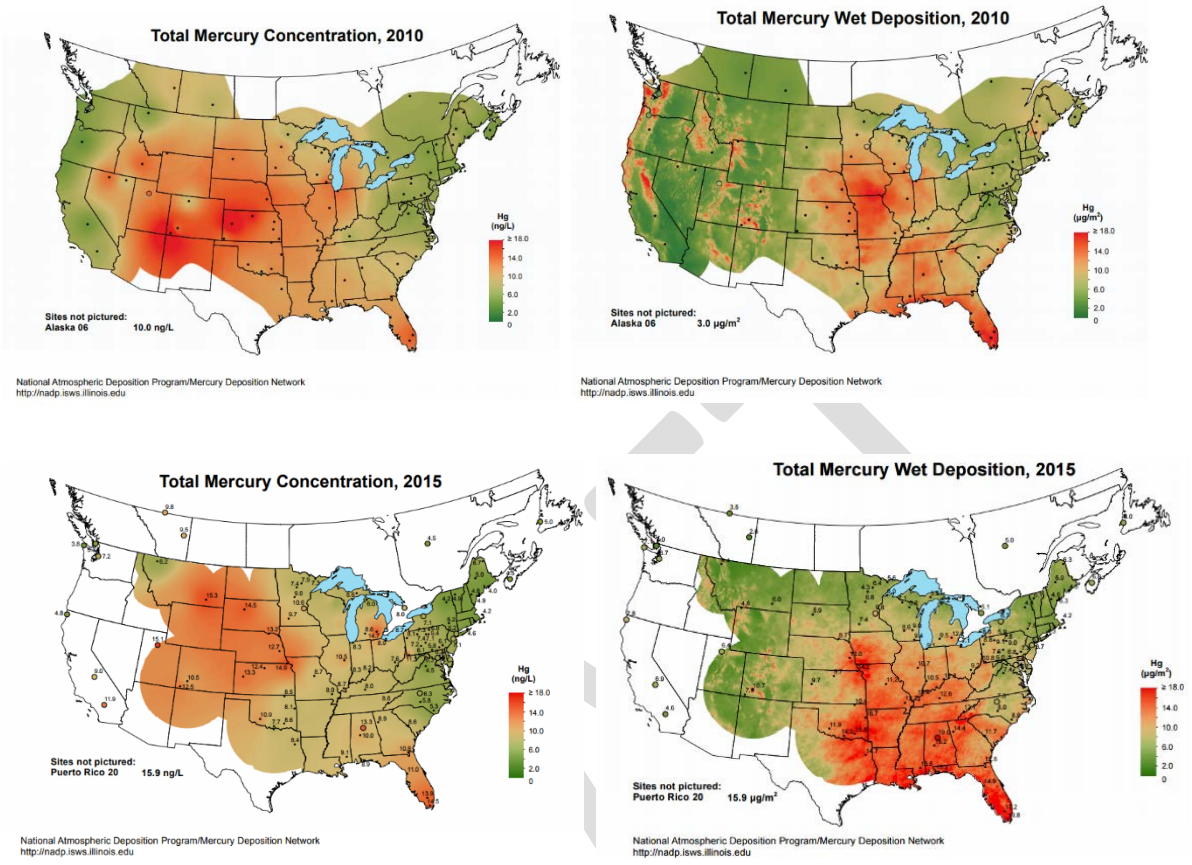


Figure4.3: Total mercury wet concentration and deposition as measured across North America for 2010 (above) and for 2015 (below). All years available at http://nadp.isws.illinois.edu.

Although mercury is transported around the world in the atmosphere, there are distinct regional patterns in mercury concentrations and deposition. A few studies shed light on the extent of such variation, which has implications for how much mercury will be available to ecosystems and humans.

In North America, significant wet deposition of mercury is found along the U.S. Gulf Coast, and somewhat inland. Wet mercury deposition in these areas strongly correlates with higher precipitation. Highest concentrations are found in the western areas where precipitation is lowest and dominated by winter snow. Data through the mid-2000s showed general decreases in eastern U.S. concentrations, with significant decreases at about half of these sites. Fewer significant trends were seen in the Southeast, but the general tendency was for decreasing concentrations. Two sites in the West (Colorado, Washington) showed the same decreases. No significant concentration increases were noted,

with little change in the Upper Midwest concentration or deposition. Regional trend analyses revealed significant positive trends in mercury concentration in the Rocky Mountains, Plains, and Upper Midwest regions for the more recent time periods.

Trends of atmospheric mercury over time have been investigated for many Canadian measurement sites. Linear trends were estimated for all available data from each site rather than limiting the analysis to only overlapping time periods. In all cases, the data show a decrease in mercury concentrations, though the latest trend data are from 2010.

Atmospheric mercury concentrations recorded at remote Chinese sites are elevated compared with those observed in remote areas in Europe and North America and at other sites in the Northern Hemisphere. In Chinese urban areas, the highly elevated concentrations were mainly derived from local anthropogenic mercury emissions, whereas regional anthropogenic emissions and long-range transport from domestic source regions are the primary causes of the elevated mercury concentrations at remote sites. Wet deposition fluxes of mercury at urban sites in China were higher compared with those in North America and Europe, but wet deposition fluxes of mercury at remote sites were in the lower range of those observed in North America and Europe. In the Republic of Korea, local coal combustion was a main cause of enhancing mercury concentrations in urban, whereas rural areas were also affected by secondary formation of different mercury species.

Atmospheric mercury levels in central Europe are elevated, as expected due to influence from anthropogenic sources like coal combustion. Coastal Arctic sites in Norway have slightly higher levels than those observed at Greenland and more inland in Finland and Sweden, which might be due to summertime evasion from the ocean or due to the fact that Svalbard receives several direct transport episodes from the continent, especially in winter and spring. Inter-annual variability is large among European sites, but a significant reduction has occurred since the early 1990s, due to declines in primary anthropogenic source releases.

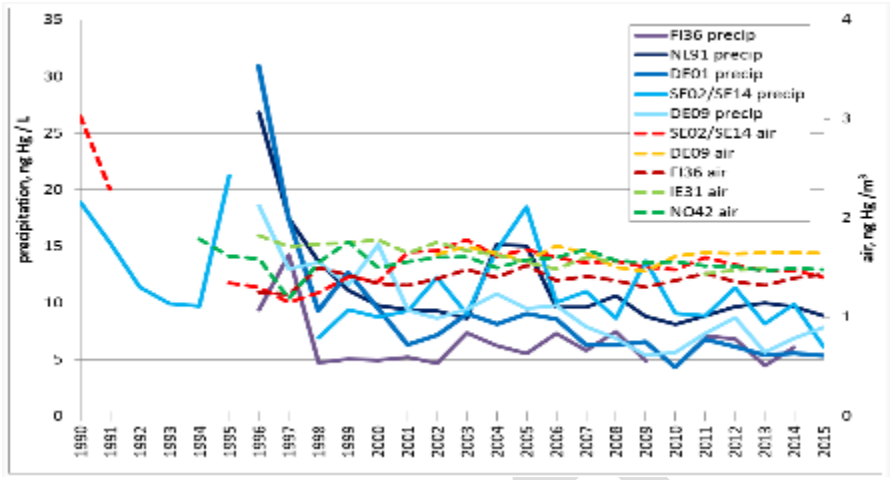


Figure 4.4: Time series of mercury in air and precipitation at selected EMEP stations, 1990-2015. Located far from anthropogenic emissions, Polar Regions can be seen as open-air laboratories to improve our understanding of these atmospheric processes. Ten-year trends in atmospheric mercury at Arctic sites show a slight decrease at Alert in Arctic Canada but no trend at Zeppelin on Svalbard. The influence of different air masses is the likely explanation for the difference.

Vertical profiles of mercury in the atmosphere and the distribution mercury plumes

Contrary to previously measured vertical profiles, inside the boundary layer the gaseous elemental mercury background concentration was found to be 10 to 30% higher than in free tropospheric air. Inside each layer, gaseous elemental mercury is evenly distributed.

On several research flights in the U.S., large mercury point sources were sampled, mainly coal-fired power plants in the Southeast U.S. For some of the largest mercury emitters in the U.S., the observations suggest substantially higher mercury emissions than are estimated in emission inventories. Flights over the highly industrialized area of Chicago-Gary suggest that there may be many smaller emission sources not accounted for in existing emission inventories, or that the re-emission of mercury is underestimated in that region.

Large-scale pollution plumes in the upper troposphere, as measured from commercial aircraft, show how mercury is carried from sources to distant regions. Plumes thousands of kilometres in size have been measured over Africa, South America, and Asia. The sources of the Asian plumes were largely industrial and urban, whereas those from Africa and South America were primarily from biomass burning. Forest fires in Siberia and in the Southeast U.S. have also produced large mercury plumes.

5. Atmospheric Pathways, Transport, and Fate of Mercury

Mercury has a long environmental lifetime and cycles between the atmosphere, ocean, and land. Mercury released to the atmosphere can travel globally: it undergoes atmospheric reactions, deposits to the Earth's surface, and can continue to cycle between surface and atmosphere for decades to centuries and longer. Using a combination of models and measurement, work since GMA 2013 has addressed aspects of mercury's transport and fate, including emissions, atmospheric chemistry, removal processes, modelling, and historical trends. In addition, several other studies have provided additional insights into regional and local mercury cycling.

Emissions and different types of mercury

Accurate emission inventories are important, as is an understanding of how their uncertainty relates to the implementation of the Minamata Convention. The observed decrease in atmospheric mercury in the United States is consistent with significant regional decreases in emissions upwind of measurements sites shown in global as well as U.S. and Canadian national inventories. Additionally, the observed increase in mercury concentrations measured in the Southern Hemisphere at Cape Point over the last decade is consistent with the estimated increase in mercury emissions from artisanal and small-scale gold mining in the Southern Hemisphere over the same period. Some studies suggest that there has been a 20% decrease in global anthropogenic mercury emissions between 1990 and 2010. However, changes in the way emissions inventories have been produced and the quality and completeness of information on which they are based makes it difficult to reliably compare global estimates produced at different times.

Since GMA 2013, the discussion of emission speciation—the chemical and physical forms in which mercury is emitted—has also continued. While mercury emission and speciation from anthropogenic sources have been quantified and updated with a reasonable consistency, estimates of natural mercury emission from the Earth's surfaces, including re-emission from previously deposited mercury, remain very uncertain. The range of error is comparable to the total anthropogenic emission of mercury. This limits our understanding of global and regional mercury cycling budgets. The primary challenge in quantifying mercury release from natural surfaces is the lack of understanding of fundamental processes driving the releases from different surfaces.

Atmospheric chemistry

New information has solidified our knowledge about mercury oxidation reactions, including the importance of bromine chemistry in mercury oxidation. Models including these reactions have shorter mercury lifetimes in the atmosphere and can reproduce some free tropospheric observations. Recent model intercomparisons have shown that there remain challenges in reproducing observed concentrations and patterns in several areas.

The major obstacle to understanding the processes by which mercury reacts in the atmosphere and interacts with atmospheric particles is that the nature of oxidised mercury compounds in the atmosphere remains uncertain. Furthermore, bromine distribution in the atmosphere is not well documented, adding further uncertainty to any conclusions that may be drawn about its role in atmospheric mercury reactions. Uncertainties in measurement techniques challenge our ability to further advance model-measurement comparison of mercury species. Further coordination between measurement and modelling communities to address measurement biases will enhance our understanding of atmospheric mercury processes.

Removal processes

Mercury removal from the atmosphere occurs via wet and dry deposition. Wet deposition measurement-model comparisons, in particular in convective storms, have provided insight into the vertical distribution of mercury in the troposphere as well as oxidation processes. Dry deposition remains more poorly quantified than wet deposition, and there remains disagreement among models on its global magnitude. More sites measuring mercury in precipitation would help estimate ecosystem deposition fluxes and refine models.

The type of storm affects how much mercury will be deposited by precipitation and also where in the atmosphere the mercury will come from. Convective storms, ones that typically produce thunder and lightning, have deposition rates more than one and half times those of horizontal rainclouds. Convective storms can scavenge mercury from as high as 10 kilometers in the atmosphere. Thunderstorms in the

Northeast U.S. have less wet deposition than thunderstorms in the Southeast, due to differences in cloud dynamics between the two regions.

Mercury is taken up by leaves in growing plants. Deciduous trees are a mercury sink during the growing season, which may explain some atmospheric mercury depletion events in forest areas. When the leaves fall, they carry mercury down to the surface, creating another form of deposition to soils. Dry deposition of mercury has been found to be important in inland Arctic tundra, where it may account for 70% of the deposited mercury. This result, however, appears to contradict other studies showing that terrestrial surfaces are a net source of gaseous elemental mercury.

Results from mercury modelling

Recent model development has advanced our ability to simulate mercury transport in the atmosphere between different geographical regions and account for multi-media cycling of mercury, including the importance of legacy mercury. New modelling results based on the updated global mercury emissions inventory for 2015 provided up-to-date estimates of mercury dispersion on a global scale, source apportionment of mercury deposition to various terrestrial and aquatic regions, and the contributions of different emission sectors to mercury atmospheric loads.

Global natural sources are the main contributors for mercury deposition over all regions except East Asia. Deposition over East Asia is dominated by anthropogenic emissions with a relative contribution of domestic sources of 50%. Transpacific transport of East Asian emissions is the major foreign source of mercury deposition in North America. Europe, Southeast Asia, and the Indian subcontinent also make significant contributions to mercury deposition in some receptor regions.

The current state of mercury dispersion in the atmosphere and deposition to various terrestrial and aquatic regions was studied by an ensemble of chemical transport models using the new inventory of anthropogenic mercury emissions in 2015 prepared for this assessment. The global distribution of gaseous elemental mercury concentration in the surface air in 2015 simulated by the model ensemble shows a latitudinal gradient from the temperate latitudes of the Northern Hemisphere to the high latitudes of the Southern Hemisphere. These results are generally consistent with observations from monitoring sites and other studies.

Wet deposition is relatively equally distributed between the Northern and Southern Hemispheres and reflects the influence of multiple factors including anthropogenic emissions, oxidation chemistry, and precipitation patterns. Wet deposition is higher in areas inside and downwind of the industrial regions of Asia, North America, and Europe as well as over the high precipitation zones in the Tropics. The lowest wet deposition levels are in arid areas of Greenland, Northern Africa, and Antarctica. The simulations reproduce measured levels of wet deposition in North America, Europe, and Australia reasonably well.

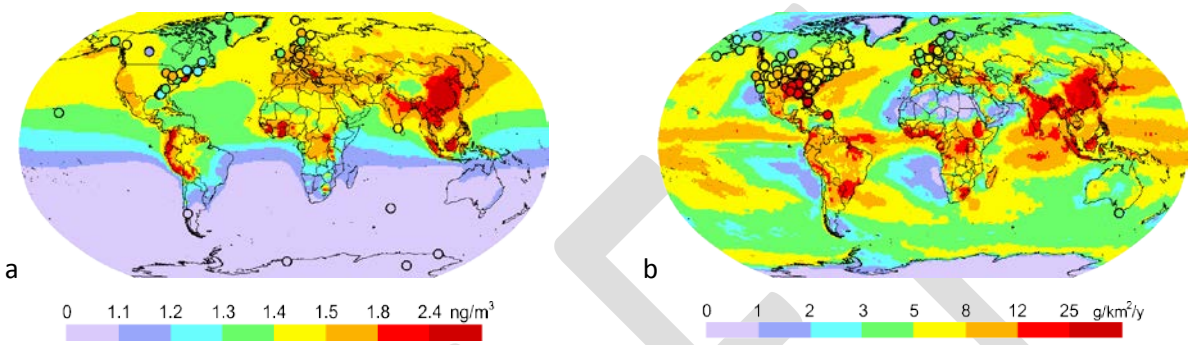


Figure 5.1: Global distribution of model ensemble median gaseous elemental mercury concentration in surface air (a) and wet deposition flux (b) in 2015. Circles show observed values in the same colour scale.

The regional pattern of deposition generally follows that of gaseous elemental mercury concentration, with the exception of relatively low wet and dry deposition in the Middle East and CIS countries and elevated deposition in Africa and South America. Over most of the regions average dry deposition is higher than wet deposition by 20-120%. In contrast to terrestrial regions, wet deposition to the ocean is higher than dry deposition.

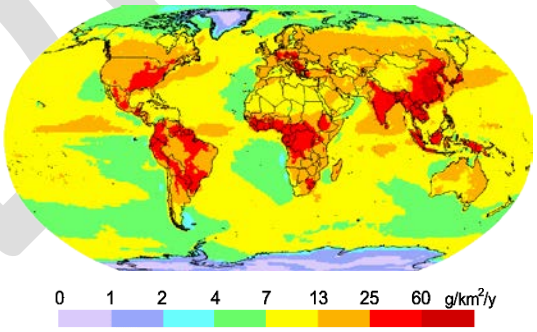
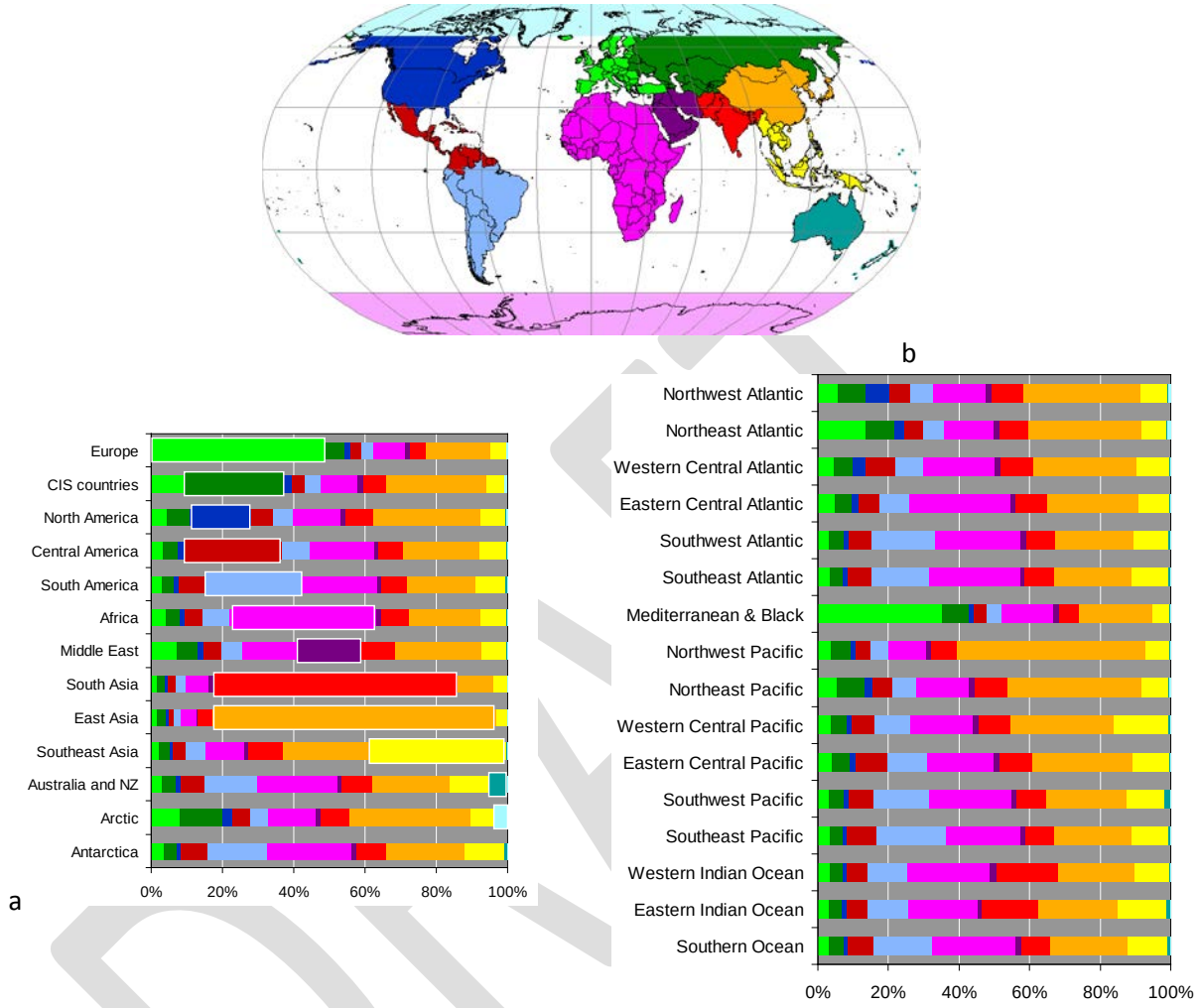


Figure 5.2: Global distribution of the model ensemble median total (wet and dry) Hg deposition in 2015

Deposition from direct anthropogenic emissions represents the mixture of domestic emissions and atmospherically transported mercury from sources located in other regions (foreign emissions). The share of foreign sources varies from 100% in Antarctic to 23% in East Asia. The largest foreign

618 contributors are characterized by large anthropogenic emissions as well as active artisanal and small-
619 scale gold mining.



620 ***Figure 5.3. Model ensemble median source apportionment of Hg deposition from direct anthropogenic emissions***
621 ***to various terrestrial (a) and aquatic regions (b) in 2015. The colors depict source regions, indicated in map***
622 ***above.***

623 The domestic shares in anthropogenic deposition show an increase since 2010in East Asia (from 76% to
624 77%) and South Asia (58% to 66%), which is explained by the increase in Asian anthropogenic emissions
625 since 2010. Domestic and foreign anthropogenic sources contribute almost equally to the total
626 anthropogenic mercury deposition in Europe. In North America, the share of domestic sources shows a
627 reduction from 23% to 15%, is consistent with the reduction in North American anthropogenic emissions
628 since year 2010. Remote regions including the Arctic and Antarctic are predominantly influenced by the
629 long-range transport of atmospheric mercury from East Asia and Africa.

East Asia and Africa remain the largest contributors to the global ocean reservoirs, owing to their large anthropogenic emissions. A number of these ocean reservoirs—particularly the Northwest Pacific-- also receive substantial anthropogenic mercury deposition and have a large total capture fisheries production.

To assess the relative roles of different emission sectors, all sources were aggregated into four general groups: (i) power generation, (ii) industrial sources, (iii) intentional use and product waste, and (iv) artisanal and small-scale gold mining. Mercury deposition from the power generation group is largely restricted to a number of industrial regions in East and South Asia, Europe, North America, and South Africa, where the majority of large stationary combustion sources are located. Emissions from the industrial sectors group are more widely distributed over the world. Therefore, significant deposition from industrial sources covers wide areas in Asia, Europe, North and South America, and Africa. The impact of the intentional use and product waste group of sectors is also mostly related to major industrial regions but its contribution is considerably lower. The majority of artisanal and small-scale gold mining emission sources are located in low latitudes of the both Hemispheres. Mercury emissions from this sector are transported globally, but the most significant deposition occurs closer to emission sources and thus largely impacts South America, equatorial Africa, and East and Southeast Asia.

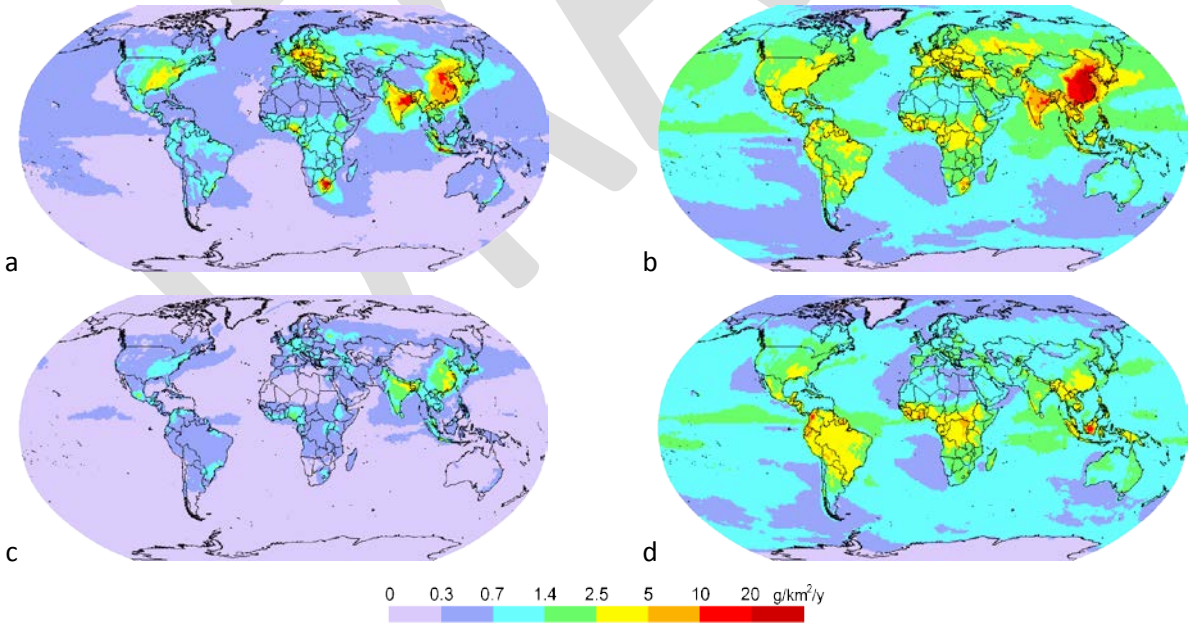
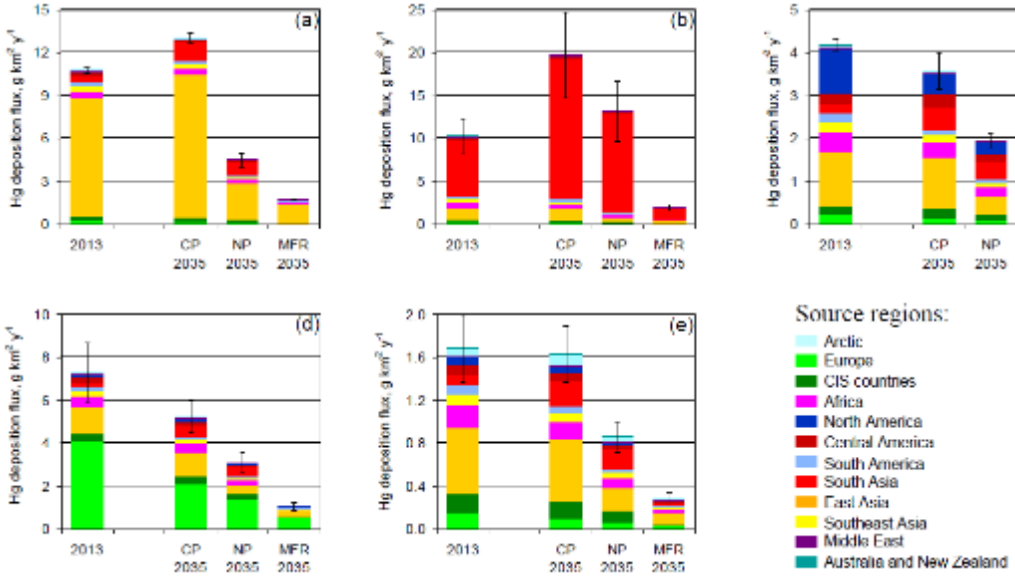


Figure 5.4. Global distribution Hg deposition (model ensemble median) from the four groups of emission sectors in 2015: (a) – Power generation; (b) – Industrial sources; (c) – Intentional use and product waste; *(d) – ASGM.*

Historical trends and future scenarios

Recently, declines have been observed in both atmospheric mercury and wet deposition in Europe and North America, on the order of 1-2% per year, that differ by region. Some modelling studies have reproduced these trends, attributing some regional variations to declines in emissions. Observed trends, however, are small compared with uncertainties in surface-atmosphere fluxes, anthropogenic sources, and attributable fraction. Future changes under policy scenarios could reduce mercury deposition in the future; however, the influence of climate change and legacy mercury complicates our ability to assess these potential future changes in models.

Recently, several modelling studies have investigated future changes of atmospheric mercury concentration and deposition due to changes in anthropogenic emissions, land use and land cover as well as climate change. The "Current Policy" scenario predicted a considerable decrease (20-30%) of mercury deposition in Europe and North America and strong (up to 50 %) increase in South and East Asia. According to the "New Policy" scenario, a moderate decrease in mercury deposition (20-30%) was predicted in all regions except for South Asia. Model predictions based on the "Maximum Feasible Reduction" scenario demonstrated consistent mercury deposition reduction on a global scale. It should be noted that the geogenic and legacy sources were assumed to be unchanged in this study.



667 ***Figure 5.5. Source apportionment of Hg deposition from direct anthropogenic sources (average of two models) in***
668 ***2013 and 2035 in various geographical regions: (a) East Asia, (b) South Asia, (c) North America, (d) Europe, (e),***
669 ***and the Arctic. Whiskers show deviation between the models. Contribution of natural and secondary emissions***
670 ***are not shown. Source: Pacyna et al. (2016).***

671 Even if anthropogenic emissions stay unchanged, mercury deposition will continue to increase due to
672 effect of the legacy of anthropogenic production emissions accumulated in the ocean. Generally, the
673 atmosphere responds quickly to the termination of future emissions, but long-term changes are
674 sensitive to a number of factors, including historical changes in anthropogenic emissions, air-sea
675 exchange, and mercury burial in deep ocean and coastal sediments.

676

677

678

6. Anthropogenic Releases of Mercury to Water

As with mercury emissions to air, releases of mercury to water come from a variety of sectors of human activity in addition to natural sources. Mercury that is not emitted to air in these processes may be released to water instead, either directly or through washing of waste materials or through weathering of waste deposits. Releases of mercury directly to water may be the largest contributor to freshwater mercury levels. Artisanal and small-scale gold mining is the largest single activity causing mercury releases worldwide. It is considered separately, as estimates for this sector concern combined releases to both water and land. These are believed to account for about 1221 tonnes of mercury releases worldwide. Other sources included in the 2015 estimate account for 593 tonnes of mercury releases, considerably higher than the 2010 estimate of 185 tonnes, mostly due to improvements in methods used to estimate releases and the inclusion of three more sectors in the latter estimate. Municipal wastewater, coal-fired power plants, and coal washing are all major contributors to global release totals. In addition, changes in methods for compiling the estimate prevent a direct comparison of the two figures.

Methods for estimating global anthropogenic mercury releases

GMA 2018 produced a new global inventory of primary anthropogenic mercury releases to aquatic systems. This new inventory has the target year of 2015, though such recent information is not available for all sectors and countries. As a result, the actual data used come from the 2000-2015 period.

Various methods are employed to estimate releases of mercury at the plant or facility, national, regional, and global level. In general, they fall under one of the three main groups:

Group 1 includes the chlor-alkali industry, oil refining, and large-scale gold and non-ferrous metal production. The UN Environment's Toolkit provides a means of estimating mercury releases to water and land as a proportion of mercury emissions to air. We use these factors together with the most recent mercury emission inventory (Chapter 3) to calculate the releases to water. Sectors included in this first group are those included also in 2010 inventory.

Group 2 is made up of sectors for which estimates were derived based on measured mercury concentrations and associated volumes of wastewater released and other relevant activity data. The

sectors included are municipal wastewater, wastewater from coal-fired power plants, and coal washing. All are new addition to the global release inventory and were not addressed in the 2010 inventory.

Group 3 covers releases from wastes associated with the use of mercury-added products: batteries, measuring devices, lamps, electrical and electronic devices, dental applications, and other uses. Releases are estimated from regional patterns of consumption of mercury and mercury-containing products, considering also the specific pathways by which different products will release mercury to water. This is a new methodological approach from that used in the 2010 inventory.

Initially, estimates of mercury releases for all sectors were made on the country level, as the majority of input data are country specific. Based on the country-level information, mercury release estimates were then summarised according to the same sub-continental regions used in the air emission inventory.

The selection of the sectors and activities to be included in the aquatic inventory was driven by previously established knowledge and assumptions about their relative importance. The categorization of different sectors was, to the extent possible, kept comparable with that used for the air emission sectors. The release estimates in the new inventory include the following release sectors:

- Production of non-ferrous metals (primary production of aluminium, copper, lead and zinc)
- Production of mercury metal
- Production of gold from large-scale mining
- Mercury releases from oil refining
- Production of gold from artisanal and small-scale gold mining
- Mercury releases from chlor-alkali industry (mercury cell technology)
- Mercury releases from mercury-added products (batteries, measuring devices, lamps, electrical and electronic devices, dental applications, and other uses) use and waste disposal
- Mercury releases with municipal waste-water
- Mercury releases from coal-fired power plants
- Mercury releases from coal washing

The first seven items on the list are those included previously in the 2010 inventory. Other items from the list are new addition to the 2015 inventory and comprise categories for which relative contribution of mercury releases to aquatic systems is considered to be significant.

Additional sectors and anthropogenic activities, not taken into account in this inventory, might be responsible for the release of additional mercury to local aquatic systems. Considering the relatively low expected importance of these sectors, and the lack of data to support a global estimate, these sectors were not included in the 2015 inventory. Other possible sources of mercury releases to aquatic systems also not assessed here are vinyl-chloride monomer production, aluminium fluoride production, cellulose-production, and titanium dioxide production. In addition, even among the sectors included in the inventory, some processes leading to mercury release may not have been considered, again due to lack of information.

Given the global scope of this assessment, there are several limitations of this work. The estimates presented here are just that–estimates. The use of alternative approaches and assumptions might result in significantly different values. An additional limitation is the possible double counting on one hand and the potential for underestimation of releases on the other. The current inventory of global anthropogenic mercury releases to aquatic systems is nonetheless an important step towards filling a major gap in inventories of anthropogenic mercury releases to the environment.

Global anthropogenic mercury releases in 2015

The total estimated inventory of anthropogenic mercury releases from sources for which there was enough information to provide quantitative estimates is about 593 tonnes, not including artisanal and small-scale gold mining (see Box).

BOX: Artisanal and small-scale gold mining

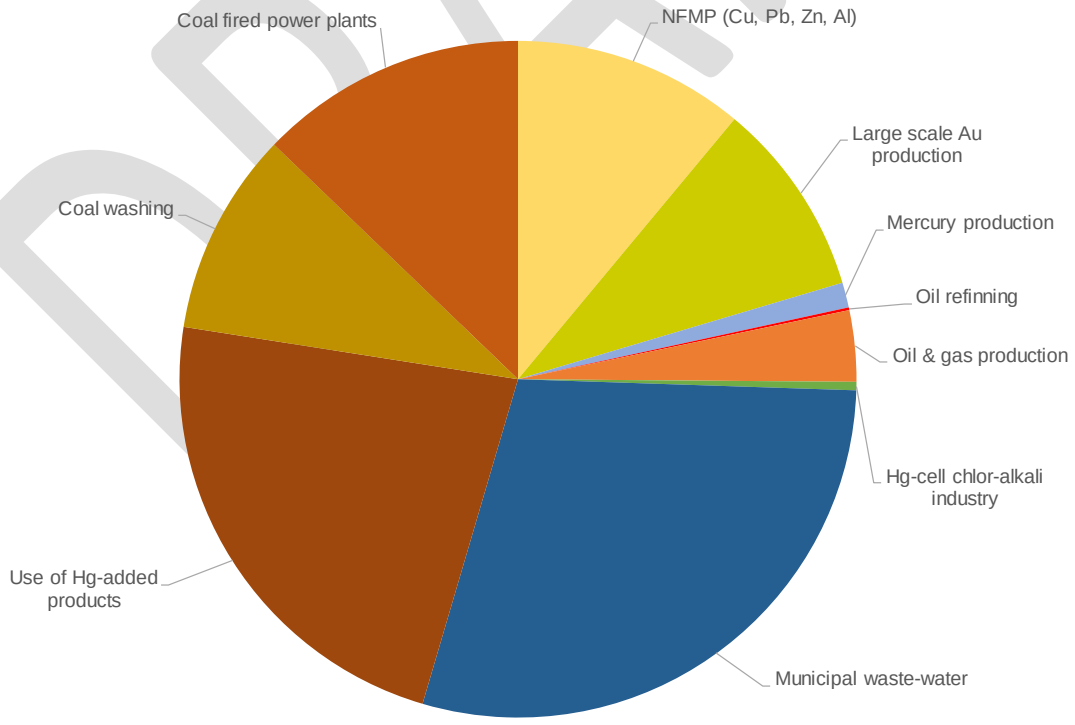
Releases associated with artisanal and small-scale gold mining remain a “special” sector in the inventory, due to large uncertainties in how mercury is released and whether those releases are to land or water. In addition to the direct losses occurring during ore amalgamation, large quantities of mercury are accumulating in soils and sediments surrounding artisanal and small-scale gold mining sites over time. This accumulated mercury has potential to be remobilised and enter aquatic systems. It is estimated that mercury releases from this sector to water and land in 2015 were about 1221 tonnes, or more than twice the combined releases from other sectors included in the inventory. The vast majority of these releases occur in South America (55%) and East and Southeast Asia (30%), followed by Sub-Saharan

763 Africa (7%) and Central America and the Caribbean (5%). Other regions where artisanal and small-scale
764 gold mining is done contribute a minor share of the total.

765

766 Apart from releases to water and land resulting from artisanal and small-scale gold mining, the majority
767 of the global anthropogenic releases of mercury to aquatic systems are associated with the waste
768 treatment (43%), the ore mining and processing (40%), and the energy sector (17%). Overall, the new
769 inventory is dominated by releases from non-ferrous metal production and two waste treatment
770 sectors, resulting from the use and disposal of mercury added products, and disposal of municipal
771 wastewater.

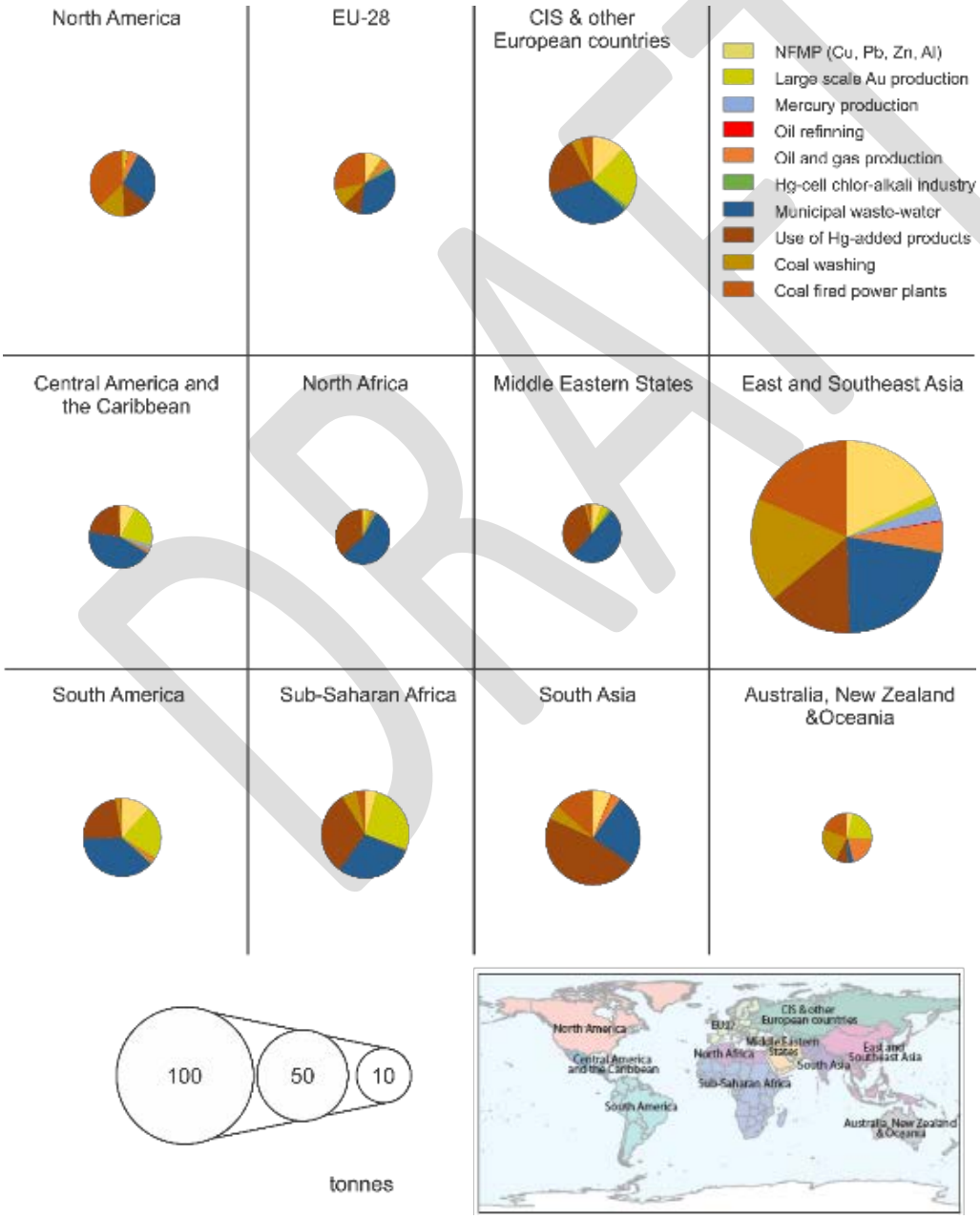
772 The three newly added sectors (municipal wastewater, coal-fired power plants, and coal washing)
773 account for most of the increase from the 2010 estimate of 185 tonnes and the 2015 estimate of 593
774 tonnes of anthropogenic mercury releases. In addition, there were some methodological changes
775 preventing a direct comparison between the two inventories.



776

777 ***Figure 6.1. Proportions of global anthropogenic mercury releases to water in 2015 inventory from different***
778 ***sectors***

779
780
781 East and Southeast Asia contribute the most to the global mercury release inventory. This is driven by
782 large population and associated large industrial and other activities. As this region is a dominant source
783 of mercury releases from all sectors, the distribution of releases among sectors reflects the global
784 pattern. Elsewhere, the relative contributions of mercury releases from different sectors varies widely,
785 reflecting differences in technological and socio-economic status.



786

Figure 6.2. Regional pattern of global anthropogenic mercury releases to water in 2015 inventory from different sectors, not including artisanal and small-scale gold mining.

Releases from selected sectors

Mercury releases from *copper, lead, zinc, aluminium, mercury, and large-scale gold production* were estimated to be 88.5 tonnes in the 2010 inventory and 242 tonnes in the 2015 inventory. About half comes from large-scale gold production.

The 2015 inventory suggests that *municipal sewage* contributes more than a quarter of the global mercury release total. The phase-out under the Minamata Convention of many products that contain mercury is expected to decrease mercury releases in municipal sewage. Anticipated improvements in wastewater treatment around the world is also expected to decrease mercury releases.

The 2015 inventory considers mercury releases in wastewater from *coal-fired power plants* and those resulting from *coal washing*. Together both releases are estimated to contribute nearly a quarter of the global inventory. In addition, tens of tonnes of mercury per year accumulate in slurry ponds at coal washing sites globally, creating a hazard for local aquatic systems.

Mercury releases from *oil refining* were very similar in the 2010 and 2015 inventories, largely because the same methods were used and production levels remained about the same.

With new methods and new data, the 2015 inventory shows that *mercury-added products* are a major source of mercury releases, second only to municipal wastewater globally. The use of mercury in products, such as batteries, lamps, dental applications, and others, is in decline and so are resulting mercury releases, especially in developed countries.

7. Trends in Atmospheric Mercury and Mercury in Aquatic Biota

Mercury emitted to the atmosphere is almost entirely in an inorganic form. When it is deposited to land or water, it is still in an inorganic form. Mercury released directly to water is also almost entirely inorganic. Once in the water, however, inorganic mercury can be transformed into methylmercury. This organic form of mercury is far more toxic than the inorganic forms and can also bioaccumulate and biomagnify as it moves through the food web. Because methylation of mercury occurs primarily in water, aquatic animals are generally more exposed to, and have higher tissue concentrations of, mercury than land animals. The consumption of fish and marine mammals is thus the most common pathway of human exposure to mercury.

Recent advances in understanding mercury methylation and demethylation

Mercury is methylated by bacterial processes in sediments and the water column of large water bodies, such as the ocean and large lakes. The concentration of methylmercury in any given aquatic environment is the net result of many competing processes of formation, transport, and destruction. Methylmercury can exceed 20% of total mercury in the open ocean, a much higher proportion than in most other places. In biota, the fraction or methylmercury increases as it moves up the food web, reaching as high as 90% in certain tissues of top predators.

Reducing total mercury emissions to the environment can be expected to ultimately reduce methylmercury in biota. The time that this will take in a specific ecosystem, however, depends greatly on the details of local conditions and processes. It is not possible, therefore, to make general predictions about the effects that actions to reduce mercury emissions and releases will have over time, as the answers will vary greatly.

In the last few years, a number of studies have challenged the idea that methylation occurs primarily in sediments and that methylmercury levels in coastal water columns are largely determined by the levels in underlying sediments. Results from coastal marine ecosystems show a range of results, from high sediment influence to minimal correlation between sediment levels and water column levels of methylmercury. Furthermore, demethylation appears to play a larger role in methylmercury levels than was previously realized. Understanding of the role of nutrients in methylation is similarly evolving, as is the role of oxygen levels in water and sediments. Together, these and similar findings about other

influences on methylation and demethylation show how variable the processes and outcomes can be in different areas, in different seasons, and over time.

In both coastal seas and open oceans, there is increasing evidence for active mercury methylation in the oxygenated water column of open oceans. This most likely occurs inside decaying organic particles, where oxygen-free conditions provide ideal conditions for methylation. The profile of methylmercury concentrations in the open ocean water column depends on both physical and biological factors. In addition, mercury methylation may also occur within sea ice.

The response of mercury levels in aquatic biota to changes in atmospheric mercury concentrations

In addition to methylation and demethylation processes, many other processes and factors affect the uptake of mercury by aquatic biota. The complexity of these processes, along with the large inventories of legacy anthropogenic and natural mercury stored in the terrestrial and aquatic systems, dictate that the biotic mercury trends may or may not follow the same trends as in atmospheric mercury. Even if they do follow similar trends, there could be a significant time lag between them. Four case studies illustrate the variation that can be expected, from North America, Europe, China, and the Arctic. These are the locations where parallel long-term data are available for mercury in biota and the atmosphere.

Atmospheric mercury concentrations in the four regions show different trends. In North America and Europe, mercury concentrations in the air declined by 10-40% between 1990 and 2010. This decline is also seen in wet deposition of mercury. Both trends are likely to be a result of declining mercury emissions in the two regions. Since 2010, however, mercury concentrations appear to have remained broadly constant, with increases in some areas and decreases in others. Anthropogenic mercury emissions in China increased rapidly from 1978 to as recently as 2007. Mercury emissions in China are reported to have plateaued around 2007 to 2010, and may be showing a declining trend in the past few years. In the Arctic, defined here as the region north of 60^{o}N latitude, atmospheric mercury concentrations have also been declining, but at a markedly slower rate than elsewhere.

<u>Mercury in fish and birds in lakes and coastal waters of North America</u>

A large number of studies have reported inconsistent, diverging, or mixed mercury trends in aquatic biota throughout North America. The early declines in mercury levels in biota are most likely due to the decrease in atmospheric mercury concentrations and deposition rates. The subsequent reversal or stasis may be due to increasing local emissions, food web changes, climate change, or other factors.

Mercury trends in fish from hundreds of small lakes in Ontario, Canada, varied by lake and by species of fish, demonstrating the complexity of ecosystem responses to changes in atmospheric mercury deposition. Results from coastal waters in eastern Canada showed relatively constant mercury levels in biota in recent years despite decreases in airborne mercury. It is possible that changes in feeding behavior play a role in the lack of biotic mercury response to declining atmospheric mercury.

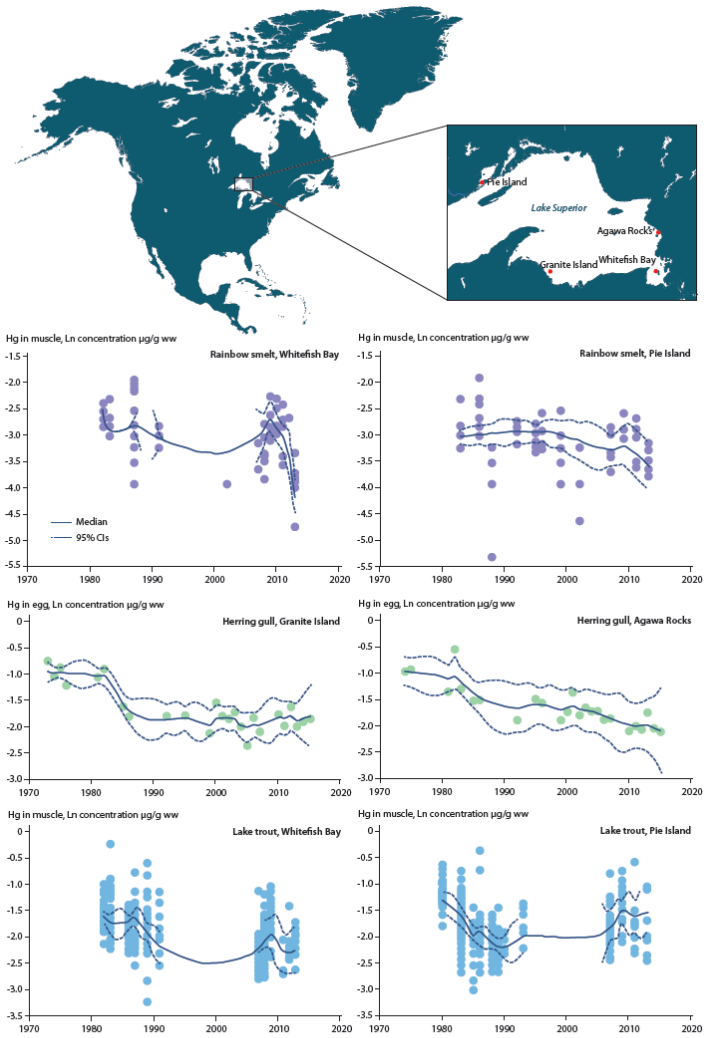
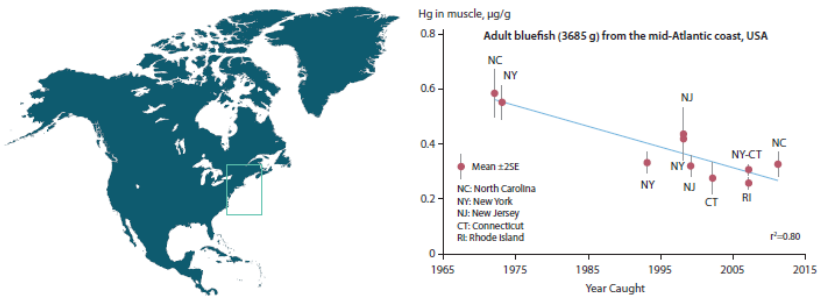


Figure 7.4. Mercury trends in fish and waterfowl of Lake Superior. The plots show Hg concentrations for rainbow smelt (planktivorous), lake trout (piscivorous) and herring gull (piscivorous). (Blukacz-Richards et al., 2017).



877

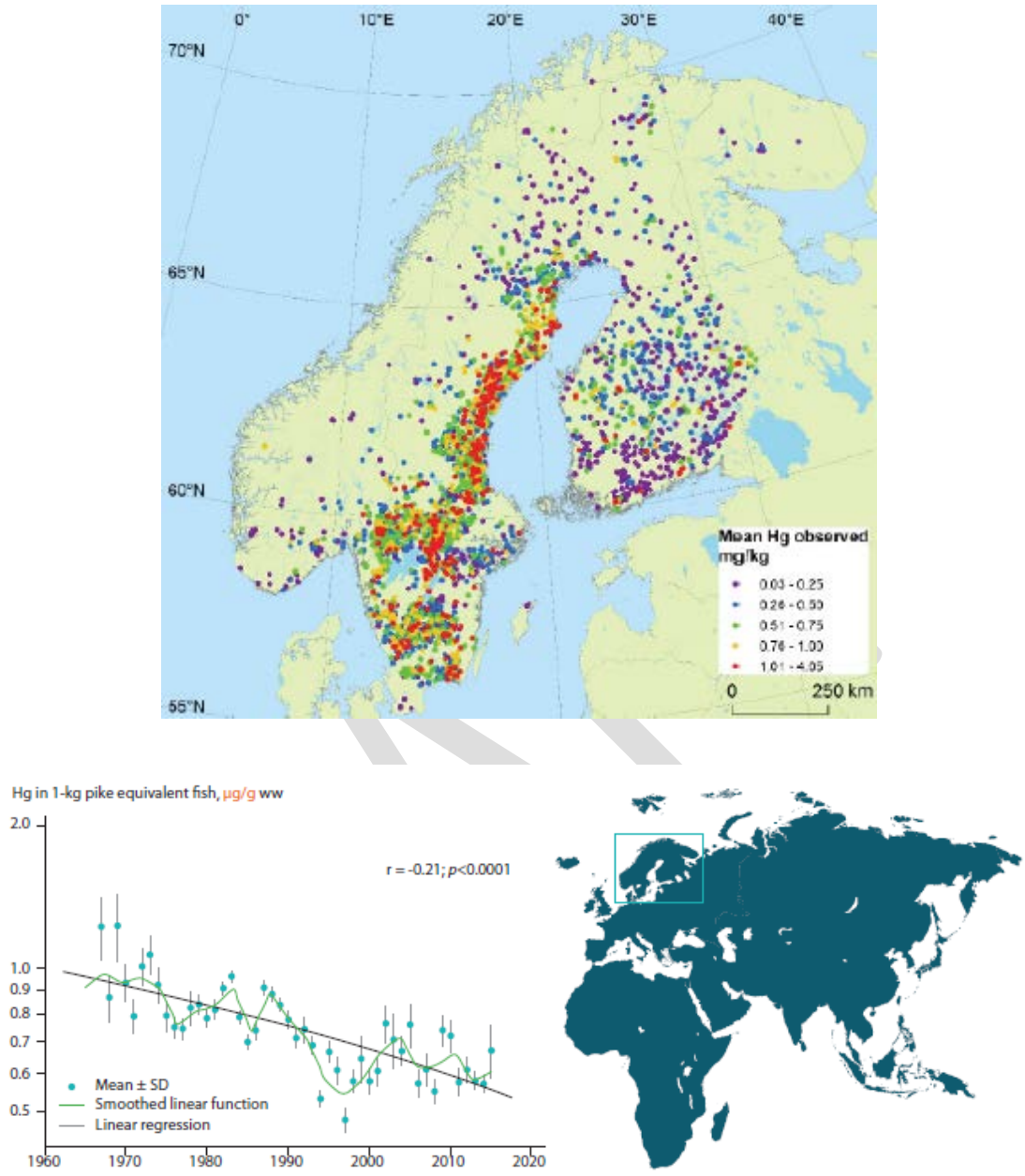
878 ***Figure 7.1. Upper graphic) Mercury trends in fish and waterfowl of Lake Superior. The plots show Hg***
879 ***concentrations for rainbow smelt (planktivorous), lake trout (piscivorous) and herring gull (piscivorous). Lower***
880 ***graphic) Mercury trends in the piscivorous bluefish (Pomatomus saltatrix) along the northeast coast of the USA***
881 ***from 1972 to 2011.***

882

883 Mercury in freshwater fish in Fennoscandia

884 Mercury levels in various species of freshwater fish across Sweden, Finland, Norway, and the Kola
885 Peninsula in Russia were affected in some cases by historical, local releases directly to water, and in
886 other cases by deposition of atmospheric mercury. As expected, lakes that were affected by local
887 pollution sources had higher mean observed mercury concentrations in fish than lakes that were
888 predominantly affected by atmospherically deposited mercury. The levels in fish showed a consistent
889 and significant decreasing trend, matching well with the general declining atmospheric mercury trend
890 over Northern Europe.

891



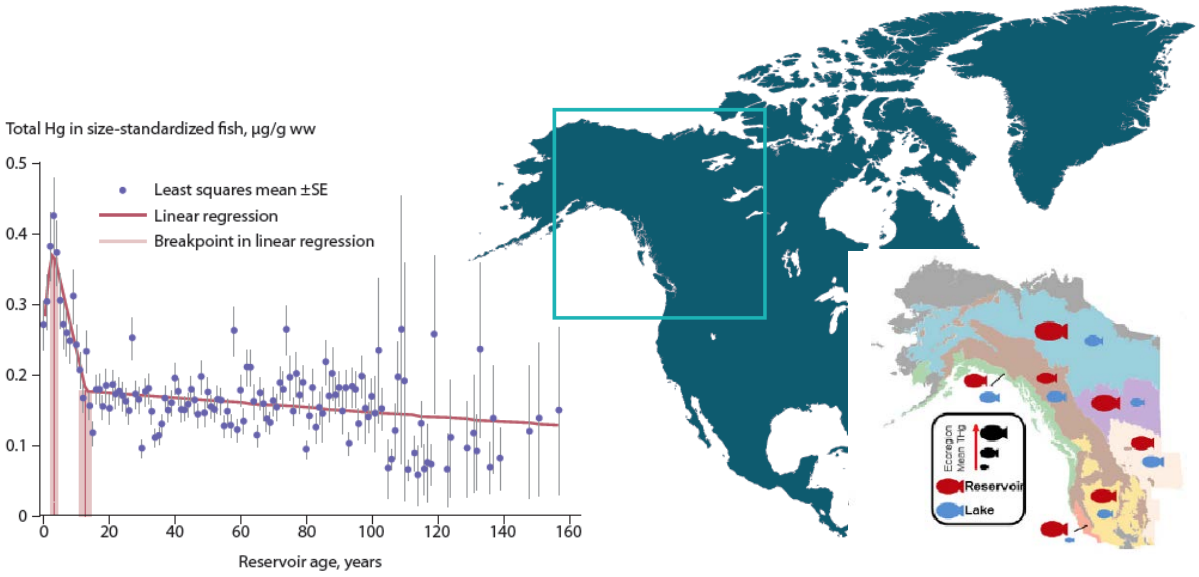
892

893 ***Figure 7.2. Mercury concentrations in five main freshwater fish species (Arctic char, brown trout, perch, pike and***
894 ***roach) over the past 50 years (1965-2015) across Fennoscandia. A) Map showing the locations of the 2,775 lakes***
895 ***and the median observed fish Hg concentration (without normalization) in each of the lakes. B) Temporal trends***
896 ***of the fish Hg after being normalized to "standard 1-kg pike Hg concentrations". Each circle represents mean Hg***
897 ***concentration per year. The solid line represents a smoothed linear function and the dotted line represent a***
898 ***linear regression (r = –0.21; p<0.0001). Error bars represent ±one standard deviation. Data from Braaten et al.***
899 ***(2017).***

900

901 Mercury in fish in reservoirs in North America and Europe versus China

902 Some of the longest time series of aquatic mercury data exist for man-made reservoirs due to concerns
903 about the effects they have on mercury methylation rates and thus on fish mercury levels. In North
904 America and Europe, new dams flood vegetation and organic matter in submerged soil, stimulating
905 microbial mercury methylation. Fish methylmercury concentrations peaked on average three years after
906 the dam was built, declined rapidly for about a decade, and then continued a slow decline for many
907 decades afterwards.



908

909 ***Figure 7.3. Fish tissue Hg trends from reservoirs across western North America. The data show least squares***
910 ***mean total mercury concentrations (µg/g ww±standard error) in size-standardized fish. Least squares mean***
911 ***account for the effects of ecoregion, waterbody, species, and sampling year. Vertical grey dashed lines and***
912 ***shaded regions indicate estimated breakpoints (±standard error) from segmented linear regression (solid line) on***
913 ***fish mercury concentration when accounting for the effects of ecoregion, waterbody, species, and sampling year.***
914 ***(From Willacker et al 2016).***

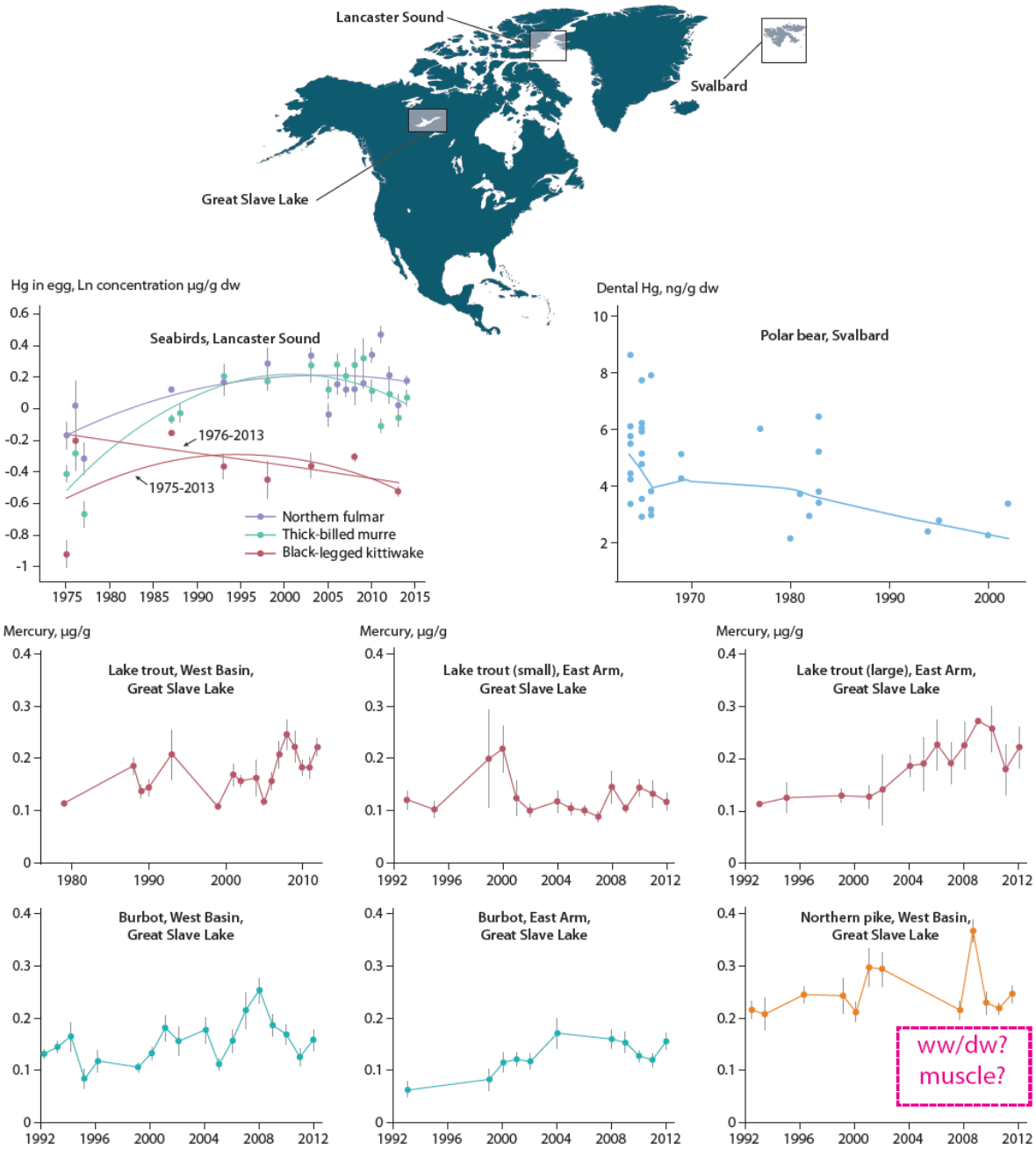
915

916 Reservoirs in China, however, present a different story. There, reservoirs support aquaculture for human
917 consumption. The fish mercury concentrations from these reservoirs are typically low due to biodilution,
918 as there are more fish in which to spread the available mercury. In the drainage of the Wujiang River, a

large tributary of the Changjiang (Yangtze River), a series of reservoirs were built between 1960 and 2008. In contrast to the rapid increase in fish mercury levels seen in North American and European reservoirs immediately after they were filled, fish mercury is found at low levels in all the Chinese reservoirs studied. Methylmercury production does increase as the reservoir ages and aquaculture activities increase.

Mercury in Arctic animals

In the Arctic, increasing trends in mercury have been found in marine species in Arctic North America and west Greenland. In east Greenland and European Arctic, methylmercury levels have generally decreased. Different trends in emissions in Asia, North America, and Europe could play a role, as could changing bioavailability of mercury or ecosystem functioning due to climate change. Mercury levels in polar bears in Svalbard have decreased, due to lower environmental levels of mercury. In the southern Beaufort Sea, by North America, however, declining mercury levels in male polar bears are most likely as a result of changing foraging patterns rather than changes in atmospheric mercury deposition. Eggs from thick-billed murres also show different patterns in different parts of the Canadian Arctic, indicating changes in feeding patterns in some cases and changes in environmental conditions or climate change in others.



937

938

939 ***Figure 7.4. Mercury trends in Arctic aquatic biota. Top right) Year vs. dental Hg concentrations (ng/g dw) in polar***
940 ***bears from Svalbard, aged from 3 to 10 years. Smoothing lines (robust, locally weighted scatter plot smoothing***
941 ***system based on the LOWESS algorithm) represent the fitted non-linear trend of the values. From Aubail et al.***
942 ***(2012). Top left) Annual mean Hg concentrations (ug/g dry weight; ln-transformed) adjusted for trophic position***
943 ***in eggs of thick-billed murres, northern fulmars, and black-legged kittiwakes from 1975 to 2014. from Braune et***

al. (2016). Lower panel) Hg concentrations in burbot and lake trout collected from the West basin and east Arm of Great Slave Lake. from Evans et al. (2013).

Causes of the mismatch between atmospheric and aquatic mercury trends

In contrast to the recent decadal datasets described above, the available century-scale methylmercury trends generally matched remote glacial ice core archives of atmospheric mercury concentrations and deposition. Starting in the mid- to late-19th century, mercury concentrations in the atmosphere and in aquatic biota increased steadily up to about the 1970s-80s. As atmospheric and biological monitoring has become more widespread and frequent over the last two to three decades, a mismatch between the aquatic biotic and atmospheric mercury trends has become apparent. This mismatch may be due primarily to large inventories of mercury in soil and the ocean that are subject to different geochemical, climate, and ecosystem processes. Whereas the levels of methylmercury used to be determined by the availability of mercury, now there is sufficient mercury in the environment that methylmercury may instead limited by the rate of methylation. Methylation rates in turn are affected by a wide range of conditions and factors, creating highly variable outcomes from place to place.

In soil and terrestrial environments, there is relatively little mercury methylation. Soils nonetheless release inorganic mercury into aquatic systems and emit it into the air. Soils also affect aquatic organic carbon levels that influence methylation rates in oceans, lakes, and reservoirs. Atmospheric mercury trends may thus have little influence on biotic mercury trends in many aquatic ecosystems, as noted in the case studies above. Once methylmercury is present in aquatic ecosystems, its uptake by biota is affected by changes in ecosystem structure and dynamics. Thus, atmospheric mercury levels are only one factor in determining methylmercury levels in aquatic animals. Aquaculture, overfishing, and invasive species are among the changes that can have large effects on methylmercury levels.

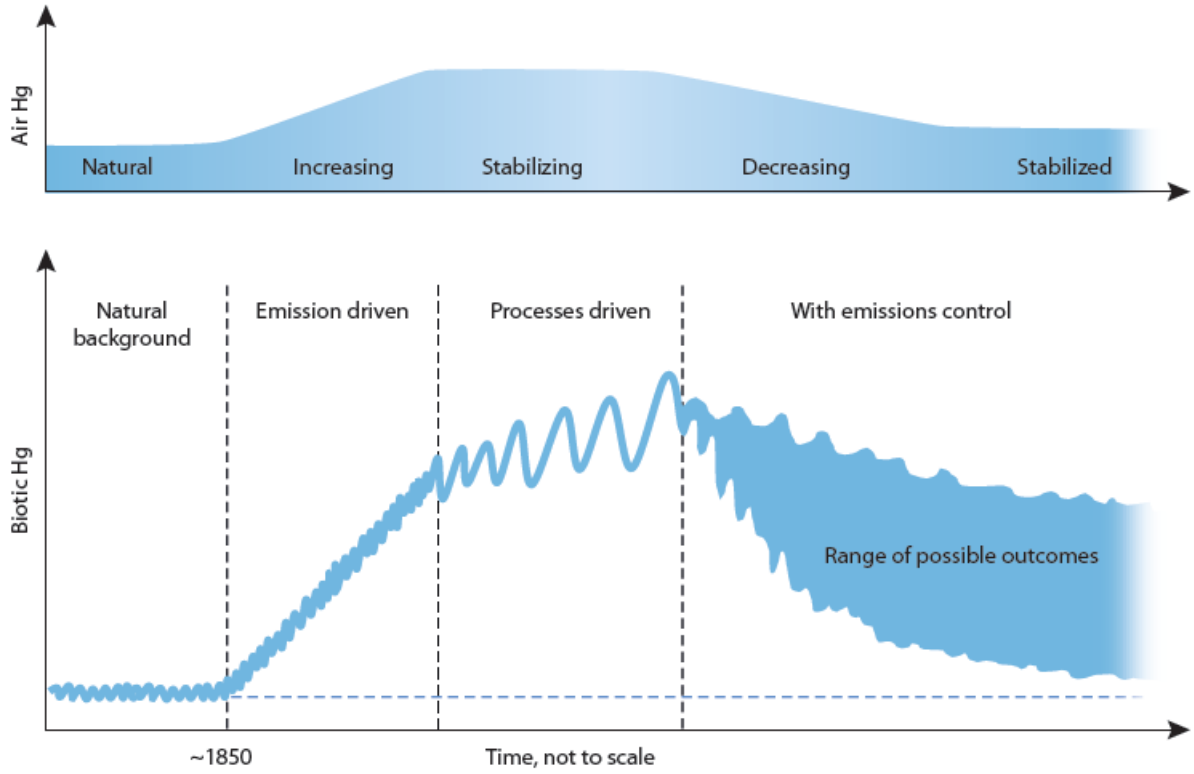
Globally, the broad effects of climate change are believed to be the ultimate contributor to the mismatch between environmental mercury and mercury levels in biota. In the Arctic, the rapid decline in sea ice has influenced mercury distribution and transport, altered mercury methylation and demethylation rates, promoted changes in primary productivity, and shifted food web structures. The impact of climate change on mercury in biota has also been observed in lower latitude regions.

The implications of mercury emission regulations on mercury levels in biota

The fact that trends in mercury in biota do not always follow trends in atmospheric mercury should not discourage actions taken to reduce mercury emissions and releases. Instead, implementation of the Minamata Convention and related actions are necessary to achieve long-term results and to cause declines in mercury as soon as possible.

Mercury in aquatic ecosystems is determined not only by the natural or anthropogenic influx of mercury, but also by the internal processes that control methylation and biological uptake of mercury. As mercury accumulates in water bodies relative to the addition of new emissions or releases, internal biogeochemical processes become the determining steps in bioaccumulation. Prior to anthropogenic influences, inputs of mercury to aquatic systems was generally low, and so were its biotic concentrations. Around the mid-19th century, as anthropogenic mercury emissions increased sharply, aquatic mercury concentrations responded rapidly due to increasing mercury deposition. Once an aquatic ecosystem has accumulated sufficient mercury, however, additional increases become secondary to the amount already stored in the system. In these cases, bioaccumulation draws predominantly on this legacy mercury, affected by internal processes rather than new mercury inputs.

As mercury emissions and releases are controlled by the Minamata Convention, a new phase may emerge. Anthropogenic mercury emissions and releases will decrease, leading to decreased atmospheric concentrations. Legacy mercury in oceans and soils, however, will remain a major source of inorganic mercury to be turned into methylmercury and accumulate in the food web. The decline in mercury in aquatic biota will thus take much longer than the decrease in mercury emissions and atmospheric concentrations, and in some cases may even increase in the short term. Further attention is needed on the fate and effect of legacy mercury that is already stored in environmental reservoirs, on the factors and processes that affect the recovery time of mercury in biota, and on effective remediation and adaptation strategies for communities facing mercury contamination.



997

998 ***Figure 7.5. A schematic representation of evolution in the mercury concentrations in the air (top panel) and***
999 ***aquatic biota (bottom panel), showing changes over time in the principal drivers of mercury bioaccumulation.***
1000 ***Modified from Wang et al. (2010).***

1001

1002

1003

8. Mercury Concentrations in Biota

Certain conditions favour the production of methylmercury, including moderate levels of sulphate, low oxygen, high dissolved organic carbon, acidified waters, and frequent wetting-drying cycles. These factors are important in assessing ecosystems sensitivity to both mercury input and the potential for methylation. Areas with high mercury deposition do not necessarily have high methylmercury levels and consequent uptake into the food web. Areas with low mercury deposition may still have high levels of methylmercury in predatory fish and animals. All of this is of concern because methylmercury is a potent neurotoxin that can cause physiological, neurologic, behavioural, reproductive, and survival harm to fish and wildlife. It readily biomagnifies, increasing in concentration as it moves up the food web. As a result, top predators in a food web may have concentrations of methylmercury in their tissues ten million or more times higher than the concentrations found in the area's water. Organisms with elevated methylmercury levels and those posing risks for human exposure are often used as bioindicators of mercury contamination in an ecosystem.

Methylmercury in biota

The availability of methylmercury to high trophic level organisms varies widely around the world. As an example, some of the lowest air mercury wet deposition levels measured in the United States and southern Canada are in Kejimkujik National Park in Nova Scotia, Canada, yet methylmercury exposure of fish and birds is some of the highest in North America, often exceeding ecological health thresholds. Most lakes in this area are sensitive to mercury input and have high methylation rates. Ultimately, the identification of such biological mercury hotspots can be made through the collection of existing biotic data and modelling ecosystem sensitivity at regional or global scales.

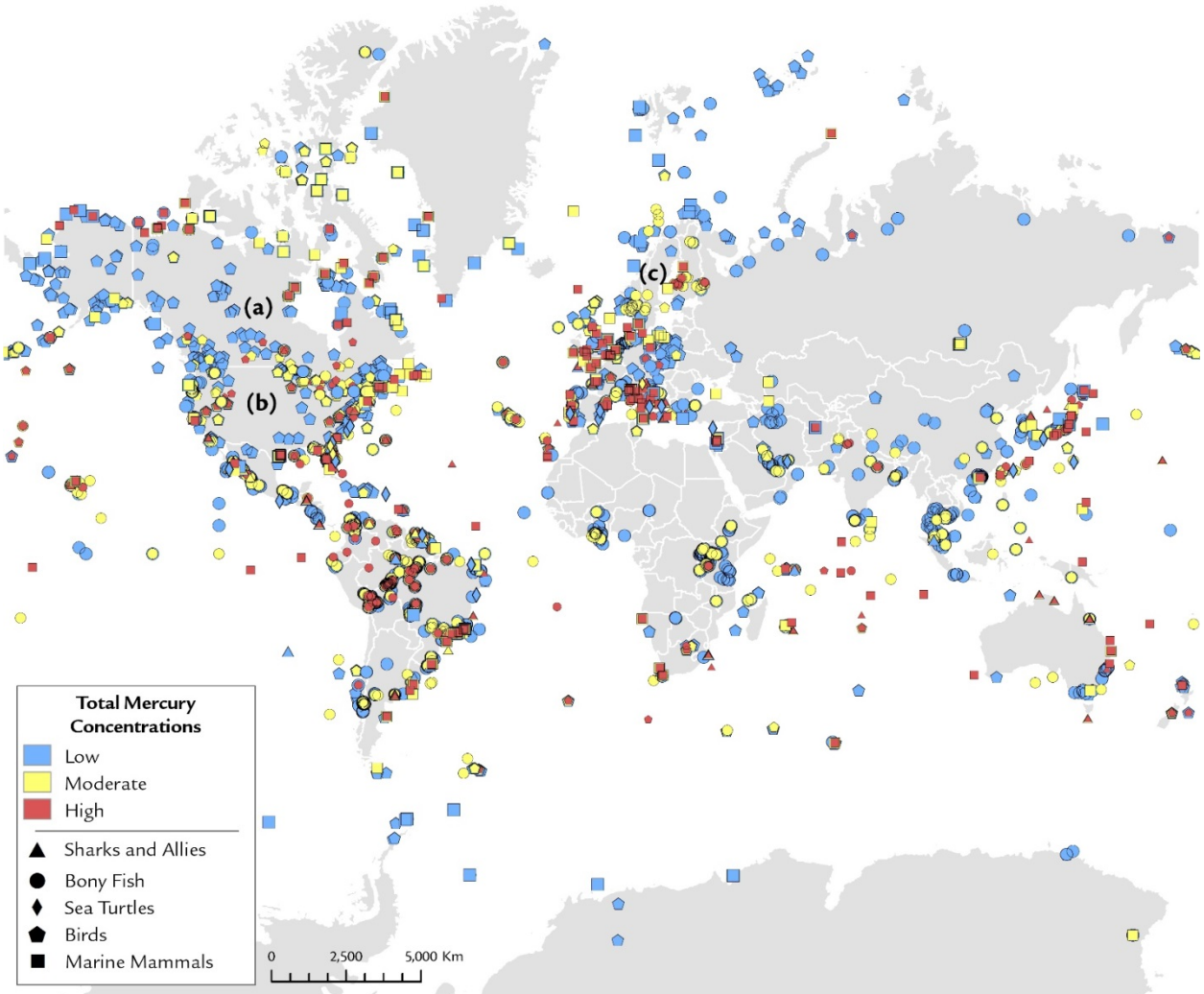


Figure 8.1. Distribution of five major taxa and their total Hg concentrations in three risk categories based on mean data derived from a survey of the available peer-reviewed English literature. Risk categories by major taxa and tissue type are: (1) cartilaginous fish (sharks and allies) and (2) bony fish muscle (ppm, ww): <0.22=low, 0.22-1.0=moderate, >1.0=high; (3) sea turtle muscle and egg (ppm, ww): <0.22=low, 0.22-1.0=moderate, no samples were >1.0; (4) bird body feathers (adult; ppm, fw): <10.0=low, 10.0-20.0=moderate, >20.0=high; bird blood (adult; ppm, ww): <1.0=low, 1.0-3.0=moderate, .3.0=high; eggs (ppm, ww): <0.5=low, 0.5-1.0=moderate, >1.0=high; (5) marine mammal muscle (ppm, ww): <0.22=low, 0.22-1.0=moderate, >1.0=high. Letters indicate additional available fish Hg samples that were not mapped: (a) 186,000 additional samples available in Canada; (b) 162,700 additional samples available in the United States; (c) >50,000 additional samples available throughout Scandinavia.

While tracking mercury emissions, deposition, and releases are important tools for understanding patterns of environmental mercury loads, the relationship between deposition and concentrations biota is poorly understood. Trends in mercury concentrations are thought to differ among ocean basins because anthropogenic emissions have strongly declined in North America and Europe, leading to large declines in atmospheric concentrations, especially in the Atlantic Ocean. This trend may also explain observed declines in mercury concentrations in bluefin tuna between 2004 and 2012 in the North Atlantic Ocean. In contrast to the Atlantic, both atmospheric emissions and freshwater releases of mercury have been increasing in Asia, leading to increased mercury pollution in the North Pacific Ocean. There is evidence for increases in mercury concentrations in North Pacific tuna over the past several decades.

In Ontario, Canada, one of the largest consistent mercury biomonitoring efforts in the world provides a long-term look at mercury concentrations in fish. Although mercury emissions in North America are declining, other factors affect the way methylmercury levels respond over time. Higher precipitation rates, for example, appear to be one cause of increasing levels of methylmercury in fish in Ontario lakes. One projection suggests that nearly all lakes in the province will have some form of "do not eat" advisories by 2050 for people fishing there.

Biomonitoring programs

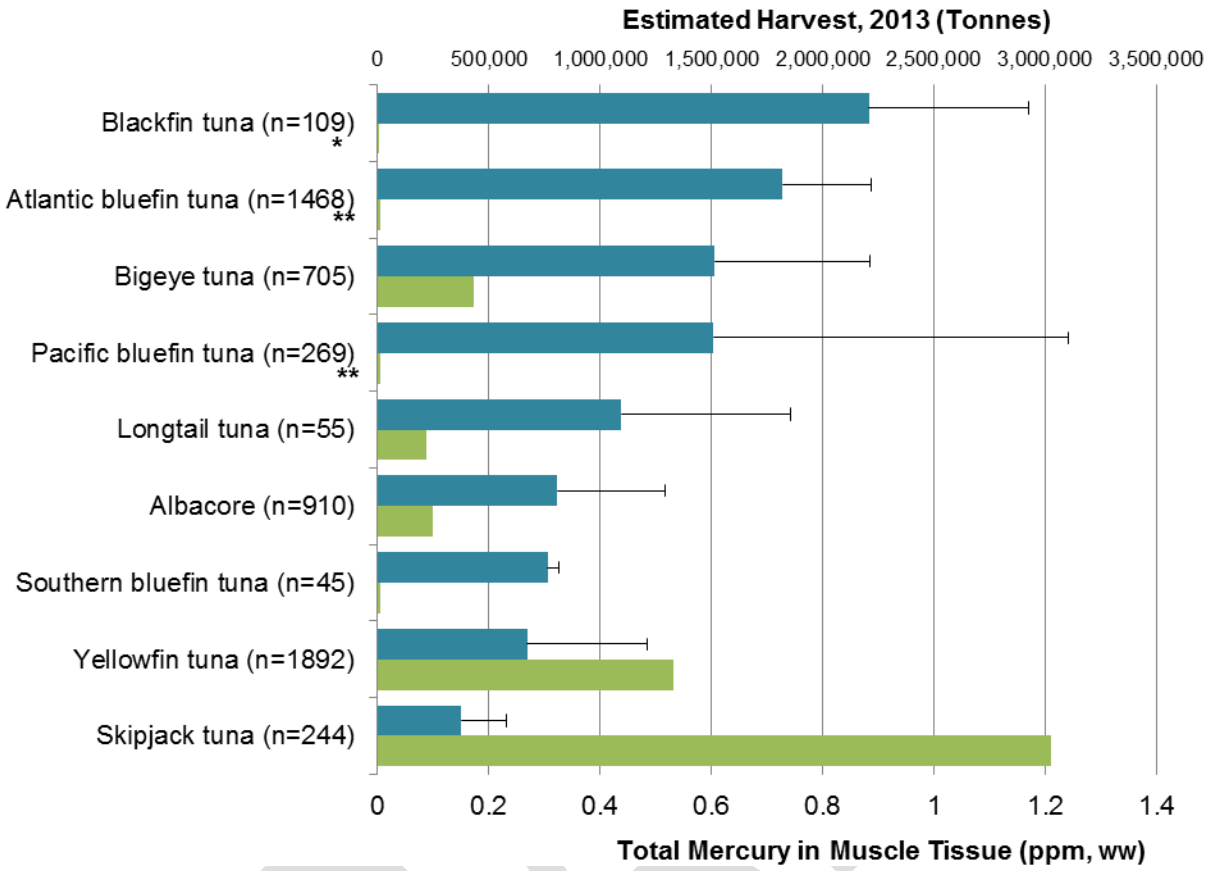
An analysis of the geographical coverage of mercury biomonitoring networks reveals a general lack of national initiatives around the world. No such activities are being undertaken in Africa and Australia. Most Asian countries are minimally involved, with the notable exceptions of Japan and the Republic of Korea. In North America, Canada's Northern Contaminants Program focuses on the measurement of contaminants, including mercury, in fish and wildlife that are traditional foods of northern Indigenous peoples. One of the strengths of the program is the interdisciplinary approach taken to assess and monitor mercury risks to ecological and human health through the participation of Indigenous organizations, environmental scientists, and human health professionals.

In addition to national programs, hundreds of local studies provide a comprehensive and geographically balanced global data platform about existing biotic mercury concentrations. Unfortunately, some of the countries with the highest fish consumption are poorly covered by biomonitoring efforts, including

much of Latin America, Western and Central Africa, many parts of Asia including the Indo-Pacific, and most of the small island developing states around the world. Local scientific studies can make a significant and welcome contribution toward better identifying where, what, and when to conducting biomonitoring.

Bioindicators for human health

Patterns of dietary methylmercury uptake in humans can be shown by fish species and by ocean basin. Many freshwater lakes and rivers have elevated mercury concentrations in fish, especially in the tropics and in temperate regions such as Scandinavia, Russia's Kola Peninsula, and Canada and the northern U.S. In the Arctic, fish, birds, and marine mammals are regularly taken by Indigenous communities as important sources of protein, vital nutrients, minerals, and fatty acids, and are important for cultural and overall well-being.



1083

1084 ***Figure 8.2. Arithmetic mean +/- SD of global total Hg concentrations (ppm, ww) in muscle tissue of nine tuna***
1085 ***species, compared with the FAO harvests estimates (in tonnes) and tuna with harvests of 10-15,000 tonnes are***
1086 ***depicted with ** while tuna with harvest of <5,000 tonnes are depicted with *.***

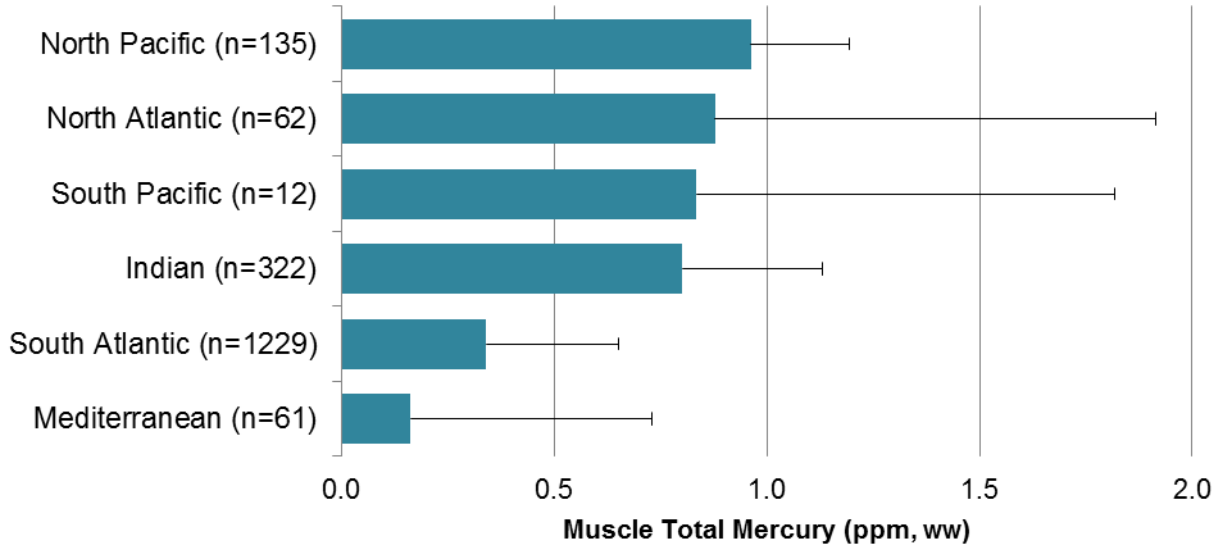


Figure 8.3. Arithmetic mean +/- SD of global total Hg concentrations (ppm, ww) in dorsal muscle tissue of swordfish from known ocean basins.

These and other considerations suggest a number of strong candidates for biomonitoring in relation to human health. Tuna are one of the most important global sources of marine fish, with commercial harvests of nearly 3.5 million tonnes per year. Mercury concentrations vary widely by species and ocean and tuna are a major source of human exposure to mercury worldwide. Swordfish have important commercial value and are a substantial income source for many Small Island Developing States (SIDS). They also tend to have high mercury concentrations, which poses a risk for human health and can limit the ability of the fishing nations to export their catch. Switching to other fish species may be difficult due to overfishing. Thus, swordfish monitoring can be important for human health and for economic reasons.

Several regions have long-term records of mercury levels. In the Arctic, mercury levels have increased by a factor of ten over the past 150 years, but the trend has become inconsistent in the past three decades. Nonetheless, the importance of fish and wildlife to Arctic residents and the extensive monitoring record make the region an important area for further study. The rapid rate of climate change in the Arctic amplifies its significance for global understanding of mercury trends. The major river basins of South America, including the Magdalena, Orinoco, Amazon and La Plata, support a large freshwater fishery, providing livelihoods for small-scale artisanal fishermen as well as major commercial enterprises. Diets

high in fish in this region are linked to high human exposure. Of particular concern are areas affected by artisanal and small-scale gold mining. Future biomonitoring would produce valuable information in areas with those and other mercury point sources within tropical ecosystems that appear to be sensitive to elevated methylation rates.

Bioindicators for ecological health

Many species of fish and wildlife are at risk to the adverse impacts of mercury. The selection of a particular organism or suite of bioindicators depends on the objective, such as ecosystem health, detection of spatial or temporal trends, human health, particular effects, or sampling techniques. As with bioindicators of human health, those for ecological health include several species groups that have high mercury levels or are otherwise important for understanding mercury in the environment. Many sharks, skates, and rays have muscle mercury concentrations that are well above the human health advisory levels set by the World Health Organization (WHO) They are of particular concern because they have high conservation status and they are often used for food.

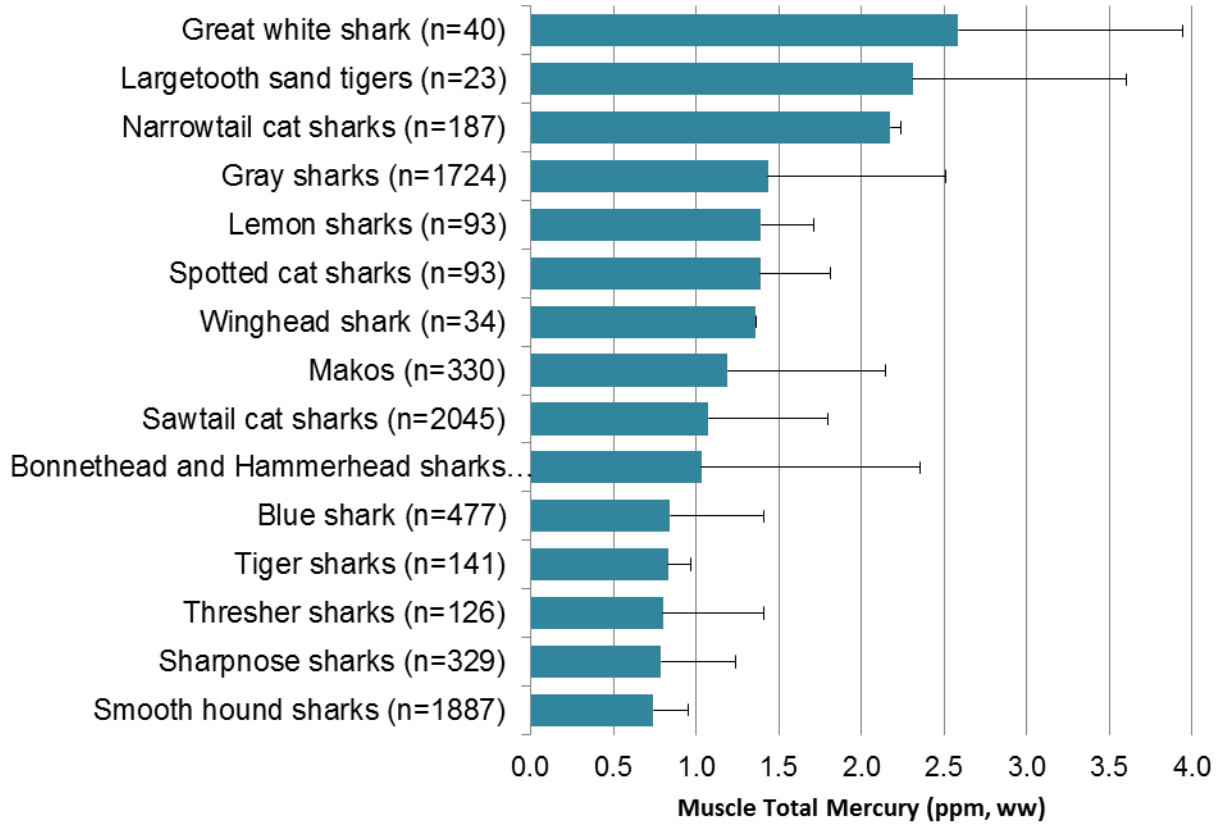
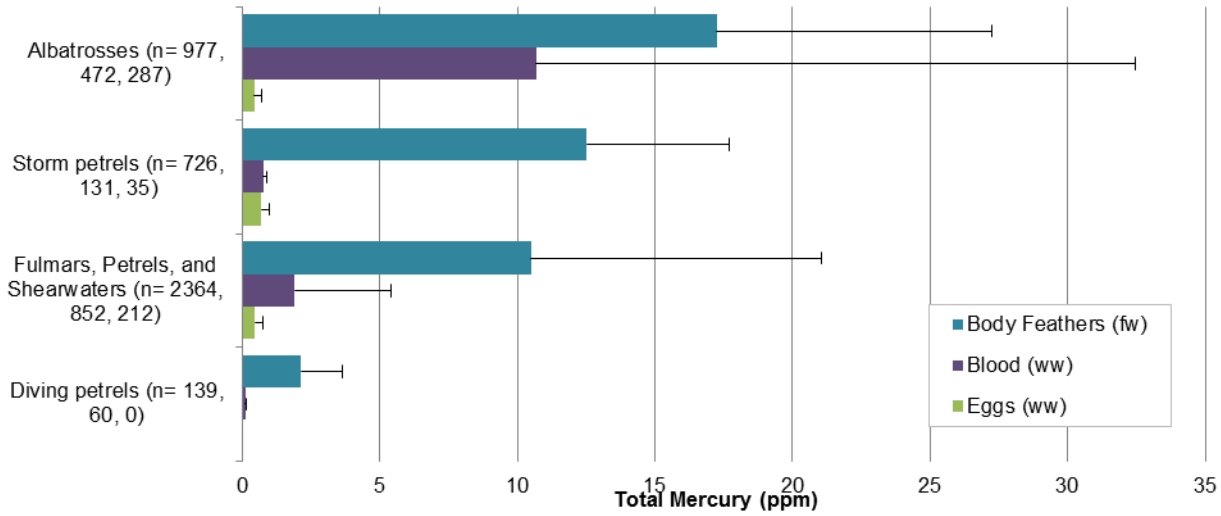


Figure 8.4. Arithmetic mean +/- SD of global total Hg concentrations (ppm, ww) in muscle tissue of sharks by genus from the Orders of Mackerel and Ground Sharks.

Most seabirds are situated high in the food web, and thus can be highly exposed to methylmercury. The study of a group of seabirds with contrasting ecologies from the same region allows determination of methylmercury availability for multiple marine zones and therefore a more complete view of the ecosystem. Variation in mercury contamination in seabirds can reveal differences in the degree of contamination between major ocean basins, as well as latitudinal gradients of contamination within basins, and trends at a series of both spatial and temporal scales.



1132

1133 ***Figure 8.5. Arithmetic mean +/- SD of global total Hg concentrations (ppm) in three tissues (fw in feathers, ww***
1134 ***in blood and eggs) of seabird families within the Order Procellariformes.***

1135 Loons have been used as bioindicators of methylmercury availability in both their breeding and
1136 wintering areas for several decades. In Canada, the Common Loon and its prey are being used to
1137 evaluate the success of national regulatory standards to reduce mercury emissions. New findings on
1138 elevated mercury exposure and migration behavior in songbirds suggest the potential for substantial
1139 adverse health effects, especially for long-distance migrants.

1140 Toothed whales and some seals are the marine mammals of greatest concern for human and ecological
1141 health purposes. Mercury concentrations associated with neurochemical effects are found regularly in
1142 brain tissues from these species. Many subsistence communities, mostly in the Arctic, depend on the
1143 harvest of narwhal, beluga, pilot whales, ringed seals, and other marine mammals. Toothed whales
1144 appear to be one of the most vulnerable groups of marine mammals to the dietary uptake of
1145 methylmercury.

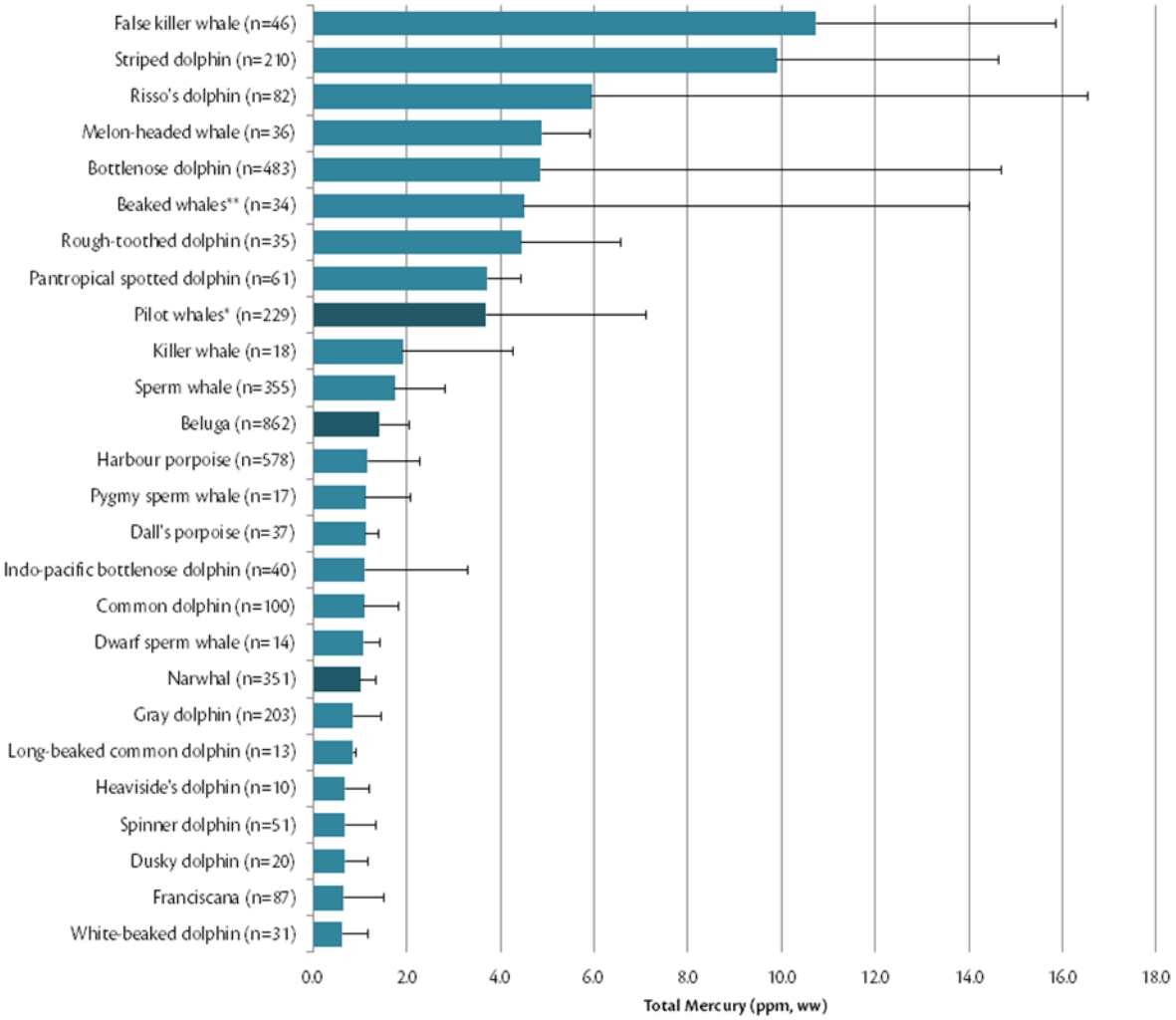


Figure 8.6 Average total Hg concentrations (ppm, ww) in muscle tissue of toothed whales by species (except beaked whales were combined under the family, Hyperoodontidae, and the two species of pilot whales were grouped).

Critical knowledge gaps

While there are large biological mercury datasets, they are generally inadequate for determining changes in biotic mercury exposure at regional or global scales over decadal time periods. Global climate change, as one prominent example, will alter future levels of mercury concentrations across many landscapes. How specific climate-related changes to landscape processes relate to changes in biotic mercury exposure is relatively unknown. Biomonitoring can build from existing programs, which are

generally found within developed countries at local, national, and sometimes regional levels. A more global, cost-efficient, and reliable biomonitoring approach that can connect existing biomonitoring programs and national projects could be achieved with a structured plan.

9. Mercury Levels and Trends in Human Populations Worldwide

Mercury is a naturally occurring element that can enter the ecosystem via natural or anthropogenic processes. Mercury has three major chemical forms relevant to human exposures: elemental mercury, inorganic mercury compounds, and organic mercury compounds. The most important form of organic mercury is methylmercury, though ethylmercury is used as a preservative in some vaccines. The source, environmental fate, exposure, and toxicity of these different mercury forms varies. Human exposures to elemental and inorganic mercury may occur in occupational settings and via contact with products containing mercury.

Mercury and human health

Seafood is the main source of protein for about one billion people worldwide. For many communities, therefore, dietary consumption of fish, shellfish, and marine mammals that are contaminated with methylmercury is the most important source of exposure. Rice grown in sites heavily contaminated with mercury may also be a source of methylmercury exposure for many communities.

Mercury is a pollutant of global concern principally due to its adverse effects on human health. Everyone in the world is exposed to some amount of mercury. All forms of mercury are toxic but the principal effects differ. Exposures to elemental mercury may affect the nervous system. Exposures to inorganic mercury compounds may affect the kidneys. Exposures to methylmercury are associated with adverse effects on brain development. The latter has received the most attention largely due to notorious methylmercury poisoning events in Japan and Iraq following high exposures. Studies on the toxicity of methylmercury carried out over recent decades have provided a growing body of evidence that chronic, relatively low-level methylmercury exposures can be associated with a range of other adverse health outcomes as well, affecting for example the cardiovascular and immune systems.

1189

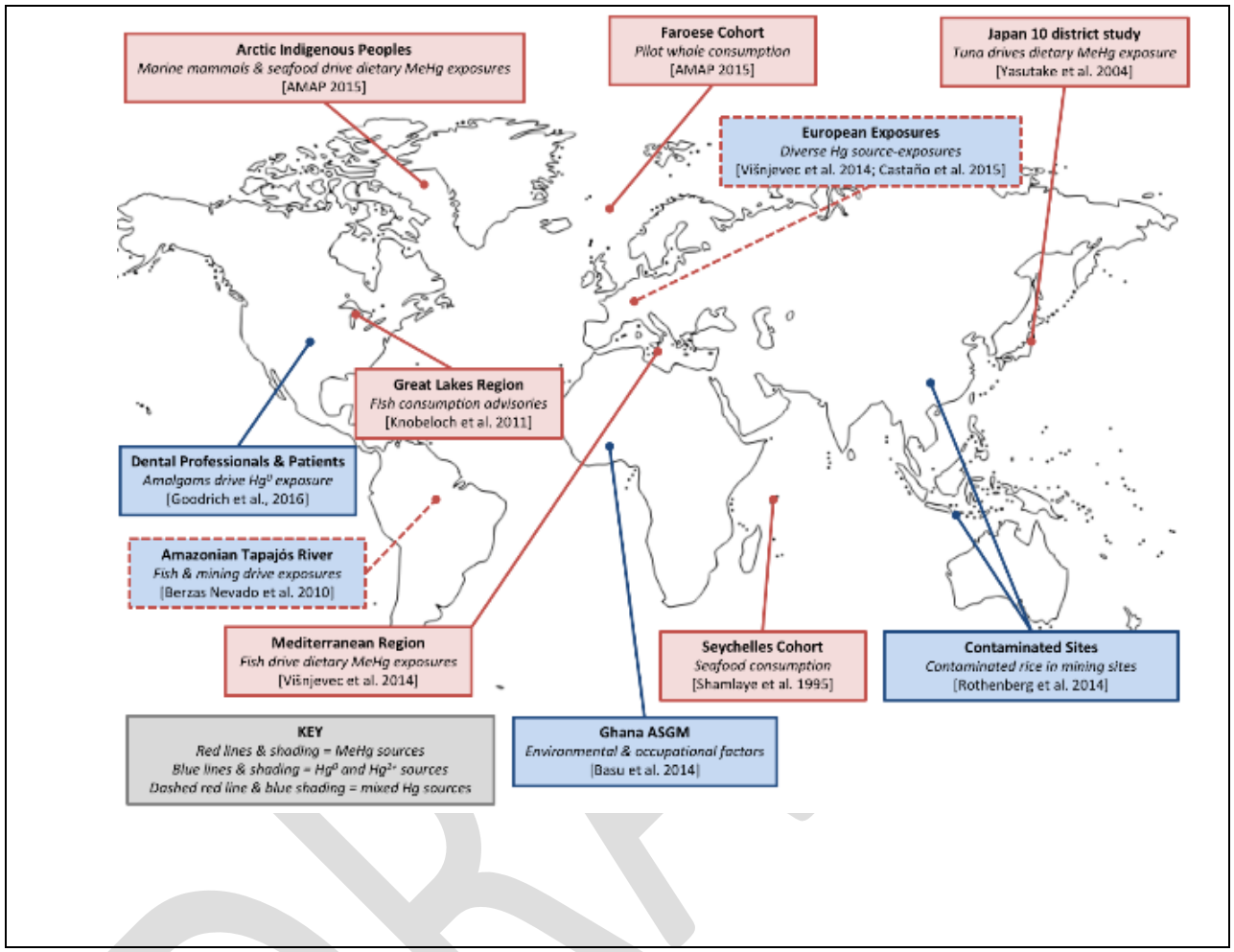


Figure 9.1. Selected studies across the world depicting strong and representative evidence of mercury source-exposure relationships.

1190

1191

1192 **Mercury exposure assessment using biomarkers**

1193 Human exposure to mercury is estimated by the measurement of mercury in human tissue and other
1194 samples. The most commonly used biomarkers are the concentrations of mercury in hair, urine, blood,
1195 and umbilical cord blood.

Most of the mercury in hair is methylmercury. Mercury taken up in hair remains there, providing an integrated measure of exposure that can be tracked over time as hair grows. Hair is also easy to collect and transport, though care must be taken to distinguish mercury within the hair from mercury that has fallen on the hair during activities such as artisanal and small-scale gold mining. Urine analysis primarily provides information about exposure to inorganic and elemental mercury, although methylmercury may also contribute to the burden of urinary mercury, particularly among avid seafood consumers. Like hair, urine is a relatively easy and non-invasive sample to collect. Mercury measured in whole blood provides information about exposures to both methylmercury and inorganic mercury within the past month or two. The measurement of mercury in umbilical cord blood provides information about developmental exposure. Blood collection, storage, and transport pose certain logistical, ethical, and financial barriers, however.

When multiple biomarker measures are taken from a given individual, and also combined with surveys about diet and behaviour, a deeper exposure assessment of mercury exposure is possible. In general, careful measurement of mercury content in hair and urine offers the most convenient and cost-effective way to monitor mercury, particularly in resource-limited settings.

Mercury levels in humans

This initial global assessment of human exposure to mercury focuses on three study population categories. *National human biomonitoring programs* are usually sponsored or run by official government agencies and provide high quality data. *Longitudinal birth cohort studies* are usually well designed and most pertinent for establishing exposure-outcome relationships. They tend to provide high quality exposure data for vulnerable groups and can be used to explore trends in space and time and to examine connections between mercury sources and biomarkers of exposure. *Cross-sectional studies on vulnerable populations* here focus on two broad groups: those exposed to inorganic mercury from point sources such as artisanal and small-scale gold miners and people living and working in contaminated sites, and those exposed to methylmercury via their diets such as Indigenous Peoples, fishers, and coastal communities.

National data were available from Belgium, Canada, the Czech Republic, France, Germany, the Republic of Korea, Slovenia, Sweden, and the U.S. The total sample population was 121,437 people, from whom

there were 192,675 biomarker measurements of mercury exposure. Across the national programs, the majority of participants had blood mercury levels that fell below 5 micrograms per liter. In adults, blood mercury levels were just over twice as high as in children. Urine mercury levels were consistent across the countries from which data were obtained, with a majority of the values falling below 3 micrograms per liter. Like blood, urine mercury levels were higher in adults than in children.

Figure9. 2. Comparison of median blood total mercury (□g/L) measurements across children (<19 years) and adults from national biomonitoring datasets between the years 2003-2014. Note, for Belgium and France that blood mercury values were estimated based on hair mercury levels in women (adults) and children (both sexes).

Changes in mercury exposure over time were evaluated by reviewing national datasets in which there were two or more comparable sampling periods. For blood mercury, datasets from four countries were reviewed and in general they showed declining exposures. For urinary mercury, similar decreases can be observed, particularly in the U.S. dataset where the most recent mercury levels are approximately half of what they were a decade earlier. Urinary mercury values now in the U.S. are similar to those in Canada.

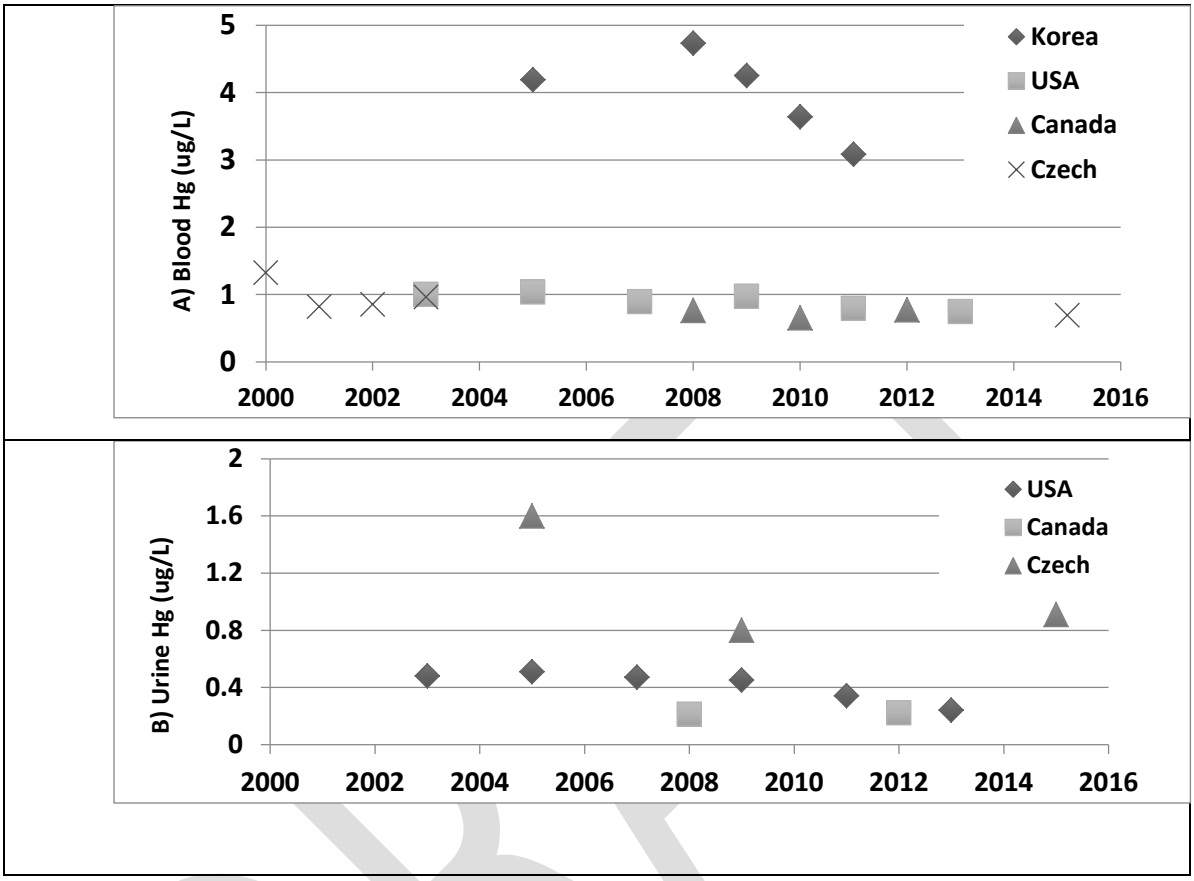


Figure 9.3. Temporal trends of adult A) blood and B) urinary total mercury (□g/L; median values) measurements across the national biomonitoring studies in which data was available from 2+ comparable sampling periods.

Thirty-two *birth cohort studies* from 17 countries included at least one mercury exposure measurement during pregnancy or birth, as well as a follow-up time period in which an outcome measurement was taken. The total sample population of these birth cohort studies was 23,374 mother-child pairs from which 47,699 biomarker measurements were taken. In general, these birth cohort studies focused on methylmercury exposures. There are some noteworthy observations. Groups consuming large amounts of fish and seafood or marine mammals have the highest mercury exposures, though people in the Faroe Islands and the Seychelle Islands have seen dramatic decreases from previously very high levels of

mercury. Elsewhere, Mediterranean populations had higher levels than people in Asian, who in turn were higher than those in North America and Europe. A range of health outcomes were measured in newborns, infants, toddlers, or children. These span a range of exposures so are not limited to groups or regions with high overall exposure to mercury.

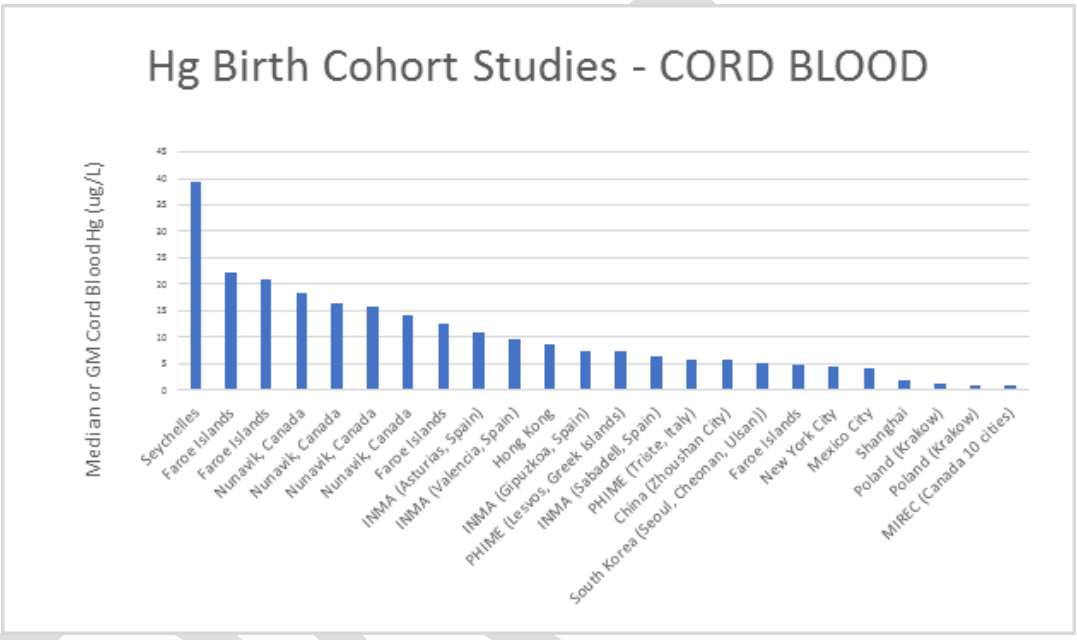
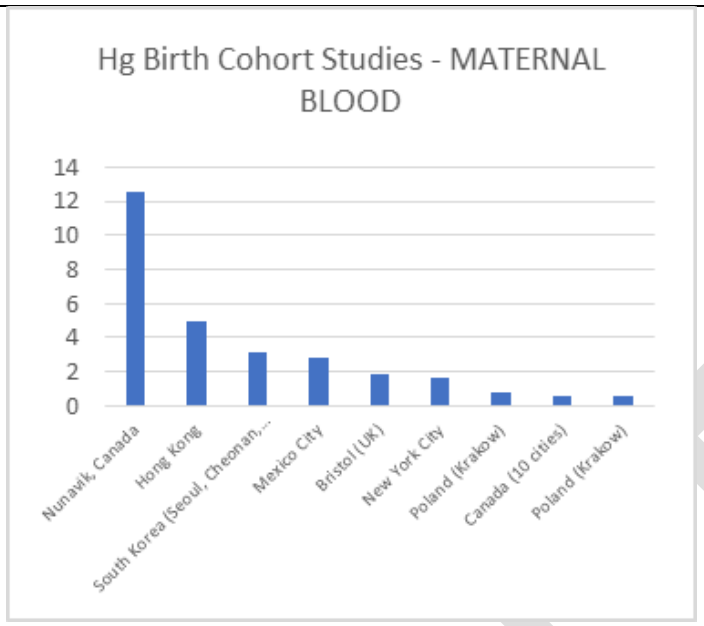


Figure 9.4. Cord blood mercury measurements (□g/L) across the birth cohort studies.



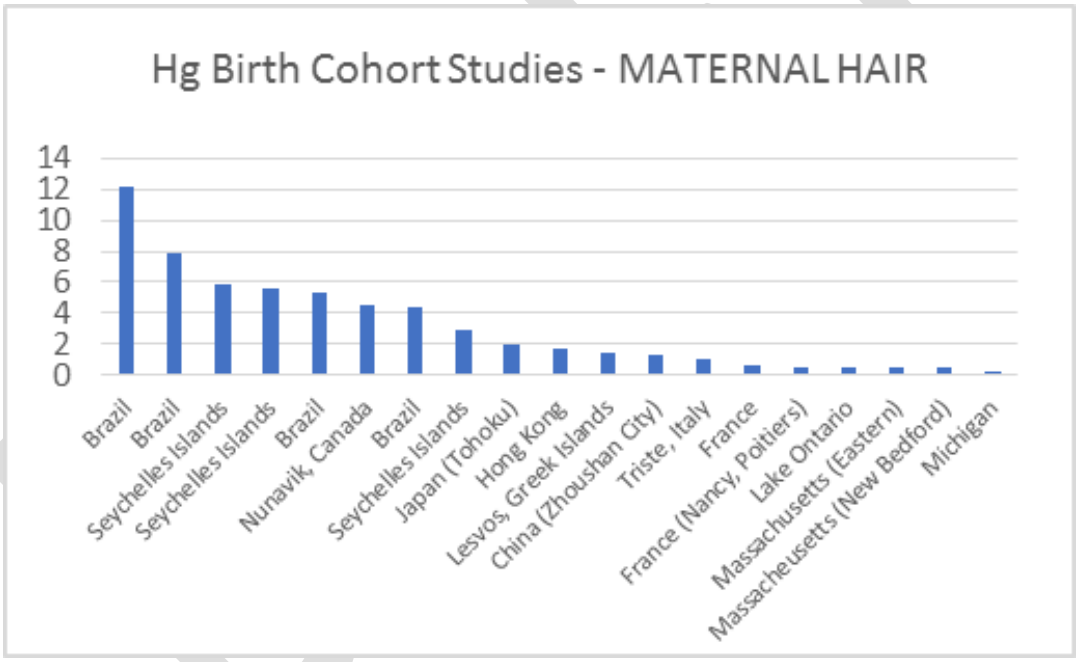


Figure 9.5. Maternal A) blood (ug/L) and B) hair (□g/g) mercury values across the birth cohort studies.

1263

1264

1265

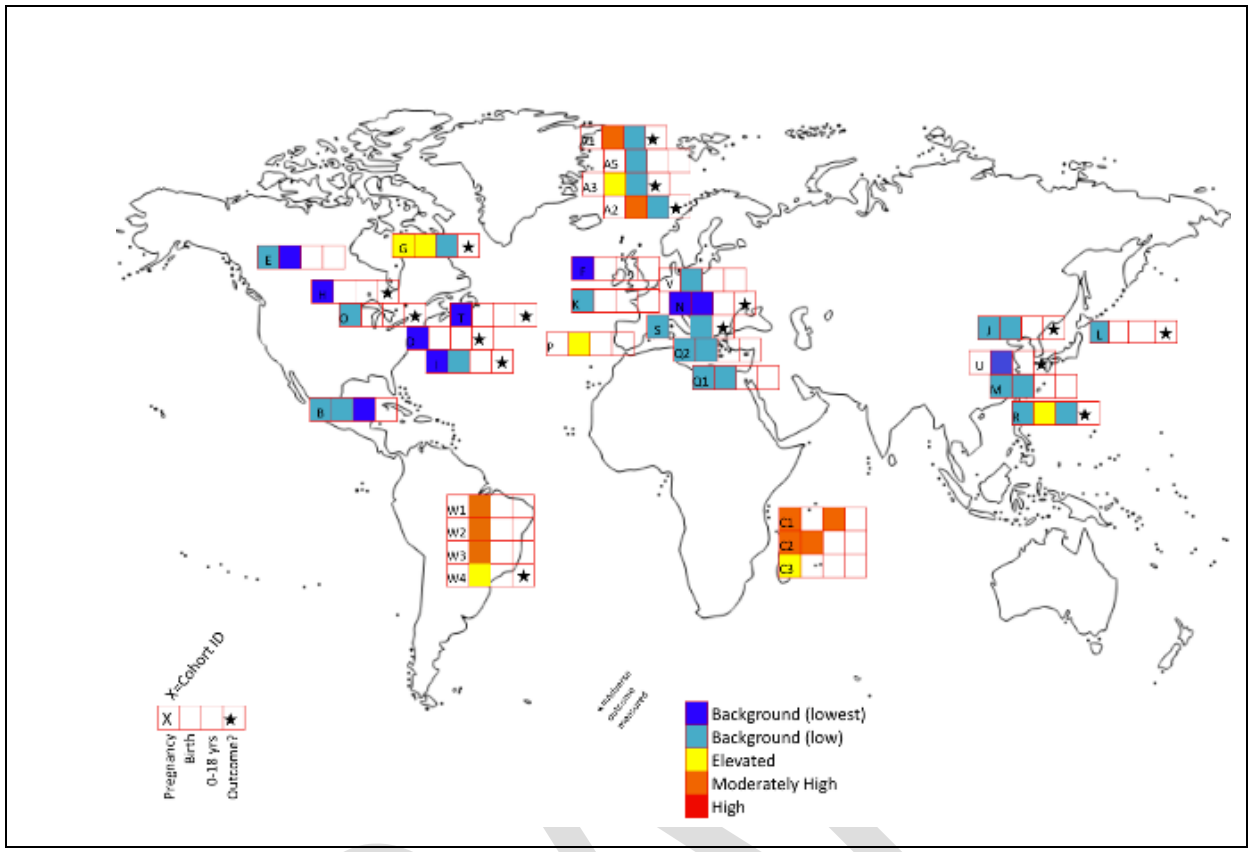


Figure9. 6. Map outlining the locations of the selected mercury birth cohort studies. Data represent 32 cohort studies and 46,185 mercury biomarker measures. The cohort ID is indicated in the first box as a letter (see Appendix 4 for details). The first three boxes refer to group average mercury measures taken during pregnancy, at birth, and up until age 18, respectively. Blank cells represent lifestages without a mercury measurement. If the final box has a star, then a mercury-associated adverse outcome was reported in that cohort. Color codes are based on the work by Višnjevec Miklavčič et al. (2014) with minor modifications as detailed in Appendix 3.

1266

1267

1268 Among *vulnerable groups*, methylmercury-contaminated seafood poses a particular risk-benefit
1269 dilemma. Seafood provides many valuable nutrients and associated health benefits, but also tends to
1270 contain high levels of methylmercury. Not surprisingly, mercury exposures are highest among gold
1271 mining communities along rivers, such as those in the Amazon Basin, who have high occupational and
1272 environmental exposure, and also Arctic Indigenous Peoples who consume marine mammals and fishes.
1273 In addition, many Indigenous Peoples worldwide are reliant upon traditional foods such as fish and
1274 marine mammals for sustenance and so may also be exposed to methylmercury. Per capita seafood

consumption in these communities is 15 times higher than in non-Indigenous groups. In addition, such traditional foods also form a strong basis for the culture, spirituality, recreation, and economy of many of these communities and so contamination of food by mercury presents an issue of environmental justice.

Artisanal and small-scale gold mining continues to grow rapidly, with upwards of 15 million miners involved worldwide and potentially 100 million people living in their communities. There are a number of public health concerns in artisanal and small-scale gold mining communities as well as a growing number of human biomonitoring studies. Mercury levels among such miners tend to be high on average, with some individuals at extremely high levels of exposure.

Remaining questions and prospects for action

Human mercury exposure data are completely lacking in a number of countries and geographic regions. Given that the Minamata Convention is motivated by human health concerns, there is a need for nationally representative data so that changes in human exposure over time and space may be gauged. Carefully taken measures of mercury in hair and urine are particularly suitable as they provide useful information and the samples are relatively cheap and easy to take.

Elevated exposures to methylmercury are a concern for key groups for which there exist a relatively robust dataset. These include Arctic populations (e.g., Indigenous Peoples) who consume fish and marine mammals, tropical riverine communities (e.g., Amazonian), coastal and/or small-island communities who are avid seafood consumers, and individuals who either work or reside in or near artisanal and small-scale gold mining sites. In addition to these groups, there is growing awareness of the mercury exposures faced by other highly exposed groups, such as those living in mercury contaminated sites, consumers of rice from contaminated sites, and users of skin-lightening creams, though there remain few data concerning these groups from which to draw strong conclusions.

Many studies focus on development exposures during pregnancy and childhood though there are also concerns about mercury susceptibility during other lifestages. Much remains to be learned about the range of physiological systems affected by mercury, about interactions among mercury and other

chemicals and environmental factors including climate change, and concerning the role of genetic differences in mediating exposure biomarker levels or exposure-outcome relationships.

There are also success stories to be noted. Many steps to limit mercury exposures may be effective. The approximately two-fold decline in urinary mercury levels in the U.S. over the past decade is likely due to improvements in dental materials and practices that reduce contamination from fillings in teeth. Similar trends have been observed in German children and among U.S. dental professionals. Across the Arctic, mercury exposures remain elevated but have dropped over the past two decades, probably as a result of local dietary advisories and changing consumption patterns. In other places, mercury exposures have decreased as a result of dietary consumption advisories, as has been seen in both the Faroe Islands and the Seychelles. Within the artisanal and small-scale gold mining sector, urinary mercury levels are significantly lower in workers from licensed sites versus unlicensed ones in Ghana. It can be expected that further efforts will continue to yield beneficial results.

Key Findings

Chapter 2

There has been considerable debate about the effect of mercury emissions from New World silver and gold mining from the 16th to late 19th centuries on global mercury levels, especially in the oceans. This legacy mercury still has an impact on the world's mercury cycle today. The weight of evidence from historical information and environmental records suggests that the global effect of these emissions was smaller than previously thought. Nonetheless, evidence suggests that, human activities past and present have increased total mercury concentration in the today's atmosphere by about 450% above natural levels (those before 1450 CE).

Current anthropogenic mercury emissions are estimated to be approximately 2500 tonnes per year. This includes the inventory of 2220 tonnes prepared for this Assessment plus an estimate of undocumented releases from sources not included in the inventory.

The cumulative effect on today's oceanic mercury cycle of several centuries of emissions has been dramatic, with approximately two-thirds of the overall increase in marine mercury concentrations occurring before 1920 mainly due to precious metal mining and associated cinnabar refining. About one-fifth of the overall increase has been due to coal combustion since 1920, and the remaining tenth or so of the increase due to other industrial activities.

Marine mercury concentrations are still expected to take decades to centuries to recover following decreases in mercury emissions.

To improve scientific knowledge about mercury, a better understanding of natural inputs and processes is needed, along with more accurate and complete anthropogenic emissions inventories.

Chapter 3

Anthropogenic emissions of mercury to the atmosphere currently amount to more than 2000 tonnes per year, accounting for about 30% of mercury emitted annually to the atmosphere, the remainder coming

from natural processes (60%) that result in re-emission of mercury previously deposited to soils and water (much of which is itself derived from earlier anthropogenic emissions and releases), and natural sources (ca. 10%).

A new global inventory of mercury emissions to air from anthropogenic sources in 2015 quantifies emissions from 20 key sectors at about 2220 tonnes. Additional emissions of the order of tens to hundreds of tonnes per year may arise from smaller anthropogenic sources not currently detailed in the global inventory work.

Global emissions of mercury to the atmosphere in 2015 are approximately 20% higher than they were in 2010. Continuing action to reduce emissions has resulted in modest decreases in emissions in some regions (North America and EU) but emissions have increased in most other regions. Increased economic activity in these regions (including recovery following the economic down-turn that may have influenced global emissions in 2010) therefore appears to have more than offset any efforts to reduce mercury emissions.

Regional and sectoral attribution of the 2015 global emissions inventory indicates that emissions patterns in 2015 are very similar to those in 2010. The majority of the 2015 emissions occur in Asia (49%; primarily East and South-east Asia) followed by South America (18%) and Sub-Saharan Africa (16%). In the latter two regions, emissions associated with artisanal and small-scale gold mining account for about 70 and more than 80% of emissions, respectively. That sector also accounts for a significant part of emissions in Central America and the Caribbean (40%) and East and South-east Asia (25%), and constitutes almost 38% of the global total. In other regions, emissions associated with energy production and industrial emissions predominate.

Stationary combustion of fossil fuels and biomass is responsible for about 24% of the estimated global emissions, primarily from coal burning (21%). Main industrial sectors remain non-ferrous metal production (15% of the global inventory), cement production (11%) and ferrous metal production (1,.8%). Emissions from wastes from mercury-containing products comprise about 7.5% of the 2015 global inventory.

Comparing emissions estimates produced using different methodologies and procedures provides important insights into the limitations of reporting procedures, availability of key information, and

uncertainties associated with emissions quantification. Multiple approaches are essential for verifying emissions and release estimates and validating national reporting.

Chapter 4

Data from existing air mercury monitoring networks show a clear gradient of mercury concentration between the northern and southern hemispheres. The map of existing networks and their spatial distribution, however, show geographical coverage gaps of large areas (i.e., Africa, Latin America and the Caribbean, Russia) that are key for long-range transport analysis and identification of source-receptor regions relationship.

Sufficient data do not exist to assess the global temporal trend in atmospheric mercury concentration and deposition. Data from Europe, Canada, the United States show general decrease in the level of mercury in air.

Close cooperation among existing monitoring networks is needed to support global actions to reduce mercury emissions by:

- Ensuring sustainability of a long-term monitoring program covering both hemispheres
- Assuring comparability among different monitoring data sets by promoting the adoption of common methods and standards
- Promoting experiments for testing and validating new methods and technologies for mercury monitoring
- Supporting nations as they develop their own monitoring programs by promoting a continuous capacity building and transfer of knowledge program in cooperation with UN Environment.

Chapter 5

Significant progress has been made since GMA 2013 in all key areas of interest regarding the atmospheric mercury cycle. Uncertainties remain in quantifying emissions, particularly from certain regions and sectors and in mercury speciation. Mercury emission rates from natural surfaces need to be better constrained.

New information has solidified our knowledge about mercury oxidation reactions, including the importance of bromine chemistry. The precise nature of the reactions and identity of the resulting products remain the subject of speculation.

Mercury removal from the atmosphere occurs via wet and dry deposition. Dry deposition remains more poorly quantified than wet deposition, and there remains disagreement among models on its global magnitude.

Both model simulations and natural archives provide evidence for peak atmospheric mercury concentrations during the second half of the 20th century and declines in more recent decades. Future changes under policy scenarios could reduce mercury deposition in the future, but the influence of climate change and legacy mercury complicates our ability to assess these potential future changes.

Atmospheric mercury concentrations are highest in the temperate latitudes of the Northern Hemisphere and lowest in the high latitudes of the Southern Hemisphere. The highest concentrations are in East, South, and Southeast Asia due to high levels of anthropogenic emissions as well as in equatorial Africa and South America because of active artisanal and small-scale gold mining.

Total mercury deposition is more equally distributed between the Northern and Southern Hemispheres. Total mercury deposition rates are the highest in large industrial regions such as South, East, and Southeast Asia and the lowest in remote regions such as the Arctic and Antarctica. Regions with active artisanal and small-scale gold mining are also subject to a relatively high total mercury deposition rate.

Atmospheric deposition from direct anthropogenic emissions is the mixture of domestic emissions and atmospherically transported mercury from sources in other regions. The share of domestic sources varies from more than 65% in Asia to less than 5% in the Arctic and Antarctica. In East and South Asia, anthropogenic mercury deposition is dominated by the contribution from domestic sources (77% and 66%, respectively). Domestic and foreign anthropogenic sources contribute almost equally to the total anthropogenic mercury deposition in Europe.

In North America, the share of domestic sources has declined from 23% to 17%, due to the reduction in North American anthropogenic emissions since 2010. Regions with active artisanal and small-scale gold mining (Africa, South and Central America) also receive a relatively large fraction of anthropogenic

deposition from domestic sources (30-38%). The largest foreign contributors to various receptor regions are East Asia, Africa, South America, and Southeast Asia.

East Asia and Africa remain the largest contributors to the global ocean reservoirs, owing to their large anthropogenic emissions (20-50% and 10-27%, respectively). The only exception is the Mediterranean and Black Seas, where the contribution from European anthropogenic emissions (20%) dominates over East Asian and African sources.

Mercury deposition from the power generation sectors is largely restricted to a few industrial regions, with the largest contribution in Europe and South Asia. Deposition from industrial sources covers wider areas in Asia, Europe, North and South America, and Africa. The impact of emissions from intentional use and product waste is insignificant in all the regions. Mercury emissions from artisanal and small-scale gold mining are transported globally, but the most significant deposition occurs closer to the sources and largely impacts South America, equatorial Africa, and East and Southeast Asia.

Chapter 6

The 2015 global inventory of anthropogenic mercury releases to aquatic environments is about 600 tonnes. The new inventory is more complete and reinforces the importance of these sources in the global context. The current inventory of global anthropogenic mercury releases to aquatic systems is an important step towards filling a major gap in inventories of anthropogenic mercury releases to the environment.

Quantifiable releases to water from anthropogenic sources comprising 10 key sectors are included in the inventory, with some new important sectors added and newly evaluated in 2015 compared to 2010, such as releases associated with municipal wastewater, coal washing and that from coal fired power plants. Methodological changes and these newly added sectors drive much of the relatively large difference between the 2010 and 2015 anthropogenic mercury release inventories.

For the first time, the inventory was extended to include primary releases to land and solid waste streams from some of the sources considered. The magnitude of these terrestrial mercury pathways can be on the order of tens to hundreds of tonnes per year may. If not treated properly, this terrestrial mercury can act as potential secondary source of mercury to both water and atmosphere.

The regional pattern of the global release inventory indicates both similarities and differences with atmospheric emission patterns. Excluding artisanal and small-scale gold mining, for which combined releases to water and land are estimated, the majority of releases to water occur in Asia (56%; primarily East and South-east Asia) followed by Europe and CIS countries (14%, primary EU28), Latin America (11%), and Sub-Saharan Africa (8%).

By sectors, the majority of the global anthropogenic mercury releases are relatively equally distributed between the ore mining and processing (40%) and the waste treatment sectors (43%), followed by the energy sector (17%). The relative contribution of sectors within individual regions varies a lot and depends on the technological and socio-economic status of the region. For example, releases resulting from artisanal and small-scale gold mining, the major single anthropogenic source of mercury releases, occur primarily in South America (50%) and East and South East Asia (35%).

In future assessments of aquatic mercury releases, it is reasonable to anticipate that additional releases may be included from sectors and activities not quantified in the 2015 inventory due to the lack of information or from smaller anthropogenic sources not currently included in the global inventory.

Uncertainties associated with release estimates for 2015 are still large and are mainly the result of either unavailable or unreliable information.

Chapter 7

Sediments are not the only important source of methylmercury in aquatic environments.

Water column methylation occurs in coastal waters, open oceans, and large lakes.

The factors controlling water-column methylation are complex and remain poorly understood.

The availability of mercury may no longer be the limiting factor on methylmercury production in lakes and oceans. As large amounts of legacy mercury are stored in many aquatic ecosystems, the rate at which mercury methylation occurs becomes increasingly important. This means that reductions in emissions may take time to show up as reductions in methylmercury levels in biota, as the legacy mercury already present in aquatic systems will continue to produce methylmercury for some time to come.

Chapter 8

Environment mercury loads are at levels of concern for ecological and human health around the world.

Exposure to mercury varies greatly by species, related to methylmercury concentrations in the environment, food web structure, metabolism, lifespan, and other factors.

Areas that have biota with methylmercury high enough to have significant biological impacts are known throughout the world and can be linked to both contaminated sites and ecosystems sensitive to mercury input.

Species and species groups that can best achieve biomonitoring objectives can generally be identified through current knowledge, such as fish and marine mammals of greatest concern for human health purposes.

Chapter 9

All people are exposed to some amount of mercury. For many communities worldwide, dietary consumption of fish, shellfish, and marine mammals that are contaminated with methylmercury is arguably the most important source of exposure. Exposures to elemental and inorganic mercury mainly occur in occupational settings or via contact with products containing mercury.

There is great variability in mercury exposure worldwide.

There remains the utmost concern about mercury exposure in vulnerable groups who are sensitive owing to extrinsic (e.g., high exposures) and intrinsic (e.g., physiological) factors. Elevated mercury exposures in key groups of concern for which there exist a relatively robust dataset include Arctic populations (e.g., Indigenous Peoples) who consume fish and marine mammals, riverine (e.g., Amazonian), coastal and/or small-island communities who are avid fish and seafood consumers, and individuals who either work or reside at artisanal and small-scale gold mining sites.

Assessing mercury exposure is relatively straightforward by the use of biomarkers. Measures of mercury in hair and urine samples are particularly suitable as they provide information on the two main forms of mercury. Their collection is relatively non-invasive, requires no specialized training or handling, and is relatively cheap.