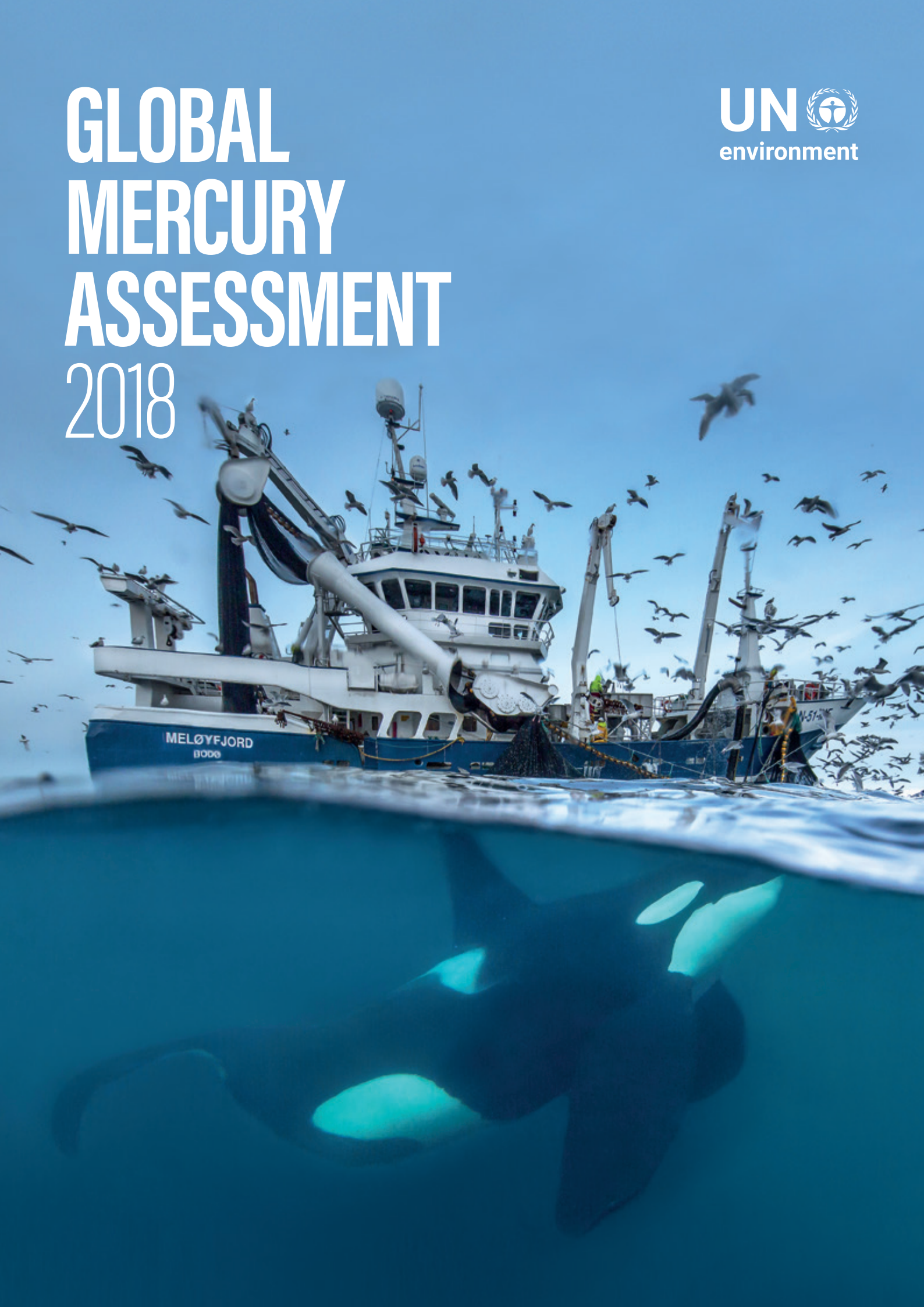
GLOBAL MERCURY ASSESSMENT 2018

UN environment



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GLOBAL MERCURY ASSESSMENT 2018

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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.

1 **A new global inventory of mercury emissions to air from anthropogenic sources in 2015 quantifies global emissions from 17 key sectors at about 2220 tonnes.** There are also smaller anthropogenic sources that are not yet possible to quantify in the detailed global inventory. Emissions from these additional sources are evaluated to total on the order of tens to hundreds of tonnes per year. They would therefore not significantly change the total global emissions inventory but may be of local or regional significance.

2 **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 European Union. 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.

3 **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.

4 **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 (2%). Emissions from waste that includes mercury-added products comprise about 7% of the 2015 global inventory.

5 **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, known as legacy mercury. Historical emissions up to the end of the 19th century, mainly from gold and silver mining in the Americas, and mercury (cinnabar) mining and refining contributed more to the present-day anthropogenic mercury in soils and the oceans than all 20th century industrial sources combined. The presence of legacy mercury and the potential for climate change to influence its remobilization complicates our ability to assess potential future changes.

6 **Artisanal and small-scale gold mining introduced about 1220 tonnes of mercury into the terrestrial and freshwater environments in 2015, but this amount cannot be reliably separated between discharges to soils and releases to water.** Global releases of anthropogenic mercury from other sources to aquatic environments totalled about 580 tonnes in 2015. The major sectors contributing to these 580 tonnes are waste treatment (43%), ore mining and processing (40%), and energy (17%).

7 **Natural production of methylmercury in the oceans and in some lakes is often not limited by the input of inorganic mercury.** Other factors such as climate change and changes in terrestrial and aquatic ecosystem processes are playing increasingly important roles in the mercury cycle, affecting the distribution, chemical interactions and biological uptake of mercury in the environment.

8 **Reductions in mercury emissions and resulting declines in atmospheric concentrations 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 previously deposited into soils, sediments, and aquatic systems.

9 **Mercury loads in some aquatic foodwebs are at levels of concern for ecological and human health.** Anthropogenic mercury emissions and releases, current and legacy, are the major contributors to increased mercury levels and exposure.

10 **All people are exposed to some amount of mercury.** For many communities worldwide, dietary consumption of fish, shellfish, marine mammals, and other foods is the most important source of methylmercury exposure. Exposures to elemental and inorganic mercury mainly occur in occupational settings (including artisanal and small-scale gold mining) or via contact with products containing mercury. There remains high concern for vulnerable groups including some indigenous populations and other populations with high dietary or occupational exposure to mercury.

The Global Mercury Assessment 2018 is based on improved information for estimating emissions and releases and improved understanding of the mercury cycle in the environment. In addition, the 2018 report provides new information about mercury exposure in animals and humans. These improvements are the result of mercury research and monitoring around the world. They provide a strong base of knowledge to support actions to reduce mercury emissions and releases and to reduce ecosystem and human exposure.

Further improvements in our understanding of mercury can further refine the ability to identify efficient actions to reduce mercury pollution and its effects. Such improvements include basic research on aspects of the mercury cycle as well as systematic monitoring methods to expand the geographic coverage of measurements of mercury pollution. As a chemical element, mercury cannot be destroyed. Mercury removed from fuels and raw materials in order to reduce emissions will result in mercury-contaminated waste, which in turn can be a source of releases.

Mercury removed from emissions and from releases must still be managed responsibly to avoid it becoming a waste management problem or a secondary source. Understanding how mercury removed from current uses and sources is currently managed and how it can be safely managed and stored in the future will help account for the full life-cycle of mercury that is mobilized through human activity, safeguarding the environment and humans when it is removed.

1 INTRODUCTION

Background and mandate

Global inventories for mercury emissions to air from human sources have been produced at approximately five-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 Minamata 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 to the GMA. The GMA 2018 has been prepared in response to a request from the Governing Council of UN Environment (now the UN Environment Assembly) in 2013 to update the Global Mercury Assessment 2013 (GMA 2013) for delivery no later than 2019.

Cyril Villemain/UN Environment

Developing the 2018 Report

As in 2008 and 2013, the Technical Background Report to the GMA 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). The chapters on emissions to air and releases to water use both national and independently compiled global data on activity levels to derive estimates of emissions and releases using a standardized methodology. As such the resulting estimates are not official national estimates. 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; the AMAP mercury expert group; the UN Economic Commission for Europe Convention on Long-range Transboundary Air Pollution groups; industry; and non-governmental organizations. Each chapter was prepared by a team of experts and then reviewed to ensure its scientific accuracy. The evaluation of information on 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. In this report, "mercury" refers to the chemical element in all forms, in contrast to the Minamata Convention, which distinguishes "mercury" from "mercury compounds." To the extent possible, the information comes from the published scientific literature, supplemented where necessary by other sources. Since the GMA 2018 is intended as a basis for decision making, emphasis is given to anthropogenic emissions (mercury going into the atmosphere) and releases (to water), 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 8). In addition to updating GMA 2013, new sections are included on observed levels of mercury in biota (Chapter 7) and observed levels and trends 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 UNDERSTANDING THE GLOBAL MERCURY CYCLE

Mercury is emitted to the atmosphere and released to waters and land as a result of anthropogenic or 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, or be transported further by water, or be taken into the food web. Over the course of centuries or longer, 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, a toxin of high concern 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 efforts to reduce mercury emissions to air and releases to water and land will affect mercury concentrations in the environment, including biota and humans.

▼ Volcanically active areas are natural sources of mercury emissions.

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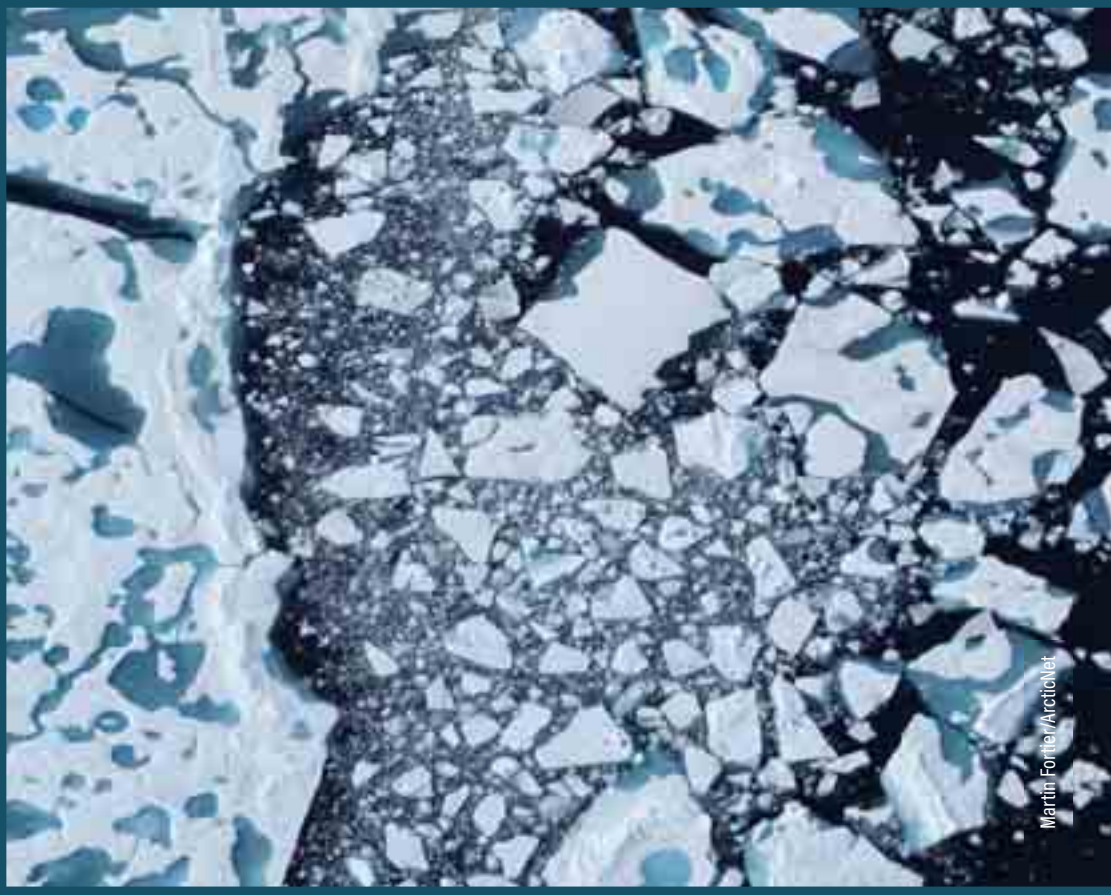
Current understanding and questions

The 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 tripled 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 in terms of total storage. Mercury from historical human activities now in soils and oceans acts as a reservoir by being available for re-emissions to air, maintaining atmospheric mercury concentrations at higher levels than would be the case only from current emissions.



▲ Loss of sea ice in the Arctic due to climate change allows greater exchange of mercury between the oceans and the atmosphere.

Since The 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 previously. For the oceans, 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 16th 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 historical 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.

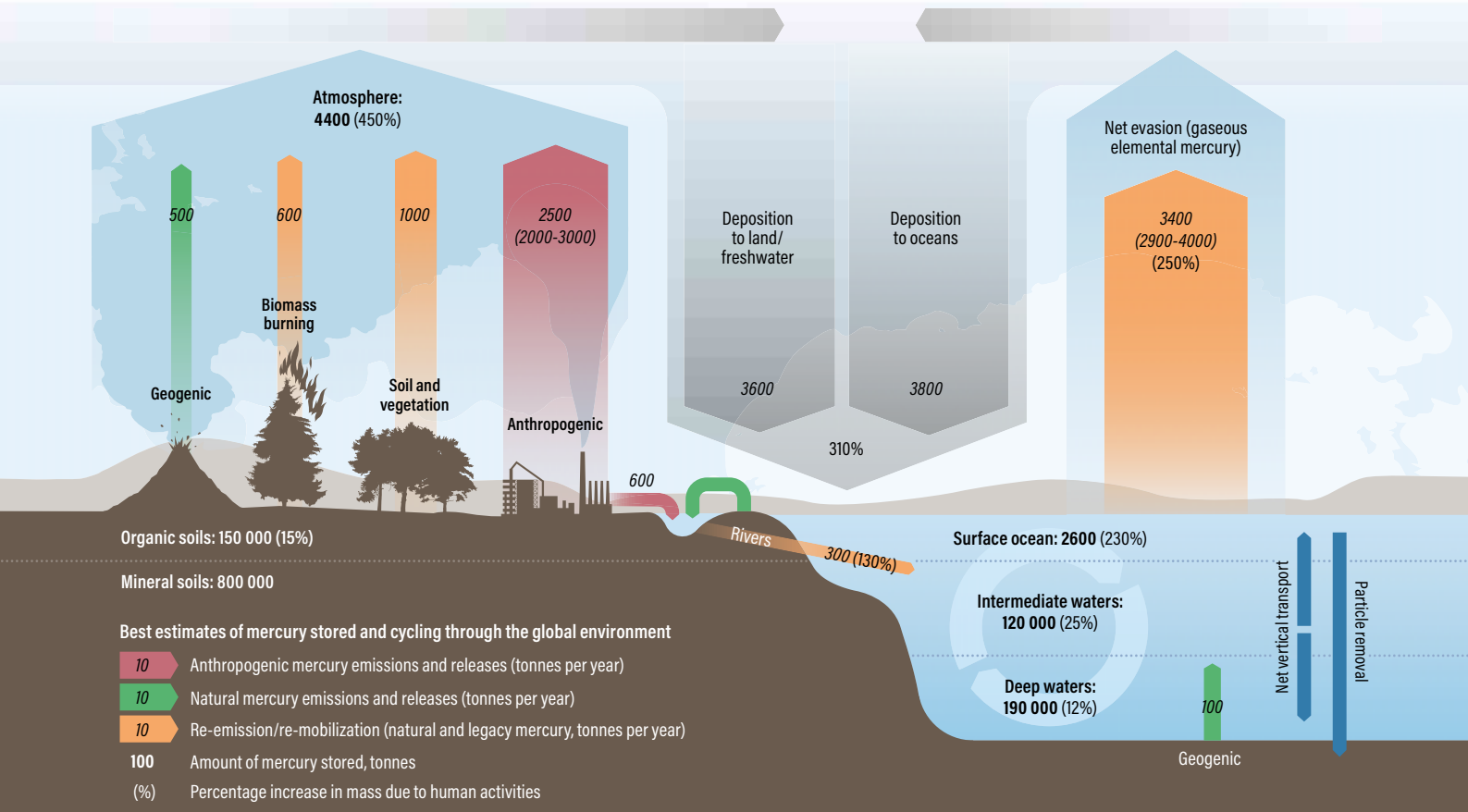
Revised global and oceanic total mercury budgets

With these new findings in mind, recent modelling indicates that mining since the 16th century 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 model 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 the GMA 2018, showing the stores and movement of mercury in the global environmental system. Most of the changes from the GMA 2013 are relatively small, though the emissions from soils and vegetation are notably lower than the previous average. Based on this revised global budget, the mercury budget in the world's oceans was updated as well.

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 some of the 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.

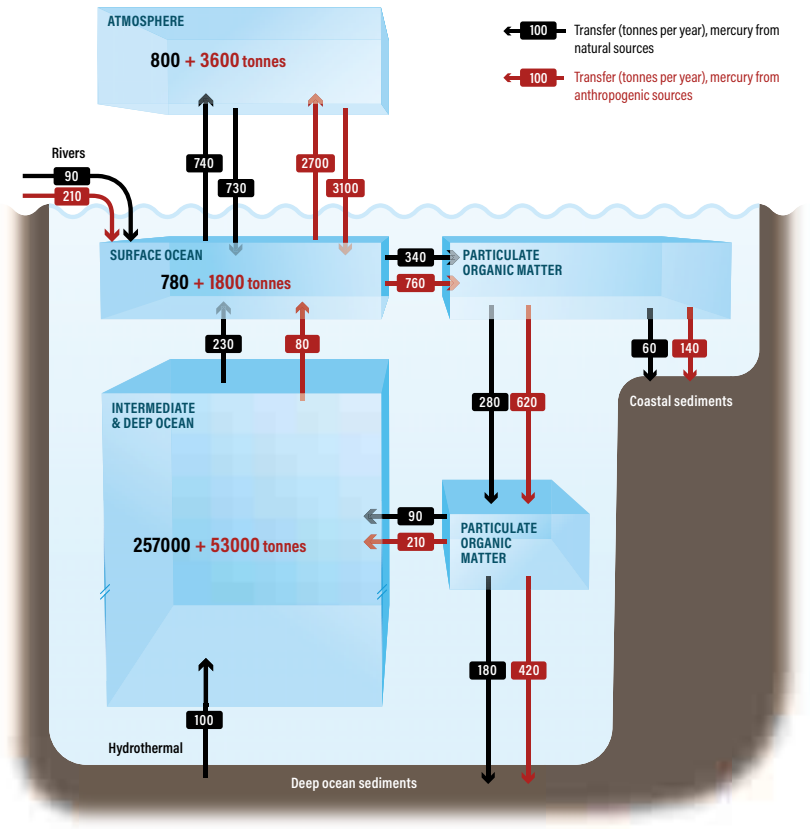
▼ The updated global mercury budget shows the impact of human activities on the mercury cycle and the resulting increase in mercury accumulated in soils and oceans.



The Stephen Low Company

▲ Hydrothermal vents on the sea floor release mercury to deep ocean waters.

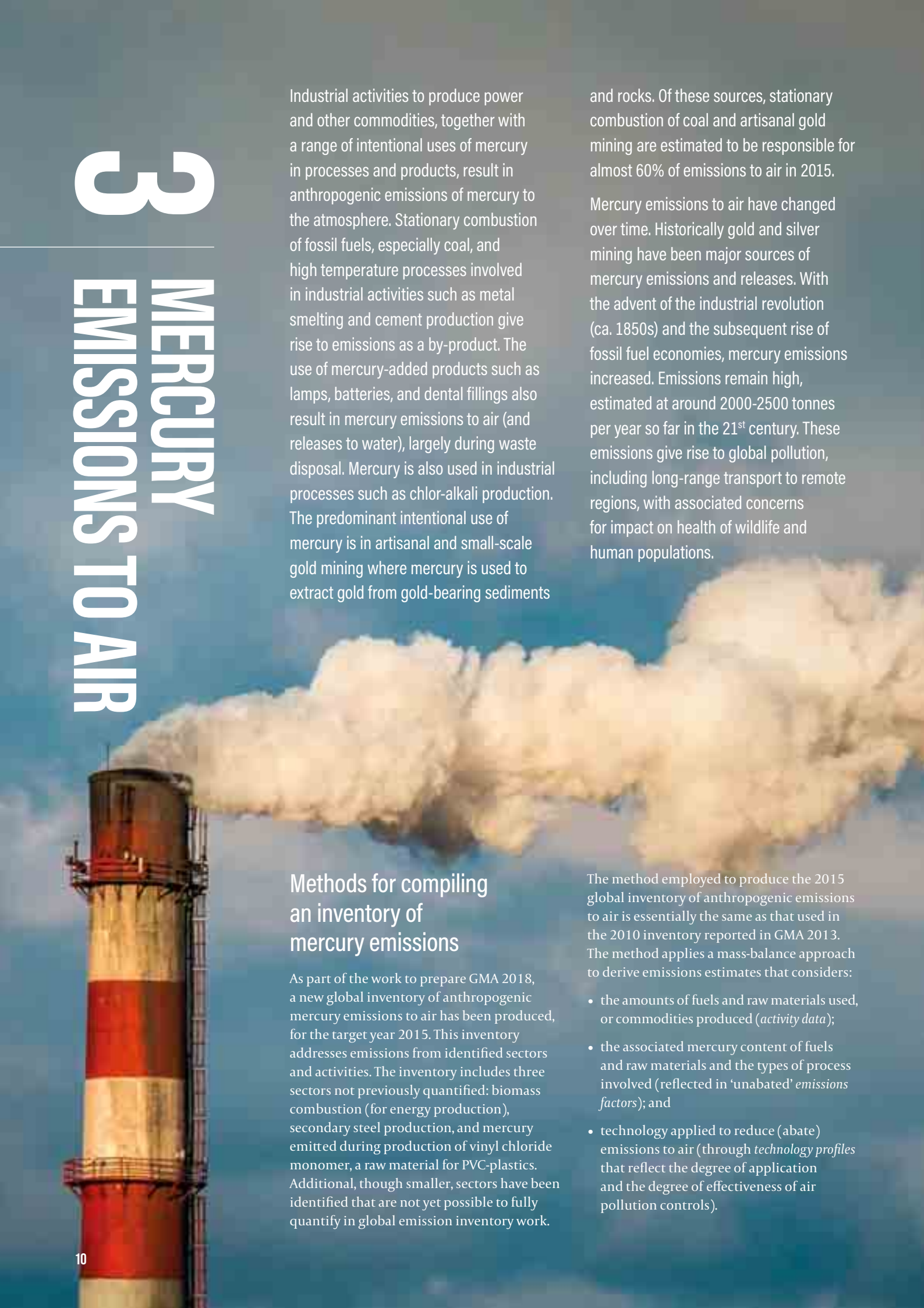
▶ The amount of mercury removed by burial in deep ocean sediments is small compared to the amounts currently deposited at the surface of the ocean. This leads to a build up of mercury in ocean waters.



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-added 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. The predominant 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 so far in 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 identified sectors and activities. The inventory includes 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 PVC-plastics. Additional, though smaller, sectors have been identified that are not yet possible to fully quantify 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.

In addition to the improvements in emission inventory methodology, improved information on national emissions have been made available from national research and inventory efforts in many countries.

Methodological improvements applied in the 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 refning	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 estimated to be 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. 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. These unquantified 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 give an approximate range to this estimate of anthropogenic emissions of 2000-2820 tonnes. 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 increased emissions from some industrial sectors, appear to be largely due to increased economic activity in some regions, notably East Asia. Emission increases have to some extent been offset by decreases in coal use and installation of sulphur dioxide and mercury control technologies in China. 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.

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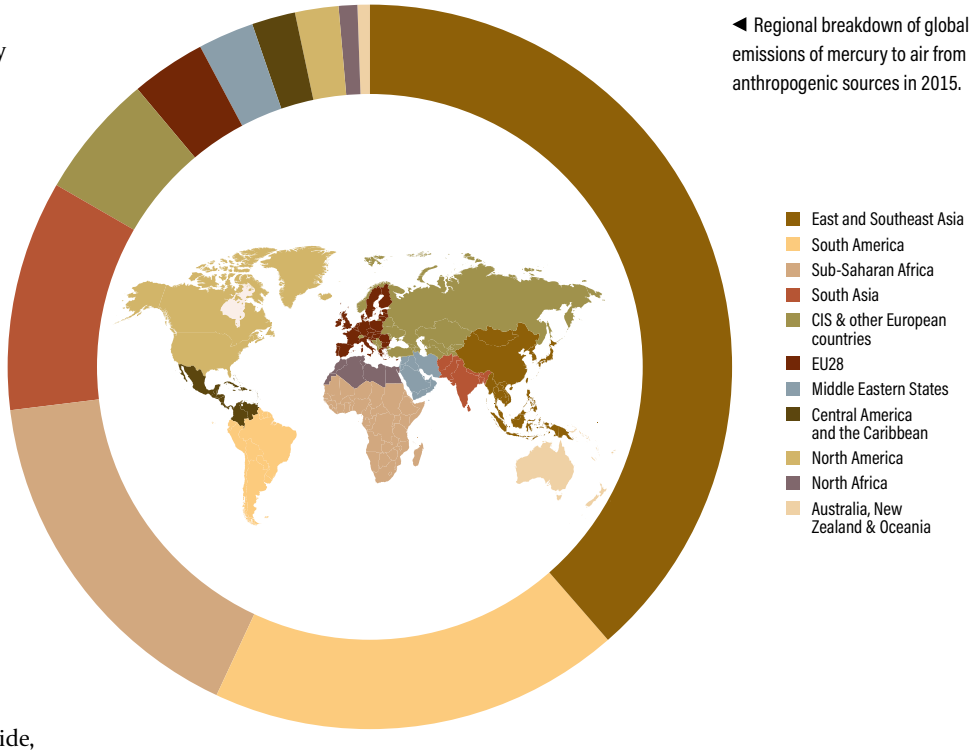
Summary of results by region

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 (ASGM) accounts for about 70% and up to 80% of the emissions from South America and Sub-Saharan Africa, respectively.



◀ Regional breakdown of global emissions of mercury to air from anthropogenic sources in 2015.

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 former Soviet Union (CIS) and other European countries outside the European Union, 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 European Union (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-added 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 Asia, 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.

▼ Quantities of mercury emitted to air from anthropogenic sources in 2015, by different sectors in different regions.

	Sector group (emissions, tonnes)				Regional total (range), tonnes	% of global total
	Fuel combustion	Industry sectors	Intentional-use (including product waste)	Artisanal and small-scale gold mining		
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 Southeast Asia	229	307	109	214	859 (685-1430)	38.6
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

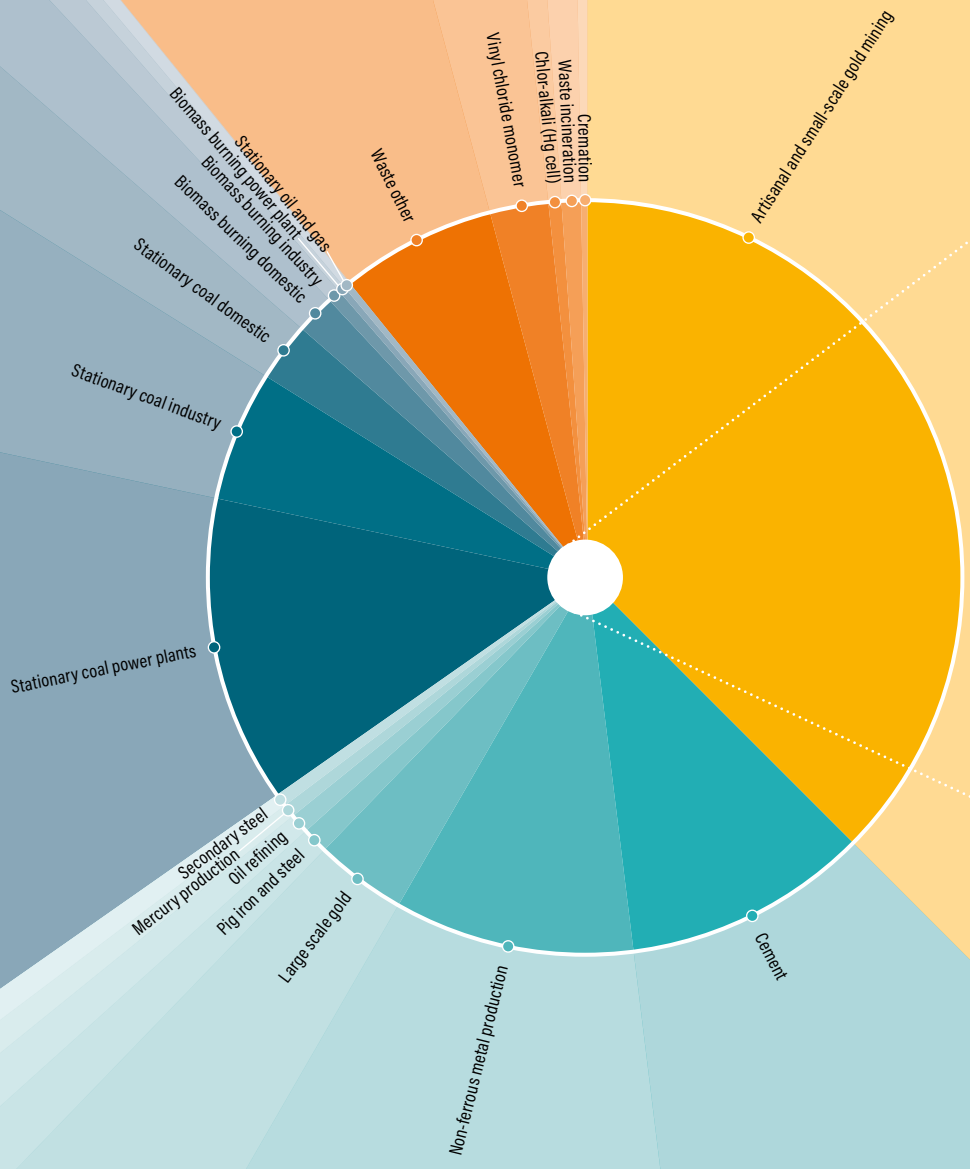
Comparison of regional results

▲ The relative pattern of regional contributions from the major sector categories to the global mercury inventory is heavily influenced by emissions from artisanal and small-scale gold mining.

Larry C. Price

Breakdown of global 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-added product waste (7%), stationary combustion of other fuels including biomass (3%), ferrous-metal production (2%), and other sources (2%) make up the rest.



▶ Proportions of global emissions of mercury to air from different anthropogenic source sectors in 2015.

Kemal Jufri/Panos Pictures/Felix Features

r.classen/Shutterstock.com

▼ Quantities of mercury emitted to air from anthropogenic sources in 2015, by different sectors.

Sector	Mercury emission (range), tonnes	Sector % of total
Artisanal and small-scale gold mining (ASGM)	838 (675-1000)	37.7
Biomass burning (domestic, industrial and power plant) *	51.9 (44.3-62.1)	2.33
Cement production (raw materials and fuel, excluding coal)	233 (117-782)	10.5
Cremation emissions	3.77 (3.51-4.02)	0.17
Chlor-alkali production (mercury process)	15.1 (12.2-18.3)	0.68
Non-ferrous metal production (primary Al, Cu, Pb, Zn)	228 (154-338)	10.3
Large-scale gold production	84.5 (72.3-97.4)	3.8
Mercury production	13.8 (7.9-19.7)	0.62
Oil refining	14.4 (11.5-17.2)	0.65
Pig iron and steel production (primary)	29.8 (19.1-76.0)	1.34
Stationary combustion of coal (domestic/residential, transportation)	55.8 (36.7-69.4)	2.51
Stationary combustion of gas (domestic/residential, transportation)	0.165 (0.13-0.22)	0.01
Stationary combustion of oil (domestic/residential, transportation)	2.70 (2.33-3.21)	0.12
Stationary combustion of coal (industrial)	126 (106-146)	5.67
Stationary combustion of gas (industrial)	0.123 (0.10-0.15)	0.01
Stationary combustion of oil (industrial)	1.40 (1.18-1.69)	0.06
Stationary combustion of coal (power plants)	292 (255-346)	13.1
Stationary combustion of gas (power plants)	0.349 (0.285-0.435)	0.02
Stationary combustion of oil (power plants)	2.45 (2.17-2.84)	0.11
Secondary steel production *	10.1 (7.65-18.1)	0.46
Vinyl-chloride monomer (mercury catalyst) *	58.2 (28.0-88.8)	2.6
Waste (other waste)	147 (120-223)	6.6
Waste incineration (controlled burning)	15.0 (8.9-32.3)	0.67
Total	*2220 (2000-2820)*	*100*

Colour coding indicates main sector groups
(**Stationary combustion**, dark blue; **Industry**, light blue; Sectors associated with **Intentional use**, dark orange; **ASGM**, light orange).

* Sectors included for the first time in the 2015 inventory.

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 were 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 also updated with respect to those applied in the original 2010 inventory presented in the GMA 2013. Changes in inventory methods from one assessment to the next complicate comparisons between inventories produced at different times, and make it impossible to compare the 2010 and 2015 inventories with those prepared for earlier years.

Estimated global emissions of mercury to the atmosphere from anthropogenic source 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 and some sectors, but increasing emissions are seen in most other regions. Increased economic activity, as reflected in activity data, seems to be a major factor in driving up emissions associated with certain industrial sectors in a number of regions. In this respect, differences between 2010 and 2015 may also reflect recovery following the financial crisis in 2008 that may have influenced global emissions in 2010. These factors appear to have more than offset any (technological) efforts to reduce mercury emissions in most regions.

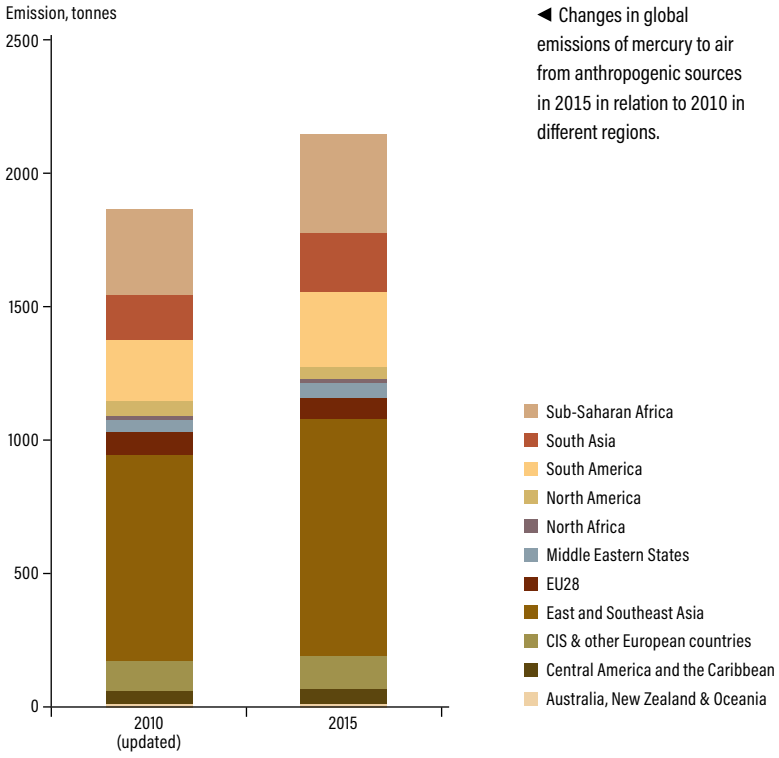
Mercury emissions to air have decreased between 2010 and 2015 in two of the eleven world regions: North America and the EU. In the case of North America in particular, shifts in fuel use (from coal to oil/gas) in the energy sector, combined with introduction of control measures that have high efficiency

▼ Changes in emissions from 2010 to 2015 (tonnes) from different sectors (columns) in different regions (rows). Increases are shown in orange and decreases in blue. Size of coloured bars indicate the percentage change.

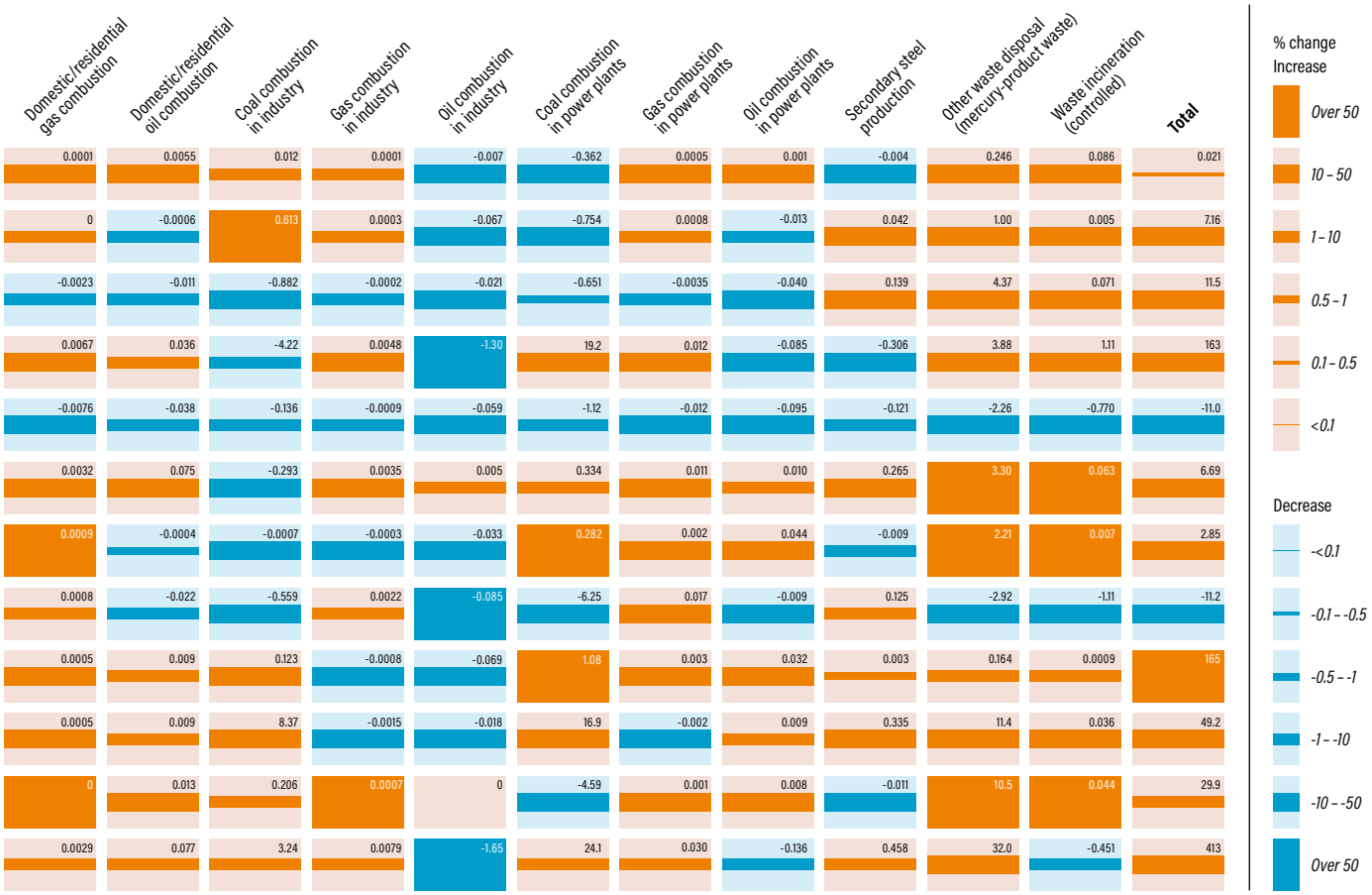
	Artisanal and small-scale gold mining	Biomass burning	Cement production	Cremation emissions	Chlor-alkali production (mercury process)	Non-ferrous metal production	Large-scale gold production	Mercury production	Oil refining	Primary iron and steel production	Domestic/residential coal combustion
Australia, New Zealand & Oceania	0	0.004	0.063	-0.019	0	-0.016	0.029	0	-0.005	-0.005	-0.009
Central America and the Caribbean	2.22	0.128	0.247	-0.119	0	-1.75	3.64	1.92	0.001	0.023	0.027
CIS & other European countries	0.675	0.077	1.58	0.055	-0.221	1.55	5.61	-0.635	0.018	0.155	-0.668
East and Southeast Asia	-30.2	-0.631	31.8	-0.486	0	83.0	-2.82	0.338	0.681	1.77	3.25
EU28	0	0.256	-1.36	-0.582	-2.98	-1.34	0.172	0	-0.036	0.090	-0.608
Middle Eastern States	0.225	-0.090	2.78	-0.002	0	0.092	0.362	0	0.017	0.109	-0.574
North Africa	0	-0.006	0.499	-0.0005	0	-0.669	0.602	-0.034	-0.025	-0.024	0
North America	0	-0.038	0.607	-0.034	-0.91	-0.029	0.076	0	0.064	0.017	-0.181
South America	163	0.224	1.00	-0.195	0.106	-1.14	1.24	0	-0.006	-0.157	0.009
South Asia	3.38	1.12	6.31	0.241	-1.88	2.00	-0.035	0	0.537	1.12	-0.809
Sub-Saharan Africa	19.9	1.35	3.03	-0.0026	0	-3.88	2.54	0	-0.008	-0.041	0.906
Total	159	2.39	46.5	-1.14	-5.89	77.8	11.4	1.59	1.24	3.06	1.34

to reduce mercury emissions at major point sources appears to be a major factor. In all other regions, however, mercury emissions increased.

Higher global 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 dwarfed by 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.



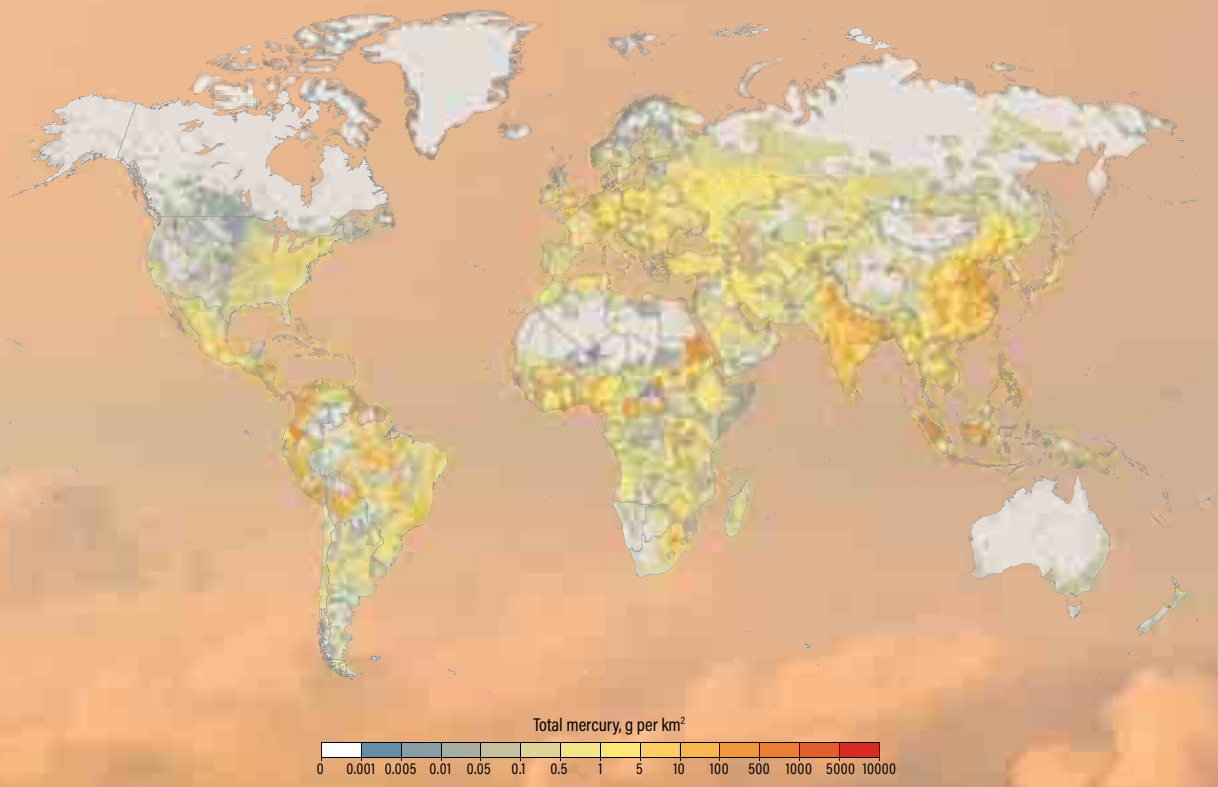
◀ Changes in global emissions of mercury to air from anthropogenic sources in 2015 in relation to 2010 in different regions.



Where the emissions occur

The regional breakdown of emissions shown on previous pages is a first step in analyzing global patterns of mercury emissions. But the regions are large, and the precise location of the actual emissions may have large implications for transport and fate of the mercury. For example, mountain ranges and weather patterns can affect air movement, and so the same amount of mercury emitted in one place may be transported in a different direction from mercury emitted a relatively short distance away. Finer-scale distribution of mercury emissions is necessary for modeling mercury distribution and deposition around the world. As can be seen in the map below, mercury emissions vary greatly from place to place within each region. Data of this kind help explain differences in atmospheric mercury measurements at different monitoring stations, as well as patterns in mercury deposition around the world.

▼ Spatially distributed emissions in 2015.



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Comparing GMA global inventory estimates with national inventories

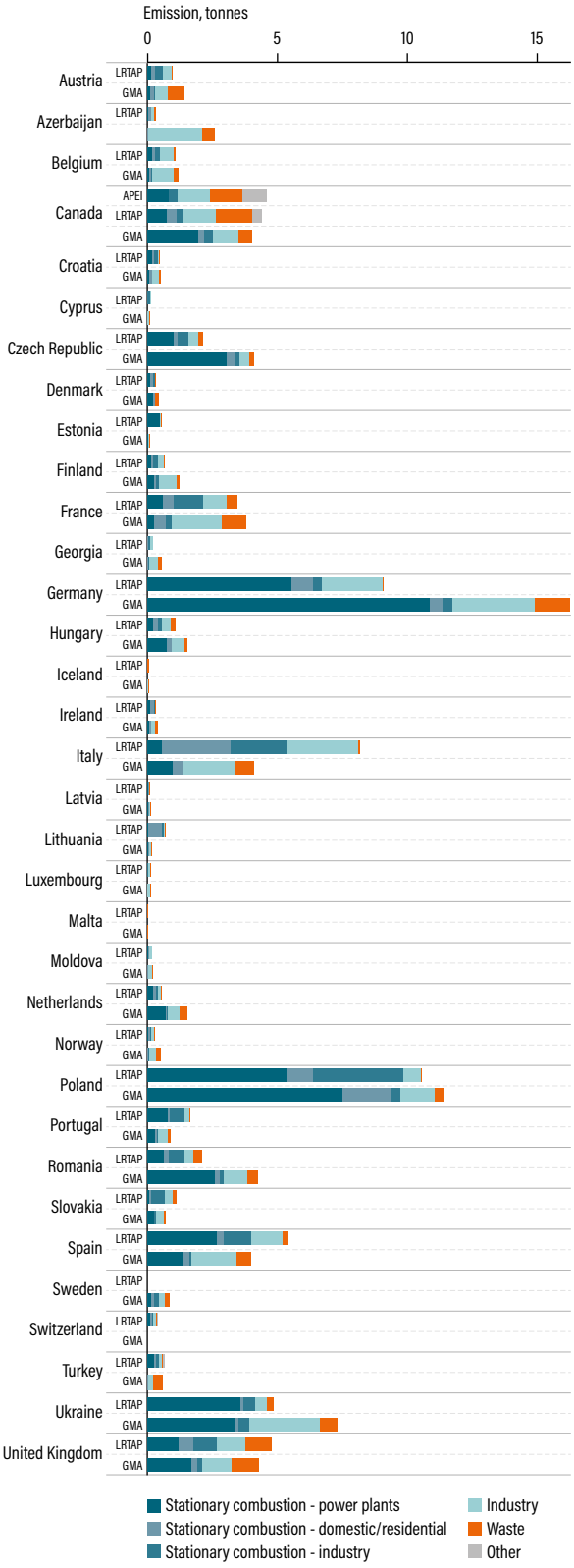
The target for the GMA 2018 air emissions inventory activity remains the production of a robust **global** inventory for the target year of 2015, for a defined set of sectors for which reliable global estimates can be produced. Although it presents emission estimates broken down by sector for each of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

A major new development since GMA 2013 is that more than 150 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. Many countries have started developing national action plans on artisanal and small-scale gold mining, including establishing baseline data for this sector. The preparation of national inventories and estimates 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 prepared in response to reporting obligations for the UN ECE Convention on Long-range Transboundary Air Pollution or the Minamata Convention, 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 the few MIAs that were available at the time of preparing the GMA 2018 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 tens to hundreds of tonnes. Emissions estimates associated with many of these additional sources have a high level of uncertainty.



▲ Comparison of GMA emission estimates for 2015 with emissions reported for some countries under the UN ECE Convention on Long-range Transboundary Air Pollution.

4 LEVELS OF MERCURY IN AIR

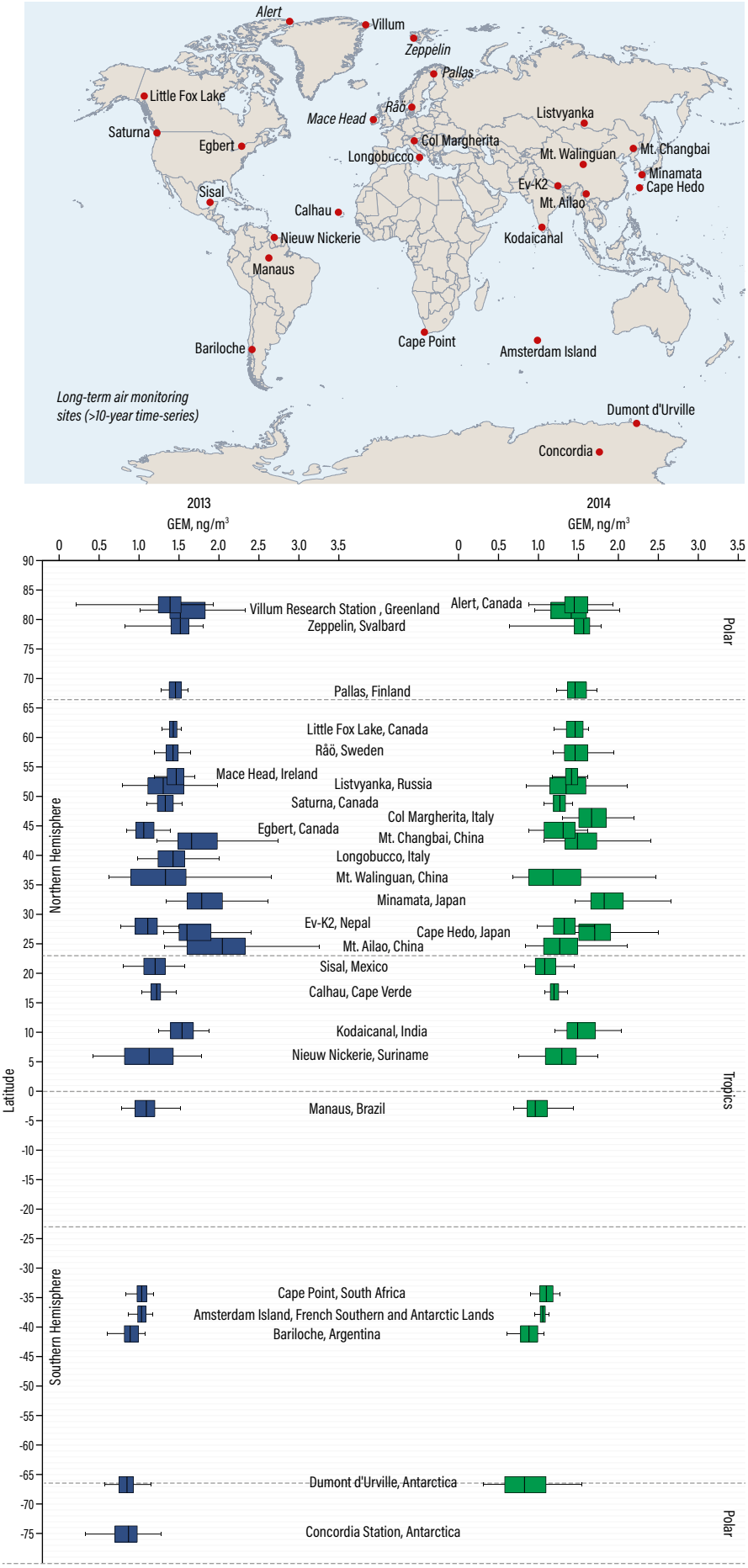
There are several major global and regional mercury monitoring networks around the world. Although there are monitoring sites in both the northern and southern hemispheres, there are still large regions that lack any sites and hence any data, such as Africa, Latin America and the Caribbean, and Russia. Nonetheless, much can be said about mercury levels in the world's atmosphere. Globally, mercury levels are higher in the northern hemisphere, due to the presence of more emission sources. Regionally, mercury levels in the atmosphere reflect the presence of local sources as well as transport pathways that can carry mercury plumes for thousands of kilometres.

Pure Earth

Spatial variability in the Southern and Northern Hemispheres

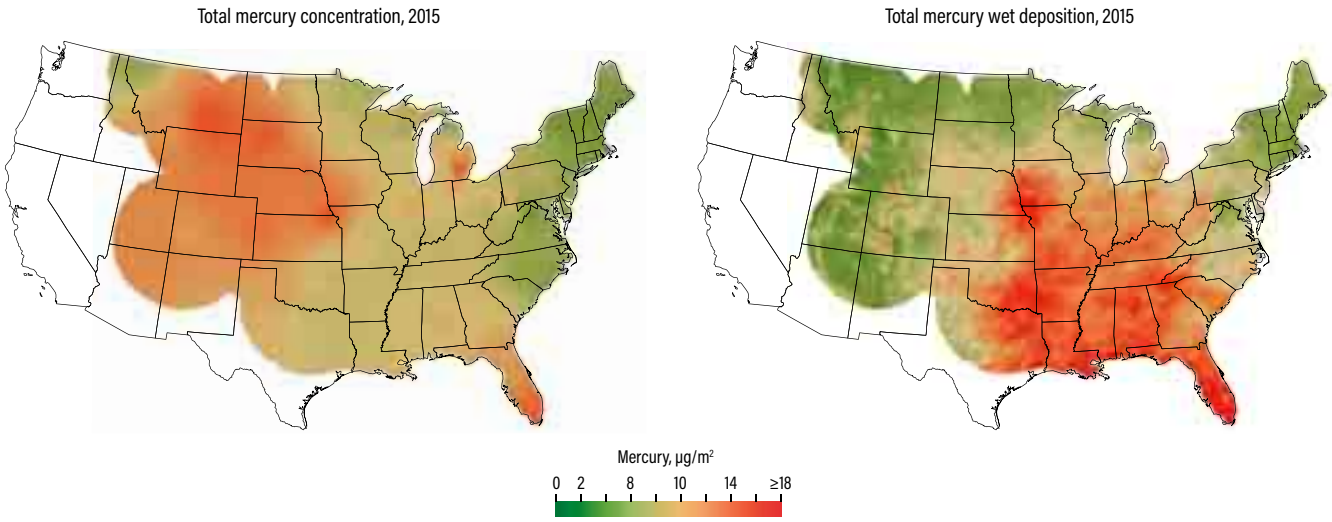
There is a clear gradient of mercury concentrations between the Northern and Southern hemispheres, confirming that the gradient observed is mostly driven by local and regional sources, which can be anthropogenic, natural, or a combination of both. Seasonal variations of gaseous elemental mercury concentrations 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 at all European sites was the amount of precipitation, with highest precipitation resulting in highest deposition. 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.



▶ Latitudinal trends in gaseous elemental mercury at air monitoring stations shown on the map above in 2013 and 2014, also showing sites with long-term (>10 years) monitoring.

Regional variability in atmospheric mercury



▲ Total mercury concentrations and wet deposition in the USA in 2010 and 2015.

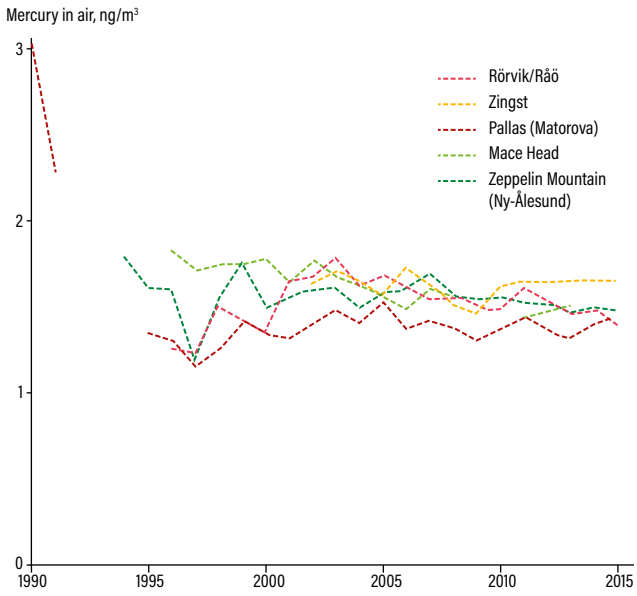
Although mercury is transported around the world in the atmosphere, there are distinct regional patterns in mercury concentrations and deposition. A few studies shed light on the extent of such variation, which has implications for how much mercury will be available to ecosystems and humans.

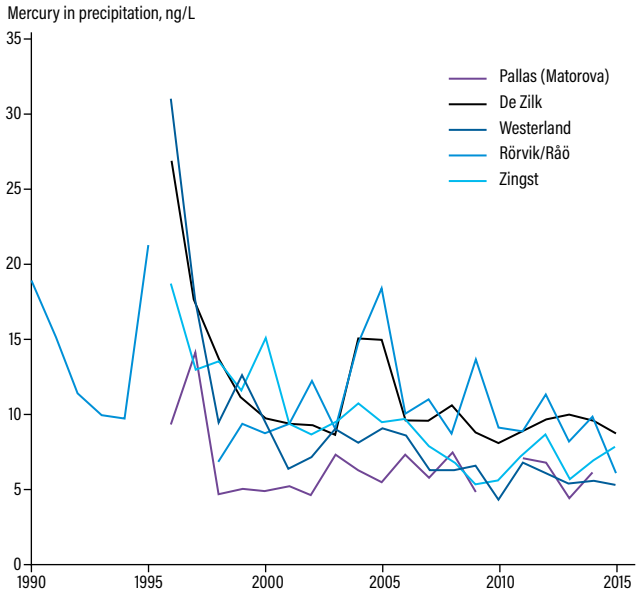
In North America, significant wet deposition of mercury is found along the U.S. Gulf Coast, and somewhat inland. Wet mercury deposition in these areas strongly correlates with higher precipitation. By contrast, the highest concentrations are found in the western areas where precipitation is lowest and 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.

Spatial and temporal trends of atmospheric mercury have been investigated for many measurement sites across Canada for over 20 years. Linear trends were estimated for all available data from each site. In all but 2 sites in western Canada, the data show a decrease in mercury concentrations.

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 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 areas, whereas the concentrations of different airborne mercury species in rural areas were also affected by chemical reactions occurring in the atmosphere.

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 farther inland in Finland and Sweden, which might be due to summertime evasion from the ocean or due to the fact that the High Arctic archipelago of 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, attributed to declines in primary anthropogenic source emissions.





▲ Trends in mercury in air and precipitation at selected stations in Europe.

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

Recent research has provided new insights into mercury patterns in the atmosphere. 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 indicating the influence of this source (not included in emission inventories) for atmospheric mercury cycling.

On several research flights in the U.S., plumes from 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 (USA) 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.

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 at higher elevations. Inside each layer of the atmosphere, gaseous elemental mercury is evenly distributed.

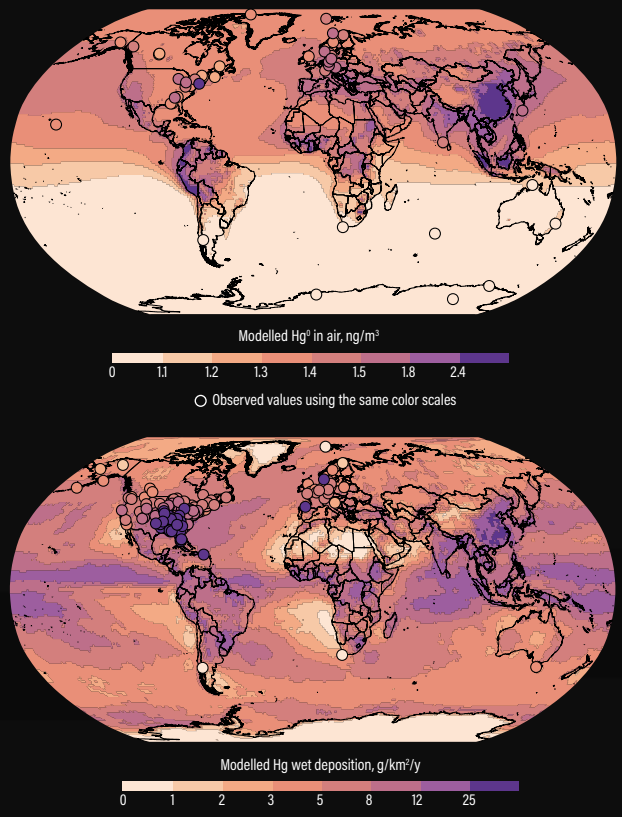
5 ATMOSPHERIC PATHWAYS, TRANSPORT, AND FATE OF MERCURY

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 and an understanding of their uncertainty are important for 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 emissions 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.



▲ Modelled gaseous elemental mercury concentration in surface air and wet deposition in 2015 compared with observed values (circles).

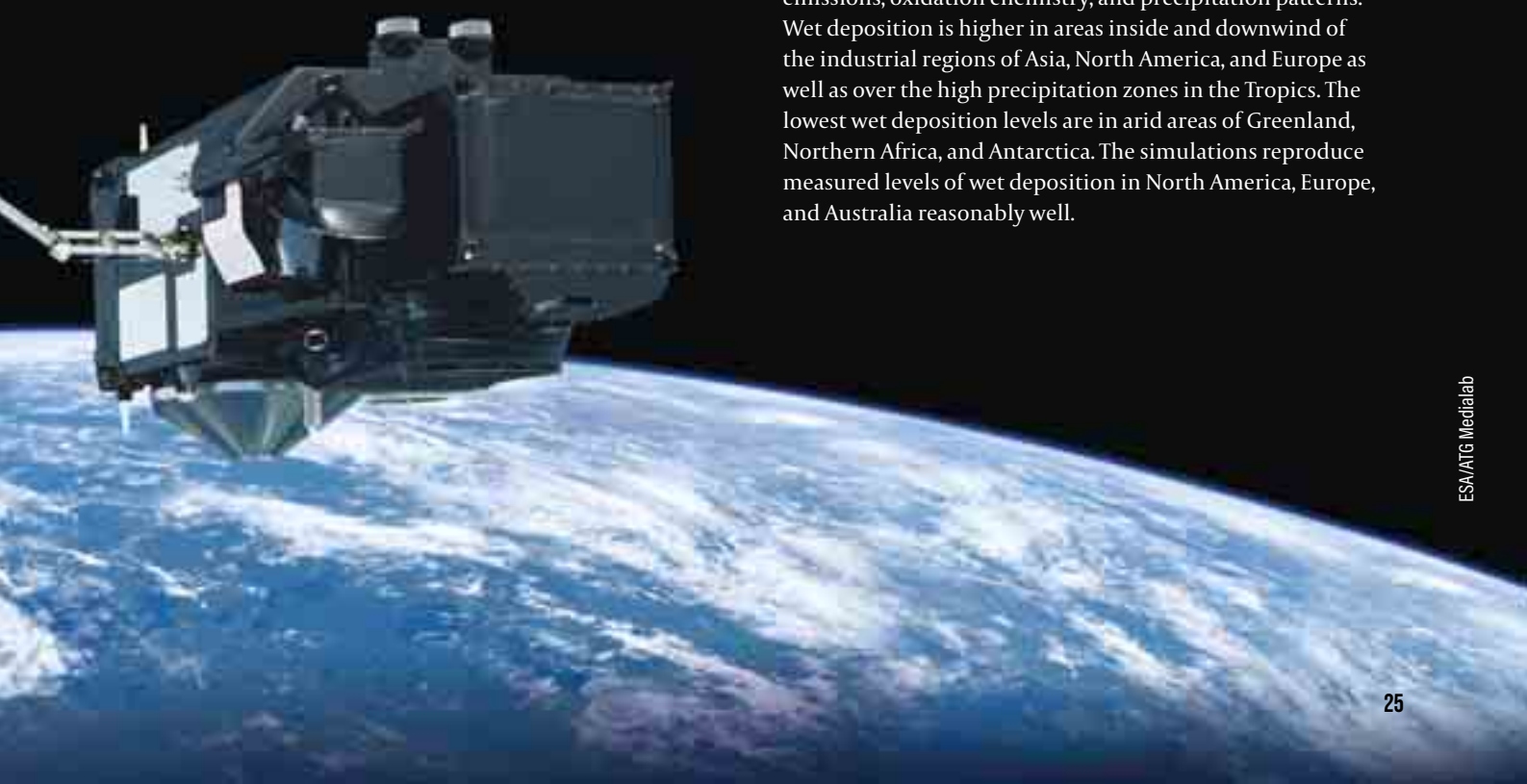
Results from mercury modelling

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.

Re-emissions of mercury and natural sources are the main contributors for mercury deposition over all regions except East Asia. Deposition over East Asia is dominated by direct anthropogenic emissions. 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.

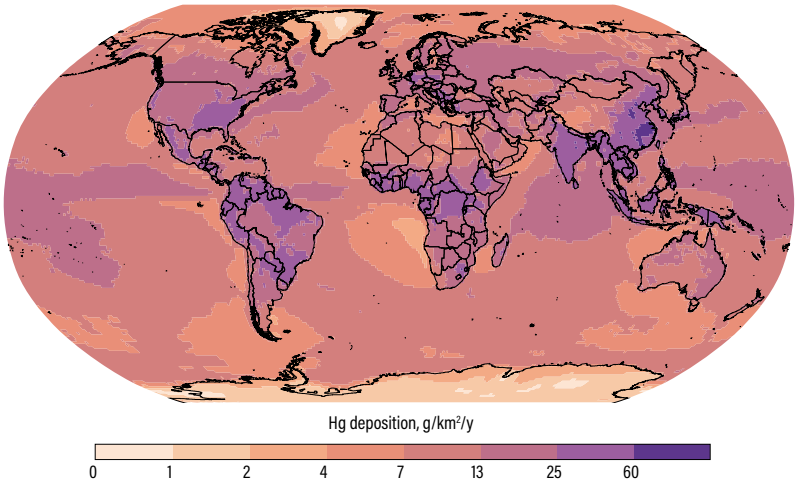
The current state of mercury dispersion in the atmosphere and deposition to various terrestrial and aquatic regions was studied by an ensemble of chemical transport models using the new inventory of anthropogenic mercury emissions in 2015 prepared for this assessment. The global distribution of gaseous 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.

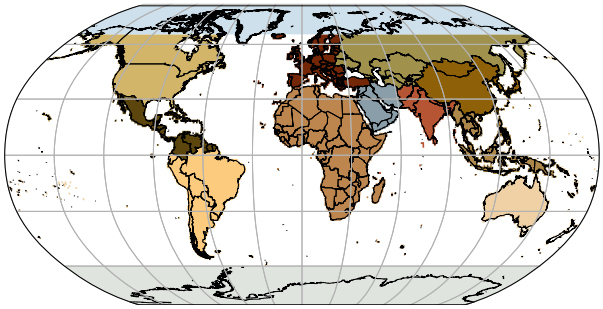


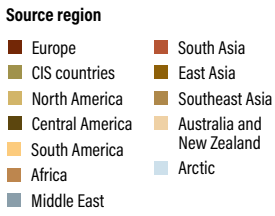
ESA/ATG Medialab

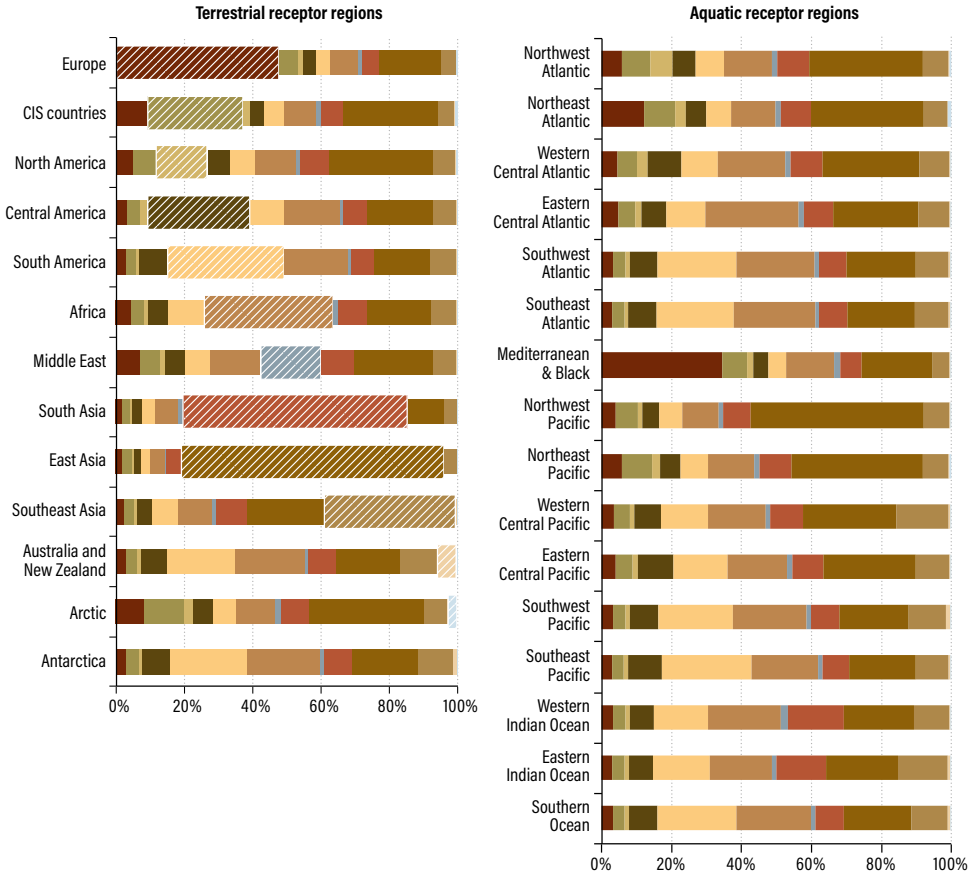
The regional pattern of deposition compared with atmospheric concentrations of gaseous elemental mercury shows relatively low wet and dry deposition in the Middle East and former Soviet Union countries and elevated deposition in Africa and South America. Over most of the regions average dry deposition is higher than wet deposition by 20-120%. In contrast to terrestrial regions, wet deposition to the ocean is higher than dry deposition.



► Modelled total (wet and dry) mercury deposition in 2015.







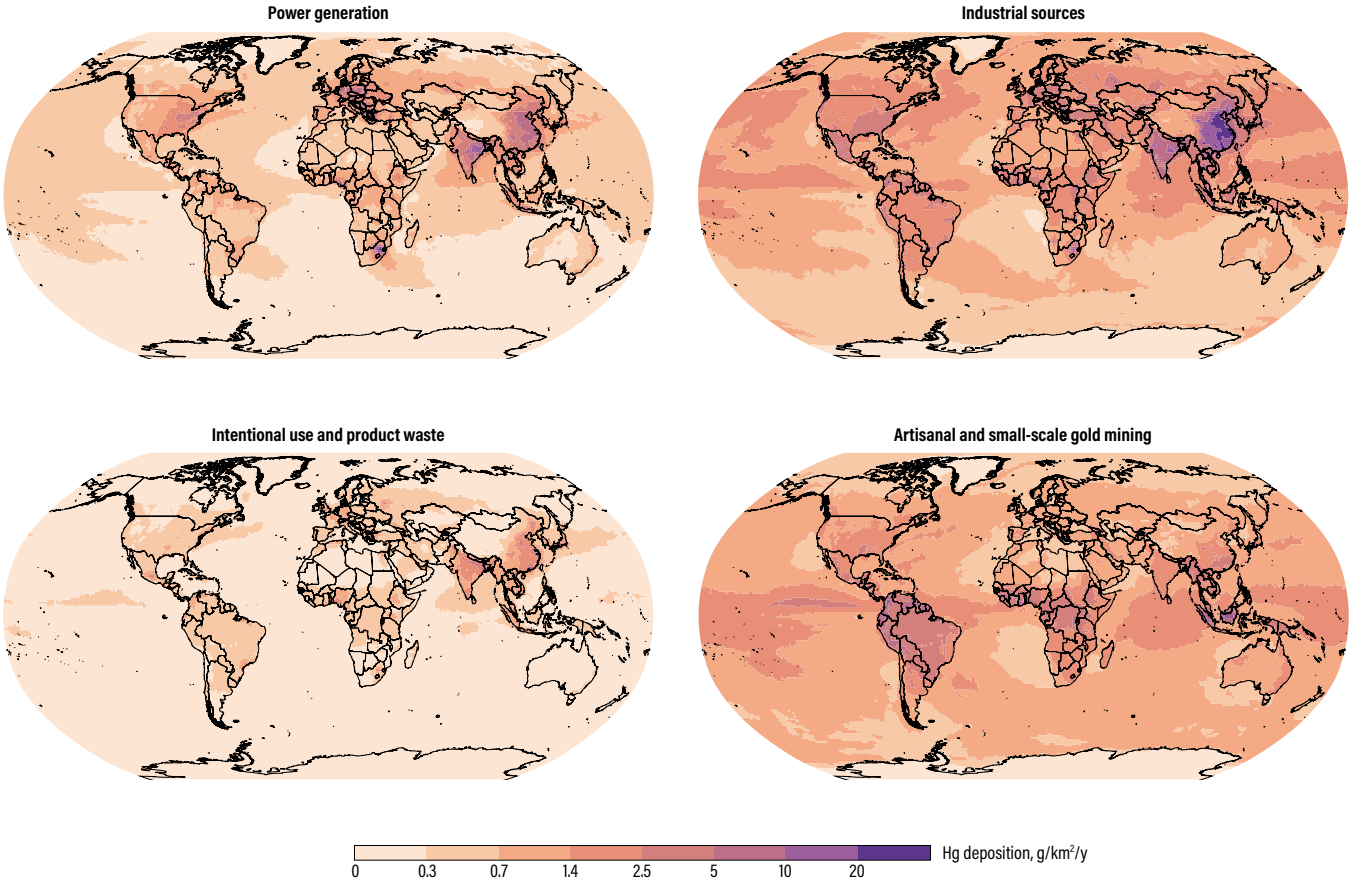
Deposition from direct anthropogenic emissions represents the mixture of domestic emissions and atmospherically transported mercury from sources located in other regions (foreign emissions). The share of foreign sources varies from 100% in Antarctic to 23% in East Asia. The largest foreign contributors are characterized by large anthropogenic emissions as well as active artisanal and small-scale gold mining.

◄ Source apportionment of mercury deposition from anthropogenic emissions to various terrestrial (left) and aquatic regions (right) in 2015. Colors depict source regions, indicated in map above: hatching shows the deposition in a particular region that originates from the region itself.

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

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.

▼ Modelled mercury deposition in 2015 from major emission sectors.



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Atmospheric chemistry

New information has improved 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 better reproduce some free tropospheric observations. Recent model intercomparisons have shown that there remain challenges in reproducing observed concentrations and patterns.

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.

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.

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 kilometres 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.

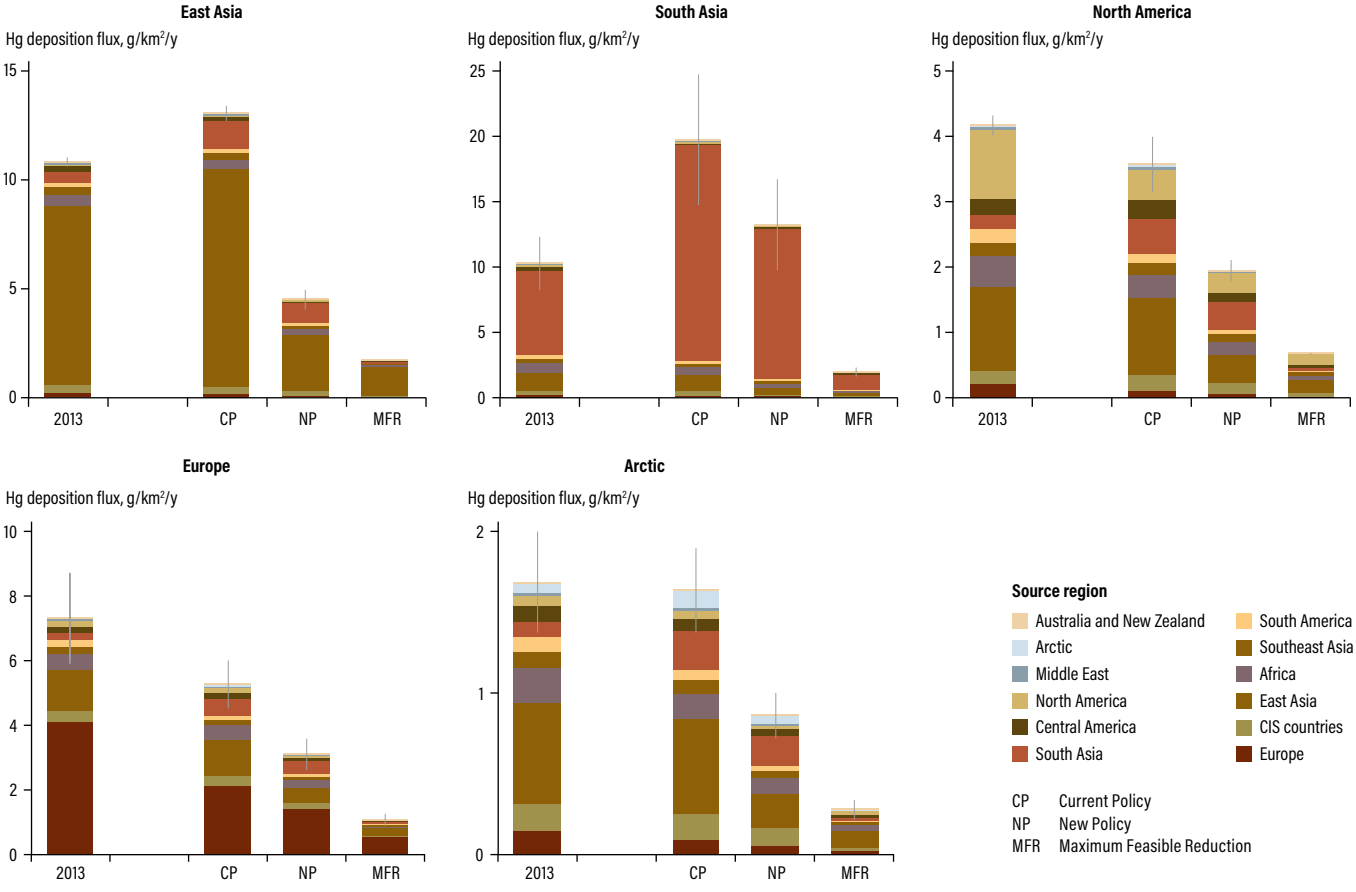
Historical trends and future scenarios

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 changes of atmospheric mercury concentration and deposition through 2035 due to changes in anthropogenic emissions, land use and land cover as well as climate change. The "Current Policy" scenario, in which no policy changes are made, predicted a decrease (20-30%) of mercury deposition in Europe and North America and an increase (up to 50 %) in South and East Asia. According to the "New Policy" scenario, in which policies that have been proposed are adopted, a 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.

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

▼ Source apportionment of mercury deposition in various geographical regions from anthropogenic sources in 2013 with projections for 2035 under three scenarios (current policy, new policy, and maximum feasible reduction), based on results from two models. Re-emissions of mercury deposited in earlier years from anthropogenic sources are not included.



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. Globally, 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. In the following discussions, it is considered separately, as estimates for this sector include releases to both water and land. Together, these are believed to account for about 1220 tonnes of mercury releases worldwide. Other sources included in the 2015 estimate account for about 580 tonnes of mercury releases to water.

W. Eugene Smith/Magnum Photos

Methods for estimating global anthropogenic mercury releases

The 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 or regions. As a result, the actual data used come from the 2000-2015 period.

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 estimates in the release inventory include the following 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

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.

Various methods were 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 in relation to mercury emissions to air. These factors were used together with the most recent mercury emission inventory (Chapter 3) to calculate the releases to water.

Group 2 is made up of sectors for which estimates were derived based on measured mercury concentrations and associated volumes of wastewater released and/or other relevant activity data. The sectors included are municipal wastewater, wastewater from coal-fired power plants, and coal washing.

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.


W. Eugene Smith/Magnum Photos

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.

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 580 tonnes, not including artisanal and small-scale gold mining (see Box).

Apart from releases to water and land resulting from artisanal and small-scale gold mining, the majority of global anthropogenic releases of mercury to aquatic systems are associated with the broad categories of waste treatment (42%), ore mining and processing (42%), and the energy sector (16%). Overall, the inventory is dominated by releases from non-ferrous metal production and two sectors within the waste treatment category, which are the use and disposal of mercury added products and the disposal of municipal wastewater.

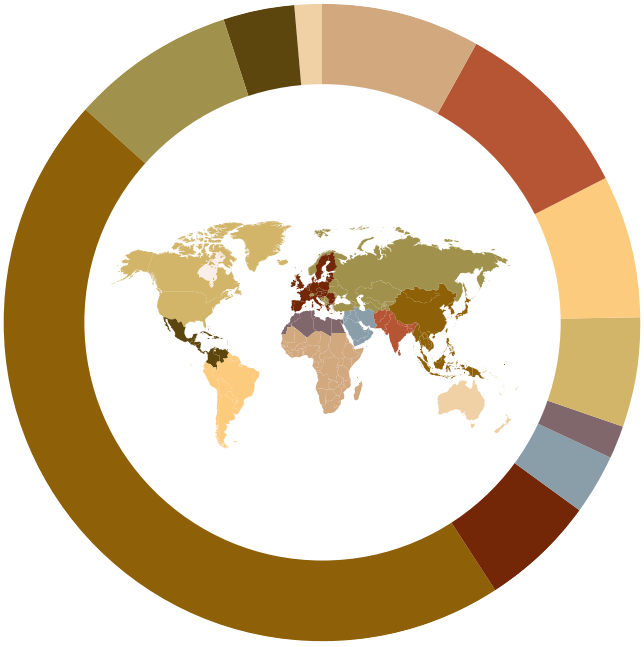
Minzayar Oo/Panos Pictures/Felix Features

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 combined mercury releases from this sector to water and land in 2015 were about 1220 tonnes, more than twice the estimated releases to water from other sectors included in the inventory. The vast majority of releases from artisanal and small-scale gold mining occur in South America (53%), East and Southeast Asia (36%), and Sub-Saharan Africa (8%). Other regions where artisanal and small-scale gold mining activities are undertaken — Central America and the Caribbean, CIS and other European countries, South Asia, and the Middle East — contribute a minor share of the total.

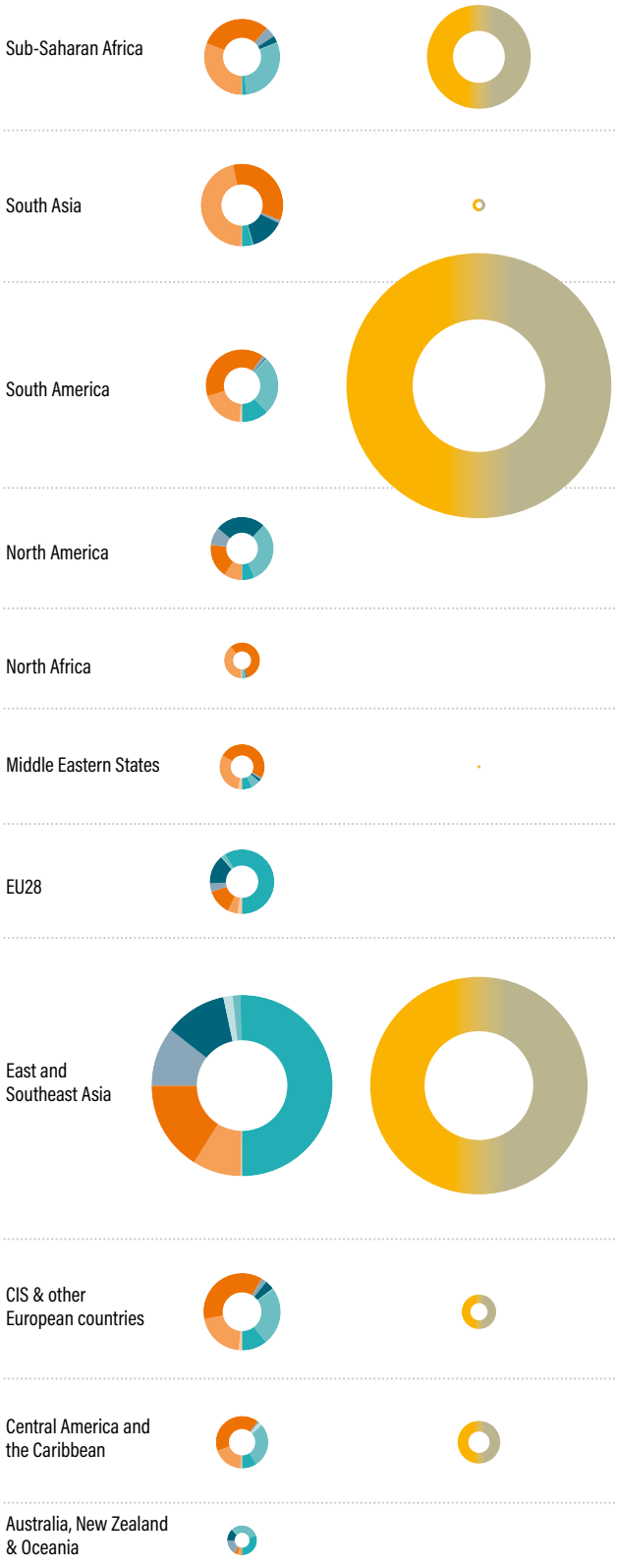
Summary of releases by region

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

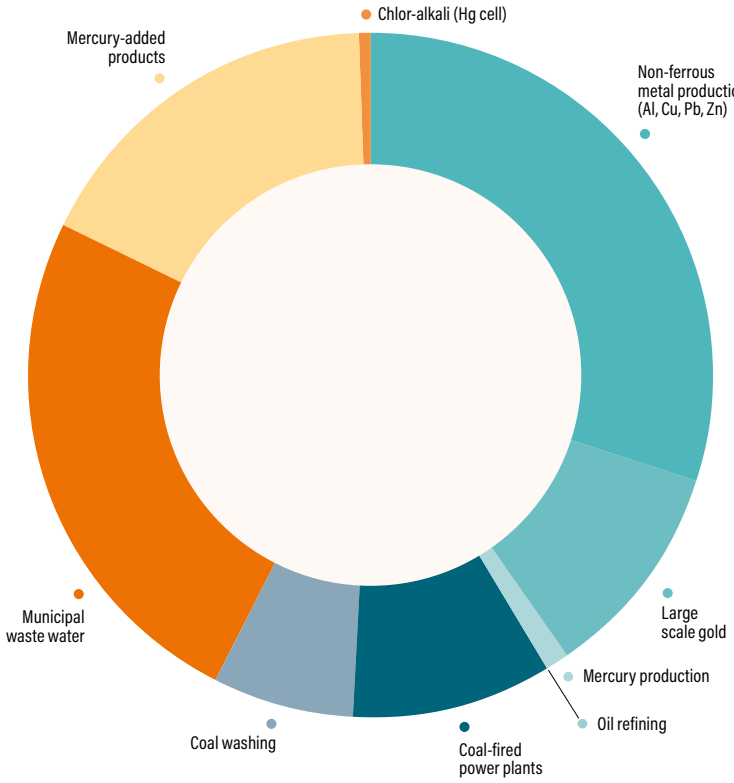


- Sub-Saharan Africa
- South Asia
- South America
- North America
- North Africa
- Middle Eastern states
- EU28
- East and Southeast Asia
- CIS and other European countries
- Central America and the Caribbean
- Australia and New Zealand

▲ Contribution to global mercury releases to water (excluding releases from artisinal and small-scale gold mining) in 2015 from different regions.



▶ Regional pattern of global anthropogenic mercury releases to water in the 2015 inventory from different sector groups (centre column), and contributions from artisinal and small-scale gold mining to releases to both water and land (right column); releases to water alone from artisinal and small-scale gold mining activities cannot yet be distinguished.



▲ Contribution to global mercury releases to water in 2015 from different anthropogenic source sectors, excluding artisinal and small-scale gold mining.

Releases from selected sectors

The 2015 global inventory of releases to water excludes releases from artisanal and small-scale gold mining, which are treated separately.

Mercury releases from *copper, lead, zinc, aluminium, mercury, and large-scale gold production* were estimated to be about 240 tonnes or 40% of the inventory. About a quarter comes from large-scale gold production.

Municipal sewage contributes about a further 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 *municipal wastewater treatment* around the world are also expected to decrease mercury releases.

The 2015 inventory shows that *mercury-added products* are also a major source of mercury releases. 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.

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 about 15% 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.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Potential secondary sources of mercury releases

In addition to direct releases to water, some of the sectors discussed here contribute mercury to land, general waste and sector-specific storage, which can be equally if not more important to the global mercury cycle. For example, zinc production is responsible for an estimated 4200 tonnes of mercury per year. Large-scale gold mining is estimated to put 2700 tonnes of mercury into soils each year, 45 times more than it releases directly to water. A further 940 or so tonnes of mercury from mercury-added products enters the solid waste stream, of which only 6% is estimated to be stored safely. A rough estimate of anthropogenic mercury input to soils is 7000-8000 tonnes. All of this mercury becomes a potential secondary source of releases to water as well as emissions to air. A great deal remains unknown about this pathway of mercury pollution.

7 MONITORING MERCURY CONCENTRATIONS IN BIOTA

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. Such circumstances need to be recognized and understood 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 times higher or more 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

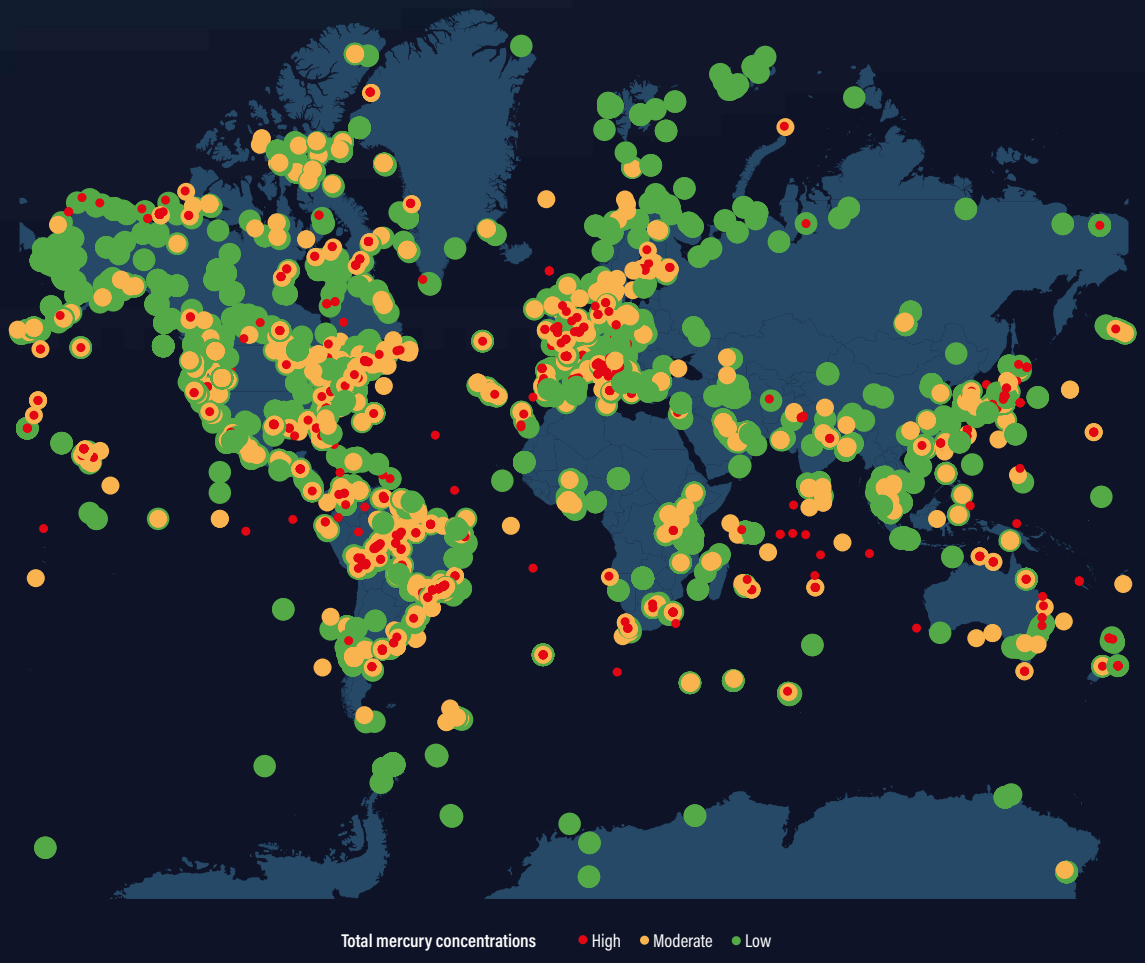
The availability of methylmercury to high trophic level organisms varies widely around the world. As an example, some of the lowest air mercury wet deposition levels measured in the United States and southern Canada are in Kejimkujik National Park in Nova Scotia, Canada, yet methylmercury exposure of fish and birds is some of the highest in North America, often exceeding health thresholds for these species. 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.

Ricardo Funari/BrazilPhotos/Alamy Stock Photo

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 that 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 more 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, when, and on what to conduct biomonitoring.



▼ Mercury concentrations measured in biota at various locations around the world.

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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.

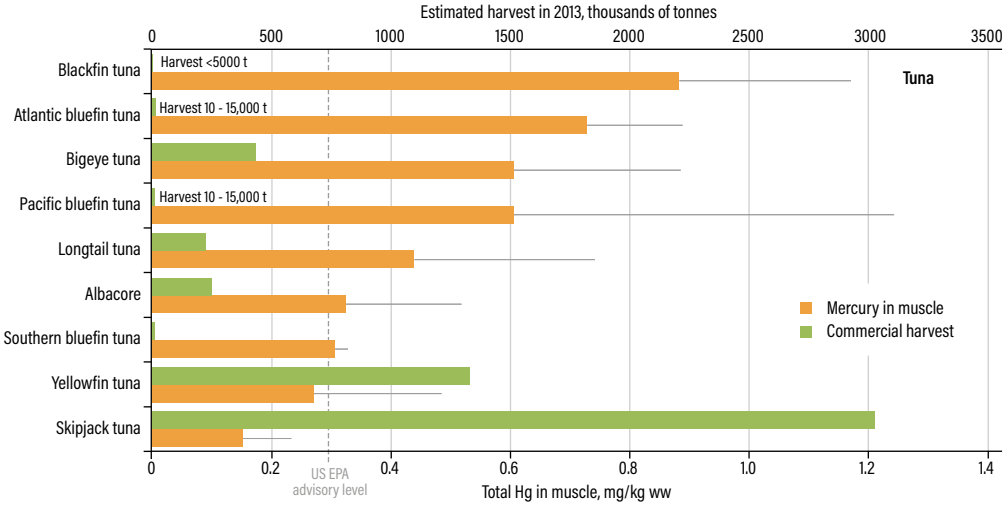
These and other considerations suggest a number of strong candidates for biomonitoring in relation to human health. Tuna are one of the most important global sources of marine fish, with commercial harvests of nearly 3.5 million tonnes per year. Mercury concentrations vary widely by species and ocean 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.

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.

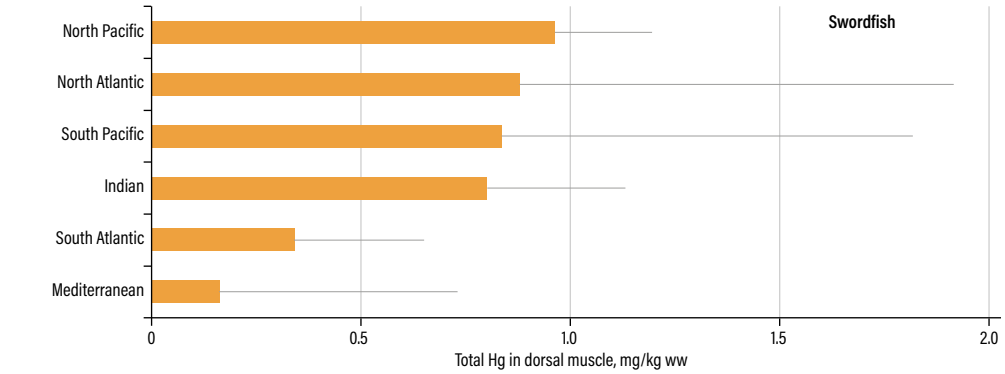
W. Eugene Smith/Magnum Photos

Bioindicators for ecological health

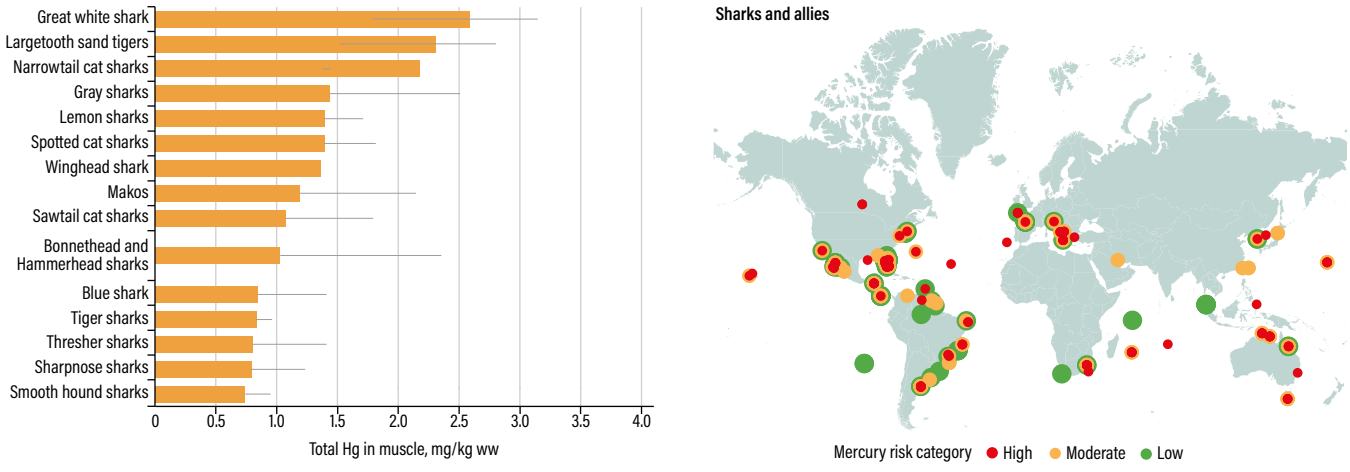
Many species of fish and wildlife are at risk to the adverse impacts of mercury. The selection of a particular organism or suite of bioindicators depends on the objective, such as ecosystem health, detection of spatial or temporal trends, human health, particular effects, or sampling techniques. As with 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.



◀ Mercury concentrations in muscle tissue of nine tuna species and commercial harvest levels of the same species worldwide.



◀ Mercury concentrations in dorsal muscle tissue of swordfish from different ocean basins.



▲ Mercury concentrations in muscle tissue of various shark species.

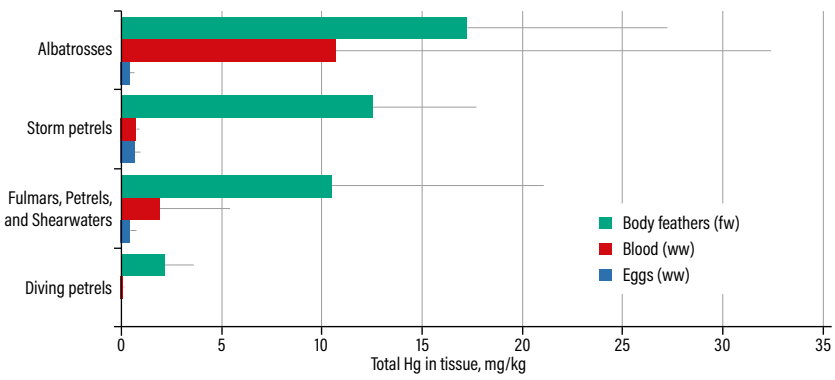
Ondrej Prosicky/Shutterstock.com

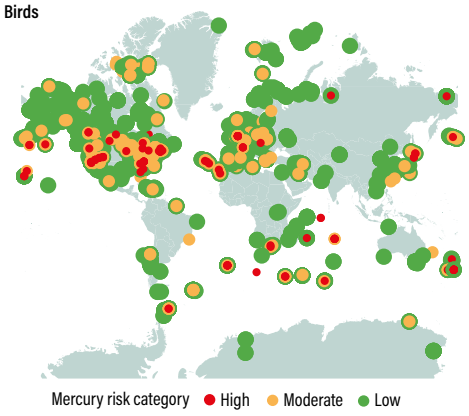
Daniel Poleschook

Most seabirds are situated high in food webs, 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.

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

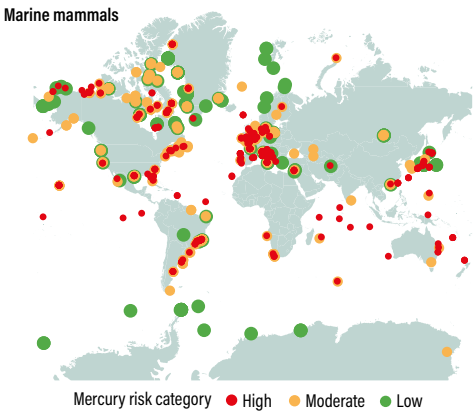
▼ Mercury concentrations in three tissues of seabird families.

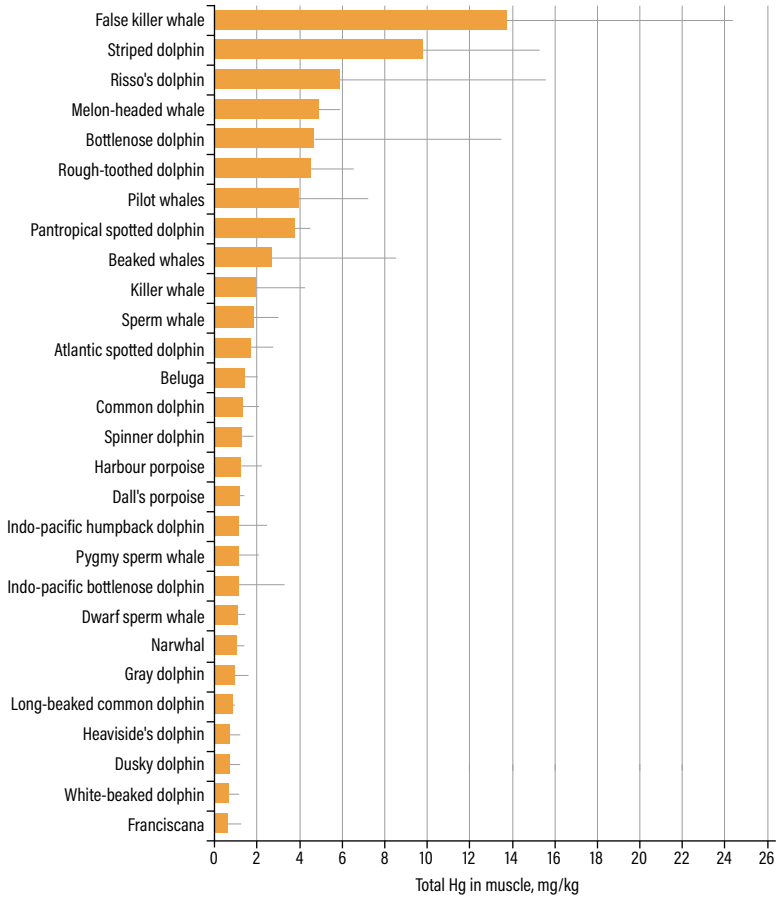




▼ Mercury concentrations in muscle tissue of various species of toothed whales.

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





Sea Turtles

Mercury risk category

Moderate Low

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8 UNDERSTANDING TRENDS IN 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 and sediments, 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 aquatic systems, 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. The factors controlling the rates of methylmercury formation and decomposition are diverse, as are the factors controlling methylmercury accumulation in biota. It is clear, however, that reductions in emissions and releases of inorganic mercury will ultimately reduce methylmercury concentrations in biota in the long-term, although short-term trends may reflect local environmental conditions instead.

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 demethylation. In biota, the fraction or methylmercury increases as it moves up the food web, reaching over 95% in certain tissues of top predators.

In the last few years, a number of studies have challenged the idea that methylation occurs primarily in sediments. Furthermore, demethylation appears to play a larger role in controlling 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 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 as well as deep lakes and reservoirs, 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. In addition, mercury methylation may also occur within sea ice.

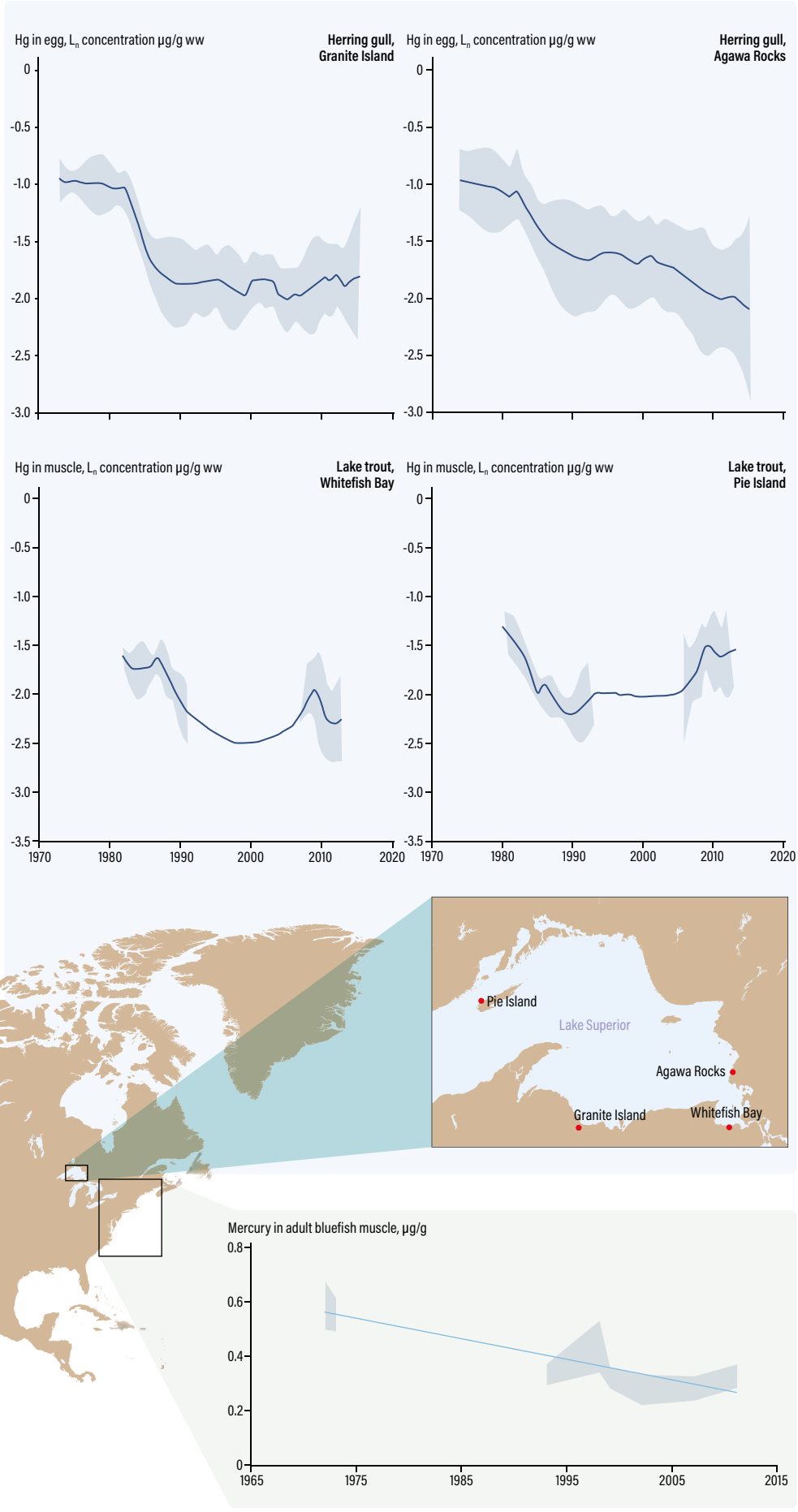
The response of mercury levels in aquatic biota to changes in atmospheric mercury concentrations

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 biotic mercury trends may or may not follow the same short-term trends as 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, Asia, and the Arctic. These are the locations where parallel long-term data are available for mercury in biota and the atmosphere.

Mercury in fish and birds in lakes and coastal waters of North America

A large number of studies have reported inconsistent, diverging, or mixed mercury trends in aquatic biota throughout North America since the 1970s. The early declines in mercury levels in biota were 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, sulfur deposition, or other factors.

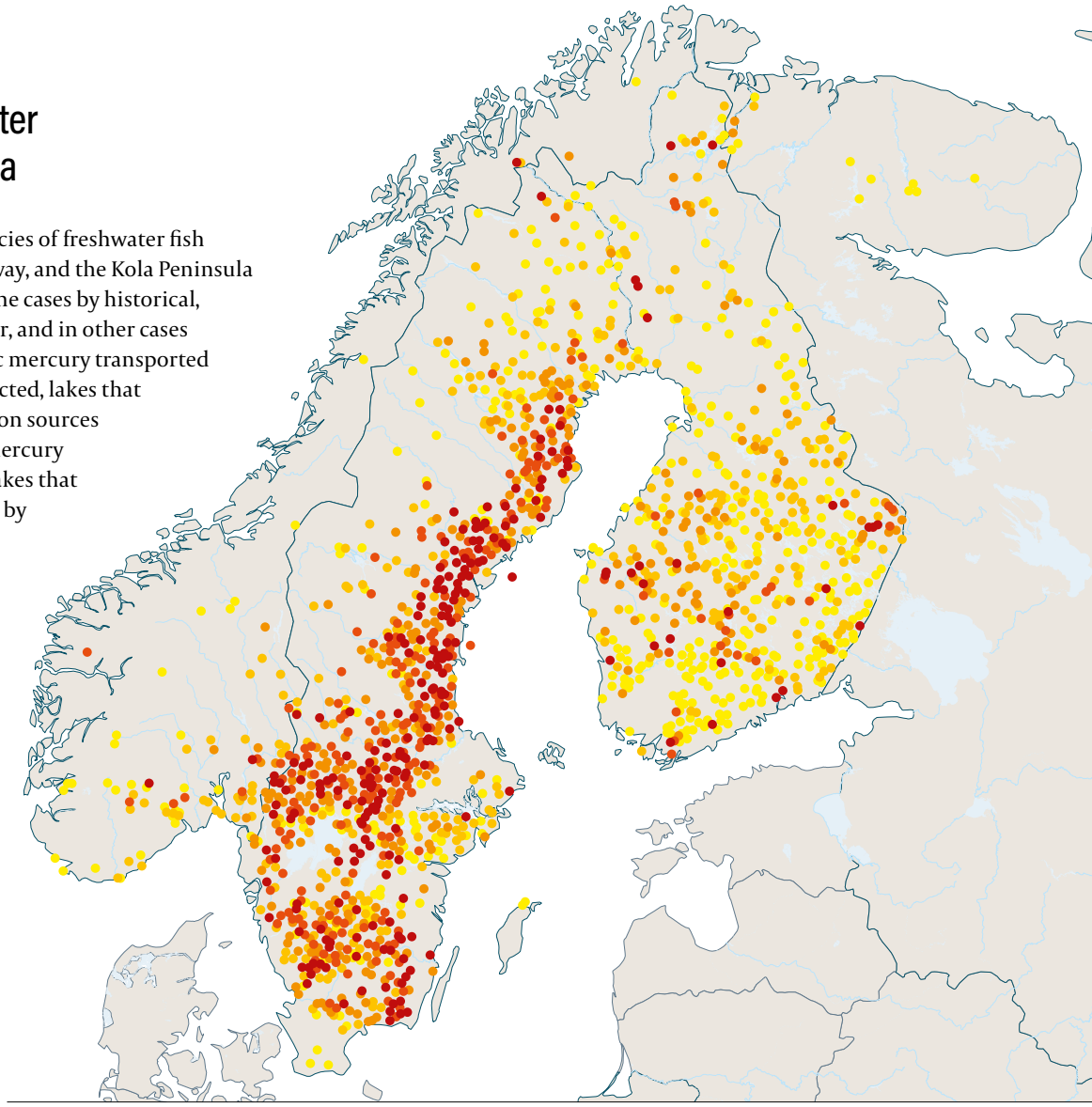
Mercury trends in fish from hundreds of small lakes in Ontario, Canada, varied by lake and by species of fish, demonstrating the complexity of ecosystem responses to changes in atmospheric mercury deposition. Results from coastal waters in eastern Canada showed relatively constant mercury levels in biota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

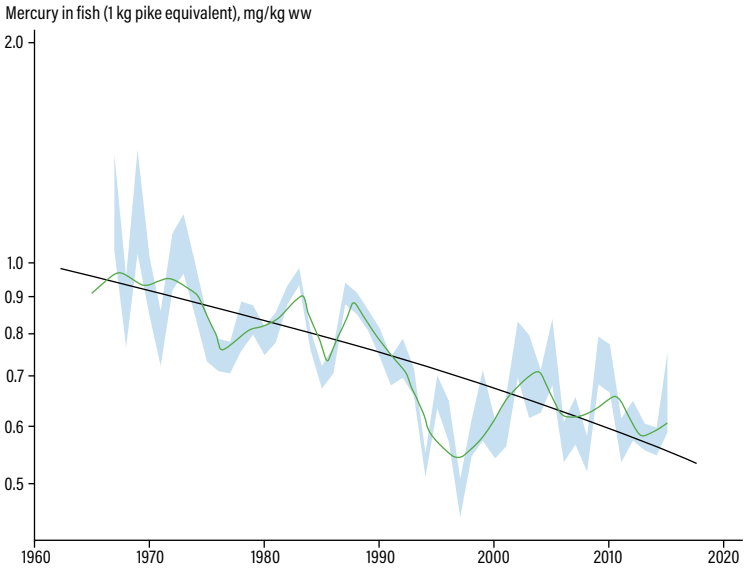


▶ Mercury trends in herring gulls and lake trout in Lake Superior and bluefish on the northeast coast of the USA from 1972 to 2011.

Mercury in freshwater fish in Fennoscandia

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



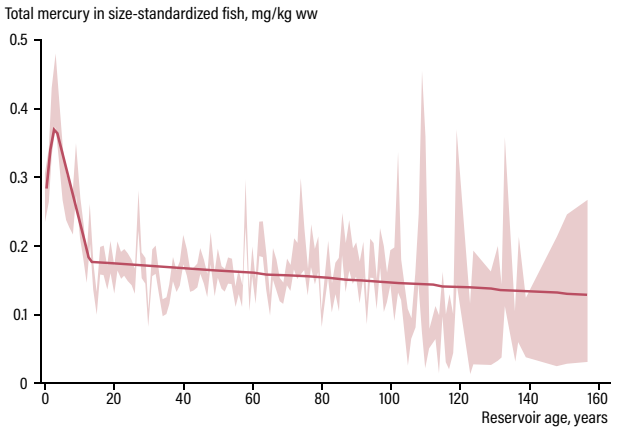


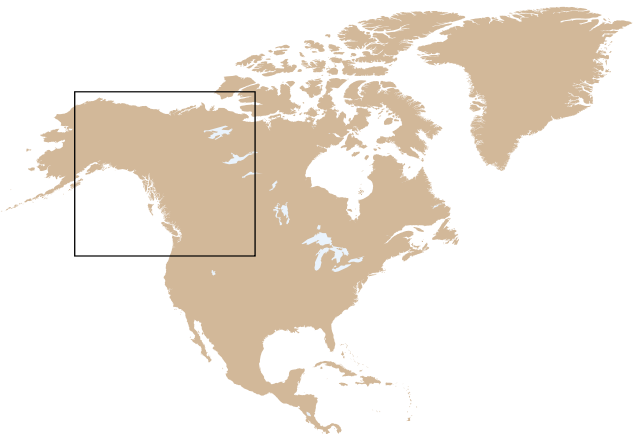
▲ Average mercury concentrations in five freshwater fish species across Fennoscandia, showing geographic distribution and trends from 1965 to 2015.

Mercury in fish in reservoirs in North America and Europe versus Asia

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

Reservoirs in Asia, however, present a different story. There, most reservoirs support aquaculture for human consumption. The fish mercury concentrations from these reservoirs are typically low due to biodilution, as there are more fish in which to accumulate 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 reservoirs studied in this region.

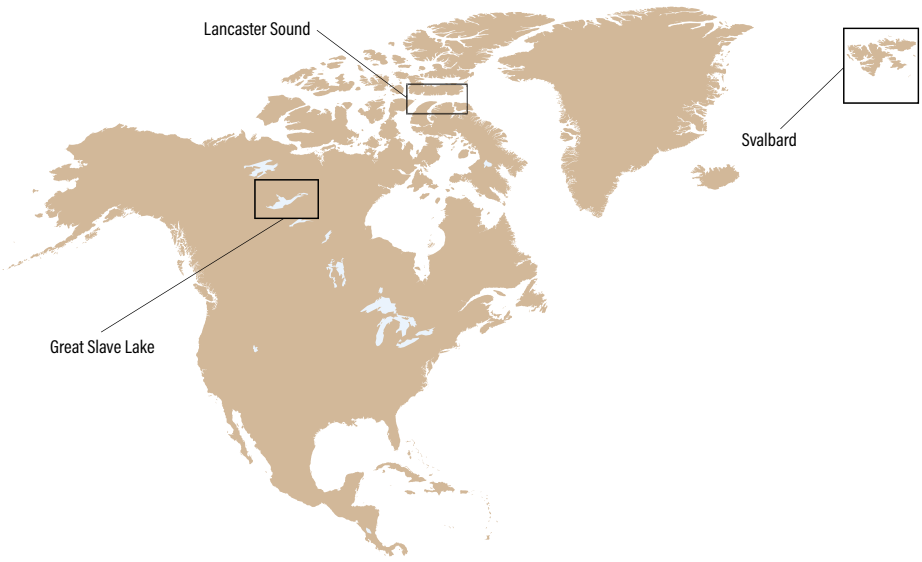


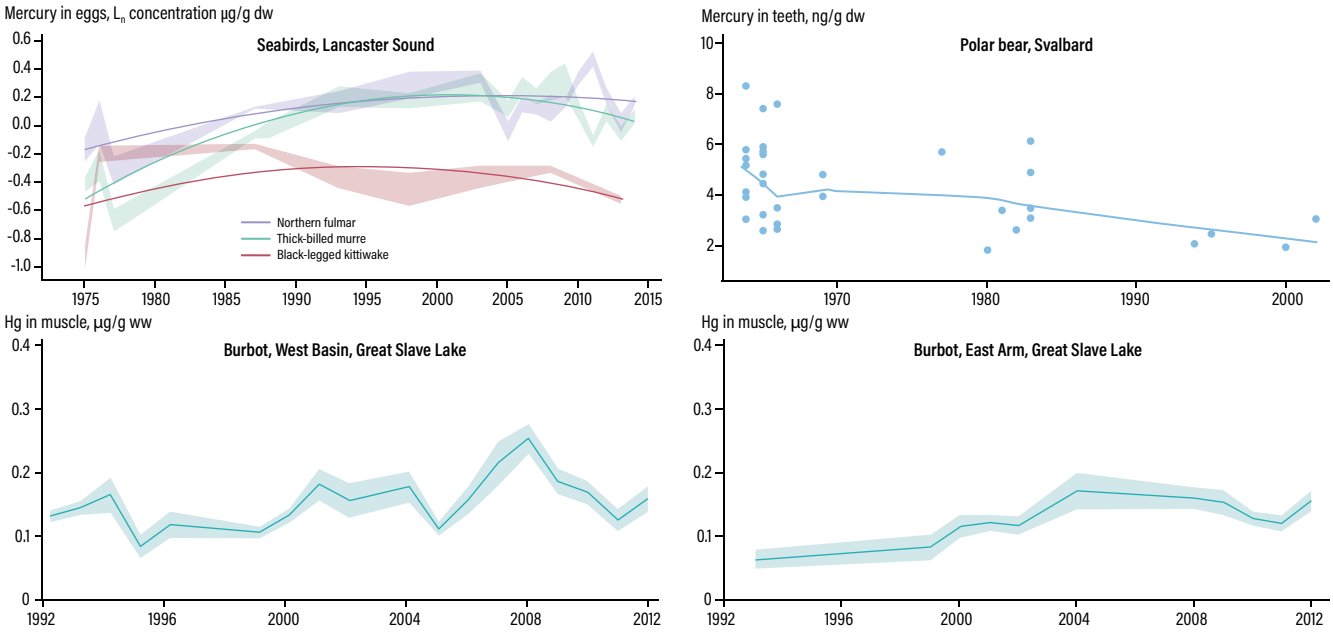


▲ Mercury trends by age of reservoir in fish tissues from reservoirs across western North America.

Mercury in Arctic animals

In the Arctic, increasing trends in mercury have been found in some marine species such as ringed seals in Arctic North America and polar bears in west Greenland. In east Greenland and European Arctic, mercury 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, however, declining mercury levels in male polar bears are most likely 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.





▲ Mercury trends in various aquatic animals across the Arctic.

Frits Steenhuisen

Causes of the mismatch between atmospheric and aquatic mercury trends

In contrast to the recent decadal datasets described above, the available century-scale mercury trends in biota 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 in biota used to be determined by the availability of mercury, now there is sufficient mercury in the environment that mercury levels in biota may instead be limited by the rates of methylation and demethylation as well as other factors influencing bioaccumulation, creating highly variable outcomes from place to place.

In soil and terrestrial environments not including wetlands, 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 short-term influence on biotic mercury trends in many aquatic ecosystems, as noted in the case studies above. 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 among the most important contributors 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.

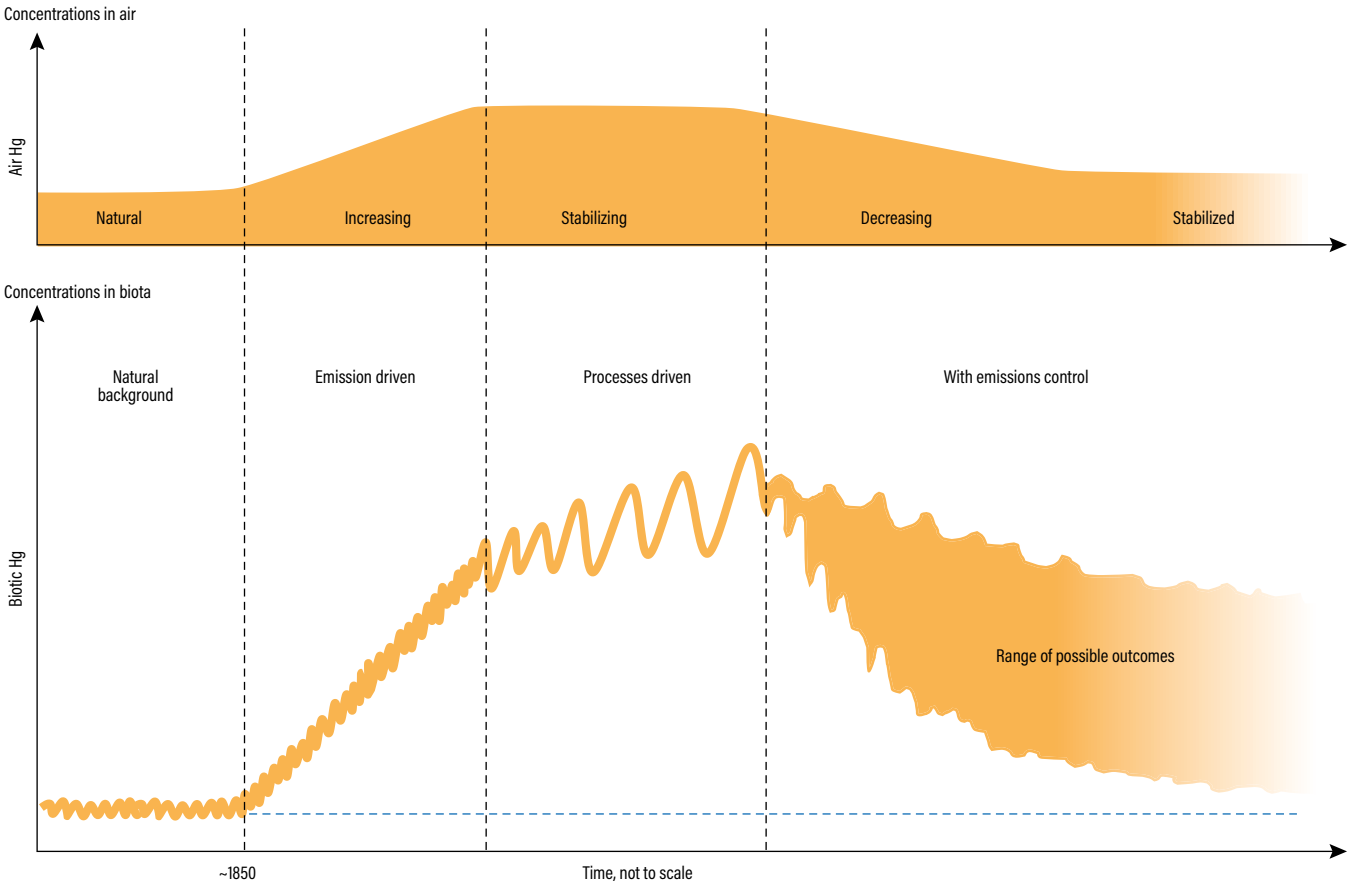
Ricardo Funari/BrazilPhotos/Alamy Stock Photo

The implications of mercury emission regulations on mercury levels in biota

The fact that short-term 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.

Prior to anthropogenic influences, inputs of mercury to aquatic systems were generally low, and so were biotic concentrations. Around the mid-19th century, as anthropogenic mercury emissions increased sharply, aquatic mercury concentrations responded rapidly due to increasing mercury deposition and methylmercury formation. Once an aquatic ecosystem had accumulated sufficient mercury, however, additional increases became secondary to the amount already stored in the system. In these cases, methylation and bioaccumulation were controlled primarily by internal processes rather than new mercury inputs.

As mercury emissions and releases in future 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 the environment, 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.



▲ A schematic representation of the response of mercury concentrations in biota to changes in mercury concentrations in air, as the limiting factors in bioaccumulation change.

Minzayar Oo/Unearth-NRGI/Panos /Felix Features

9

MERCURY LEVELS AND TRENDS IN HUMAN POPULATIONS WORLDWIDE

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

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. 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. Dietary exposure to methylmercury is primarily through fish, shellfish, and marine mammals. Groups with high consumptions of these foods are likely to have higher exposure, but these foods also provide numerous health benefits, posing a dilemma for overall well-being. Fetuses and infants are also vulnerable to effects from mercury, so pregnant women and recent mothers are also a concern for mercury exposure.

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 mercury exposure for some communities.

Mercury is a pollutant of global concern principally due to its adverse effects on human health. Everyone in the world is likely 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, especially in fetuses. 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.

Mercury exposure assessment using biomarkers

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

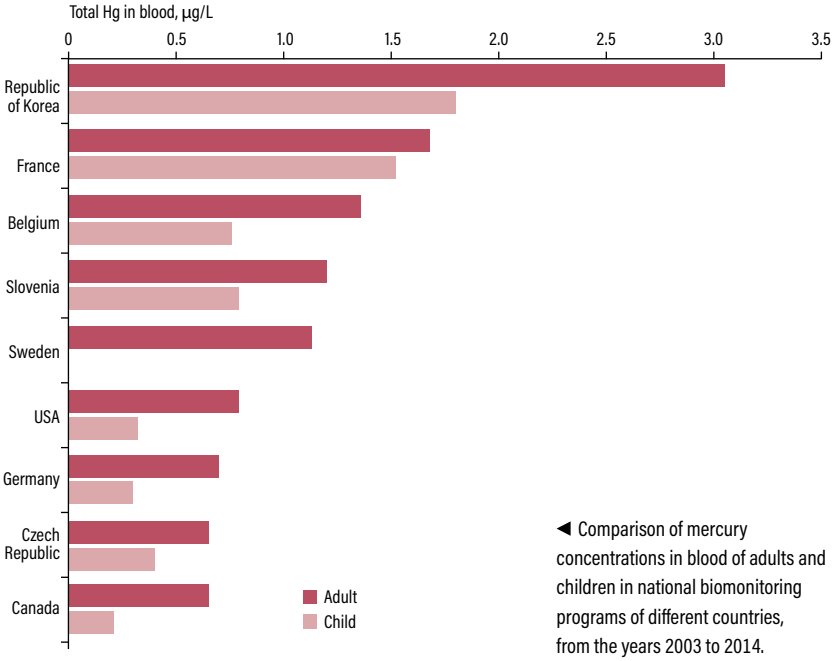
Most of the mercury in hair is methylmercury. Mercury taken up in hair remains there, providing an integrated measure of exposure that can be tracked over time as hair grows. Hair is also easy to collect and transport, though care must be taken to distinguish mercury within the hair from mercury that 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.

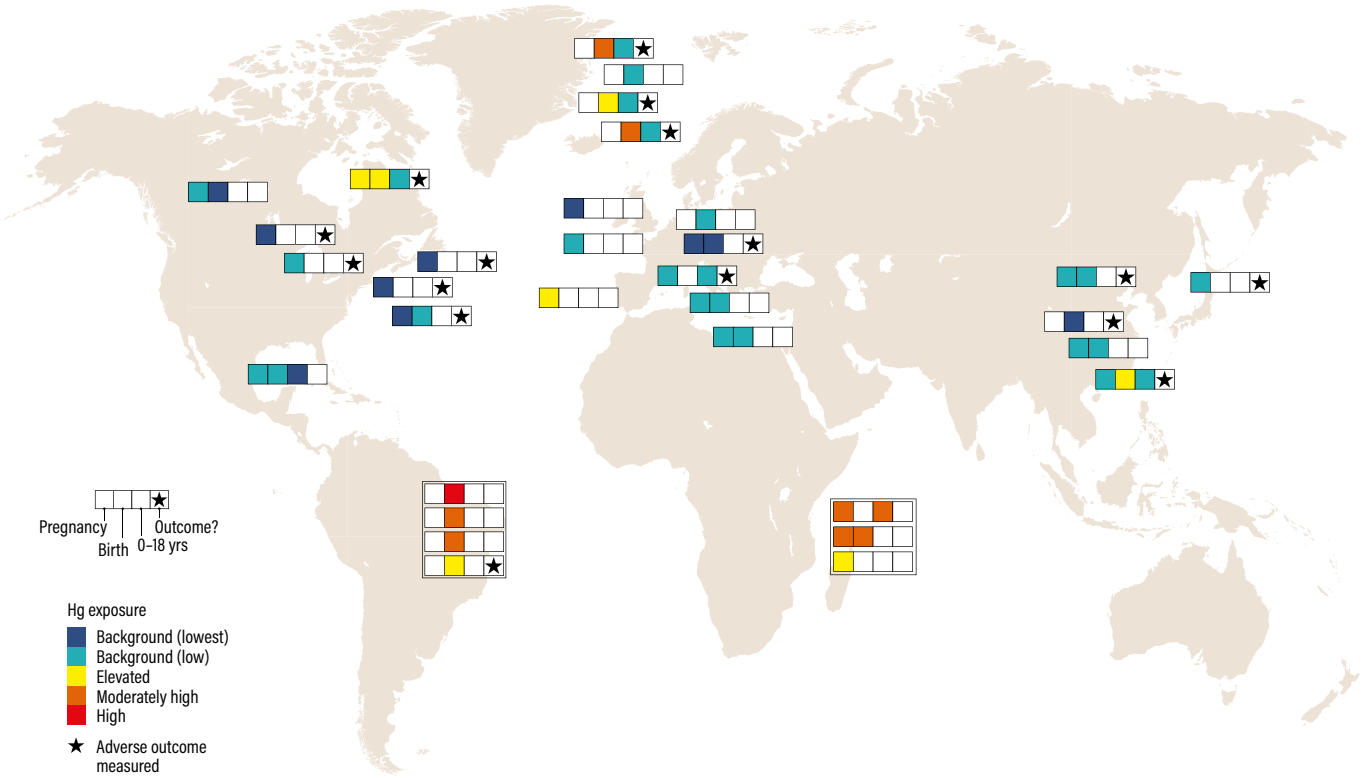

Kemal Jufri/Panos Pictures/Felix Features

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 tend to 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* can be used to increase understanding of mercury exposures in different population groups. Here,



◀ Comparison of mercury concentrations in blood of adults and children in national biomonitoring programs of different countries, from the years 2003 to 2014.



▲ Locations of mercury birth cohort studies showing mercury exposure levels and detection of mercury-associated adverse outcomes.

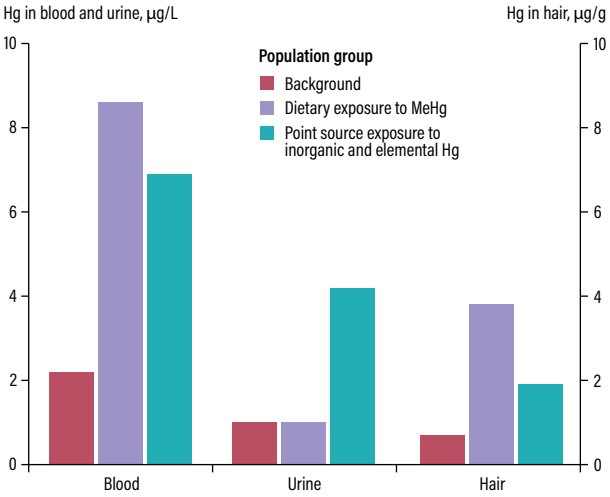
the focus is on four groups: the general background population, with no particular or significant exposure to mercury; those who are vulnerable because of exposure to point sources of elemental or inorganic mercury such as artisanal and small-scale gold mining or mercury-contaminated sites; people exposed to relatively high levels of methylmercury through their diet; and populations vulnerable through fetal exposure.

National human biomonitoring 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 121,413 people, from whom there were 192,651 biomarker measurements of mercury exposure. Across the national programs, the majority of participants had blood mercury levels that fell below 5 micrograms per litre. 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 litre. Like blood, urine mercury levels were higher in adults than in children.

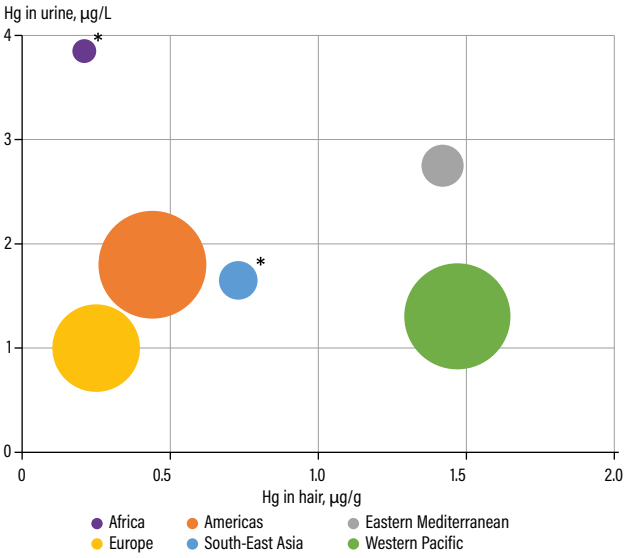
Changes in mercury exposure over time were evaluated by reviewing national datasets in which there were two or more comparable sampling periods. For blood mercury, datasets from four countries were reviewed and in general they showed declining exposures. For urinary mercury, similar decreases can be 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.

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, with umbilical cord blood mercury levels often exceeding 10 micrograms per litre. On the other hand, people in the Faroe Islands and the Seychelle Islands have seen dramatic decreases from previously very high levels of mercury. Elsewhere, Mediterranean populations tended to have higher levels than people in Asia, whose levels in turn were generally higher than those in North America and Europe. A range of mercury-exposure-related 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.

From the *cross-sectional studies* information was taken from 265 scientific articles, which together include184,510 mercury biomarker measurements taken from 167,830 individuals from 73 countries. The results in general correspond well with those from national biomonitoring studies. The cross-sectional data also highlight geographic differences in exposure. For example, hair mercury levels from the Western Pacific, Eastern Mediterranean, and Southeast Asia were higher than those in the Americas, Europe, and Africa. These results can help establish background mercury levels for the general population in areas with no significant exposure to mercury sources.



▲ Median blood, urine and hair mercury levels across different population groups following a systematic review of 265 relevant cross-sectional studies from 73 countries.



▲ Bubble plot of hair and urine Hg levels from cross-sectional studies on background populations according to WHO geographic regions. The size of the bubble reflects the sample size. The asterisk indicate that urinary Hg levels from background populations in Africa and South-East Asia were not available, and thus urinary Hg levels from all populations within these regions was used.

Among *vulnerable groups*, methylmercury-contaminated seafood poses a particular risk-benefit dilemma. Seafood provides many valuable nutrients and associated health benefits, but some seafood also contains high levels of methylmercury. The median blood mercury concentration among groups is about four times higher than in the general background population. Indigenous Peoples in many areas of the world, especially Inuit in the Arctic and groups in the Amazon region, generally experience high exposure to mercury, most likely through their reliance on traditional foods such as fish and marine mammals for sustenance. 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,

Ian Berry/Magnum Photos

and economy of many of these communities and so contamination of food by mercury presents an issue of environmental justice.

Another vulnerable group includes those working and living in artisanal and small-scale gold mining areas. This practice 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, nearly three times that of the general population, with some individuals at extremely high levels of exposure.

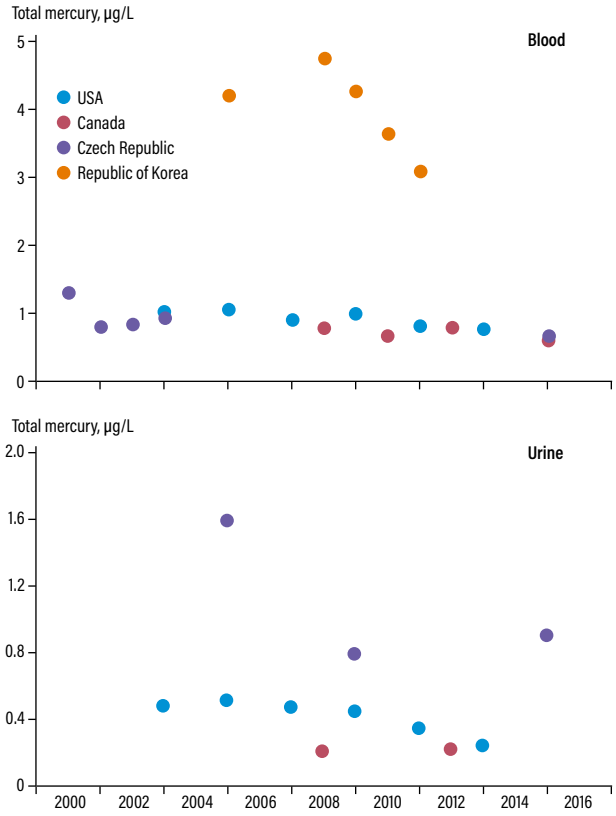
Prospects for action

All populations are exposed to some amount of mercury, and there is great variability in exposures around the world. Population groups at high risk are Arctic peoples who consume fish and marine mammals; tropical riverine communities (especially in the Amazon Basin) who consume fish and in some cases may be exposed to mining; coastal or small-island communities who substantially depend on seafood; and individuals who either work or reside among artisanal and small-scale gold mining sites. However, despite a relatively large database of mercury biomarker measurements compiled here, data are completely lacking in a number of countries and geographic regions. More, good quality, nationally representative data would allow changes in human exposure over time and space to be gauged. Programs to harmonize mercury biomonitoring activities across regions will contribute to better quality data.

Brian Skerry/Getty Images

Many studies focus on developmental 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 between 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. While mercury exposures may differ between men and women because of differences in diet, occupation, behaviour and physiology, this has not been systematically studied and warrants further attention.

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.



▲ Trends in mercury concentrations in blood and urine of adults from national biomonitoring studies.

GLOBAL MERCURY ASSESSMENT 2018

PHOTOGRAPHS

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