– SUPPLEMENTARY MATERIAL –

GUIDANCE ON MONITORING OF MERCURY AND MERCURY COMPOUNDS TO SUPPORT THE EFFECTIVENESS EVALUATION OF THE MINAMATA CONVENTION

Draft of 15 July 2021

This document contains technical information to supplement the “Guidance on Monitoring of Mercury and Mercury Compounds to Support the Effectiveness Evaluation of the Minamata Convention”. It is comprised of two parts – Part A on monitoring programmes organized per matrix (air, biota and human biomonitoring), including an overview of existing gaps and an annex providing a non-exhaustive list of standard operating procedures; and Part B on quality assurance and quality control in laboratory analysis and data management, including annex containing a draft template for submission of monitoring data.

PART A. REVIEW OF EXISTING MERCURY MONITORING PROGRAMMES

1. Atmospheric Mercury Monitoring

1.1 Multi-country monitoring programmes

Global Mercury Observation System (GMOS)

The Global Mercury Observation System (GMOS)[1] network includes over 30 monitoring sites in both Southern and Northern Hemispheres generating comparable data on mercury in air and precipitation samples in both hemispheres. It continues to operate many of the sites in coordination with national programs and regional agreements. Monitoring stations are located mostly at background sites in order to intercept major intercontinental and continental air mass transport patterns. GMOS monitoring sites have been classified as “Master” or “Secondary” sites. Master stations are those where Gaseous Elemental Mercury (GEM, i.e. the gas phase mercury in its ground electronic state), Gaseous Oxidized Mercury (GOM, i.e. the oxidized gas phase mercury compounds), Hg associated with suspended particulate matter (PBM2.5) and Hg in precipitation are continuously measured. Secondary stations are those where only GEM and Hg in precipitation are continuously measured. GMOS is expanding its geographical coverage in areas where no mercury monitoring programs are in place (i.e., Africa, Latin America) by using Passive Air Samplers (PASs). GMOS is also part of GOS4M and is aimed to support the Convention as well as research projects and programs.

EMEP protocol

The UNECE Convention on Long Range Transboundary Air Pollution, through its EMEP protocol, funds five scientific centres to support technical work related to assessing the air pollution situation in Europe (CLRTAP has 51 Parties while the EMEP protocol has been ratified by 47 Parties). These centres are the Centre for Emission Inventories and Projections (EMEP-CEIP), the Chemical Coordination Centre (EMEP-CCC), the Meteorological Synthesizing Centre West (EMEP-MSC-W), the Meteorological Synthesizing Centre East (MSC-E) and the Centre for Integrated Assessment Modelling (EMEP-CIAM). In collaboration with experts from Parties, emission data, observations and modelling results are used to assess

[1] www.gmos.eu.

transboundary fluxes of pollutants to support the development of abatement strategies. The Convention's 1998 Protocol on Heavy Metals includes mercury in its scope. EMEP models for assessing mercury fluxes have a global spatial scale. The Air Convention is driven by effects of air pollution on human health and ecosystems. Therefore, it also supports specific programs that aim at assessing the environmental and health impact of air pollution and responses to pollutant emission mitigation strategies, coordinated under the Working Group on Effects (WGE). In particular, seven networks (six Integrated Cooperative programmes, ICPs, on Forests, Waters, Integrated Monitoring, Materials, Vegetation and Modelling and Mapping; and one Task Force on Health) dedicated to effect monitoring on various ecosystems have been running since the 1980s. Recently a report summarizing trends analysis of mercury in fish was published by ICP Waters. The Air Convention, WGE and EMEP can add value to other international frameworks, and most European programs make direct use of the Air Convention infrastructures and its data (including the EU NEC directive, AMAP, HELCOM and OSPAR). For instance, the WMO Global Atmosphere Watch takes advantage of the Air Convention efforts on disseminating data of atmospheric composition. The Minamata Convention is explicitly mentioned in the EMEP strategy and, it may be possible for the Minamata Convention to explore opportunities for taking advantage of already existing capacities and infrastructures in operation under CLRTAP, as this may ensure the efficient use of resources and harmonization among different UN-policies related to the environment based on the same data and source-receptor relationships across the various themes. The latter is particularly beneficial for Parties which are signatories to both the LRTAP and Minamata Conventions.

Asia Pacific Mercury Monitoring Network

The Asia Pacific Mercury Monitoring Network (APMMN)[2] is a cooperative effort to systematically monitor wet deposition and atmospheric concentrations of mercury in a network of stations throughout the Asia-Pacific region. The Network has monitoring sites in Fji, Indonesia, Japan, Philippines, Sri Lanka, Taiwan, Thailand and Vietnam, among others. APMMN objectives are to (1) determine the status and trends in concentrations of ambient mercury species, and wet, dry, and total atmospheric deposition of mercury, (2) develop a robust dataset for regional and global modelling, (3) assist partner countries in developing monitoring and assessment capacity, and (4) share data and monitoring information. Since its launching in 2012, the Network has developed and adopted SOPs, based on those of the National Atmospheric Deposition Program (NADP), to monitor mercury in rainwater, developed standardized quality assurance, and established three mercury wet deposition pilot sites. New partners continue to join the Network, which is expanding the mercury wet deposition monitoring coverage in the region. The Network also continues to explore networking atmospheric mercury monitoring systems into a harmonized network, including continuous atmospheric monitoring and atmospheric mercury monitoring using manual-sampling protocols.

Arctic Monitoring and Assessment Programme

The Arctic Monitoring and Assessment Programme (AMAP)[3] is an Arctic Council Working Group that focuses on the preparation of assessments that describe sources, pathways, levels, trends and effects of anthropogenic pollutants in the Arctic environment, including humans. AMAP's geographical coverage extends from the High Arctic to the sub Arctic areas of Canada, the Kingdom of Denmark (Greenland and the Faroe Islands), Finland, Iceland, Norway, the Russian Federation, Sweden and the United States, including associated marine areas. AMAP information is based largely on ongoing national and

[2] http://apmmn.org.
[3] www.amap.no.

international monitoring and research activities. AMAP assessments are scientifically independent and subject to international peer review. Priority issues addressed by AMAP include persistent organic pollutants (POPs), heavy metals (particularly mercury), climate change, and ocean acidification. On the basis of its assessment work, AMAP produces policy-relevant recommendations for action that are addressed to the Arctic Council, governments and relevant international bodies; AMAP has been tasked by the Arctic Council to support work ongoing under relevant international conventions. AMAP assessments are publicly and freely available from its website.

AMAP Thematic Data Centres compile data from relevant monitoring and research activities and make them available under strict conditions that protect the rights of data originators. AMAP Thematic Data Centres exist for:

- *Atmospheric contaminants data:* at the Norwegian Institute for Air Research (NILU),[4] and are accessible through their EBAS database;
- *Marine contaminants data:* at the International Council for the Exploration of the Sea (ICES)[5] in Denmark, and are accessible through their online EcoSystemData warehouse;
- *Radioactivity data, including both sources and levels and trends:* at the Norwegian Radiation and Nuclear Safety Authority.[6]

In addition, freshwater and terrestrial contaminants datasets have been compiled in the SynCon database at the University of Alaska, Fairbanks, USA. Other international data reporting initiatives are under development as part of the Sustaining Arctic Observing Networks (SAON) initiative.

Global Passive Air Sampling Project

The government of Canada (Environment and Climate Change Canada (ECCC)) is funding a pilot study to assess the feasibility of using a passive air sampler for gaseous mercury (MerPAS®[7]) on a global scale to establish a baseline concentration in remote locations. Passive air sampling will aim to serve in conjunction with currently deployed active and passive mercury sampling investigations by other research/monitoring groups by creating a network of networks.

In order to get the best global coverage for air monitoring, the study aims to develop a global network made up of currently existing networks in combination with the expansion of some of those networks to reduce areas with no coverage. Together with the Crown-Indigenous Relations and Northern Affairs Canada, the ECCC – Atmospheric Mercury Measurement Network Chemicals of Emerging Arctic Concern (CEAC) – Northern Contaminants Program (ECCC-AMM-NCP) Arctic mercury passive sampling network was initiated in 2019 in order to complement active air monitoring activities conducted across the country. The mercury passive samplers are also being deployed in collaboration with other monitoring networks including the Global Atmospheric Passive Sampling (GAPS) network, the Asia Pacific Mercury Monitoring Network (AMPPN), and the American-led National Atmospheric Deposition Network (NADP). As of January 2021, there were 47 sites being actively monitored through the study (Figure S.1).

The study continues to seek collaboration with other interested networks and countries to complete the global coverage. The study is not limited to the MerPAS® sampler (for instance, the GMOS sites are using

[4] www.nilu.com.
[5] www.ices.dk.
[6] www2.dsa.no.
[7] MerPAS® was developed by the University of Toronto Scarborough developed in collaboration with Environment and Climate Change Canada.

a mercury passive sampler that was developed in Italy), and currently operating networks may independently initiate their own passive sampling at select sites and an intercomparison of techniques could be made. The data generated by the study will be properly quality controlled with accepted standard methods (e.g. EPA method 7473) and housed on the ECCC data portal.

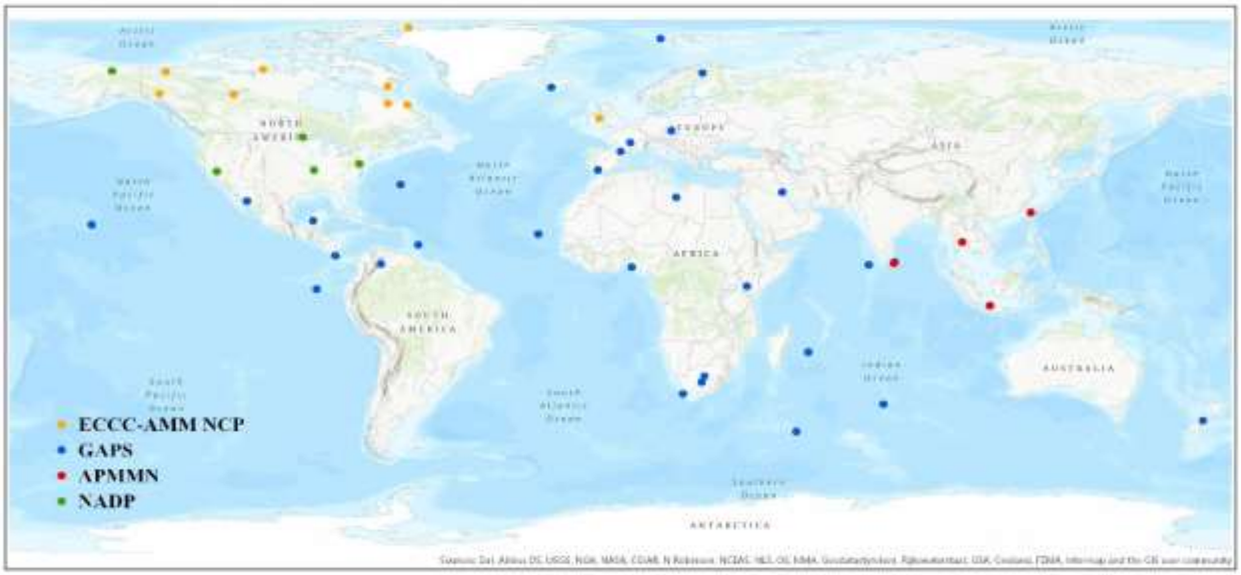

Figure S.1. Forty-seven active sites across the globe being actively monitored by Environment and Climate Change Canada – Atmospheric Mercury Measurement – Northern Contaminants Program (ECCC-AMM-NCP) in collaboration with the Global Atmospheric Passive Sampling (GAPS) network, the Asia Pacific Mercury Monitoring Network (AMPPN), and the American-led National Atmospheric Deposition Network (NADP) as of January 2021.

1.2 National atmospheric mercury monitoring programs[8]

Canada

Considerable atmospheric Hg monitoring and research has taken place across Canada through both ongoing networks and independent research programs since the early 1990s. Most monitoring began as independent research programs to measure total gaseous mercury (TGM). Over time, the parameters measured have evolved and the breadth and volume of data collected are significant. Realizing the benefits of a community, researchers joined forces to create the Canadian Atmospheric Mercury Measurement Network (CAMNet) in 1994. CAMNet was operated by Environment and Climate Change Canada (ECCC) from 1994 to 2007, with between 7 and 15 sites across Canada. Since 2007, other research programs have undertaken atmospheric mercury monitoring in Canada and, as of 2017, these individual programs have been consolidated and fall under ECCC – Atmospheric Mercury Monitoring (ECCC-AMM) network. In 1996, Canada joined the United States-led Mercury Deposition Network (MDN) and began collecting wet deposition samples for THg and, at some sites, methyl mercury (MeHg). Canada has had up to 18 precipitation monitoring sites operating as part of the network over time. Finally, during the early 2000s, to meet increasing research needs, considerable advancements were made in instrument capabilities to collect and analyse Hg species in the air. From 2002 onward, some CAMNet sites began continuous measurements that could distinguish among gaseous elemental mercury (GEM), reactive gaseous mercury (RGM) and particulate mercury (TPM) (collectively termed speciated atmospheric mercury). Currently, Canada has 10 air monitoring sites across the country with a

[8] In alphabetical order.

variety of different mercury species collected. The data are managed through an open data portal through the ECCC website.

Denmark

The Kingdom of Denmark provides atmospheric mercury monitoring data from Greenland to AMAP through its national program and data is collected at the monitoring Station Villum Research Station, in North Greenland. In Greenland, continuous measurements of GEM in the atmosphere have been measured since 1999. Snow samples of total mercury in surface snow have been measured since year 2010. Data is provided to the AMAP thematic data centre.

Mercury has been monitored regularly in Greenlandic biota in marine, freshwater and terrestrial species in North, West and East Greenland since the late nineties. Biota data is available on the ICES portal.[9]

Human levels of mercury have been measured in Greenlandic Inuit communities in the blood of mother child cohorts since the late nineties. Mercury is also monitored in several mother child cohorts from the Faroese population and in marine and terrestrial biota. The Faroese and Greenlandic studies have been reported in assessment by AMAP (see above). Denmark is presently co-leading, jointly with Canada, the Human Health Assessment Group under AMAP.

Denmark has participated in several programs among others, the former EU program DEMOCOPHES where mercury was monitored in mother child cohorts.

Japan

Japan has been conducting a variety of mercury monitoring in humans and the environment. Environmental monitoring includes monitoring of atmosphere, water, marine environment, and humans. Ministry of the Environment of Japan (MOEJ) has been conducting “Marine Environmental Monitoring Survey” and “Survey of the Exposure to Chemical Compounds in Human” that includes long term mercury monitoring on various environmental media and the human body. Monitoring of Hazardous Air Pollutants has monitored Total Gaseous Mercury concentrations using a gold-trap more than 250 sites throughout the country once a month since 1998. Baseline monitoring of atmospheric Hg species and Hg in wet deposition has been running using continuous measurement systems since 2007 at Cape Hedo, Okinawa. Total mercury monitoring and analysis on seawater and sediments has been studied in “Marine Environmental Monitoring Survey” for nearly 40 years around Japan’s exclusive economic zone (EEZ). In addition, total mercury analysis on marine products has been conducted for the last 20 years. Under “Survey of the Exposure to Chemical Compounds in Human”, total mercury in blood, and total and methyl mercury in diet of the general population has been conducted for the last 6 years. Japan has also conducted capacity development on mercury monitoring introducing gold amalgamation trap – atomic absorption spectrometry (Official monitoring method in Japan) for the participants from more than 20 countries through several capacity building programs. Japan also will work to establish atmospheric mercury monitoring program in Asia-Pacific region, with close cooperation with APMMN and other relevant countries.

Norway

The Norwegian Environment Agency monitors hazardous chemicals including mercury in air and precipitation, lakes, fjords, marine areas and in terrestrial environment. The following monitoring programs include mercury; contaminants in coastal waters (Hg in marine biota, data series from 1980;

[9] www.ices.dk/marine-data/data-portals/Pages/DOME.aspxor.

riverine inputs and direct discharges (Hg in river water); contaminants in urban fjords (Hg in biota, sediment and water); contaminants in terrestrial and urban environment (Hg in biota); contaminants in lakes (Hg in biota), (data series from 1980); monitoring of long range transported contaminants (Hg in air, moss and precipitation, data series from 1990). Monitoring is mainly conducted in organisms such as cod, blue mussels, trout, seabirds, zooplankton, shrimps, bird of prey, earthworms and foxes. The Norwegian Polar Institute operates a monitoring program that covers Svalbard and Jan Mayen (Hg in top-predators like arctic fox and polar bear, data series from 1990). In addition, the Institute for Marine Research operates several monitoring programs with Hg in commercial oceanic fish species. Monitoring is both close to hotspot sources like industry and cities and in pristine areas like air monitoring on Svalbard. A majority of our monitoring are time trend monitoring providing datasets that are particularly useful to answer the policy questions in the effectiveness evaluation of the Minamata Convection. pa. The monitoring programs have both national funding and funding from regional programs such as EMEP, AMAP, OSPAR and EU Water Framework Directive.

Norway also provides facilities for the ICP Waters Programme Centre,[10] where the Norwegian Environment Agency provides financial support in addition to support from the UNECE.

Republic of Korea

National atmospheric mercury monitoring is undertaken as part of the Korean Air Pollution Monitoring Network by the Ministry of Environment since 2014. In the network, as of 2017, there are 12 active monitoring sites for Total Gaseous Mercury (TGM), including 2 sites for atmospheric speciated mercury (GEM, GOM, and PBM2.5) and 5 sites for wet deposition in mercury. Annual TGM data are available in online.[11]

South Africa

Atmospheric mercury monitoring started in South Africa in 1995 at the Cape Point Global Atmosphere Watch (GAW) station operated by the SA Weather Service. The CPT site was the first site in the southern hemisphere to start with continuous mercury monitoring. In 2007, wet deposition sampling started during the rainy season from May to September at CPT. With the start of the South African Mercury Network (SAMNet) in 2020, a coordinated mercury network to expand the monitoring activities in the country, there are now 3 continuous ambient stations, 5 passive sampling locations and 3 wet deposition sites located throughout the country.

United States

The National Atmospheric Deposition Program's Mercury Deposition Network (MDN) makes long-term measurements of Hg in precipitation (wet deposition) across North America. The MDN began monitoring in 1996. The MDN sites follow standard procedures, and uniform precipitation collectors and rain gauges to make weekly-integrated measurements of THg in a combined precipitation measurement (wet only). Currently, the MDN has 106 active sites. All MDN samples are analysed for THg concentration and invalid samples are identified using standard protocols. Subsamples for some sites are analysed for methyl mercury (MeHg). Valid and invalid results are provided for use by the scientific community. In addition, The NADP's Atmospheric Mercury Network (AMNet) measures atmospheric Hg that contributes to Hg deposition using automated, continuous measurement systems, and standardized

[10] www.icp-waters.no.
[11] www.airkorea.or.kr

methods. Currently, there were 21 AMNet sites, and data from the AMNet are available on the NADP website.[12] AMNet observations have been made since 2009 and are made continuously and qualified and averaged to one- and two-hour values. Validated data are released for use by the scientific community, and also released in annual figures of Hg variability for sites meeting certain criteria.

1.3 Databases

Global Observation System for Mercury (GOS4M)

The Global Observation System for Mercury (GOS4M)[13] is a flagship initiative of the Group on Earth Observation (GEO), an intergovernmental partnership that aims to promotes open, coordinated and sustained data sharing and infrastructure for better research, policy making, decisions and action across many disciplines. GOS4M overarching goal is to support interested parties in the implementation of the Minamata Convention by (a) promoting a close cooperation between existing mercury monitoring networks and programs in order to facilitate the access to available data and knowledge on mercury levels in different environmental matrixes by the scientific community, policy makers and stakeholders; (b) contributing to improve the global coverage of currently available mercury monitoring data by promoting the establishment of new monitoring sites in areas that do not have monitoring capabilities and facilities; (c) promoting intercomparison campaigns of monitoring methods and technologies as well as validation of existing modelling frameworks and tools used to assess the fate of mercury in and between atmospheric and terrestrial compartments; (d) increasing the availability and quality of Earth Observation data acquired by in-situ, off-shore and satellite sensors that contribute to improve our capability to track mercury releases, establish source-receptor relationships, assess their fate and impact with changing emission regimes and climate; (f) fostering harmonization of metadata description, archiving and data sharing methodologies used by existing mercury monitoring networks and programs; (g) contributing to the development of downstream services designed to perform cost-benefit analysis of different strategies aiming to reduce the level of mercury in environmental media and human exposure; (h) developing advanced web services aiming to facilitate the access and use of state-of-the-art scientific information and data by policy makers and stakeholders. GOS4M is currently defining its governance and partnership with an overarching aim to support interested parties in the effectiveness evaluation of the Convention.

Emission Database for Global Atmospheric Research (EDGAR)

The Emission Database for Global Atmospheric Research (EDGAR) updated the global mercury emission inventory, which is included in EDGARv4.tox2; three different forms of mercury have been distinguished: gaseous elemental mercury, gaseous oxidized mercury and particle bound mercury. Three retrospective emissions scenarios were also developed and evaluated with the GEOS-Chem 3-D mercury model in order to explore the influence of speciation shifts, to reactive mercury forms in particular, on regional wet deposition patterns.[14]

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[12] http://nadp.slh.wisc.edu/amnet/default.aspx.
[13] http://www.gos4m.org.
[14] http://edgar.jrc.ec.europa.eu/overview.php?v=4tox2.

1.4 Modelling of mercury in ambient air

There are numerous dynamical global modelling frameworks that capture the atmospheric transport and deposition of mercury after it is emitted from anthropogenic and natural sources. These include models run by many international networks and independent research groups (e.g., EMEP, Echmerit, GEM-Mach-Hg, GEOS-Chem). These models have been extensively evaluated against observational data and subject to numerous international intercomparison efforts as part of past synthesis reports (GMA, UNEP, HTAP).

The advantage of these models is that they can be used to test hypotheses on the drivers of changes in atmospheric Hg cycling by means of scenario analysis (e.g. emission perturbations, process studies, what-if-scenarios). Moreover, by tagging individual emissions or by means of emission perturbations these models can be used for detailed source apportionment studies.

Data required to run these models include spatially and temporally resolved emissions inventories and meteorology. Several global emissions inventories are available from different groups, but they require harmonization. Any new emissions data generated will need to be integrated in the current global emissions inventories as a top priority for future modelling assessments.

1.5 Gaps in mercury data in ambient air

Figure S.2 shows current efforts to monitor atmospheric mercury. From this figure, it can be inferred that data gaps on atmospheric mercury could be filled by expanding on existing programs. Such expansions would include areas within South America, Africa, the Caribbean, parts of Asia, the Russian Federation and Oceania. The following approaches are proposed for filling gaps:

- Couple current monitoring of TGM/GEM with new technologies (including passive and active mercury sampling);
- Create new and/or expand current monitoring networks, where possible, to fill data gaps;
- Employ currently used standard procedures for data collection and treatment, where possible;
- Compare measurement technologies and data treatment across networks;
- Continue to fill geographical data gaps using manual active or passive sampling methods;
- If feasible, couple manual active or passive air measurements with active and wet/dry deposition measurements;
- Conduct sampling at least quarterly (either averaged with active sampling data or integrated over the course of three months with passive sampling) to assess seasonal variations;
- When choosing new sampling sites, prioritize the filling of the information and data gaps identified in Global Mercury Assessment 2018 and other relevant literature.

The elaboration of future strategies aiming to fill geographical gaps in atmospheric mercury monitoring data would require the operation of about 30 monitoring sites, including manual active or passive air sampling, in each large geographical areas, such as Africa, Latin America and the Russian Federation, placed in locations that could provide information on regional/local background mercury concentrations. The suggested number of sites is only indicative; a larger number of sites using manual active or passive air sampling would certainly allow for better geographical coverage and representativeness of the regional/local emission regimes, meteorology and transport/deposition patterns.[15]

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[15] A cost analysis for air monitoring, including the proposed sampling, can be found in document UNEP/MC/COP.3/INF/15, part I, section 4.

Figure S.2. Existing monitoring networks measuring mercury concentrations in air. [The information in this figure is outdated and will be updated in the coming weeks following a call for submission of information on existing monitoring programmes]

2. Monitoring Mercury in Biota

2.1 Multi-country biota monitoring programmes

ICP Waters[16]

Another example of collating and using long-term Hg biomonitoring for the benefit of both human and ecological health is ICP Waters, where a freshwater fish database was collated from national monitoring programs in Finland, Norway, Sweden and the Russian Federation (Kola Peninsula) (Braaten et al. 2017; Braaten et al. 2019). A total of 66 464 fish records were entered, and limited to 54 563 records after quality assurance and data evaluation, from 2775 lakes, for the period 1965 to 2015. The main aim of ICP Waters is to assess, on a regional basis, the degree and geographical extent of the impact of atmospheric pollution on surface waters, and in 2017 ICP Waters published a report on mercury

[16] www.icp-waters.no.

concentrations in fish. The report presents an extensive database of more than 50 000 measurements of mercury in fish from approximately 3000 lakes throughout Fennoscandia, sampled between 1965 and 2015. The report discusses the usefulness of such databases for assessments of impacts of environmental policy on mercury in freshwater fish, and is available from the ICP Waters webpage.

The minimum data requirements, in addition to lake coordinates, to be included in the ICP Waters database were fish parameters species, length, weight and mercury concentrations. Preferred additional fish data included age, sex, maturity stage and stable carbon and nitrogen isotopes (Figure S.4). Stable nitrogen isotopes give information on trophic level, and trophic level is strongly associated with Hg concentrations in fish. In order to relate Hg in aquatic biota to external pressures (pollution), it is necessary to be able to account for internal foodweb dynamics that also control Hg in aquatic foodwebs. To examine differences between fish species and to disentangle the cause for the different magnitude of decreases (or increases) in fish Hg concentrations over time, data on age and trophic level indicators would be necessary.

Database specification	**Data specifications**	**Description**
*Geographical location**	(latitude, longitude)	Given as WGS84 decimals
*Geographical name**	Lake name	Official name given in the local language
Fish parameters		
• *Length**	• Centimetres, cm	• Total fish length (not fork length)
• *Weight**	• Grams, g	• Total weight
• Age	• Years	• Decided by inspection of operculums, scales or otoliths
• Sex	• 1 = male, 2 = female	• Decided by inspection of reproductive glands
• Maturity stage	• 1-12	• Classified by Dahl (1917), described by Jonsson and Matzow (1979)
*Fish species name**	Species name	English and Latin name given
Fish chemical measurements		
• *Mercury**	• mg/kg, ppm	• Numbers given as wet weight
• Stable isotopes	• δN and δC	• Dried samples, not baseline corrected

Figure S.4. Summary of data included in the ICP Waters database. *Note:* Not all parameters exist for all entries in the database. Parameters written in italics with an asterisk were considered a minimum required information for a measurement to be included in the database. Supporting data (lake and catchment data, land use, water chemistry, etc) helped distinguish effects of external pressures (direct inputs, air pollution). Supporting data was ranked by relative importance.

Global Environment Monitoring System - Food Contamination Monitoring and Assessment Programme

The World Health Organization (WHO) Global Environment Monitoring System - Food Contamination Monitoring and Assessment Programme, commonly known as GEMS/Food, has one of the best global systems for collecting fish Hg data through their network of collaborating centres and recognized national institutions (WHO 2018).

EAF-Nansen Programme in Africa and Asia

The EAF-Nansen Programme "Supporting the Application of the Ecosystem Approach to Fisheries Management considering Climate and Pollution Impacts" is an initiative to support the implementation of the ecosystem approach in the management of marine fisheries and to support scientific capacity building throughout Africa and Asia (http://www.fao.org/in-action/eaf-nansen/en/). The goal of the project is to promote sustainable utilization of marine living resources and improved protection of the marine environment (Bianchi et al. 2016). The program is executed by FAO in close collaboration with the Institute of Marine Research of Bergen, Norway and funded by the Norwegian Agency for Development Cooperation (NORAD). This project collects marine fish from off-shore marine ecosystems in several countries throughout continental Africa and Asia to evaluate contaminants, including mercury and methylmercury, and nutrients within a food security context. During the current phase of the project the NANSEN Programme has worked closely with Large Marine Ecosystem projects and other projects around Africa and throughout marine areas located in Asia and this programme is closely linked with the UN Decade of Ocean Science. Several marine fish species are collected on oceanographic surveys undertaken by the Research Vessel Dr. Fridtjof Nansen through the EAF-NANSEN programme and all fish mercury and methylmercury data are owned by each individual country where the fish are collected. Data access in support of the Minamata Convention on Mercury Effectiveness Evaluation is dependent on the individual policy of each country owning the data and therefore data access cannot be fully guaranteed and data requests may be facilitated by UN-FAO in coordination with the country where fish were collected.

Norway-Russia Barents Sea Ecosystem Assessment

Additionally, the Institute of Marine Research conducts an extensive annual ecosystem survey of the Barents Sea in the Arctic using a statistically valid time series approach and collecting data at the same spatial locations (stations) at the same time of year (Eriksen et al. 2018). This ecosystem cruise takes approximately 6 weeks to complete and runs from August to October of every year and is conducted in close collaboration with Russia and one its research vessels. In 2019, seawater and biota from the Barents Sea were collected and analyzed for mercury and methylmercury with new time series mercury and methylmercury data in fish, sediment and seawater being collected from 2021 onward. Ancillary measurements for biota that are included in this investigation include: species name, total fish length, weight, fat levels, and stable isotopes of carbon (δ13C) and nitrogen (δ15N). Additionally, Ancillary measurements for seawater mercury and methylmercury samples include water column depth, temperature, conductivity, and dissolved oxygen. Samples taken during these cruises could be used in support of temporal trend modelling in benthic and pelagic marine species to evaluate the effectiveness of the MCM.

2.2 National monitoring programs[17]

Canada

Canada's Northern Contaminants Program is one of Canada's flagship programs for monitoring contaminants in its vast Arctic territory (NCP 2017). Since its establishment in 1991, the program has focused on the measurement of contaminants (including Hg) in fish and wildlife that are traditional foods of northern Indigenous peoples. One of the strengths of the program is the interdisciplinary approach taken to assess and monitor risks of Hg to the environment and human health through the participation of Indigenous organizations, government departments (at federal and territorial levels), environmental scientists, and human health professionals. Activities are managed under five subprograms: 1) human health, 2) environmental monitoring and research, 3) community-based monitoring and research, 4) communications, capacity and outreach, and 5) program coordination and Indigenous partnerships.

Monitoring of mercury in fish and wildlife under the Northern Contaminants Program includes terrestrial, freshwater and marine species in focal areas across northern Canada. Many of those samples are collected by Indigenous hunters in nearby communities as part of their subsistence activities. Annual measurements track temporal trends of Hg bioaccumulation, and retrospective analyses of archived tissues from government specimen banks have provided opportunities to extend some time series (e.g., Braune 2007). Intensive spatial sampling of several species including Arctic char (Evans et al. 2015) and ringed seal (Brown et al. 2016) have generated complimentary information on geographic variation. Data on mercury levels in wildlife can be used for human dietary exposure assessments, while community-based projects may focus on species that are local priorities but not covered by routine monitoring.

Canada also carries out some monitoring of biota, including fish, bird and other wildlife, under other national and regional programs, such as the Chemicals Management Plan, which acts to safeguard human health and the environment and includes a number of proactive measures to ensure that chemical substances are managed properly, and the Canada-Alberta Oil Sands Environmental Monitoring Program, where the governments of Canada and Alberta are working with Indigenous peoples and their communities, stakeholders and environmental agencies to ensure the oil sands region is developed in an environmentally responsible way.

Norway

Another national program is operated by the Institute of Marine Research in Bergen, Norway. It has one of the largest seafood surveillance programs for mercury, methylmercury and other contaminants in farmed and wild fish and shellfish taxa. This programme utilizes nationally accredited laboratories and methods and regularly participates in inter-laboratory comparisons and is connected to the Codex Alimentarius food safety programme operated by the Food and Agriculture Organization of the United Nations (UN-FAO) and the Norwegian Food Safety Authority (Julshamn et al. 2004). Funding for this program is permanent and the surveillance is driven by regulations to test and ensure that all fish and shellfish that are exported globally are free of contaminants including mercury and methylmercury. Commercially relevant species and their prey are analyzed every year for mercury and methylmercury. The Institute of Marine Research also collaborates with CNRS / University of Pau, France to measure low-level, high resolution mercury speciation and mercury stable isotopes in seawater, sediment and

[17] In alphabetical order.

seafood species to further understand source apportionment and mercury methylation-demethylation dynamics in different marine ecosystem compartments.

Several commercially important marine teleost species[18] are routinely sampled and analysed for mercury and methylmercury using an accredited laboratory and reproducible analytical chemistry methods (see Table S.1).

All marine fish and shellfish mercury and methylmercury data sampled from Norwegian waters are owned and housed at the Institute of Maine Research.[19] Mercury concentration data from this database are freely available and includes the major commercially relevant species in Norway. Ancillary measurements include species name, total fish length, weight, fat levels, and stable isotopes of carbon (δ13C) and nitrogen (δ15N). Additionally, a number of other contaminants are also measured in these samples. Mercury and methylmercury data are measured on both fillet and liver tissue samples.

Table S.1. Mean Se:Hg molar ratio, Hg and Se concentrations (mg kg−1 ww), HBVSe, Hg intake as percentage of TWI (TWI %), consumption limit per week, landed catch from Norwegian fisheries and percentage of total catch (% Catch) for fish species from NEAO.

Species	N	Se:Hg molar ratio	Hg	Se	HBVSe	TWI % (2 servings)	TWI % (4 servings)	Consumption limit per week (g)	Landed catch from Norwegian fisheries (in tons, 2017)*	% catch
Blue whiting	75	41.6	0.04	0.48	6.11	15	30	2241	399210	20.6
Atlantic mackerel	1042	43.3	0.04	0.55	7.00	16	32	2114	221588	11.4
Atlantic herring	1810	39.3	0.05	0.52	6.60	17	34	2019	526167	27.2
Plaice	198	23.2	0.06	0.38	4.76	23	45	1510	848	0.04
Haddock	245	17.4	0.07	0.32	3.97	26	52	1317	113776	5.9
Saithe	439	16.9	0.07	0.29	3.59	26	53	1295	177196	9.2
Atlantic cod	2105	16.4	0.08	0.27	3.44	28	56	1208	412441	21.3
Wolffish	89	21.3	0.09	0.44	5.57	35	69	983	6451	0.3
European eel	185	11.2	0.11	0.30	3.73	40	80	851	12	0.001
Redfish	185	22.9	0.13	0.56	7.05	48	96	710	22582	1.2
Pollack	58	8.1	0.14	0.38	4.65	52	104	652	2028	0.1
Greenland halibut	546	10.3	0.14	0.42	5.23	54	108	631	16687	0.9
European hake	92	5.4	0.19	0.34	4.12	72	145	469	5307	0.3
Common ling	294	7.7	0.22	0.41	5.00	82	164	415	18481	1.0
Atlantic halibut	53	9.7	0.38	0.48	5.45	142	283	240	2648	0.1
Tusk	943	5.1	0.44	0.49	5.46	163	327	208	10191	0.5
Blue ling	79	1.9	0.72	0.38	2.09	270	540	126	244	0.01
All species#	8438	17.7	0.17	0.41	5.08	65	130	521	1935857	100

Note: TWI % and HBVSe were calculated from mean values. Species are sorted according to Hg concentrations. Data are from NEAO sampled during 2006–2015. Colours represent low risk (green), moderate risk (yellow) and high risk (red). Source: Azad et al. (2019).

[18] Atlantic cod (*Gadus morhua*), Atlantic halibut (*Hippoglossus hippoglossus*), Atlantic herring (*Clupea harengus*), Atlantic mackerel (*Scomber scombrus*), blue ling (*Molva dypterygia*), blue whiting (*Micromesistius poutassou*), common ling (*Molva molva*), European eel (*Anguilla anguilla*), European hake (*Merluccius merluccius*), Greenland halibut (*Reinhardtius hippoglossoides*), haddock (*Melanogrammus aeglefinus*), plaice (*Pleuronectes platessa*), pollack (*Pollachius pollachius*), redfish (*Sebastes spp*.), saithe (*Pollachius virens*), tusk (*Brosme brosme*) and wolffish (*Anarhichas spp*.) (Azad et al. 2019).

[19] https://sjomatdata.hi.no.

United States of America

While there are several long-term mercury biomonitoring programs in the United States, none currently encompass broad areas of the country. Geographic specific programs are in the Great Lakes and marine coastal areas for fish – oversight is by the U.S. Environmental Protection Agency. As a more local level, the State of New York, United States has established a long-term and comprehensive programme to monitor mercury levels in biota. Its 50-year dataset on freshwater fish Hg data (n=33,502 individuals) and birds (n=9,751) depicts exposure across nearly half of the state through the use of standard grids (Evers et al. 2020). Mercury exposure data can be placed in relevant categories that are relevant to screening benchmarks that can be related to risks to fish, birds, and humans for multiple endpoints from behavioural to reproductive impairments. Such fine-level, standardized data can be used for understanding broader spatial gradients and temporal trends.

2.3 Databases

Global Biotic Mercury Synthesis (GBMS) Database[20]

The Biodiversity Research Institute (BRI) compiles mercury data from peer-reviewed published literature into a single database, the Global Biotic Mercury Synthesis (GBMS) Database (Evers et al. 2018). This database includes details about each organism sampled, its sampling location, and its basic ecological data. From each reference, mercury concentrations are averaged (using weighted arithmetic means) for each species at each location. Data from the GBMS database can be used to understand spatial and temporal patterns of mercury concentrations in biota. This information can also help establish baseline concentrations for a particular species and identify ecosystems most at risk to mercury inputs.

The report, Mercury in the Global Environment, presents data on mercury concentrations in biota of concern in Article 19 of the Minamata Convention (i.e., marine and freshwater fish, sea turtles, birds and marine mammals), which are extracted from the GBMS database. Data have been compiled from 1,095 different references, representing 119 countries, 2,781 unique locations, and 458,840 mercury samples from 375,677 total individual organisms (Evers et al. 2018).

Meanwhile, the hundreds of local studies conducted by the global scientific community that are reflected within the GBMS database provide a relatively comprehensive global data platform containing existing biotic Hg concentrations. Based on the GBMS database, some of the regions with the highest fish consumption are poorly covered by biomonitoring efforts (e.g., Central America and the Caribbean Sea, western and central Africa, the southern Asian mainland, Indo-Pacific Asia). These and other spatial analyses and identification of best bioindicators can be reviewed in Evers and Sunderland (2019). Additional efforts are needed to develop and implement projects to fill geographic and ecosystem gaps. Although national efforts can serve as hubs for biomonitoring networks, local scientific studies can also make significant contributions toward better identifying what species, where, and when to conduct biomonitoring.

Together, these data can help raise awareness of potential risks and benefits of consuming key food items and thereafter help inform resource managers and decision makers about the species and places in which mercury represents a potential risk to human health, which can be partly based on harvest data by the Food and Agriculture Organization. The GBMS database also represents a valuable tool for: (i) integrating mercury science into important policy decisions related to the Minamata Convention on

[20] www.briwildlife.org/gbms.

Mercury, (ii) use by existing networks such as the Arctic Monitoring Assessment Programme (AMAP), [21] and (iii) protecting human health and the environment.

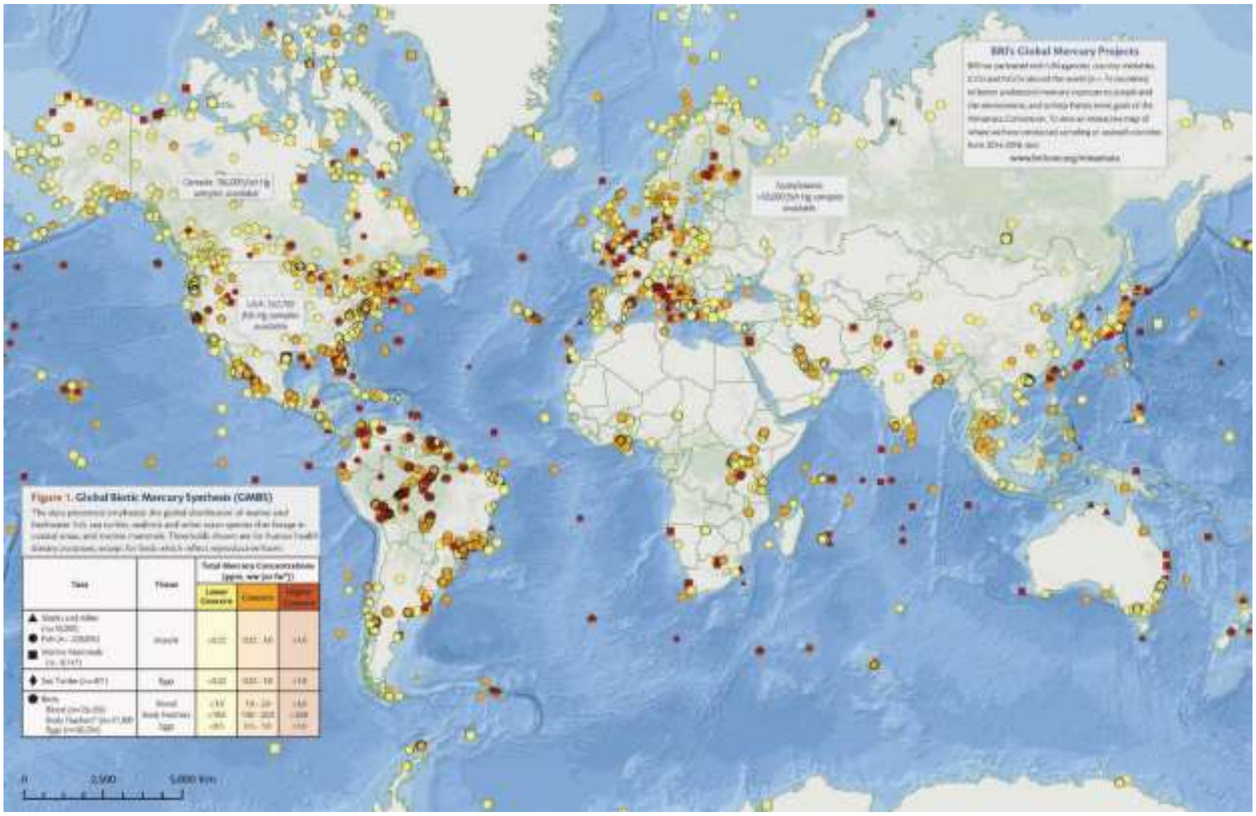

Figure S.2. Distribution of average mercury concentrations across 2,781 locations around the world. *Source:* Evers et al. (2018).

Arctic Monitoring and Assessment Programme

The Arctic Monitoring and Assessment Programme (AMAP) is one of the best examples of how to operate a long-term Hg biomonitoring field program for the benefit of both human and ecological health (AMAP 2011, 2015).

2.4 Modelling of mercury levels in biota

Numerous models are available for considering how methylmercury bioaccumulates in aquatic food webs. These models can be used on a local scale to consider how measured methylmercury concentrations in sediment and water contribute to concentrations accumulated in fish consumed by wildlife and humans. These applications are local in nature and can inform a global assessment on a case specific basis.

Several academic groups are developing coupled global models that link anthropogenic mercury releases on a global scale to accumulation in marine fish. Development of such integrated models is highly encouraged. Marine fish are an appropriate endpoint because pelagic marine predators that migrate across large ocean regions are often the dominant source of methylmercury exposure for fish-

[21] An example of regional program data and project availability can be found for the Arctic under the AMAP Project Portal (www.amap.no/data) by using the key word "mercury".

consuming populations. For example, more than 40% of population-wide exposure in the United States and Japan is from canned and fresh tuna only.

Input data for these modelling exercises draw on research in the global fisheries community on factors affecting fisheries production, including climate change as well as modelled concentrations of methylmercury in seawater. The global biotic mercury database developed as part of the 2018 Global Mercury Assessment provides valuable evaluation data for these model simulations. Enhancing this database will add to the credibility of marine fish bioaccumulation models that can be used to project the impact of future policy scenarios on fish mercury concentrations.

There are major challenges linking mercury levels in biota with mercury concentration in the surrounding abiotic matrices such as air and water especially considering post depositional processes, trophic position, changes in food web structure and complexity, and broad-scale drivers such as environmental chemistry factors (e.g., pH, DOC), temperature, geography, species growth rates, and climate change (Braune et al. 2015, 2016).

Marine ecosystems

Models for mercury concentrations in aquatic environments span regional tools for estuaries, as well as global models for the marine environment. Mercury concentrations and trends in estuaries tend to be site specific and are difficult to extrapolate to broader spatial patterns. Measurement and modeling efforts in these regions are local in nature and measurements are difficult to obtain due to potential contamination issues.

Available tools for modelling mercury in marine environments include several coupled atmospheric-ocean simulations, though these are not as widely applied as the air models. Examples include the simulations for inorganic and methylmercury species in the global oceans by several academic and government groups (e.g., Massachusetts Institute of Technology general circulation model (MITgcm), Environment and Climate Change Canada model, ongoing Japanese modelling efforts (FATE-Hg).

Inputs needed for the models include atmospheric deposition from a coupled atmospheric simulation. Mercury discharges from rivers to marine regions can also be regionally important, particularly in coastal/shelf areas with productive fisheries. Atmospheric inputs for these models are well established, but there is substantial uncertainty in estimates of global riverine discharges. Collection of global data on total mercury and methylmercury in rivers flowing into the ocean is needed.

Evaluation data on speciated mercury concentrations in marine regions needed for evaluation of oceanic simulations are currently being collected by existing networks such as the GEOTRACES and CLIVAR programs, and ad hoc research programs. New data will be incorporated into global modelling efforts as they become available. Development of an enhanced database on speciated mercury concentrations in seawater covering horizontal and vertical distributions would be useful,

Terrestrial ecosystems (including surface water and groundwater environments)

Mercury concentrations in surface and groundwater environments are highly variable, difficult to measure, and reflect local runoff and ecosystem conditions. Concentrations in water are highly variable due to periodic storm events and episodic aquatic mercury releases, runoff, erosion, productivity and other factors that affect removal. Due to the localized nature of these environments, current dynamical models do not include them. This is encouraged as an area/linkage for development in future global terrestrial models that include hydrology.

An alternate approach for considering spatial patterns in mercury concentrations in terrestrial ecosystems is the development of GIS-based spatial models that consider the co-location of ecosystem factors that are known to influence methylmercury production (e.g., inorganic mercury deposition, organic carbon, sulfate deposition, pH, wetlands). This analysis is proposed as a method for identifying spatial regions likely to have elevated methylmercury concentrations in biota, where biological monitoring is a priority due to potential risks to human and ecosystem health.

Global terrestrial models that can project future scenarios in soil mercury concentrations as part of integrated modelling assessment are also available. One example is the Global Terrestrial Mercury Model (GTMM), which is coupled to an atmospheric mercury model (GEOS-Chem). Ongoing work is evaluating the coupling of global air-land simulations with riverine inputs of mercury to marine regions. This research is still being developed in academic community and will contribute to integrated modelling activities in support of the Minamata Convention in the future to assess the impacts of climate change and emissions on future trends in environmental concentrations.

Development of watershed models that capture the complexity of Hg biogeochemistry and accurately predict stream Hg and MeHg concentrations and fluxes remains a major unmet research need (Hsu-Kim et al., 2018). Used within a single watershed, multiple mechanistic and empirical models that each capture the dynamics of a particular component of Hg have proven useful (Golden et al., 2012). Simulating MeHg in those same watersheds has proven even more difficult (Knightes et al., 2014). Carroll and Warwick (2016) successfully modelled both Hg and MeHg in a contaminated system in which soil bank erosion was the dominant process contributing to in-stream fluxes. In this case, in-depth a priori knowledge of the system was pivotal, as four different flow regimes were needed to capture differences in Hg loading mechanisms. Evaluation of empirical data and hydrology within a watershed will be necessary to guide the appropriate application of process-based watershed specific models in the future (Oswald and Branfireun, 2014;Zhu et al.,2018;Eklöf et al., 2015;Berndt et al., 2016). While Hg and MeHg modelling is still developmental, modelling that tests the effects of climate change is critical to guide future watershed management (Goldenet al., 2013).

2.5 Gaps in mercury data in biota

The usefulness of the data on mercury concentrations in fish and wildlife that has been generated from existing programmes varies for the purposes of the Minamata Convention according to the objectives of those programmes and the associated understanding needed for those objectives.

Current programmes, other than the GEMS/Food, do not cover all geographical regions and even though there may be existing biotic Hg data for many areas, those data may be of limited use for monitoring Hg because they are not bioindicators of interest, are not in specific areas that have value to meeting the Convention objectives, are not collected with a standardized approach, or have low value from a temporal standpoint. Information and monitoring efforts are particularly sparse in developing countries within tropical biomes and across marine ecosystems.

A review of the geographical coverage of Hg biomonitoring networks revealed a general lack of regional initiatives around the world, especially in Africa and Australia (UNEP 2016). Most Asian countries are minimally involved with national initiatives to monitor Hg levels in biota, with notable exceptions being Japan and the Republic of Korea where more extensive programs exist. For South America, the are a multitude of biotic Hg studies, however, there are very few biomonitoring programs. Conversely, Hg biomonitoring is ongoing in many countries within Europe (with some of the best developed biomonitoring programs found in Norway) and across North America. Environmental Specimen Banks can be used as monitoring tools to provide long term trends for contaminants in the environment, including mercury, as outlined within the EU.

Table S.2 shows a matrix of available data for trophic level 3 or greater from terrestrial biomes and associated marine areas that can respond to the operational questions supporting the Effectiveness Evaluation (see chapter 4). Generally, data availability is sufficient for tracking temporal trends and spatial gradients for all major taxa as bioindicators for both human health and the environment in the Arctic (AMAP 2005, 2011), as well as for fish in North America and Europe (covering parts of the boreal and temperate mixed forests). There are some mercury monitoring programs that include birds within the U.S. and southern Canada.

Data gaps are most notable within the tropical rainforest biome and associated marine areas – they are most problematic when coupled with mercury releases from artisanal small-scale mining activities and other major mercury source types. Information for marine mammals is generally missing as well, except for the Arctic Ocean.

While assessments of the fate of Hg in the environment are necessary to allow for effectiveness evaluations of mercury emission reduction measures, they are often hindered by lack of data and limited understanding of the Hg cycling processes (Braaten et al., 2018). Knowledge gaps relate to re-emission of deposited mercury, catchment inputs of mercury to headwaters and retention along the aquatic continuum. The rate at which decreased emissions of mercury to the atmosphere will result in lower loading of mercury to surface waters (and reduced exposure of aquatic ecosystems to mercury) is difficult to predict, especially given the large stores of legacy mercury present in soils and lake sediments and the complexity of mercury mobilization and transport mechanisms. However, tracking of mercury isotopes has shown that biotic exposures do respond to changes in emissions and often faster than expect (Harris et al. 2007; Lepak et al. 2019). The quantification of key elements in an environmental mercury profile has proven useful for highlighting available data sources and data gaps, in addition to the highlighted limited ability to compare independent estimates of mercury fluxes obtained from various sources and with different approaches (Braaten et al., 2018).

While MeHg accumulation in biota and its impact at the individual level have been documented, less is known about the impact on biodiversity and ecosystem services. The observed effects of direct exposure to Hg in areas of high biodiversity value and species endemism (e.g. near or downstream artisanal and small-scale gold mining operations) as well as biomagnification and bioaccumulation of MeHg in species of global concern – for example, various avian invertivore and piscivores and many marine mammals – suggest that mercury may exacerbate the impact of habitat degradation and overharvesting, and contribute to global loss of biodiversity by forcing vulnerable species closer to collapse and possible extinction (e.g. Evers and Sunderland 2019; Palacios-Torres et al. 2017; Wintle et al. 2011). Studies have hypothesized that elevated MeHg concentrations may have significant impacts on the market value of some ecosystem services, such as recreational and commercial fisheries, if MeHg exposure reduces the viability and sustainability of fish populations, especially at higher trophic levels due to biomagnification effects (e.g. Lusk et al. 2005).

Table S.2. Assessment of global mercury data availability*

TERRESTRIAL BIOMES AND ASSOCIATED MARINE AREAS	ECOLOGICAL HEALTH BIOINDICATORS			HUMAN AND ECOLOGICAL HEALTH BIOINDICATORS		
	Freshwater Birds	Marine Birds	Marine Mammals	Freshwater Fish	Marine Fish	Marine Mammals
Arctic Tundra and Arctic Ocean	XXX	XXX	XXX	XXX	XXX	XXX
Boreal Forest-Taiga and N. Pacific and Atlantic Ocean	X	X	Data gap	XX	X	Data gap
Temperate Mixed Forest and Pacific and Atlantic Ocean	XX	X	Data gap	XX	X	Data gap
Tropical Rainforest and S. Pacific and Atlantic and Indian Ocean	Data gap	Data gap	Data gap	Data gap	Data gap	Data gap

* Data availability was rated as follows: at poor (Data gap), insufficient (X), good (XX) and excellent (XXX) levels for trophic level 4 bioindicators within major biomes and associated marine areas for both ecological and human health bioindicators. The data availability category "excellent levels" indicate information is available for tracking both temporal trends and spatial gradients.

3. Human Biomonitoring

3.1 Multi-country human biomonitoring programmes

Global - WHO/UN Environment

As part of the Global Mercury Assessment 2018 (UNEP 2019), a World Health Organization (WHO)-sponsored activity conducted a systematic search of the recent (2000 to 2018) literature to assess our current understanding of human exposures to mercury. In doing so, the work identified 312 high-quality studies from 75 countries from which 424,858 mercury biomarker measurements from 335,991 individuals were analysed (Basu et al. 2018).

European Human Biomonitoring Initiative (HBM4EU)[22]

A joint effort of 30 countries that aims to coordinate and advance human biomonitoring in Europe. The work aims to generate evidence of actual exposure to chemicals by Europeans and make linkages with health outcomes to support policy making.

Arctic Monitoring and Assessment Programme (AMAP)[23]

AMAP falls under Arctic Council, and is mandated to: 1) monitor and assess the status of the Arctic region with respect to pollution and climate change; 2) document levels and trends, pathways and processes, and effects on ecosystems and humans, and propose actions to reduce associated threats for consideration by governments; and 3) produce sound science-based, policy-relevant

[22] https://www.hbm4eu.eu.
[23] https://www.amap.no.

assessments and public outreach products to inform policy and decision-making processes. The 2021 AMAP Mercury Assessment will be published in late 2021 with the Summary for Policy Makers report available (AMAP 2021).

3.2 National human biomonitoring programs[24]

Some countries run human biomonitoring programs that aim to yield nationally representative data. These programs are usually sponsored or run by official government agencies, and tend to provide high quality data (e.g., random sampling of an adequate population size; use reference laboratories for mercury analysis). However, national biomonitoring programs that consider mercury exposure are only carried out in 9 countries to date,[25] and international representation is mostly limited to higher income regions. Within many countries, there are examples of good biomonitoring studies focused on sub-populations or geographic regions. Taken together, information from these biomonitoring studies provide useful information on the design and conduct of such studies as well as the analysis and communication of the results. Table S.3. provides examples provided by parties and stakeholders.

Table S.3. Examples of existing national-level human biomonitoring studies*

COUNTRY	DESCRIPTION
Belgium	FLEHS survey run by Vlaanderen Departement Omgeving
Canada	Human Biomonitoring of Environmental Chemicals
	Canadian Health Measures Survey (CHMS) is an on-going national survey which collects information from Canadians about their general health. Since 2007, the CHMS has collected biomonitoring data, including mercury in blood. Publicly available reports provide the results of biomonitoring from each two-year cycle as well as provide a comparison between datasets from multiple cycles.
	Inuit Health Surveys programme to be overseen and administered by the Canadian national Inuit organization, Inuit Tapiriit Kanatami (ITK)
	First Nations Food, Nutrition, and Environment survey, implemented in the eight Assembly of First Nations (AFN) regions situated south of the 60th parallel over a 10-year period from 2008 to 2018. The survey included 92 First Nations communities, and obtained hair mercury results from 3,404 adults.
Czech Republic	CZ-EHMS run by the National Institute of Public Health; annual biomonitoring survey since 1994.
France	Elfe by Santé publique France (survey of ~1,800 pregnant women in 2011)
	ENNS by Santé publique France (survey of 1364 children in 2006)
Germany	German Environmental Survey, GerES

[24] In alphabetical order.
[25] Belgium, Canada, Czech Republic, France, Germany, Republic of Korea, Slovenia, Sweden, and USA.

	German Environmental Specimen Bank (includes annually collected and analysed human samples)
	Mercury in urine
	Count of tooth surfaces with amalgam fillings
Republic of Korea	KoNEHS (run by Korean Ministry of Environment) every 3 years since 2009.
Slovenia	SLO-HBM run by Jozef Stefan Institute every 2 years since 2008.
Sweden	Riksmaten by Swedish National Food Agency
United States	US CDC National Biomonitoring Program

*** As submitted by parties and stakeholders. More information may be found on the design and conduct of the studies, as well as the analysis and communication of the results, through the links provided.

3.3 Modelling of mercury levels in human populations from seafood exposure

Policy scenarios leading to different levels of anthropogenic mercury releases can be linked to exposure of some human populations using an integrated model that links atmospheric, terrestrial and oceanic simulations to fish bioaccumulation models. To link these simulations to exposures for seafood consuming populations, additional data on seafood consumption preferences and their geographic origin are needed. These data are available for some populations such as the United States and China on a per-capita basis and could be developed for other regions.

Extensive data also available from the Sea Around Us project (http://www.seaaroundus.org/) on a global basis for the harvests of marine fisheries, and by extension methylmercury flows, from the global oceans to subsistence populations that may be vulnerable to high levels of exposure. Similar data projects for freshwater fisheries are currently under development in the academic community.

To link modelled exposure levels to blood mercury concentrations of fish consuming populations, a toxicokinetic model describing human metabolism of mercury is needed. A well-established one compartment model is typically used for such assessment, but the academic literature has identified major discrepancies between modelled and measured blood mercury levels stemming from differences in methylmercury uptake and elimination across individuals. These differences are thought to reflect specific genetic traits, variability in the human microbiome, and modification of methylmercury availability based on the nutritional profile of co-ingested foods. This is an active area of research that is expected to progress to improve quantification of this pathway in the next several years.

These types of modelling exercises do not capture human exposures from contaminated sites and ASGM. These regions would benefit from a spatial analysis of environmental factors associated with elevated methylmercury production and biotic concentrations leading to human exposures.

Integrated modelling frameworks can illustrate pathways by which primary releases of mercury to the atmosphere, land and water reach methylmercury in fish and wildlife as well as exposure of some fish consuming human populations. At present, integrated modelling frameworks are under development and available as a research product. Integrated models have not previously been applied or compared in global assessment efforts. Coupled atmosphere-ocean and atmosphere-terrestrial have been published in the peer-reviewed literature by a few research groups. Models for food web bioaccumulation of methylmercury are also available from selected groups and can be used to describe accumulation patterns at the ecosystem scale (lakes, wetlands, estuaries, contaminated sites) and for global marine food webs. The most difficult link in integrated modelling frameworks is to human exposure and health outcomes due to the diversity of dietary preferences, food consumption patterns and individual variability in toxicokinetics affecting methylmercury uptake and elimination. All these components of integrated modelling frameworks are rapidly developing in the scientific community.

3.4 Gaps in mercury human biomonitoring data

There is great variability in exposures around the world and across/within population groups. Arguably the greatest data gap concerns the many countries and regions without any mercury biomonitoring data without which evidence-based decision making is hampered. Notably, nearly 70% of the data in the Global Mercury Assessment 2018 biomonitoring dataset was represented by just 8 countries (Republic of Korea, China, Japan, United States, Brazil, Saudi Arabia, Canada, and the Russian Federation).

There is also great variability in the quality of biomonitoring studies. From the Global Mercury Assessment 2018 (UNEP 2019) as detailed in Basu et al., 2018, many published studies simply do not report the year in which their population was sampled and thus cannot be used in efforts that aim to understand baseline conditions and temporal changes. In general, most of the included studies suffered from selection bias (e.g., need more information on how populations were sampled including more randomization and details on exposure sources; need more information on age and other demographic variables), exposure detection bias (e.g., need studies to carefully report on quality control steps taken including the use of reference materials and participation in quality assurance programs), and statistical and other biases (e.g., need studies to have IRB approvals, and for more detailed exposure surveys like FFQs).

Moving forward, guidelines such as the ones we outline in this report (including the references contained within) should be followed to help increase the quality and utility of mercury biomonitoring data. As an example, studies using the WHO protocol for assessment of prenatal exposure to methylmercury are recommended to fill the data gaps and obtain the global picture needed for effectiveness evaluation. This WHO protocol was piloted between 2015 and 2017 in diverse settings, including China (rice consumers), Ghana (seafood consumers), India (local industrial contamination, seafood consumers), Kyrgyzstan (mercury primary mining), Mongolia (artisanal and small-scale gold mining, ASGM), and the Russian Federation (freshwater fish consumers). This project showed that the generation of data using the WHO protocol in low- and middle-income countries is cost-effective, practical, and feasible. The project also built local capacity to conduct relevant studies, which can therefore be repeated over time and in a range of locations to fill gaps. Using the WHO protocol would enable the collection of comparable data (e.g., hair samples from 250 people per study location, with minimum diversity recommended). The studies would be country driven; local ethical clearance (i.e., that of an institutional review board) would be required, and the studies would be conducted within the national health system; therefore, country approval would be a given. Each country would own its data and the submission of results would be voluntary.

Paragraph 1 (d) of article 17 of the Convention calls for the parties to facilitate the exchange of epidemiological information concerning health impacts associated with exposure to mercury and mercury compounds, in close cooperation with the World Health Organization and other relevant organizations, as appropriate. In line with that article of the Convention, the compilation and exchange of data on mercury levels obtained through human biomonitoring should be undertaken.

To facilitate the generation of globally representative human biomonitoring data and trend information, which will be most relevant for effectiveness evaluation, the monitoring group established under the global monitoring arrangements for effectiveness evaluation should be kept informed of the studies planned and carried out.

Data quality issues are covered by the WHO protocol (and other ones listed in the guidance document). Measurement results must be analytically comparable across laboratories/studies. To ensure comparability, each national survey would need to follow the WHO-harmonized standard operating procedures for sampling and analytical methods and develop procedures for quality assurance and quality control that cover the pre-analytical phase. The availability of appropriate reference materials (samples with a certain level of mercury) would support internal quality assurance. External quality assurance should be done through international inter-laboratory comparison investigations. Coordination of the studies would help to ensure appropriate quality control measures.

The WHO protocol also covers data management, analysis and evaluation issues, including whether this should be done at the national and/or international level. The protocol recommends that participating countries conduct statistical analyses at the national level and submit anonymized data to a central database for statistical analysis. The aim of a statistical analysis at the international level is to assess associations between biomarker values and predictors such as age, gender and fish consumption habits (collected via questionnaire) in a pooled dataset. The WHO protocol also addresses data communication issues, and the human health assessments of the Arctic Monitoring and Assessment Programme (AMAP) address those issues for indigenous peoples in the Artic region in particular. Communication issues include the communication of results within the country, to the individuals participating in the study and to policymakers. It should be noted that some countries may already have national guidelines relating to the communication of results.

The Global Environment Facility-funded project "Develop a Plan for Global Monitoring of Human Exposure to and Environmental Concentrations of Mercury" (UNEP/MC/COP.3/INF/19) has shown that the generation of data using the WHO protocol in developing countries is cost-effective, practical and feasible. The project has built local capacity to conduct the relevant studies, which can therefore be repeated over time and in a range of locations to fill gaps.

4. Global Modelling Capabilities

The global modeling capabilities outlined in Table S.4 below provide a formalization of our scientific understanding of different mechanisms affecting mercury behavior. They provide tools for linking and spatially/temporally extrapolating data collected globally as part of ongoing research, policy activities and data provided by civil society. Models within different media vary in their availability, as indicated in the table. Integrated models are under development and are expected to be available by 2023.

Table S.4. Summary of existing modelling availability and gaps to be filled.

MODEL TYPE	AVAILABILITY	MODEL INPUT AVAILABILITY	GAPS STILL TO BE FILLED
Emissions Inventories	Available AMAP, EDGAR, Streets	Socioeconomic activity data (production, population, gross domestic product) Material flow and policy specifications	Harmonized inventory Time-resolved emissions Mercury emission factors to be refined (regional, site, etc.) Data on mercury content of commodities Consistency across sectors and non-mercury policies to be explored (e.g., energy)
Air	Available EMEP, Echmerit, GEM-Mach, GEOS-Chem, GRAHAM	Global emissions	Harmonized emissions inventories to be established
Ocean	Available MITgcm, NEMO, FATE-Hg	Spatially resolved global atmospheric Hg inputs (wet + dry) Concentrations of Hg and MeHg in rivers (globally)	Seawater Hg species data somewhat sparse but improving Data on Hg and MeHg in global rivers largely lacking
Watershed	Research product: some availability Estuaries (site specific); Freshwater and rivers (site specific)	Watershed-specific biogeochemical parameters Site-specific mercury releases	Understanding of site-specific biogeochemical processes Contributions of permafrost thaw, deforestation Small-scale gold mining releases High overall uncertainty
Soils and land:	Research product: some availability Global soils: Global Terrestrial Mercury Model (GTMM) ASGM contaminated sites (not yet integrated into global	Atmospheric deposition (model input) Emissions releases to land and water (very preliminary and coarse spatial resolution) Few data on runoff from contaminated sites Global land cover data and atmospheric inputs	MeHg simulation for terrestrial environments other than site-specific assessments still to be done Ground-truthing global "hot spot" analysis is needed; data on locations of ASGM and releases and/or contaminated sites needed Hydrology-resolving terrestrial models

	models but would be useful)		
Food web	Research product: some availability Global models for plankton; fish under development Food web bioaccumulation models for specific marine ecosystems Food web model for freshwater ecosystems (site specific)	Water MeHg (model for global scale) Fisheries biomass production from primary productivity globally Trophic interactions	Global fish model under development; could link to marine mammals/ birds Trophic level 4 data in Asia and Africa to be collected
Human exposure and health	Some availability Exposure of marine fish consumers (globally) Toxicokinetic model linking MeHg ingestion and blood and hair concentrations and outcomes Freshwater fish and rice consumers (site-specific data, if applicable) Occupational exposures at ASGM sites (site specific)	Biomass and MeHg concentrations in fish consumed by different subsidence populations globally (model); Dietary intake data for different human populations National biomonitoring data (model evaluation)	Mechanisms affecting relationships between external MeHg exposure and blood concentrations and outcomes for different populations are uncertain (research evolving) Variations of toxicokinetic parameters within and between population groups
Mass flow	Some availability, further applications straightforward Global mass flow model	Inputs of Hg to system of interest Timescales of relevant processes	Small spatial scale implementations
Generalized Linear/additive models	Multiple implementations, further applications straightforward R, Python, Matlab	Application-specific	Comparable datasets for wide applicability Rich ancillary datasets

Abbreviations: ASGM, artisanal and small-scale gold mining; Hg, mercury; MeHg, methylmercury.

Annex

INDICATIVE LIST OF RELEVANT STANDARD OPERATING PROCEDURES (SOPs)

A. ATMOSPHERIC MERCURY MONITORING

Document name	Description	Source
Methods for the determination of TGM and GEM	GMOS measurement procedures for the determination of TGM and GEM (mercury in air)	GMOS
Method for the determination of total mercury in precipitation	GMOS measurement procedures for the determination of mercury in precipitation	GMOS
Methods for the determination of speciated ambient Hg	GMOS methods for the determination of speciated ambient Hg (gaseous elemental mercury (GEM), particulate bound mercury and gaseous oxidized mercury (GOM))	GMOS
EPA Method 7473 (SW-846): Mercury in Solids and Solutions by Thermal Decomposition, Amalgamation, and Atomic Absorption Spectrophotometry	EPA's Selected Analytical Methods for Environmental Remediation and Recovery (SAM) lists this method for preparation and/or analysis of solid and wipe samples for mercury, mercuric chloride, and methoxyethylmercuric acetate.	US EPA
Air Sampling Standard Operating Procedures Operator's Manual	This SOP contains detailed instructions for tasks the site operator is required to routinely perform. The tasks are identified as "daily", "monthly" and "as required".	Canadian Air and Precipitation Monitoring Network (CAPMoN)
Manual of measurement method of hazardous air pollutants – Monitoring of mercury in the Ambient Air (*Japanese only*)	The measurement method for mercury in the ambient air, as described in the "Manual of Measurement Method of Hazardous Air Pollutants" comprises of Gold Amalgamation Trap, Thermal Desorption and Cold Vapor Atomic Absorption Spectrometry.	Ministry of the Environment Japan (MOEJ)
RDMQ2004 training manual for quality controlling (QC) and quality assuring (QA) atmospheric mercury measurement data collected with the Tekran 2537A, 1130 and 1135 models	This training manual provides a tour of the RDMQ2004 interface, and outlines the procedures for quality controlling (QC)/quality assurance (QA) of gaseous elemental mercury (GEM), reactive gaseous mercury (RGM) and particulate mercury (PHg) from data collected with the Tekran 2537A, 1130 and 1135 models, respectively.	Environment and Climate Change Canada (ECCC)
Manual for Total Gaseous Mercury Measurements	This Standard Operating Procedures (SOP) manual has been created for CAMNet and outlines the procedures followed within this network as they apply to the instrumentation. S. Steffen and B. Schroeder (1999)	Canadian Atmospheric Mercury Measureme nt Network (CAMNET)
Atmospheric Mercury Network Site Operations Manual		NADP

B. BIOTA MONITORING

Document name	Description	Source
Optimizing fish sampling for fish - mercury bioaccumulation factors		USGS
Models of Mercury in Fish		USGS
Isotopic tracers in fish in Northeast provide clue to mercury sources		USGS
Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories, Volume I: Fish Sampling and Analysis.		USEPA
Standard operational procedures for the monitoring of mercury and methylmercury in fish and shellfish	The SOP is specifically focused on a monitoring plan to estimate the reduction of mercury and methylmercury level in fish and shellfish and to identify potentially highly-exposed population groups.	Blancheman che and Tressou
Determination of methylmercury in seafood by direct mercury analysis	The application scope of this SOP is the determination of methylmercury in seafood/fishery products. The method is based on a double liquid-liquid extraction, first with an organic solvent and then with a cysteine solution. The final quantification is done with a direct mercury analyzer.	CALDERÓN et al (1999)
Mercury analysis in liver and hair samples of Caribou and Muskoxen via	This SOP describes how to measure mercury via the direct mercury analyser DMA80.	Environment and Climate Change Canada
Determination of Mercury in Environmental Samples by Direct Solid Analysis	This guideline describes a method for determining the mercury content in biological samples by means of direct solid analysis using DMA-80 Direct Mercury Analyser with integrated autosampler. This guideline is used for the routine testing of a variety of biological samples, including muscle tissue, eggs, bladder wrack, shoots and leaves.	Federal Environment al Agency, Germany
Bird Field Sampling Methods – Collection of Tissues for Mercury Analysis	This SOP focuses on non-lethal methods for collection of samples in birds for mercury analysis.	Biodiversity Research Institute (BRI)
Fish Field Sampling Methods – Collection of Tissues for Mercury Analysis	This sampling protocol is designed as a guide for the collection, processing, and shipping of fish tissue samples for the measurement of total mercury. Sample collection following these general protocols will allow comparisons to be made across sampling sites and assist in identifying potential mercury hotspots posing risk to both human and ecosystem health.	Biodiversity Research Institute (BRI)

C. HUMAN BIOMONITORING

Document name	Description	Source
International Ethical Guidelines for Health-Related Research Involving Humans, 4th Edition	Guidance on ethical conduct of research from the World Health Organization in collaboration with the Council for International Organizations of Medical Sciences	Council for International Organization s of Medical Sciences
Data Management Plan (DMP)		HBM4EU
Statistical Analysis Plan		HBM4EU
WP10 Data Management and Analysis Task 10.4 Statistical Analysis		HBM4EU
SOP 1 : Selection of Participants and Recruitment		HBM4EU
SOP 2 : Quality Assurance for Recruitment and Fieldwork		HBM4EU
SOP 3: Procedure for Obtaining Human Samples		HBM4EU
Study Protocols, SOPs and Guidelines, Tailored and Transferred Questionnaires for Recruitment and Sampling		HBM4EU
Prioritised List of Biomarkers, Matrices and Analytical Methods for the 2nd Prioritisation Round of Substances		HBM4EU
Interviewer Manual to the Basic Questionnaire for 2nd Round Priority Substances		
Matrix-Specific Questionnaires to Accompany the Sampling of Urine and Blood		HBM4EU
Guidance for Identifying Populations at Risk from Mercury Exposure	UNEP and World Health Organization (WHO). 2008. "Guidance for Identifying Populations At Risk From Mercury Exposure." UNEP and WHO: Geneva, Switzerland.	UNEP and WHO
Guidance for Conducting Fish Consumption Surveys	US EPA. 2016. "Guidance for Conducting Fish Consumption Surveys. EPA 823-B-16-002." Washington, DC.	HBM Experts Group
Strengthening the Reporting of Observational Studies in Epidemiology (STROBE): Explanation and Elaboration	Vandenbroucke, Jan P, Erik Von Elm, Douglas G Altman, Peter C Gøtzsche, Cynthia D Mulrow, Stuart J Pocock, Charles Poole, James J Schlesselman, and Matthias Egger. 2007. "Strengthening the Reporting of Observational Studies in Epidemiology (STROBE): Explanation and Elaboration." .	HBM Experts Group
Protocols for Environmental and Health Assessment of Mercury Released by Artisanal and Small-Scale Gold Miners	Veiga, Marcello M., and Randy Baker. 2003. "Protocols for Environmental and Health Assessment of Mercury Released by Artisanal and Small-Scale Gold Miners." UNIDO.	HBM Experts Group
Assessment of Prenatal Exposure to Mercury: Human	.	WHO

Biomonitoring Survey The First Survey Protocol		
Assessment of Prenatal Exposure to Mercury: Standard Operating Procedures		WHO
Human biomonitoring in artisanal and small-scale gold mining: ethical and scientific principles		WHO

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Document name	Description	Source
GMOS Standard Operational Procedure – Method for the determination of DGM in water	This SOP was the first SOP for DGM measurements in water exist so far. It is based on several peer-reviewed publications on DGM measurements and USGS SOP for determination of DGM in water by purge and trap, and cold vapour atomic fluorescence spectrometry (CVAFS).	GMOS
Compendium method IO-5: Sampling and analysis for vapor and particle phase mercury in ambient air utilizing cold vapor atomic fluorescence spectrometry (CVAFS)	This method describes procedures for collection and analysis of vapor phase and particulate Hg, in order to provide an EPA-approved, accessible sampling and analytical methodology, for uniform monitoring of atmospheric mercury levels.	
Method 1631, Revision E: Mercury in Water by Oxidation, Purge and Trap, and Cold Vapor Atomic Fluorescence Spectrometry		US EPA
Guidance for Implementation and Use of EPA Method 1631 for the Determination of Low-Level Mercury		US EPA

777 **E. OTHER RELEVANT SOPs**

Document name	Description	Source
Instructions for Electronic Submission of Data on Chemical Contaminants in Food and the Diet	This document outlines the protocols to be followed by participating institutions (WHO collaborating Centres for food contamination monitoring and National GEMS/Food Centres) when submitting electronic data. The protocols require a mapping between the national food classification and the GEMS/Food coding system. The document was updated in March 2021.	WHO

EMEP Manual for Sampling and Analysis	Operating procedure and quality assurance manual of the European Monitoring and Evaluation Programme (EMEP), including sections on offline measurements of particle-phase inorganic composition following European protocols.	EMEP
Ambient air quality	Standard method for the measurement of Pb, Cd, AS, and Ni in the PM 10 fraction of suspended particulate matter.	European Committee for Standardization

PART B. DATA COLLECTION AND MANAGEMENT

Quality assurance and quality control in laboratory analysis

Laboratory operations cover a wide range of activities including sample reception, field sampling support, sample transfer, storage and data reporting. Obtaining high quality and consistently accurate measurements is possible by following strict QA/QC procedures throughout the entire process through sampling, analysis and data handling. Implementing these crucial steps can ensure reliability of data, and facilitate a comparison of mercury measurements across different monitoring networks. Therefore, QA/QC procedures will be the foundation for obtaining globally comparable data that can be used in the Effectiveness Evaluation of the Convention.

While many QA/QC procedures are specific to the matrix or mercury species being sampled, or to the sampling or analytical method being used, some general actions to improve laboratory quality control are universally applicable. These actions include but are not limited to:

- Good laboratory practice and sample handling practice, including detailed chain-of-custody documentation (worksheets, logbooks, etc.) that records every step in the collection, handling and preparation of samples;
- Detailed documentation of analytical procedures;
- Calibration of analytical equipment following manufacturers' protocols;
- Traceable and routine accuracy checks (spikes, blinds, blanks, duplicates/triplicates and certified reference materials);
- Appropriate safety measures during sampling and laboratory analysis;
- Storage of unaltered raw data in electronic form in at least two physically different and safe locations;
- Automatic processing and data quality control for rapid and accurate delivery of data.

A non-exhaustive list of SOPs for good measurement practice and laboratory analysis methodologies is available in the annex to this document.

Intercomparison studies

To ensure quality and comparability of data, laboratories participating in the monitoring efforts under the Effectiveness Evaluation may wish to participate in, and benefit from, intercomparison studies. Such studies would not only help gauge the quality of data from individual laboratories but also help detect unknown problems in analytical procedures and address them to improve data quality.

Specific actions to implement intercomparison studies for mercury monitoring include but are not limited to:

- Supporting the exchange of knowledge and information among laboratories;
- Using standard samples containing known mercury concentrations from at least two accredited facilities;
- Engaging support to determine each laboratory's analytical performance and identify any bias in the analytical protocol.

Data quality

Quality assurance and quality control during data processing and evaluation are important components in any monitoring effort and will play a key role in providing comparable data for the Effectiveness Evaluation.

Advances in cyberinfrastructure and sampling methods can now generate enormous quantities of mercury data, including some in near real-time. As such, the challenge is no longer how much data is available and existing gaps, but rather the quality of the data. Data processing involves both automatic quality control and manual review components. The purpose of applying these measures is to arrive at a data set that represents the concentration of mercury in the matrix being monitored and to clearly distinguish against any artifacts.

Ensuring consistent data quality is a resource intensive task. The producer of monitoring data is responsible for the design and maintenance of an appropriate data archive, and different programmes have their own data handling and archiving processes. In the context of the Effectiveness Evaluation, mercury monitoring networks and data warehouses that have successfully applied methods of ensuring good data quality should be encouraged to share their experience.

Metadata

Metadata are additional information collected about the specifics on the how, when, and where data are gathered and are generally needed for proper interpretation of the target measurements. Mercury data without metadata are incomplete, and by themselves of limited value; at the same time metadata are of no use for data interpretation on their own. Metadata describe a dataset, what was collected, where and when the data, the methods employed, the measurements made, and other critical information. They also include information where relevant on data ownership and attribution.

The observed changes of Hg levels in environmental matrices that will contribute to the effectiveness evaluation will be obtained both through statistical and model-based analyses. Therefore, the used data quality management plan should be described or referenced as part of the metadata of a dataset to ensure their comparability.

Key metadata information, both general and matrix-specific, include the following:

General

- Overall aim and brief description of the study
- Geographical scope
- Characteristics of monitoring site(s), including geographic coordinates, altitude
- Monitoring frequency
- Monitoring period (start and finish date, time in UTC)
- Environmental matrix
- Mercury species
- Measurement method
- QA/QC procedures and SOPs used

Atmospheric mercury monitoring

- Sampling method
- Ancillary measurements (precipitation & meteorological data, emission inventories, air quality tracers, sulfate deposition, land cover and land use, leaf area index)

Biota Mercury monitoring

- Mercury species
- Biota taxon or species
- Description of study population, including exposure/vulnerability, sample size and sampling strategy
- Sampled tissue(s) and storage condition (e.g., wet weight or dry weight storage)
- Ancillary measurements (climate variables, habitat type, taxa ecology, age category, morphometrics (e.g. weight and length), foraging ecology)

Human biomonitoring

- Description of study population, including exposure/vulnerability, sample size and sampling strategy
- Ethics certificate
- Sampled tissue(s)
- Ancillary measurements (diet, occupational and other exposures, dental amalgam status, level of education, socio-economic status)

Data flagging

The purpose of the data flagging process is to further improve the overall quality of the data collected. This process involves the reviewing of field and laboratory measurements and metadata for problems (e.g data gaps, error messages) and inaccuracies. Data flagging can be performed at different steps in the process, from gathering to analysing the data, and by different people, including the actual data providers as well as those comparing data originated from different monitoring programmes.

Several networks (e.g AMNet, CAMNet) and databases have this capability and satisfactory results were achieved when different networks automated flagging criteria and data were used, for example in GEM measurements (Steffen et al., 2012, D'Amore et al., 2015).

Data storage

The storage of mercury data for the Effectiveness Evaluation may require the use of one or more platforms where data can be accessed, analysed, compared and shared. As noted in Chapter 4, to the extent possible and in accordance with requirements of individual data providers, data used in the Effectiveness Evaluation should follow the FAIR[26] and CARE[27] principles to facilitate sharing and ethical use of monitoring data.

Mercury data from existing programmes and databases provide a starting point for compiling comparable mercury monitoring data for the Effectiveness Evaluation. In addition, comparable monitoring data used in the Effectiveness Evaluation may be augmented by comparable data that is currently unpublished, if made available, as well as monitoring measurements from academia and research, as appropriate, and data from new monitoring initiatives. This may be accomplished through a well-documented and transparent set of "data flags" that will enable the use of data from different sources with different levels of QA/QC (see above).

Identifying one or more knowledge platforms where mercury data from different sources can be compared will be an important next step for the Effectiveness Evaluation. A possible way forward in this

[26] Wilkinson et al. (2016).
[27] "CARE Principles for Indigenous Data Governance: https://www.gida-global.org/care.

regard is to establish a web-based, interactive knowledge platform as a means for sharing and comparing data. In this regard, access to monitoring data could be facilitated by linking existing data centres rather than creating a new structure. There are some newly established monitoring stations/programs that submit their monitoring data to existing data centres *(e.g. EBAS,* GOS4M).

A key consideration in data management solutions for the Effectiveness Evaluation is that any data infrastructure used should be adequately resourced (both financially and in relation to thematic and IT expertise available at the data center) and have a reasonable prospect for secure and sustainable operations over the long-term (on the order of decades). UNEP's World Environment Situation Room,[28] which includes geo-referenced, remote-sensing and earth observation information integrated with statistics and data on the environmental dimension of sustainable development, is an example of a sustainable platform.

Data gathering

Another key consideration for obtaining comparable data for the Effectiveness Evaluation (particularly monitoring data that are not part of existing data centres) is that data gathering from different programmes and initiatives will require, in addition to mercury measurements, the submission of a set of metadata describing the monitoring activity and associated ancillary data.

To facilitate the collection and analysis of comparable monitoring data during periodic cycles of Effectiveness Evaluation, a standard format for the submission of data may help each stakeholder to plan, organize and describe their data according to such minimum requirements. A draft of such a format is presented in the annex below as a basis for testing and assessing what is the minimum required information for the submission of monitoring data for the Effectiveness Evaluation.

[28] https://wesr.unep.org.

PROTOTYPE OF A TEMPLATE FOR SUBMISSION OF MINIMAL ESSENTIAL DATA FROM MERCURY MONITORING STUDIES[29]

Please select one or multiple options for each item, as appropriate. * Indicates mandatory fields.

A. Submission details		
1. Date of submission:*		<Text entry>
2. Name:*		<Text entry>
3. Address:*		<Text entry>
4. Email:*		<email field>
5. Country:*		<list of countries>
B. Aim and scope of the study		
6. Overall aim of the study:*		□ Descriptive measure □ Exposure assessment □ Temporal trends □ Attribution assessment □ Risk assessment □ Other, please specify: <Text entry>
7. Brief description of the study:*		<Text entry – max. 150 words >
8. Geographic scope:		□ Sub-national □ National □ Multi-Country Details on the geographic scope: <Text entry>
9. Characteristics of the monitoring site(s):*	Human settlements:	□ Remote or unpopulated areas □ Low population density areas (<1,000 persons per square Km) □ High population density areas (>1,000 persons per square Km)
	Point sources:	□ Near ASGM sites □ Near sources other than ASGM sites, please specify: <Text entry>

[29] This draft prototype must be tested, updated, and validated in diverse settings before its usefulness as a tool in the Effective Evaluation of the Convention can be assessed.

	Ecosystems:	□ Oceanic □ Island or coastal areas □ Wetland / mangroves □ Lakes and rivers □ Terrestrial areas
		□ Other, please specify: <Text entry>
10. Co-location of monitoring site(s):		□ Co-located with other Hg monitoring networks or other relevant measurement activities – please explain: <Text entry> □ No
11. Monitoring frequency:		□ Single time point □ Continuous □ Monthly □ Yearly □ Other, please specify: <Text entry>
12. Monitoring period:		From: <Date> To: <Date>
13. Environmental matrix:*		□ Air » Go to section C □ Biota » Go to section D □ Human biomonitoring » Go to section E
C. Atmospheric mercury monitoring		
14. Sampling method:*		□ Continuous analyzers □ Manual trap methods □ Passive samplers □ Wet deposition samplers □ Dry deposition samplers □ Other, please specify: <Text entry>
15. Ancillary measurements:		□ Precipitation & meteorological data □ Emission inventories □ Air quality tracers (incl. SO_2, CO_2, CO, PM2.5) □ Atmospheric deposition of sulfate □ Land cover □ Land use □ Leaf area index □ Other, please specify: <Text entry>

D. Biota mercury monitoring		
16. Biota:*		□ Fish □ Reptiles □ Birds □ Mammals □ Other, please specify: <Text entry>
17. Taxon or species:		<Text entry>
18. Brief description of the study population in terms of mercury exposure:		<Text entry – max. 150 words >
19. Study population sample size:		<Number entry>
20. Study population sampling strategy:		□ Random □ Not random □ Other, please specify: <Text entry>
21. Sampled tissue(s):		□ Blood □ Muscle □ Fur □ Feathers □ Eggs □ Other, please specify: <Text entry>
22. Ancillary measurements:	Biota:	□ Species name □ Weight □ Length □ Age, sex and maturity stage
	Surrounding (sea)water and sediments:	□ Spatial coordinates, temperature, depth, pH □ Dissolved oxygen □ Organic carbon (total or dissolved) □ Salinity
	Inland areas:	□ Spatial coordinates □ Landscape characteristics (e.g. lake and catchment morphology) □ Pollution deposition patterns □ Local pollution history
	Stable isotopes:	□ Carbon ($\delta^{13}C$) □ Nitrogen ($\delta^{15}N$) □ Mercury ($\delta^{202}Hg$) □ Mercury ($\delta^{199}Hg$)

		□ Other, please specify: <Text entry>
E. Human biomonitoring		
23. Brief description of the study population in terms of mercury exposures/vulnerability		<Text entry – max. 150 words >
24. Ethics certificate:		Institutional Review Board (IRB): <Text entry> Date issued: <Date field> *Please attach copy of ethics certificate*.
25. Study population exposure/vulnerability:*	Demographics:	□ General population □ Early lifestage (fetus, newborn, children) □ Women in child-bearing age □ Pregnant women
	Environmental and dietary exposure:	□ Indigenous Peoples and local communities □ People living in islands or coastal areas □ People living near ASGM sites □ People living near sources other than ASGM sites, please specify: <Text entry>
	Occupational exposure:	□ Primary mercury mining □ Artisanal and small-scale gold mining (ASGM) □ Non-ferrous ore mining (e.g. zinc, lead, copper) □ Chlor-alkali production □ Vinyl chloride monomer (VCM) production □ Alcetaldehyde production □ Coal-fired power plants □ Oil and natural gas processing □ Healthcare (using mercury-containing measuring and control devices) □ Dentistry □ E-waste recyclers □ Healthcare waste processors □ Manufacture of mercury containing devices (e.g. mirrors, paint, fluorescent lights, batteries, barometers) □ Agriculture (using certain pesticides)
		□ Other, please specify: <Text entry>
26. Study population sample size:		<Number entry> Justification of sample size: <Text entry>

27. Study population sampling strategy:		□ Random □ Not random □ Other, please specify: <Text entry>
28. Study population gender:		% female: <Number entry>
29. Study population age:	Interval:	Min.: <Number entry> Max.: <Number entry
	Percentage:	% 0 – 5 years of age: <0-100> % 6 – 15 years of age: <0-100> % 16 – 50 years of age: <0-100> % 51 years of age and older: <0-100>
30. Sampled tissue(s):		□ Whole blood □ Urine □ Hair □ Other, please specify: <Text entry>
31. Ancillary measurements:		□ Diet info □ Known occupational and other exposures □ Amalgam status □ Education □ Socio-economic status
E. Measurement and quality control		
32. Mercury species:*	Air matrix:	□ Gaseous Elemental Mercury (Hg^0, GEM) □ Gaseous Oxidized Mercury (Hg^{II}, GOM) □ Total Gaseous Mercury (TGM = GEM + GOM) □ Particle-bound mercury (PBM)
	Biota or human matrices:	□ Total mercury □ Methyl mercury
		□ Other, please specify: <Text entry>

33. Measurement method:*		□ Cold-vapor atomic fluorescence spectroscopy (CV-AFS) □ Cold-vapour atomic absorption spectroscopy (CV-AAS) □ Inductively coupled plasma mass spectrometry (ICP-MS) □ Multi-collector inductively coupled plasma mass spectrometry (MC-ICP-MS) □ Direct Mercury Analyzer (DMA) □ Cation exchange membranes □ High-resolution measurements (PBM2.5, GOM) □ Other, please specify: <Text entry>
34. QA/QC procedures performed:		□ Replicates □ Sample dilution □ Blanks □ Certified reference material(s) □ Initial and continuing calibrations □ Determination of measurement precision □ Determination of detection limit □ Inter-laboratory comparison □ Other, please specify: <Text entry>
35. Standard Operating Procedures which were applied:*	Sample collection and handling:*	□ Please attach SOP or indicate publicly available source <Web address> □ Not available
	Analytical measurement:*	□ Please attach SOP or indicate publicly available source <Web address> □ Not available
	Data validation and QA/QC:*	□ Please attach SOP or indicate publicly available source <Web address> □ Not available
	Data analysis and reporting:*	□ Please attach SOP or indicate publicly available source <Web address> □ Not available
36. Additional information regarding measurement methods, standard procedures, data validation and QA/QC:		<Text entry>

Additional information	
37. Additional information:	Please attach document and/or provide <Web address>

References [to be completed]

AMAP. 2021. 2021 AMAP Mercury Assessment. Summary for Policy-makers. https://www.amap.no/documents/doc/2021-amap-mercury-assessment.-summary-for-policy-makers/3510

Basu, Niladri, Milena Horvat, David C Evers, Irina Zastenskaya, Pál Weihe, and Joanna Tempowski. 2018. "A State-of-the-Science Review of Mercury Biomarkers in Human Populations Worldwide between 2000 and 2018." Environmental Health Perspectives 126 (10): 1–14. https://doi.org/10.1289/EHP3904

Evers, D.C., Taylor, M., Burton, M., and Johnson, S. 2018. Mercury in the Global Environment: Understanding spatial patterns for biomonitoring needs of the Minamata Convention on Mercury. Biodiversity Research Institute. Portland, Maine. BRI Science Communications Series 2018-21. 21 pages.

Evers, D.C. and E. Sunderland. 2019. Technical Information Report on Mercury Monitoring in Biota: Proposed components towards a strategic long-term plan for monitoring mercury in fish and wildlife globally. UN Environment Programme, Chemicals and Health Branch, Geneva, Switzerland. 40 pp. https://wedocs.unep.org/bitstream/handle/20.500.11822/30821/Report_Moni_Biota.pdf

Evers, D.C., A. Sauer, D. Burns, N. Fisher, A. Sauer, D. Bertok, E. Adams, M. Burton, and C.T. Driscoll. 2020. Mercury in New York: Spatio-temporal patterns and risk to ecosystem and human health. Ecotoxicology 29:1565–1589

UNEP. 2019. "Global Mercury Assessment 2018." Geneva, Switzerland