DRAFT Information Document
Background information on mercury monitoring

Supporting document for the draft report on the work of the ad hoc group of technical experts on effectiveness evaluation

Also open for comment: 1 August to 5 September 2019
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This information document consists of two parts and supplements texts shown in the report Annex 1 text in particular. The first part contains information on monitoring activities organized per environmental media and adds also background in the chapter on biota providing background on approaches to organize activities for biotic monitoring under oceanic and continental frameworks. Part 2 provides a draft structure and elements of the guidance for global monitoring, as included in the terms of reference for the global monitoring arrangements described in Annex 3 of the report of the ad-hoc group of technical experts on effectiveness evaluation (UNEP/MC/COP.3/X)."

In developing this document, information on mercury monitoring were collected from parties and other stakeholders, and made available to the ad-hoc group for its meeting in April 2019. The submissions and meeting documents are available from the Convention website.[1]

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[1] http://www.mercuryconvention.org/Meetings/Intersessionalwork/tabid/7857/language/en-US/Default.aspx

PART I: Overview of available monitoring data, existing gaps, and approaches for filling these gaps

1. AIR

Mercury levels in ambient air have been measured in some locations for a very long period. These data have contributed to the discussion on the global nature of the mercury issue. The current available data is collected by various national and global network owners using different sampling methods. A number of suitable methods are available, and the available sampling techniques considered suitable to obtain globally comparable data were identified and reviewed. It was recognized that none of the currently available data had global coverage, but that there are suitable methods to obtain such global data (as identified in GMA 2018).

The expert group recommended that air concentration data be collected as total gaseous mercury (from both active and passive sampling), and wet deposition data be collected to understand total deposition. It is important that there is agreement on the specified time period over which to report averaged data, as this may be reported monthly, annually or seasonally (noting that 'seasonal' may have different meanings i.e. summer/winter, wet/dry etc.). In addition, the requirement for data completeness also needs to be specified. In considering data obtained at different monitoring sites, the type of monitoring site, and the reason for collecting the data should be elaborated. A number of existing data sets with available comparable data were highlighted, and are presented in more detail in the next section.

The group agreed that there is a significant geographical coverage of ambient air monitoring of mercury, but that there are gaps in certain regions. These geographical gaps should be identified and a plan should be in place to cover them. These include gaps in Africa, Latin America, the Caribbean, certain parts of Asia and the Pacific and in Russia. These gaps could be covered with a combination of passive sampling as well as some additional active sampling. It was noted that some passive sampling is already producing data, but that further information to ensure global comparability will be needed as some of these techniques are new. In some countries, manual active sampling has been used and has produced reliable data sets. As part of filling the gaps, establishing some sites where combination of established and new methods including, for example, active and passive sampling, as well as wet deposition measurements are carried out (i.e. supersites), would improve data availability and improve confidence in the comparability of different sampling methods. A global ambient mercury monitoring program should be developed to systematically identify future monitoring sites. It is considered necessary that in the initial periods, data collection should be done more frequently (e.g. monthly sampling) to fill in the current regional information gaps. Once there is sufficient information available, the frequency could be adjusted to match other regions. It may be useful to look at lessons learned from Stockholm Convention and to GOS4M activities (Global Observation System for Mercury, http://www.gos4m.org/), in particular the necessary sustainability of the sampling and analysis, to allow proper capacity building in countries lacking such experience.

Other air data which may be comparable and implemented in future plans include atmospheric speciation data (gaseous oxidized mercury and particle bound mercury).

There are a variety of active sampling methods by combination of automated vs. manual gold traps, detection by CVAFS vs. AAS, and several suppliers including Tekran, Lumex, NIC, and PSA. Further technical review of methods may be needed. Passive sampling methods include methods which are currently available as well as those under development, including active carbon (Canadian), titanium dioxide (GMOS) and gold beads (Republic of Korea/Thailand) or gold cores (Radiello tubes, Italy-Denmark). Preliminary results have been produced also by the UN Environment-GEF project "Development of a Plan for Global Monitoring of Human Exposure to and Environmental Concentrations of Mercury".

Review of available activities and networks for AIR

International (global) programs for monitoring include the following.

GOS4M

The Global Observation System for Mercury (GOS4M) (www.gos4m.org) is a Flagship initiative of the Group on Earth Observation (GEO – www.earthobservations.org) and is part of the GEO Work Programme (2016-2025). GOS4M has a strong foundation built on the outcomes of the former GEO Task on Health Surveillance [HE-02 "Tracking Pollutants"] established as a part of the GEO Work Plan (2009-2015). GOS4M overarching goal is to support interested parties in the implementation of the Minamata Convention on Mercury by (1) 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; (2) 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. The use of Passive Air Samplers (PASs) is considered a cost-effective method for achieving this goal; (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 an harmonization the 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 as part of the GEO Work Programme 2020-2022. Its overarching aim is to support interested parties in the effectiveness evaluation of the MCM.

GMOS

The **GMOS** (Global Mercury Observation System) network (www.gmos.eu) includes over 30 monitoring sites in both Southern and Northern Hemispheres and is the only global network able to provide 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 part of GEO Flagship "Global Observing System for Mercury (**GOS^{4}M**)" (www.gos4m.org) and S(S is aimed to support the MCM as well as research projects and programs.

[EDGAR

Emission database for global atmospheric research (Global Emissions EDGARv4.tox2 (November 2017)

The EDGAR Team 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. The paper "Evaluating EDGARv4.tox2 speciated mercury emissions ex-post scenarios and their impacts on modelled global and regional wet deposition patterns" published open access in Atmospheric Environment (https://www.sciencedirect.com/science/article/pii/S1352231018302425), describes the emissions inventory (see section A). 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

http://edgar.jrc.ec.europa.eu/overview.php?v=4tox2]

Regional programs for monitoring include the following:

The **UNECE Convention on Long Range Transboundary Air Pollution** funds through its EMEP protocol five scientific centers to support its 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 centers 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 Modeling (EMEP-CIAM). In collaboration with experts form the Parties, emission data, observations and model results are used to assess transboundary fluxes of pollutants to support the development of abatement strategies. The Convention has 7 protocols setting emission target (including the 1998 Protocol on Heavy Metals (which includes Mercury). 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. In particular, networks dedicated to effect monitoring on various ecosystems run for a long time. Recently a report summarizing trends analysis of mercury in fish was published by the group in charge of water issues. The Convention and EMEP can add value to other international frameworks (the Minamata Convention is explicitly mentioned in the EMEP strategy), and most European programs make direct use of the Convention infrastructures and its data (including the EU NEC directive, AMAP, HELCOM and OSPAR). Also WMO Global Atmosphere Watch take advantage of the Convention efforts on disseminating data of atmospheric composition. It is therefore suggested that the Minamata Convention explores the opportunities for taking advantage of already existing capacities and infrastructures in operation under CLRTAP, as this will minimize the use of resources and at the same time secure that the basis for different UN-policies related to the environment are harmonized and based on the same data and source-receptor relationships across the various themes. The latter is particularly beneficial for Parties which as signatories to both the LRTAP and Minamata Conventions.

APMMN: The Asia Pacific Mercury Monitoring Network (APMMN) (apmmn.org/) 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 objectives of the network are (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 modeling, (3) assist partner countries in developing monitoring and assessment capacity, and (4) share data and monitoring information. The program launched in 2012, through discussion of ca. 30 scientists in the region including the United States, Japan and Korea. Participants identified key monitoring gaps in the region and articulated the need for a coordinated, Asia-wide network to monitor mercury transport and deposition; and this is the basis of the objectives of APMMN. Since launching, the program developed and adopted APMMN 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 program 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.

AMAP: The Arctic Monitoring and Assessment Programme (AMAP) (www.amap.no/) 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 information is based largely on ongoing national and 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 freely available from its website: www.amap.no

National programs for environmental mercury monitoring include the following:

Canada

Atmospheric mercury monitoring in Canada began in the early 1990s. Since that time, the number and location of measurement sites has changed and, as of 2017, the current sites for atmospheric mercury monitoring have been consolidated and fall under Environment and Climate Change Canada – Atmospheric Mercury Monitoring or ECCC-AMM network. Canada measures Total Gaseous Mercury (TGM), Mercury in wet deposition and atmospheric speciated mercury (reactive gaseous mercury (RGM), particulate mercury (PHg) and gaseous elemental mercury (GEM)). These data are collected through a group of research programs and follow the same protocols and procedures for data collection and quality control. The data are produced on an open data portal through Environment and Climate Change Canada.

Canada provides atmospheric mercury monitoring data to AMAP through its national Northern Contaminants Program (NCP). Canada has the longest Arctic atmospheric Hg record in the world having measured TGM and atmospheric speciated mercury at Alert, Nunavut since 1995 and 2002, respectively. NCP also monitors TGM in the western region of the Canadian Arctic at Little Fox Lake, Yukon. These data follow all the ECCC-AMM protocols described below.

Kingdom of Denmark

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, Station Nord, 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 center.

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 ICES: http://www.ices.dk/marine-data/data-portals/Pages/DOME.aspxor.

Human levels of mercury have been measured in Greenlandic inuits 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 the Arctic monitoring and Assessment Programme (AMAP). Kingdom of Denmark is presently the co-lead in the Human Health Assessment Group, AMAP.

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

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 methods. Currently, there were 21 AMNet sites, and data from the AMNet are available on the NADP website (http://nadp.slh.wisc.edu/amnet/default.aspx). AMNet observations have been made since 2009 and are made continuously and qualified and averaged to one-hour (GEM in ng m-3) and two-hour values (GOM, and PBM2.5, in pg m-3). Valid data are released for use by the scientific community, and also released in annual figures of Hg variability for sites meeting certain criteria.

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 (www.airkorea.or.kr).

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); 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); monitoring of long range transported contaminants (Hg in air, moss and precipitation). Monitoring is mainly conducted in organisms such as cod, blue mussels, trout, seabirds, zooplankton, shrimps, bird of prey, earthworms and foxes. 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 national trends for mercury dating back to 1984. The national monitoring is founded in regional programs such as EMEP, AMAP, OSPAR and EU Water Framework Directive.

Norway also provides facilities for the ICP Waters Programme Centre, where the Norwegian Environment Agency provides financial support. 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 the Centre published a report on mercury 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 web page (http://www.icp-waters.no/).

Table 1.1 * Global Review of existing mercury monitoring sites that are part of in national, regional and global networks (based on UN Environment, 2016).

National / regional area	Program/ network/ inventory - dates of Hg measurements	Number of monitoring stations/ sites	Managing institution	Main URLs

National networks

Australia	The Australian National Pollutant inventory (NPI) – from 1996 onwards	2		https://data.gov.au/dataset/npi
Austria	Network for Mercury impacts in forest foliage - – from 1983 (as bio-monitoring) onwards	Not available	Austrian Federal Research Centre for Forests controls	http://www.bioindikatornetz.at
Brazil	Mercury monitoring sites – running dates not available	Not available	CETESB, the environmental agency of the State of São Paulo	http://www.cetesb.sp.gov.br/2014/10/27/cetesb-realiza-treinamentos-internacionais-sobre-pops-e-mercurio/
Canada	The Canadian Air and Precipitation Monitoring Network (CAPMoN) & others (including AMAP) – from 1994 onwards (see Section 3.2.5)	3 for air measurements	CAPMoN	https://www.ec.gc.ca/rs-mn/default.asp?lang=En&n=6C2AD92E-1
		+7 for air measurements	Environment and Climate Change Canada	http://nadp.sws.uiuc.edu/
		+ 2 remote	Canadian Northern Contaminants Program (NCP) – Environment Canada	
China	Mercury monitoring sites (including GMOS sites)	9 for air measurements	Institute of Geochemistry, CAS	
China (Taiwan)	Wet deposition Network – from 2009 onwards	11	Environmental Protection Administration	
		+ 1 remote		
Hungary	Hungarian Air Quality Monitoring Network – from 2010 onwards	1	Hungarian Meteorological Service	
Republic of Korea	Mercury Monitoring Network in Korean Air Pollution Monitoring Network – from 2009 onwards	12 TGM / 1 Hg speciation / 4 Hg precipitation	National Institute of Environmental Research in the Ministry of Environment	https://seoulsolution.kr/en/content/air-pollution-monitoring-network www.airkorea.or.kr (Korean only)
Japan	Mercury Monitoring Networks – from 1998 onwards	5	National Institute for Minamata Disease (NIMD) and the National Institute for Environmental Studies (NIES)/ Ministry of Environment (MOE)	https://www.env.go.jp/en/chemi/mercury/bms.htmlhttp://www.env.go.jp/press/104568.html (Japanese only) http://www.env.go.jp/air/osen/monitoring/mon_h27/index.html (Japanese only)

Poland	Polish State Environmental Monitoring programme – from 2000 onwards	5	Inspection of Environmental Protection	http://www.gios.gov.pl/en/state-of-the-environment/state-environmental-monitoring
Indonesia	Mercury Monitoring Site	1		http://apmmn.org
Switzerland	Mercury Monitoring Site	1		https://www.hfsjg.ch
United Kingdom	National Metals Network and National Atmospheric Emission Inventory – running dates na	2	Department for Environment, Food and Rural Affairs (DEFRA); Centre for Ecology and Hydrology (CEH)	http://www.auchencorth.ceh.ac.uk/node/211 https://uk-air.defra.gov.uk/networks/network-info?view=metals http://naei.defra.gov.uk/overview/pollutants?pollutant_id=15
Vietnam	Mercury Monitoring System – from 2014 onwards	1	Vietnamese Centre for Environmental Monitoring (CEM) of the Vietnam Environment Administration (VEA)	

Global and Regional networks

Global network	Global Mercury Observation System (GMOS)	Several stations in both hemispheres	CNR-IIA, Division of Rende, Italy	www.gmos.eu
Regional Network	European Union Network under EU Directive 2004/107/EC	Several stations in Europe	European Environment Agency (EEA)	http://cdr.eionet.europa.eu/ https://www.eea.europa.eu/publications/92-9167-058-8/page010.html
	European Monitoring and Evaluation Programme (EMEP)	Several stations in Europe	EMEP Organization	http://emep.int/index.html
	National Atmospheric Deposition Program (NADP)	Many stations in USA, Canada (see Section 4.2.4)	NADP Program Office	http://nadp.sws.uiuc.edu/mdn/
	Asia Pacific Mercury Monitoring Network (APMMN)	Several stations in the Asia-Pacific Region	APMMN	http://apmmn.org/
	Arctic Monitoring and Assessment Programme (AMAP)	Several stations across the circum-Arctic Region	AMAP	https://www.amap.no/about/the-amap-programme

How can the data flow?

Most of the atmospheric mercury data is currently collected through operational networks. New passive mercury sampling is being introduced into these networks with the analysis of the samples conducted in laboratories currently capable.

The overall idea will be for passive air samples to be analysed by a lab in the region or could be analysed by a lab in one country. Currently, there are several pilots studies being undertaken to attempt to fill in some of the gaps.

- Study 1: will be made in conjunction with the Global Atmospheric Passive Sampling (GAPS) program and all samples will be analysed in one lab for proof of concept
- Study 2: As part of ERA-PLANET programme (www.era-planet.eu) the GMOS network (www.gmos.eu) is expanding its geographical coverage in Africa (i.e., Congo, Ivory Coast) and Latin America, to start with, by using Passive Air Samplers (PASs), information and data will be made available on the official GMOS web portal (www.gmos.org).

Technology transfer:

Labs would have to be trained on the analysis process and interlab comparison would have to be done.

Intercomparability

In order to provide globally comparable monitoring data, an intercomparison exercise of different PASs produced by different groups worldwide is in progress, it is aimed to provide the degree of agreements between different PASs technologies in measuring TGM/GEM in ambient air. More information on past and onging intercomparison exercises is reported in the Table above.

Proposal for data housing: Quality Controlled (QC'd) data from existing regional and global monitoring networks can be linked to the GEO Flagship GOS4M (Global Observation System for Mercury, www.gos4m.org) database which is supported by several countries and programs. GOS4M is part of the GEO (Group on Earth Observation) Work Programme and is supported by ERA-PLANET programme (www.era-planet.eu) and a newly approved programme E-SHAPE (www in preparation); both these programmes have secured financial resources to support the GOS4M operation until the end of the 2023. The GOS4M is designed and aimed to support interested parties in the implementation of the Minamata convention by providing up to date monitoring data and tools for explaining spatial and temporal trends of observed levels of mercury in ambient airC(. GOS4M will make available a virtual working environment (Minamata Knowledge Hub) to allow policy makers and stakeholder to co-design different policy scenarios and assess the likely effectiveness of measures that parties may wish to undertake.

Data collected from all the networks for this purpose will be collected by a team of expert scientists and will undertake temporal and spatial analyses. This data will also be provided to global and regional modelling teams to develop analysis of the collected information. Information will then be consolidated into a monitoring report. This report will be provided to the EE committee along with the other high level reports.

2. Human matrices

Available networks for Human Biomonitoring

Some of the regional and national programmes summarized above include human biomonitoring. Other human biomonitoring progammes include the following;

United States: National Biomonitoring Program

https://www.cdc.gov/biomonitoring/Mercury_BiomonitoringSummary.html

Canada: Human Biomonitoring of Environmental Chemicals

https://www.canada.ca/en/health-canada/services/environmental-workplace-health/environmental-contaminants/human-biomonitoring-environmental-chemicals.html

Within Canada on a regional level, there are regular Inuit Health Surveys taking place, some of which are (co-)funded by the Northern Contaminants Program (NCP), for example the Nunavik Inuit Health Survey[2],[3]. Also, the Government of Canada’s Budget 2018 announced ‘$82 million over 10 years, with $6 million per year ongoing, for the co-creation of a permanent Inuit Health Survey’. This work will be overseen and administered by the Canadian national Inuit organization, Inuit Tapiriit Kanatami (ITK), and will be able to provide valuable information with regards to mercury levels in Canadian Inuit.

Germany:

German Environmental Survey, GerES

https://www.umweltbundesamt.de/en/topics/health/assessing-environmentally-related-health-risks/german-environmental-survey-geres

German Environmental Specimen Bank (includes annually collected and analysed human samples)

https://www.umweltprobenbank.de/en/documents

Mercury in urine:
https://www.umweltprobenbank.de/en/documents/investigations/results/analytes?analytes=10003+10028&sampling_areas=&sampling_years=&specimen_types=10037

Count of tooth surfaces with amalgam fillings:
https://www.umweltprobenbank.de/en/documents/investigations/results/biometrics?sampling_areas=&sampling_years=&specimen_types=10005

Europe: European Human Biomonitoring Initiative (HBM4EU)

https://www.hbm4eu.eu/

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[2] https://www.inspq.qc.ca/pdf/publications/resumes_nunavik/anglais/ExposureEnvironmentaContaminantsInNunavikPersistentOrganicPollutantsAndNewContaminants.pdf

[3] https://nrbhss.ca/en/what-qanuilirpitaa-2017

3. Biota

A. Introduction – Why is it important to monitor Hg in biota?

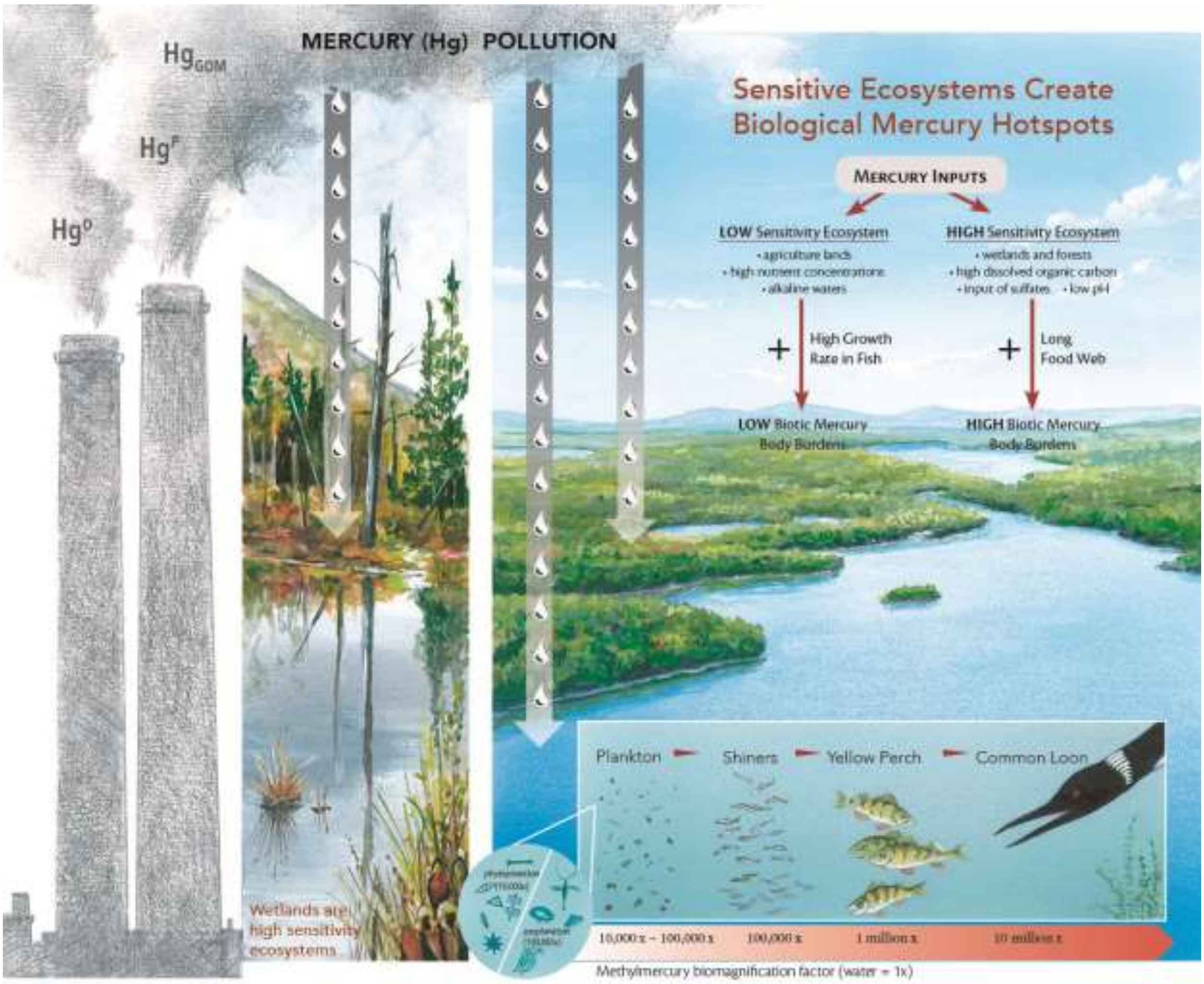
Inorganic mercury enters ecosystems through the air (e.g., from coal-fired power plants and incinerators), water (e.g., from chlor-alkali facilities and diffuse sources in watersheds and rivers), and land (e.g., from landfills and other contaminated sites) (Kocman et al. 2017, Streets et al. 2017, Hsu-Kim et al. 2018; Obrist et al. 2018). Once in the environment, mercury can be converted to methylmercury by bacteria and other microbes (Gilmour et al. 2013, Yu et al. 2013).

Methylmercury is toxic, and can accumulate in the tissues of fish, wildlife and humans, causing numerous negative health effects. The extent to which mercury is methylated and made available in the environment is complex and can be influenced by numerous factors. Specific ecological conditions can facilitate the production and bioavailability of methylmercury. For example, bacteria often produce more methylmercury under moderate amounts of sulphate and low oxygen conditions (Gilmour et al., 1998, Hsu-Kim et al. 2013); these conditions are especially prevalent in wetland ecosystems (Branfireun et al., 1996). Furthermore, areas with abundant dissolved organic carbon (DOC) from decaying organic matter may generate and transport methylmercury more readily than areas that are low in DOC (Schartup et al. 2015) and areas that are acidified from deposition of sulfur oxides from sources such as fossil fuel combustion may be important environments that are sensitive for mercury methylation (Branfireun et al., 1999, Wyn et al. 2009).

In areas where wet and/or dry mercury deposition is relatively low or moderate, effects on biota may be disproportionately high if conditions promote methylmercury production. Conversely, ecosystems with low methylation potential may have low levels of methylmercury despite heavy anthropogenic mercury contamination. The decoupling of inorganic mercury sources with methylmercury production and bioavailability is evident at local (Evers et al. 2007) and landscape levels (Eagles-Smith et al. 2016). The complexity of mercury cycling makes it challenging to predict exposure levels in upper trophic level fish and wildlife from environmental mercury concentrations alone (Gustin et al. 2016, Sunderland et al. 2016).

Therefore, identifying appropriate bioindicators based on their relationship with sensitive ecosystems is a critical first step in assessing risk to ecological and human health through the long-term mercury monitoring of the Minamata Convention (Figure 1).

Figure 3.1. Mercury emissions can be transported hundreds and thousands of kilometers from their sources before being deposited on the landscape. Once deposited, the potential impact of mercury on the environment depends largely on ecosystem sensitivity. Understanding which ecosystems are most susceptible and also which organisms can serve as appropriate bioindicators is a critical component of effective mercury monitoring.



B1.0 Biotic tissues of interest:

In assessing samples, it is recommended to assess muscle tissues for fish and marine mammals; for birds, blood should be used for short term data, muscle or eggs should be used for medium term and feathers can be used for long term results (Table 1). It is considered to be sufficient to assess total mercury for all keratin-based and muscle tissues (assuming greater than 90% of the total mercury, on average, is methylmercury) using either wet weight or dry weight. Samples should be georeferenced, with the level of detail varying according to the objective of the sampling.

Standard operating procedures are available for example through national /regional monitoring programs, however additional more universal protocols may need to be agreed on for other sampling which is not covered by this process. Inter-tissue conversions are generally feasible to help provide a way to have standardized, and therefore comparable, tissue mercury concentrations.

Table 3.1 Major biota groupings and tissues recommended for MeHg monitoring. All tissues can be non-lethally sampled (including biopsies of liver and kidney).

Group	Matrix	MeHg proportion	Sample prep type^{a} (preferred is underlined)	Analysis type	Source reference for MeHg %	Comments

Fish	Muscle fillet	>95% (but varies)	ww or dw	THg	Bloom, 1992	Dark muscle is significantly higher than white muscle (Bosch et al., 2016). New evidence indicates that %MeHg may be lower for some fish species and some cooking approaches (Wang et al., 2013) and 10% of fish should be analyzed for MeHg content
	Muscle biopsy	>95% (but varies)	dw	THg	Peterson et al., 2004	dw is best owing to moisture loss concerns. Muscle biopsy to muscle fillet has a $r^2 = 0.96$. Biopsy plug depth may impact Hg measured – 5 mm plugs are best below dorsal fin (Cizdziel et al., 2002) and are without skin and adipose tissue
	Fin clips	unknown	dw	THg	Cerveny et al., 2016	There is a significant correlation between fin clips and muscle fillet ($p<0.01$)
	Blood	>95%	ww or dw	THg	-	Assumed to be >95% MeHg based on other vertebrates
Sea turtles	Scutes	>95%?	fw (or dw if scutes need washing)	THg	Schneider et al., 2015	Recommended and assumed nearly all MeHg as scutes are composed of keratin
	Blood	>95%?	ww or dw	THg	-	Assumed to be >95% MeHg based on other vertebrates
	Muscle	>95%?	ww or dw	THg	-	Assumed to be >95% MeHg based on other vertebrates
Birds	Blood	>95%	ww or dw	THg	Rimmer et al., 2005; Edmonds et al., 2010	Elimination of MeHg in blood comprises an initial fast phase, with half-time of 1 day, and a slow terminal phase with half-time between 44-65 days. Molt is a crucial factor in determining the rate of MeHg elimination (Monteiro and Furness 2001)
	Feather	~100%	fw (or dw if feathers are washed due to external contamination)	THg	Burger, 1993	If feathers are not washed, fw = dw because mean feather moisture is <1%, n = 490; R. Taylor, Texas A&M, USA pers. comm.
	Eggs	>96%	ww or dw or fww	THg	Ackerman et al., 2013 (96% for 22 species)	ww and dw can be problematic if eggs are not collected immediately after laying (Dolgova et al. 2018)
	Muscle	>95%	ww or dw	THg		MeHg comprised over 99% of total Hg in breast muscle of waterfowl (Sullivan and Kopec 2018)
	Eggshells and membranes	>95%	dw	THg	Peterson et al., 2017	Membranes are assumed to be primarily MeHg, but shells are entirely inorganic Hg

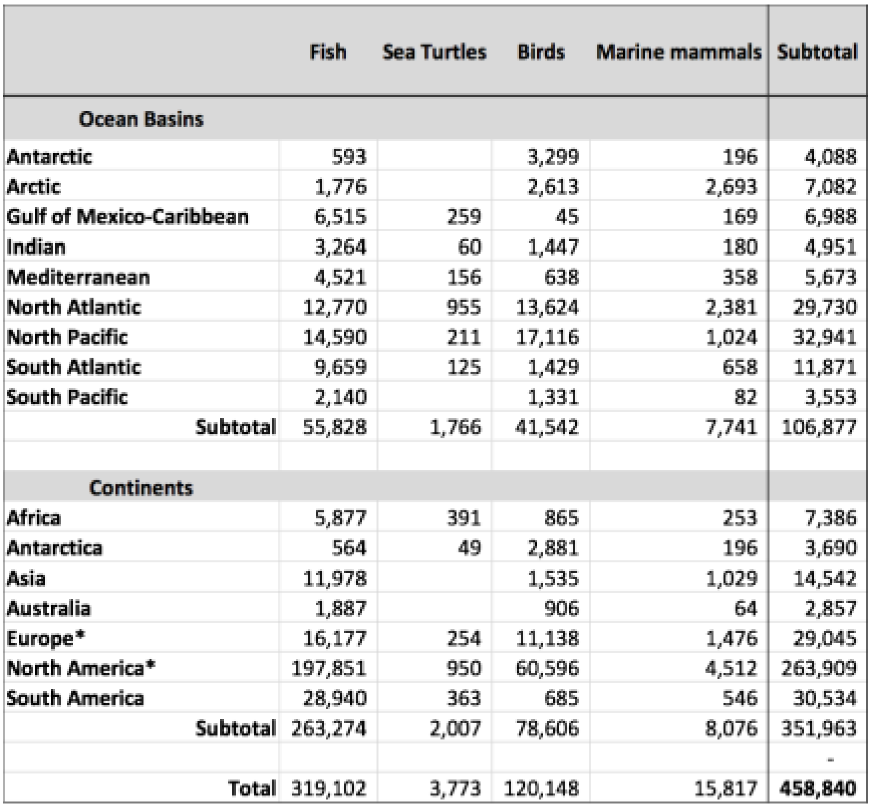
	Liver and kidney	5–7% in loons and mergansers; 56–90% in egrets; 88% (20–100%) terns and shorebirds	dw	MeHg	Scheuhammer et al., 1998; Spalding et al., 2000; Eagles-Smith et al., 2009b	These tissues are not recommended for monitoring; %MeHg can vary widely
Mammals	Skin	>90%	dw	THg	Wagemann et al., 1998	Muktuk (in marine mammals) includes layers of skin and blubber
	Fur or hair	>90%	fw (or dw if fur needs to be washed)	THg	Evans et al., 2000	Fur/hair may not relate to blood and muscle depending on growth patterns (Peterson et al., 2016)
	Muscle	>90%	ww or dw	THg	Wagemann et al., 1998	
	Liver and kidney	3–12% in whales/seals; 57–91% in mink/otter	dw	MeHg	Wagemann et al., 1998; Evans et al., 2000	These tissues are not recommended for monitoring; %MeHg can vary widely

B2.0 Biotic Hg data:

Biodiversity Research Institute (BRI) has compiled mercury data from published literature into a single database, the Global Biotic Mercury Synthesis (GBMS) Database. 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 (Table 2, Figure 2; for more information, see: http://www.briloon.org/uploads/BRI_Documents/Mercury_Center/Publications/For%20Web%20GBMS%20Booklet%202018%20.pdf).

Table 3.2. Summary of mercury samples by major taxa across major ocean basins and continents.



	Fish	Sea Turtles	Birds	Marine mammals	Subtotal
Ocean Basins					
Antarctic	593		3,299	196	4,088
Arctic	1,776		2,613	2,693	7,082
Gulf of Mexico-Caribbean	6,515	259	45	169	6,988
Indian	3,264	60	1,447	180	4,951
Mediterranean	4,521	156	638	358	5,673
North Atlantic	12,770	955	13,624	2,381	29,730
North Pacific	14,590	211	17,116	1,024	32,941
South Atlantic	9,659	125	1,429	658	11,871
South Pacific	2,140		1,331	82	3,553
Subtotal	55,828	1,766	41,542	7,741	106,877
Continents					
Africa	5,877	391	865	253	7,386
Antarctica	564	49	2,881	196	3,690
Asia	11,978		1,535	1,029	14,542
Australia	1,887		906	64	2,857
Europe*	16,177	254	11,138	1,476	29,045
North America*	197,851	950	60,596	4,512	263,909
South America	28,940	363	685	546	30,534
Subtotal	263,274	2,007	78,606	8,076	351,963
					-
Total	319,102	3,773	120,148	15,817	**458,840**

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: (1) integrating mercury science into important policy decisions related to the Minamata Convention on Mercury; (2) use by existing networks such as the Arctic Monitoring Assessment Programme (AMAP); and (3) protecting human health and the environment. GBMS was also the basis for the UN Environment's Global Mercury Assessment – 2018 and the results of which were featured (see: http://mercuryconvention.org/).

B3.0 Mercury monitoring programs:

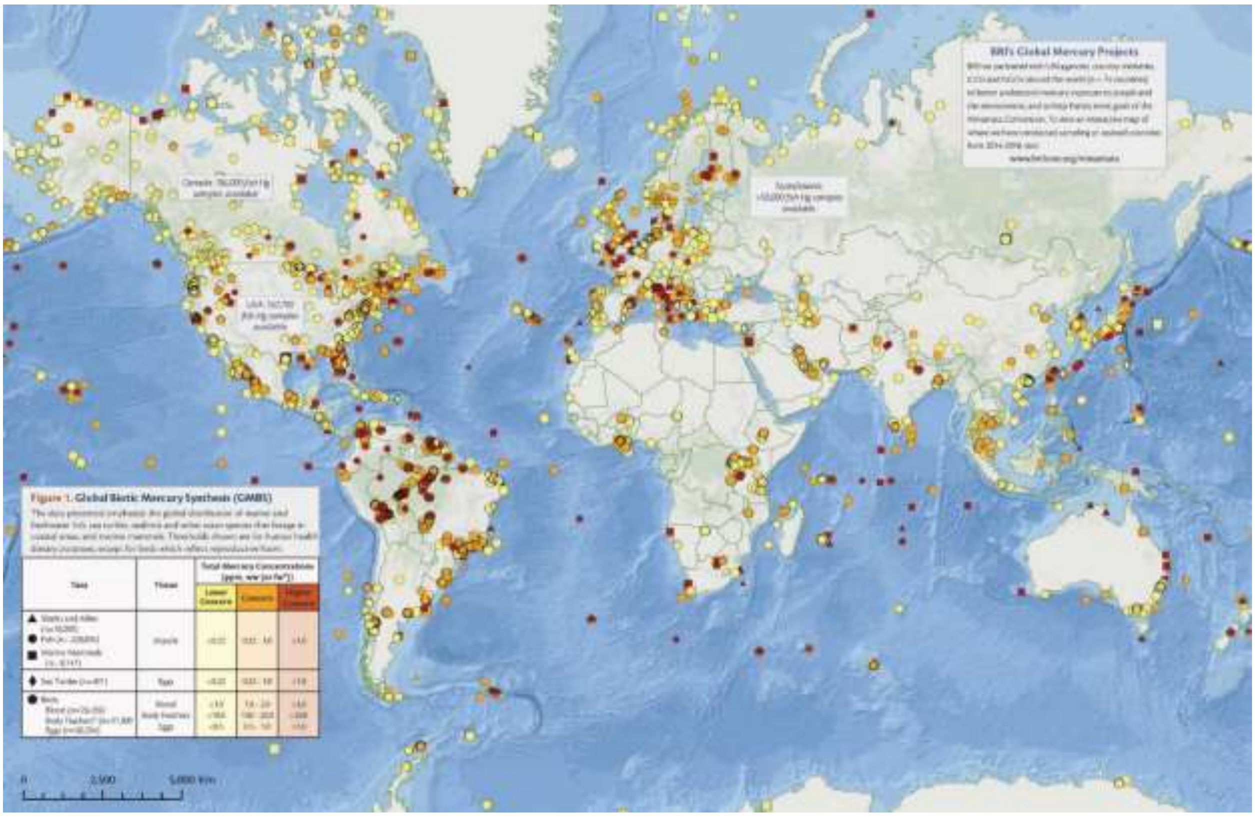
The Arctic Monitoring and Assessment Programme (AMAP) is one of the best examples of how to operate a long-term Hg biomonitoring field program for the benefit of both human and ecological health (AMAP 2011, 2015). Whereas, the WHO Global Environment Monitoring System - Food Contamination Monitoring and Assessment Programme, commonly known as GEMS/Food, has one of the best global systems for collecting fish Hg data through their network of collaborating centers and recognized national institutions (WHO 2018).

A review of the geographical coverage of Hg biomonitoring networks reveals 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. Conversely, Hg biomonitoring is ongoing in many countries within Europe, Oceana and across the Western Hemisphere. 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.

One of the better examples for a national Hg biomonitoring effort is Canada's Northern Contaminants Program – an integrated initiative for Hg monitoring throughout Canada's 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 (Figure 3). One of the strengths of the program is the interdisciplinary approach taken to assess and monitor risks of Hg to ecological 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.

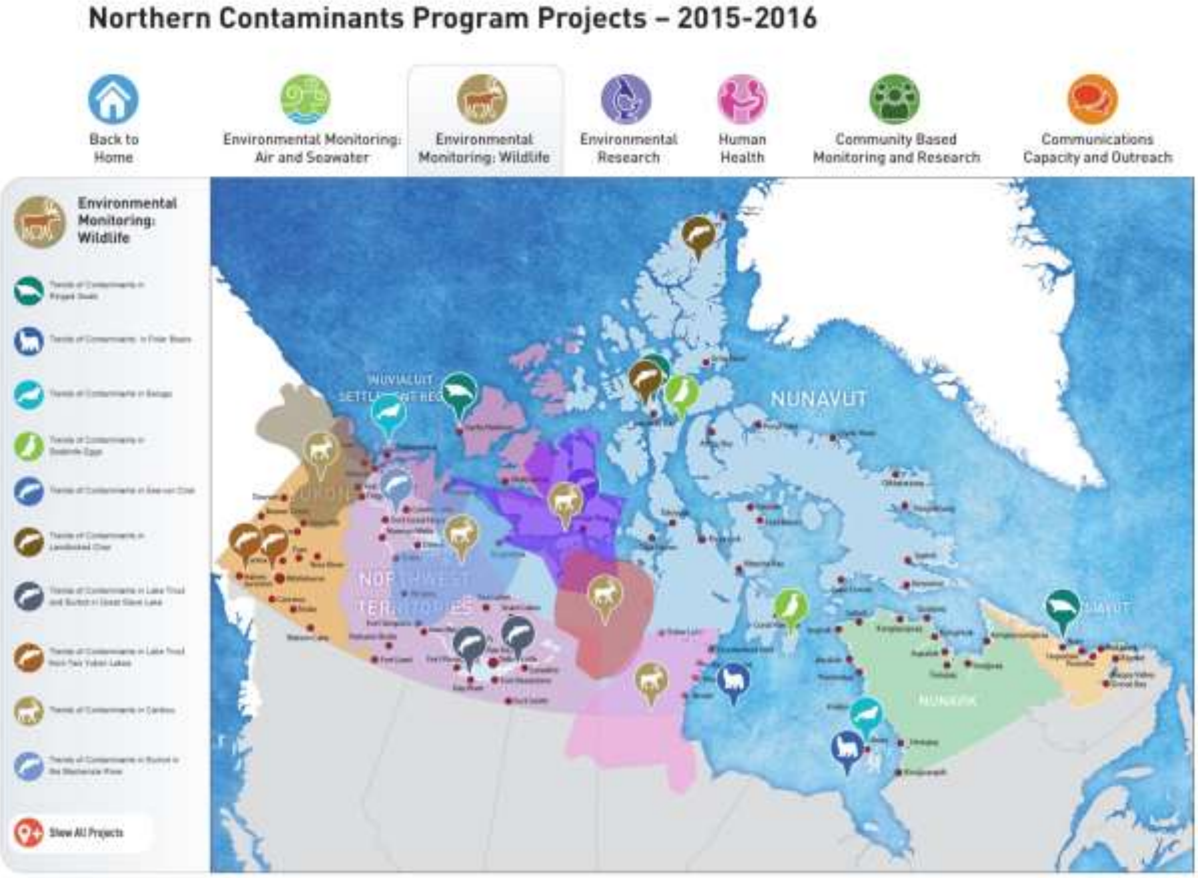
A strategic long-term plan guides the development of subprograms and the links between them. For example, monitoring of Hg in biota is supported by Hg measurements in air as well as focused research on environmental processes that control Hg bioaccumulation. Data generated on Hg in wildlife can be used for human dietary exposure assessments, while community-based projects may focus on species that are local priorities but not covered by routine monitoring.

Figure 3.2. Distribution of average mercury concentrations across 2,781 locations around the world (Evers et al. 2018).



Monitoring of Hg in fish and wildlife under the Northern Contaminants Program includes terrestrial, freshwater and marine species in focal areas across northern Canada (Figure 2). 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.

Figure 3.3. Map of long-term sampling sites for Arctic fish and wildlife monitored annually under Canada's Northern Contaminants Program in terrestrial, freshwater, and marine ecosystems. Biotic monitoring is one of several interdisciplinary subprograms (identified at the top of the map) to assess and monitor risks of contaminants (including Hg) to ecological and human health.



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). 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.

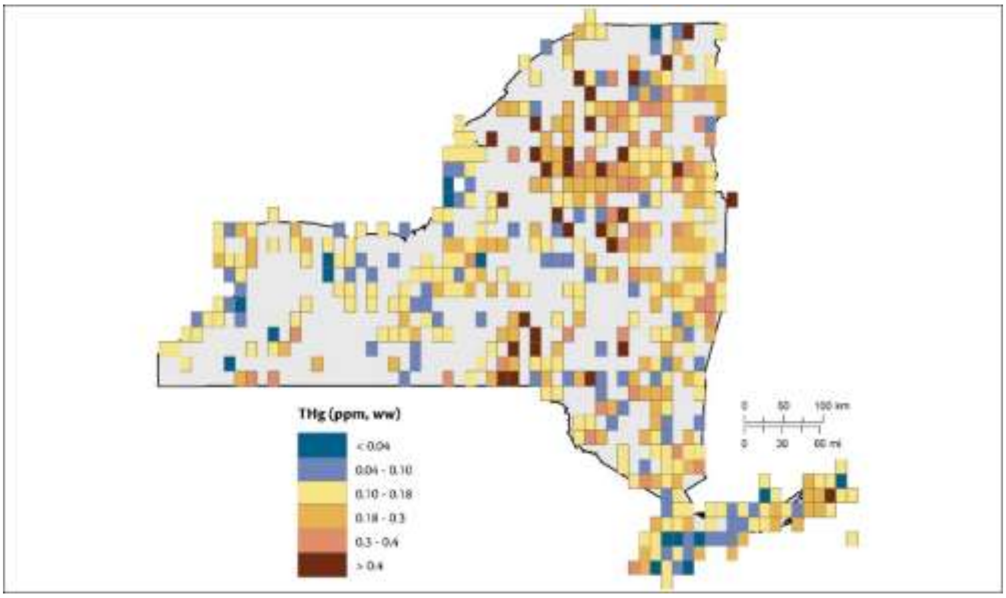
One example of a local project that has established long-term monitoring of mercury using biota (e.g., fish and birds) is in New York State, United States (Evers et al. 2019). A 50-year dataset on freshwater fish Hg data (n=33,502 individuals) and birds (n=9,751) depicts exposure across nearly half of the state through the use of standard grids – in this case each grid represents 250 square kilometers. 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 behavioral to reproductive impairments. Such standardized data can be used fairly for understanding spatial gradients (Figure 4) and temporal trends.


Screening Benchmarks

(whole body fish total Hg in ppm, ww)

- >0.04 ppm in diet of fish (Depew et al. 2012b—effects to fish reproductive success)
- >0.30 ppm in diet of fish (Scheuhammer et al. 2015—reduces reproductive success in fish)
- 0.10-0.18 ppm in diet of birds (Depew et al. 2012a—adverse effects on behavior for avian piscivores)
- 0.18-0.40 ppm in diet of birds (Depew et al. 2012a—significant reproductive impairment for avian piscivores)
- >0.40 ppm in diet of birds (Depew et al. 2012a—reproductive failure for avian piscivores)

Figure 3.4. Mercury exposure for six categories in fish and birds for New York State, United States.



To provide sustainable and long-term biomonitoring capacity in key regions around the world (e.g., Arctic, tropical areas associated with artisanal small-scale gold mining, and islands), the focus should be placed on expanding and stabilizing existing national initiatives that use relevant sample sizes that can meet statistical power for confidence in understanding spatial gradients (e.g., ecosystem sensitivity spots; Evers et al. 2011) and temporal trends (Bignert et al. 2004). Moreover, it is crucial to foster international collaboration and coordination among national or local projects to create harmonized regional approaches, and to strive, where possible, to integrate biomonitoring activities into an interdisciplinary framework to assess ecological and human health risk that can be stitched together to represent regional and eventually global spatiotemporal patterns.

C. Comparability and Gaps

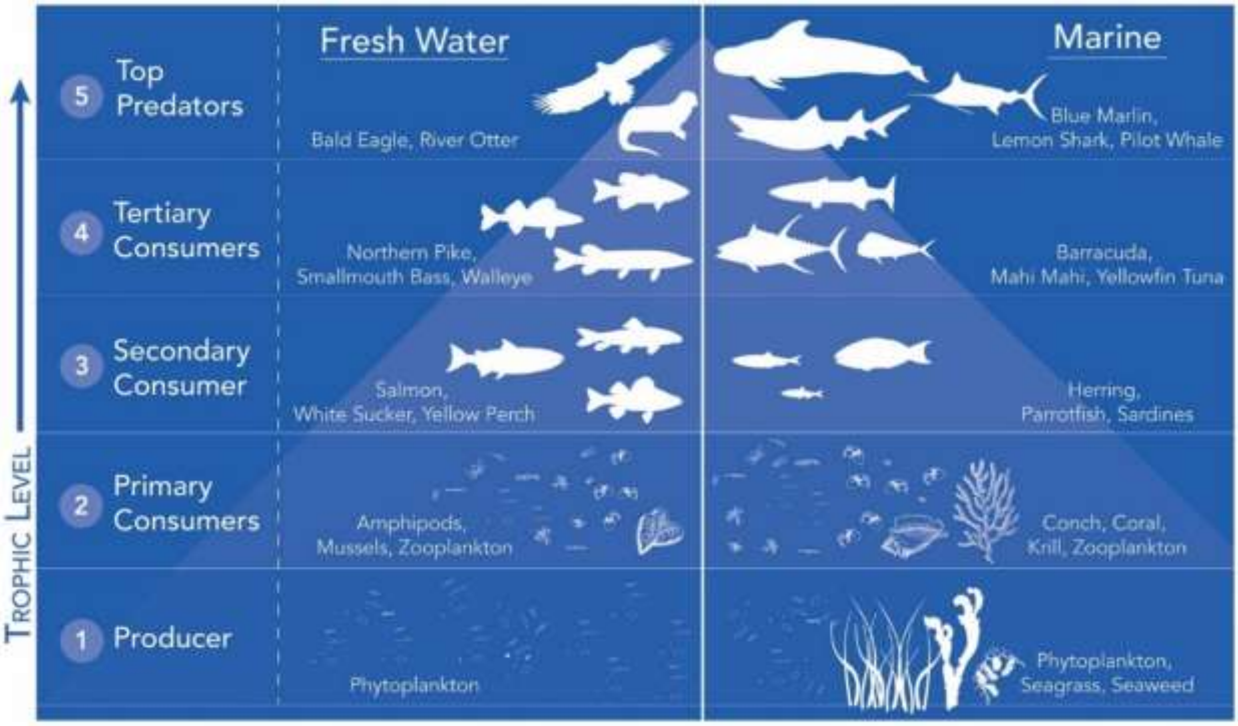
By identifying critical knowledge gaps and adopting quantitative and replicable approaches, a harmonized mercury monitoring effort for biota can be developed and made available to countries. A standardized approach that quantifies where, when, how, and what to monitor for tracking environmental inorganic Hg loads, their changes over time, and potential impacts on human and ecological health is feasible.

Although there are large biological Hg datasets available (as previously demonstrated), they do not provide the ability to determine changes in biotic Hg exposure at regional or global scales over decadal periods (with the important exception of the Arctic biome because of the Arctic Monitoring Assessment Programme). Robust statistical approaches are critical for confidently tracking biotic Hg concentrations in the many different biomes around the world, and controlling for the effects of other factors, such as global climate change, altered foraging habitat, changes in primary productivity and changing growth rates that can drive changes in biotic MeHg concentrations with no actual change in environmental Hg loads (Eagles-Smith et al., 2018).

C1.0 Comparability

An important element for a standardized global biotic mercury monitoring program is the selection of the proper species or groups within relevant geographic areas, such as biomes. Bioindicators most appropriate for assessing human health and the environment are those that are at the upper trophic levels, which best reflect the ability of methylmercury to biomagnify through the food web (Figure 5). For biotic mercury monitoring purposes, trophic level 4 (tertiary consumers) or 5 (top predators) bioindicator are best for evaluating the effectiveness of reducing environmental mercury loads around the world.

Figure 3.5. Trophic level categories for both freshwater and marine ecosystems.



The choice of species or groups greatly varies because of their distribution and habitat preferences. However, the best way to standardize differences in mercury exposure levels is to base monitoring on trophic level 4 and 5 species. Species and groups have been categorized by trophic level for most taxa and subsequently bioindicators can be identified by the four major terrestrial biomes and associated aquatic areas to represent both human health and the environment. Many species and groups currently are characterized for mercury exposure and are therefore suitable choices (Table 3).

Table 3.3. Examples of trophic level 4 biota that could serve as bioindicators with major biomes and associated nearshore areas (based on Evers et al. 2018).

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	Loons	Fulmars, Murres	Polar Bears, Seals	Arctic Char, Arctic Grayling	Halibut, Cod	Beluga, Narwhal
Boreal Forest-Taiga and N. Pacific and Atlantic Ocean	Loons, Eagles, Osprey, Songbirds	Osprey, Petrels	Mink, Otter, Seals	Pike, Walleye	Bluefish, Tuna	Pilot Whale
Temperate Mixed Forest and Pacific and Atlantic Ocean	Loons, Grebes, Egrets, Herons, Osprey, Terns, Songbirds	Cormorants, Osprey, Terns	Otter, Seals	Bass, Walleye	Barracuda, Mackerel, Sharks,Tuna	Pilot Whale
Tropical Rainforest and S. Pacific and Atlantic and Indian Ocean	Egrets, Herons, Kingfishers, Songbirds	Albatrosses, Frigatebirds, Shearwaters, Terns, Tropicbirds	Otter, Seals	Catfish	Barracuda, Grouper, Mahi mahi, Sharks, Swordfish, Tuna	Pilot Whale

C2.0 Data Gaps

Based on the knowledge of existing biotic mercury data and within the interest of using comparable data (i.e., trophic level 4 or greater), for relevant terrestrial biomes and associated aquatic areas, a matrix of available data that can respond to overarching questions related to temporal trends and spatial gradients can be developed (Table 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.

Table 3.4. Assessment of global mercury data availability at poor (Data Gap), good (X) and excellent (XX) 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.

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	XX	XX	XX	XX	XX	XX
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

D. Options for filling gaps through existing mercury monitoring programs

The choice of trophic level 4 or 5 bioindicators by biome and general ecosystem type (i.e., land, freshwater, marine) is influenced by objective (e.g., tracking temporal trends or spatial gradients) and several other factors (Table 5). In the Arctic, standard bioindicators have been selected to monitor mercury for human health and the environment and represent a long-term existing dataset and confidence for future coverage. In the boreal and taiga biome, the National Contaminants Programme in Canada and various fish monitoring efforts in Scandinavia provide excellent examples of standardized programs, especially in freshwater lakes. For temperate biomes in the western hemisphere, existing efforts are primarily in place in the U.S. and Europe for freshwater ecosystems and some marine areas – although they rarely reflect long-term datasets. In tropical biomes, there are few existing datasets and even fewer existing monitoring programs for land, freshwater and marine ecosystems. Across the open ocean basins (outside of the Arctic and Antarctic Oceans), commercial fisheries for tuna and billfish provide an excellent platform for long-term, sustainable and cost effective monitoring of mercury based on existing and regular capture.

Table 3.5. Practicality, feasibility, comparability and cost effectiveness of tracking mercury in trophic level 4 bioindicators by biome and ecosystem.

Biome	Ecosystem	Influenced by MC Article	Practicality & Feasibility Ranking	Sustainability Ranking	Comparable Ranking	Cost effectiveness Ranking	Existing Monitoring Program/ Data Coverage
Arctic	**Land**	1, 8	5	5	5	5	AMAP
	Freshwater	1, 8	5	5	5	5	AMAP
	Marine	1, 8	5	5	5	5	AMAP
Taiga - Boreal	**Land**	1, 8	3	4	5	4	Continuous data sets available in Canada through NCP and in parts of Scandinavia
	Freshwater	1, 8	4	5	5	5	Continuous data sets available in Canada through NCP and in parts of Scandinavia
	Marine	1, 8	3	3	4	3	Some data sets, few monitoring programs
Temperate	**Land**	1, 8, 9	4	4	4	4	Some data sets, few monitoring programs
	Freshwater	1, 8, 9	5	5	4	5	State, provincial, and country long-term Hg monitoring programs for fish often in place in U.S. Europe, and some in eastern Asia
	Marine	1, 8	5	5	5	5	Very few data sets, no monitoring programs; however, commercial fisheries provide long-term monitoring abilities with tuna and billfish
Tropical	**Land**	1, 7, 8, 9	3	3	3	4	Very few data sets, no monitoring programs

	Freshwater	1, 7, 8, 9	4	4	4	4	Very few data sets, no monitoring programs; largest data gap and largest environmental impact from ASGM Hg sources
	Marine	1, 7, 8	5	5	5	5	Very few data sets, no monitoring programs; however, commercial fisheries provide long-term monitoring abilities with tuna and billfish

Ranking: 1 = low, 2 = moderate low, 3 = moderate, 4 = moderate high, 5 = high

The practicality, sustainability, comparability, and cost effectiveness are all factors to consider for mercury monitoring in biota. For the Arctic biome, AMAP has been meeting these needs since 1991 and is expected to continue to monitor mercury and other contaminants in the foreseeable future. In the taiga and boreal areas of the northern hemisphere comparable mercury data are very feasible (because of relatively similar taxa), and in Canada, the U.S. and Scandinavia the practicality and sustainability of Canada's Northern Contaminants Program and those directed by the other country's respective governments makes running mercury monitoring programs cost-effective. The major exception for this region being Russia.

In the temperate biome, there are strong programs in monitoring biota in the freshwater ecosystems (not as strong on land and marine areas, but still functioning) across the U.S., Europe and in parts of eastern Asia. Southern hemisphere mercury monitoring efforts for biota in temperate biomes are not as strong as the northern hemisphere and could significantly add to the knowledge of mercury cycling (e.g., Argentina, Chile, and Australia).

In tropical areas, very few mercury monitoring efforts are in place. Environmental mercury-related research has been significant in some countries, such as Brazil and China, but are not as robust for monitoring mercury in biota as in temperate areas. The practicality, sustainability and comparability are also all challenging because of limited infrastructure and history of monitoring activities, however, the cost-effectiveness would likely be high. Tropical areas are especially important for monitoring mercury using biota for Article 7, because it would be challenging to know if the Minamata Convention was effective in protecting human health and the environment from artisanal small-scale gold mining activities.

One factor in particular, global climate change, will alter future Hg concentration levels across the landscape (Sundseth et al., 2017), especially in marine ecosystems (McKinney et al., 2015; Sundseth et al., 2015), subarctic and temperate lakes (Chen et al., 2018), temperate estuarine ecosystems (Willacker et al., 2017), and terrestrial ecosystems (Eagles-Smith et al., 2018). Specific effects of global climate change include enhanced air-seawater exchange, melting of polar ice caps and glaciers, increased thawing of permafrost, and changes in estuarine sulfur biogeochemistry. But, how these landscape processes relate to changes in biotic Hg exposure is relatively unknown. Sunderland et al. (2018) showed global climate change is changing fish harvest methylmercury exposures from species such such as cod and pollock that are sensitive to climate driven warming of seawater.

Iterative efforts to link realistic and applied biomonitoring efforts at local levels with science groups aimed at assisting the Conference of Parties of the Minamata Convention will ultimately help keep pace with the many emerging scientific findings that may fill existing information gaps that are key for global policymaking.

E. Available modelling capabilities to assess changes in global mercury levels (relevant for biota)

The compilation of existing biotic Hg data is an important approach to understand broad spatial gradients and temporal patterns. Models based on existing data and scientific findings are useful for extending observations in space and time.

Recent global modelling efforts show 49% of global Hg^{II} deposition occurs over the tropical oceans (Horowitz et al., 2017). The equatorial Pacific region is an essential commercial harvesting location for many large pelagic species such as tunas that are responsible for a large fraction of human exposure to MeHg (Sunderland et al., 2018). Thus, linking elevated Hg deposition to MeHg formation in the ocean and associated biological exposures is an important goal of ongoing research. Similarly, understanding the relationship between enhanced deposition of Hg in India and China and other regions of intense coal use in Europe and the U.S. (Giang et al., 2015; Corbitt et al., 2011) and biological concentrations in inland food webs is essential for linking changes in benefits from future emissions reductions to human and ecological exposures.

In freshwater ecosystems, a global meta-analysis suggests that Hg biomagnification through food webs is highest in cold and low productivity systems (Lavoie et al. 2013), however large contaminated sites (e.g., ASGM areas) are likely important driver of variability in tropical freshwater biota concentrations (Obrist et al. 2018). One recent effort to characterize global aquatic Hg releases to inland ecosystems is therefore especially important for understanding the spatial distribution of these locations (Kocman et al., 2017).

Understanding of how mercury released from ASGM and associated conversion to MeHg, exposures, and impacts on human and ecological health is poor (Affum et al., 2016). It is expected that some of the ASGM-derived inorganic Hg into the air, water, and land reaches aquatic food webs and is transferred into higher trophic-level organisms, but this may vary greatly across these continents. Yet, the associated patterns over time and space are critical to understand for developing biomonitoring activities in a time-efficient and cost-effective manner.

E1.0 Spatial gradients

The availability of MeHg to high trophic level organisms is not uniform. Some ecosystems are more sensitive to inorganic Hg input than others (Driscoll et al., 2007; Eagles-Smith et al., 2016) and it is in these areas that biological MeHg hotspots can form and are especially pronounced in higher trophic-level organisms (Evers et al., 2007). For terrestrial ecosystems, such areas are generally associated with wetlands and other temporally wetted habitats and can be particularly pronounced in ecosystems with water chemistry variables such as low pH, moderate to high dissolved organic carbon concentrations, and low to moderate primary productivity. In particular, fluctuating water levels can have a particularly important contribution in generating higher methylation rates and increases in MeHg bioavailability (Willacker et al., 2016); and, may happen at daily (tidal), monthly (artificial reservoirs and pools), or seasonal (river floodplains and dry tropical areas flooded during the wet season) timeframes, as well as under managed areas (rice agriculture).

Therefore, the determination of areas that may have elevated MeHg availability are generally not directly related to the deposition or release of inorganic Hg into the environment. For example, compared to the USA, relatively low precipitation-weighted mean concentrations and deposition of total Hg are in Kejimkujik National Park in Nova Scotia, Canada (an average of <5 ng/L and <7.5 ug/m^2 of Hg per year for the past four years of available data; Dastoor and Larocque, 2004; Dastoor et al., 2015; NADP, 2017), yet the biotic MeHg exposure is some of the highest in North America where fish and birds within the National Park well exceed ecological health thresholds (i.e., 0.30 and 3.0 μg/g ww, respectively; Evers et al., 1998; Burgess and Hobson, 2006; Burgess and Meyer, 2008; Wyn et al., 2009, 2010). This is because most lakes in the area are sensitive to inorganic Hg input and have high methylation potential and MeHg bioavailability owing to a combination of low pH, high dissolved organic carbon, high percentage of shoreline wetlands, and low primary productivity. Ultimately, identification of biological MeHg hotspots can be made through the collection of existing biotic data (Evers et al., 2011; Ackerman et al., 2016; Eagles-Smith et al., 2016) and modelling ecosystem sensitivity at regional or global scales.

In marine regions, spatial patterns in biological MeHg concentrations are less resolved but will be facilitated by the development of a global biotic database of mercury concentrations in marine species and supporting modeling efforts to help explain observed spatial patters. Differences in MeHg concentrations across ocean basins are apparent in the literature. The highest reported concentrations of MeHg in seawater have been reported in some regions of the Southern Ocean, which also have elevated concentrations of MeHg in some food webs (Cossa et al. 2011). Considerable spatial variability in seawater MeHg concentrations has been reported among other ocean basins, with highest levels in subsurface waters of the most biologically productive areas (Bowman et al., 2014; 2016; Cossa et al., 2009; Kim et al., 2017; Munson et al., 2015: Sunderland et al., 2009). The Arctic appears to to have higher concentrations of MeHg in near-surface seawater, which may reflect unique microbial activity resulting from the combination of stratification, freshwater discharges and ice cover (Lehnherr et al., 2011; Heimbürger et al., 2015; Schartup et al., 2015).

Several modeling approaches are available for linking atmospheric deposition of mercury to concentrations in food webs. In addition to the empirical approaches for characterizing spatial patterns in concentrations, a variety of ecosystem models and global models are available. Ecosystem models are usually forced by measured atmospheric inputs for a specific system and then linked to a hydrological model and food web models. Examples of past applications include lakes (Knightes et al., 2009; Harris et al., 2007) and coastal ecosystems (Sunderland et al., 2010; Schartup et al., 2015; Calder et al., 2016). Global food web models are still under development.

For the global oceans, simulated methylmercury concentrations in seawater (Figure 6a) and data on fish mercury concentrations in the commercial seafood market (Karimi et al. 2012) allow estimations of the flow of mercury in marine biota to different regions globally (Figure 6b). Fisheries catch data are available at the 0.5 degree resolution for the global oceans from the Sea Around Us database. These data can be used to better understand the types of fish harvested in different countries globally, the consumption preferences by subsistence consumers, and associated methylmercury exposures from dietary intake.

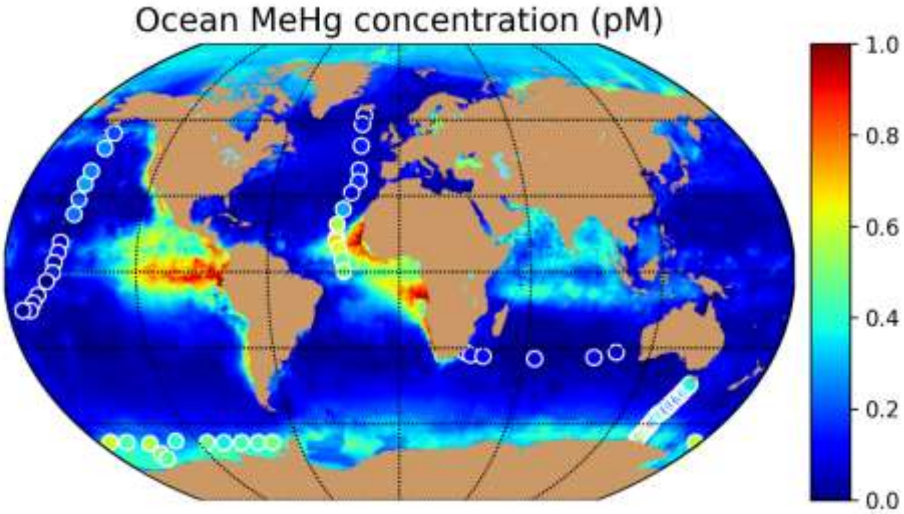


Fig.3.6a. Example of simulated methylmercury concentrations in seawater from Li, Thackray et al., in preparation.

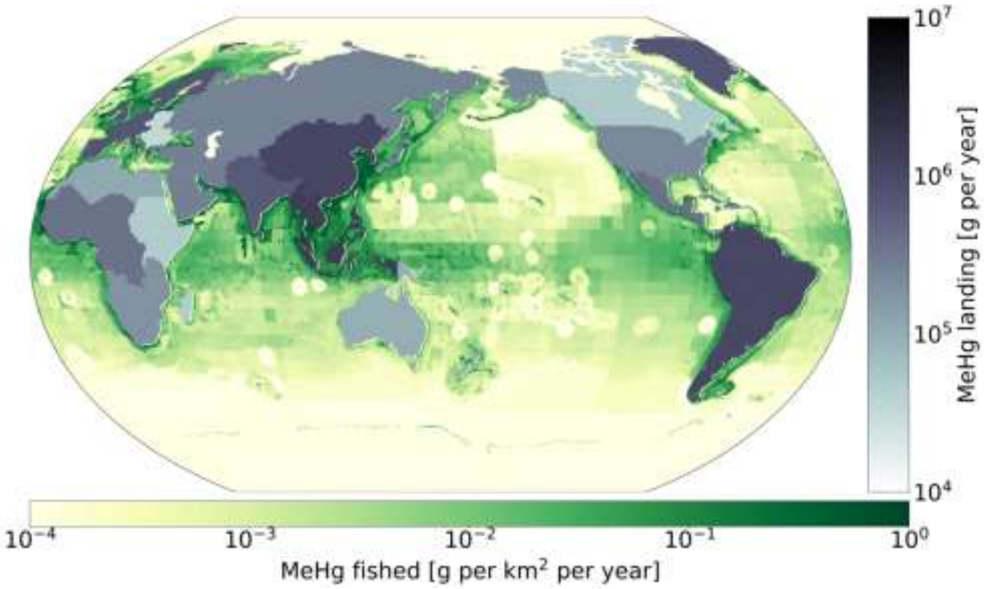


Fig. 3.6b. Example of methylmercury harvested in seafood extracted from the world's oceans from Li, Thackray et al., in preparation.

E2.0 Temporal trends

New models simulating the deposition of Hg from anthropogenic emissions at global scales (using three anthropogenic emissions scenarios) indicate a best case scenario of a decrease of up to 50% in the Northern Hemisphere and up to 35% in the Southern Hemisphere by 2035 (Pacyna et al., 2016). Although tracking Hg emissions, deposition, and releases are important tools for understanding patterns of environmental Hg loads (Sundseth et al., 2017) the relationship between modelled (or measured) deposition and MeHg concentrations in biota is poorly understood. Trends in inorganic Hg concentration are thought to differ among ocean basins because anthropogenic emissions have strongly declined in North America and Europe, leading to large declines in atmospheric concentrations, especially in the Atlantic Ocean (Zhang et al., 2016). Lee and Fisher (2016) postulated that this may also explain observed declines in Atlantic bluefin tuna MeHg concentrations between 2004 and 2012 in the North Atlantic Ocean – which are supported in measured Hg concentrations in blue marlin (*Makaira nigricans*; Barber and Cross, 2015).

The relationship of changing fish MeHg concentrations in different ocean basins is germane to a better understanding of the geographic origins of seafood by country or region. For example, for the USA, 45% of population-wide MeHg exposure originates from open oceans (particularly the Pacific Ocean), 37% from domestic coastal ecosystems, and 18% from aquaculture and freshwater fisheries (Sunderland et al., 2018).

By contrast, both atmospheric emissions and freshwater discharges of Hg have been growing on the Asian continent leading to increased Hg pollution in the North Pacific Ocean (Amos et al., 2014, Streets et al., 2009; Sunderland et al., 2009; Zhang et al., 2015). Most recent data indicate the rate of growth in Hg emissions has been slowed by widespread implementation of emissisions controls on new coal-fired utilities (Streets et al., 2017). Temporal data on fisheries in the North Pacific are more limited but some researchers have suggested that there is evidence for increases in tuna MeHg concentrations over recent decades (Drevnick et al., 2015), which is further supported by additional analysis of bigeye tuna for the same area (Drevnick and Brooks, 2017).

In North America, long-term biomonitoring in Arctic freshwater (Chételat et al., 2015) and marine (Rigét et al., 2011; Braune et al., 2015) ecosystems provides an important regional platform for examining temporal trends through Canada’s Northern Contaminants Program and AMAP. In addition, in the Canadian province of Ontario projected temporal trends in over 200,000 game fish analyzed since 1970 indicate increasing MeHg concentrations in more than 250,000 lakes (which, when including the Great Lakes, represents about a third of the world’s freshwater). Using one of the largest consistent Hg biomonitoring efforts in the world, a robust long-term trend in fish Hg concentrations can be determined. Using Hg concentrations in the muscle of walleye, northern pike, and lake trout, it is projected that 84–100% of the 250,000+ lakes will have “do not eat” advisories by 2050 for sensitive human populations (Gandhi et al., 2014, 2015).

Although inorganic Hg emissions in North America are declining, other factors such as global emissions, climate change, invasive species, and local geochemistry may be impacting the response time and magnitude of biotic MeHg trends for this region (Gandhi et al., 2014). Climate drivers such as higher precipitation rates may be especially important in this area causing increased MeHg concentrations for both cool and warm water gamefish (Chen et al., 2018). Experimental data have suggested increased discharges of terrestrial natural organic matter, due to climate change, may drive trophic shifts at the base of aquatic food webs that lead to increased biomagnification of MeHg (Jonsson et al., 2017). Recent work on MeHg uptake and trophic transfer of marine food webs in the Northwest Atlantic Ocean suggest that most variability in MeHg concentrations in marine plankton can be explained by differences in dissolved organic carbon (Schartup et al., 2018).

The influence of climate change on Hg cycling only increases the importance of generating baseline data for MeHg in bioindicators. An example can be found in Canada where total Hg levels in aquatic birds and fish communities have been monitored across the Canadian Great Lakes by Environment and Climate Change Canada at 22 stations for the past 42 years (1974–2015) (Blukacz-Richards et al., 2017). For the first three decades, Hg levels in gull eggs and fish declined at all stations. In the 2000s, trend reversals were apparent for many stations and in most of the Great Lakes, although the specific taxa responsible varied. While strong trophic interactions among birds and fish are apparent, there also appears to be a high likelihood of trophic decoupling in some ecosystems. This indicates the importance not only of long-term Hg biomonitoring efforts, but also study designs that include other parameters such as food web structure (Pinkney et al., 2015), watershed disturbances including novel factors such as beaver activity (Brigham et al., 2014), and especially those related to climate change (magnitude and frequency of storm events, increasing wildfire activity, etc.; Sundseth et al., 2015).

F. Baselines

Environmental conditions of biotic mercury concentrations are well known for many areas of the world and for many taxa. Baseline identification will ultimately reflect the geographic areas and taxa that best respond to the many objectives within the Minamata Convention.

G. Other technical input (how to create the global monitoring report, data repository and options for visualization(s)

The biotic section of the global mercury monitoring report should be based on the Global Biotic Mercury Synthesis (GBMS) database that was developed and currently maintained by Biodiversity Research Institute, Portland, Maine, USA and partly funded through UNEP STAP. GBMS was used as the basis for the UN Environment’s Global Mercury Assessment for 2018. Information in GBMS is useful for developing spatial and temporal baselines.

The data repository could be embedded within Environment Live (http://environmentlive.unep.org/) or with other existing global data repositories, such as within Global Earth Observation System of Systems (GEOSS). The biotic mercury database that represents scientifically peer-reviewed information could be queried to permit quick access by Parties of available data. Results from queries should be in tabular and visual forms (e.g., bar charts, histograms, etc.).

H. Proposed monitoring approach for biota

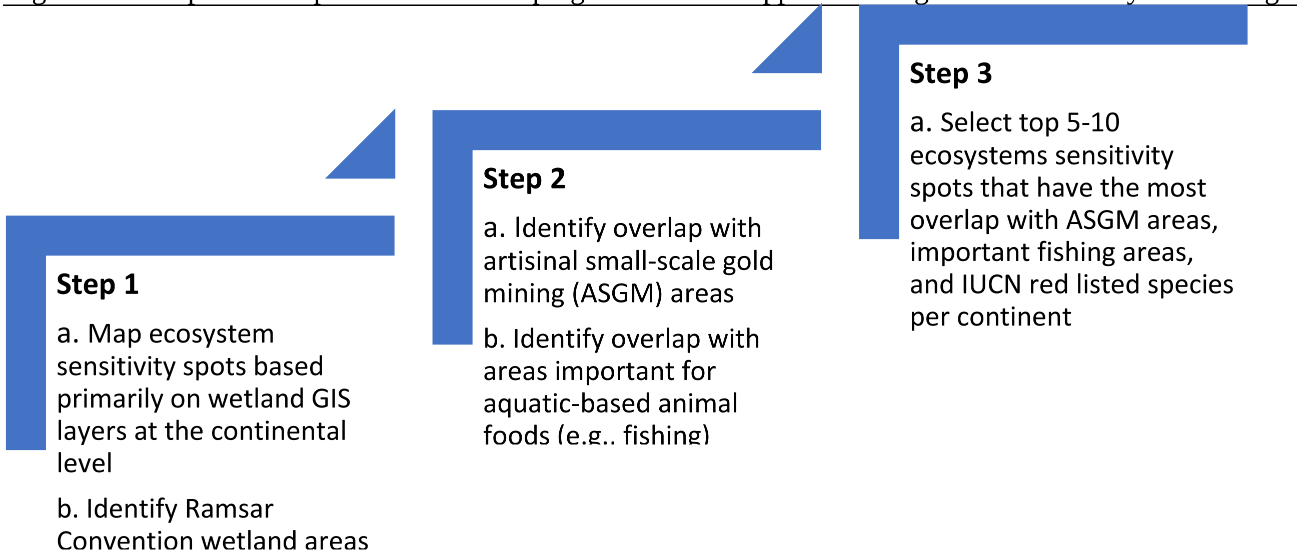
Two overarching biotic mercury monitoring approaches proposed herein differ for continents and oceans.

H1.0 Continental Framework for Integrated Mercury Monitoring

To identify the best locations for global mercury monitoring requires multiple defined steps (Figure 7). ***Step 1a*** is to understand the complexities of a landscape and its ability to methylate mercury and make it available in the foodweb. Mercury methylation is highest in wetlands – and, potentially greatest in estuarine wetlands such as mangroves. Forested areas are also an important factor for increasing dry deposition rates of atmospheric mercury, while agricultural areas tend to dampen methylation rates (Driscoll et al. 2007). Many of the most important wetland areas in the world are identified and protected through the Ramsar Convention (https://www.ramsar.org/) and their 2,341 locations covering 252,489,973 ha will be identified through ***Step 1b***.

The mapping of ecosystem sensitivity spots for each continent at a global level will depend on the resolution of interest. Watersheds are the most relevant base area (i.e., polygon) for mapping and they can greatly vary in size – as an example, mapped herein are drainage basins within each continent (Figure 8).

Figure 3.7. Stepwise components for developing a continental approach using biota for mercury monitoring.



Step 1

a. Map ecosystem sensitivity spots based primarily on wetland GIS layers at the continental level

b. Identify Ramsar Convention wetland areas

Step 2

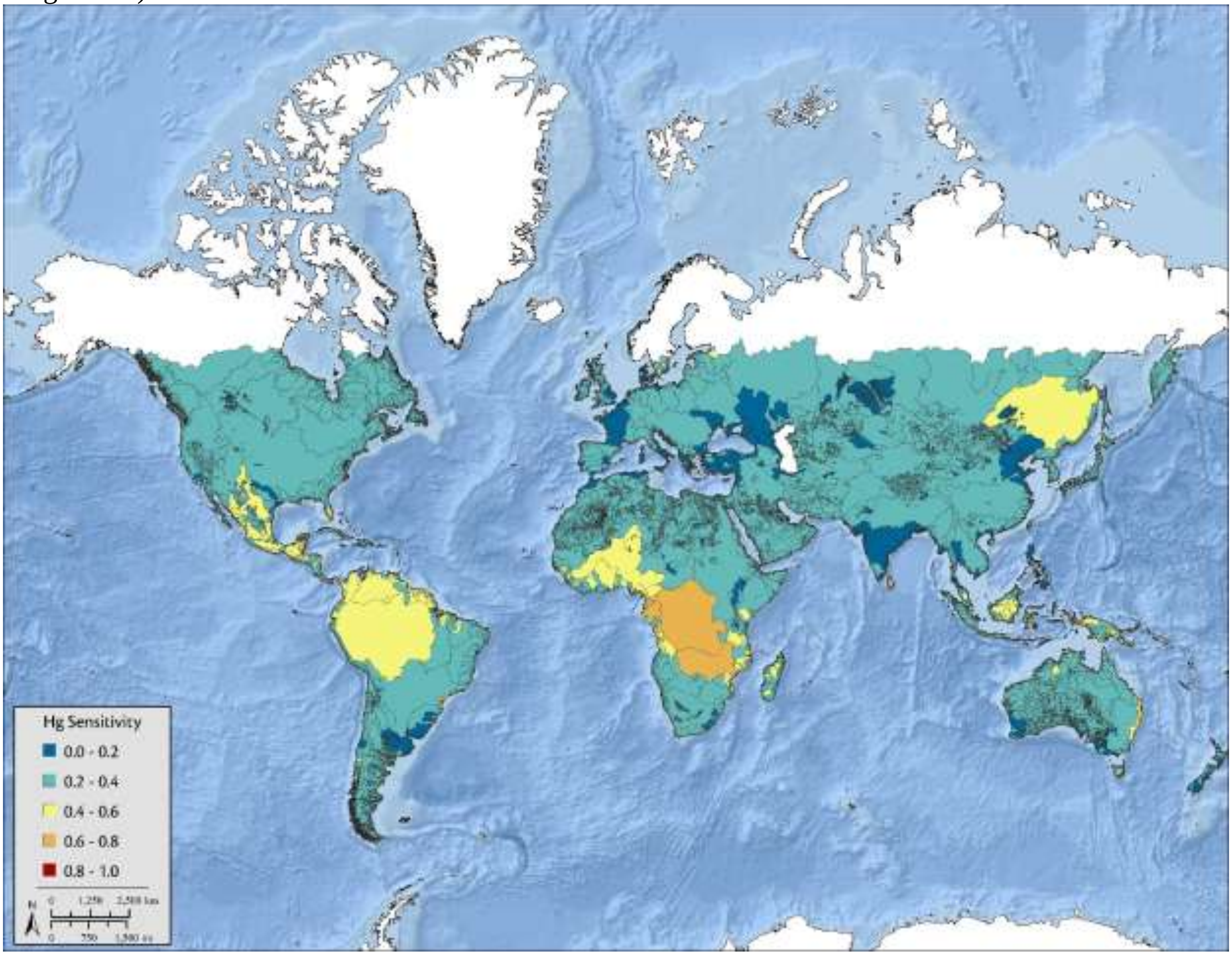
a. Identify overlap with artisinal small-scale gold mining (ASGM) areas

b. Identify overlap with areas important for aquatic-based animal foods (e.g., fishing)

Step 3

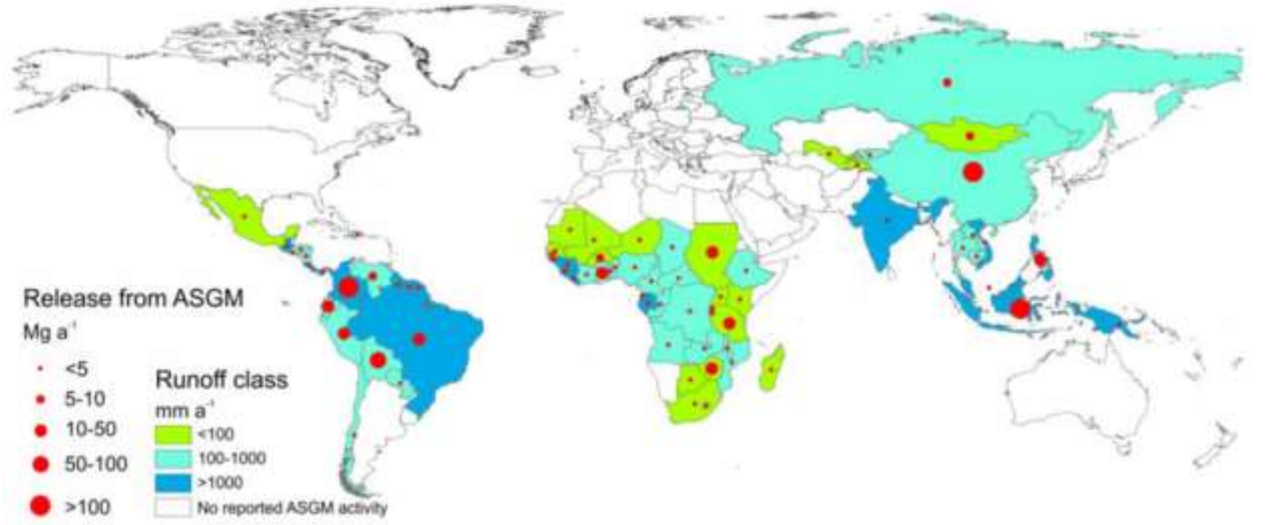
a. Select top 5-10 ecosystems sensitivity spots that have the most overlap with ASGM areas, important fishing areas, and IUCN red listed species per continent

Figure 3.8. Sensitivity of ecosystems to mercury input in five categories within river drainages at a global level (northern latitudes are not included at this time and are covered by the Arctic Monitoring Assessment Programme).



Step 2 includes the identification and potential overlap with ecosystem sensitivity spots of three important elements that will help prioritize areas of greatest concern for protecting human health and the environment. ***Step 2a*** includes the mapping of artisanal small-scale gold mining as it is the top mercury source in the world, with particularly high activities in parts of South America, Africa and Asia (Figure 9). The level of existing biotic mercury data in many of these ASGM areas is minimal based on the GBMS database, which creates an elevated priority in better understanding the potential impacts to human health and the environment.

Figure 3.9. Level of artisanal small-scale gold mining activities.



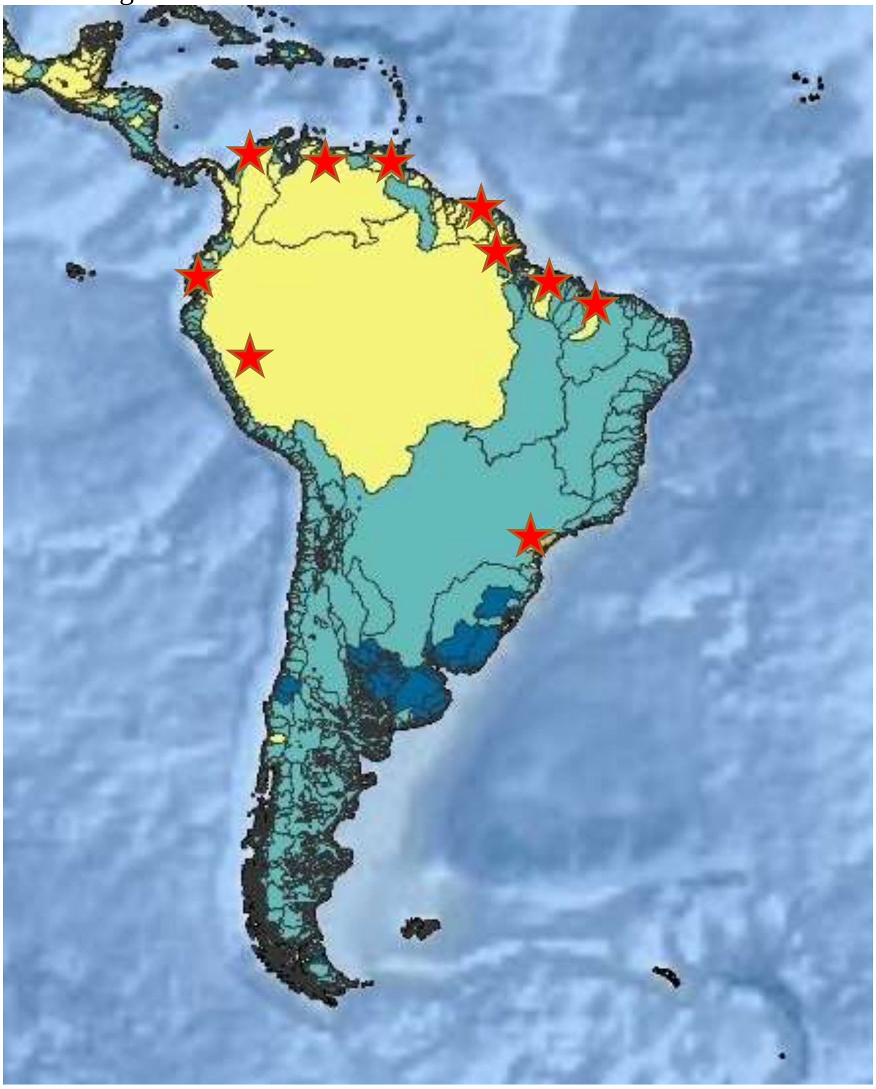
Step 2b responds to the need of which ecosystem sensitivity spots overlap with areas important for extracting aquatic-based animals for human consumption – generally fish, but can include many invertebrates and other vertebrates such as river turtles and crocodiles. Such areas are not easily captured by existing GIS layers, therefore discussions at the national level will need to be made.

Step 2c includes the need and the ability to reflect protection of the environment from the impacts of mercury at the highest importance of conservation through the identification of rare, threatened and endangered species of animals as identified by the Red List that is overseen by the International Union for Conservation of Nature (https://www.iucnredlist.org/). Only species that are at trophic level 4 or higher will be considered for this element.

Following the analyses and prioritization of where the three Step 2 elements overlap with ecosystem sensitivity spots for mercury within each of the six continents of concern (not including Antarctica), ***Step 3*** will involve the selection of 5-10 of the highest ranked areas in each continent (see Figure 10 for an example). The ranking system will quantitatively define each of the Step 2 elements by their intensity and extent within the drainage areas that are most sensitivity to the methylation of mercury released or deposited.

The selection of 5-10 ecosystem sensitivity spots for ***Step 3a*** that are made on this basis will also include an internal mercury monitoring design that has both intensive and cluster sites – as described in the U.S. EPA's MercNet (USEPA 2008). Within each ecosystem sensitivity spot there will be an intensive site (or hub) where there will be a greater ability and interest to monitor mercury in multiple compartments (e.g., air, biota and humans; with an emphasis on trophic level 4 bioindicators under ***Step 3b***), to account for annual variation (e.g., wet vs. dry seasons), and measurements/models of mercury loading. Whereas cluster sites include less intensive sampling and are chosen to expand the geographic relevance of the intensive site measurements (e.g., include habitats and ecosystems that may differ from the intensive site to better inform geographic scaling of temporal trends, spatial gradients and risk to biota). The number of cluster sites may range from 3-5, depending on local ecosystem variability and objectives.

Figure 3.10. An example of the potential selection of intensive sites in South America based on the three-step process and knowledge of the elements within each step. Most sites, identified as red stars, would be in association with intensive ASGM areas and/or in the river deltas that are important for consolidating upstream mercury input, are conducive for high methylation rates, and are crossroads for human activities for food. Note – this is only an exercise to understand potential process – these are not sites chosen for mercury monitoring in biota.



H1.1 Summary of Continental Sampling Framework

As part of the sampling framework for tracking mercury within and adjacent to continents, a matrix that details existing and needed coverage by mercury monitoring networks is possible for seven regions in the world (Table 6). A range of 5-10 intensive sites (n=30 samples) across three broad ecosystems (i.e., freshwater, nearshore marine, and terrestrial [wetlands]) would adequately cover large landscapes, when associated with three cluster sites (n=20 samples) with each intensive site. Wetlands chosen should be prioritized as being part of the Ramsar Convention for Wetlands. The approximate coverage using existing mercury data within monitoring programs is estimated for each of the seven regions.

Sampling timing should be coordinated at times of the years that match similar seasonality (i.e., summer) and/or wet-dry cycles (i.e., wet season). Sampling frequency can be every year for intensive sites and every three years in cluster sites to best capture local variability of methylmercury availability within different habitat types. For example, using this approach in the Central American and Caribbean Region (for 10 sites) would result over a three year period of an analyses of 300 samples/year for intensive sites (n=900 samples over three years) and 600 samples for the three-year period for cluster sites (n=600); therefore, 1,500 samples over three years or 500 samples/year.

H1.2 Summary of Sampling Framework by Region of Interest

For North America, each of the three broad ecosystems can be covered through existing mercury monitoring programs for biota – which include AMAP, NCP, USEPA and various efforts by states and Canadian provinces. Site selection is needed and should be distributed across three biomes including Arctic tundra, boreal forest-taiga, and temperate mixed forest. There can be 100% coverage using existing mercury data collection.

For Europe (especially western and central), freshwater and marine ecosystems can be covered through existing mercury monitoring programs for biota – which include CEMP, JAMP and HELCOM efforts. Gaps could be filled for freshwater Ramsar wetlands. There can be 80% coverage using existing mercury data collection.

For Asia, there is a mix of coverage for each broad ecosystem, but only covers a limited number of countries and is mostly outside of ASGM area. Existing mercury monitoring programs for biota are primarily in China, Japan, and the Republic of Korea. There are many gaps in countries with sensitive ecosystems (e.g., tropical rainforests, mangroves and estuaries) that are associated with major ASGM point sources. There may be approximately 50% coverage using existing mercury data collection.

For South American, there have been many studies emphasizing biotic mercury concentrations in the Amazon River basin, but existing mercury monitoring programs are generally lacking. Because ASGM activities are common and are often associated with wetland communities, there are many high priority gap areas that need more information to better protect human health and the environment. There is less than 20% coverage using existing mercury data collection.

For Central America and the Caribbean, there are very few mercury monitoring studies or programs. One new effort, the Caribbean Region Mercury Monitoring Network has generated new mercury concentrations for key seafood bioindicators and serves as a good platform for long-term monitoring. There is less than 10% coverage using existing mercury data collection.

For Africa, there are very few mercury monitoring studies or programs, with some countries such as Ghana, that have had recent robust efforts. Because of numerous and large ASGM activities and the lack of existing mercury data coverage, many African countries represent major data gaps. There is less than 10% coverage using existing mercury data collection.

For Australia, New Zealand and Small Island Developing States (SIDS; except the Caribbean Region) there are very few mercury monitoring programs. Heavy reliance in seafood and the large data gaps of mercury concentrations exist. There is less than 10% coverage using existing mercury data collection.

Table 3.6. Sampling strategy for trophic level 4 or greater biota (see Table 3) for the Continental Sampling Framework. Listed are the number of intensive sites (with a sample size of 30 at each site); each which should include another 3 cluster sites (with a sample size of 20 at each site) to account for local variability. Monitoring program coverage based on UNEP (2016).

Region of Interest	**Freshwater (lakes/rivers)**	**Nearshore Marine (estuaries/reefs)**	**Terrestrial (freshwater wetlands)**	**Estimated numbers of samples (based on 30 samples per trophic level 4 bioindicator)**	**Approximate coverage (%) using existing Hg data and monitoring programs***
North America (not including Central America and Caribbean)	3 sites – existing coverage by U.S. states and Canadian provinces, NCP, and AMAP	5 sites – existing coverage by USEPA, NCP and AMAP	2 – existing coverage by U.S. states, NMP and AMAP	None needed – provided by existing entities	100% (official existing site selection will be needed)
Europe	3 sites – existing coverage by the EU and specifically Sweden, Norway, Spain, UK, and Poland	5 sites – existing coverage by CEMP, JAMP, and HELCOM	2 sites – no or minimal existing coverage	None needed – provided by existing entities	80% (official existing site selection will be needed)
Asia	3 sites – existing coverage in China and Republic of Korea; further coverage need near ASGM sites	5 sites – existing coverage in Japan and Republic of Korea	2 sites – existing coverage in China; further coverage needs near ASGM sites and rice fields	150 in intensive sites 300 in cluster sites	50% (official existing site selection; new sites will need to be identified)
South America	3 sites – existing coverage is minimal and especially needed near ASGM sites	5 sites – existing coverage is minimal, some by Colombia and Brazil	2 sites – existing coverage is minimal and especially needed near ASGM sites	250 in intensive sites 500 in cluster sites	<20% (new sites will need to be identified)

Central America and Caribbean Sea	3 sites (Central America) – no existing coverage	5 sites – beginning coverage by CRMMN	2 sites (Central America) – no existing coverage	300 in intensive sites 600 in cluster sites	<10% (new sites will need to be identified)
Africa	3 sites – existing coverage is minimal and especially needed near ASGM sites	5 sites – existing coverage is minimal outside of defined studies	2 sites – existing coverage is minimal and especially needed near ASGM sites	300 in intensive sites 600 in cluster sites	<10% (new sites will need to be identified)
Australia, New Zealand, and SIDS (not including the Caribbean Sea)	None	8 sites – existing coverage is minimal in Australia and by SPREP	None	240 in intensive sites 480 in cluster sites	<10% (new sites will need to be identified)

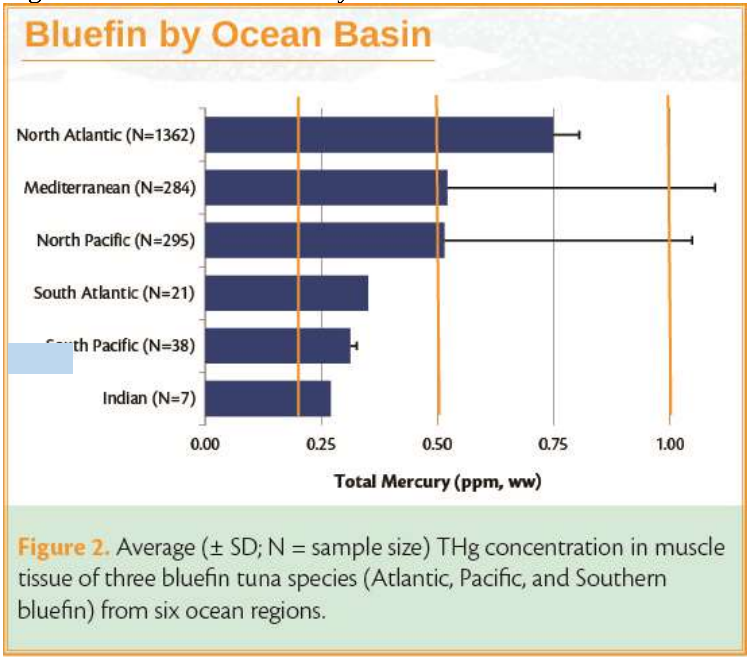
NCP=Northern Contaminants Program (Canada), AMAP = Arctic Monitoring Assessment Program, USEPA = United States Environmental Protection Agency, CRMMN = Caribbean Region Mercury Monitoring Network, SPREP = Secretariat of the Pacific Regional Environment Programme, CEMP = Coordinated Environmental Monitoring Programme, JAMP = Joint Assessment and Monitoring Programme, HELCOM = Baltic Marine Environment Protection Commission – Helsinki Commission

H2.0 Oceanic Framework for Integrated Mercury Monitoring

The approach for monitoring mercury in oceanic areas greatly differs from the continental approach. The cycling and movement of mercury in the world's oceans varies by hemisphere, basin and juxtaposition with the continental land masses. Therefore, mercury concentrations in fish, birds, and marine mammals varies significantly.

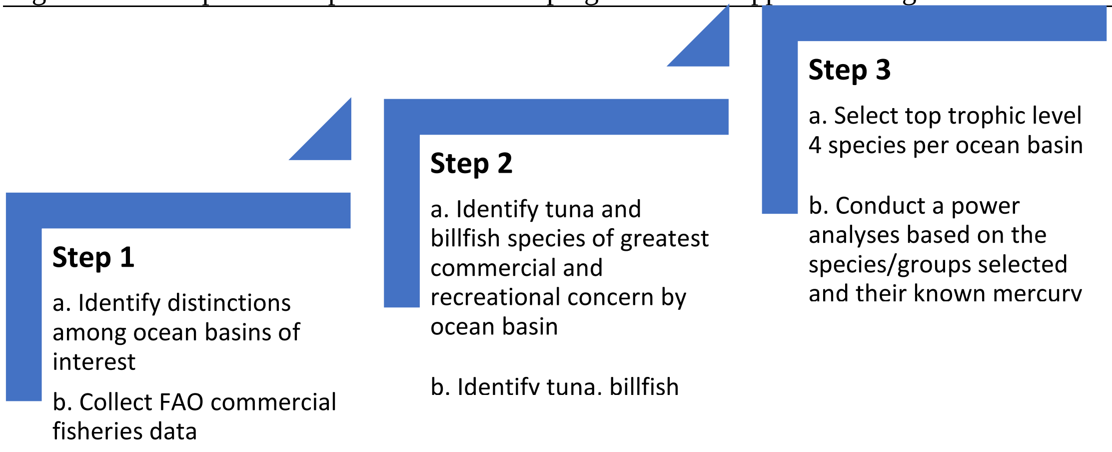
For example, bluefin tuna (representing three sibling species – the Atlantic, Pacific and Southern) have average mercury concentrations in their muscle tissue across six ocean regions that may vary three-fold (Figure 11). Reasons for this variation differ and need to be accounted for when globally monitoring mercury in oceanic areas.

Figure 3.11. Muscle mercury concentrations in bluefin tuna in six ocean basins.



Therefore, recommended is a three-step approach for a global mercury monitoring approach for biota (Figure 12). ***Step 1a*** is related to ***Step 1b***, to best define the distinctions among the ocean basin limits (and the number of ocean basins of interest), likely related to the United Nations' Food and Agriculture Organization (FAO) interest and how they define commercial fishing areas (Figure 13).

Figure 3.12. Stepwise components for developing an oceanic approach using biota for mercury monitoring.



Step 1

a. Identify distinctions among ocean basins of interest

b. Collect FAO commercial fisheries data

Step 2

a. Identify tuna and billfish species of greatest commercial and recreational concern by ocean basin

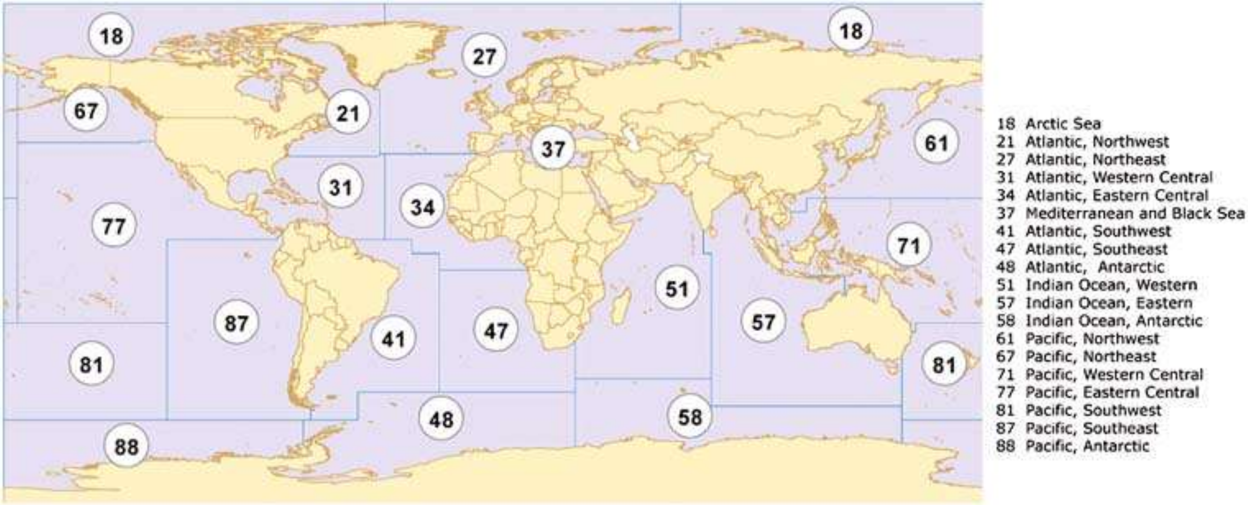
b. Identifv tuna. billfish

Step 3

a. Select top trophic level 4 species per ocean basin

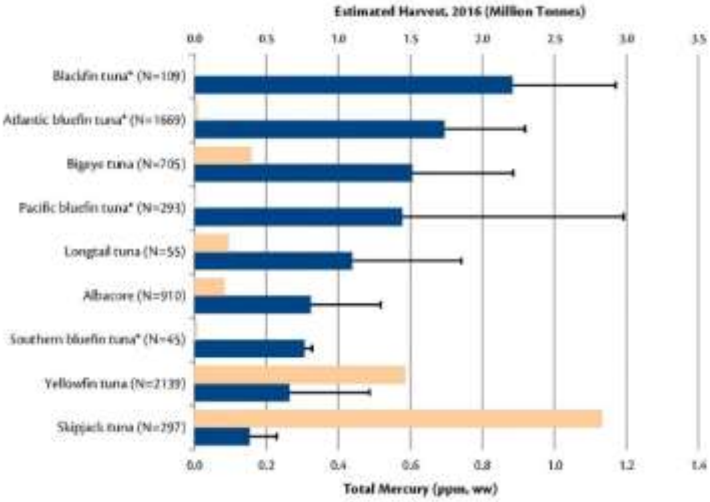
b. Conduct a power analyses based on the species/groups selected and their known mercurv

Figure 3.13. Food and Agriculture Organization of the United Nation's defined fishing areas.



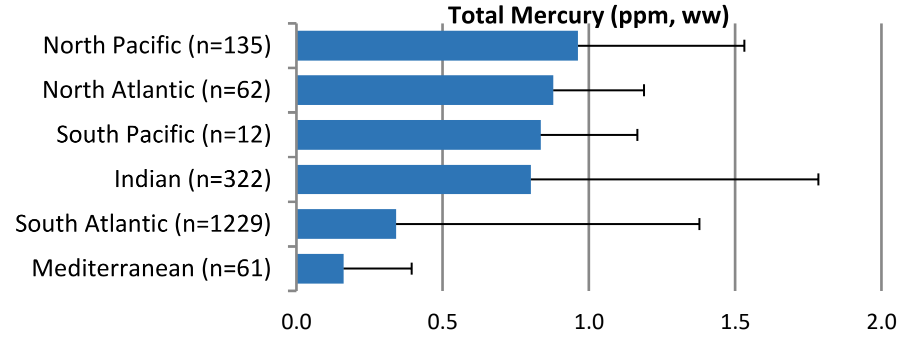
For ***Step 2a***, based on the GBMS database, the species of highest mercury concern with the greatest interest for human consumption are tuna and billfish (e.g., swordfish). The mercury concentrations in tuna vary greatly by species because of their growth rates, ultimate size, age, trophic level, and ocean basin (Figure 14). Smaller commercially captured species, such as skipjack and yellowfin tuna have lower mercury concentrations, while larger species tend to have higher levels, such as bluefin species. Tuna species with the greatest commercial interest are skipjack and yellowfin.

Figure 3.14. The mercury concentrations in nine species of tuna and their related FAO estimated harvest.



For ***Step 2b*** and assuming the use of trophic level 4 species that are within the tuna and billfish groups, spatial gradients are best determined through similar species that have global ranges. The bluefin tuna complex (representing three sibling species) is present in the Atlantic (north and south), Indian and Pacific (north and south) oceans, as well as the Mediterranean Sea and Caribbean Seea. The bluefin tuna complex tends to have some of the highest mercury concentrations, which when properly adjusted for size and age, can be compared across the world's temperate and tropical oceans. Billfish, in particular swordfish, are also relevant for making comparisons across the world's oceans (Figure 15). Lastly, to best track mercury concentrations in trophic level 4 fish in the Arctic Ocean, Atlantic cod are used by AMAP and are the best species for regional comparisons.

Figure 3.15. The mercury concentrations in six ocean basins for swordfish.



H2.1 Summary of Oceanic Sampling Framework

As part of the sampling framework for globally tracking biotic mercury in oceanic basins, a matrix that details existing and needed coverage by mercury monitoring programs is possible for eight ocean basins of interest (Table 7). A range of 4-6 sampling sites (n=30 samples/site) would adequately characterize ocean basins of interest for both temporal and spatial objectives.

To track temporal changes, especially those that may happen within a decade, smaller commercially and regularly captured species, such as the skipjack and yellowfin tuna, are good bioindicators for measuring changes in environmental mercury loads (Drevnick et al. 2015, Drevnick and Brooks 2017); bluefin tuna can be used for decadal changes (Lee et al. 2016). ***For Step 3a***, a matrix of trophic level 4 or greater marine fish species that could be globally monitored for spatial gradients and temporal trends is feasible (Table 7). Determining the ultimate sample size through a power analyses (***Step 3b***) is dependent of the species chosen, their range of mercury concentrations, the defined ocean basin distinctions, and the home range of the fish populations. Initial sample sizes are 30 individuals per site.

Because there are known significant differences in muscle mercury concentrations in same-tuna (Nicklisch et al. 2017) and same-billfish species (Figure 15) among major ocean basins of interest, understanding spatial gradients is an important component for incorporating into tracking temporal changes. The co-location of sites that can provide fish muscle mercury concentrations for tracking both temporal changes and spatial gradients requires careful consideration.

Sampling timing should be coordinated at times of the years that match similar seasonality (i.e., summer) and/or weather patterns (e.g., El Nino). Sampling frequency can be rotated every other year. For example, using this approach in the Pacific Ocean (for 3 sites in the north basin and 3 sites in the south basin) would result over a two year period of an analyses of 180 samples for tracking temporal changes and 180 samples for characterizing spatial gradients (or 360 samples).

Sampling efforts for tuna and billfish species can be coordinated with existing commercial fisheries around the world. Therefore access to known-sized fish, from known waters, and at selected times can realistically be coordinated in a cost effective way. Once a global sampling design is defined, sample handling, shipping and analyses can be coordinated from most countries (as show by a recent global effort for measuring mercury in fish; Buck et al. 2019).

H1.2 Summary of Sampling Framework by Ocean Basin of Interest

For the Arctic Ocean, there is existing coverage of sampling and mercury analyses by the AMAP program and national entities, such as Norway. There can be 100% coverage using existing mercury data collection.

For the Mediterranean Sea, there is existing coverage of sampling and mercury analyses, but there may need to be a need for harmonizing analytical standards for meeting EU needs. The Adriatic Sea has especially elevated biota mercury concentrations and should be a long-term tracking site. There can be 80% coverage using existing mercury data collection.

For the Indian Ocean, there is existing coverage of sampling and mercury analysis as coordinated by the Indian Ocean Commission, especially with SIDS on the western side, such as the Seychelles and Mauritius. Further efforts are needed on the eastern side. There may be 50% coverage using existing mercury data collection. Swordfish may be an important focal bioindicator.

For the Caribbean Sea, there is not existing coverage of sampling and mercury analyses other than some island countries measuring mercury in a small number of individuals (usually yellowfin tuna). The new Caribbean Region Mercury Monitoring Network provides a newly established structure for harmonized efforts across many countries, which are increasingly exporting tuna to the EU. There is < 10% coverage using existing mercury data collection.

For the Pacific Ocean – North, there is existing coverage of sampling, but not a coordinated effort for analyzing mercury. Both Japan and the U.S. have commercial fisheries in this basin and could provide a cost-effective platform for collecting samples for future mercury analyses. There is 100% coverage for sampling and <10% coverage using existing mercury data collection.

For the Pacific Ocean – South, there is existing coverage of sampling, but not a coordinated effort for analyzing mercury. The U.S. have commercial fisheries in this basin and could provide a cost-effective platform for collecting samples for future mercury analyses. There is 100% coverage for sampling and <10% coverage using existing mercury data collection.

For the Atlantic Ocean – North, there is existing coverage of sampling, but not a coordinated effort for analyzing mercury. Both the U.S. and the EU have commercial fisheries in this basin and could provide a cost-effective platform for collecting samples for future mercury analyses. There is 100% coverage for sampling and <10% coverage using existing mercury data collection.

For the Atlantic Ocean – South, there are limited existing coverage of sampling, and no coordinated efforts for analyzing mercury. Commercial fisheries in this basin are less common than the northern part of the Atlantic Ocean and the Pacific Ocean. There is <10% coverage for sampling and <10% coverage using existing mercury data collection.

Table 3.7. Sampling strategy for trophic level 4 or greater biota (see Table 3) for the Oceanic Sampling Framework. Listed are the number of sites (with an initial sample size of 30 fish at each site) for both objectives of monitoring temporal trends and spatial gradients of mercury.

Ocean Basin of Interest	**Monitoring Temporal Trends**[1]	**Monitoring Spatial Gradients**[2]	**Estimated numbers of Hg samples (based on 30 samples per trophic level 4 bioindicator)**	**Approximate coverage (%) using existing Hg data and monitoring programs***
Arctic Ocean[3]	3 sites – existing coverage of sampling and Hg analyses by AMAP and Norway	3 sites – existing coverage of sampling and Hg analyses by AMAP and Norway	180	100% (official existing site selection will be needed)
Mediterranean Sea	2 sites – existing coverage of sampling and Hg analyses	2 sites – existing coverage of sampling and Hg analyses	120	80% (official existing site selection and analytical standards will be needed)
Indian Ocean	3 sites – existing coverage of sampling and Hg analyses by the Seychelles, Mauritius and the Indian Ocean Commission	3 sites – existing coverage of sampling and Hg analyses by the Seychelles, Mauritius and the Indian Ocean Commission	180	50% (official existing site selection and analytical standards will be needed)
Caribbean Sea	2 sites – no existing coverage of sampling and Hg analyses by the CRMMN	2 sites – no existing coverage of sampling and Hg analyses by the CRMMN	120	<10% (new sites will need to be identified)
Pacific Ocean - North	3 sites – existing coverage of sampling by Japan and the U.S., but not Hg analyses	3 sites – existing coverage of sampling by Japan and the U.S., but not Hg analyses	180	100% coverage for sampling and <10% for Hg (new sites will need to be identified)
Pacific Ocean - South	3 sites – existing coverage of sampling by U.S., but not Hg analyses	3 sites – existing coverage of sampling by U.S., but not Hg analyses	180	100% coverage for sampling and <10% for Hg (new sites will need to be identified)
Atlantic Ocean - North	3 sites – existing coverage of sampling by U.S. and EU, but not Hg analyses	3 sites – existing coverage of sampling by U.S. and EU, but not Hg analyses	180	100% coverage for sampling and <10% for Hg (new sites will need to be identified)

Atlantic Ocean - South	3 sites – existing coverage of sampling, but not Hg analyses	3 sites – existing coverage of sampling, but not Hg analyses	180	<10% for sampling and Hg (new sites will need to be identified)

[1] Focal bioindicator – Yellowfin Tuna (*Thunnus albacares*)

[2] Focal bioindicator – Bluefin Tuna species (*Thunnus* spp.) and Swordfish (*Xiphias gladius*)

[3] Arctic Ocean focal bioindicator - Cod (*Gadus* spp.) – because tuna are not regularly distributed in the Arctic Ocean.

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4. Cost analysis

In response to the request from COP to for the options and recommendations mentioned in the preceding subparagraph, compare the options for filling the identified gaps in global mercury monitoring for their cost-effectiveness, practicality, feasibility and sustainability, global coverage, and regional capabilities, the ad hoc group developed a table of cost, practicality, feasibility, sustainability, comparability and coverage of difference monitoring methods.

Monitoring method	**Method**	**Cost issues**	**Practicality**	**Feasibility & Sustainability**	**Comparability**	**Coverage**
Air Measurements						
Active TGM	Gold trap CVAFS	50K instrument Experienced operator Annual 5-10K costing (gold traps, argon etc) Requires housing and power Require laboratory analysis	Good for low concentration levels of Hg in air Data produced at 5 min temporal resolution Works well in established air monitoring networks Excellent standardized sampling, analysis and QC methods Not practical for remote sites with no power and compressed argon is required	Requires sustained funding and high level technical capacity , regular maintenance and compressed gases supply	Has been proven compatible through many research studies and through active ongoing monitoring programs. Well documented in the scientific literature. Data is frequently used in model and measurement intercomparison.	Has been shown to be used to describe global, regional and local coverage
	Gold trap semi continuous	Cost is 150-220/trap and 20$ per lab analysis by AAS	It is very practical, cost effective – allows to monitor using a simple pump and housing for the trap. It can be used for 24-48 hr sampling frequency; it can be housed in an automated sequential system.	It is very cost-effective for monitoring remote sites, does not require significant electrical power (<1 KW) is limited and no technical assistance is available on site.		Used primarily in Asia Pacific region

Monitoring method	Method	Cost issues	Practicality	Feasibility & Sustainability	Comparability	Coverage
	Atomic absorption spectrometry with Zeeman background correction		Works of air, water and soil sample tests (dry and wet deposition)			Has been shown to be used to describe global, regional and local coverage: environmental and human biomonitoring
	Portable air mercury analyser	15-28K One-day trained operator Annual cost up to 0-1$K: for spare filters and yearly maintenance. No gold traps, no compressed gases.	Low to high Hg concentrations (can be used for background monitoring and at industrial & contaminated sites). Continuous data acquisition (1 s). Can be used for automobile, boat, aerial surveys	Very cost-effective for remote sites monitoring, rapid revealing of contaminated sites, mercury hot spots, sources of the Hg emissions. Robust design for field applications. Low maintenance. Used worldwide as a field analyser for the UNIDO Global Mercury Project		
	On-line air mercury monitor	35-39 K One-day trained operator Annual cost up to 1-3K: for spare filters and yearly maintenance. Requires housing and power. No gold traps, no compressed gases	Background monitoring, can be used for contaminated industrial sites. 10 s temporal resolution. Can be used in mobile applications. Fully automated.	Very cost-effective for remote sites monitoring. Low running cost, low maintenance		
	Multifunctional mercury analyser	35-45K Three-days trained operator Annual cost up to 1-5K: for CRMs and spare parts. No gold traps, no compressed gases	Direct analysis of air, water, solids, biota, human biomonitoring (HBM). Lab and field applications	Very cost-effective for remote sites monitoring and human biomonitoring. Robust design. Low maintenance. Used worldwide as a field analyser for the UNIDO Global Mercury Project		

Monitoring method	**Method**	**Cost issues**	**Practicality**	**Feasibility & Sustainability**	**Comparability**	**Coverage**
Passive Hg	Sorbent trapping (carbon, titanium dioxide) Analysis with AAS and CVAFS	Cost of individual PAS of~$100 and 20$ per lab analysis plus shipping costs	Weather influence is unclear (humidity, wind, etc.)	Some in the implementation phase and some in the research pahse		
Wet deposition	There are several wet-only samplers available and in use by existing networks	Cost of acid-cleaned bottles 100 and 20$ per sample for lab analysis	It is available as sequential automated system (up to 8 samples) or as single sampler. In both cases requires technical assistance an human intervention, especially for single sampler.	It allows to estimate the direct atmospheric input to Earth's surface by wet scavenging without the contribution from dry deposition.	Used throughout WEOG and ASIA Pacific. Many studies showing comparability and large coverage areas	It is used at several master sites in existing regional and global monitoring networks
Active speciation	RGM collection on KCl denuder, PHg on quartz filter, GEM on gold trap	Cost 150K for instrumentation. Operational requirements ~$20K/yr for experts	Practical for experienced users who have power and access to argon supply, requires housing and considerable attention. Not practical for cost effective requirements and for global reproducibility	Has been used in WEOG for long term networks and processes research studies. Not feasible for global monitoring dues to operational requirements and cost	This method uses an operational definition of the mercury species and is comparable within strict guidelines of using instrumentation	Used in WEOG countries effectively
Passive speciation	Various					
Water sampling and analysis						
Lab analyser	MeHg	36K just for analyser	Expensive to purchase, need lab to properly sample and anlayse		Most of the commercial equipment show comparable results	

Monitoring method	**Method**	**Cost issues**	**Practicality**	**Feasibility & Sustainability**	**Comparability**	**Coverage**
	Total Hg – Cold Vapour Atomic Fluorescence Spectroscopy (CVAFS)			Similar costing to wet deposition water samples above	Most of the commercial equipment show comparable results. Concern lies in contamination of sampling.	
	Mercury isotopes: Inductively coupled plasma – mass spectrometry					Currently mainly done for research purposes and not monitoring networks
Total Mercury Approximate cost per sample in university or commercial laboratory	Clean hands-dirty hands sampling into certified clean glass bottles; field acidification with trace grade HCl; standard analyses on Tekran (or other) THg analyser	Analytical costs: ~$75/sample; Costs of bottles, acid, gloves, etc: ~$5/sample	Methodology is well known and reasonably easy to undertake sample analysis	Should be easy to find commercial laboratories to undertake this kind of analysis	Need to right laboratory to undertake analysis but can be very comparable	
Methyl Mercury Approximate cost per sample in university or commercial laboratory	Clean hands-dirty hands sampling into certified clean glass bottles; field acidification with trace grade HCl; standard analyses on Tekran (or other) MeHg analyser	Analytical costs: ~$175/sample; Costs of bottles, acid, gloves, etc: ~$5/sample	Methodology is well known and reasonably easy to undertake sample analysis	Should be easy to find commercial laboratories to undertake this kind of analysis	Need to right laboratory to undertake analysis but can be very comparable	
Biotic sampling and analysis						

Monitoring method	Method	Cost issues	Practicality	Feasibility & Sustainability	Comparability	Coverage
Trophic Level 4 muscle tissue for fish, birds and mammals, keratin-based tissues for birds and mammals, and bird eggs (total Hg used since MeHg reflects >90% of Hg in nearly all cases) NOTE: Fish muscle can be analyzed as wet weight (ww) if fresh; if not, dry weight (dw) analyses is needed. Blood and keratin tissues do not generally need lab preparation. Eggs require homogenization and freeze drying (unless fresh)	Direct Mercury Analyzer (DMA), carried by several companies including Milestone and Nippon; CVAA / CVAF can be used but more expensive	Existing lab per sample cost using a DMA with no sample preparation is $35 to $55. Sample preparation increases cost by $5 to $15/sample Cost for a dual-cell DMA is ~ $40k Operational requirements (service contract and consumables kit) ~ $6k/yr Analytical balance is $2k Freeze dryer ($9k) and homogenizer ($3.5k) may also be needed for conducting dry weight analyses	Low cost, rugged and time efficient - has a 4 hour running time for ~30+ samples/run (allowing room for duplicates, blanks and calibration needs). Has a relatively small countertop footprint. Does not require an experienced lab manager	DMAs are already used globally and individual machines last well over a decade, analyzing thousands of samples annually, with usually relatively few maintenance issues – as long as a service contract is in place with annual maintenance.	Analyses is very replicable and comparable across different DMAs and with CVAA/ CVAF instruments Generally minor tissue preparation needed (with some important exceptions, such as attaining tissue dry weight)	Is being used by most labs for total Hg analyses in biotic tissues around the world.
Human Health media sampling and analysis						

Monitoring method	Method	Cost issues	Practicality	Feasibility & Sustainability	Comparability	Coverage
Human scalp hair (total mercury)	Cold vapour atomic absorption/fluorescence spectrometry (CVAAS/CVAFS) 10 mg of hair (first cm) digested Analysed by ICP-MS	Direct mercury analyser - 50-55K instrument Trained lab staff Annual 7-10K costing (gold traps, oxygen, etc) Cost for one sample analysis – 20 – 50 USD Cost for one sample analysis around 40 USD	Reliable and accurate determination at the typical mercury concentrations range for environmental exposure Highly suitable for measurement of low concentrations (long-time exposure) Short analysis time ICP-MS: can provide a suite of other elements, but requires highly trained technicians	Used globally; confirmed feasibility in the WHO/UNEP pilot surveys; Used by reference laboratories and for proficiency test;	Doesn't require samples digestion prior to analysis; likelihood pf sample contamination is minimal; little chemical wastes sample contamination; amount of hair can be reduced; Analysis is replicable ICP:Highly robust method where performance can be supported by multiple external quality assessment program	Most commonly used for mercury HBM (publications, reports on monitoring data)
Cord blood (total mercury)	Cold vapour atomic absorption spectrometry	Direct mercury analyser - 50-55K instrument Trained lab staff Annual 7-10 K costing (gold traps, oxygen, etc) Cost for one sample analysis – 20-50 USD	Reliable and accurate determination at the typical mercury concentrations range for environmental exposure Highly suitable for measurement of low concentrations (long-time exposure) Short analysis time	Used globally; confirmed feasibility in the WHO/UNEP pilot surveys; Used by reference laboratories and for proficiency test;	Doesn't require samples digestion prior to analysis; likelihood pf sample contamination is minimal; little chemical wastes sample contamination; amount of hair can be reduced; Analysis is replicable	Most commonly used for mercury HBM (publications, reports on monitoring data)

Monitoring method	Method	Cost issues	Practicality	Feasibility & Sustainability	Comparability	Coverage
Total mercury in whole blood	Dilution (0.5 ml) in NH3 solution ICP-MS determination	around 35 USD	ICP-MS: can provide a suite of other elements, but requires highly trained technicians		Highly robust method where performance can be supported by multiple external quality assessment program	
Hg speciation (MeHg-Hg+-EtHg) in whole blood	TMAH digestion (0.2ml) SPME-GC-ID-ICP-MS (solid phase micro extraction gas chromatography coupled with isotope dilution	around 120 USD	Hyphenated -ICP-MS technics need highly skilled technicians. Full speciation of 3 species in the same analysis. Summation of the three species can be considered as total mercury		Summation of the three species give very comparable results with total analysis ICP-MS	

5. Modelling capabilities

1. The global modeling capabilities outlined 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 (see para 2-20) vary in their availability, as indicated in the table D. Integrated models (see paragraph 21) are under development and are expected to be available by 2023.

Socio-Economic Scenarios and Emissions

2. A large variety of models and quantitative techniques can simulate socio-economic systems to forecast where mercury is present in society and where it might eventually enter the environment. Models can be used to develop scenarios that represent baseline and different policy alternatives. Inputs to these models include commercial data (e.g. amount of mercury in products), technological performance, economic information, energy data, demographic information, policy specifications, and institutional analysis. Outputs can include emissions and releases of mercury as well as other socio-economic parameters. Other types of models that are relevant to understanding socio-economic systems of relevance to mercury include life-cycle analysis, materials flow analysis, input-output, and economic models. Developing and evaluating these models draws on expertise that bridges natural science, social science, and engineering.

Air

3. There are numerous dynamical global modeling 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, GEOS-Chem, GRAHAM) and new models from different groups are welcome. 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).

4. 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. New emissions data generated as part of the MC MIAs need to be integrated in the current global emissions inventories as a top priority for future modeling assessments.

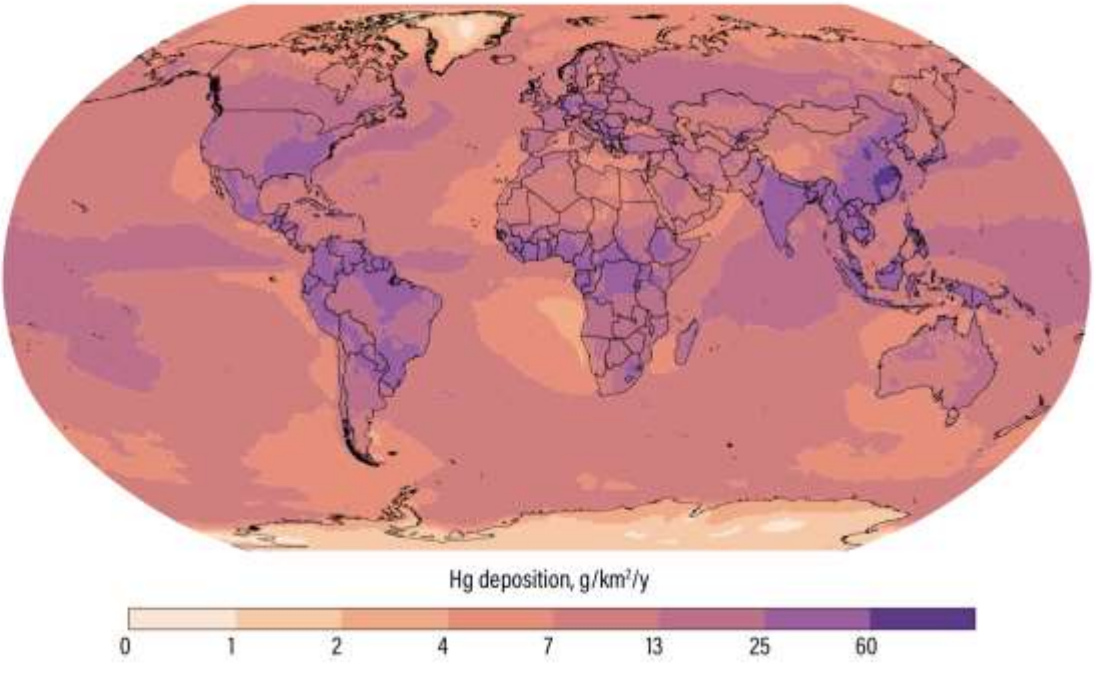

Figure 5.1. Global atmospheric deposition simulated using an ensemble of global atmospheric chemical models. Figure from Global Mercury Assessment, 2019.

5. Evaluation data are needed to evaluate trends in atmospheric mercury concentrations in response to actions implemented under the Minamata Convention (see article 8 rationale).

6. In support of the Minamata Convention, output provided by these models can include global simulations of atmospheric mercury concentrations and deposition for different policy scenarios representing different levels of air emissions reductions from human sources. Atmospheric simulations can also attribute emissions sources contributing to atmospheric mercury deposition to terrestrial and aquatic receptors.

Marine ecosystems

7. 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. While we encourage measurement and modeling efforts in these regions, such efforts are local in nature and measurements are difficult to obtain due to potential contamination issues.

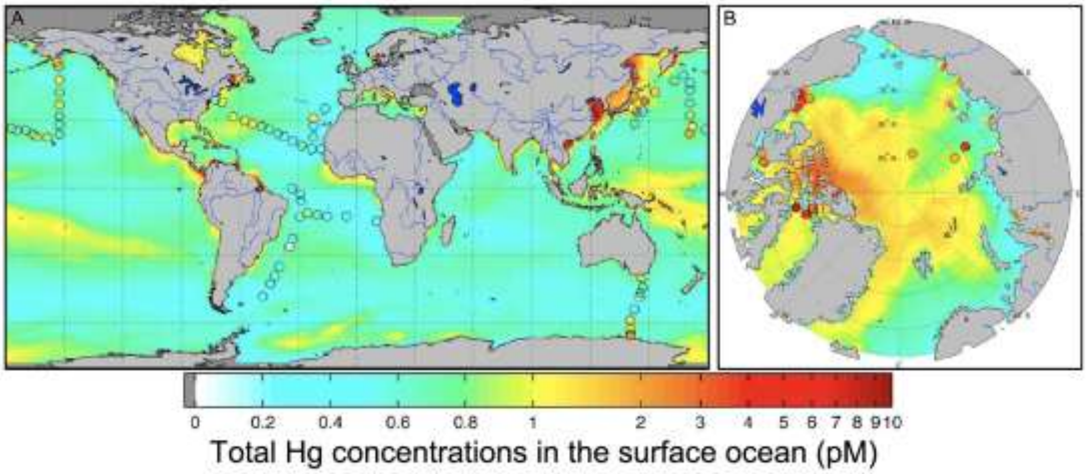

Figure 5.2. Modeled total Hg concentrations in the upper 10 m of the ocean. Figure from Zhang et al. (2015).

8. Here we focus on the global tools and the marine environment as the pathway for methylmercury exposure from marine fisheries. Available tools for modeling mercury in marine environments include several coupled atmospheric-ocean simulations and new models from other regions are highly encouraged and supported. These are not as widely applied as the air models and can be considered research applications at this point in time. 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 modeling efforts (FATE-Hg).

9. Inputs needed for the model 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 by there is substantial uncertainty in estimates of global riverine discharges. We therefor encourage collection of global data on total mercury and methylmercury in rivers flowing into the ocean.

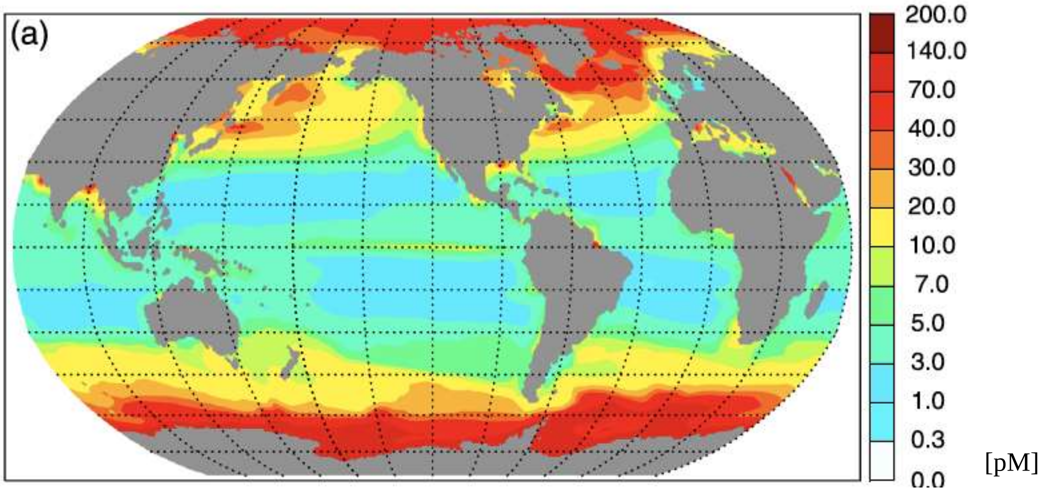

Figure 5.3. Modeled methylated mercury concentrations in the ocean surface mixed layer in the NEMO model. Figure from Semeniuk and Dastoor (2017).

10. 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 modeling efforts as they become available. While development of an enhanced database on speciated mercury concentrations in seawater covering horizontal and vertical distributions is strongly encouraged, such measurements are typically collected by analytical specialists to ensure data quality since artifact and contamination issues are common.

Terrestrial ecosystems (including surface water and groundwater environments)

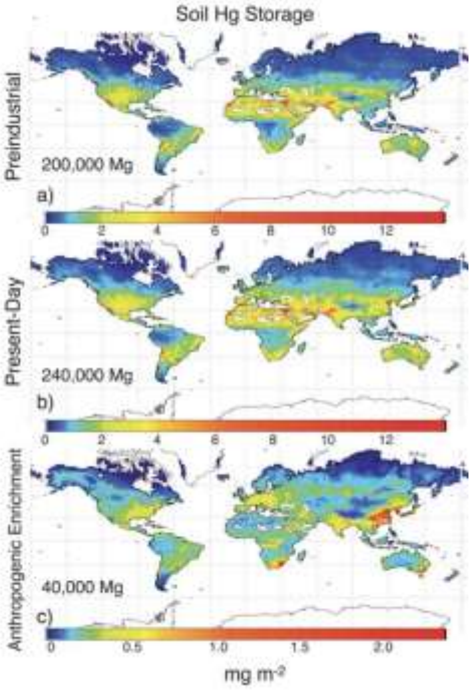

Figure 4. Global Terrestrial Mercury Model output. Figure from Smith-Downey et al. (2010)

11. 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.

12. 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.

13. Global terrestrial models that can project future scenarios in soil mercury concentrations as part of integrated modeling 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 modeling 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.

Biota

14. 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.

15. Several academic groups are developing coupled global model that link anthropogenic mercury releases on a global scale to accumulation in marine fish. Development of such integrated model 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-consuming populations. For example, more than 40% of population-wide exposure in the United States and Japan is from canned and fresh tuna only.

16. Input data for these modeling exercises draw on research in the global fisheries community on factors affecting fisheries production, including climate change as well as modeled 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.

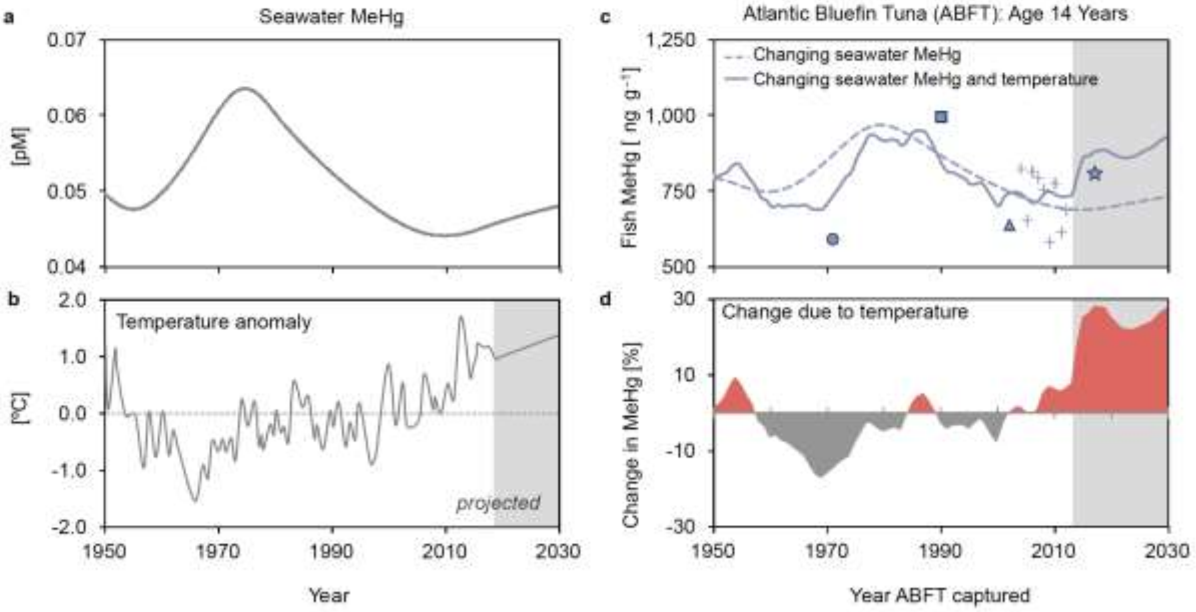

Figure 5.5. Modeled change in concentrations of Atlantic bluefin tuna (ABFT) to changes in seawater methylmercury concentrations and seawater warming. Figure from Schartup et al. (2019).

Human exposure

17. 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.

18. 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.

19. To link modeled 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 modeled 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.

20. These types of modeling 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.

21. Integrated modeling 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 modeling 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. With additional model evaluation, updates should be available to begin policy-relevant analyses by 2023. 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 modeling 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 modeling frameworks are rapidly developing in the scientific community.

PART II: Elements of monitoring guidance document

Part II of the present information document provides a draft structure and elements of the guidance for global monitoring, as included in the terms of reference for the global monitoring arrangements described in Annex 3 of the report of the ad-hoc group of technical experts on effectiveness evaluation (UNEP/MC/COP.3/X).

These elements are to support implementation of monitoring arrangements put in place by the Minamata Convention and provide guidance for example on how information is to be collected, analyzed, statistically treated, reported and visualized in order to provide a comparable information for the Conference of the Parties as required in para 2 of article 22.

It is expected that the elements be further elaborated and guidance document be developed under the COP-agreed monitoring arrangements to enable global monitoring activities to be undertaken as early as possibile to support the first cycle of effectiveness evaluation, and be updated on the basis of technical progress at least once per effectiveness evaluation cycle.

Finally, the guidance document should also contain relevant standard operating procedures for implementation of monitoring arrangements in the core matrices in annexes of the guidance for reference of experts.

Proposed Table of Contents

The following table of contents is proposed for the guidance document.

1. Acknowledgements
2. List of abbreviations and glossary of terms
3. Introduction and objectives
4. Mercury monitoring in the environment
5. Sampling and sampling preparation (organized per media)
    - core matrices - air, human, biota
    - other matrices - water
6. Analytical methodology
7. Data Handling
8. Statistical Considerations
9. Outline of the global monitoring reports
10. References

11. Annex 1: Standard operation procedures and protocols
    - air
    - human matrices
    - biota
    - …
12. Annex 2: Review/list of monitoring networks

Elements to be included in the guidance document.

1. Acknowledgements

Text to be developed.

2. List of abbreviations and glossary of terms

Text to be developed.

3. Introduction and objectives

(Preliminary draft text)
The objective of the Minamata Convention, per Article 1, is "to protect the human health and the environment from anthropogenic emissions and releases of mercury and mercury compounds."

Further, Article 22 of the Minamata Convention in paragraph 2 stipulates that the arrangements to be put in place for the effectiveness evaluation are to provide comparable monitoring data on the presence and movement of mercury and mercury compounds in the environment, as well as the trends in the levels of mercury and mercury compounds as observes in biotic media and vulnerable populations.

Therefore, the main purpose of the guidance is to support monitoring arrangements put in place by the Minamata convention and provide guidance for example on how information is to be collected, analyzed, statistically treated, and reported in order to provide a comparable information for the Conference of the Parties as required in para 2 of article 22.

In addition, the monitoring arrangements in place need also accommodate using existing mercury monitoring programmes and in other cases support the establishment of new activities, namely to bridge the identified geographical gaps in data coverage and therefore the guidance would provide information in this regard.

Further, for providing support to the periodic effectiveness evaluation of the Minamata Convention, the guidance also describes a regime for the preparation of global monitoring reports that are for consideration by the Effectiveness Evaluation Committee and COP as relevant.

Last but not least, the guidance document should also contain relevant standard operating procedures for implementation of monitoring arrangements in the core matrices in annexes of the guidance for reference of experts.

4. Mercury monitoring in the environment

Text to be developed, explaining what media are covered and why, and how the monitoring data are used in effectiveness evaluation.

5. Sampling and sample preparation (organized per media)

Text to be drafted, organized per media. Following is preliminary elements for air.

The expert group recommended that air concentration data be collected as total gaseous mercury (from both active and passive sampling), and wet deposition data be collected to understand total deposition.

The follwing elements require further elaboration:

a) reporting period: It is important that there is agreement on the specified time period over which to report averaged data, as this may be reported monthly, annually or seasonally (noting that 'seasonal' may have different meanings i.e. summer/winter, wet/dry etc.).
b) metadata/data completeness: In considering data obtained at different monitoring sites, the type of monitoring site, and the reason for collecting the data should be elaborated.
c) The group agreed that there is a significant geographical coverage of ambient air monitoring of mercury, but that there are gaps in certain regions. These geographical gaps should be identified and a plan should be in place to cover them. These include gaps in Africa, Latin America, the Caribbean, certain parts of Asia and the Pacific and in Russia.

Sampling methods
There are a variety of active sampling methods by combination of automated vs. manual gold traps, detection by CVAFS vs. AAS, and several suppliers including Tekran, Lumex, NIC, and PSA. Further technical review of methods may be needed.
Passive sampling methods include methods which are currently available as well as those under development, including active carbon (Canadian), titanium dioxide (GMOS) and gold beads (Republic of Korea/Thailand) or gold cores (Radiello tubes, Italy-Denmark).

Preliminary results have been produced also by the UN Environment-GEF project "Development of a Plan for Global Monitoring of Human Exposure to and Environmental Concentrations of Mercury".[4]

6. Analytical methodology

Text to be drafted, organized per media. This section may also include a review of mercury analysis capacity worldwide, such as the following..

The UN Environment organized a survey with the objective of developing a Mercury Laboratory Databank. Invitation letters were sent and on-line questionnaire for submission of information into the databank was open from 1 August 2016 till 15 October 2016. A total of 188 laboratories provided information on their sampling and analytical capacities[5].

In addition, a pilot Global Assessment of Laboratories Analysing Mercury was organized in summer 2018 (August-October) as a first round of the global proficiency testing[6]. Participation was by invitation only and invitees were selected from the Mercury Laboratory Databank organized by UN Environment, Chemicals and Health Branch. There were 80 laboratories invited, 42 laboratories from 29 countries registered for the global assessment and 38 laboratories from 28 countries worldwide delivered results.

Test materials for total mercury analyses used included three matrices: (i) test solution of analytical standards and (ii) naturally contaminated samples of biota: (a) fish samples, and (b) human scalp hair samples. No matrix was compulsory in this pilot laboratory assessment, therefore there was no full participation in analyses of individual matrices. It is quite encouraging to see a good agreement of reported data with reference values for the individual test samples provided by both developed and developing countries.

Almost 90% of all laboratories analysed the standard solution and 80% of the delivered results presented satisfactory z-score. Lower amount, 84% of all laboratories analysed biota sample (fish) and almost 85% were with satisfactory z-scores outcome. 73.7% laboratories analysed human scalp hair and there were 82% of satisfactory z-scores outcome. Full report is available online[7].

7. Data Handling

Text to be drafted, organized per media. Following is preliminary elements for human exposure.

Data quality issues are covered by the WHO protocol. Results of the measurements must be analytically comparable between laboratories/different studies. To ensure comparability, each national survey would need to follow the WHO harmonized SOPs 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) supports internal quality assurance. External quality assurance should be done through international inter-laboratory comparison investigations (as was done for the WHO/UNEP/GEF Project). Coordination of the studies will contribute 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. It recommends that participating countries conduct statistical analyses at the national level and submit anonymized data for statistical analysis to a central database. The aim of a statistical analysis at the international level is to assess associations between biomarker values and predictors such as age, gender, fish consumption habits, etc. (collected via questionnaire) in a pooled dataset. Data communication issues are also addressed in the WHO protocol. These communication issues include communication of the results within the country, to the individuals

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[4] report is available online:

[5] UN Environment communication in the COP1 document INF 15, databank is available online as beta version : http://informea.pops.int/HgPOPsLabs/index.html

[6] see full report from the pilot assessment is available online: https://www.unenvironment.org/resources/report/final-report-global-assessment-laboratories-analysing-mercury-first-round-2018

[7] see footnote 4 above

participating in the study and to policy makers. It should be noted that, in some countries, national guidelines relating to communication of results may already exist.

8. Statistical Considerations

Text to be developed.

9. Outline of the global monitoring reports

Text to be developed.

10. References

Text to be developed.

11. Annex 1: Standard operation procedures and protocols

Text to be developed. This annex will provide a link to the standard operating procedures organized per media - air, human matrices, biota]

Currently available SOPs

Air
Practical instructions to use CNR-IIA Passive Air Samplers (PASs) for Total Gaseous Mercury (TGM) monitoring (https://www.unenvironment.org/resources/toolkits-manuals-and-guides/practical-instructions-use-cnr-iia-passive-air-samplers-pass)

Human matrices
Assessment of prenatal exposure to mercury: standard operating procedures (2018)
http://www.euro.who.int/en/health-topics/environment-and-health/chemical-safety/publications/2018/assessment-of-prenatal-exposure-to-mercury-standard-operating-procedures-2018

Assessment of prenatal exposure to mercury: human biomonitoring survey (2018) - the first survey protocol
http://www.euro.who.int/en/health-topics/environment-and-health/chemical-safety/publications/2018/assessment-of-prenatal-exposure-to-mercury-human-biomonitoring-survey-2018

Biota
Standard OperationalProcedures for the Monitoring of Mercury and Methylmerury in Fish and Shellfish (https://wedocs.unep.org/bitstream/handle/20.500.11822/26560/SOP_Mercury_minitoring_Fish.pdf?sequence=1&isAllowed=y)

12. Annex 2: List of reference materials

Category	Material	T-Hg	MeHg	Manufacturer
Hair	Human hair powder	X	X	International Atomic Energy Agency
Food	Lichen powder, Cabbage powder	X		
Biota	Freeze-dried tuna meat, Freeze-dried scallop, Cotton cellulose powder, Freeze-dried clam	X	X	
Sediment	Lake sediment, Coastal sediment, Marine sediment	X		
Urine	Frozen human urine	X		National Institute of Standards and Technology
Biota	Oyster tissue, Lake Superior fish tissue, Lake Michigan fish tissue, Bovine liver	X	X	
Sediment	Estuary sediment, New York/New Jersey Waterway Sediment, Inorganics in marine sediment, Sediment for solid sampling	X		

Soil	Soil containing lead from paint, New Jersey soil, San Joaquin soil, Montana soil	X		
Plant	Apple leaves, Peach leaves, Spinach Leaves, Tomato leaves, Pine needles	X		
Food	Typical diet, Wheat flour, Rice flour, Green tea leaves	X		
Waste	Hard rock mine waste, Domestic sludge, Industrial sludge	X		
Biota	Dogfish liver, Fish protein, River prawn, Cuttlefish, Lobster Hepatopancrea	X	X	National Research Council Canada
Sediment	Marine sediment	X		
Hair	Human hair powder	X	X	National Institute for Environmental Studies
Biota	Freeze-dried fish meat powder	X		
Soil	Air-dried sieved soil	X		
Soil	Forest soil, Hg added forest soil	X		Japan Society for Analytical Chemistry
Soil	Heavy meal added forest soil	X		
Sediment	Marine sediment, Lake sediment	X		National Metrology Institute of Japan
Biota	Freeze-dried cod meat, Freeze-dried swordfish tissue	X	X	

13. Annex 3: Review/list of monitoring networks

A relevant text is currently available in the part 1 to this INF document and it needs to be regularly updated to cover existing activities at the global, regional and national levels.