Mercury Assessment 2021 – Assessment Scoping

(version December 2019)

I. Assessment Outline (content and coordinating lead authors)

II. Assessment timeline

III. Policy-relevant questions guiding the assessment work

I. Assessment Outline, Content and Coordinating Lead Authors

Chapter/Section	Section annotations	General notes
1. **Introduction**	The introduction will identify the objectives of the assessment, introduce the quesiton-based approach, and provide readers with a guide to the content and structure of the report.	The chapter will introduce the following questions: How can the results of the AMAP assessment contribute to work under the Minamata Convention? What are Arctic indigenous people's perspectives and how are indigenous peoples contributing to the study of mercury contamination issues? Coordinating lead authors: EG leads, Simon Wilson Contributors: Eva Kruemmel, Magali Houde (PP perspectives); Eva Kruemmel/Simon Wilson/contact group on Minamata-related aspects
PP perspectives[1]: (proposed as seperate chapter; see 9) • What is the history of the contributions of Indigenous regions and communities to mercury work in the Arctic? • Map of Arctic activities involving Indigenous regions and communities • Descriptions of community-based/driven projects. Specific examples to be given (Canada, US, Greenland, Russia – if available). • What are examples of how/where Indigenous knowledge is being utilized and how does it contribute to the overall knowledge on mercury/impacts of mercury in the Arctic? • What are recent efforts to include Indigenous Knowledge and observations of ecological impacts of climate changes in wildlife mercury monitoring? May be combined with above point, or deleted,	PP perspectives: • It will be important to synthesize the information provided by contributors to answer the questions in your outline. A map would be great, and identifying similarities and differences among projects (categorizing them maybe?) might be informative. Detailed descriptions of a few strong examples of community-driven research will be useful, but please try to avoid presenting too much detail for individual projects that may not be directly	

[1] The introduction chapter willl include an introduction to PP perspectives as part of the framing of the report. Substantive material addressing this issue will constitute a separate chapter/section in the report and/or be part of the concluding chapter.

depending on contributions. • What are challenges encountered in integrating different ways of knowing e.g., Western science (numerically recorded) and Indigenous Knowledge (mostly orally communicated)? • What are perspectives of Indigenous Peoples on past and future Arctic contaminants research, how Indigenous Knowledge should be utilized, and how a partnership/co-production of knowledge approach should be conducted?	relevant to answering the chapter questions.	
2. **Temporal trends of mercury in arctic media and biota**		The chapter seeks to address the primary questions: • Are concentrations of mercury changing significantly in Arctic air and snow over time? • Are concentrations of mercury changing significantly in biota over time? • How does geographically based weighting affect the spatial and/or temporal trends of mercury in biota? Coordinating lead authors: Frank Riget, Adam Morris, Phillipe Thomas Potential Contributing Authors: Sara Pedro (marine mammals), Karista Hudelson (landlocked char/fish), Sandy Steffen, Geoff Stupple and Torunn Berg (air), Kristin Eccles (geographically weighted regression/stats expert) **Context**
2.1. Introduction & Literature Review 2.1.1. Summary of recent literature, focusing on post-2005 publications (approximately the end of the publication dates for last Hg Report) 2.1.2. Summary of previous meta-analysis results from AMAP 2011 report		
2.2. Datasets & Methods 2.2.1. Overview of all available data/trends 2.2.2. Selection criteria for analyses a. Length of trend/number of years/number of samples per year b. Tissues c. Filtering by age, length, sex, other factors 2.2.3. Summary of the species/trends selected for analyses	2.2.2.c = No covariate adjustments for this report – truncating and/or filtering datasets only.	

2.2.4. Statistical approach a. Linear and non-linear trend assessment b. Geographically weighted regressions**Dependent on significance of output**		**Human health is covered elsewhere as are sediment cores. These do no seem to fit the conceptual model of this chapter** **Case studies of interest can be identified here, but we will not be discussing them as part of the trends chapter**
2.3. Meta-Analysis of Trends 2.3.1. Assessment of the adequacy of the available datasets 2.3.2. Environmental Media a. Air b. Snow 2.3.3. Wildlife (by country/region as directed by stats output) a. Fish b. Mammals and birds 2.3.4. Latitudinal and longitudinal discussion (High versus Subarctic, European versus Canadian/American Arctic) 2.3.5. Comparison of meta-analysis results with previous AMAP report 2.3.6. Comparison of meta-analysis with recent published trends	2.3.1 = i.e., ability to detect a 5 % annual change at □= 0.05, and power level of 80 % or greater); Can use “Less Detectable Trend” output from new stats model, then filter those trends into power analysis where they are assessed more closely** 2.3.2 = (by country/region if applicable – may only have Canadian data) ; data analysis will be completed by data contributors for air/snow 2.3.4 = dependent on output/results	
2.4. Geographic Weighted Regression Analysis of Trends	Phil & Kristin will lead this portion	
2.5. Key Conclusions	To set up and frame the rest of the report, with suggested/interesting products and case studies.	
	Case studies of interest (can be suggested for further study in other	

	sections/chapters as appropriate) • Southern Beaufort Sea polar bears (McKinney/Pedro) – short trend but unique approach (not appropriate for meta-analysis) • Landlocked char in Canada and Greenland (Muir/Kirk/Hudelson) – several long-term trends throughout the Canadian Arctic and in Greenland (Riget) – covariate (length) and climate change-related effects have been explored • Ringed seals – extensive coverage in both Canada and Greenland – likely best circumpolar model animal • Data on trends in human biomedia have been provided by Bryan Adlard and will be considered for inclusion in chapter 2 and or chapter 7.	
3. Changes in Arctic mercury levels: emissions sources, pathways and budgets		Coordinating lead author: Ashu Dastoor Contributors: Simon Wilson (global emissions – from GMA work) The chapter seeks to address the primary questions: Where does mercury in the Arctic environment come
3.1. Introduction	(Ashu)	
3.2. Emissions and releases	3.2 = global emissions/releases of Hg to air, water and soils - including sections on speciation, spatial distribution and an uncertainties	

<table>
<tr><td></td><td>section for the use of emissions in models – Simon Wilson and Frits Steenhuisen)</td><td rowspan="3">from, and how does it get there?

1. What (and how much are the sources of mercury emissions to air contributing to mercury in Arctic environments?
2. How much mercury does atmospheric circulation transport to Arctic environments?
3. How much mercury do terrestrial systems transport to downstream environments in the Arctic?
4. How much mercury does ocean circulation transport to the Arctic Ocean?
5. How much mercury do ice sheet, icecaps and glaciers contribute to Arctic environments?
6. What are the relative contributions of natural, contemporary anthropogenic and remissions of Hg to Arctic environments?
7. What is the relative contribution of local anthropogenic vs long-range anthropogenic sources of mercury to Arctic environments?
8. How much mercury is circulating in Arctic environments?</td></tr>
<tr><td>3.3. Models</td><td>3.3 = 3-d atmospheric, 3-d coupled air-soil-ocean models, and 0-d mass balance models; general introduction of models here but Hg processes details in sections below by ??</td></tr>
<tr><td>3.4. Pathways and spatial distributions
3.4.1. Atmosphere
a. Processes
3.4.1.a.1. Atmospheric circulation
3.4.1.a.2. Atmospheric chemistry
3.4.1.a.3. Removal by precipitation
3.4.1.a.4. Bidirectional air-ground exchange
b. Spatial distribution
c. 3.4.1.3 Source apportionment
d. 3.4.1.4 Changes related with global emissions and pathways related with meteorology
3.4.2. Terrestrial (the Arctic watersheds)
a. Processes
b. Spatial distribution
c. Source apportionment by Arctic watersheds from measurements and models
d. Changes related with global emissions and pathways
3.4.3. Marine</td><td>3.4.1.a.1 = explain role of meteorology, major air transport pathways and modeling with respect to transport and physical processes (Ashu Dastoor)

3.4.1.a.2 = lab, field, computational and modeling perspective (Theodore Dibble and team)

3.4.1.a.3 = explain Hg partitioning and removal in liquid and solid precipitation (Huiting Mao)

3.4.a.1.4 = update from GMA 2018 (by ??)

3.4.1.b = model evaluation & air and deposition distributions – yearly and by season Hg accumulation (so that ensemble potential snowmelt Hg can be calculated (Oleg Travnikov;</td></tr>
</table>

a. Process b. Spatial distribution c. Source apportionment d. Changes related with global emissions and pathways e. Coastal erosion	Andrei Ryjkov) 3.4.1.c = by Arctic watersheds and Arctic Ocean (Oleg Travnikov; Andrei Ryjkov) 3.4.1.d = Modellers could do an additional model run for 2010 and a run keeping meteorology constant for 2010 and 2015; these runs can help explain the impact of changes in anthropogenic emissions and meteorology 3.4.2 = (Peter Outridge and others) 3.4.2.a = big picture – explain watersheds, major riverine transport, removal, seasonality, export pathways 3.4.2.b = of major riverine exports – also provide the Hg deposition from models for the Arctic watersheds which can be delivered during snowmelt for comparison 3.4.3 = (Peter Outridge; Lars-Eric Heimbuerger) 3.4.3.b = also provide the Hg	

	deposition to the Arctic Ocean from models for comparison 3.4.3.e = (Peter Outridge) Structure of 3.4 might be a bit complicated – simplify?	
3.5. Mass balance in the Arctic and Arctic Ocean	3.5 = come up with most recent diagram of total Hg in the Arctic Ocean with uncertainty ranges – Peter Outridge, Ashu Dastoor and others	
3.6. Key Conclusions		
4. Changes in Arctic mercury levels: Processes affecting mercury fate and biological uptake	Explaining observed trends in terms of processes; focus on processes In the Arctic leading to mercury uptake by biota, especially the production and loss of methylmercury [NB chapter 5 not 4]	Coordinating lead authors: Michelle Nerentorp, Feiyue Wang The chapter seeks to address the primary questions: 1. How does Hg move from the abiotic environment to biota? - Speciation and bioavailability - Methylation/demethylation (refer to question 2 for details) - Uptake pathways (including habitat-specific feeding or cross-ecosystem subsidies) - Seasonality 2. How, when and where is Hg methylated in the Arctic? - Lakes/wetlands - Estuaries
4.1. Introduction		
4.2. Mercury Transformation Processes 4.2.1. Redox between Hg(0) and Hg(II) 4.2.2. Methylation and demethylation **4.2.3.** Relationship with organic matter		
4.3. Biological uptake processes 4.3.1. Speciation and bioavailability 4.3.2. Uptake pathways (including habitat-		

specific feeding or cross-ecosystem subsidies) 4.3.3. Bioaccumulation and biomagnification at the base of the food chain **4.3.4.** Bioaccumulation and biomagnification at higher trophic levels (including role of food chain length, transfer and physiological/life history influences on bioaccumulation in top predators)		- Seawater - Snow/sea ice 3. What are the processes affecting mercury uptake at the base of the food chain? 4. What are the processes affecting mercury uptake at higher trophic levels (including role of food chain length, transfer and physiological/life history influences on bioaccumulation in top predators) 5. What are the effects of the sea ice environment on Hg uptake? 6. What are the effects of organic carbon on Hg uptake? 7. "Summary": What characteristics in the Arctic promote Hg bioaccumulation? Textbox 4.1: Relationship between Hg(0), inorganic Hg(II), and methylmercury
4.4. Terrestrial 4.4.1. Tundra ecosystem **4.4.2.** Lake ecosystem		
4.5. Estuarine 4.5.1. Mixing, transport and transformation in the estuaries **4.5.2.** Case studies: the Mackenzie, Nelson, etc		
4.6. Marine 4.6.1. Sub-surface enrichment of methylmercury 4.6.2. Shelf processes **4.6.3.** Sea ice processes		
4.7. Terrestrial-Marine Coupling 4.7.1. Rivers 4.7.2. Glacier melts **4.7.3.** Permafrost thawing		
4.8. Mass balance of methylmercury in the Arctic and Arctic Ocean	**c**ome up with most recent estimates/diagrams – can we do a contemporary box and a pre-industrial box?	

4.9. Key Conclusions		
5. How does climate change influence mercury in the Arctic environment and in biota?		The chapter seeks to address the primary question: How does climate change influence mercury in the Arctic environment and in biota? Coordinating lead authors: Melissa McKinney (biota), John Chételat (abiotic trends) Contributors: Marc Amyot, Ashu Dastoor, Heleen A. de Wit, Thomas A. Douglas, Kyle Elliott, Igor Eulaers, Marlene Evans, Jerome Fort, Mary Gamberg, Lars-Eric Heimburger, Kimmo Kahilainen, Igor Lehnherr, Robert Letcher, Lisa Loseto, Adam Morris, Daniel Obrist, Amanda E. Poste, Heli Routti, Kyra St Pierre, Alexandra Steffen, Roman Teisserenc, Hans Fredrik Veiteberg Braaten, Feiyue Wang, David Yurkowski
5.1. Introduction		
5.2. Physical change in the Arctic 5.2.1. Atmosphere 5.2.2. Marine environments 5.2.3. Terrestrial environments 5.2.4. Freshwater environments		
5.3. Ecological change in the Arctic 5.3.1. Marine ecosystems 5.3.2. Terrestrial ecosystems 5.3.3. Freshwater ecosystems		
5.4. Effects on Hg transport processes 5.4.1. Atmospheric deposition 5.4.2. Catchment transport 5.4.3. River transport 5.4.4. Ocean currents		
5.5. Effects on Hg biogeochemical processes 5.5.1. Inorganic mercury redox processes 5.5.2. Methylmercury production and decomposition		
5.6. Effects on Hg bioaccumulation 5.6.1. Uptake of methylmercury in food webs 5.6.2. Shifts in diet and food web composition 5.6.3. Growth and bioenergetics influences		

5.7. Conclusions and recommendations		
6. What are the levels and biological effects of mercury in key Arctic species?		The chapter seeks to address the primary question: What are the levels and biological effects of mercury in key Arctic species? Coordinating lead authors: Rune Dietz, Rob Letcher Co-authors: Josh Ackermann, Niladri Basu, Tomasz M. Ciesielski, Jean-Pierre Desforges, Collin A. Eagles-Smith, Igor Eulaers, Jerome Fort, C. Alex Hartman, Mark P. Herzog, Bjørn Munro Jenssen, Lisa Loseto, Sarah H. Peterson, Heli Routti, Christian Sonne and Simon Wilson Data and sample contributors: Aqqalu R. Asvid, Phil Thomas, Maria Dam, Ingeborg G. Hallanger, Lisa B. Helgason, M. Houde, Kathrin Hoydal, Audrey Jæger, Lisa Loseto, Cecilie Miljeteig, Anders Mosbech, Derek C.G. Muir, Anders Mosbech, Sanna Túni Nielsen, Sara H. Peterson, Frank Rigét, Anna Roos, Halvor Saunes, Ursula Siebert, Gary Stenson, Jens Søndergaard, Gabriel Treu and Gisli Vikingson • The 2018 AMAP Assessment of biological effects of POPs and mercury reports on results from recent wildlife studies to measure mercury levels in different tissues and organs to assess any related health effects. The proposed Mercury 2019-2021 Assessment will refer to
6.1. Introduction		
6.2. Combined effects 6.2.1. What is known about the combined effects of contaminants, and other types of environmental stressors? 6.2.2. What role does mercury speciation play in uptake and toxic effects?		
6.3. Is there any evidence that tissue mercury concentrations at present are harmful to Arctic biota (exposure in relation to effect thresholds)? 6.3.1. Methodology 6.3.2. Marine mammals a. Cerebral exposure and potential neurological effects of mercury on Arctic marine mammals b. Liver related effects of mercury on Arctic marine mammals c. Comparison of marine mammal hair concentrations with effect guidelines. 6.3.3. Terrestrial mammals a. Cerebral exposure and potential neurological effects of mercury on	6.3.1 = Here the methods will be described also the geographical information and trends will be linked to transport, precipitation and the food chain system in different regions resulting in potential regional hot spots. 6.3.2 b = The AMAP 2018 Effect Assessment results will be expanded with data additional recently collected marine mammal species i.e. toothed whales from toothed whale work DFO, GINR, NTNU, MFRI and TIHO and CHANGE (Aarhus University, AU) (if supported by DANCEA). It will also be explored to what extent information on kidneys, muscle and blood is available and	

Arctic terrestrial mammals b. Liver related effects of mercury on Arctic terrestrial mammals c. Comparison of terrestrial mammal hair concentrations with effect guidelines of Hg and other essential elements. 6.3.4. Marine birds 6.3.5. Terrestrial birds 6.3.6. Marine fish 6.3.7. Freshwater fish 6.3.8. Invertebrates	what these data can contribute to the overall picture of exposure and effects 6.3.2 b = Here unpublished data are available from AU covering Greenland, Canada and Svalbard and NPI have additional data from the Barents Sea and the Svalbard-Chukotka areas where new papers will be submitted/be available in 2019. 6.3.3.a = maybe no data at all due to the low exposure of terrestrial mammals 6.3.3.b = additional data in relation to AMAP 2018 Assessment is likely to be available from Gamberg et al. on caribou and muskoxen 6.3.4 = The AMAP 2018 Assessment data will be expanded with info for additional species from ArcTox Project (adding feather information to blood, liver and egg data) 6.3.5 = Here additional feather information can be added to blood, liver and egg data from the AMAP	that work but will not repeat most for the 2018 Effect Assessment, but the former chapter 4. “Challenges and new approaches to assess biological effects” is where we have additional information and additional matrices (hair and feathers) we want to include. Here we will fill out some of the significant gaps in regional and species coverage that were identified in the 2018 AMAP effect assessment. In addition, the 201-19 published literature and additional new studies is included. • The 2011 mercury assessment calls for work to explore the effects of multiple stressors including chemical, environmental and nutritional factors on the toxicity of mercury in Arctic biota. The 2018 AMAP assessment of biological effects of POPs and mercury identifies methods that could be extended in their application to provide additional information on mercury toxicity in the 2021 AAR4 Mercury Assessment.

	2018 Assessment results. 6.3.6 = No geographical risk assessment was conducted for lower trophic levels in the AMAP 2018 Effect Assessment, so new data, which have appeared since the 2011 Hg Assessment from marine fish will be explored 6.3.7 = New data which have appeared since the 2011 Hg Assessment from freshwater fish will be explored. 3.3.8 - Limited information has previously been extracted on Arctic invertebrates and will be explored in the 2019-2021 Hg assessment. MISSING – reference to the discussion that spatial trends would be covered in this chapter by focussing on individual (key) species; polar bear, ringed seal, caribou, polar cod, arctic char, etc.	
6.4. Conclusions and recommendations		
7. What is the impact of mercury contamination on		Coordinating lead authors: Pal Weihe, Niladri Basu

human health in the Arctic?		Contributing authors: Eva Kruemmel, Khaled Abass
7.1. Introduction	- Emphasize mercury health impacts, and recent key health papers (incl. UN Global Mercury Assessment) - Multiple stressors, burden of disease (e.g., Lancet Commission on Pollution and Health) -Minamata Convention context - Cross-reference with other chapters	
7.2. Global influences on mercury exposure in the North	- Integrate with other chapters which detail sources and processes by which mercury gets to the Arctic ecosystem - Societal shifts (e.g., dietary transition, economic transitions, trade) - Some mention of future projections - Perhaps brief Minamata Convention remark here as well	
7.3. Dietary influences on mercury exposure in the North 7.3.1. Exposure to mercury-contaminated traditional foods 7.3.2. Nutrition transition 7.3.3. Modeling exposures	**7.3.1** - Review dietary survey / FFQ results (types, portion size, frequency) - Review levels of Hg in relevant food items (perhaps also nutrients) - For above 2 items, develop a list of top 3-5 items across different sites as a resource - Draw comparisons to	

	southern/other populations - Brief mention of bioavailability and food preparation angles - Brief mention of nutrients - Provide a figure or table comparing Inuit with other populations **7.3.2** - Importance of this dimension (societal, cultural, nutritional, etc.) -Examples, trends **7.3.3** Some examples may include: - Older Canuel et al. paper in Environ Health Perspect as background (why “default” models do not work) -Khaled’s work in Norway and elsewhere - Wania’s work - Rune Dietz hunting surveys - Some mention of genetic polymorphisms - Ideally we provide evidence and recommendations of an Inuit-specific model - Summary figure or table possibly; maybe compare model parameters between Inuit and Caucasian population to highlight key differences in exposure and physiology	
7.4. How mercury biomarker levels compare to	- Start with brief review of mercury	

guidelines 7.4.1. Pregnant women 7.4.2. Adults 7.4.3. Children	biomarkers. - From UN Global Mercury Assessment: make comparisons here with other notable populations including typical background population as well as other high exposed populations. - Some mention of genetic polymorphisms (here or elsewhere) - Could possibly mention here the effectiveness evaluation and costs associated with human biomonitoring studies (reference WHO Hg Biomonitoring Report)	
7.5. What are the health effects of mercury in the North? 7.5.1. General mechanisms of toxicity 7.5.2. Neurological 7.5.3. Cardiovascular 7.5.4. Other 7.5.5. Mercury and other health issues	7.5.5. Other health issues: co-stressors e.g., zoonotics, TB, suicide, etc.; burden of disease	
7.6. What are risk communication and risk management strategies?	Written based on Human Health report	
7.7. Conclusions and recommendations	Add Effectiveness Evaluation comments here.	
8. What are the likely changes in mercury concentration in the Arctic atmosphere and		The chapter seeks to address the primary question:

ocean under future emissions scenarios?		What are the likely changes in mercury concentration in the Arctic atmosphere and ocean under future emissions scenarios? Coordinating lead authors: Noelle Selin, Amina Schartup Contributing authors: Kaitlin Bowman, Marilena Muntean, Anne Soerensen, Frits Steenhuisen, Oleg Travnikov Key references: Angot, H., Dastoor, A., De Simone, F., Gårdfeldt, K., Gencarelli, C. N., Hedgecock, I. M., … Dommergue, A. (2016). Chemical cycling and deposition of atmospheric mercury in polar regions: Review of recent measurements and comparison with models. Atmospheric Chemistry and Physics, 16(16), 10735–10763. https://doi.org/10.5194/acp-16-10735-2016 Chen, L., Zhang, W., Zhang, Y., Tong, Y., Liu, M., Wang, H., … Wang, X. (2018). Historical and future trends in global source-receptor relationships of mercury. Science of the Total Environment, 610–611, 24–31. https://doi.org/10.1016/j.scitotenv.2017.07.182 Corbitt, E. S., Jacob, D. J., Holmes, C. D., Streets, D. G., & Sunderland, E. M. (2011). Global source-receptor relationships for mercury deposition under present-day and 2050 emissions scenarios.
8.1. Introduction	Introduction to the policy question: What are the likely changes in mercury concentration in the Arctic atmosphere and ocean under future emissions scenarios? Future emissions scenarios make assumptions about future economic activities, energy use, and associated emissions of pollutants, which affect climate change, other air pollutants, and mercury. The introductory section describes the different timescales of changes, including the short, medium, and long term, in both the atmosphere and the ocean. For the atmosphere, in the short term, concentration changes and mercury deposition will follow changes in emissions in different regions and their relative contributions and can be calculated based on source-receptor information. In the medium term (years to decades), enhancements in "legacy emissions" from current and future emissions will affect trajectories. On timescales of decades and longer, changes as a result of climate changes will influence the Arctic. For the ocean, the timescales of ocean circulation may result in a lag relative to	

	changes in the atmosphere, but many of these changes will overlap.	Environmental Science and Technology, 45(24), 10477–10484. https://doi.org/10.1021/es202496y Dastoor, A. P. and Durnford D. A. (2014), Arctic Ocean: is it a sink of source of atmospheric mercury?. Environmental Science and Technology, 48 (3),1707-1717. https://doi.org/10.1021/es404473e Dastoor, A., Ryzhkov, A., Durnford, D., Lehnherr, I., Steffen, A., & Morrison, H. (2015). Atmospheric mercury in the Canadian Arctic. Part II: Insight from modeling. Science of the Total Environment, 509–510, 16–27. https://doi.org/10.1016/j.scitotenv.2014.10.112 Fisher, J.A., Jacob, D. J., Soerensen ,A. L., Amos, H. M.,Steffen A., and Sunderland, E. M. (2012), Riverine source of Arctic Ocean mercury inferred from atmospheric observations. Nature Geoscience, 5, https://doi:10.1038/NGEO1478 Fisher J. A., Jacob, D. J., Soerensen ,A. L., Amos, H. M., Corbitt, E. S., Streets, D. G., WangQ., Yantosca, R. M., and Sunderland, E. M. (2013). Factors driving mercury variability in the Arctic atmosphere and ocean over the past 30 years. Global Biogeochemical Cycles, 27, https://doi:10.1002/2013GB004689. Giang, A., Stokes, L. C., Streets, D. G., Corbitt, E. S., & Selin, N. E. (2015). Impacts of the Minamata Convention on mercury emissions and global deposition from coal-fired power generation in Asia. Environmental Science and Technology, 49(9), 5326–5335. https://doi.org/10.1021/acs.est.5b00074
8.2. Emissions scenarios: comparison of existing literature estimates	This section will review and compare existing literature that develops emission scenarios relevant to projecting Arctic atmosphere and ocean mercury concentrations in the future. First, it will briefly review (with reference to other chapters) different estimates and current trajectories of emissions globally, and current understanding of emissions in regions that affect the Arctic. It will then review and compare previous efforts to project emissions forward in time. It will address the question of whether there are substantial differences in assumptions among different emissions scenarios of relevance to the Arctic. Table and graph: This section will present a table including available literature projections of future emissions, globally and for key regions affecting the Arctic. Entries included in the table will cover assumptions in the base year, time scale of emissions, policy scenarios addressed (including mercury and non-mercury scenarios such as climate scenarios), underlying	

	activity projections (e.g. energy and coal use), technology application assumptions, and mercury speciation. A graph will illustrate the global-scale trajectories of emissions. Changes in mercury concentrations in the atmosphere: This section reviews modeling analyses that project changes in mercury concentrations in the Arctic atmosphere based on the emissions scenarios outlined above. It will review current modeling capability to identify changes in mercury concentrations in the Arctic atmosphere, and the limitations of existing models in doing so based on their ability to simulate present-day concentrations. For the short-term, it will use results from previous modeling on source-receptor matrices to estimate the implications of emissions changes within and outside Arctic on Arctic atmospheric concentration. For the medium and longer term, it will review methodologies to account for legacy emissions and climate change in current available atmospheric	Muntean, M., Janssens-Maenhout, G., Song, S., Giang, A., Selin, N. E., Zhong, H., Zhao, Y., Olivier, J. G. J., Guizzardi, D., Crippa, M., Schaaf, E., Dentener, F. (2018). Evaluating EDGARv4.tox2 speciated mercury emissions ex-post scenarios and their impacts on modelled global and regional wet deposition patterns. Atmospheric Environment, 184, 56-68, https://doi.org/10.1016/j.atmosenv.2018.04.017. Pacyna, J. M., Travnikov, O., Simone, F. De, Hedgecock, I. M., Sundseth, K., Pacyna, E. G., … Kindbom, K. (2016). Current and future levels of mercury atmospheric pollution on a global scale. Atmospheric Chemistry and Physics, 16(19), 12495–12511. https://doi.org/10.5194/acp-16-12495-2016 Rafaj, P., Bertok, I., Cofala, J., & Schöpp, W. (2013). Scenarios of global mercury emissions from anthropogenic sources. Atmospheric Environment, 79(2013), 472–479. https://doi.org/10.1016/j.atmosenv.2013.06.042 Rafaj, P., Cofala, J., Kuenen, J., Wyrwa, A., & Zyśk, J. (2014). Benefits of European climate policies for mercury air pollution. Atmosphere, 5(1), 45–59. https://doi.org/10.3390/atmos5010045 Semeniuk, K., and Dastoor A. (2017), Development of a global ocean mercury model with a methylation cycle: Outstanding issues, Global Biogeochemical Cycles, 31, 400–433, doi:10.1002/2016GB005452. Soerensen, A. L., D. J. Jacob, A. T. Schartup, J. A. Fisher, I. Lehnherr, V. L. St. Louis, L.-E.

	models. A few approaches in the literature can address the magnitude of these effects, which will be compared to the short-term estimates using source-receptor information.	Heimbürger, J. E. Sonke, D. P. Krabbenhoft, and E. M. Sunderland (2016), A mass budget for mercury and methylmercury in the Arctic Ocean, Global Biogeochem. Cycles, 30, doi:10.1002/2015GB005280. Steenhuisen, F., & Wilson, S. J. (2019). Development and application of an updated geospatial distribution model for gridding 2015 global mercury emissions. Atmospheric Environment, 211(December 2018), 138–150. https://doi.org/10.1016/j.atmosenv.2019.05.003 Streets, D. G., Zhang, Q., & Wu, Y. (2009). Projections of Global Mercury Emissions in 2050. Environmental Science & Technology, 43(8), 2983–2988. https://doi.org/10.1021/es802474j Sundseth, K., Pacyna, J. M., Pacyna, E. G., Munthe, J., Belhaj, M., & Astrom, S. (2010). Economic benefits from decreased mercury emissions: Projections for 2020. Journal of Cleaner Production, 18(4), 386–394. https://doi.org/10.1016/j.jclepro.2009.10.017 Outridge, P. M., Macdonald, R. W., Wang,F., Stern, G. A., and Dastoor, A. P. (2008) A mass balance inventory of mercury in the Arctic Ocean. Environmental Chemistry, 5, 89–111. https://doi:10.1071/EN08002 Zhang, Y., D. J. Jacob, S. Dutkiewicz, H. M. Amos, M. S. Long, and E. M. Sunderland (2015), Biogeochemical drivers of the fate of riverine mercury discharged to the global and Arctic oceans, Global Biogeochem. Cycles, 29, doi:10.1002/2015GB005124. Zhang, H., Holmes, C. D., & Wu, S. (2016). Impacts
8.3. Changes in mercury concentrations in the ocean	This section reviews existing models that simulate changes in mercury concentrations and speciation in the Arctic ocean, focusing on their strengths and limitations. Most of the existing ocean models are retrospective and quantify the importance of legacy mercury, reservoir sizes, and the relative importance of different mercury sources. Projection efforts to date have been focused on the impact of changing riverine inputs or atmospheric deposition to the Arctic ocean as calculated by models under different scenarios discussed in the previous sections. But to assess the relative influence of emissions, releases, and climate change to Arctic ocean mercury concentrations in medium- and long-term, models that also consider changes in ocean circulation, sea ice formation, biogeochemistry and speciation of mercury are needed. Such models are under development and will be discussed in this chapter.	

8.4. Summary and conclusions	The summary section draws policy-relevant conclusions from the discussion about different trajectories of future mercury concentrations in the Arctic ocean and atmosphere.	of changes in climate, land use and land cover on atmospheric mercury. Atmospheric Environment, 141, 230–244. https://doi.org/10.1016/j.atmosenv.2016.06.056
9. Indigenous Perspectives (Proposed)		Coordinating lead authors: Eva Kruemmel, Magali Houde The chapter seeks to address the primary questions: - What is the history of the contributions of Indigenous regions and communities to (mercury) work in the Arctic? - Definition of Indigenous Knowledge vs local knowledge, community-based monitoring - What are the known contributions of Indigenous Peoples to mercury contamination research? - What are examples of how/where Indigenous Knowledge is being utilized and how does it contribute to the overall knowledge and presentation of results on mercury/impacts of mercury in the Arctic? - What are recent efforts to include Indigenous Knowledge and observations of ecological impacts of climate changes in wildlife mercury monitoring? - What are challenges encountered in integrating different ways of knowing e.g., Western science (numerically recorded) and Indigenous Knowledge (mostly orally communicated)? - What are perspectives of Indigenous Peoples on

		past and future Arctic contaminants research, how Indigenous Knowledge should be utilized, and how a partnership/co-production of knowledge approach should be conducted?
10. Conclusions and Key Findings		Coordinating lead authors: EG leads and all coordinating lead authors

II. Assessment Timeline

The provisional timeline for the work is as follows:

December 2018: AMAP MEG meeting Ottawa – provisional sign-up for contributions to the assessment

January-March 2019: Coordinating leads … collect/compile/organize materials; communicate with and organize potential contributors – with coordinating leads taking the initiative to contact contributors and with the Secretariat facilitating (e.g. arranging conference calls).

Engage scientific assistant?

Review/confirm drafting-groups/contributors for gaps/resource needs

May 2019: First order 'zero draft' (structure of section/pasted texts and/or notes on planned contributions)

Coordinating leads teleconference calls, including call with human health experts to discuss human health sections

June-September 2019: Upgrade zero draft (internal coordination between section leads for overlaps, etc.)

Coordinating leads teleconference call(s)

October 2019:

Coordinating leads teleconference call(s)

21-23 October: AMAP MEG meeting

Review of the structure of the complete report

Preliminary overview of trends

Compilation of first draft

November 2019-February 2020:

Update time trend data from chapter 2 and make available to coordinating sections.

Revision of first draft (fill gaps, harmonize)

Coordinating leads teleconference call(s)

March 2020: Send for National Data Review

April-May 2020:

Revise and preparation of peer review draft

May 2020:

Coordinating authors drafting meeting to address peer review comments

June 2020: Send for peer review

Second half of 2020: Engage science writer (summer); Address peer review comments (autumn); Production of technical report; Preparation of SPM; delivery to AMAP WG

2021: Assessment delivery

III. Policy-relevant questions guiding the work of the AMAP mercury expert group

Outline SPM	Notes/subsidiary questions addressed	Outline Scientific Assessment	Coordinating leads / Contributors* *(tracking by co-leads/Secretariat)*
Overall Mercury Assessment			*Coordinating leads:* John Chetelat, Rune Dietz
Part A: Framing the Assessment			
Question 1. How can the results of the AMAP assessment contribute to work under the Minamata Convention?	- How can the assessment results be used with respect to coordination of regional monitoring activities, contributing to Minamata effectiveness evaluations, engagement with future possible GMA work, etc.? - Will ongoing considerations and future developments to the Minamata Convention imply needs to redirect AMAP work on mercury in the 10-year period after 2021, including possible implications for air, biota and human monitoring needs to support Minamata effectiveness evaluation?	**Chapter 1. Introduction** • Aims of the new assessment – <u>updating</u> previous AMAP assessments • The relationship between AMAP work and international initiatives (Minamata Convention) • Mercury issues of concern to PPs • Structure of the assessment and readers guide	*Coordinating lead(s):* Co-leads *Minamata Contact group:* Alexandra Steffen, Corinne Stocco, Eija-Riitta Venäläinen, Noelle Selin, Eva Kruemmel, Simon Wilson *Tracked by:* SW
Question 2. What are Arctic indigenous people's perspectives and how are indigenous peoples contributing to the study of mercury contamination issues?	- What is the history of the contributions of Indigenous regions and communities to (mercury) work in the Arctic? - What is Indigenous Knowledge vs local knowledge, and community-based		*Coordinating lead(s):* Eva Kruemmel, Magali Houde *Contributors:* Jean Allen, Marc Amyot, Niladri Basu, Amy Caughey, Marlene Evans, Mary Gamberg, Sarah Kalhok, Gary

	monitoring? - What are the known contributions of Indigenous Peoples to mercury contamination research? - What are examples of how/where Indigenous Knowledge is being utilized and how does it contribute to the overall knowledge and presentation of results on mercury/impacts of mercury in the Arctic? - What are recent efforts to include Indigenous Knowledge and observations of ecological impacts of climate changes in wildlife mercury monitoring? - What are challenges encountered in integrating different ways of knowing e.g., Western science (numerically recorded) and Indigenous Knowledge (mostly orally communicated)? - What are perspectives of Indigenous Peoples on past and future Arctic contaminants research, how Indigenous Knowledge should be utilized, and how a partnership/co-production of knowledge approach should be conducted? - This section would highlight indigenous participation and their unique contributions to the study of mercury in the Arctic. Objectives would need to be clearly defined, with broad input		Stern, Philippe Thomas, Enooyaq Sudlovenick, Rune Dietz, Eija-Riitta Venäläinen, Hannu Kiviranta, Arja Rautio, Enooyaq Sudlovenick *Tracked by:* JC

	and discussion in the initial stages of developing the chapter. The chapter could focus on recent efforts to include indigenous knowledge in wildlife contaminants monitoring and observations of ecological impacts of climate change, with a focus on mercury, and to address mercury contamination issues of local concern for some indigenous communities. For example, within Canada, there are several Arctic community-based projects with indigenous participation in the study of wildlife mercury contamination; in Greenland in particular, local hunters are deeply involved in the wildlife sampling to study mercury (as well as other contaminants) and effects on wildlife. If the emphasis is on documenting efforts to conduct this type of work, then there is sufficient material to meet this objective by 2021.		
Part B: Changing levels of mercury in the Arctic			
Question 3. How are mercury levels changing in air, biota, and humans?	- Are mercury levels in Arctic media increasing or decreasing, and why? - Evaluation of temporal trends would include updating statistical analyses of mercury time-series in air and biota to include additional years of data, and reviewing new literature concerning trends in environmental media and	**Chapter 2.** Temporal trends in air, biota and humans *(a summary of results /analysis of available time series)*	*Coordinating lead(s):* Frank Riget, Adam Morris, Philippe Thomas *Contributors:* Bryan Adlard, Birgit M. Braune, Marlene Evans, Mary Gamberg, Robert Letcher, Melissa McKinney, Derek Muir, Alexandra Steffen, Gary Stern, Geoff Stupple , Rune Dietz, Christian Sonne,

	environmental archives such as sediment and ice cores, and related conclusions on reasons for observed trends. - Are the temporal trends developing differently in different geographical areas of the Arctic?		Maria Dam, Katriina Kyllönen, Jussi Vuorenmaa, Tommi Malinen, Kimmo Kahilainen, Jerome Fort, Torunn Berg, Heli Routti, Michelle Nerentorp, Simon Wilson *Tracked by:* JC, SW, RD
Question 4. Where does mercury in the Arctic environment come from, and how does it get there?	- What (and how much are the sources of mercury emissions to air contributing to mercury in Arctic environments? - How much mercury does atmospheric circulation transport to Arctic environments? - How much mercury do terrestrial systems transport to downstream environments in the Arctic? - How much mercury does ocean circulation transport to the Arctic Ocean? - How much mercury do ice sheets, icecaps and glaciers contribute to Arctic environments? - What are the relative contributions of natural, contemporary anthropogenic and remissions of Hg to Arctic environments? - What is the relative contribution of local anthropogenic vs long-range	**Chapter 3:** Changes in Arctic mercury levels - emissions sources *(explaining observed trends in terms of emissions)*	*Coordinating lead(s):* Ashu Dastoor *Contributors:*, Peter Outridge, Henrik Skov, Katriina Kyllönen, Jussi Vuorenmaa, Aurélien Dommergue , Lars-Eric Heimbuerger, Jeroen Sonke , Roman Teisserenc , Michelle Nerentorp, Oleg Travnikov, Noelle Selin , Daniel Obrist, Marilena Muntean *Tracked by:* JC, SW

	anthropogenic sources of mercury to Arctic environments? - How much mercury is circulating in Arctic environments? - Arctic-relevant information will be extracted from ongoing (joint AMAP/UN-Environment) work to prepare the 2018 GMA updates information on (global) emissions of mercury to air and releases to water from anthropogenic sources (in 2015). - Where available, new information on anthropogenic sources located in or close to the Arctic will be reviewed and highlighted in the AMAP mercury update assessment, together with new work aimed at distinguishing natural from anthropogenic sources. - Long-range transport of mercury to the Arctic from other regions of the world; atmosphere, ocean, and river transport will be assessed. The 2018 GMA work provides updated information on atmospheric transport and regional source-receptor relationships, and discusses new insights into the global mercury budget/cycle (which affects Arctic mercury through ocean, river and air pathways) as well as an updated mercury budget model for the Arctic Ocean.		
Question 5. What is the fate of mercury entering the Arctic	- How does Hg move from the abiotic	**Chapter 4:** Changes in Arctic mercury levels – processes affecting mercury	*Coordinating lead(s):* Michelle

environment?	environment to biota? - How, when and where is Hg methylated in the Arctic? - What are the processes affecting mercury uptake at the base of the food chain? - What are the processes affecting mercury uptake at higher trophic levels (including role of food chain length, transfer and physiological/life history influences on bioaccumulation in top predators) - What are the effects of the sea ice environment on Hg uptake? - What are the effects of organic carbon on Hg uptake? - What characteristics in the Arctic promote Hg bioaccumulation? - Do we have new knowledge that extends our understanding of atmospheric mercury deposition in the Arctic, including atmospheric mercury depletion events? Do we know more about how much of the mercury deposited in the Arctic is readily available to biota? - What new knowledge do we have regarding the fate of mercury entering marine systems? Can we ascertain how methylmercury enters Arctic food webs and do we have a better understanding the Arctic marine	transport and fate *(explaining observed trends in terms of processes)*	Nerentorp, Feiyue Wang *Contributors:* Marc Amyot, John Chételat, Ashu Dastoor, Kathleen Munson, Katriina Kyllönen, Jussi Vuorenmaa, Tommi Malinen, Kimmo Kahilainen, Liisa Ukonmaanaho, Aurélien Dommergue , Lars-Eric Heimbuerger, Jeroen Sonke , Roman Teisserenc , Oleg Travnikov, Daniel Obrist *Tracked by:* JC, SW

	methylmercury cycle? - The 2018 GMA work provides updated information and new insights into processes that govern the global mercury budget/cycle (which affects Arctic mercury through ocean, river and air pathways). This information would form a framework for addressing some of these questions.		
Question 6. How does climate change influence Arctic mercury?	- How does climate change influence Arctic mercury? - Do we have new information to better develop a more detailed understanding of the impact of climate change on mercury including methylation processes, and changes in food webs with associated changes in, e.g., contaminant biomagnification? - A lot of new data and information about climate impacts on a wide range of processes (geochemical cycling, methylation in the Arctic ocean and freshwater ponds, biological-uptake, permafrost thaw potentially releasing huge amounts of natural Hg, climate influences in particularly on biotic Hg trends, etc.) exists that would be reviewed. - Hg isotopes have been increasingly employed in various studies and seem to offer a promising new source of information (for process studies in particular) that would be worth	**Chapter 5:** Changes in Arctic mercury levels - climate change influences (on biotic and abiotic systems) *(explaining observed trends in terms of climate change impacts)*	*Coordinating lead(s):* Melissa McKinney (biota), John Chételat (abiotic trends) *Contributors:* Marc Amyot, Birgit M. Braune, Ashu Dastoor, Rune Dietz, Marlene Evans, Mary Gamberg, Robert Letcher, Adam D. Morris, Derek Muir, Kathleen Munson, Frank Rigét, Gary Stern, Philippe Thomas, Feiyue Wang, Jerome Fort, Heli Routti, Michelle Nerentorp, Daniel Obrist *Tracked by:* RD - biotic, JC - abiotic)

	reviewing.		
Part C: Effects of mercury and levels in key species around the Arctic			
Question 7. What are the levels and biological effects of mercury in key Arctic species?	- Are there geographic hotspots of mercury in key biota? - What are the toxicological effects of mercury in Arctic biota? - Is there any evidence that tissue mercury concentrations at present are harmful to Arctic biota? - The 2018 AMAP assessment of biological effects of POPs and mercury details results from recent wildlife studies to measure mercury levels in different tissues and organs to assess mercury induced health effects. The proposed mercury update assessment will refer to that work and not repeat it. However, it may address and fill some significant gaps in (regional and species) coverage that were identified and also update the 2018 products to incorporate results from additional new studies (additional species/ regions) that are currently underway. - The 2011 mercury assessment calls for work to explore the effects of multiple stressors (both chemical and environmental) and nutritional factors on the toxicity of mercury in biota. The	**Chapter 6.** Levels of mercury and effects in key species around the Arctic *(update of biological effects assessment and implications for ecosystem health - structured according to sub-sections on key species incorporating spatial trends)*	*Coordinating lead(s):* Rune Dietz, Robert Letcher *Contributors:* Marc Amyot, Niladri Basu, Birgit M. Braune, Adam D. Morris, Philippe Thomas, Feiyue Wang, Jean Pierre Desforges, Igor Eulaers, Christian Sonne, Maria Dam, Olivier Chastel, Jerome Fort, Heli Routti *Tracked by:* RD

	2018 AMAP assessment of biological effects of POPs and mercury identifies methods that could be extended in their application to provide additional information in response to this question in a 2021 update.		
Question 8. What is the impact of mercury contamination on human health in the Arctic?	- What are global influences on mercury exposure in the northern peoples? - What are the dietary influences on mercury exposure? - How do human tissue mercury levels compare to guidelines? - What are the health effects of mercury in humans? - What are risk communication and risk management strategies to address dietary Hg exposure in the Arctic? - What are the implications of the Minamata Convention effectiveness evaluation arrangements for human mercury exposure monitoring in Arctic communities? - The AMAP HHAG is compiling updated information on human exposure to mercury and associated health effects on Arctic population groups; other groups are also working in this area. The group should consider how this information could also be incorporated in an updater assessment of mercury in the Arctic to increase its accessibility	**Chapter 7.** Human exposure and health implications *(extract of human health assessment information focusing on exposure, reasons for changing exposure and implications for human health)*	*Coordinating lead(s):* Pal Weihe, Niladri Basu *Contributors:* Amy Caughey, Rune Dietz, Christian Sonne, Eva Kruemmel *Tracked by:* RD, SW

	to, e.g. work connected with the Minamata Convention. - Recent human exposure studies in Canada have typically used dietary survey information as their basis. An Ambio paper (Dietz et al 2018) presents a methodology to quantitatively estimate human mercury exposure from subsistence harvesting data in the North Water region – that could also be further explored using subsistence harvesting data from other Arctic areas if available. Such work is currently underway from other regions in Greenland.		
Part D: What does the future hold			
Question 9. What are the likely changes in mercury concentration in the Arctic atmosphere and ocean under future emissions scenarios?	- The 2011 AMAP assessment identified a need to gather more accurate information on worldwide economic and social variables, to improve future emissions scenarios also in the light of the Minamata Convention. The GMA 2018 does not include projections of future emissions, so this is an area of work that should be further developed in order to better understand possible implications for ecosystems.	**Chapter 8.** Changes in mercury concentration in the Arctic atmosphere and ocean under future emissions scenarios	*Coordinating lead(s):* Noelle Selin, Amina Schartup *Contributors:* Ashu Dastoor, Gary Stern?, Jesper Christensen, Oleg Travnikov, Marilena Muntean; E. Sunderland? *Tracked by:* JC, SW
		Chapter 9. Conclusion (including conclusions regarding):	*Coordinating lead(s):* Co-leads

		• How can the results of the AMAP assessment contribute to work under the Minamata Convention? • What are Arctic indigenous people's perspectives and how are indigenous peoples contributing to the study of mercury contamination issues?	

* list of contributors will be supplemented as additional contributors are identified; for details see notes in Ottawa workshop spreadsheet