# Future mercury levels in fish: model vs. observational predictions under different policy scenarios

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**Table S1.** Anthropogenic and natural mercury emission inventories applied in atmospheric Models.

| **References (models)**<br>⬇ **Scenarios** | **Anthropogenic** | **Natural** |
|---|---|---|
| (Corbitt et al. 2011) (Geos-Chem)<br>A1B, A2, B1, and B2 | (Pacyna et al. 2010) – base year emissions<br>(Streets et al. 2009) – future emission scenarios | GEOS-Chem parameterization – geogenic/ legacy emissions |
| (Lei et al. 2014) (CAM-Chem/Hg)<br>A1B, B1, and A1F1 | (Pacyna et al. 2006) – base year emissions<br>(Streets et al. 2009) – future emission scenarios | (Lei et al. 2013) – natural/legacy emissions<br>(Witt et al. 2008; Aiuppa et al. 2007) – volcanic emissions<br>(IPCC 2001) – forest & grassland burning<br>(Smith-Downey et al. 2010) – terrestrial Hg storage |
| (Vijayaraghavan et al. 2014) (CTM)<br>A2 and B2 | (EPRI 2006) – base year emissions<br>(Streets et al. 2009) – future emission scenarios | (Seigneur et al. 2004) – natural/legacy re-emissions |
| (Giang and Selin 2016) (Geos-Chem)<br>No policy and Minamata | (Pacyna et al. 2006) – base year emissions<br>(Streets et al. 2009) – future emissions | GEOS-Chem parameterization |
| (Pacyna et al. 2016) (GLEMOS and ECHMERIT)<br>CPS, NPS, and MFR | (AMAP/UNEP, 2013) – baseline emissions<br>(Streets et al. 2009; 2011; 2017) – historical and future scenario emissions<br>(Pacyna et al. 2006; 2010) – earlier global anthropogenic inventories | (Pirrone et al. 2010) – volcanic / geogenic emissions<br>(Smith-Downey et al. 2010) – terrestrial storage and natural re-emissions |
| (Angot et al. 2018) (Geos-Chem)<br>NPS and MFR | (AMAP/UNEP, 2013) – base year emissions | (Pirrone et al. 2010; Bagnato et al. 2011) – geogenic emissions |

| | | |
|---|---|---|
| | (Streets et al. 2011) – historical emissions (2000 BCE–2008 CE)<br>(Pacyna et al. 2016) – future scenarios | |
| (Perlinger et al. 2018) (Geos-Chem)<br>Minimal regulation, Policy-in-action, and aspirational scenario | (AMAP/UNEP, 2013) – baseline emissions<br>(Streets et al. 2009; 2011; 2017) – historical and future scenario emissions | (Pirrone et al. 2010; Bagnato et al. 2011) – geogenic<br>GEOS-Chem parameterization – natural/legacy emissions |
| (Chen et al. 2018) (Geos-Chem)<br>A1B, constant emissions, Hg control, and zero emissions | (Streets et al. 2011) – emissions (2000 BCE–2008 CE)<br>(Horowitz et al. 2014) – commercial-product emissions (1850–2008)<br>AMAP/UNEP (2018) – baseline emissions<br>(Streets et al. 2011) – emissions (1850–1970) by region<br>(Streets et al. 2009; Amos et al. 2013) – future scenario emissions | (Pirrone et al. 2010; Bagnato et al. 2011) – geogenic emissions |
| (Y. Zhang et al. 2021) (Geos-Chem)<br>A1B, NPS-delayed, and MFR | AMAP/UNEP (2013) – base year emissions<br>(Streets et al. 2009; Pacyna et al. 2016) – future scenario emissions | Default GEOS-Chem datasets |
| (H. Zhang et al. 2021) (Geos-Chem)<br>A1B, B1 | (Pacyna et al. 2010; Zhang et al. 2012) – base year emissions<br>(Streets et al. 2009; Corbitt et al. 2011) – future scenario emissions | (Mason 2009; Bagnato et al. 2011) – geogenic emissions<br>(Holmes et al. 2010) – biomass burning and soil evasion<br>(Selin et al. 2008) – prompt terrestrial re-emission<br>(Holmes et al. 2010; Zhang et al. 2016) – ocean evasion |

**Table S2.** Acronyms and descriptions for climate-oriented and hybrid mercury emission scenarios.

| Scenarios | Descriptions |
|---|---|
| BAS (Baseline) | Assumes continuation of air-quality and climate policies in force up to 2012, without introducing additional mercury or emission-control measures beyond 2030. |
| CLIM (Climate Mitigation) | Incorporates a 2 °C global climate policy, achieving substantial reductions in fossil-fuel use and associated mercury emissions by 2050. |
| CLIM+MFR | Climate mitigation scenario with maximum feasible mercury reduction measures, representing the lowest achievable global Hg emissions. |
| Net-Zero | Net-zero energy pathway (< 1.5 °C by 2100) combined with current-legislation Hg and air-quality policies. |
| Net-Zero + Hg MFR | Combines net-zero climate policy with maximum Hg-specific controls, yielding the lowest feasible Hg emissions by 2050. |

| | |
|---|---|
| SSP1-2.6 | A lower-bound emissions scenario reflecting strong emphasis on sustainability and intensive control of climate-forcing agents. |
| SSP2-4.5 | A middle-of-the-road scenario reflecting moderate socioeconomic development and continuation of current trends without strong climate mitigation. |
| SSP5-3.4 | An overshoot scenario characterized by short-term growth in fossil fuel use and minimal consideration of climate control measures until 2040 followed by aggressive mitigation after mid-century. |
| SSP5-8.5 | An upper-bound emissions scenario in which fossil-fuel use continues with little consideration of climate mitigation or transition to clean technologies. |

**Table S3.** Full forms of abbreviations used for meteorological datasets and drivers in atmospheric Hg models.

| **Acronym / Model** | **Descriptions** |
|---|---|
| GEOS | Goddard Earth Observing System |
| ECHAM5 | The fifth-generation atmospheric general circulation model developed at the Max Planck Institute for Meteorology in Hamburg, based on the operational forecast model framework from ECMWF. |
| WRF | Weather Research and Forecasting |
| ECMWF | European Centre for Medium-Range Weather Forecasts |
| NCEP | National Centers for Environmental Prediction |
| NCAR | National Center for Atmospheric Research |
| ECCC | Environment and Climate Change Canada's |
| GEM | Global Environmental Multiscale |
| GCM | General circulation model |
| CCSM | Community Climate System Model |
| NCAR-MM | National Center for Atmospheric Research - Mesoscale Model |
| NOAA | National Oceanic and Atmospheric Administration |
| NCDC | National Climatic Data Center |
| MERRA-2 | Modern-Era Retrospective analysis for Research and Applications, Version 2 by NASA's Global Modeling and Assimilation Office (GMAO) |
| GISS-GCM | Goddard Institute for Space Studies - general circulation model |

**Table S4.** Summary of variables used in PCA and MLRM analyses.

| **Scenarios** | **Change in fish MeHg (% yr$^{-1}$)** | **Change of Hg deposition (% yr$^{-1}$)** | **Watershed (km$^2$)** | **Lake Area (km$^2$)** | **Wetland (%)** | **Average depth (m)** | **Waterbodies** |
|---|---|---|---|---|---|---|---|
| SRES A2 | 0.114 | 0.264 | 17.040 | 1.070 | 4.030 | 6.400 | Mendums Pond, NH |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| SRES B2 | -0.318 | -0.346 | 17.040 | 1.070 | 4.030 | 6.400 | Mendums Pond, NH |
| NPS | -0.275 | -0.383 | 183.100 | 7.148 | 14.285 | 5.570 | Lakes in Maine, ME |
| MFR | -0.550 | -0.645 | 183.100 | 7.148 | 14.285 | 5.570 | Lakes in Maine, ME |
| Policy-in-action | -0.250 | -0.341 | 190.000 | 9.700 | 14.210 | 15.000 | Lakes in Michigan's UP, MI |
| Aspirational | -1.477 | -1.477 | 190.000 | 9.700 | 14.210 | 15.000 | Lakes in Michigan's UP, MI |
| Policy-in-action | 0.438 | 0.277 | 190.000 | 9.700 | 14.210 | 15.000 | Michigan's UP with Adirondack's deposition |
| Policy-in-action | -0.857 | 0.277 | 190.000 | 9.700 | 8.800 | 15.000 | Adirondack area, NY |
| Reduction in deposition, 50 % | -0.633 | -1.020 | 4.200 | 0.200 | 1.000 | 2.000 | Eagle Butte Lake, SD |
| Reduction in deposition, 50 % | -1.041 | -1.020 | 0.810 | 0.120 | - | 4.800 | Lake Barco, FL |
| Reduction in deposition, 50 % | -1.163 | -1.020 | 50.000 | 3.600 | 4.000 | 5.000 | Pawtuckaway Lake, NH |
| Reduction in deposition, 50 % | -1.571 | -1.020 | 220.000 | 35.000 | 25.000 | 2.300 | Lake Waccamaw, NC |
| Reduction in deposition, 50 % | -1.510 | -1.020 | 2190.000 | 9.900 | 8.000 | 0.250 | Brier Creek, GA |

Note: For NPS and MFR, "Lakes in Maine" reflect the averaged characteristics of 20 modeled lakes.

**Table S5.** MLRM results testing whether lake characteristics alone predict changes in fish MeHg by 2050 in the model world.

| | Coef | std err | t | P>\|t\| | [0.025 | 0.975] |
|---|---|---|---|---|---|---|
| const | -0.6521 | 0.432 | -1.509 | 0.175 | -1.674 | 0.370 |
| Watershed | -0.0003 | 0.000 | -0.924 | 0.386 | -0.001 | 0.000 |
| LakeArea | -0.0687 | 0.045 | -1.526 | 0.171 | -0.175 | 0.038 |
| Wetland | 0.0582 | 0.061 | 0.947 | 0.375 | -0.087 | 0.203 |
| AverageDepth | 0.0072 | 0.039 | 0.187 | 0.857 | -0.084 | 0.099 |

**Table S6.** MLRM results testing lake characteristics together with scenario-specific Hg deposition as predictors of changes in fish MeHg by 2050 in the model world.

| | **Coef** | **std err** | **t** | **P>\|t\|** | **[0.025** | **0.975]** |
|---|---|---|---|---|---|---|
| const | −0.1249 | 0.275 | −0.454 | 0.666 | −0.799 | 0.549 |
| Watershed | −0.0002 | 0.000 | −1.219 | 0.269 | −0.001 | 0.000 |
| LakeArea | −0.0656 | 0.025 | −2.599 | 0.041 | −0.127 | −0.004 |
| Wetland | 0.0685 | 0.035 | 1.982 | 0.095 | −0.016 | 0.153 |
| AverageDepth | −0.0264 | 0.023 | −1.136 | 0.299 | −0.083 | 0.030 |
| Deposition | 0.7864 | 0.195 | 4.032 | 0.007 | 0.309 | 1.264 |

## Code, data, or code and data availability

Custom scripts used for statistical analyses are available from the corresponding author upon reasonable request. All data analysed in this study are available from the cited publications. Any compiled datasets are available from the corresponding author upon reasonable request.

## Supplement link

The link to the supplement will be included by Copernicus.

## Author contributions

Henna Gull compiled and curated the data, conducted the analyses, and led the writing of the manuscript. Hoin Lee cross-checked and validated the compiled data. Ju Hyeon Lee provided critical feedback and contributed to manuscript revision. Hélène Angot provided scientific feedback and suggestions that helped improve the manuscript. Sae Yun Kwon supervised the study and contributed to conceptualization and manuscript revision. All authors reviewed and approved the final manuscript.

## Competing interests

The authors declare that they have no conflict of interest.

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