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Response of Freshwater Systems to Local and Global Changes in Mercury Emissions

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Abstract. Lakes and other waterways, and the biota in those waterways, receiving their mercury burden primarily via atmospheric deposition can be expected to exhibit responses to changes in deposition over an extended time period. A projected control strategy for power plant emissions of mercury was imposed on modeled U.S. plants, while international emissions were modeled for two Chinese emission scenarios: a "business-as-usual" scenario and an "expedited controls" scenario. Levels of mercury in fish were simulated in a New England lake located close to a large U.S. power plant. Results indicated that fish responses to mercury emissions changes were spread over several years, and that even severe reductions in U.S. emissions were masked by non-U.S. emissions growth.

Key words: Mercury, methylmercury, emissions, ecosystem dynamics

Introduction

Recent trends in mercury emissions display an increase in U.S. domestic emission regulations but a continued up-tick in non-U.S. mercury emissions. It is of interest to predict how the foodfish in particular waterways can be expected to respond to changes in emissions globally and locally. Global emissions reaching the U.S. are dominated by mercury emitted from the Asian mainland, particularly from China. One scenario of interest is a Chinese alternative scenario wherein mercury emissions are reduced selectively by the co-benefit reductions due to an acceleration of control introduction for other purposes.

Methods

The studied site, Mendums Pond, was located in southeastern New Hampshire, New England, U.S.A. Mendums Pond is a well-characterized New England pond in Strafford County, New Hampshire, with a surface area of 102.39 ha within a watershed of 1442.3 ha. Water volume is 6.567×106 m^3, with a mean depth of 6.4 m and maxium depth of 15.9 m. Mercury deposition was derived from a run of the GEOS-Chem global model providing boundary conditions to a 20-km resolution run of the EPRI TEAM regional-scale model using 2004 global and domestic source emissions of mercury. U.S. utility emissions of mercury were lowered by 90% to simulate a maximum-control scenario (without regard to emissions speciation). In the "expedited controls" scenario, Chinese mercury emissions were reduced to the levels specified in the "policy" scenario in UNEP (2011).

Fish levels of mercury over time in the different fish trophic levels present in Mendums Pond were simulated using the Mercury Cycling Model, v. 3. MCM simulates mercury dynamics in the biotic and abiotic compartments in drainage lakes. It is a mechanistic model that incorporates processes including inflows and outflows via surface and groundwater contributions, particulate settling, atmospheric deposition, air/water gaseous exchange, in-situ transformations (e.g. methylation, demethylation, methylmercury photodegradation, Hg(II) reduction), and bioenergetics related to methylmercury fluxes in fish.

Results and Discussion

Preliminary results using a higher-resolution regional deposition model indicate that even stark reductions in U.S. national mercury emissions, at least from a single source category, are barely noticeable in the form of reduced levels of mercury in the highest tropic-level fish. Seasonal variation in fish levels of mercury at each trophic level are unaffected by a simulated step drop in U.S. emissions, due to the dominant role generally played by non-U.S. emissions growth under the BAU scenario.

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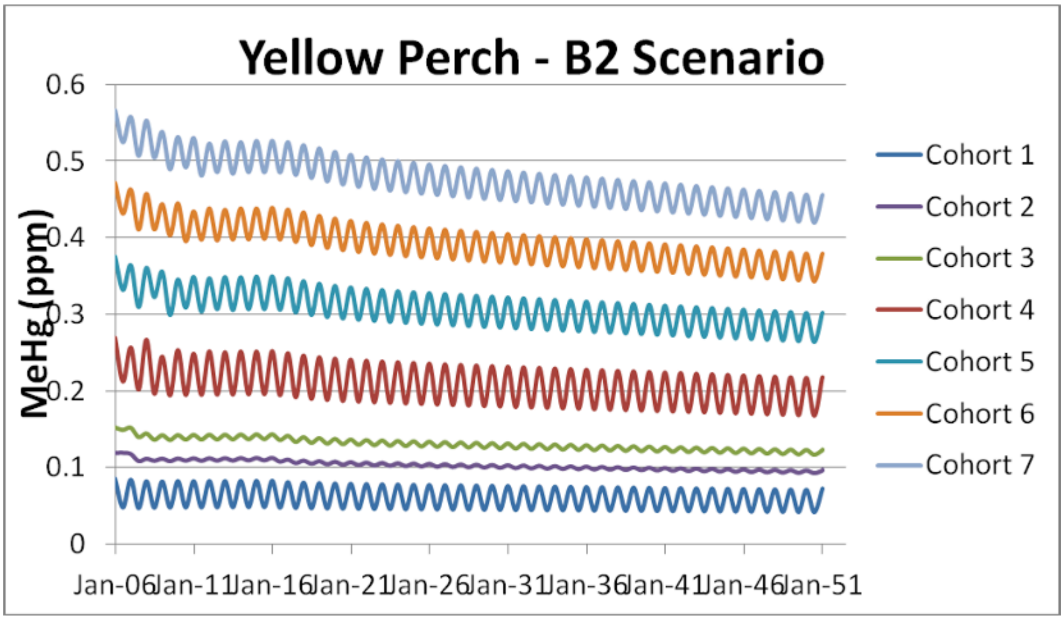

Fig. 1. Response of yellow perch to a step decline in U.S. utility mercury emissions and an expedited-control scenario on Chinese mercury emissions (100-km resolution deposition input).

For the alternative rapid-control scenario imposed for Chinese emissions, no significant differences were observed in fish levels of mercury for several years following the step decline in U.S. emissions; however, steady drops in annual-average body burden of mercury are evident after a lapse of roughly ten years. This appears to be due to the long lifetime of the highest trophic level fish in the receiving waters, so that older larger fish retain the record of higher deposition rates prior to the initiation of both U.S. and Chinese emissions cuts. As young-of-year mature over a decade or more to displace the oldest fish, their exposure to lower and lower levels of deposited mercury result in annual-average declines in their body burden (Figure 1).

Conclusion

Although the slow response of temperate-zone lakes to even steep changes in mercury deposition is well understood, the dominance of non-U.S. contributions to the deposition is now apparent from the results of this model experiment. Using measured lake quality data in running the simulations avoided modeling an unrealistic environment, but nevertheless showed that older larger fish may take decades to reflect significant drops in emissions imposed in a single time step. The interannual and inter-trophic level reservoirs of mercury in a lake's fish represent slowly evolving reservoirs of the substance carried between fish generations that smooth and filter any time changes in the body burdens of mercury in fish.

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