IMPACTS OF ENVIRONMENTAL CHANGE ON METHYLMERCURY BIOACCUMULATION IN MARINE ECOSYSTEMS

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Introduction

Methylmercury (MeHg) is a potent neurotoxin that is associated with many adverse health effects in people. Long-term dietary exposure to MeHg has been associated with neurocognitive delays in children including long-term IQ deficits, attention deficit disorder, and reductions in verbal function and memory. Chronic low levels of exposure are typically observed among frequent seafood consumers. Inorganic mercury is converted to MeHg by microbial reactions known to be sensitive to physical and chemical conditions such as temperature and the presence and composition of dissolved organic matter (DOM). MeHg entry into food-webs is known to be affected by phytoplankton abundance and community composition. Experimental data also indicate uptake of MeHg into cells is affected by both temperature and DOM.

Climate-driven changes are expected to significantly alter seawater temperature, phytoplankton concentrations and size distribution, and DOM composition. Higher temperatures and nutrient-rich freshwater inputs will result in higher primary production, which in turn shifts phytoplankton size distribution toward larger cells, and larger cells have lower MeHg concentrations. On the other hand, freshwater inputs can result in water column stratification; Schartup et al. (2015) showed that stratification can enhance MeHg production and uptake in coastal waters. The overall result of these conflicting effects on MeHg levels in commercially important fish species is unknown.

Here we investigate the impacts of ecosystem changes on biota MeHg concentrations in the Gulf of Maine region by developing a generic model for MeHg bioaccumulation in marine food-webs. We parameterize the model to reflect the species and diet composition of the Gulf of Maine system, where MeHg data are available for model evaluation. We build on general knowledge of bioaccumulation in aquatic food-webs and quantitatively account for the impacts of shifts in environmental conditions. We apply the model to investigate the relative importance of changes in seawater temperature, water MeHg and DOM concentrations, and how trophic structure in the Gulf of Maine ecosystem have affected MeHg bioaccumulation. We use this analysis to gain insight into the potential effects of future changes on marine MeHg bioaccumulation and MeHg exposure through fish consumption.

Methods

We include three size classes of phytoplankton to account for size-dependent MeHg accumulation. We estimate the relative abundance of different phytoplankton size classes using the empirical relationships developed from Uitz et al. (2006) that describe the size distribution of plankton communities as a function of surface chlorophyll-a concentrations. MeHg concentrations in phytoplankton are modeled as a function of seawater MeHg and DOM. For all organisms other than phytoplankton, our model draws conceptually from several species-specific studies for MeHg bioaccumulation and general knowledge of organic contaminants bioaccumulation in aquatic food-webs. Differential equations for each species that describe bioenergetics based MeHg uptake and elimination to compute weight-normalized concentrations are solved using Runge Kutta numerical integration. MeHg levels in each species are calculated from rates of dietary uptake, uptake from water/gill ventilation, elimination, and growth dilution. For all species, food consumption needed to meet energy requirements for growth and wet weights at any time, is calculated from standard bioenergetics, including terms for respiration, and combined excretion and egestion. We fit a bioenergetics model to respective age-dependent lengths and weights determined from von Bertalanffy (1938) growth functions and use the associated energy requirements to determine food consumption.

Results

Our model successfully reproduces plankton and fish MeHg levels (Fig. 1 A and B) in the Gulf of Maine. We find that increases in parameters that affect uptake of MeHg by phytoplankton such as chlorophyll-a and DOM have an overall smaller impact than water MeHg concentrations (Fig. 1C). Higher trophic level fish MeHg levels are most sensitive to changes in water MeHg levels and temperature, and shifts in diet (Fig. 1D).

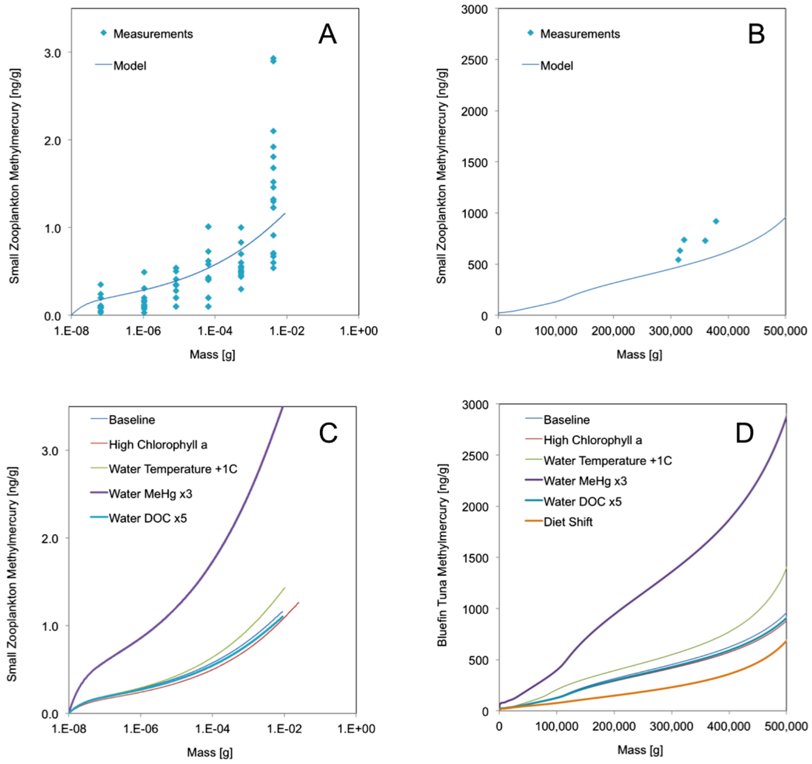

Figure 1: A&B. Comparison of modeled and measured biota MeHg content versus mass of plankton cell or fish. C&D. Effect of temperature, chlorophyll a, diet, water MeHg and dissolved organic carbon (DOC) concentrations on plankton and Bluefin tuna MeHg content.

Conclusion

This work suggests that enhanced stratification and subsequent increase in water MeHg concentration could have a larger impact on fish MeHg levels than changes in phytoplankton size distribution. Shifts in fish diet due to over-fishing and/or prey availability can also significantly alter high-trophic-level fish MeHg content.

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