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Modeling mercury bioaccumulation in largemouth bass in the Sacramento-San Joaquin River Delta and tributaries

Abstract

The Sacramento-San Joaquin River Delta (Delta) and associated tributaries have elevated mercury (Hg) concentrations in largemouth bass (*Micropterus salmoides*) and other sport fish species. Strong spatial variation in Hg concentrations in sport fish has resulted in development of watershed- specific consumption advisories for this region. We used mechanistic models of largemouth bass Hg accumulation to determine whether the spatial variation in largemouth bass Hg may result from differences in fish growth, consumption, or metabolic activity. A bioenergetics and Hg mass balance model was parameterized with local data on Hg in bass and prey, estimated bass growth rates, and water temperature. Model simulations spanned the range of local estimated bass growth rates. The largest changes in final Hg concentrations occurred when growth was reduced by increasing metabolic activity while holding consumption rate constant. Results indicated potential changes in final bass Hg concentrations ranging from -15% to +16%. This variation is far surpassed by the fivefold variation in prey Hg concentrations among locations. Our findings do not support the hypothesis that spatial variation in bass Hg results from spatial variation due to growth, consumption, or activity. Instead, spatial variation in fish Hg in this region likely results from variation in food web exposure to bioavailable methyl-Hg.

Introduction

In California, extensive gold and mercury (Hg) mining activity has resulted in the historic release of large amounts of mercury into watersheds, rivers, and lakes (Nriagu 1994, Conaway et al. 2004, Alpers et al. 2005). One of the most striking patterns in fish Hg exposure in the region is substantial spatial variation among locations **(Figure 1)** (Slotton et al. 2002, Davis et al. 2007). We describe preliminary modeling results regarding potential drivers of spatial variation in Hg accumulation for largemouth bass (*Micropterus salmoides*).

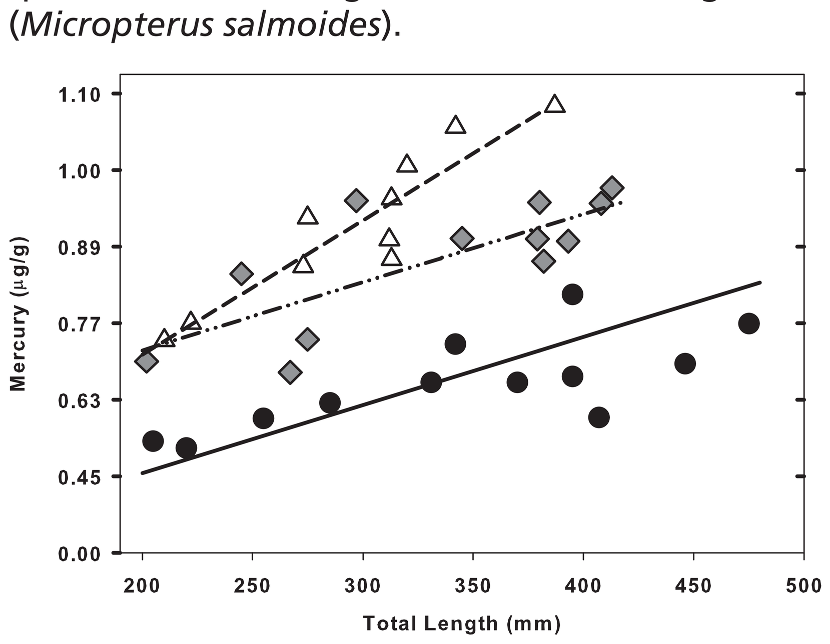

Figure 1 Mercury versus length in largemouth bass at three sampling locations in the Sacramento-San Joaquin River Delta, CA (2000). Regression lines show best fit results from polynomial regression analysis (Davis et al. 2007). ● (solid line) = a Delta site. ◊ (dot and dash line) = a San Joaquin River site. Δ (dotted line) = a Mokelumne River site. Y-axis is on a square-root transformed scale. Note that tissue Hg at a given length varies as much as two-fold among locations.

Background and objectives

- Study objective: evaluate effect of varying growth, consumption rate, and metabolic activity on Hg bioaccumulation
- Some literature suggests negative associations between growth rates and tissue Hg (Essington and Houser 2003, Simoneau et al. 2005)
- Bioenergetic models exhibit parameter uncertainty for metabolic activity and consumption rates (Trudel and Rasmussen 2001, Bajer et al. 2004)
- Model calibrations combining bioenergetic and Hg mass balance models can help estimate and constrain these parameters (Trudel and Rasmussen 2001, 2006).

Mechanistic Model

- A mechanistic model was used to evaluate the effects of growth, consumption and activity on tissue Hg concentrations.
- A combined bioenergetics and Hg mass balance model (Trudel and Rasmussen 2001, 2006) run on a daily time step in MATLAB.
- Modelling approach allows assessment of these factors independently of other factors.
- The mechanistic model focused on processes of Hg uptake and loss for individual largemouth bass **(Figure 2)**.
- Growth may be changed by changing two model input parameters
  - Proportion of maximum (ad Librium) consumption (pmax)
  - Exponent to depict change in metabolic activity with mass (ACTe)

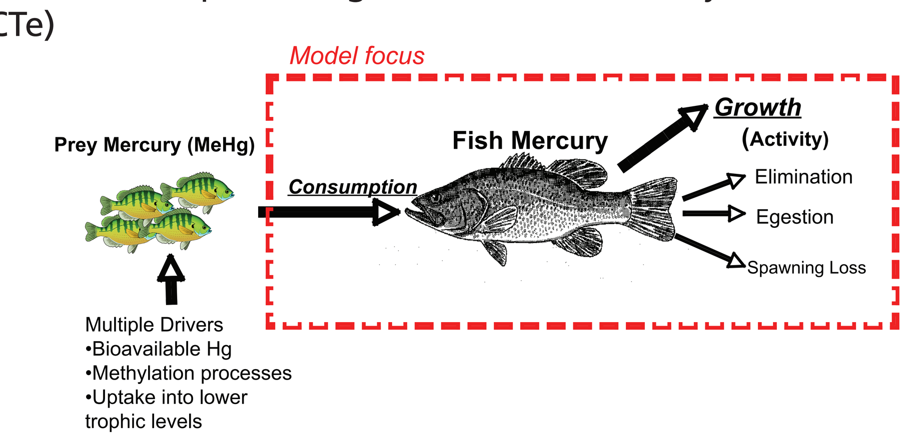

Figure 2 Conceptual depiction of Hg mechanistic model used in this study

Approach

- Develop empirical growth rate estimates using local age, length, and weight data **(Figure 3)**
- Fit mechanistic model to empirical tissue Hg and to upper and lower bounds of observed growth rates
  - Estimate pmax (consumption parameter) and ACTe (activity parameter) for range of growth scenarios **(Table 1)**.
- Rerun model across potential range of pmax and ACTe to determine predicted change in Hg
- Compare potential variation in Hg to that due to varying prey Hg

Table 1 Representative parameter values for initial model calibration. Model was calibrated to result in weight and tissue Hg concentration. Calibration results for activity parameter (ACTe) and consumption parameter (pmax) were then used to constrain future simulations.

Parameter	Parameter type	Upper Value	Lower Value
Weight at 7 yr (g)	Calibration	2500	1030
Hg at 7 yr (ppm)	Calibration	0.42	0.42
pmax	Fitted	0.767	0.608
ACT^{e}	Fitted	0.123	0.101

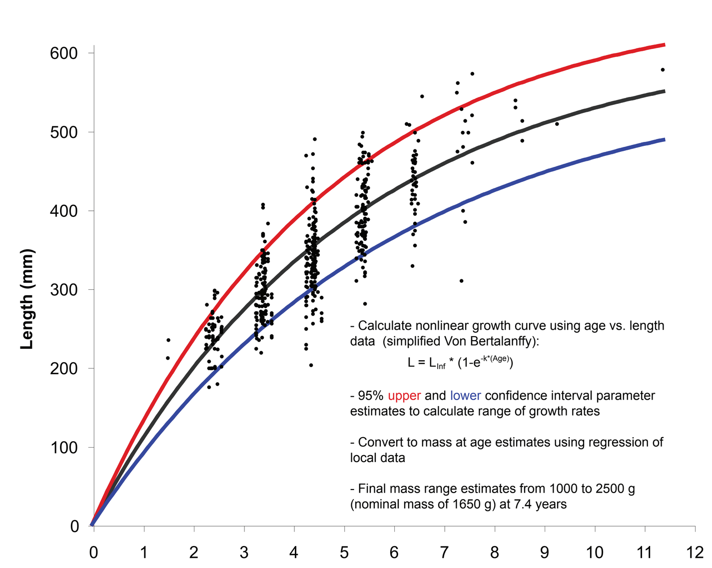

Figure 3 Range of potential growth rates was estimated by fitting a simplified Von Bertalanffy curve to scale-derived growth data. Black line (—) is best fit. Blue (—) and red (—) lines are 95% lower and upper confidence estimates of parameter values.

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Results

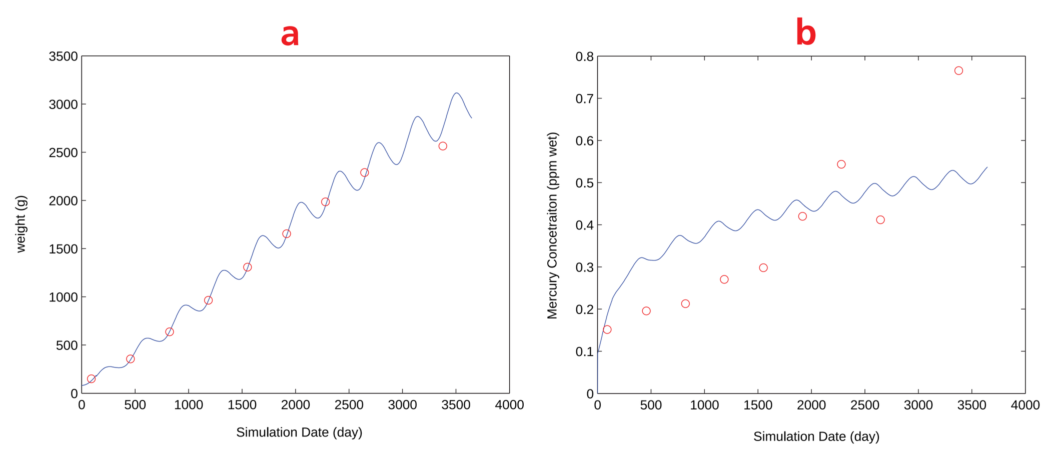


Figure 4 Representative output of a model calibration. Blue line (—) represents model output. Red dots (o) represent calibration data. **a.** Model fit to empirical weight data. **b.** Model fit to empirical Hg concentration. Note the oscillation in body mass and tissue Hg, resulting from temperature dependence of bioenergetic processes.

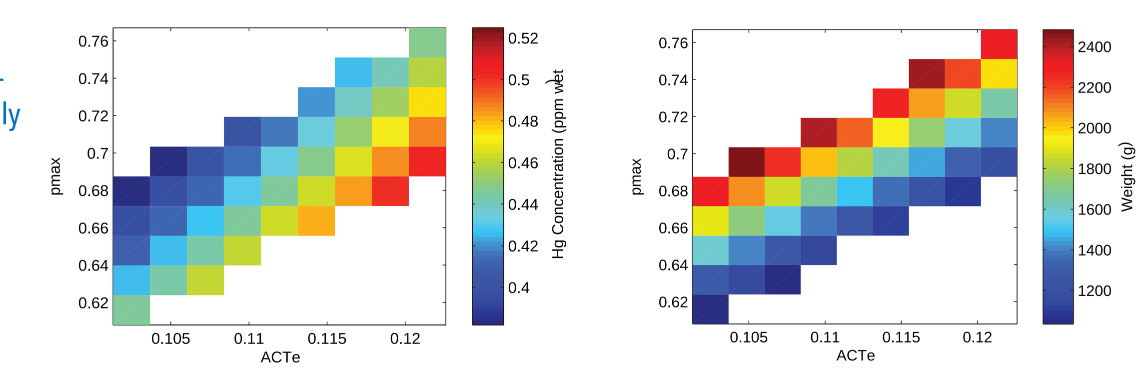


Figure 5 Output of simulations across the range of potential activity and consumption parameters. Only results within range of empirically observed growth rates **(Figure 1, Table 1)** are included. **a.** Hg concentration increases with ACTe, indicating a positive association between metabolic activity and Hg. Concentrations decrease as pmax increases, indicating a negative association between Hg and consumption rate. **b.** Body weight strongly increases with pmax. This explains the positive consumption vs. Hg association as resulting from "growth dilution."

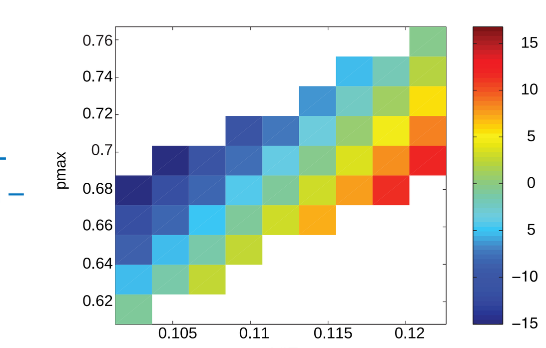
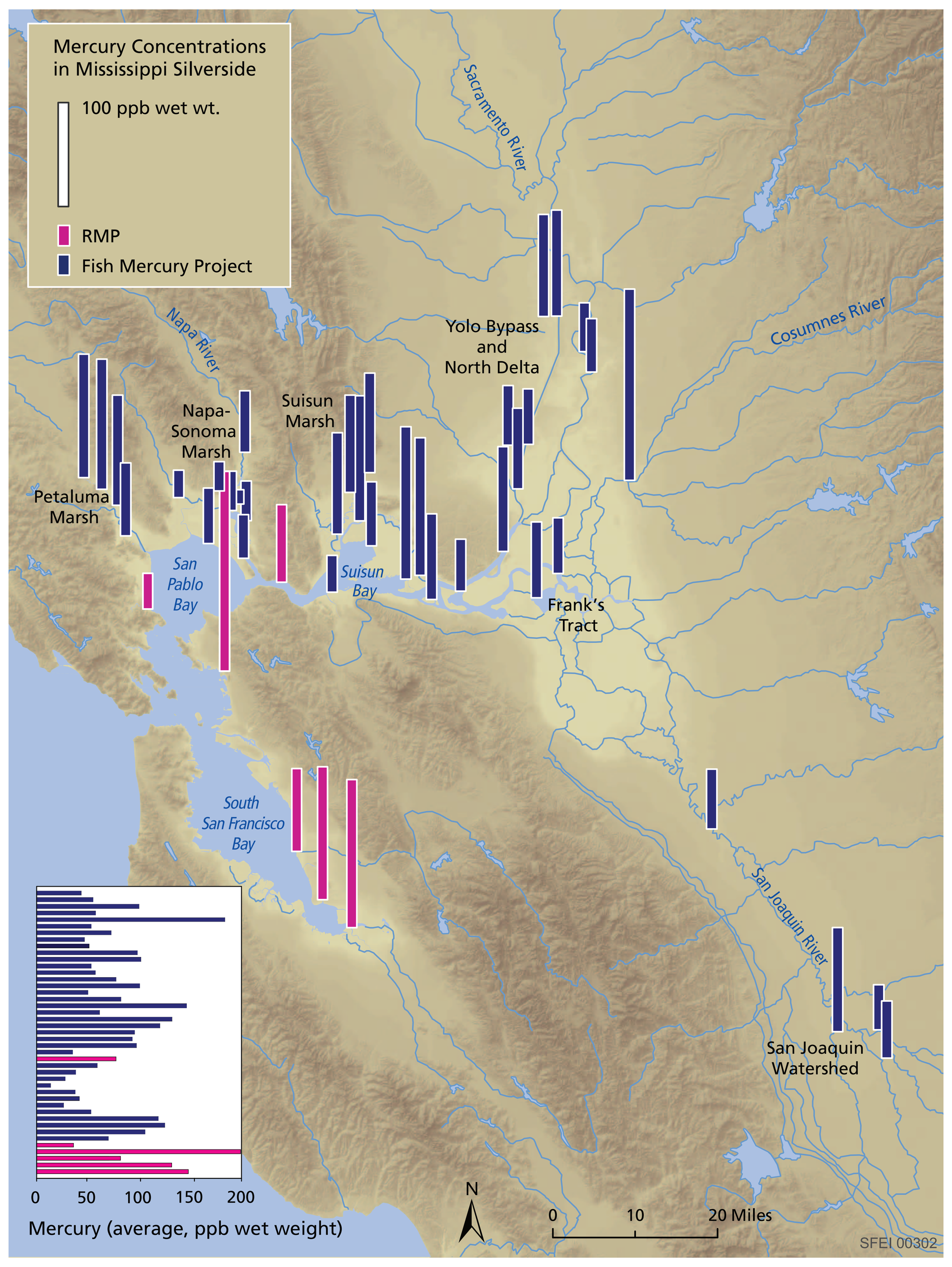


Figure 6 Percent difference in modeled Hg from nominal value Across the range of empirically observed growth rates, Hg varies between – 15% and + 16% of nominal value.

Figure 7 Empirical range of Hg concentrations in Mississippi silversides (*Menidia audens*) collected from the Bay-Delta region in 2006. Based on silverside data, there is a greater than 400% difference in prey Hg concentrations among sampling locations.



Discussion

- The model calibration resulted in a good fit to empirical growth data but the fit to Hg data could be improved **(Figure 4)**.
  - Simulations with increasing prey Hg over time have better fit (data not shown) suggesting the need to incorporate dynamics of predation.
- Seasonal oscillations **(Figure 4)** suggest need to evaluate temporal dynamics.
  - Is Hg in sportfish more sensitive to management actions in the summer vs. winter?
  - What is the response rate of bass to management actions that reduce Hg bioavailability
- Parameter values were constrained to generate realistic growth rates **(Table 1 and Figure 5)**.
- Variation in Hg accumulation due to modifying growth, activity, and consumption (± 16%; **Figure 6**) less than variation resulting from differences in prey Hg (>400%; **Figure 7**).
- Results suggest importance of Hg bioavailability at the base of the food web, rather than fish growth.
  - Reductions in Hg loading and methylation will reduce exposure to fish, wildlife, and humans.
  - Importance of process studies on the drivers of Hg bioavailability in the system (Marvin-DiPasquale and Agee 2003, Pickhardt et al. 2006).