Science TO RESULTS

MERGANSER:

Predicting Mercury Levels in Fish and Loons in New England Lakes

U.S. EPA | SCIENCE AT THE EPA NEW ENGLAND REGIONAL OFFICE

SCIENCE lies at the heart of the mission of the U.S. Environmental Protection Agency (EPA). The Agency must rely on cutting edge research, accurate measurements and effective technology to implement its programs to protect the environment and human health. Without sound science and credible data, EPA can not wisely set environmental and health standards, clean up contaminated sites, measure ambient air and water quality conditions, or identify the new technologies or practices that will reduce releases to the environment. These fact sheets share with you some of our EPA New England's laboratory capabilities and exemplify some of the very best science we do to meet our agency mission.

INTRO:

MERGANSER (Mercury Geospatial Assessments for the New England Region) was developed by EPA New England and a team of mercury (Hg) researchers to relate atmospheric Hg deposition and lake and watershed characteristics to Hg concentrations in fish and fish-eating wildlife (common loons). The empirical modeling approach is similar to that used in the New England SPARROW model, which provides estimates of nutrient loadings in rivers. MERGANSER provides predicted mercury levels in fish and loons via a web-based interactive tool for 4,404 lakes in New England. This model can be used by environmental scientists and managers to assess the risk of Hg contamination in fish and loons throughout New England and to help plan Hg-pollution reduction efforts.

WHAT IS THE PROBLEM?

Mercury is a neurotoxin that poses a risk of neurological damage to humans and wildlife. Pregnant women and children are especially susceptible to mercury exposure and are advised to limit mercury-containing foods in their diets. Elemental mercury is present at low concentrations in the Earth's crust. However, when power plants and other industries burn coal for energy production, mercury and other trace heavy metals are emitted into the atmosphere. Mercury is then transported as a gas regionally, and even globally, and deposited during both dry- and wet-weather conditions on land and water (Figure 1). Other sources of mercury pollution include municipal and medical-waste incinerators, although these are now relatively minor mercury sources in the northeastern U.S. due to environmental regulations covering these facilities.

Of concern to human and ecological health is the transformation in the environment of mercury to its organic form, methylmercury (MeHg), which can be retained by organisms throughout the food web. This retention causes MeHg to bioaccumulate (increase in concentration over time) and biomagnify (increase in concentration in animals at higher levels of the food chain). Thus, fish consumption is a major MeHg exposure pathway for both humans and fish-eating wildlife (piscivores) such as loons (Figure 2).

Currently, all 50 states in the U.S. have advisories to limit fish consumption because of high Hg levels in fish (Figure 3). Although Hg contamination is a problem nationwide, it is especially prevalent in the northeastern U.S. This region is impacted by long-distance transport of mercury from industrial sources and, in many places, has environmental conditions conducive to production of MeHg.

In 1989, EPA conducted an extensive fish-tissue sampling study in New England and found that many lakes thought to be "pristine" had fish with high Hg levels. In addition, other studies found that many loons, which feed on fish from these lakes, have elevated Hg levels in their eggs, feathers and blood.

Research shows that Hg concentrations in fish and loons depend on many factors including the atmospheric deposition of mercury, watershed characteristics (e.g., watershed size, slope, soil type, land uses), temperature, water

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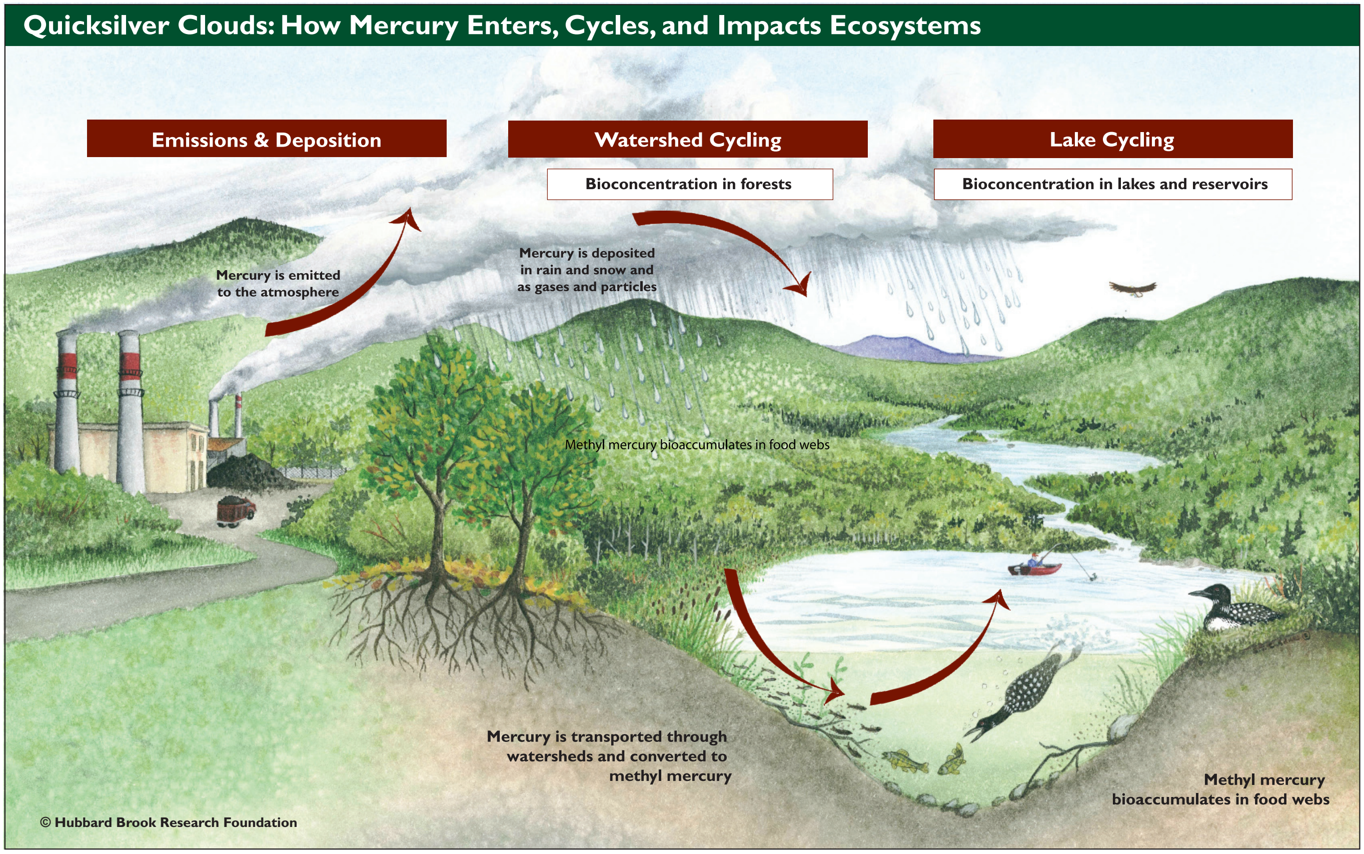

FIG 1 How mercury enters and impacts the ecosystem

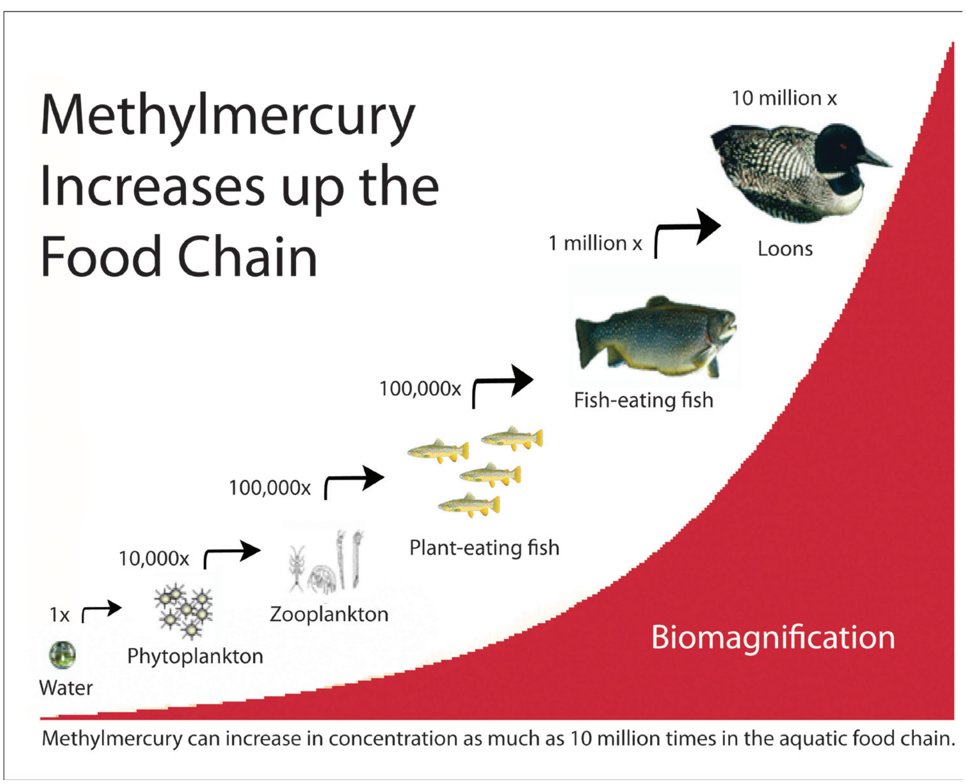

FIG 2 MeHg increases up the food chain (source: National Park Service and SERC Institute)

chemistry (e.g., pH, dissolved organic carbon (DOC) concentration) and other factors. The number of variables and complexity of food webs makes it difficult to predict Hg levels in fish and piscivores.

WHY IS A MODEL NEEDED?

Since 2001, EPA New England has worked with a team of mercury researchers in the Northeast to gather information on mercury, including its sources, transport, deposition, and concentration in fish and loons, as well as lake and watershed characteristics that may be associated with elevated Hg levels in wildlife. The research team recognized that an environmental model was needed to integrate these datasets to find relationships among environmental factors and Hg levels in fish and loons. Such a model could be used as a tool for environmental scientists and managers to assess the risk of Hg contamination in fish and piscivores in watersheds throughout New England and to help plan Hg-pollution reduction efforts.

WHAT MODELING APPROACH WAS USED?

The research team used a modeling approach similar to the one used for the New England SPARROW model, which was developed to estimate nutrient loadings in rivers. Use of an empirical model allowed us to fit a regression equation to a large set of empirical data to quantify the relationship between dependent and independent variables. A dependent variable is a characteristic whose value changes in response to the presence or absence of other factors or independent variables. In this model, the dependent variables are Hg concentrations in fish tissue ("fish Hg") and loon blood ("loon Hg"). Independent variables include Hg-source and watershed-related variables (e.g., atmospheric Hg deposition, watershed area, wetland area, percent forest canopy area) that are known to influence Hg transport, fate and bioaccumulation. Candidate predictor (independent) variables were selected because of their availability for all lakes studied in New England. The best-fit regression equations were used to identify statistically significant predictors for observed fish Hg and loon Hg. The model can then be used to predict Hg concentrations in fish or loons in unsampled lakes.

The model, named MERGANSER ("Mercury Geospatial Assessments for the New England Region"), was developed using a Geographic Information System (GIS) because datasets were linked to specific geographic locations (Figure 4).

WHAT ARE THE COMPONENTS OF MERGANSER?

MERGANSER includes 4,404 New England lakes of 8 hectares (about 20 acres) or more in size (called "MERGANSER lakes"). A total of 56 independent spatial variables were tested for statistical significance as predictors of Hg concentrations in fish tissue and loon blood in MERGANSER lakes and lake watersheds. A list and description of all independent variables used in MERGANSER is available on a MERGANSER link at an EPA website (www.epa.gov/aed/html/wildlife/index.html).

Fish Hg data were obtained from EPA's Wildlife database (http://oaspub.epa.gov/aed/wildlife.search), which includes water-quality and fish Hg data from EPA's Regional Environmental Monitoring and Assessment Program (REMAP) and from monitoring programs of the six New England states. Fish data were available from 1988 to 2006, with the majority of data from 1996 to 2006. Of the 4,404 MERGANSER lakes, 351 lakes had fish-tissue Hg values with 3,470 individual values from 12 species (Table 1).

Loon Hg data used in MERGANSER were generated by the BioDiversity Research Institute (BRI) in Maine (http://www.briloon.org/). These data are in the form of standardized adult "Female Loon Units" (or FLUs), which are normalized units that take into account gender, age, and type of loon tissue sampled (e.g., blood, egg). Data on loons were from single-territory lakes, which are large enough to support a breeding pair of loons, but too small for a second pair of loons (60 to 200 acres). In total, 254 FLU values were used from 87 lakes.

WHAT ARE THE RESULTS OF MERGANSER?

MERGANSER allows a user to choose a MERGANSER lake and any one (or more) of 12 fish species (Table 1) as well as fish length. Specifying fish species and length are important because fish species vary in their rate of mercury bioaccumulation, and older (larger) fish often contain higher concentrations of Hg. The model then predicts the concentration of Hg in fish tissue and loon blood in the selected lake. MERGANSER provides error bounds on predicted fish Hg and loon Hg. The model can

FISH SPECIES	ABRV.	# OF SAMPLED FISH HG VALUES	WATER
YELLOW PERCH	YLP	937	WARM
LARGEMOUTH BASS	LMB	813	WARM
WHITE PERCH	WHP	391	WARM
SMALLMOUTH BASS	SMB	364	WARM
EASTERN CHAIN PICKEREL	ECP	151	WARM
BROWN BULLHEAD	BNB	187	WARM
LAKE TROUT	LKT	215	COLD
BROOK TROUT	BKT	148	COLD
LANDLOCKED SALMON	LLS	89	COLD
PUMPKINSEED SUNFISH	PKS	70	WARM
BLUEGILL	BLG	55	WARM
WHITE SUCKER	WHS	50	WARM

TABLE 1

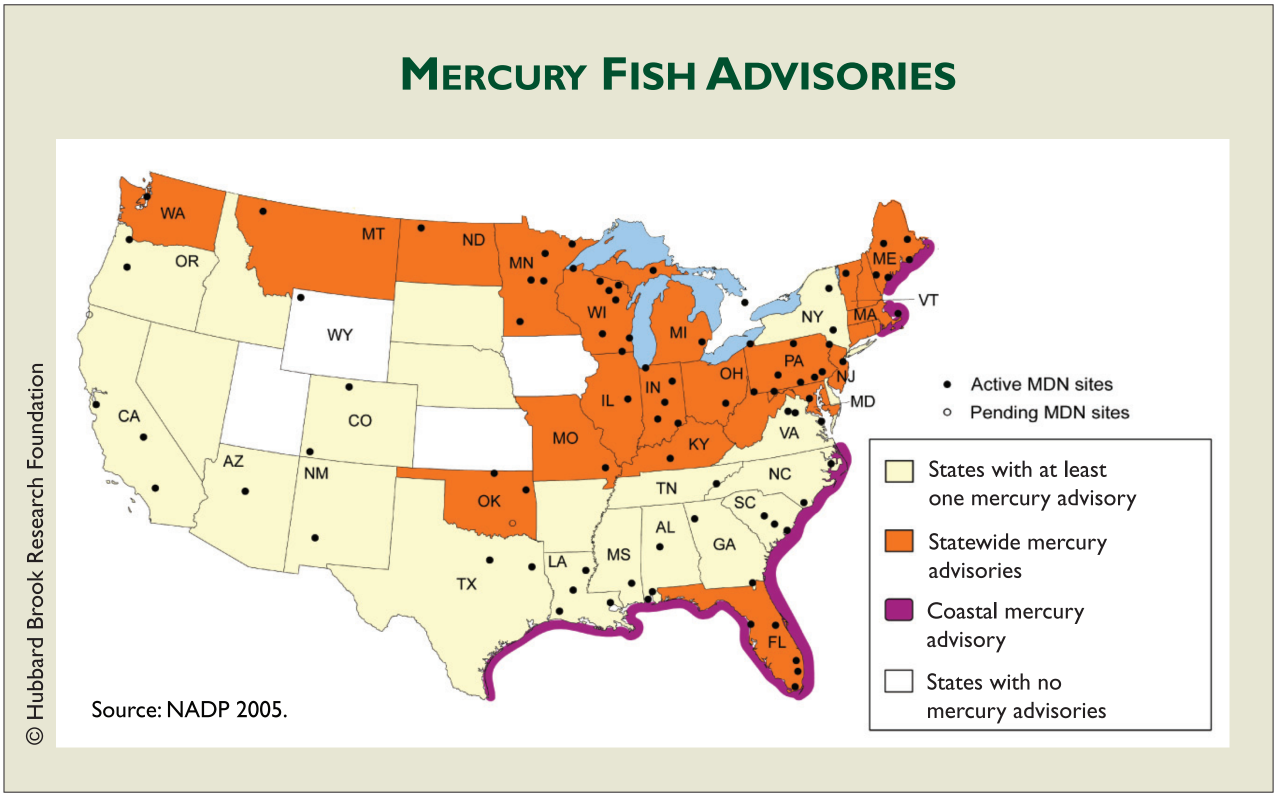

FIG 3 Map of Hg fish advisories in 2005.
As of 2008, all 50 states had issued Hg fish advisories.

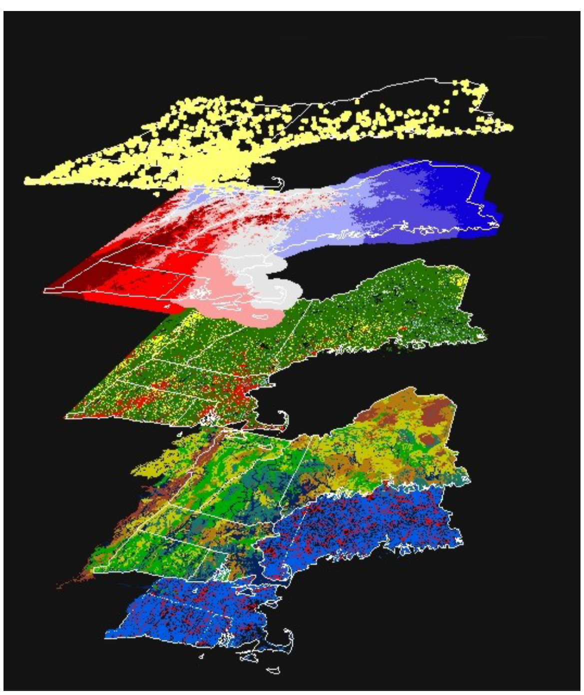

FIG 4 GIS is used to display and analyze spatial data.

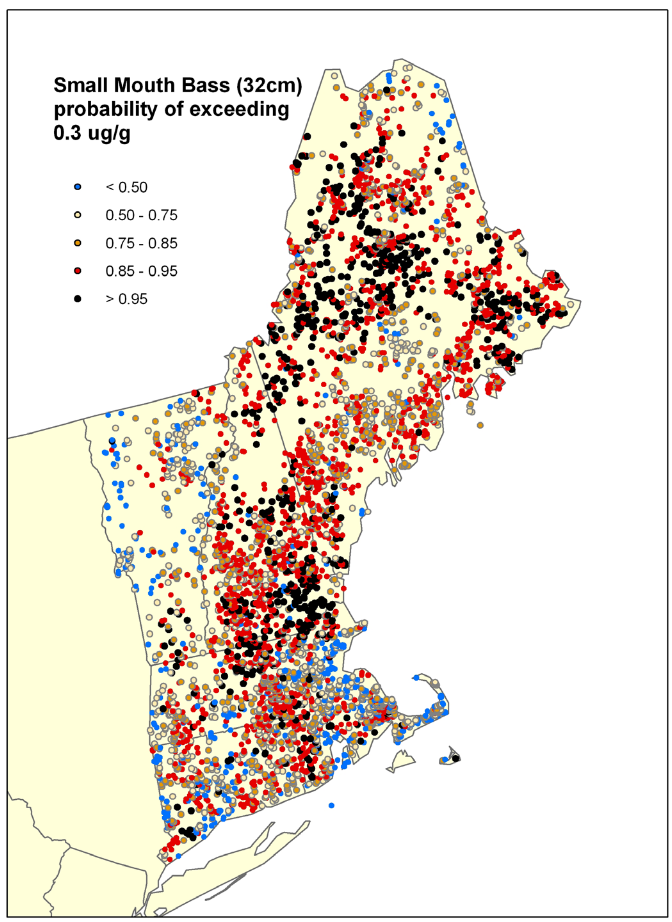

FIG 5 Model results for smallmouth bass - probability of exceeding 0.3 µg/g.

PREDICTOR VARIABLE	COEFFICIENT
INTERCEPT	-10.77963
LN (TOTAL HG DEPOSITION) (µg/M2/YR)	0.27433
LN (WATERSHED AREA) (KM2)	0.01522
LN (% FOREST CANOPY AREA)	0.18195
LN (% WETLAND AREA)	0.06983
POPULATION, 2000 CENSUS	0.00001158
LN (SLOPE) (Y/X)	-0.16268
LN (MEAN ANN TEMP) 1971-2000 (DEGREES C)	-0.37709
LN (% AGRICULTURAL LAND)	0.02328
WEIGHTED WATERSHED ALKALINITY (UNITLESS)	-0.11574
% SHRUBLAND & TOTAL HG DEPOSITION	0.00977
% FOREST CANOPY & TOTAL HG DEPOSITION	0.00371
TOTAL HG DEPOSITION & WATERSHED ALKALINITY	0.21519

TABLE 2

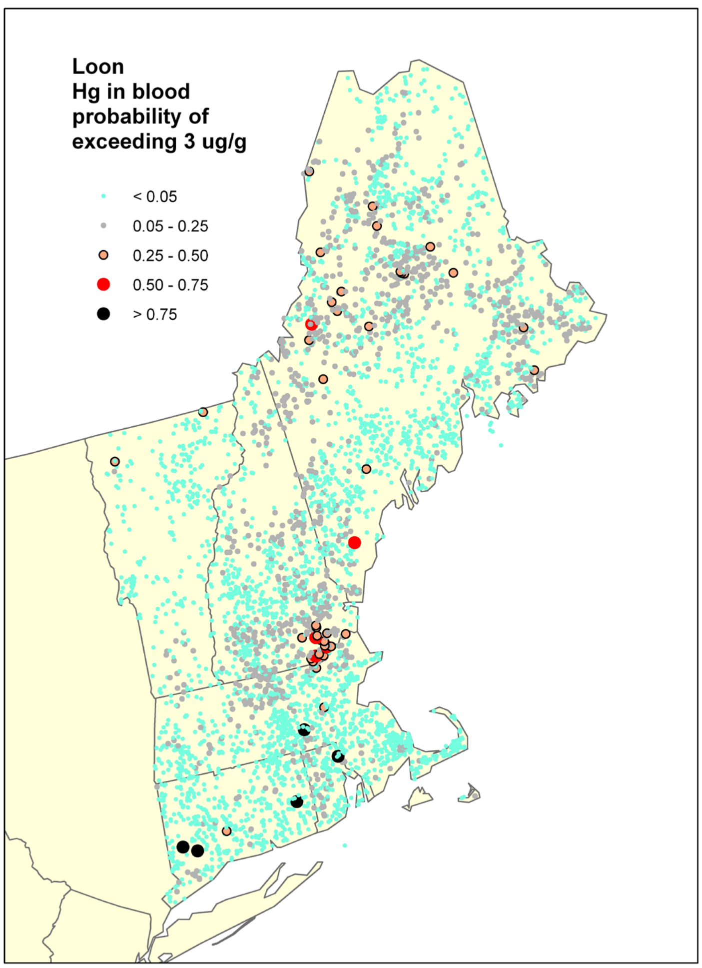

FIG 6 Model results for loon Hg (as FLU).

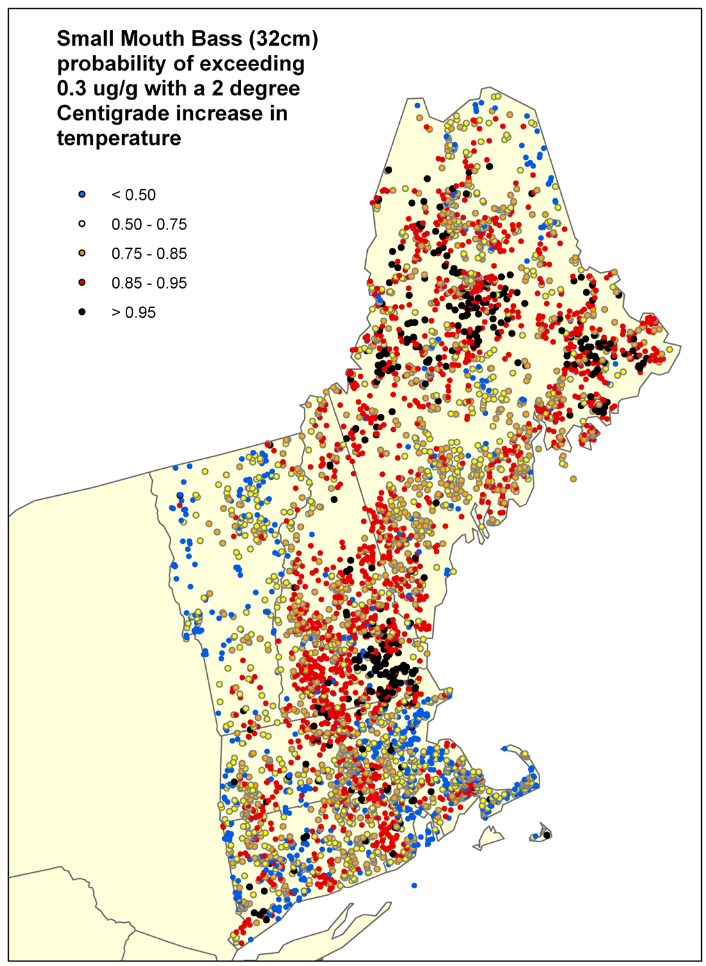

FIG 7 Model results for 32-cm smallmouth bass with a region-wide 2° Celcius in average annual temperature.

also be used to predict the probability that fish Hg for a given lake, fish species and length will exceed EPA's recommended fish mercury limit established to protect human health (0.3 µg/g) (300 parts per billion).

Of 56 candidate variables, nine were found to be statistically significant predictors of Hg in fish tissue and loon blood, and, therefore, were included in the final model: total Hg deposition, watershed area, percent forest canopy area, percent wetland area, percent agricultural land, human population, watershed slope, mean annual temperature, and watershed alkalinity (Table 2). MERGANSER also includes three interaction terms, which means that the effect of one independent variable on the dependent variable (i.e., fish Hg or loon Hg) depends on the value of another independent variable. As shown on Table 2, the three interaction terms are percent scrub-shrub land and total Hg deposition, percent forest canopy and total Hg deposition, and total Hg deposition and watershed alkalinity. The model explains about 63 percent of the variance in Hg levels of all fish and loon samples included in the model. Model results may vary slightly from those shown in Table 2 with adjustments to model runs.

An important point is that the empirical modeling approach used in MERGANSER demonstrates correlation, but does not prove any causal mechanisms. The research team inferred likely causal mechanisms linking independent to dependent variables and reasons for positive or negative values of correlations. These interpretations were supported by other studies.

Examples of model results are shown on Figures 5 and 8 for 32-cm smallmouth bass and Figure 6 for common loon. Under current conditions (Figure 5), the median Hg concentration in smallmouth bass in all MERGANSER lakes is predicted to be 0.53 µg/g, with fish in 90 percent of the lakes exceeding EPA's recommended limit.

For loons (Figure 6), MERGANSER gives a median Hg concentration of 1.07 µg/g Hg (as FLU) for loons in all MERGANSER lakes, with 58 percent of these watersheds at moderate to high risk for having loons with blood concentrations greater than 1 µg/g Hg. Blood Hg levels above 1 ug/g are considered "elevated," or above normal background levels. Loons start to exhibit reproductive, behavioral, and physiological changes between 1 and 3 ug/g in blood.

Model results show that fish Hg and loon Hg respond to the gradient of total Hg deposition across New England, decreasing from southwest to northeast. The forest canopy of New England enhances dry Hg deposition (Miller et al., 2005). This is demonstrated by the positive interaction of total Hg deposition with the percent of shrub-scrub land and forest canopy. The significance of watershed alkalinity in MERGANSER is consistent with independent evidence that fish Hg is higher in more acidic lakes (e.g., Driscoll et al., 2007). This is also supported by the positive coefficient on the interaction term of total Hg deposition with watershed alkalinity.

The relation of land cover to fish Hg was similar to many other studies. The amount of wetlands in a watershed can be a significant factor because wetlands are primary sites of Hg methylation and DOC production (e.g., Mitchell et al., 2008). For the MERGANSER dataset, the amount of wetlands in a watershed was a better predictor of fish Hg than the percent of wetlands bordering a lake, but other studies have found stronger linkages between fish Hg and these bordering wetlands.

The presence of agricultural land was a weak predictor of fish Hg, possibly due to the tendency for mercury to be transported from cultivated areas with eroding soil. Some of these soils may contain mercury from past use of mercury as a fungicide as well as from atmospheric deposition.

MERGANSER predicts that fish Hg will be affected by natural landscape features, making some lakes inherently more vulnerable to increased Hg concentrations in fish tissue. For example, fish Hg is predicted to increase with watershed size, but decrease with watershed slope. The inverse relationship between fish Hg and slope may be explained by runoff rates, with higher rates allowing less time for mercury deposited from the atmosphere to be transformed to MeHg before discharge via runoff into a lake.

MERGANSER also predicts that fish Hg and loon Hg will be affected by human-mediated factors at regional and national, and even global, scales. For example, an increase in fish Hg is predicted for increases in human population density, and for decreases in mean annual temperature. Increased population may indicate disturbance of the landscape, which can mobilize mercury. The temperature effect may be due to the slower growth of fish under colder conditions, resulting in a greater amount of mercury per mass of fish tissue over a longer life cycle (Simoneau et al., 2005).

HOW WILL MERGANSER RESULTS BE USED?

MERGANSER data and results are available to all as a web-based interactive tool (http://www.epa.gov/aed/html/wildlife/index.html) for identifying aquatic ecosystems in New England at risk for mercury contamination. The model provides predicted mercury concentrations in fish tissue and loon blood for 4,404 "MERGANSER lakes" (20 acres or more in size).

For fish, an example prediction is the probability that a 32-cm (13 in) smallmouth bass will exceed the MeHg limit established to protect human health (0.3 µg/g) (Figure 5). Such predictions can be used by states to reassess existing advisories or to produce probability-based fish-consumption advisories. Predictions can also be used to check whether lakes are likely to meet target fish-tissue Hg concentrations established by the Northeast Regional Mercury Total Maximum Daily Load (TMDL) (NEIWPCC, 2007).

MERGANSER also can be used to predict changes in fish Hg or loon Hg as a result of changes in atmospheric Hg deposition, temperature changes due to climate change, or changes in land use. Predictions are available under "current" conditions, which are those conditions (human population, air temperature etc.) used to build the MERGANSER model and under "future" conditions," which reflect "what if" scenarios, such as a 2-degree Celsius rise in air temperature or a 10-percent increase in agricultural land throughout the region.

For example, scenario testing suggests that increasing average annual air temperature by a few degrees tends to reduce fish Hg (Figure 8). This is consistent with the fact that fish generally grow faster in warmer climates, thus reducing the time for MeHg to bioaccumulate. In addition, increasing temperature enhances plankton growth, diluting mercury in this food source (Chen et al., 2005).

MERGANSER results for common loons are useful to U.S. EPA and other agencies for making ecological risk estimations, which characterize the probability of adverse population effects of mercury to wildlife in watersheds under both "current" and "future" conditions.

IS MERGANSER USEFUL IN OTHER AREAS OF THE US?

Although MERGANSER was developed to predict human health and ecosystem risk in New England, the model improves understanding of the factors that increase the risk of Hg contamination in fish and wildlife (using common loons as an indicator). MERGANSER provides a modeling approach and initial model results for other regions of the U.S. Model variables and coefficients can be modified by inputting data specific to those other regions. Models for regions with forested, humid watersheds like those of New England should be similar to MERGANSER. However, predictor variables and coefficients are likely to be quite different in regions, such as the southwestern U.S., with arid watersheds and few natural lakes.

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