Environ Monit Assess
DOI 10.1007/s10661-006-9466-4

A Critical Analysis of Illinois' Fish Mercury Monitoring Program, 1974–1998

David G. Jenkins

Received: 21 March 2006 / Accepted: 23 August 2006

Abstract Mercury contamination in fish is a serious public health concern that contrasts with other health benefits of eating fish. Like most US states, Illinois has monitored fish mercury contamination for decades to warn the public of mercury exposure risks by consuming fish. Has this monitoring program been effective in detecting public mercury exposure risks? I analyzed fish mercury contamination data from Illinois inland lakes (1974–1998; >2,300 samples, 18 fish species, 149 lakes) and found that: (a) sampling and analyses have been severely limited since 1985; (b) sampling effort varied widely among lakes and species, and (c) trends and spatial patterns were confused by this variability. As a result of a severely limited and nonstrategic monitoring program, public mercury exposure risks via Illinois fish consumption remain unclear, despite much effort over many years. Illinois monitors fewer fish per angler than many US states, but is not alone in this regard. Illinois should resurrect and redesign its fish contaminant monitoring program to one that strategically and systematically assesses human mercury exposure risk. Other US states and nations may also benefit from similar retrospective examinations of monitoring programs intended to protect public health.

D. G. Jenkins (✉)
Department of Biology, University of Central Florida,
4000 Central Florida Blvd.,
Orlando, FL 32816-2368, USA
e-mail: dgjenkin@mail.ucf.edu

Keywords Methylmercury · Exposure risk · Lake · Watershed · Largemouth bass · Retrospective analysis

1 Introduction

Fish is often recommended as part of healthy diet (Hu et al. 2002; Kromhout, 2001; Simopoulos, 1991, 1999), but fishes also bioaccumulate and bioconcentrate various environmental contaminants, and can serve as a source of these contaminants in the human food supply (A. Sigel & H. Sigel, 1997; Wiener, Krabbenhoft, Heinz, & Scheuhammer, 2002). Mercury (Hg) has been prominent in this regard due to its effects on human neurological development, especially among populations consuming fish as a large proportion of their diet (Birke, Johnels, Plantin, Sjostrand, Skerfving, & Westermark, 1972; Davidson et al., 1998; Fitzgerald & Clarkson, 1991; Ratcliffe, Swanson, & Fischer, 1996; Schober et al., 2003).

Regulatory agencies attempt to curtail sources of contaminants and issue public advisories on fish consumption, including bans on consumption in some cases. Risk assessment decisions that form the underlying rationale for regulatory actions require information on both exposure risk and dose-responses, and many states have long been monitoring fish contamination for exposure assessment. For example, the State of Illinois has monitored contaminants in multiple fish species of multiple waters since 1974. Data are examined by the interagency Illinois Fish

Contaminant Monitoring Program (IFCMP) for annual decisions regarding individual lakes, fish species and sizes, and in some cases, statewide advisories.

Like most US states, Illinois issued in 2002 a statewide advisory on predator fish consumption, based on methylmercury contamination [Illinois Department of Public Health Fish Advisories (IDPH); http://www.idph.state.il.us/envhealth/fishadv/fishadvisory02.htm]. This prudent decision was based on evidence of prenatal and neonatal health risks upon exposure (NRC, 2000; US EPA, 1997a, 1997b), rather than exposure assessments based on Illinois' long-term monitoring results (IDPH).

Ideally, a statewide monitoring effort would inform regulatory decisions, and would be designed to best inform anglers of health risks due to fish consumption, proportional to contamination and fishing activity. In reality, budgetary support for fish mercury monitoring dictates the extent and intensity of a state monitoring program, and states vary in their reinvestment of angler-generated funds (i.e., fishing license fees and taxation of fishing-related purchases) into fish contaminant monitoring (Figure 1). Illinois ranked 9th in the number of 1996 anglers (US FWS, 1997), but ranked only 36th out of 40 states in a national survey of fish mercury monitoring records during 1990–1995 (US EPA, 1999). However, Illinois was not alone in the 1990s in its paucity of mercury monitoring per angler: other states may also be considered lacking in this regard (Figure 1). Therefore, analyses of Illinois' fish mercury monitoring program may be instructive for monitoring programs in multiple states.

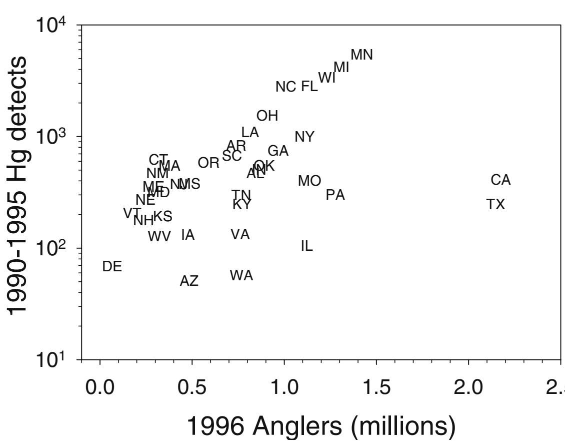

Figure 1 Relationship between the scale of statewide fish mercury contamination efforts (reported as the number of detections 1990–1995; US EPA, 1999) and estimated number of freshwater anglers in 1996 (US FWS, 1997). Note the logarithmic scale for monitoring effort (number of detects).

No synoptic analysis of mercury contamination trends in fish of Illinois lakes has been conducted to assist in public health decisions or to indicate potential adjustments to the monitoring program, though Lake Michigan mercury contamination has been the focus of multiple studies (e.g., Cleckner, Esseks, Meier, & Keeler, 1995; Grieb, Driscoll, Gloss, Schofield, Bowie, & Porcella, 1990; Landis, Vette, & Keeler, 2002; Mason & Sullivan, 1997) and was excluded from this analysis. The purpose of this study was to analyze 25 years (1974–1998) of data on mercury contamination in inland lakes and reservoirs (hereafter collectively "lakes") of Illinois. I asked three questions:

(1) Has fish mercury contamination changed, and if so, did the monitoring program respond to that change? Contamination could change over time in (a) incidence of detectable Hg in fish or (b) Hg concentrations in fish with detectable Hg. Increased incidence or concentrations would indicate more monitoring is needed through time, while decreasing contamination through time may justify less monitoring.

(2) Did fish mercury contamination vary spatially, and if so, was the monitoring regime balanced appropriately? Spatial variation may be expected due to local Hg sources, including point source effluents and regional air pollution sources (Landis et al., 2002), and would indicate a spatially structured monitoring regime that should be weighted to the most heavily contaminated lakes.

(3) Did mercury contamination vary among fish species, and if so, was the monitoring regime targeted appropriately? Based on biomagnification of methylmercury (Wiener et al., 2002), predatory fish species (e.g., largemouth bass) should bear more Hg and advisories against consumption of predator fish (e.g., IDPH) are justified. Interspecific variation would also indicate monitoring consistently targeted to key species (e.g., predators).

2 Materials and Methods

Data from original fish contaminant analysis records of the Illinois Environmental Protection Agency (IEPA) for the 25-year period (1974–1998) were entered in spreadsheet software. Very few data have been collected since 1998 due to budget restrictions and were not readily available: it is likely that conclusions based on long-term records would not change with the addition of more recent, but very sparse, data. Ten percent of entries were randomly selected and directly proofread, plus outliers in analyses were proofed to ensure accurate data entry. In total, 4,032 samples were analyzed by IEPA for various contaminants (primarily organic compounds), representing 18 fish species from 149 lakes and distributed among 10 major watersheds. Of that total, 2,326 samples (57.8% of total) were analyzed for mercury. Detection limits for mercury were maintained at 0.01 mg kg^{-1} (fresh weight) throughout the study period and do not contribute to any variations through time. However, data were not consistently collected for all lakes, fish species and years: this variation in the monitoring program limited statistical analysis options. Rather than analyze data from individual lakes that varied greatly in sampling effort, data were analyzed at the watershed level to condense presented results and to aggregate marked variation among lakes in the number of available data records. This aggregation may mask variation among lakes due to water quality, etc. (Rose et al., 1999), but enabled a more cogent summary of results.

Some data sets (e.g., watersheds) were not distributed normally and did not exhibit homogeneous variance after transformations for several comparisons. Instead, nonparametric analyses (Kruskal–Wallis tests, followed in some cases by Dunn's multiple comparisons test; Zar, 1999) were used. The Kruskal–Wallis test is a nonparametric analog of parametric analysis of variance, and Dunn's test is analogous to parametric multiple comparison tests (e.g., Tukey's HSD) and is designed for unequal sample sizes (Zar, 1999). Linear regressions were employed where appropriate, as were histograms, box plots, and simple trends over time. Statistical analyses were conducted with SPSS (version 11.5), or via spreadsheet (Dunn's test).

3 Results

3.1 Has fish mercury contamination changed, and if so, did the monitoring program respond to that change?

Mercury contamination was considered in terms of incidence and concentration. Mercury was detectable in ≥80% of analyzed fish from Illinois inland lakes until 1980. The portion of fish with detectable Hg concentrations dropped from >90% in 1980 to ≤20% in 1984 and thereafter (Figure 2). A constant analytical detection limit (0.01 mg/kg) and presumed technological improvements in extraction and analysis cannot explain this trend; it can only be due to (a) reduced contamination, or (b) changes in sampling regime.

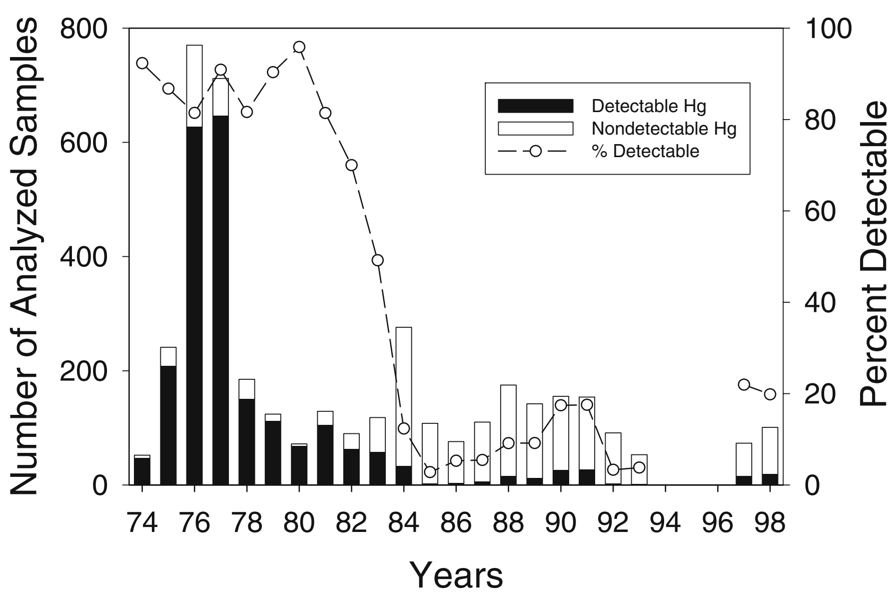

Figure 2 Number of fish samples analyzed for Hg in Illinois inland lakes, 1974–1998 (*total bar height*). *Black bars* represent samples with detectable Hg concentrations (≥0.01 mg kg^{-1}) and *white bars* represent nondetectable Hg (<0.01 mg kg^{-1}). *Circles* represent the percent of samples with detectable Hg concentrations (right-hand scale). No samples were collected 1994–1996.

If contamination was reduced, then both Hg concentrations and contamination frequency should have decreased over time. However, [Hg] in fish with detectable concentrations increased during this time. Overall median [Hg] in fish for all years studied was 0.10 mg kg^{-1} fresh weight, and the fraction of fish that exceeded that median in 1985–1998 was significantly greater than during 1974–1984 (Mann–Whitney test, P=0.003), despite having fewer fish sampled with detectable concentrations during the latter period. In other words, Hg concentrations in fish of Illinois lakes increased through the years, when detected. Therefore, the monitoring program appeared to confound apparent trends in fish Hg contamination, due to results presented below.

3.2 Did fish mercury contamination vary spatially, and if so, was the monitoring regime balanced appropriately?

Watersheds were significantly different in fish tissue Hg concentrations (Kruskal–Wallis; P<0.001), but sampling effort across the state was not targeted to Hg contamination patterns (Figure 3). For example, lakes in the Kaskaskia, Big Muddy and Sangamon River watersheds were heavily sampled but differed in detection frequency and contamination, while lakes in the Little Wabash and Rock River watersheds were infrequently sampled but Hg was either commonly detectable (Little Wabash) or tended to have higher concentrations than most other watersheds (Rock;

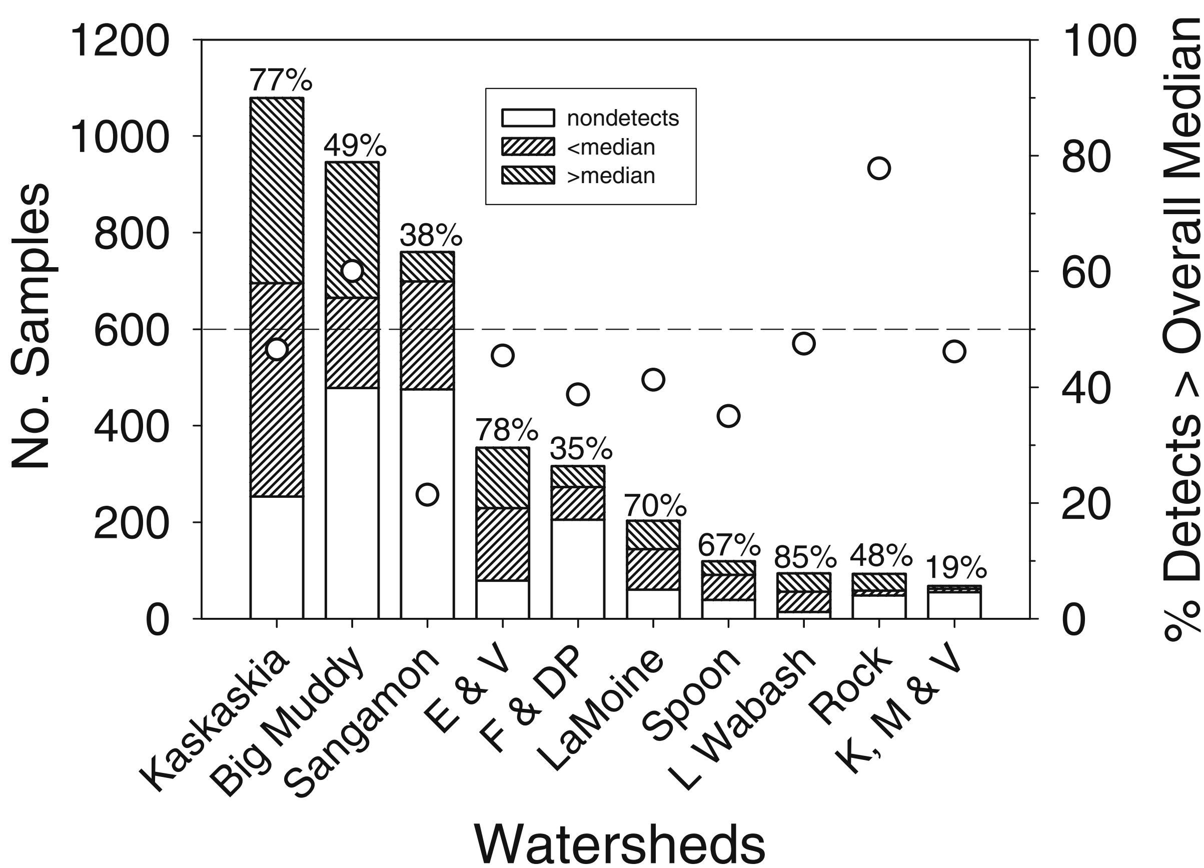

Figure 3 Number of fish samples per watershed (all years combined). Watersheds are listed in decreasing order of the total number of samples, and *bar segments* represent the portion of samples with detectable [Hg] > or < overall median concentrations (0.10 mg kg^{-1}), or nondetectable concentrations (<0.10 mg kg^{-1}). *E & V*, Embarras and Vermillion; *F & DP*, Fox & Des Plaines; and *K, M & V*, Kankakee, Mackinaw & Vermilion Rivers. *Values above each bar*=% of samples that contained detectable Hg concentrations. *Circles*=% of detectable samples in a watershed with concentrations > overall median Hg concentration of 0.1 mg/kg (*horizontal dashed line, scaled on right axis*). The majority of detectable [Hg] values in fish of Big Muddy and Rock River watersheds exceeded the statewide median Hg concentration, indicating that lakes in those watersheds were more likely to have higher Hg fish contamination than other lakes.

Figure 3). In addition, less contaminated watersheds (e.g., Sangamon) were more frequently sampled after 1985 than more contaminated watersheds (e.g., Rock).

Lakes within a watershed also varied in contamination and sampling effort. For example, most (77%) fish samples from the Kaskaskia River watershed had detectable Hg (Figure 3) and median values for most Kaskaskia watershed lakes were roughly consistent with the statewide median (0.1 mg Hg kg^{-1} fresh wt.). However, Kaskaskia River watershed lakes were significantly different for mercury fish tissue Hg concentration (Kruskal–Wallis test, $P<0.001$). Nineteen lakes were sampled within the Kaskaskia watershed during the 25 years, but two (Shelbyville and Carlyle) accounted for 73% of all detections in the watershed. Spatial variation in fish tissue Hg contamination did not correspond well with spatial and temporal patterns of sampling effort among lakes and watersheds, which contributed to the counter-intuitive trends in fish tissue Hg concentrations (Question 1, above) statewide.

3.3 Did mercury contamination vary among fish species, and if so, was the monitoring regime targeted appropriately?

As expected given the limited sampling effort and the variable nature of fish surveys, composition of sampled fish communities varied in space and time. Given that different fish species tend to bear different [Hg], and that larger fish are more likely to accumulate greater [Hg], patterns and trends revealed above reflect the specific fish sampled. Four fish species comprised 63% of all fish samples and 56% of all Hg detections among 36 species (plus an "unknown" category) and are presented here: largemouth bass (*Micropterus salmoides*; 20%), common carp (*Cyprinus carpio*; 22%), bluegill sunfish (*Lepomis macrochirus*; 7%), and channel catfish (*Ictalurus punctatus*; 14%). For the 1,307 fish tissue Hg concentrations among those four species, 742 values also had both weight and length of the fish recorded. Fish weight was used to adjust for fish size because weight and length were strongly correlated ($P<0.001$) for all species and because more weights were recorded (N=1,052) than lengths (N=818).

Mercury concentrations were significantly different among the four dominant species (Kruskal–Wallis test; $P<0.001$), because largemouth bass had significantly more mercury than the other species (Dunn's test; $P<0.001$; Figure 4a). Heavier largemouth bass tended to contain greater [Hg] (linear regression $R^2=0.151$, $P<0.001$), but watersheds were also significantly different for [Hg] in largemouth bass (Kruskal–Wallis test; $P<0.001$). Largemouth bass in the Rock River watershed had the greatest tissue Hg concentrations, and bass in the Sangamon River watershed had the least mercury contamination, consistent with analyses of all fish samples (see Figure 2). Also, watersheds differed in timing of available data.

Less contaminated species were more commonly analyzed after sampling was greatly reduced during the 1980s and progressively came to dominate fish composition of collected samples (Figure 4b). This trend plus spatial variation described above contributed to the incidence-concentrations paradox (Question 1).

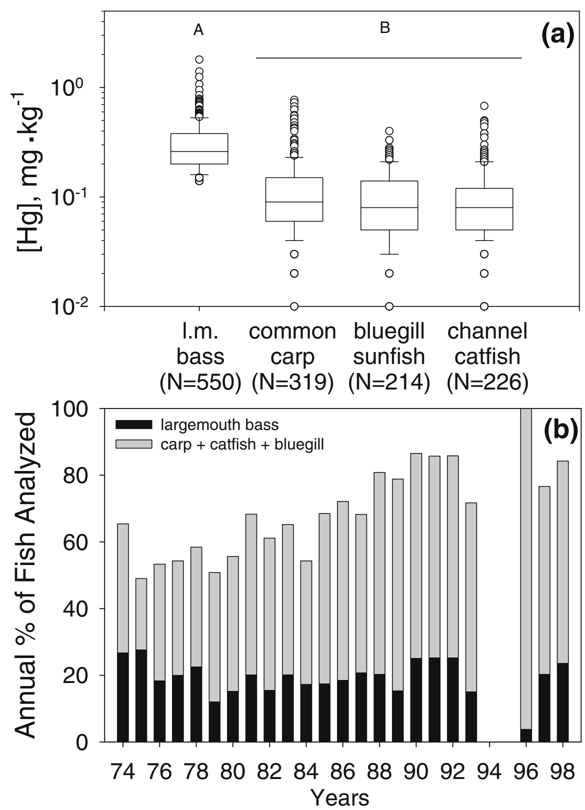

Figure 4 Mercury concentrations in the four most frequently sampled and analyzed fish species. (a) Largemouth bass had significantly more Hg than the other three species (Dunn's test; $P<0.001$), which did not significantly differ. (b) Largemouth bass were roughly 20% of analyzed fish throughout the 25 years, but less contaminated fish (carp, bluegill sunfish and channel catfish) became a greater proportion of analyzed samples through the years.

4 Discussion

Overall, the dramatic reduction in fish contaminant monitoring has hampered Illinois' ability to accurately inform its citizens of potential mercury exposure risks by consuming fish from inland lakes. Two decades of very limited monitoring is especially troublesome given that tissue Hg concentrations in fish have not decreased. As an apparent result of limited support for fish contaminant monitoring for two decades, the mercury monitoring program has been heavily swayed by coinciding needs to sample for other contaminants (e.g., PCBs, DDT, chlordane) with different distributions among species and lakes, and the occasional availability of personnel to scientifically sample fish while conducting other assigned tasks.

This mercury monitoring program "drift" has contributed to monitoring data that seem paradoxical (Question 1), spatially mismatched (Question 2), or poorly targeted to key sport fish (Question 3). If a full program existed (perhaps comparable to the scale of the program in the 1970s), increasing tissue Hg concentrations observed among fewer fish with detectable Hg might have indicated underlying sampling problems (i.e., inadequate spatial representation and interspecific differences in [Hg]). Instead, sampling effort was not adaptively managed during the program to strategically sample lakes, watersheds, and fish species most heavily contaminated with mercury and preferred as sport fish. In addition, the sampling program did not account for water quality differences among lakes that potentially affect Hg contamination (Rose et al., 1999). Analyses here did not account for those potential affects either: water quality data would first need to be collected and matched with Hg sampling efforts.

Given the constraints outlined above, the IFCMP issued a statewide advisory for consuming predatory fish, based on health risks for pregnant women and children due to mercury consumption (NRC, 2000) and well-recognized biomagnification of methylmercury (Wiener et al., 2002). While this advisory was consistent with advisories of other states (US EPA, 2003), fish consumption advisories alone are only partially effective (Anderson, Hanrahan, Smith, Draheim, Kanarek, & Olsen, 2004; Knobeloch, Anderson, Imma, Peters, & Smith, 2005); strategic monitoring programs that assess exposure risk are better than blanket restrictions based only on health risk studies (NRC, 2000). In addition, actions based on partial (and often outdated) exposure risk information may be overly conservative in some lakes (e.g., those in the Sangamon River watershed).

Public perception of Illinois fishing value appears to have declined recently in terms of the time spent fishing and associated expenditures (Table I). As a result, state revenues based on fishing licenses and fishing-related taxes have decreased, which only serves to further restrict the ability of the state to reactivate its monitoring program to adequately evaluate actual exposure risks. And because fish contaminant monitoring has been severely limited, the IFCMP acted in the public's best interest by issuing a statewide advisory against eating predatory fish due to Hg contamination. Thus the State of Illinois may desire to increase fishing-related revenues but find itself struggling to convince anglers to spend their fishing money in Illinois.

How might Illinois break this cycle? The State of Illinois demonstrated in the 1970s that it can implement a substantial sampling and analysis program, and should fund an aggressive, statistically

Table I Illinois inland lakes fishing statistics, estimated for 1996 and 2001

Category	1996	2001	Change
1. Total IL Anglers (% of US)[a,b]	991,000 (3.4%)	986,000 (3.5%)	−5,000 (0.1%)
2. Total days fishing (% of US)[a,b]	12,567,000 (2.6%)	11,110,000 (2.5%)	−1,457,000 (−0.1%)
3. Average expenditure per angler	$998	$399	−$599
4. Estimated total expenditures (line 1 × line 3), in millions of $	$989.0	$393.4	−$595.6
5. Illinois expenditures as % of US total[b]	4.4%	1.9%	−2.5%

Data were extracted from US FWS (1998) and US FWS (2003) and apply only to the population ≥16 years old. Expenditure data were not adjusted for inflation.

[a] Illinois anglers in ponds, lakes and reservoirs (excluding Lake Michigan and rivers and streams).

[b] US total for freshwater fishing, except Great Lakes.

designed, multiyear monitoring effort, consistent with US Environmental Protection Agency guidelines (US EPA, 2000) and with the goal of assessing current statewide Hg exposure risks in comparison to those of the 1970s. That greatly enhanced sampling program should also collect water quality data in sampled lakes. After those analyses are completed, the State could then implement a more cost-effective strategic monitoring program that targets contaminated lakes and key fish species, and compares those results to reference lakes. For example, lakes found to have fish populations contaminated with Hg could be matched in water quality to lakes with low Hg contamination for further monitoring and better-informed advisories. Other lakes with little or low contamination could be placed on a less frequent monitoring schedule. With such a monitoring program in place, the State of Illinois could provide substantive information for the safety of its citizens and attract anglers to fish in selected lakes. Until then, anglers would be well advised to heed the statewide advisory against consuming predatory (and other) fish due to presumed mercury contamination.

Finally, this study was conducted on the premise that results may be instructive for programs that monitor fish mercury contamination in other states and nations. How does your government's program to monitor fish mercury contamination compare?

Acknowledgments I thank Lance Range and Celeste Crowley for their help: this effort would not have been possible without their assistance.

References

Anderson, H. A., Hanrahan, L. P., Smith, A., Draheim, L., Kanarek, M., & Olsen, J. (2004). The role of sport-fish consumption advisories in mercury risk communication: A 1998–1999 12-state survey of women age 18–45. *Environmental Research,* 95, 315–324.

Birke, G., Johnels, A. G., Plantin, L. O., Sjostrand, B., Skerfving, S., & Westermark, T. (1972). Studies on humans exposed to methyl mercury through fish consumption. *Archives of Environmental Health, 25*, 77–91.

Cleckner, L. B., Esseks, E. S., Meier, P. G., & Keeler, G. J. (1995). Mercury concentrations in 2 great waters. *Water Air and Soil Pollution, 80*, 581–584.

Davidson, P. W., Myers, G. J., Cox, C., Axtell, C., Shamlaye, C., Sloane-Reeves, J., et al. (1998). Effects of prenatal and postnatal methylmercury exposure from fish consumption on neurodevelopment: Outcomes at 66 months of age in the Seychelles Child Development Study. *Journal of the American Medical Association, 280*, 701–707.

Fitzgerald, W. F., & Clarkson, T. W. (1991). Mercury and monomethylmercury: Present and future concerns. *Environmental Health Perspectives, 96*, 159–166.

Grieb, T. M., Driscoll, C. T., Gloss, S. P., Schofield, C. L., Bowie, G. L., & Porcella, D. B. (1990) Factors affecting mercury accumulation in fish in the Upper Michigan peninsula. *Environmental Toxicology and Chemistry, 9*, 919–930.

Hu, F. B., Bronner, L., Willett, W. C., Stampfer, M. J., Rexrode, K. M., Albert, C. M., et al. (2002). Fish and omega-3 fatty acid intake and risk of coronary heart disease in women. *Journal of the American Medical Association, 287*, 1815–1821.

Knobeloch, L., Anderson, H. A., Imma, P., Peters, D., & Smith, A. (2005). Fish consumption, advisory awareness, and hair mercury levels among women of childbearing age. *Environmental Research, 97*, 220–227.

Kromhout, D. (2001). Diet and cardiovascular diseases. *Journal of Nutrition, Health & Aging, 5*, 144–149.

Landis, M. S., Vette, A. F., & Keeler, G. J. (2002). Atmospheric mercury in the Lake Michigan basin: Influence of the Chicago/Gary urban area. *Environmental Science & Technology, 36*, 4508–4517.

Mason, R. P., & Sullivan, K. A. (1997). Mercury in Lake Michigan. *Environmental Science & Technology, 31*, 942–947.

National Research Council (2000). *Toxicological effects of methylmercury* (344 pp.). Washington, DC: National Academy Press.

Ratcliffe, H. E., Swanson, G. M., & Fischer, L. J. (1996). Human exposure to mercury: A critical assessment of the evidence of adverse health effects. *Journal of Toxicology and Environmental Health, 49*, 221–270.

Rose, J., Hutcheson, M. S., West, C. R., Pancorbo, O., Hulme, K., Cooperman, A., et al. (1999). Fish mercury distribution in Massachusetts, USA lakes. *Environmental Toxicology and Chemistry, 18*, 1370–1379.

Schober, S. E., Sinks, T. H., Jones, R. L., Bolger, P. M., McDowell, M., Osterloh, J., et al. (2003). Blood mercury levels in US children and women of childbearing age, 1999–2000. *Journal of the American Medical Association, 289*, 1667–1674.

Sigel, A., & Sigel, H. (Eds.) (1997). *Metal ions in biological systems, Vol. 34 Mercury and its effects on environment and biology* (604 pp.). New York: Marcel Dekker.

Simopoulos, A. P. (1991). Omega-3 fatty acids in health and disease and in growth and development. *American Journal of Clinical Nutrition, 54*, 438–463.

Simopoulos, A. P. (1999). Essential fatty acids in health and chronic disease. *American Journal of Clinical Nutrition, 70*, 560S–569S.

US EPA (1997a). *U.S. Environmental Protection Agency Mercury Study Report to Congress, Vol. I: Executive summary* (EPA-452/R-97-007). Retrieved April 8, 2005, from http://www.epa.gov/ttn/oarpg/t3/reports/volume1.pdf.

US EPA (1997b). *U.S. Environmental Protection Agency Mercury Study Report to Congress, Vol. II: An inventory of anthropogenic mercury emissions in the United States* (EPA-452/R-97-004). Retrieved April 8, 2005, from http://www.epa.gov/ttn/oarpg/t3/reports/volume2.pdf.

US EPA (1999). *U.S. Environmental Protection Agency national survey of mercury concentrations in fish data base summary, 1990–1995* (EPA-823-R-99-014). Washington, DC: US EPA.

US EPA (2000). *U.S. Environmental Protection Agency guidance for assessing chemical contaminant data for use in fish advisories. Vol. 1: Fish sampling and analysis* (3rd edn.; EPA 823-B-00-007).

US EPA (2003). *U.S. Environmental Protection Agency update: National listing of fish and wildlife advisories* (EPA-823-F-03-003). Washington, DC: US EPA.

US FWS (1997). *U.S. Department of the Interior, Fish and Wildlife Service and U.S. Department of Commerce, Bureau of the Census 1996 national survey of fishing, hunting, and wildlife-associated recreation* (FHW/96 NAT). Retrieved August 25, 2004, from http://www.census.gov/prod/3/97pubs/fhw96nat.pdf.

US FWS (1998). *U.S. Department of the Interior, Fish and Wildlife Service, and U.S. Department of Commerce, Bureau of the Census 1996 national survey of fishing, hunting, and wildlife-associated recreation* (Illinois report no. FHW/96-IL). Retrieved August 25, 2004, from http://www.census.gov/prod/3/98pubs/ilfhw698.pdf.

US FWS (2003). *U.S. Department of the Interior, Fish and Wildlife Service and U.S. Department of Commerce, U.S. Census Bureau 2001 national survey of fishing, hunting, and wildlife-associated recreation* (Illinois report no. FHW/01-IL-Rev). Retrieved August 25, 2004, from http://www.census.gov/prod/2003pubs/01fhw/fhw01-il.pdf.

Wiener, J. G., Krabbenhoft, D. P., Heinz, G. H., & Scheuhammer, A. M. (2002). Ecotoxicology of mercury. In D. J. Hoffman, B. A. Rattner, G. A. Burton, Jr., & J. Cairns, Jr. (Eds.), *Handbook of ecotoxicology* (2nd edn., pp. 407–461). Boca Raton, FL: CRC Press.

Zar, J. H. (1999). *Biostatistical analysis* (4th edn.) Upper Saddle River, NJ: Prentice Hall.