Environmental Assessment and Risk Analysis Element

NJDEP

Research Project Summary

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Assessment of Total Mercury Concentrations in Fish from Rivers, Lakes and Reservoirs in New Jersey

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Abstract

In 1996-97, Academy Natural Sciences, Philadelphia (ANSP) conducted a study of mercury levels in freshwater gamefish in New Jersey. A total of 258 fish samples from 30 water bodies were analyzed. These included single fillet samples of 58 largemouth bass, 58 chain pickerel and 109 large specimens of other commonly consumed species and 32 whole-body analysis of forage fish species. The results of this study are consistent with ANSP 1992-93 mercury in fish research in New Jersey. The highest mercury concentrations were in fish from the Pine Barrens region and marginal to the Pine Barrens. Mercury levels varied greatly in fish from industrial areas, northern and northwestern waterways and cold-water streams. Mercury concentrations typically increased with species trophic level, but among-species variation within each group was observed. Highest levels were typically found in piscivorous species (e.g., chain pickerel, largemouth bass), as well as in larger and older specimens of all species analyzed. Lower mercury concentrations were seen in a wide variety of commonly consumed species including perch, sunfish, crappie, catfish and bullhead. Mercury levels in samples of forage fish varied by species and location. Elevated mercury concentrations in chain pickerel were explained by models identifying a decreaseing gradient from low alkalinity, high DOC, low pH sites (e.g., Pine Barrens), to higher alkalinity, low DOC, high pH sites (e.g. some northern lakes). For chain pickerel, mercury concentrations were typically higher in fillets verses whole body, with median ratios of 1.3 times greater than the whole body. In addition, the results of the 1994-95 NJDEP 15 lake follow-up study (reported herein) are in agreement with the ANSP 1992-93 study and this investigation. Also reported herein is a review of the entire five-study database (1100 samples) showing that mercury is ubiquitous in New Jersey freshwater systems. Although regional differences exist (e.g., Pine Barrens), mercury has been found in freshwater fish from all geographical areas of the state. Mercury levels for the Pine Barrens and non-Pine Barrens fish are consistent over the entire database. Elevated mercury levels are identified in top trophic level species, in individual specimens from each trophic level and in larger and/or older specimens of all species. While mercury concentrations were generally found to be less in lower and bottom trophic level species, mercury concentrations in some of these most commonly consumed species were greater than NJDEP thresholds that can trigger fish consumption advisories.

Introduction

Bioaccumulation of mercury in fish is of concern because of potential human health effects from fish consumption, as well as potential effects on fish-eating wildlife. Human-caused inputs of mercury to the environment have occurred from industrial point source discharges, various nonpoint sources (e.g., mercury in pesticides), release of traceable quantities of mercury in coal (e.g., by power plants), and processing of mercury-containing products and waste (e.g., by incineration). Atmospheric transport can contribute significant quantities of mercury to waterbodies without point sources. For example, mercury is found in fish from remote Arctic lakes, and mercury concentrations in fish from Midwestern and Canadian lakes (e.g., Minnesota, Michigan, Ontario) have led to consumption advisories. Contaminated soil and sediment can lead to continued inputs after cessation of direct discharge. In New Jersey, atmospheric inputs may come from both local and distant sources, while aquatic inputs may have come from industrial use of mercury within the state.

Fish bioaccumulate mercury mainly in the form of methylmercury, an organic complex produced by bacteria from inorganic mercury. Rates of methylation of mercury vary with environmental factors such as pH, and these differences may control the level of bioaccumulation in fish. Differences in bioaccumulation between sites may be due to differences in lake chemistry, productivity, and lake/basin geometry. The reasons for these relationships are not fully understood. Within a single waterbody, however, mercury concentrations tend to be highest in piscivorous species (fish that eat other fish), and tend to increase with the age and/or size of a fish.

Government agencies in different states, provinces and countries currently use a variety of regulatory criteria for determining whether mercury concentrations in fish are too high for safe consumption by humans. The most common thresholds are 1.0 mg/kg wet weight (used by the FDA for restriction of commercial sale of fish) and 0.5 mg/kg (with advisories of no or restricted consumption of fish with higher concentrations). In 1994, NJDEP/DSRT and the Toxics in Biota Committee (TIBC) derived a risk-based criteria for mercury concentrations as low as 0.08 mg/kg as a trigger for advisories of restricted consumption among the most vulnerable segments of the human population, such as children and pregnant women. Differences in these criteria spring from several sources, including the amount of fish assumed to be eaten per year, the dose-response relationship employed, and the level of risk considered to be tolerable.

Background

In 1992-93 ANSP, with funding by NJDEP/DSRT conducted a preliminary screening assessment of mercury in freshwater fishes of New Jersey (ANSP, 1994a). The study found mercury concentrations of concern in several species of freshwater fish from a number of lakes, rivers and reservoirs throughout the state. These preliminary data were used to develop the initial mercury related consumption advisories for recreationally caught freshwater fishes in New Jersey. In 1994, ANSP completed two other studies, one in Camden County (ANSP, 1994b) and one in the reservoirs of northeastern New Jersey (ANSP, 1994c). In 1994-95, DSRT and the New Jersey Department of Health and Senior Services (DHSS) analyzed mercury in a variety of fish specimens from fifteen of the 55 lakes that had been sampled in the 1992-93 ANSP preliminary screening study. The findings of that follow-up study were used to design this latest mercury in fish research and are reported herein. In addition to the results of this investigation this report includes an overview of all five studies, comprising over 1,100 mercury in fish samples. The entire five-study database has been reviewed by TIBC for revision of the current fish consumption advisories.

Study Design

The direction of the 1996-97 ANSP study is to address some of the issues unresolved by the preliminary screening assessment. The objectives of this study are to:

- Provide more extensive spatial data on mercury concentrations in New Jersey freshwater fish.
- Provide information on roles of different tropic pathways within sites on mercury bioaccumulation.
- Provide information on mercury concentrations in species of fish “commonly consumed”.
- Compare concentrations of mercury in fillets and the whole body of selected specimens.
- Provide a basis of predicting mercury concentrations in fish from waterbody chemistry and geology.
- Provide an assessment of the entire five-study NJDEP/ANSP mercury in fish database.

The *a priori* stratification of the waterways to be sampled was established based on geographical location, geological setting of the waterbody, and water chemistry (pH). The stratification was designed to represent the gradient in water chemistry from highly acidic, low alkalinity sites in the Pine Barrens through alkaline sites in carbonate regions in northern New Jersey. Separate strata were set up for large, unique lakes, and for sites in industrial regions that have known or likely histories of point source mercury contamination. This stratification regime was a modification of one that was used for the earlier 1992-93 study, thereby allowing use of data from that study for comparison.

Because of the large number of waterbodies in New Jersey (4000+), only a subset could be sampled. Sites sampled for this study were sites that had shown high or variable mercury concentrations in previous studies, or for which little information was available. Priority was given to Pine Barrens sites, sites marginal to the Pine Barrens, sites in industrial areas, cold-water streams, northern lakes, and sites in the northwestern part of the state. Emphasis was placed on those strata for which little data were available in the 1994 ANSP report, for which mercury bioaccumulation was potentially relatively high, and/or for which the 1994 ANSP report data showed high variability among sites. Table 1 is the list of waterbodies sampled in the 1996-97 ANSP study. The list was developed using NJDEPE /Division of Fish, Game and Wildlife (1992) “Places to Fish” list of public waters, USGS topographic maps, and New Jersey county stream drainage maps.

Table 1. - Waterbodies sampled in 1996-97 ANSP mercury sampling program.

Waterbody	Strata
Boonton Reservoir	Northern Carbonate Lake
Butterfly Bog	Pines Barrens Lake
Cedar Lake	Coastal Plain
Crater Lake	Northern Midland Lake
DeVoe Lake	Coastal Plain Lake
Delaware River above Camden	Delaware River
Delaware River below Camden	Delaware River
Double Trouble Lake	Pine Barrens Lake
Echo Lake Reservoir	Northern Carbonate Lake
Green Turtle Lake	Northern Carbonate Lake
Greenwood Lake	Unique Lake
Groves Mill Pond	Northern Midland Lake
Hainesville Pond	Northern Midland Lake
Malaga Lake	Coastal Plain Lake
Oak Ridge Reservoir	Northern Midland Lake
Passaic River @ Hatfield Swamp	Northern Industrial River
Pompton River @ Lincoln Park	Northern Industrial River
Pompton River @ Pequannock R.	Northern Industrial River
Raritan River @ Millstone Creek	Northern Industrial River
Raritan River @ Neshanic Station	Northern Industrial River
Raritan R., South Branch @ Clairmont stretch	Cold-water Stream
Tom's River, Ridgeway Branch	Pine Barrens River
Rockaway /Whippany River	Northern Industrial River
Speedwell Lake	Northern Midland Lake
Steenykill Lake	Northern Midland Lake
Success Lake	Pine Barrens Lake
Sunset Lake	Coastal Plain Lake
Wawayanda Lake	Northern Midland Lake
Whitesbog Lake	Pine Barrens Lake
Willow Grove Lake	Coastal Plain Lake

For the 1996-97 study, a total of 258 samples (not including QA/QC samples) of fish from the 30 sites were analyzed for total mercury. Table 2 is a list of fish species and trophic level designation sampled in this study. They include samples of 58 largemouth bass, 58 chain pickerel, and 109 large specimens of other "commonly consumed" species. In addition, a total of 32 samples of forage fish species (i.e., prey species) were sampled to determine the role of trophic transfer in mercury bioaccumulation. All gamefish samples were of a single fillet from legal size fish (where applicable). Depending on the specimen size, samples of forage fish were either whole body composite or whole body individual fish.

Table 2.- 1996-97 ANSP Freshwater Fish Species and Trophic Levels

Top Trophic Level	Lower Trophic Level	Bottom Trophic Species	Forage Fish Species
Largemouth bass	Brown trout	White catfish	Golden shiner
Smallmouth bass	Brook Trout	Channel catfish	Gizzard shad
Chain pickerel	Yellow perch	Brown bullhead	Alewife herring
Northern pike	White perch	Yellow bullhead	Creek chubsucker
	Black crappie		Bluespotted sunfish
	Rock Bass		Blackbanded sunfish
	Pumpkinseed sunfish		Juvenile sunfish
	Redbreast sunfish		Juvenile black crappie
	Bluegill sunfish		Juvenile white perch

Sampling Methods

All fish were collected by electrofishing, fish traps, haul seine, cast net, gill netting or angling. Most fish were obtained by personnel of ANSP and/or NJDEP, DSRT and Division of Fish and Wildlife (DFW). Additional specimens were made available by RMC, Inc., Tom Lloyd and Associates and by recruited private anglers. After capture, all fish were sorted by species and size, wrapped in re-washed, muffled aluminum foil, held on ice in clean plastic bags with identification tags and transported directly to the laboratory. All samples were then checked and grouped by waterbody, species and date collected and frozen until sample preparation. All sample handling was followed using chain of custody procedures.

Analytical Method

Specimen Preparation; Samples were partially or totally thawed, weighed, measured and filleted with the entire fillet on one side, including the belly flap, excluding skin. Carcass concentrations were determined for selected specimens after both fillets were removed. Carcass with a single fillet was used to estimate whole body concentrations for specimens on which only a single fillet was removed for tissue analysis. Whole-body samples were analyzed for all specimens of forage fish.

Each sample was minced and mixed, and a fraction of the sample was used for extraction and analysis. All surfaces in contact with the fillet were cleaned prior to preparation of each sample. Cleaning was done by either: a) muffling at 450°C. or b) rinsing in nitric acid and double-distilled water, solvent-cleaned in acetone followed by dichloromethane, or c) rinsing in dichloromethane. Notes were taken on the condition of each specimen, stomach contents, etc. Heads were removed as part of a separate project, and otoliths of some specimens were dissected and sectioned, allowing age estimation from banding patterns.

Analytical Analysis; Sample material was thawed either in a refrigerator overnight or during the day at room temperature. A fraction of each minced sample was tissumized. An optimal 1.0 gm (wet weight) of tissumized fish flesh was digested in 10 ml of concentrated (metal grade) nitric acid using microwave heating (CEM 1991). Digestion was in closed Teflon-lined vessels using CEM microwave model MDS-2100 (950 watts). Usually, 12 samples were digested at a time using a 5 stage-heating program in which temperature was used to control the digestion. Mercury in the diluted digestate was determined by Manual Cold Vapor Atomic Absorption (USEPA 1979). A series of standards and blank samples are part of the quality assurance/quality control methods employed, and both computer and hard copy logs were kept as a permanent record.

Statistical Analysis

Two basic statistical approaches were used to assess the differences in mercury concentrations among specimens and sites. The first estimates the mean mercury concentrations within discrete units and the second as functions of the physico-chemical parameters. A regression of mercury concentration against total length of the specimen was made for each species. Within species, different regressions were made for pHTYPEs (i.e., combination of pH group and lake/ reservoir versus river/stream) and/or pH groups. Regression models were used to calculate a predicted concentration based on specimen length, waterbody type and pH group, thereby allowing calculation of a predicted mercury concentration at a standardized length.

Investigations were made of statistical deviations from general patterns of mercury concentrations and of factors correlated with these deviations. These deviations examined the averages of the LDEV [deviations of 1n (mercury concentration) from predicted] among species within sites and among all specimens within stations as a measure of overall station variation from general pH patterns. These deviations were ranked to geographic location, type of waterbody, measures of lake and drainage size, and to characteristics of individual waterbodies. Secondly, for largemouth bass and chain pickerel, ANCOVA models were calculated using individual site as a factor nested within pH groups or pHTYPE; these estimate the significance of variation between waterbodies within groups. Apparent among-species differences in mercury concentrations may depend largely on species growth rates. Mercury concentrations were adjusted to compare fish at the sizes corresponding to standardized ages. The average size of fish of ages IV and V were estimated, and mercury concentrations at these sizes were predicted from the mercury length models. Estimates were made for different pHTYPES and pH groups.

Results/Discussion

The 1992-93 ANSP preliminary mercury in fish results (ANSP 94a) were used by NJDEP/DHSS to issue fish consumption advisories for largemouth bass and chain pickerel. Since the project was designed as a preliminary screening assessment only limited data on mercury concentrations in lower trophic level species was collected. In 1994-95, a NJDEP follow-up study was conducted to confirm the preliminary screening study results from 15 of the 55 lakes originally sampled in ANSP. The project focused upon re-sampling those waters that had fish with elevated mercury levels. Overall the results paralleled the 1992-93 ANSP findings. Table 2a & 2b show comparisons of size-adjusted (to 33.4 cm. fish) largemouth bass and chain pickerel from 1992-93 ANSP and 1994-95 NJDEP. The data were similar for the lakes sampled, with exceptions noted for both species at specific waters. While no clear definitive explanations for these differences could be attributed to either any single or combination of factors, the data provide insight into the variability of contaminant levels in wildstock fish.

Figure 2a - Station Averages of Size Adjusted Mercury Concentrations for Largemouth Bass 1992-93 and 1994-95

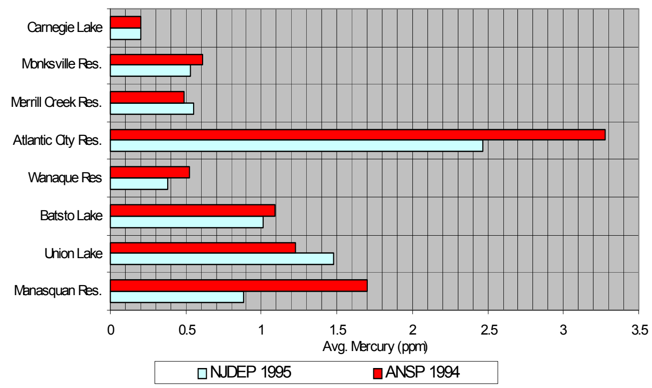
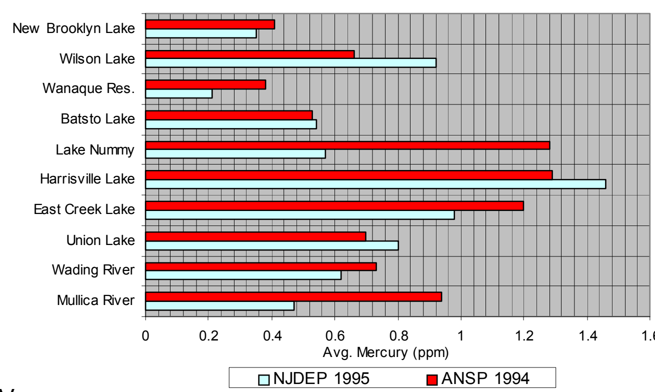


Figure 2b- Station Averages of Size Adjusted Mercury Concentrations for Chain Pickerel 1992-93 and 1994-95



The 1994-95 NJDEP project included collections of a total of 15 gamefish species (three trophic levels) and five forage fish species (one prey group). The highest mean mercury concentrations were again found in largemouth bass and chain pickerel, 1.08 ppm. and 0.78 ppm. respectively. Mercury concentrations were elevated in other top trophic level species including walleye (0.74 ppm), lake trout (0.50 ppm) and smallmouth bass (0.41 ppm). Lower levels were typically observed in the lower trophic level and forage fish species at each site. Generally, fish of all trophic levels from Pine Barrens sites had higher levels than the same species from non-Pine Barrens sites. These data provide additional site specific information of mercury residue in a variety of trophic level species and are a foundation to understanding mercury trophic transfer in New Jersey freshwater systems.

The findings from the 1994-95 NJDEP 15 lake follow-up study were used in the design of this1996-97 ANSP study. The results of the 1996-97 ANSP study were consistent with those of the preliminary mercury in fish study. The highest mercury concentrations were again in fish from the Pine Barrens region. In the 1996-97 study, sites from the northern Pine Barrens region were sampled, while the 1992-93 study included mainly southern Pine Barren sites. The similarity of results indicates that the high concentrations occur over the entire region. As in the 1992-93 study, sites at the edge of the Pine Barrens were variable in mercury concentration in fish, with some sites showing levels similar to that of Pine Barrens sites. For the 1996-97 study, sites in industrial areas were also variable in the extent of mercury contamination. Some, such as the upper Raritan River, showed low mercury concentrations, while relatively high concentrations were found in some sites in the northeastern part of the state. Fish from other northern sites generally had low or moderate concentrations of mercury. One exception was Crater Lake (in Sussex County), which was representative of lakes on sandstone ridges in northwestern New Jersey. Mercury concentrations in fish from Crater Lake were high compared to similar size specimens of the same species from other sites.

Bioaccumulation of mercury has been related to differences in water chemistry. This affects methylation rates of mercury to methylmercury, which is the form of mercury that is more readily accumulated. The relationships of mercury bioaccumulation to pH, alkalinity, conductivity and DOC (dissolved organic carbon) identified in this research are consistent with other studies. These parameters, however, are interrelated, and causal basis of their relationship could not be determined from this study. All of the parameters were significant in some of the models. Only DOC was shown to be significant in all three studies when all other parameters were included in the model.

As in 1992-93, mercury concentrations were highest in piscivorous fish such as chain pickerel and largemouth bass. Table 3 provides a comparison of mercury distribution for 1992-93 and 1996-97, by waterbody for largemouth bass and chain pickerel. The mercury ranges are the NJDEP/DHSS (TIBC 1994) human health criteria for the high-risk sub-population used in developing consumption advisories.

Table 3. Distribution of Mercury Concentrations in Largemouth Bass and Chain Pickerel in New Jersey Waterbodies in 1992-93* (55 Waters) & 1996-97 (30 Waters).

Mercury Ranges for NJDEP/DHSS Human Health Criteria **	Percent of Waterbodies With Largemouth Bass 92-93	Largemouth Bass 96-97	Chain Pickerel 92-93	Chain Pickerel 96-97
<0.07 mg/kg	0 %	0 %	0 %	0 %
0.08 - 0.18 mg/kg	16.0 %	20.0 %	6.0 %	25.0 %
0.19 - 0.54 mg/kg	56.0 %	45.5 %	53.0 %	31.5 %
≥0.54 mg/kg	28.0 %	34.5 %	41.0 %	43.7 %

* ANSP (1994a) ** TIBC (1994)

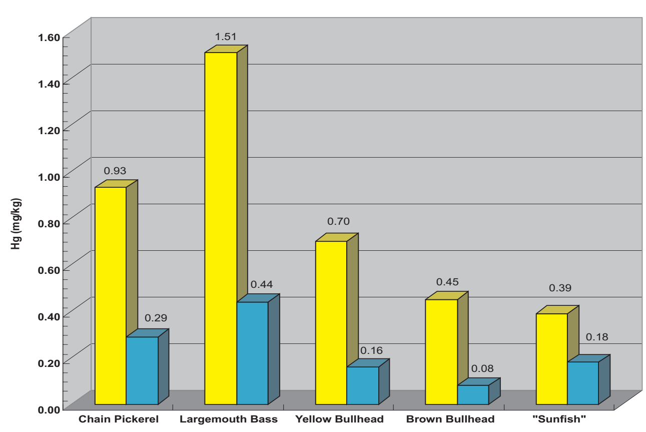
Overall the mercury levels for these two species remains fairly constant for the two periods. Increases are observed in the number of waterbodies with mercury levels for chain pickerel in the 0.08 - 0.18 mg/kg range and for largemouth bass in the >0.54 mg/kg range. Decreases were observed in the percentages of waterbodies with mercury ranges of 0.19 - 0.54 mg/kg for both species. While this data can not be used to determine trend analysis, it does illustrate the range and variability seen in mercury in fish tissue data.

The 1996-97 study also revealed lower mercury concentrations in other gamefish species, including white perch, yellow perch, rock bass, sunfish, crappies, catfish and bullhead. Comparisons of 1992-93 and 1996-97 mercury concentrations in fish from the different trophic levels showed a general increase in concentrations with trophic level, although among-species variation within each trophic group was also observed. From the 1996-97 data for lower trophic level fish, no clear difference in mercury concentrations were observed between invertebrate-eating species (e.g., sunfishes and white perch) and zooplanktivorous species (e.g., golden shiner and alewife). It is interesting to note that Pine Barrens sites contain dwarf species of sunfish (i.e., blackbanded and bluespotted sunfish) that at adult (probably 1-3 years old) are similar in size to young-of-year of the other sunfish species. These adult dwarf sunfish, however show higher mercury concentrations than similarly sized sunfish species. Since dwarf sunfish are routinely consumed by Pine Barrens chain pickerel, it has been suggested that they could be a significant contribution to the high mercury concentrations observed in gamefish species of the Pine Barrens.

Comparisons of 1996-97 ANSP mercury concentrations in fish fillet and whole body were made for eight chain pickerel, ten largemouth bass and thirteen specimens of six other species. Mercury concentrations in fillets were about 1.3 times higher than in whole body for chain pickerel. For other species, the median ratios of fillet to whole body were 1.3-1.9. This information could be useful in developing models for mercury cycling in New Jersey freshwater systems.

The results of the two NJDEP/ANSP, the one NJDEP and the two ANSP studies provide an in-depth assessment of mercury trophic transfer in New Jersey freshwater systems. A review of the data from these five studies reveals a similar pattern of mercury contamination within each study. Conclusions can be made that mercury is ubiquitous in New Jersey freshwater systems, and while regional differences are apparent, mercury has been found in freshwater fish from all geographical areas of the state. Regional differences are consistent for the entire database. Chart 1 shows fish sampled from within the Pinelands waters were higher in mercury concentrations than fish from non-Pinelands

Chart 1- Mean Mercury Concentrations (mg/kg) in Pinelands vs Non-Pinelands Fish



waters.Within this group, mercury concentrations were also higher in the waters within and marginal to the Pine Barrens than non-Pine Barrens sites. Mercury concentrations in fish varied greatly in industrial areas, northern lakes and rivers, northwestern (carbonate) waters and in coldwater streams.

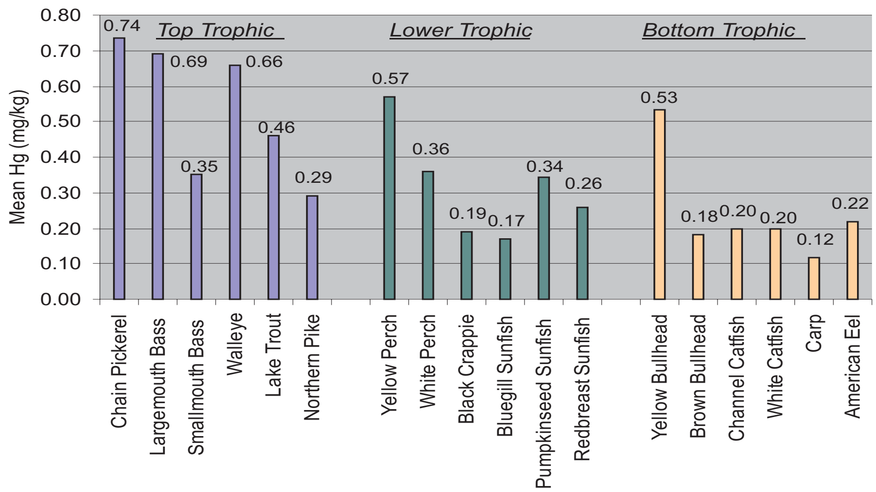
From the five-study database Chart 2 provides mean mercury concentrations for various fish species within each trophic level group. Over the entire database, mercury concentrations show an increase in concentrations with

Conclusions\Recommendations

The major conclusions of this mercury research are:

- Concentrations of mercury occur in fillets of gamefish species from a number of New Jersey freshwaters at levels exceeding the criteria that trigger consumption advisories.
- Relatively high mercury concentrations were seen in fish from the Pine Barrens region, including rivers and ponds and sites from throughout this area.
- Relatively high mercury concentrations were also seen in fish at sites marginal to the Pine Barrens region, at recently filled reservoirs and at sites which may have historical point-source contamination in the northeastern part of the state.

Chart 2 - Mean Mercury Concentrations (mg/kg) by Trophic Level Using All Five Datasets



trophic levels. As described in each study, mercury concentrations were generally highest in predatory fish (e.g., chain pickerel and largemouth bass) and in older, larger specimens in all species analyzed. Other predatory fish also show elevated levels of mercury. These include walleye, lake trout, smallmouth bass, and in individual samples of hybrid striped bass and muskellunge.

In general, lower mercury concentrations were seen in a wide variety of lower and bottom trophic level gamefish. As noted, however elevated levels of mercury have been identified in species from each of the three trophic levels. Typically, specimens of every species and trophic group had mercury levels exceeding the established NJDEP/DHSS human health criteria that trigger fish consumption advisories. These mercury in fish criteria and the assessment of potential human health hazards were developed and adopted in 1994. Many of these gamefish are commonly consumed, such as white perch, yellow perch, rock bass, sunfish (variety of species), black crappie, white and channel catfish, brown and yellow bullheads and common carp. Since per capita consumption of these species is typically greater than many piscivorous gamefish, these species may overall represent a greater human health threat than previously thought. This would be especially true for subsistence anglers, high-risk individuals and sensitive segments of the fish-consuming public.

- Concentrations were lowest in fish from coldwater streams, in some ponds and rivers in the southwestern part of the state, in the Delaware River, and in some high pH lakes in the northern part of the state.
- At most sites, mercury concentrations were highest in large, piscivorous species such as chain pickerel and largemouth bass. Relatively high concentrations of mercury were also observed in other piscivorous species (e.g., walleye, lake trout, pike) collected from a variety of sites throughout the state.
- Mercury concentrations in lower trophic levels were generally less than in piscivorous fish, but clear patterns of differences among planktivores, generalized invertebrate-feeders and bottom-feeders were not found.
- Several species of smaller, long-lived sunfish species (dwarf species) common in the Pine Barrens contain elevated mercury concentrations. These species remain small enough throughout their lives to be important forage fish, which can contribute to bioaccumulation in piscivorous species of the Pine Barrens region.
- Variations in mercury concentrations can be attributed to fish size, age and water chemistry. However, due to confounding factors (such as new reservoirs or sites with historical contamination) there is substantial variation among lakes, which is not explained by the measurements made.

- Chain pickerel mercury concentrations generally decrease along an increasing pH/alkalinity/conductivity/ decreasing DOC gradient. Mercury concentrations in largemouth bass showed a weak relationship between bioaccumulation and a pH/alkalinity/conductivity/DOC gradient, but the data was inconclusive, probably due to the widespread occurrence of this species in moderate and high pH/alkalinity/conductivity sites.
- Fillet concentrations of mercury were higher than estimated whole body concentrations. Relationships between fillet and whole body concentrations were generally consistent among species, with fillet concentrations 1.3-1.9 times higher than whole body concentrations.
- The results of this study show the occurrence of a wide variety of fish with mercury concentrations above advisory thresholds from a number of sites in the state.

Follow-up studies of several types would be valuable. These include:

- More extensive analysis of ancillary information on fish (e.g., age) and sites (e.g., pH, sulfate, alkalinity, DOC, mercury and other water quality parameters), which would allow better analysis of spatial patterns of mercury bioaccumulation, better standardization of mercury concentration for fish size and age, better prediction of the likelihood of bioaccumulation, and more information on factors controlling bioaccumulation;
- Intensive analysis of certain types of sites, including analysis and estimates of mercury inputs and concentrations in a variety of species of fish, and mercury concentrations and speciation in water, sediment and vegetation. Analysis of low pH sites, which tend to show high but variable bioaccumulation, would be of particular interest;
- Analysis of mercury and a variety of contaminants in sediments at sites that have possibly been affected by current or historical point source inputs;
- Analysis of additional waterbodies, particularly those with uncertain and/or high likelihood of mercury bioaccumulation. These data may be used in developing more consistent fish consumption advisories;
- Continued trend monitoring of mercury bioaccumulation in fish from recently filled reservoirs; and
- Assessment of concentrations and potential toxic effects in fish-eating wildlife.

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RESEARCH PROJECT SUMMARY