TRACE METAL CONCENTRATIONS IN COMMON CARP (*CYPRINUS CARPIO*) AND WALLEYES (*STIZOSTEDION VITREUM VITREUM*) IN THE UPPER WISCONSIN RIVER

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ABSTRACT

Mercury contamination has been a historical problem in the Upper Wisconsin River and was presumably caused by the use of phenyl mercuric acetate as a slimicide by the pulp and paper industry. Elevated levels of other metals in bed sediments have also been observed. Common carp and walleyes were collected from five sites in the main study area of the Upper Wisconsin River, extending from the Brokaw area to the Lake DuBay dam. Walleyes collected from the Rainbow Flowage and common carp from Range Line Lake, two relatively uncontaminated sites in northcentral Wisconsin, were used as reference samples. Four metals were analyzed, each in a selected tissue of the two species: zinc in gill filaments, cadmium and lead in liver, and mercury in axial muscle. Concentrations of mercury in common carp from the main study area were significantly higher than those in carp from the reference site. However, mercury levels in walleyes from the main study area were similar to those in walleyes from the reference site, Rainbow Flowage. Mercury concentrations in axial muscle of both species were similar to mercury levels in fish of similar size, analyzed during 1970-1973 from the same reaches of the Upper Wisconsin River. Mercury availability and cycling through biota of this system may be enhanced by rapid rates of methylation in surficial sediments, even though the most heavily contaminated sediments have been buried by subsequent deposits. In general, cadmium and lead concentrations in liver and zinc concentrations in gill filaments were not elevated in fish from the main study area, relative to values in reference samples.

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INTRODUCTION

The Upper Wisconsin River has been affected by severe water quality problems associated with discharges from pulp and paper mills and from municipalities. These waste discharges, containing high biochemical oxygen demand (BOD), have caused low summer dissolved oxygen concentrations at various sites. The recent reduction of BOD loadings by improved treatment of waste effluents is apparently allowing the fishery of the river to recover (Coble 1982). Mercury contamination of fishes, another historical problem in the Upper Wisconsin River (Kleinert and Degurse 1972), requires re-evaluation, because sport fishing and consumption of fish are expected to increase with improvement of the fishery. The Upper Wisconsin River Basin 208 Task Force (unpublished data) has also found elevated levels of other metals, including copper, lead, chromium, zinc, and manganese, in bed sediments of the river. Elevated levels of mercury were observed in riverine sediments and fish during 1970-1973, shortly after the ban on use of phenyl mercuric acetate as a slimicide by the pulp and paper industry (Konrad 1973).

Several characteristics of the Upper Wisconsin River enhance conversion of the mercury in this system to the highly toxic monomethylated form, methylmercury. Methylation rates are enhanced by the acidic nature and high organic content of the sediments (Jacob and Keeney 1974). High primary productivity, coupled with moderately oxidized bottom waters creating anaerobic surficial sediments, and mixing and mobilization of sedimentary methylmercury during high flow periods, may enhance both methylmercury production and availability of mercury to riverine biota (Phillips and Medvick 1981).

Analyses of whole fish and fish tissues have been used to survey and monitor environmental contamination, since fish accumulate many metals, industrial chemicals, and pesticides (Braun and Yediler 1980). The accumulation of metals by fish is affected by many biological and environmental factors, and fish act as integrators of environmental conditions (Giesy and Wiener 1977). The use of fish as exact indicators of pollution has been questioned (Braun and Yediler 1980); however, many inferences about metal contamination may be drawn from information on metal concentrations in fish tissues and organs. Due to the importance of fish in the human diet, they can be a pathway for transfer of contaminants to man. Analyses of metal levels in fish tissue can therefore reveal potential health hazards for humans.

In this study, zinc, cadmium, lead, and mercury were measured in various tissues of walleyes (*Stizostedion vitreum vitreum*) and common carp (*Cyprinus carpio*) from the Upper Wisconsin River and relatively uncontaminated reference sites. Zinc is an essential element that can be toxic at high exposure concentrations. Cadmium, lead, and mercury are nonessential, toxic metals (Forstner and Wittmann 1981). The specific objectives of this study were to (1) determine the degree of cadmium, lead, zinc, and mercury contamination of the two fishes, and (2) determine if mercury concentrations in fish have decreased measurably since 1970-1973.

The two species of fish selected for study are abundant in the Upper Wisconsin River. Common carp are bottom-dwelling omnivores and rank first on a biomass basis in the river's fishery (Coble 1982). Adult walleyes are piscivorous (Ney 1978) and are an important component of the sport fishery in the river, ranking sixth among species on a biomass basis (Coble 1982).

Different metals tend to accumulate in different tissues and organs of fish, therefore, analyses of each metal was performed on a tissue or organ in which it is known to concentrate. Rehwoldt et al. (1976) reported zinc concentrations in gills, a site of uptake, to be equal to that of the suspended solids in the surrounding water. Cadmium is accumulated in the liver and kidneys (Coombs 1979) and, unlike mercury, does not accumulate substantially in axial (edible) muscle tissue (Benoit et al. 1976). Lead accumulates in the gills, liver, and kidney, and appears to reach equilibrium concentrations when fish are exposed to high concentrations (Holcombe et al. 1976). Like cadmium, lead does not accumulate appreciably in axial muscle tissue (Chow 1974; Holcombe et al. 1976). Organic forms of mercury accumulate in axial musculature, liver, and kidneys and are excreted slowly (Jernelov and Lann 1971). Mercury accumulation in the edible portion of the fish can create a potential human health problem in mercury-contaminated waters. Consequently, zinc was analyzed in gill filaments, cadmium and lead in liver, and mercury in axial musculature.

DESCRIPTION OF THE STUDY AREA

The main study area of the Upper Wisconsin River extends from slightly upstream of Brokaw to the Lake DuBay Dam (Fig. 1). This portion of the river flows through a peneplain of Precambrian granitic rock of the Northern Highlands (Martin 1965). North of the studied stretch, the river flows through an area of young drift or Pleistocene glacial till. The main study area lies in a region of older drift dominated by erosional, rather than depositional, glacial processes (Finley 1965). Here, the drainage pattern of the river is dendritic, and the river valley is covered by outwash sand and gravel. The watershed of the Wisconsin River, with an area of 31,080 km^2, is dominated by forest and brushland (Finley 1965). The mean annual precipitation for Wisconsin is 79 cm, with more than two-thirds lost through evapotranspiration (Becker 1983). Average seasonal snowfall from 1930 to 1959 ranged from 127-152 cm, and the average air temperature was -9°C in January and 22°C in July (Hole 1976). The Wisconsin River is a softwater, weakly buffered, productive system. Annual means (1969-1972) of water quality parameters near Wausau are as follows: pH, 6.8; alkalinity, 27 mg/l as $CaCO_3$; and hardness, 42 mg/l as $CaCO_3$ (Wisconsin Department of Natural Resources 1972).

The Upper Wisconsin River has been significantly modified by man. A series of 19 low-head dams regulate flow for power production and flood control (Finley 1965). Sixteen pulp and paper mills are located along a 309-km stretch of the river from Rhinelander to Nekoosa (Christianson 1979). In addition to these mills, 3 other industries and 14 municipalities discharge wastes into the river (Coble 1982).

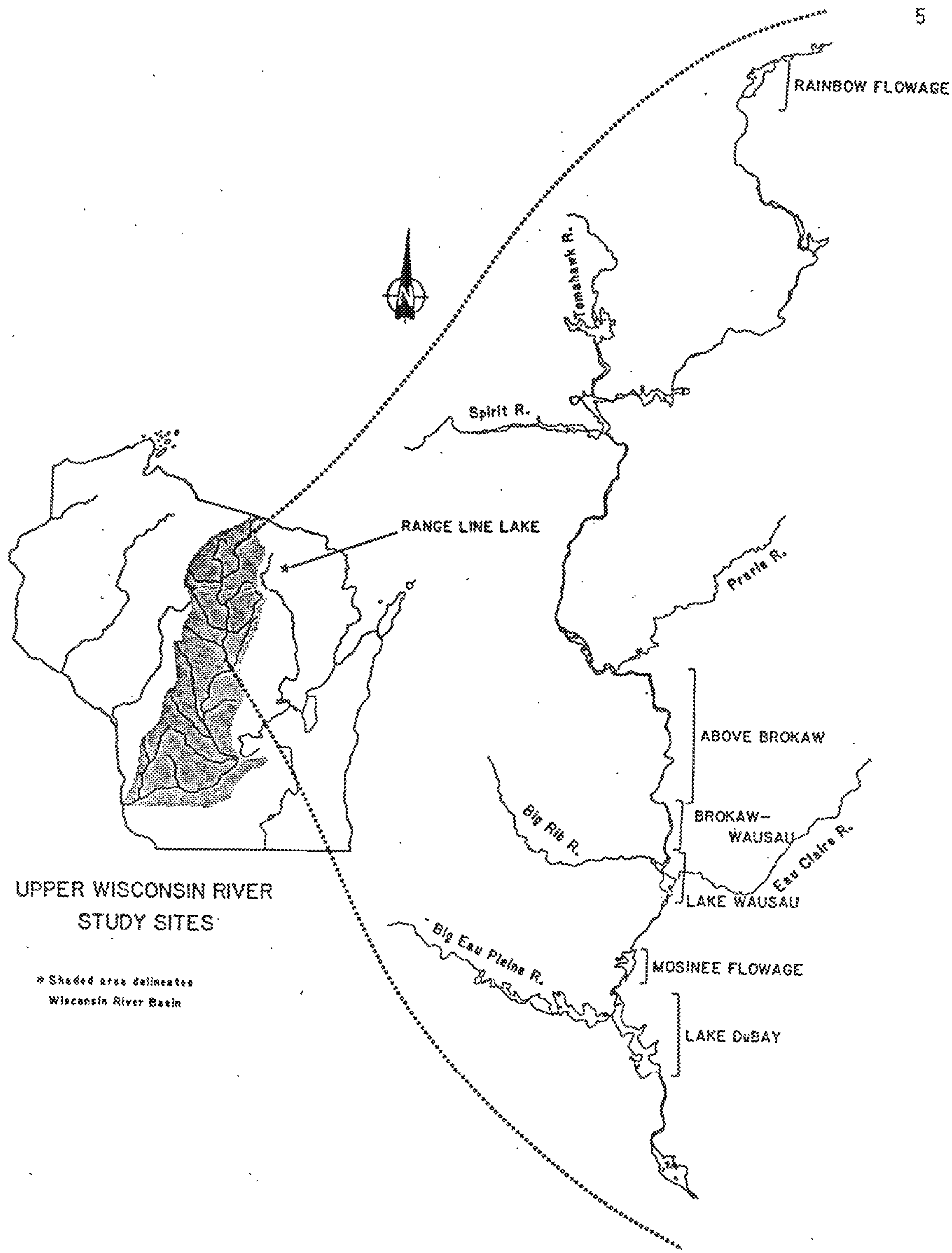

Fig. 1. Study areas on the Upper Wisconsin River and Range Line Lake.

Severe water quality problems, mainly low dissolved oxygen (DO), have occurred in the Upper Wisconsin River (Sullivan 1983). During 1973-1977, average DO concentrations during summer ranged from 2 to approximately 8 mg/l (Coble 1982). The Clean Water Act (PL-92-500) required that industries and municipalities reduce the high BOD loadings to surface waters. Water quality has subsequently improved (Sullivan 1983), and the riverine fishery has been benefiting from this improvement (Coble 1982).

Metal pollution, caused by industrial and perhaps municipal discharges to the river, has been another historical problem. Bed sediments contaminated with mercury, copper, chromium, lead, zinc, and manganese have been located (Konrad 1971; Upper Wisconsin River Basin 208 Task Force, unpublished). In 1970-1973, fish from certain areas below pulp and paper mills and a chloralkali plant contained mercury concentrations above 0.5 μg/g wet weight, which was the U.S. Food and Drug Administration's action level at that time (Kleinert and Degurse 1972). This level was raised to 1.0 ppm in June 1978 (Sheffy and Aten 1979).

The main study area of the Wisconsin River from above Brokaw to the Lake DuBay Dam contains a series of reservoirs created by four low-head dams. Lake DuBay, the study site furthest downstream, has a turnover time of 9.8 days and a sediment trapping efficiency of 28%. It is the largest reservoir in the main study area with a surface area of 28.5 km^2, a mean depth of 3.7 m, and an average volume of 1.04×10^8 m^3. This reservoir receives input from the Little Eau Pleine River and the Big Eau Pleine Reservoir, which is highly eutrophic and affects the water quality in Lake DuBay (Shaw 1978). Lake DuBay also receives discharges from a pulp and paper mill at river mile (RM) 248.9 and from a sewage treatment plant (RM 248.8).

The Mosinee Flowage receives effluents from one pulp and paper mill at RM 258.2 and one municipal treatment plant at RM 257.8. It has a surface area of 5.57 km^2, a mean depth of 2.1 m, a volume of 1.04×10^8 m^3, and a residence time of 1.4 days.

The Rothschild Dam forms Lake Wausau, an impoundment with a residence time of 2 days and a sediment trapping efficiency of 18%. It has a surface area of 7.76 km^2, a mean depth of 2.2 m, and a volume of 1.72×10^7 m^3. One sewage treatment plant at RM 263.8 discharges into this reach of the river.

The section of the river from the Wausau Dam to above Brokaw, which includes two fish sampling areas, is free-flowing. One municipal treatment plant (RM 270.4) and one pulp and paper mill (RM 271.0) are located near Brokaw.

Two additional sites, the Rainbow Flowage and Range Line Lake, were used as reference areas. The Rainbow Flowage, the reference site for walleyes, is located on the Upper Wisconsin River upstream of any known direct point sources of metals. It has a surface area of 18.1 km^2, a maximum depth of 8.2 m, and a volume of 6.19×10^7 m^3. Range Line Lake is a moderately hardwater, productive, drainage lake located in Forest County near Wabeno, Wisconsin. It has a surface area of 0.33 km^2, a maximum depth of 3.4 m, and is surrounded by upland hardwoods (60%) and wetlands (40%). Range Line Lake was chosen as a reference site for common carp due to the lack of known direct inputs of metals.

METHODS

Collection and Preparation of Fish Samples

Common carp and walleyes were each collected from six sites, five in the main study area and a reference site, as previously described. Sampling was conducted at the Wisconsin River sites during July and August 1981 and at Range Line Lake during August 1982. Walleyes from the Rainbow Flowage and common carp from Range Line Lake were used as reference samples. Fish were collected with large mesh (2.5 cm) fyke nets and an electroshocker. After capture, fish were weighed, measured (total length), placed in labeled plastic bags, stored in ice-filled coolers, transported to the laboratory, and frozen.

Scales for age determinations of walleyes were taken immediately posterior to the point of insertion of the left pectoral fin. Scale impressions were made and examined at a magnification of 38X on an Eberbach scale reader. Age assigned to each walleye was equal to the total number of completed scale annuli, according to criteria described by Tesch (1971). Ages of common carp were not determined.

Dissections of gill filaments, livers, and axial muscle tissue were performed on a clean, polyethylene work surface. Polyethylene gloves were worn, and stainless steel implements were used during dissections to minimize sample contamination. After dissection, tissues were immediately placed into tared, acid-washed plastic vials or polyethylene bags, weighed, and frozen at -4°C (Wiener and Giesy 1979).

Gill filament and liver samples were lyophilized to a constant dry weight at -60°C with a Virtis model 10-145 freeze dryer, and dry weights of samples were recorded. Whole livers and gill filaments from individual fish were digested in acid-washed porcelain crucibles in a water bath at about 60°C. Gill filaments and liver samples were digested with approximately 4 mL of concentrated Ultrex® HNO_3 (J. T. Baker Chemical Co.) per gram of dried sample. After gas production had ceased, digestates were removed from the water bath and a volume of 10% reagent grade H_2O_2, equal to that of HNO_3 used, was added to each digestate (Giesy and Wiener 1977). After gas production had again ceased, digestates were cooled, diluted to known volumes, and stored in acid-washed, polyethylene vials at 4°C until analysis.

Approximately 0.5 g of axial muscle tissue was weighed in an acid-washed, 300-mL fleaker for mercury analysis. After adding 5 mL of concentrated Ultrex® H_2SO_4 and 2.5 mL of concentrated Ultrex® HNO_3, the fleakers were placed in a 60°C water bath for 2 hr or until the sample had dissolved. The samples were then removed and after cooling, 10 mL of 5% $KMnO_4$ solution was slowly added. If a purple color did not persist, additional $KMnO_4$ was added until the color remained for at least 15 min. Thirty minutes after the addition of the $KMnO_4$, 5 mL of 5% (w/v) potassium persulfate solution was added. The fleakers were then covered and allowed to stand overnight. The samples were clarified by adding 2.5 mL of 20% (w/v) hydroxylamine sulfate-20% (w/v) sodium chloride solution. The volume was then adjusted to 100 mL in the fleaker with deionized-distilled water.

All glassware, crucibles, and polyethylene vials were washed in tap water, soaked overnight in a 50% solution (by volume) of HNO_3, rinsed in tap water three times, rinsed with a 50% solution of HCl, and then rinsed three times with deionized-distilled water.

Analyses of Fish Samples

Metal concentrations in digestates were measured with an Instrumentation Laboratory model 257 atomic absorption spectrophotometer equipped with a model 655 furnace atomizer, a model 254 autosampler, and a model AVA 440 cold vapor generator. Zinc concentrations were measured by flame atomization, cadmium and lead by graphite furnace atomization, and mercury by the cold vapor technique (Appendix I). Samples were diluted as necessary for zinc, cadmium, and lead analyses to yield absorption values within the linear range of the standard curve. Matrix interferences during cadmium and lead analyses were evaluated by standard addition techniques and were reduced by aerosol deposition of samples into a graphite microboat (Conley et al. 1981). The use of the microboat minimized matrix interferences during cadmium analyses, but not during analyses of lead. Lead concentrations were therefore determined by a three-point standard additions curve. Background interferences were minimized during analyses of cadmium, lead, and zinc with a deuterium background corrector.

Quality Assurance

Procedural blanks were taken through digestion and storage procedures to evaluate contamination from reagents and containers. Two National Bureau of Standards (NBS) reference materials, bovine liver and oyster tissue, were analyzed in conjunction with fish samples to validate procedures and analyses. Approximately 5% of the fish samples were digested and analyzed in triplicate to estimate precision.

Statistical Analyses

Statistical analyses were conducted with the Statistical Package for the Social Sciences (SPSS) software system (Nie et al. 1975; Hull and Nie 1981). A Type I error of 0.05 was used to judge significance of statistical tests.

The relationship between mercury concentrations and size or age of the fish was evaluated by simple linear regression. To adjust the mercury concentrations in fish for body size, a one-way analysis of covariance (ANCOVA) with mercury as the dependent variable, total length or wet weight as the covariate, and location as the main factor was used. However, since the assumption of homogeniety of regression slopes was not met with the raw data for mercury, the ANCOVA was performed on rank-transformed data (Conover and Iman 1982). Paired comparisons between adjusted mean mercury ranks were measured with Fisher's protected least significant difference (LSD) test (Huitema 1980).

Logarithmic-transformation of cadmium and zinc values was performed to achieve homogeniety of variances among locations. Variation between location means of both metals was then evaluated by one-way ANOVA. Paired comparisons of mean concentrations of each metal between locations were performed by Tukey's honestly significant difference (*hsd*) procedure (Dowdy and Wearden 1983). Confidence intervals for Tukey's *hsd* procedure were estimated by using the harmonic mean of the number of samples among locations, because sample sizes were unequal (Bancroft 1968). Spearman (rank) correlations were used to test the relation between body size of the fish and cadmium concentrations in liver or zinc concentrations in gill filaments (Snedecor and Cochran 1974).

Nonparametric tests were used to evaluate the lead data since the distribution of lead concentrations was highly skewed. A Kruskal-Wallis one-way ANOVA was used to evaluate the variation of mean lead values among locations. Subsequent analysis by the Mann-Whitney U test was performed to evaluate differences in lead concentrations between the main study area and the reference sites, if the Kruskal-Wallis test proved significant. The relation between body size of the fish and lead concentrations in liver tissue was evaluated by the Spearman correlation coefficient (Snedecor and Cochran 1974).

RESULTS AND DISCUSSION

Quality Assurance

Analyses of NBS bovine liver and oyster tissue yielded mean values within the certified concentration ranges for the four metals studied (Table 1). Mean recoveries from spiked fish samples were 99.6% for zinc, 104.4% for cadmium, and 94.9% for mercury. Precision (relative standard deviation, RSD) during analyses of NBS reference materials ranged from 2.4 to 23.9 for the four metals (Table 1). Triplicate analyses of fish samples yielded RSD values ranging from 2.7-8.8% for zinc, 4.1-20% for cadmium, 5.0-20% for lead, and 1.0-18% for mercury.

Metal Concentrations in Fish

A total of 125 common carp and 94 walleyes were collected from the main study area and reference sites. A one-way analysis of variance indicated that both wet weights and total lengths of the common carp analyzed varied significantly among locations ($\underline{P} \leq 0.01$). In contrast, the wet weights and total lengths of walleyes did not vary among locations.

Wet weights, total lengths, and metal concentrations of individual fish are given in Appendix II for common carp and in Appendix III for walleyes. Liver, gill, or muscle tissues for certain individuals were not analyzed due to insufficient sample mass or other procedural problems. Therefore, the actual weights and lengths of fish analyzed from the six sites varied somewhat among metals.

Mercury. Concentrations of mercury in axial muscle tissue of individual common carp ranged from 0.05 to 0.78 μg/g wet weight in the

Table 1. Results of quality assurance procedures during metal analyses of fish samples.

Procedure	Zinc	Cadmium	Lead	Mercury
Analysis of NBS bovine liver				
Certified concentration range (μg/g)	130 ± 13	0.27 ± 0.04	0.34 ± 0.08	0.016 ± 0.002
My results				
Mean concentration (μg/g)	135	0.28	0.37	0.017
RSD (%)[a]	4.3	8.1	17.2	15.1
n	10	10	12	3
Analysis of NBS oyster tissue				
Certified concentration range (μg/g)	852 ± 14	3.5 ± 0.4	0.48 ± 0.04	0.057 ± 0.015
My results				
Mean concentration (μg/g)	854	3.4	0.49	0.056
RSD (%)	3.0	6.1	2.4	23.9
n	4	5	3	10
Recovery from spiked samples				
Fish				
Mean recovery (%)	99.6	104.4	99.9[b]	94.9
RSD (%)	6.4	3.7	2.8	9.5
n	10	12	15	18
Precision during analysis of triplicate samples				
Fish				
Mean RSD (%)	5.4	11.1	12.0	11.0
Range (%)	2.7-8.8	4.1-20.3	5.0-20.0	1.0-18.1
n	8	9	6	12

[a]Relative standard deviation.
[b]Calculated from analyses of NBS reference materials.

main study area and from 0.02 to 0.53 μg/g in the reference site, Range Line Lake (Table 2). The mean concentrations in carp varied from 0.15 μg/g at Lake DuBay to 0.32 μg/g at the above Brokaw site. Carp from the reference site had a mean mercury concentration of 0.20 μg/g.

Mercury concentrations in individual walleyes ranged from 0.05 to 2.04 μg/g wet weight in the main study area and from 0.18 to 0.95 μg/g in the reference site, Rainbow Flowage (Table 3). Mean concentrations for walleyes from the main study area sites varied from 0.23 μg/g in the Brokaw to Wausau site to 0.47 μg/g in Lake DuBay. The mean mercury concentration in walleyes from the reference site was 0.35 μg/g. The U.S. Food and Drug Administration's present guideline for mercury of 1.0 μg/g wet weight was exceeded in only 2 of the 214 fish analyzed. Both of these fish were large walleye (wet weights, 2.11 and 2.92 kg) from the above Brokaw site.

Mercury concentrations in axial muscle tissue are often positively correlated with size or age of fish within a species population (Huckabee et al. 1975), and this trend was observed here (Figs. 2 and 3). Simple linear regression was therefore applied to the data, with mercury concentration in axial muscle as the dependent variable and total length, wet weight, or age (for walleye) as the independent variable in separate regression models. For walleye, highly significant (P < 0.01) regression slopes were observed between mercury concentrations and each of the three independent variables: total length, wet weight, and age (Table 4). For carp, slopes were positive and significant for five of the six sites for the simple linear

Table 2. Numbers, wet weight, total length, and mercury concentrations in axial muscle of common carp. The range is given in parentheses below each mean.

Site	n	Mean wet weight (kg)	Mean total length (cm)	Mean mercury concentration (µg/g wet weight)
Rainbow Flowage	25	3.32 (1.39-4.23)	61.7 (47.8-69.1)	0.20 (0.02-0.53)
Above Brokaw	24	1.71 (0.89-3.98)	49.2 (41.8-64.9)	0.32 (0.12-0.63)
Brokaw to Wausau	18	1.26 (0.90-2.72)	45.9 (39.3-61.7)	0.29 (0.13-0.78)
Lake Wausau	24	2.20 (1.19-4.16)	54.6 (44.6-68.2)	0.29 (0.08-0.61)
Mosinee Flowage	17	1.75 (1.06-2.82)	50.0 (42.9-59.0)	0.22 (0.05-0.52)
Lake DuBay	14	0.78 (0.47-1.85)	38.4 (31.8-52.1)	0.15 (0.06-0.29)

Table 3. Numbers, wet weight, total length, age, and mercury concentrations in axial muscle of walleyes. Range is given in parentheses below each mean.

Site	n	Mean wet weight (kg)	Mean total length (cm)	Age (yr)	Mean mercury concentration (μg/g wet weight)
Range Line Lake	15	0.39 (0.046-1.59)	28.9 (16.7-52.8)	4.3 (2-9)	0.35 (0.18-0.95)
Above Brokaw	15	0.49 (0.074-2.92)	31.5 (21.1-65.1)	3.2 (2-8)	0.45 (0.13-2.04)
Brokaw to Wausau	14	0.27 (0.065-1.32)	27.5 (20.5-50.3)	3.8 (2-8)	0.23 (0.15-0.45)
Lake Wausau	18	0.27 (0.044-0.78)	29.3 (17.7-43.9)	3.9 (1-6)	0.35 (0.14-0.86)
Mosinee Flowage	17	0.43 (0.059-1.80)	32.0 (19.0-57.8)	4.6 (2-9)	0.26 (0.05-0.99)
Lake DuBay	13	0.52 (0.029-1.69)	35.7 (15.4-55.2)	5.7 (3-10)	0.47 (0.19-0.78)

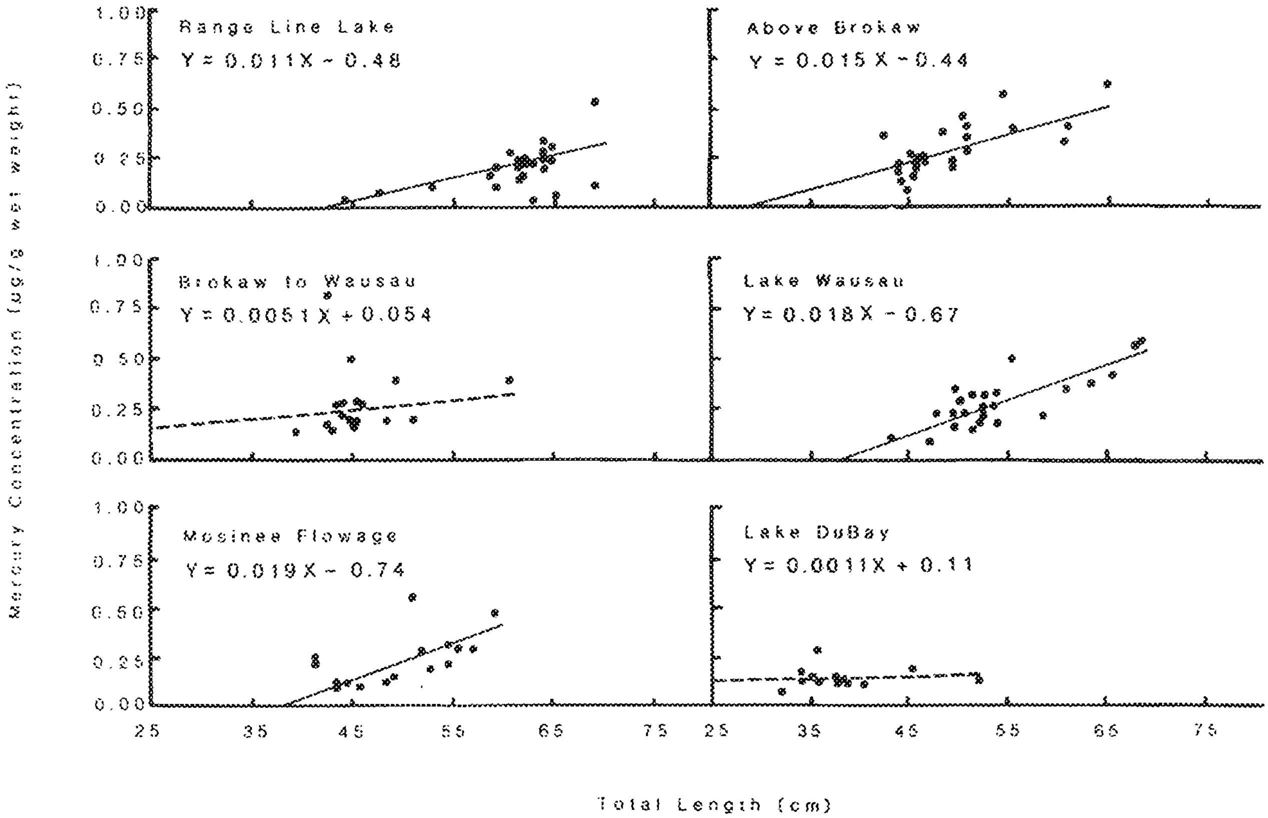

Fig. 2. Plots and simple linear regressions of mercury concentrations in axial muscle against total length of common carp in the main study area and Range Line Lake. Solid lines have slopes that differ from zero at the $\alpha = 0.01$ level and dashed lines represent nonsignificant regression slopes ($\underline{P} > 0.05$).

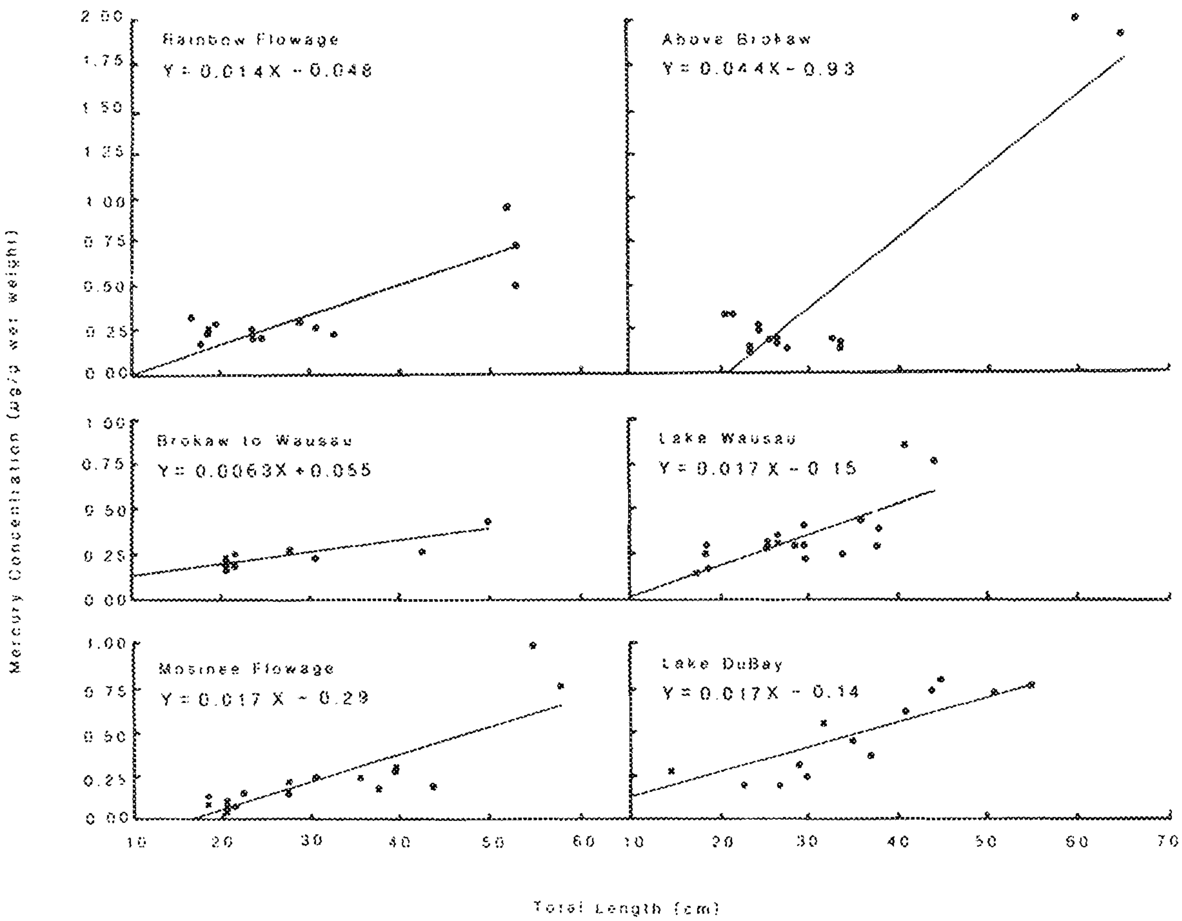

Fig. 3. Plots and simple linear regressions of mercury concentrations in axial muscle against total length of walleye from the main study area and Rainbow Flowage. All regression slopes differ from zero at the α = 0.01 level.

Table 4. Results of simple linear regressions of mercury concentrations (μg/g wet weight) in axial muscle tissue of walleye against total length (cm), wet weight (kg), and age (yr). All slopes differ from zero at the $\alpha = 0.01$ level.

Study site	Regression parameter	Independent variable		
		Total length	Wet weight	Age
Rainbow Flowage	Slope	0.0138	0.323	0.0743
	Intercept	-0.048	0.225	0.034
	r^2	0.70	0.74	0.65
Above Brokaw	Slope	0.0436	0.712	0.262
	Intercept	-0.929	0.100	-0.498
	r^2	0.86	0.92	0.70
Brokaw to Wausau	Slope	0.00633	0.182	0.0316
	Intercept	0.055	0.179	0.115
	r^2	0.70	0.78	0.57
Lake Wausau	Slope	0.0172	0.712	0.0612
	Intercept	-0.153	0.166	0.112
	r^2	0.54	0.63	0.35
Mosinee Flowage	Slope	0.0171	0.439	0.0947
	Intercept	-0.288	0.072	-0.181
	r^2	0.73	0.82	0.61
Lake DuBay	Slope	0.0171	0.385	0.0846
	Intercept	-0.139	0.272	-0.009
	r^2	0.77	0.71	0.69

regressions of mercury concentrations against wet weight, and highly significant (*P* < 0.01) for four of the six sites with total length as the independent variable (Table 5).

Since size of fish affects mercury concentration in muscle tissue, it was necessary to adjust location means to adjust for variation among samples in size of fish. One-way analysis of covariance was used with mercury concentrations as the dependent variable, either total length or wet weight as the covariate, and location as the factor. However, the assumption of homogeniety of regression slopes was not met (Dowdy and Wearden 1983). Therefore, the mean mercury concentrations and the covariates, total length and wet weight, were transformed to ranks. The ANCOVA with the rank transformation is both robust and powerful (Conover and Iman 1982).

One-way ANCOVA on rank-transformed data showed that both covariates (total length and wet weight, used singly) were highly significant (*P* < 0.01) for both species. Location was also a significant factor (*P* < 0.01) affecting mercury concentrations in the two species.

Adjusted mean ranks of mercury concentrations in walleyes from the reference site, Rainbow Flowage, were equal to, or greater than, those from the main study area (Table 6). In contrast, the adjusted mean ranks for common carp from the main study area were 3- to 6-fold greater than those for the reference site, Range Line Lake. Within each species, mean ranks of mercury concentrations adjusted for total length were similar to those adjusted for wet weight (Table 6).

Mercury concentrations reported in the literature for axial muscle tissue of common carp and walleye were summarized for comparison (Tables 7

Table 5. Results of simple linear regressions of mercury concentrations (μg/g wet weight) in axial muscle tissue of common carp against total length (cm) and wet weight (kg).

Study site	Regression parameter	Independent variable: Total length	Independent variable: Wet weight
Range Line Lake	Slope	0.0110**	0.0682*
	Intercept	-0.475	-0.024
	r^2	0.28	0.17
Above Brokaw	Slope	0.0154**	0.113**
	Intercept	-0.440	0.125
	r^2	0.49	0.44
Brokaw to Wausau	Slope	0.00508	0.0588
	Intercept	0.054	0.213
	r^2	0.02	0.03
Lake Wausau	Slope	0.0176**	0.139**
	Intercept	-0.665	-0.014
	r^2	0.70	0.70
Mosinee Flowage	Slope	0.0192**	0.181**
	Intercept	-0.736	-0.093
	r^2	0.57	0.56
Lake DuBay	Slope	0.00105	0.0996*
	Intercept	0.111	0.074
	r^2	0.01	0.35

*Slope differs from zero at the $\alpha = 0.05$ level.
**Slope differs from zero at the $\alpha = 0.01$ level.

Table 6. Adjusted mean ranks of mercury concentrations in walleyes and common carp from the reference sites and the main study area of the Upper Wisconsin River. Mean ranks were adjusted for total length or wet weight in separate one-way analysis of covariance based on ranks. Adjusted mean ranks with no letters in common are significantly different ($\alpha = 0.05$; Fisher's LSD test).

Location	Mean rank of mercury in walleye, adjusted for		Mean rank of mercury in common carp, adjusted for	
	total length	wet weight	total length	wet weight
Reference site[a]	58 a	58 a	19 c	14 c
Above Brokaw	37 b	37 b	87 a	86 a
Brokaw to Wausau	39 b	39 b	89 a	93 a
Lake Wausau	58 a	58 a	60 b	61 b
Mosinee Flowage	30 b	30 b	55 b	54 b
Lake DuBay	57 a	58 a	70 ab	74 ab

[a]Walleyes from the Rainbow Flowage and common carp from Range Line Lake.

Table 7. Zinc, cadmium, lead, and mercury concentrations in common carp from other freshwaters. A dash (--) indicates that data were unavailable.

Matrix	Metal	Metal concentration[a] (μg/g) n	Mean	Minimum	Maximum	Site and condition	Reference
Liver	Cd	15	0.79	0.24	1.67	Upper Mississippi River; polluted	Wiener et al. (1984)
	Pb	15	8.6	1.84	31.7		
Gill filaments	Zn	--	50	--	--	Danube River and Canal; polluted	Rehwoldt et al. (1976)
Muscle	Hg	10	0.3	--	--	Laboratory study; after exposure to 0.5 μg/l Hg^{++} ($HgCl_2$)	Braun and Yediler (1980)
		10	0.68	--	--		
		2	0.25	--	--	Laboratory study; after exposure to 0.5 μg/l Hg^{++} ($HgCl_2$ or $Hg(NO_3)_2$) and fed Tubificidae containing 0.2 μg/g (wet weight) mercury	
		14	0.32	--	--		
		2	0.17	--	--		
		2	0.24	--	--		
		10	0.24	--	--		
		10	6.5	--	--	Laboratory study; after exposure to 2 μg/l Hg^{++} ($HgCl_2$ or $Hg(NO_3)_2$)	
		10	4.4	--	--		
		10	9.5	--	--		
		10	5.6	--	--		
		6	0.13	0.05	0.22	Lower Mississippi River; polluted	Hartung (1974)
		--	0.22	0.07	0.30	Lake Erie; polluted	Thommes et al. (1972)
		3	0.60	--	--	Wisconsin River below Wyandotte; polluted	Kleinert and Degurse (1972)

Table 7. Continued.

Matrix	Metal	Metal concentration[a] (µg/g) n	Mean	Minimum	Maximum	Site and condition	Reference
Muscle	Hg	3	0.14	0.07	0.18	Rubicon River below Hartford, Wisconsin; polluted	
		10	0.02	0.01	0.03	Fish ponds in Israel; unpolluted	Levitan et al. (1975)
		6	0.03	0.01	0.08	Fish ponds in Israel; unpolluted	
		5	0.29	0.20	0.40	Pymatuning Lake, Ohio; nonpolluted	Aronson et al. (1976)
		14	0.26	0.20	0.45	Lake Erie; polluted	
		4	0.21	0.15	0.28	Mosquito Lake, Ohio; nonpolluted	
		17	0.25	--	--	Lake Oahe, South Dakota; polluted	Walter et al. (1974)
		86	0.92	0.38	2.2	Lake St. Clair, Canada (1970); polluted	Ogilvie (1981)
		24	0.57	0.04	1.2	Lake St. Clair, Canada (1980); polluted	
		15	0.81	0.46	1.2	Savannah River, Georgia; polluted	Georgia Water Quality Control Board (1971)

[a]Concentrations of zinc, cadmium, and lead are reported as dry weight values; mercury concentrations are reported as wet weight values.

and 8). Mercury concentrations in common carp from the main study area and Range Line Lake were generally similar to those in carp subjected to a laboratory exposure 0.5 μg/L of Hg^{+2}, but were much lower than concentrations in carp exposed to 2 μg/L of Hg^{+2} (Braun and Yediler 1980). Mercury burdens for carp from the Upper Wisconsin River were also lower than those for carp from mercury-polluted areas, such as the Savannah River, Lake St. Clair, and a downstream reach of the Wisconsin River (Table 7). However, mean values for carp from the Upper Wisconsin River and Range Line Lake were considerably higher than mean concentrations in carp reared in fish ponds in Israel.

Mean values for walleyes analyzed in this study were similar to those reported for walleyes from areas considered to be metal-polluted: Lake St. Clair, Lake Oahe, and the Tongue River Reservoir (Table 8). However, comparisons of mean mercury concentrations in axial muscle of fish from the main study area and reference sites to values from other studies are of limited utility, due to the dependence of mercury concentration on the size or age of the fish (Huckabee et al. 1975). Since size or age information were not reported with corresponding mercury concentrations in many of the cited studies, few conclusions can be drawn from these comparisons.

Mercury concentrations in muscle of common carp and walleyes collected from the Upper Wisconsin River during 1970-1973 by the Wisconsin Department of Natural Resources (Appendix IV) were compared to values reported here for 1981 (Figs. 4 and 5). Mercury concentrations

Table 8. Mercury concentrations in axial muscle tissue of walleyes from other freshwaters. A dash (--) indicates that data were not available.

Site and condition	Metal concentration (μg/g wet weight)				Reference
	n	Mean	Minimum	Maximum	
Wisconsin River above Wyandotte; polluted	1	0.62	--	--	Kleinert and Degurse (1972)
Wisconsin River, Upper Petenwell Flowage; polluted	1	5.82	--	--	
Lake Superior near Amaicon River mouth; nonpolluted	3	0.74	0.38	1.17	
Tongue River Reservoir, Montana; polluted	31	0.37	0.12	1.30	Phillips (1978)
Tongue River Reservoir, Montana; polluted	9	0.59	0.28	1.38	Phillips (1979)
Candle Lake, Canada; nonpolluted	9	0.18	0.11	0.24	Sumner et al. (1972)
Last Mountain Lake, Canada; nonpolluted	10	0.45	0.23	0.68	
Lake Oahe, South Dakota; polluted	22	0.30	--	--	Walter et al. (1974)
Lake St. Clair, Canada (1970); polluted	226	1.69	0.23	14.8	Ogilvie (1981)
Lake St. Claire, Canaca (1980); polluted	6	0.33	0.17	2.0	
Lake Erie; polluted	1	0.84	--	--	Thommes et al. (1972)

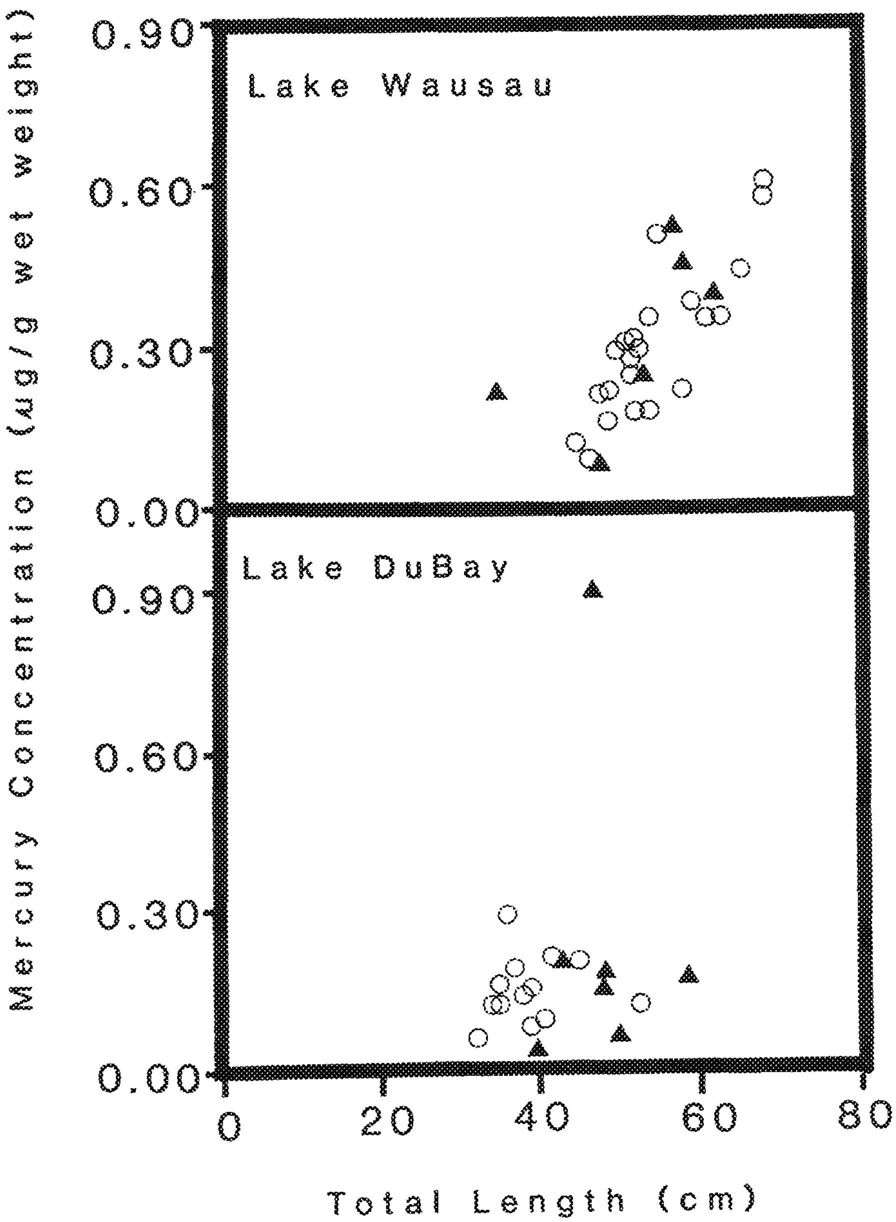

Fig. 4. Mercury concentrations in axial muscle against total length of common carp from Lake Wausau and Lake DuBay in 1981 (open circles; data from this study) and in 1970-1973 (closed triangles; data from Wisconsin Department of Natural Resources).

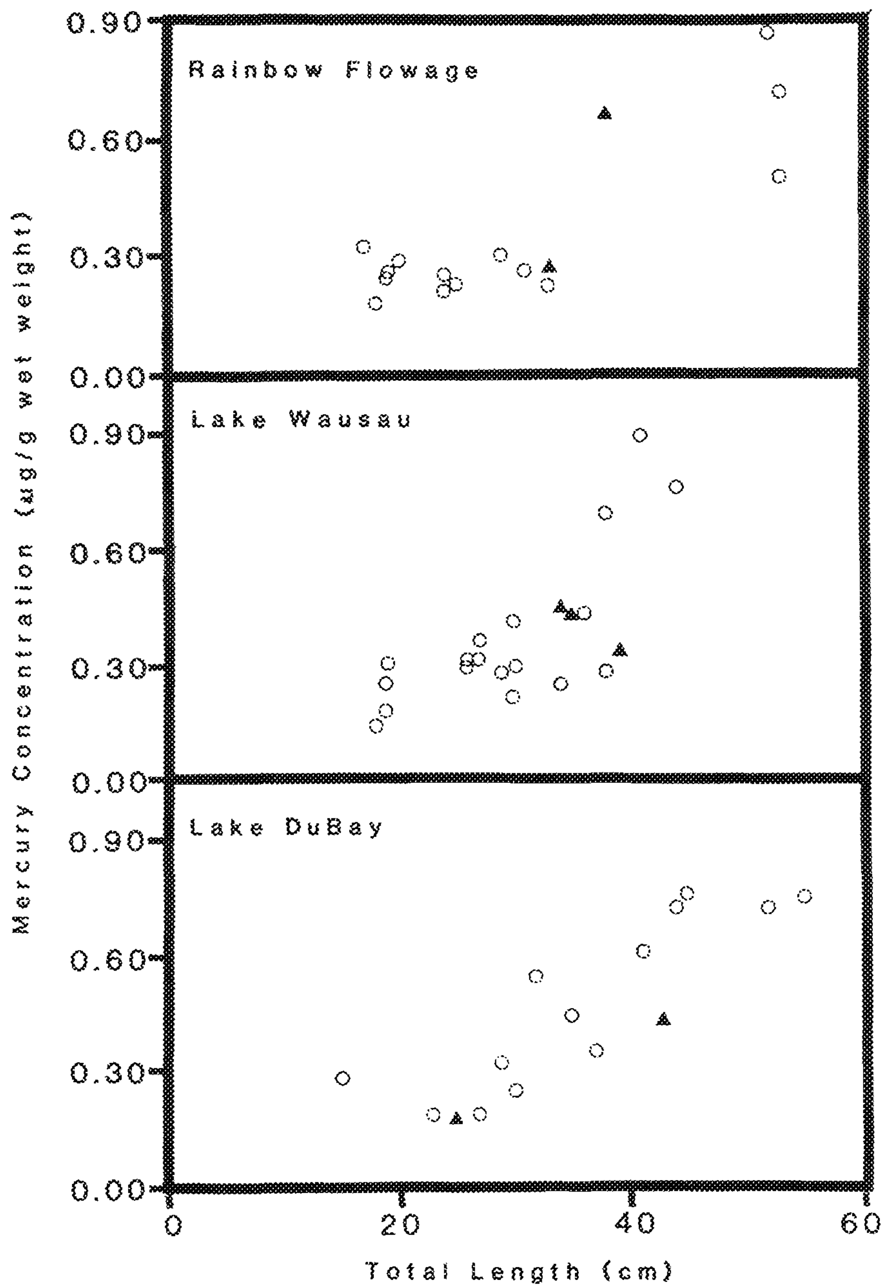

Fig. 5. Mercury concentrations in axial muscle against total length of walleyes from Rainbow Flowage, Lake Wausau, and Lake DuBay in 1981 (open circles; data from this study) and in 1970-1973 (closed triangles; data from Wisconsin Department of Natural Resources).

in both species were similar between the two periods for fish of the same size. This indicates no measurable difference in mercury concentrations of fish from 1970-1973 and 1981 and suggests that the biological availability of mercury was similar during the two periods.

Cadmium. Cadmium concentrations in common carp and walleyes from the main study area were generally not elevated relative to those in fish from the reference sites. Cadmium concentrations in livers of common carp varied significantly among locations (one-way ANOVA; $P \leq 0.001$). The greatest mean cadmium concentration in carp occurred at the above Brokaw site (Table 9). Although this value was significantly greater than the mean cadmium concentrations in carp from the other main study area sites, it did not differ significantly from that for carp from the reference site, Range Line Lake (Table 9). The mean cadmium concentration in carp from the reference site differed significantly from the mean for only one study site, Lake Wausau.

Cadmium concentrations in walleye livers varied marginally among locations (one-way ANOVA; $P = 0.054$), and no two location means differed significantly (Table 10). Therefore, the data for sites in the main study area were grouped in subsequent analyses.

The relation between cadmium concentrations in liver tissue and body size of fish was tested by Spearman (rank) correlations. A significant positive correlation occurred between cadmium levels and wet weight of common carp at three sites: Brokaw to Wausau, Lake Wausau, and Mosinee Flowage (Table 11). Similar correlations occurred between cadmium concentrations and total length of common carp at Lake Wausau

Table 9. Mean wet weight, total length (ranges in parentheses), and cadmium concentrations in liver of common carp from the main study area and Range Line Lake. Mean cadmium concentrations with no letters in common are significantly different ($P \leq 0.05$; Tukey's hsd procedure). Multiple comparisons of means were conducted on log-transformed data.

Location	n	Mean wet weight (kg)	Mean total length (cm)	Mean cadmium concentration (μg/g dry weight)
Range Line Lake	25	3.32 (1.39-4.23)	61.2 (44.3-69.3)	0.86 ab
Above Brokaw	22	1.72 (0.89-3.98)	48.9 (41.8-64.9)	1.13 a
Brokaw to Wausau	17	1.28 (0.90-2.72)	46.1 (39.3-61.7)	0.63 bc
Lake Wausau	18	2.29 (1.49-4.16)	55.5 (49.0-68.2)	0.43 c
Mosinee Flowage	17	1.75 (1.06-2.49)	50.0 (44.0-59.0)	0.43 bc
Lake DuBay	12	0.76 (0.47-1.85)	37.0 (31.8-52.1)	0.53 bc

Table 10. Mean wet weight, total length (ranges in parentheses), and cadmium concentrations in liver of walleyes from the main study area and Rainbow Flowage. Mean cadmium concentrations with no letters in common are significantly different ($P \leq 0.05$; Tukey's *hsd* procedure). Multiple comparisons of means were conducted on log-transformed data.

Location	n	Mean wet weight (kg)	Mean total length (cm)	Mean age	Mean cadmium concentration (µg/g dry wt.)
Rainbow Flowage	12	0.47 (0.038-1.59)	31.3 (16.7-52.8)	4.8 (2-9)	0.53 a
Above Brokaw	13	0.55 (0.082-2.92)	33.0 (21.1-65.1)	3.2 (3-4)	0.83 a
Brokaw to Wausau	13	0.29 (0.073-1.32)	28.0 (20.5-50.3)	--	0.78 a
Lake Wausau	16	0.31 (0.047-0.78)	31.7 (18.5-43.7)	4.1 (2-8)	0.49 a
Mosinee Flowage	13	0.43 (0.075-1.80)	34.4 (20.8-57.8)	4.6 (2-9)	0.89 a
Lake DuBay	13	0.53 (0.029-1.69)	35.0 (15.4-55.2)	6.2 (3-10)	0.36 a

Table 11. Spearman correlation coefficients ($\underline{r}_s$) between cadmium concentrations in liver tissue and total length and wet weight of common carp from the main study area and from the reference site, Range Line Lake. One (*) and two (**) asterisks indicate significance at the $\alpha = 0.05$ and $\alpha = 0.01$ levels, respectively.

Location	n	Correlation between Cd concentration and	
		Total length	Wet weight
Range Line Lake	25	0.33	0.12
Above Brokaw	21	0.21	0.14
Brokaw to Wausau	17	0.36	0.49*
Lake Wausau	18	0.47*	0.45*
Mosinee Flowage	17	0.69**	0.62**
Lake DuBay	12	-0.07	0.27
Upper Wisconsin River[a]	85	0.07	0.09

[a]Combined data for the five sites in the main study area.

and Mosinee Flowage (Table 11). For walleyes, significant but weak negative correlations were observed between cadmium concentrations and total length, wet weight, and age for fish from the main study area (Table 12). Large individual variation of whole body cadmium concentrations in fish often occur; trends in cadmium levels with weight are not common (Vinikour et al. 1980).

Mean cadmium concentrations in livers of carp from the main study area and the reference site were similar to the mean value reported by Wiener et al. (1984) for common carp liver from the Upper Mississippi River (Table 7).

The similarity of cadmium concentrations in walleyes and common carp between the reference sites and the main study area may be due to a number of factors. For example, waters of the Rainbow Flowage have lower pH and calcium levels, conditions which increase permeability of fish gill membranes and enhance cadmium uptake. Due to the relatively large particle size (primarily sand) and low organic content of the sediments, the reference site for walleyes, little cadmium is associated with the sediments (Findley 1983). Cadmium may therefore be more biologically available in the Rainbow Flowage than in the main study area, where cadmium is bound to the fine-grained, highly organic sediments.

Concentrations of cadmium in various tissues of cadmium-exposed fish are often positively rank correlated with cadmium concentrations in the water (Van Hoof and Van San 1981). However, a correlation of cadmium levels between fish tissues and bed sediments is seldom found,

Table 12. Spearman correlation coefficients ($\underline{r_s}$) between cadmium concentrations in liver tissue and total length, wet weight, and age of walleyes from the main study area and from the reference site, Rainbow Flowage. One (*) and two (**) asterisks indicate significance at the $\alpha = 0.05$ and $\alpha = 0.01$ level, respectively.

Location	n	Correlation between Cd concentration and		
		Total length	Wet weight	Age
Rainbow Flowage	12	-0.16	-0.16	-0.11
Upper Wisconsin River[a]	68	-0.26*	-0.29**	-0.39**

[a]Combined data for the five sites in the main study area.

and was not observed in this study. This lack of correlation could be due to variations in the numerous conditions that govern the availability of metals in sediments to aquatic biota (Jenne and Luoma 1977).

Zinc. Zinc concentrations in common carp and walleyes from the main study area were not elevated relative to those in fish from the reference sites. Zinc concentrations in gill filaments of common carp varied significantly among locations (one-way ANOVA; $P \leq 0.001$). The lowest mean zinc concentration occurred at the above Brokaw site (Table 13), and zinc levels in carp increased progressively with distance downstream. However, only one site, Lake DuBay, contained carp with significantly higher mean zinc concentrations than the fish from the reference site, Range Line Lake (Table 13).

Zinc concentrations in gill filaments of walleyes also varied significantly among locations ($P \leq 0.05$). However, Tukey's *hsd* procedure indicated no significant difference between any two location means (Table 14), probably due to the conservative nature of the test (Zar 1974).

Spearman (rank) correlations were used to evaluate the relation between zinc concentrations in gill filaments and body size of fish. For carp, significant negative correlations occurred between zinc concentrations and total length and wet weight at only one site, the Mosinee Flowage (Table 15). A weak correlation occurred between zinc concentrations and age of walleyes from the main study area (Table 16); all others were nonsignificant.

Table 13. Mean wet weight, total length (ranges in parentheses), and zinc concentrations in gill filaments of common carp from the main study area and Range Line Lake. Mean zinc concentrations with no letters in common are significantly different ($P \leq 0.05$; Tukey's hsd procedure). Multiple comparisons of means were conducted on log-transformed data.

Location	n	Mean wet weight (kg)	Mean total length (cm)	Mean zinc concentration (μg/g dry weight)
Range Line Lake	25	3.32 (1.39-4.23)	61.7 (44.3-69.3)	1175 bc
Above Brokaw	23	1.68 (0.89-3.98)	48.9 (41.8-64.9)	1104 c
Brokaw to Wausau	18	1.26 (0.90-2.72)	45.9 (39.3-61.7)	1315 abc
Lake Wausau	24	2.20 (1.19-3.85)	54.6 (44.6-68.2)	1446 ab
Mosinee Flowage	17	1.75 (1.06-2.49)	50.0 (44.0-59.0)	1558 ab
Lake DuBay	12	0.80 (0.48-1.85)	38.7 (31.8-52.1)	1725 a

Table 14. Mean wet weight, total length (ranges in parentheses), and zinc concentrations in gill filaments of walleyes from the main study area and the Rainbow Flowage. No two mean zinc concentrations differed significantly (Tukey's <u>hsd</u> procedure).

Location	n	Mean wet weight (kg)	Mean total length (cm)	Mean age (yr)	Mean zinc concentration (µg/g dry wt.)
Rainbow Flowage	10	0.53 (0.038-1.59)	32.2 (16.7-52.8)	4.9 (2-9)	95
Above Brokaw	15	0.49 (0.074-2.92)	31.6 (21.1-65.1)	3.2 (3-4)	91
Brokaw to Wausau	14	0.27 (0.065-1.32)	27.5 (20.5-50.3)	3.9 (2-8)	90
Lake Wausau	16	0.31 (0.047-0.78)	31.7 (18.5-43.9)	4.4 (6-1)	104
Mosinee Flowage	13	0.43 (0.075-1.80)	34.4 (20.8-57.8)	4.1 (2-8)	79
Lake DuBay	13	0.51 (0.20-16.0)	34.9 (15.4-55.2)	6.1 (3-10)	77

Table 15. Spearman correlation coefficients (r_s) between zinc concentrations in gill filaments and total length and wet weight of common carp from the main study area and from the reference site, Range Line Lake. Two asterisks (**) indicate significance at the α = 0.01 level.

Location	n	Correlation between Zn concentration and	
		Total length	Wet weight
Range Line Lake	25	-0.15	-0.16
Above Brokaw	23	0.31	0.32
Brokaw to Wausau	18	0.26	0.33
Lake Wausau	24	-0.19	-0.13
Mosinee Flowage	17	-0.84**	-0.76**
Lake DuBay	13	0.10	0.09
Upper Wisconsin River[a]	95	-0.09	-0.08

[a]Combined data for the five sites in the main study area.

Table 16. Spearman correlation coefficients (r_s) between zinc concentrations in gill filaments and total length, wet weight, and age of walleyes from the main study area and from the reference site, the Rainbow Flowage. An asterisk (*) indicates significance at the $\alpha = 0.05$ level.

Location	n	Correlation between Zn concentration and		
		Total length	Wet weight	Age
Rainbow Flowage	10	-0.43	-0.43	-0.34
Above Brokaw	15	-0.30	-0.29	-0.22
Brokaw to Wausau	14	0.19	-0.02	-0.11
Lake Wausau	16	0.20	0.20	0.10
Mosinee Flowage	13	-0.24	-0.21	-0.21
Lake DuBay	13	-0.42	-0.40	-0.46
Upper Wisconsin River[a]	71	-0.14	-0.14	-0.22*

[a]Combined data for the five sites in the main study area.

Zinc concentrations in common carp were more than 10-fold greater than those in walleyes (Tables 13 and 14). As bottom feeders, carp are known to disturb surficial sediments in search of food (Becker 1983) and are probably in closer contact with the contaminated sediments of the Upper Wisconsin River than walleyes. Jeng and Lo (1974) reported high zinc concentrations in common carp tissues from uncontaminated areas and suggested that high zinc levels in carp are natural. However, Rehwoldt et al. (1976) determined zinc in gills of common carp from the Danube River and Canal, which are metal-contaminated. Their mean zinc concentration of 50 µg/g dry weight (Table 7) was much lower than the values reported here. No quality assurance information was given, and comparisons with these data should be made with caution. In the Wisconsin River study the observed values for reference fish were as high as those for fish from the main study area, further suggesting that zinc concentrations may be naturally high in gill filaments of common carp.

Lead. Lead concentrations in liver tissue of walleyes and common carp were highly variable. Concentrations of lead in individual common carp ranged from 0.09 to 2.4 µg/g dry weight in the main study area and from 0.15 to 2.9 µg/g at the reference site, Range Line Lake (Table 17). Mean concentrations of lead in carp livers varied from 0.19 µg/g at Lake Wausau to 0.79 µg/g at the above Brokaw site. The mean lead concentration in carp from the control site was 0.53 µg/g. Lead concentrations in walleyes ranged from 0.06 to 10.7 µg/g dry weight in the main study area and from 0.06 to 3.5 µg/g in the reference area, Rainbow Flowage (Table 18). The mean concentration of lead in walleye

Table 17. Sizes, ages, and lead concentrations in liver tissues of common carp from the main study area of the Upper Wisconsin River and from the reference site, the Rainbow Flowage. The range is given in parentheses below each mean.

Location	n	Mean total length of fish (cm)	Mean wet weight of fish (kg)	Mean lead concentration (μg/g dry weight)
Range Line Lake	11	59.0 (44.3-65.2)	3.07 (1.39-3.90)	0.53 (0.15-2.9)
Above Brokaw	11	47.1 (41.8-60.7)	1.46 (0.89-2.96)	0.79 (0.34-2.3)
Brokaw to Wausau	10	45.0 (39.3-50.9)	1.17 (0.90-1.59)	0.24 (0.12-0.36)
Lake Wausau	10	56.2 (49.1-68.2)	2.38 (1.51-4.16)	0.19 (0.09-0.35)
Mosinee Flowage	11	49.0 (42.9-57.2)	1.62 (1.06-2.48)	0.28 (0.13-0.72)
Lake DuBay	11	39.1 (34.5-52.1)	0.82 (0.47-1.85)	0.64 (0.13-2.4)
Upper Wisconsin River[a]	53	47.1 (34.5-68.2)	1.48 (0.47-4.16)	0.44 (0.09-2.4)

[a]Combined data for the five sites in the main study area.

Table 18. Sizes, ages, and lead concentrations in liver tissue of walleyes from the main study area of the Upper Wisconsin River and from the reference site, the Rainbow Flowage. The range is given in parentheses below each mean.

Location	n	Mean total length of fish (cm)	Mean wet weight of fish (kg)	Mean age of fish (yr)	Mean Pb concentration (µg/g dry weight)
Rainbow Flowage	11	32.7 (18.0-52.8)	0.51 (0.046-1.59)	5.0 (2-9)	0.87 (0.06-3.5)
Above Brokaw	7	37.3 (24.1-65.1)	0.85 (0.128-2.92)	3.7 (2-8)	0.33 (0.09-0.59)
Brokaw to Wausau	11	29.1 (20.5-50.3)	0.33 (0.073-1.32)	4.0 (2-8)	0.30 (0.08-0.76)
Lake Wausau	13	31.6 (18.5-43.9)	0.31 (0.047-0.78)	4.4 (1-6)	1.52 (0.14-10.7)
Mosinee Flowage	11	32.2 (20.8-55.0)	0.39 (0.076-1.46)	4.9 (3-9)	0.36 (0.06-1.1)
Lake DuBay	12	35.7 (15.4-55.2)	0.54 (0.029-1.69)	6.1 (3-10)	1.11 (0.07-9.2)
Upper Wisconsin River[a]	54	32.9 (15.4-65.1)	0.45 (0.029-2.92)	4.7 (1-10)	0.79 (0.06-10.7)

[a]Combined data for the five sites in the main study area.

liver tissue varied from 0.30 μg/g at the Brokaw to Wausau site to 1.52 μg/g at Lake Wausau.

There was little apparent difference in lead concentrations between fish from the reference sites and the main study area. A Kruskal-Wallis one-way ANOVA performed on all sites indicated no significant variation (P = 0.14) of lead concentrations in walleye among locations. Therefore, data for all walleyes from the main study area data were grouped in further analyses. For carp, this test revealed that lead concentrations varied significantly ($P < 0.01$) among the study sites. However, further analysis of the carp data by the Mann-Whitney U-Wilcoxon rank sum W test showed that mean lead concentrations in carp from the main study area did not differ from those in carp from the reference site, Range Line Lake.

Spearman (rank) correlation coefficients revealed a significant correlation between lead concentrations and wet weight of carp from only one site, the Mosinee Flowage (Table 19). The size of the carp therefore had little relation to the lead concentration in the liver, therefore, the similarity of lead concentrations in fish from the reference site and the main study area cannot be explained by their larger size. For walleyes, significant Spearman correlation coefficients between lead in liver and total length, wet weight, and age were observed for the Rainbow Flowage sample and for the fish from all main study area sites combined (Table 20, Fig. 6). Similarly, other investigators have found that concentrations of lead in fish generally do not increase with body size (Hodson et al. 1982; Vinikour et al. 1980; Wiener and Giesy 1979).

Table 19. Spearman correlation coefficients (r_s) between lead concentrations in liver tissue and total length and wet weight of common carp from the main study area and from the reference site, Range Line Lake. An asterisk (*) indicates significance at the $\alpha = 0.05$ level.

Location	n	Correlation between Pb concentration and: Total length	Wet weight
Range Line Lake	11	-0.06	-0.20
Above Brokaw	11	-0.22	-0.32
Brokaw to Wausau	10	0.26	0.30
Lake Wausau	10	0.01	-0.17
Mosinee Flowage	11	0.59*	0.66*
Lake DuBay	11	0.10	-0.31
Upper Wisconsin River[a]	53	-0.12	-0.18

[a]Combined data for the five sites in the main study area.

Table 20. Spearman correlation coefficients ($\underline{r_s}$) between lead concentration in liver tissue and total length, wet weight, and age of walleyes from the main study area and from the Rainbow Flowage, the reference site. Two asterisks (**) indicate significance at the $\alpha = 0.01$ level.

		Correlation between Pb concentration and		
Location	n	Total length	Wet weight	Age
Rainbow Flowage	11	-0.87**	-0.87**	-0.94**
Upper Wisconsin River[a]	54	-0.43**	-0.43**	-0.54**

[a]Combined data for the five sites in the main study area.

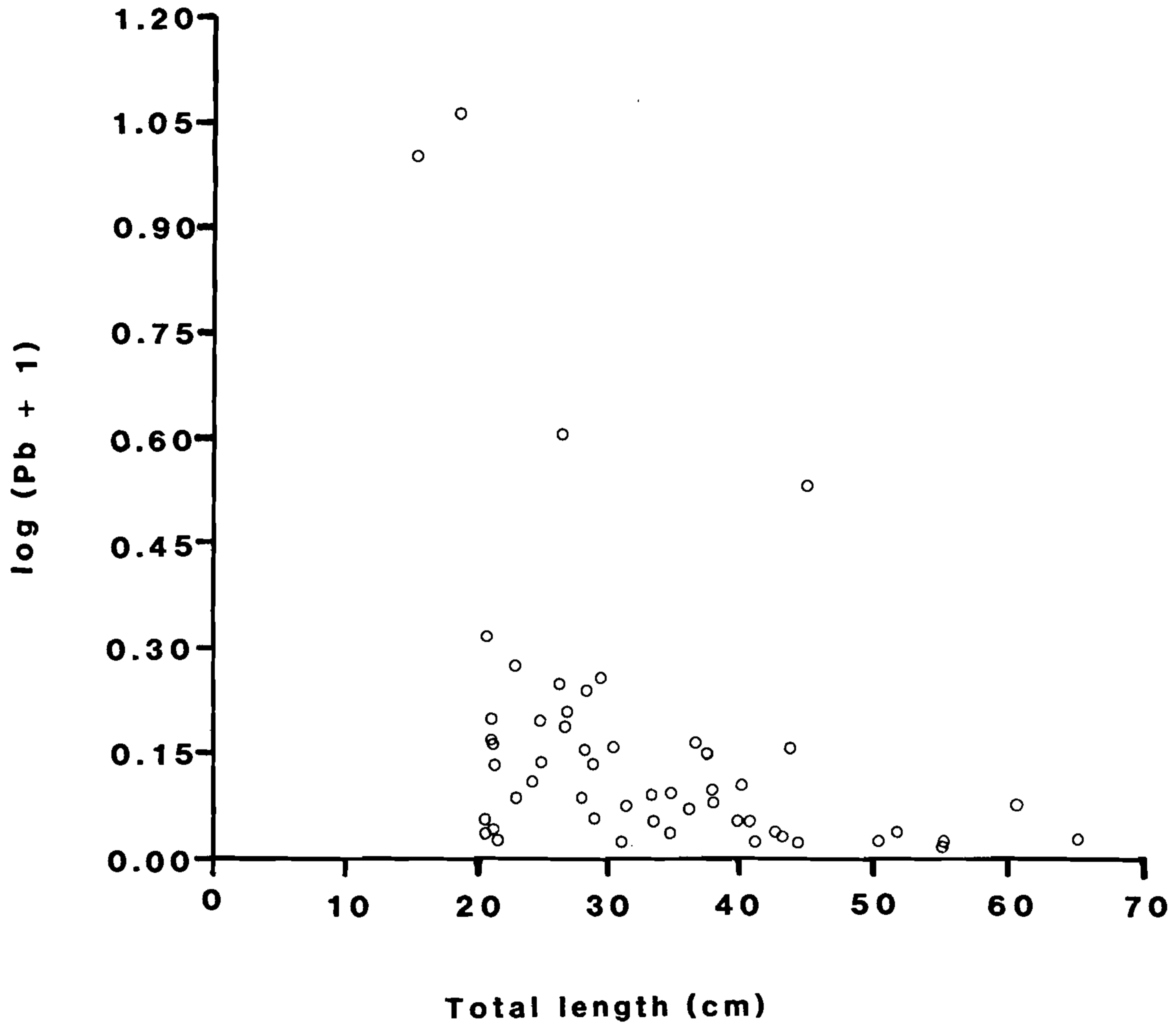

Fig. 6. Plots of log-transformed lead concentrations (μg/g dry weight) against total length of walleyes from the main study area.

Mean lead concentrations in livers of carp from the main study area and reference sites were lower than values reported for carp from the Upper Mississippi River (Table 7). Comparisons with lead concentrations in whole carp from the Upper Mississippi River to data for carp from the U.S. National Pesticide Monitoring Program indicated that carp from the Upper Mississippi had relatively high lead concentrations on a national scale (Wiener et al. 1984). Lead concentrations in surficial sediments at some Upper Mississippi River sites studied by Wiener et al. (1984) were similar to those of surficial sediments of the main study area (Findley 1983). Therefore, the biological availability of lead in the main study area of the Upper Wisconsin River may be less than in the Upper Mississippi River.

General Discussion

Mean concentrations of zinc, lead, and cadmium in fish differed little between the main study area and reference sites. Similarly, mean mercury concentrations in walleyes, adjusted for body size, did not differ between the reference site and the main study area. In contrast, mercury concentrations in carp from the reference site were lower than those in fish from the main study area, when adjusted for body size.

In a companion study, Findley (1983) found that concentrations and enrichment of mercury, cadmium, zinc, and lead in sediments were greater in the main study area than in the Rainbow Flowage. All four of these metals were also higher in surficial sediments of the main study area than in shale, a global standard for estimating background concentrations. According to the U.S. Environmental Protection Agency's criteria (U.S. Environmental Protection Agency 1981), sediments in the main study area are moderately polluted with cadmium and lead and heavily polluted with mercury and zinc. In general, little relation is apparent between concentrations of the metals studied in fish and the metal concentrations in surficial sediments of the Upper Wisconsin River. Findley (1983) also analyzed crayfish for mercury and found little relation between mercury levels in crayfish and surficial sediments; however, crayfish are less mobile than fish and probably represent more localized conditions.

Mercury concentrations in common carp and walleyes were similar to concentrations recorded in axial muscle of the same species of similar size during 1970-1973 by the Wisconsin Department of Natural Resources. Similarly, comparison of Findley's crayfish data of 1981 and to data from a 1975 study (Sheffy 1978) suggested that mercury concentrations in crayfish in 1981 were equal to or greater than, values measured in 1975. This indicates that mercury is continuing to cycle through the biological components of the system.

Adjusted mean ranks of mercury concentrations in walleyes from the Rainbow Flowage were equal to, or greater than, those for walleyes from the main study area, even though mercury concentrations were very low in sediments from the Rainbow Flowage (Findley 1983). Crayfish from the Rainbow Flowage also contained mercury concentrations similar to those from two of the five sites in the main study area (Findley 1983). The water of Rainbow Flowage is softer and of a lower pH than that in the main study area; therefore, mercury methylation and availability to aquatic organisms may be enhanced by chemical conditions in the Rainbow Flowage. A significant negative correlation between the mercury content of fish and aqueous pH was demonstrated for a number of small, oligotrophic lakes in Sweden (Jernelov et al. 1975). Low alkalinity lakes in Ontario contained walleyes with higher mercury concentrations than those from lakes with higher alkalinities (Scheider et al. 1979). The sediments of Rainbow Flowage are coarser than those at the main study area (Findley 1983), and therefore have less metal absorption capacity (Forstner and Wittmann 1981). Mercury present in the Rainbow Flowage may be more available because little can be tightly bound in the sediments. The longer residence time of the Rainbow Flowage may also influence the mercury content of the fish found there. Other investigators have reported high mercury concentrations in fish from systems with low levels of mercury in the sediments (Suckchareon 1980; Phillips and Medvick 1981; Wiener et al. 1984).

Although the Rainbow Flowage receives no direct input of metals, atmospheric loadings of mercury deposited by wet and dry deposition have probably increased in recent years. Syers et al. (1973) examined sediment cores from four softwater lakes in northeastern Wisconsin and found that in three of the four lakes, mercury concentrations were significantly higher in the surficial sediments than in precultural sediments (Syers et al. 1973). In the past, two of those lakes received some sewage inputs, but little urban runoff or industrial wastes. Syers et al. (1973) suggested that much of the mercury in the surface sediments of those lakes resulted from atmospheric deposition of mercury, possibly derived from the combustion of coal and petroleum. In another study, comparisons of mercury levels in museum preserved walleyes collected between 1865 and 1936 from Michigan lakes to those in recently collected walleyes from the same areas revealed increased mercury contamination of walleyes at three of seven sites (Kelly et al. 1975).

The form of mercury most readily taken up by fish is the highly toxic, monomethylated form, which is more soluble and available for uptake than inorganic forms (Forstner and Wittmann 1981; Yamamoto et al. 1983). Certain microbes can transform the mercuric (II) ion to the methylmercury form (Jensen and Jernelov 1967). This transformation occurs largely in the sediments, but may also occur in the water column and in the intestines of fish (Rudd et al. 1983). The production of methylmercury can be influenced by the total mercury content in the surficial sediments (Rudd et al. 1983; Wright and Hamilton 1982). However, Langley (1973) found that the methylating capacity of sediments depended more on the ability of the sediments to promote microbial activity of the methylating bacteria than on the mercury concentrations of the sediments. In fact, the rate of methylation in surficial sediments was increased 3-fold in 2 days by the addition of bacterial food that stimulated microbial activity (Rudd et al. 1983). Limnological characteristics believed to enhance mercury methylation, coincide with conditions in the impoundments of the Upper Wisconsin River (Phillips and Medvick 1981). Large populations of microbes can be supported in the bottom sediments by the organic matter from industrial and municipal discharges. Low dissolved oxygen concentrations (Coble 1982) create anaerobic conditions in surficial sediments and high water temperatures during summer, favor increased microbial activity, and therefore increased methylation of mercury at the sediment-water interface (Bisogni and Lawrence 1975). Under high flow conditions, methylmercury can be mobilized from the sediments and transported throughout the system (Park et al. 1980).

Bacterial methylation in sediments of the main study area was most rapid in the upper most centimeters of the surficial sediments (Callister 1983). Findley (1983) determined that the most contaminated strata of sediments in the main study area were 15 cm deep or more. This suggests that the available mercury is being released primarily from the less-heavily contaminated surficial sediments. Similarly, Rudd et al. (1983) found that the deeper sediments of the English-Wabigoon River System contained the most mercury, but determined that these strata were not the main source of mercury and methylmercury to the biota. The results of Callister's methylation study also indicate that a high potential exists in these sediments from methylation of mercury bound to particles of sediments (Callister 1983).

CONCLUSIONS

Mercury concentrations in axial muscle of walleyes and common carp were positively correlated with the length and weight of the fish. Rank-transformed, mean mercury concentrations of walleye of the main study area, adjusted for body size, were similar to those of the reference site, the Rainbow Flowage. However, adjusted mean ranks of mercury levels in common carp from the reference site were significantly lower than those in fish from the main study area.

Only 2 of the 214 fish analyzed, both large walleyes, contained mercury concentrations in edible muscle tissue above the action level of 1.0 μg/g wet weight established by the U.S. Food and Drug Administration. Yet, mercury concentrations in axial muscle of common carp and walleye collected during 1981 were similar to mercury levels of fish analyzed during 1970-1973 in the same reaches of river. Similarly, crayfish collected from the studied reach of the river in 1981 (Findley 1983) contained mercury levels equal to, or greater than, those collected in 1975 (Sheffy 1978). The surficial sediments of the main study area are enriched with mercury; however, the most heavily contaminated strata are buried at least 15 cm in most areas (Findley 1983). The methylation of both bound and unbound forms of mercury is potentially rapid and occurs primarily in the upper few centimeters of sediments (Callister 1983). Therefore, mercury availability to, and cycling through, the biota of the system may be enhanced by rapid methylation rates, although the most contaminated sediments have been buried by subsequent deposits.

The surficial sediments from the main study area were also enriched with cadmium, lead, and zinc (Findley 1983). However, cadmium and lead concentrations in common carp and walleyes from the main study area were not elevated relative to those in fish from the reference sites. Also, zinc concentrations in gill filaments of walleyes from the main study area did not differ from those in walleyes of the reference site, the Rainbow Flowage. Only common carp from one site, Lake DuBay, had a mean zinc concentration significantly higher than those from the reference site.

Although largely free of direct anthropogenic metal inputs, the Rainbow Flowage did not prove to be a useful reference area, perhaps due to water chemistry conditions that may enhance the availability of these metals to fish.

The most heavily contaminated sediments in the main study area have been buried (Findley 1983). Activities, such as dredging, would resuspend these layers and increase the biological availability of the metals absorbed. Therefore, these heavily contaminated strata should not be disturbed.

Lessening the conditions that enhance microbial methylation activity would help reduce mercury availability. In addition to the reduction of mercury loading, reducing the organic discharges to the system would aid in diminishing microbial activity (Wright and Hamilton 1982). This would reduce the bacterial food source and the anoxic conditions that enhance methylation (Rudd et al. 1983). Callister (1983) demonstrated that the optimum temperature for methylation in sediments from the main study area was 35°C, and that the highest observed temperature was 24°C. Activities which would increase ambient temperatures in the river system should therefore be avoided.

Since the response of mercury to changes in factors controlling partitioning are very rapid (Rudd et al. 1983), monitoring of mercury levels in fish in the future would be necessary in detecting trends in the cycling of mercury in this system. Additional investigations dealing with methylation rates and transport of mercury also would be helpful.

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Appendix I. Procedures and operating conditions during atomic absorption analyses of fish samples.

Metal	Wavelength (nm)	Atomization procedure	Program temperature (C)		Deuterium background correction	Standard additions
			Charring	Atomization		
Cadmium	213.9	Graphite furnace	300	1600	Yes	No
Lead	228.8	Graphite furnace	450	1800	Yes	No
Mercury	257.8	Cold vapor generation	--	--	No	No
Zinc	213.9	Flame	--	--	Yes	No

Appendix II. Metal concentrations, total length, and wet weight of individual common carp from the Upper Wisconsin River and the reference site, Range Line Lake. Concentrations of zinc, cadmium, and lead are dry weight values, whereas concentrations of mercury are wet weight values.

Location	Fish identification number	Total length (cm)	Wet weight (kg)	Metal concentrations (μg/g)			
				Zinc in gill filaments	Cadmium in liver	Lead in liver	Mercury in axial musculature
Range Line Lake	1	62.7	3.05	1060	0.50	--	0.15
	2	65.2	3.66	876	1.31	0.51	0.06
	3	63.6	3.57	1160	1.58	--	0.25
	4	69.1	4.14	1620	0.91	--	0.10
	5	61.7	3.06	1390	1.34	--	0.28
	6	63.4	3.90	712	0.27	0.18	0.27
	7	64.1	3.68	1100	0.40	--	0.32
	8	64.0	3.82	889	0.38	--	0.27
	9	63.7	3.73	1120	0.84	0.15	0.34
	10	64.9	3.90	1240	0.84	0.18	0.31
	11	59.5	2.90	1420	1.01	--	0.24
	12	63.5	3.59	1460	0.83	--	0.25
	13	59.5	3.35	1460	0.65	0.63	0.10
	14	64.2	3.94	1230	0.65	--	0.16
	15	44.3	1.39	1280	0.20	0.21	0.03
	16	63.0	3.82	1170	1.00	0.28	0.02
	17	47.8	1.78	1490	0.36	0.24	0.05
	18	53.1	2.24	1680	0.24	0.17	0.07
	19	59.4	2.60	613	0.83	--	0.23
	20	64.5	4.23	847	0.52	--	0.22
	21	69.3	3.89	1360	0.70	--	0.53
	22	62.9	2.92	1010	3.63	2.86	0.23
	23	62.6	3.32	1170	0.62	--	0.15
	24	64.1	3.57	1180	1.48	--	0.17
	25	61.4	3.05	828	0.48	0.40	0.27
Above Brokaw	19	46.0	1.26	727	0.45	--	0.25
	20	44.5	1.10	915	2.61	0.62	0.30
	21	48.3	1.65	1310	--	--	0.41
	22	55.1	2.41	--	--	--	0.47
	23	44.9	1.30	575	1.06	2.25	0.19
	24	43.1	1.10	1630	0.79	0.41	0.18
	25	43.5	1.09	1440	0.62	--	0.12
	26	46.0	1.45	1230	0.47	0.34	0.25
	27	47.2	1.30	1280	1.21	--	0.25
	28	49.5	1.61	1280	1.09	0.68	0.25
	29	50.0	1.64	1700	1.25	--	0.49
	30	45.0	1.31	822	1.18	0.35	0.21
	31	50.5	1.79	1040	1.17	0.58	0.28

Appendix II. Continued.

Location	Fish identification number	Total length (cm)	Wet weight (kg)	Metal concentrations (µg/g) Zinc in gill filaments	Cadmium in liver	Lead in liver	Mercury in axial musculature
Above Brokaw, cont.	32	46.7	1.36	872	0.67	--	0.26
	33	51.9	2.20	1150	0.97	--	0.37
	34	60.7	2.96	1170	1.95	0.37	0.41
	35	60.1	3.34	955	0.78	--	0.31
	36	64.9	3.98	1570	0.45	--	0.63
	37	50.2	1.71	1110	--	--	0.42
	38	54.0	2.12	976	2.57	--	0.60
	39	41.8	0.89	882	0.62	1.73	0.37
	40	48.5	1.37	1630	1.64	0.89	0.22
	41	44.1	1.05	396	0.97	--	0.20
	42	44.1	1.13	733	1.12	0.47	0.23
Brokaw to Wausau	32	42.8	0.99	2430	0.34	--	0.16
	34	49.4	1.84	1920	0.40	--	0.42
	35	61.7	2.72	1050	0.97	--	0.40
	36	50.9	1.57	1240	0.33	0.18	0.21
	37	48.5	1.59	1570	1.11	0.36	0.20
	38	45.4	1.12	1500	0.21	0.33	0.50
	39	46.2	1.25	922	1.35	--	0.28
	40	45.0	1.09	1880	0.51	0.17	0.22
	42	44.0	1.06	620	0.68	0.12	0.25
	43	46.1	1.10	1080	0.68	--	0.26
	44	44.5	1.04	1770	0.48	0.25	0.27
	46	42.0	0.94	944	--	--	0.78
	47	39.3	0.95	996	0.13	0.28	0.13
	49	45.1	1.11	931	0.68	--	0.19
	50	42.7	0.90	907	0.27	0.20	0.19
	51	42.7	0.95	593	0.42	--	0.18
	52	45.7	1.20	1610	0.64	0.35	0.27
	53	43.5	1.20	1710	1.59	0.20	0.25
Lake Wausau	20	68.2	3.85	916	0.43	0.26	0.61
	21	49.0	1.66	1380	0.27	--	0.21
	22	67.5	4.16	1820	0.66	0.09	0.58
	24	58.2	2.66	1970	0.10	0.09	0.22
	25	51.8	1.85	1550	0.62	0.27	0.24
	27	63.2	3.15	1490	0.33	--	0.36
	28	65.0	3.52	1180	1.89	--	0.44

Appendix II. Continued.

Location	Fish identification number	Total length (cm)	Wet weight (kg)	Metal concentrations (µg/g)			
				Zinc in gill filaments	Cadmium in liver	Lead in liver	Mercury in axial musculature
Lake Wausau, cont.	29	49.3	1.49	1620	0.26	--	--
	30	53.5	2.19	1340	0.32	--	0.35
	31	47.6	1.33	2160	--	--	0.21
	32	51.6	1.91	1450	--	--	0.26
	33	55.3	2.31	1440	--	--	0.50
	34	60.5	3.11	1470	--	--	0.35
	35	46.6	1.36	--	--	--	0.08
	36	51.9	1.76	1090	0.31	0.12	0.31
	37	44.6	1.19	1340	--	--	0.12
	38	51.1	1.62	1430	0.24	0.29	0.24
	39	51.8	1.75	1130	--	--	0.18
	40	50.1	1.67	1190	0.21	0.12	0.28
	41	54.4	2.04	1230	0.15	0.21	0.18
	42	51.8	1.88	1530	0.11	--	0.18
	43	49.1	1.51	1540	0.20	0.10	0.16
	44	59.3	2.64	1300	0.64	0.35	0.38
	45	51.4	1.71	1570	0.58	--	0.31
	46	53.3	1.92	1570	0.45	--	0.28
Mosinee Flowage	4	53.5	2.05	1630	0.54	0.18	0.20
	5	55.2	2.49	1240	0.26	--	0.34
	6	59.0	2.82	1170	0.70	--	0.46
	7	56.0	2.26	904	0.92	--	0.32
	8	55.1	2.48	927	0.59	0.36	0.23
	9	44.0	1.20	1840	0.14	--	0.11
	10	45.0	1.34	1930	0.22	0.19	0.11
	12	57.2	2.23	737	0.53	0.72	0.32
	14	45.7	1.27	1680	0.31	--	0.12
	15	51.4	1.83	1260	0.53	0.31	0.52
	16	45.0	1.28	1700	0.26	0.42	0.13
	17	42.9	1.06	2170	0.22	0.17	0.20
	18	49.4	1.64	1890	0.16	0.19	0.17
	19	46.1	1.23	1580	0.33	0.14	0.09
	21	52.1	1.97	1660	0.86	--	0.31
	23	48.9	1.55	2210	0.40	0.21	0.12
	25	44.0	1.12	1960	0.42	0.13	0.05

Appendix II. Continued.

Location	Fish identification number	Total length (cm)	Wet weight (kg)	Metal concentrations (μg/g) Zinc in gill filaments	Cadmium in liver	Lead in liver	Mercury in axial musculature
Lake DuBay	19	42.1	0.87	1710	--	--	0.21
	20	38.5	0.83	1350	0.41	0.32	0.15
	23	37.5	0.65	1030	0.55	2.39	0.14
	26	37.0	0.71	1540	0.63	0.31	0.19
	27	52.1	0.61	1720	0.31	0.63	0.12
	28	35.0	0.47	--	0.37	0.28	0.12
	29	33.6	0.48	2590	0.61	--	0.12
	32	45.3	1.85	1440	0.41	0.13	0.21
	33	35.6	1.15	2630	0.71	0.31	0.29
	36	34.5	0.62	1220	--	0.20	0.16
	39	31.8	0.52	1130	0.21	--	0.06
	40	38.9	0.74	1130	1.35	1.91	0.08
	42	35.4	0.59	1950	0.44	0.34	0.17
	45	40.5	0.76	2990	0.32	0.16	0.10

Appendix III. Metal concentrations, total length, age, and wet weight of individual walleye from the Upper Wisconsin River and the reference site, Rainbow Flowage. Concentrations of zinc, cadmium, and lead are dry weight values, whereas concentrations of mercury are wet weight values.

Location	Fish identification number	Total length (cm)	Wet weight (g)	Age (years)	Metal concentrations (μg/g)			
					Zinc in gill filaments	Cadmium in liver	Lead in liver	Mercury in axial musculature
Rainbow Flowage	16	19.7	61	2	--	--	--	0.29
	19	51.8	1307	8	68.6	0.38	0.06	0.95
	20	29.3	225	4	70.7	0.50	0.52	0.31
	21	24.8	121	4	84.6	1.77	0.38	0.23
	22	24.2	109	4	81.1	0.75	0.29	0.22
	23	52.6	1556	9	208.0	0.26	0.10	0.73
	24	32.7	315	5	76.6	0.41	0.38	0.23
	25	30.7	243	5	--	0.56	0.22	0.27
	26	19.1	59	3	--	--	--	0.25
	27	19.0	51	2	--	--	--	0.25
	28	23.5	97	3	--	0.39	0.76	0.26
	32	18.8	47	3	90.4	0.52	3.17	0.26
	35	16.7	38	2	97.0	0.23	--	0.33
	37	18.0	46	2	96.5	0.38	3.53	0.18
	41	52.8	1588	8	79.6	0.23	0.13	0.51
Above Brokaw	48	24.1	128	2	116.0	0.78	0.31	0.13
	49	24.9	135	2	49.1	0.39	0.59	0.28
	50	23.5	101	2	89.0	--	--	0.16
	51	21.5	82	2	178.0	3.35	--	0.34
	52	21.1	74	2	118.0	--	--	0.34
	53	33.5	318	4	92.1	0.35	0.25	0.18
	54	28.3	183	3	72.6	1.16	0.44	0.16
	55	33.7	329	4	93.1	0.79	--	0.16
	56	65.1	2920	--	87.4	0.48	0.09	1.91
	57	60.4	2110	8	88.5	0.79	0.22	2.04
	65	27.0	154	3	71.7	0.23	--	0.20
	68	27.0	171	3	77.7	1.09	--	0.17
	72	26.2	167	3	79.1	0.50	--	0.20
	73	24.8	128	3	81.3	0.47	0.39	0.24
	74	32.8	318	4	72.3	0.42	--	0.21
Brokaw to Wausau	54	20.5	78	2	93.1	0.24	0.16	0.18
	55	20.5	86	--	71.9	0.22	0.10	0.15
	56	30.5	218	3	84.9	1.11	0.46	0.23
	57	43.0	709	5	81.8	0.30	0.10	0.27
	66	50.3	1323	7	128.0	0.48	0.08	0.45
	67	21.5	81	3	112.0	1.30	--	0.26
	68	22.2	80	3	123.0	1.53	--	0.19

Appendix III. Continued.

Location	Fish identification number	Total length (cm)	Wet weight (g)	Age (years)	Metal concentrations (µg/g)			
					Zinc in gill filaments	Cadmium in liver	Lead in liver	Mercury in axial musculature
Brokaw to Wausau, cont.	69	21.3	76	3	118.0	0.55	0.10	0.15
	70	20.9	65	3	75.7	--	--	0.20
	72	21.0	73	2	72.9	1.73	0.60	0.16
	73	21.1	79	3	76.9	1.28	0.49	0.20
	76	21.3	82	3	86.3	0.63	0.37	0.22
	78	42.5	684	8	69.6	0.20	0.11	0.27
	79	28.3	176	4	68.8	0.59	0.76	0.27
Lake Wausau	50	43.9	782	6	135.0	0.21	1.47	0.76
	51	40.9	570	6	107.0	0.27	0.14	0.86
	52	37.5	479	6	113.0	0.17	0.43	0.39
	53	37.8	476	6	91.1	0.70	0.28	0.28
	54	35.6	396	6	95.8	0.73	--	0.43
	55	34.9	374	6	145.0	0.31	0.26	--
	56	33.5	302	6	103.0	0.41	0.15	0.25
	57	29.7	230	4	78.5	0.36	--	0.29
	58	28.7	194	4	75.3	0.54	0.38	0.28
	59	29.5	210	3	107.0	0.18	0.84	0.22
	60	30.4	221	4	107.0	0.37	--	0.41
	61	26.3	150	3	75.7	0.87	3.07	0.31
	62	26.6	157	3	85.0	0.31	0.57	0.36
	63	26.1	141	3	125.0	1.53	0.80	0.28
	64	26.9	157	4	67.9	0.49	0.65	0.31
	65	18.9	54	2	--	--	--	0.25
	66	18.8	52	2	--	--	--	0.18
	67	17.7	44	1	--	--	--	0.14
	68	18.5	47	1	150.0	0.45	10.71	0.30
Mosinee Flowage	51	57.8	1804	7	126.0	--	--	0.77
	52	55.0	1460	9	--	0.54	0.06	0.99
	55	38.1	451	6	80.3	0.32	0.27	0.19
	56	36.1	392	6	70.2	1.12	0.19	0.26
	57	40.2	658	7	90.3	0.49	0.29	0.28
	64	21.7	89	3	89.4	1.59	0.51	0.08
	65	19.2	59	3	--	--	--	0.10
	66	27.8	195	4	67.8	0.38	0.24	0.23
	71	21.1	78	3	85.6	1.76	0.12	0.08
	73	22.8	97	3	--	--	0.91	0.17
	74	21.0	75	2	82.7	2.95	--	0.05
	86	19.0	63	3	--	--	--	0.16

Appendix III. Continued.

Location	Fish identification number	Total length (cm)	Wet weight (g)	Age (years)	Metal concentrations (μg/g)			
					Zinc in gill filaments	Cadmium in liver	Lead in liver	Mercury in axial musculature
Mosinee Flowage, cont.	87	20.8	76	3	107.0	0.26	1.10	0.11
	103	44.0	836	7	34.1	0.22	--	0.20
	104	40.0	521	6	32.7	0.42	0.14	0.32
	105	27.7	162	3	97.4	0.61	--	0.16
	106	31.0	244	4	62.1	0.87	0.08	0.26
Lake DuBay	54	29.0	200	4	146.0	0.13	0.16	0.32
	55	36.7	388	5	84.1	0.82	0.48	0.35
	56	15.4	29	--	86.0	0.19	9.21	0.28
	61	34.6	364	6	48.2	0.42	0.10	0.44
	62	26.5	151	4	76.7	0.39	--	0.19
	63	31.5	246	4	--	0.46	0.21	0.54
	64	29.5	200	3	71.6	--	--	0.25
	75	44.4	753	6	77.0	0.49	0.07	0.72
	77	22.9	92	3	68.6	0.32	0.24	0.19
	81	21.5	80	--	73.0	0.33	0.07	--
	86	55.2	1687	10	64.9	0.05	0.08	0.75
	87	51.7	1188	8	69.1	0.46	0.12	0.72
	88	44.9	851	7	70.9	0.33	2.45	0.78
	89	41.1	607	8	61.0	0.27	0.07	0.61

Appendix IV. Mercury concentrations in fillets of common carp and walleyes collected from the Upper Wisconsin River during 1970-1973 by the Wisconsin Department of Natural Resources (Source: Sheffy and Aten 1979).

Species	Location	n[a]	Date collected (mo/da/yr)	Total length (cm)	Mercury concentration (μg/g wet weight)	Sample identification number
Walleye	Rainbow Flowage	6	7/01/70	--	0.34	00371
		1	7/01/70	33.0	0.28	00434
		1	7/01/70	38.1	0.67	00433
	Lake Wausau	3	5/16/70	--	0.85	--
		1	6/02/71	34.3	0.44	02181
		1	9/21/72	34.8	0.43	02474
		4	9/28/77	39.4	0.33	00007
	Lake DuBay	1	6/02/71	43.2	0.43	02177
		3	7/23/73	24.6	0.17	00132
Common carp	Lake Wausau	2	5/16/70	--	0.40	--
		1	10/13/70	34.8	0.21	01341
		1	6/02/71	57.2	0.52	02160
		1	6/02/71	58.4	0.45	02159
		1	6/02/71	62.2	0.40	02158
		1	7/27/73	48.0	0.08	00079
		1	7/27/73	53.3	0.24	00078
	Lake DuBay	1	6/02/71	48.3	0.15	02239
		1	6/02/71	48.3	0.18	02240
		1	6/02/71	58.4	0.17	02241
		1	9/22/72	46.7	0.89	02478
		1	7/23/73	39.6	0.04	00091
		1	7/23/73	43.2	0.21	00090
		1	7/23/73	50.0	0.06	00089

[a]Number of fish in sample.