Accumulation of dietary methylmercury by walleye and white crappie in the Tongue River Reservoir, Montana
by Denise Elaine Knight

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Zoology
Montana State University

Abstract:
Food habits and consumption rates, mercury concentrations in food organisms, and mercury accumulation rates of walleye and white crappie from the Tongue River Reservoir, Montana, were studied in detail in order to estimate mercury uptake from the diet and to compare these estimates to observed mercury accumulation rates. Analysis of stomach contents showed that walleye are predominantly piscivorous, feeding principally on young-of-the-year crappie. Age 0 crappie were also important food items for white crappie, however zooplankton and aquatic insects were prominent in their diets as well. Diet composition of both species varied with fish size and season, and white crappie diets varied with time of day. Annual food consumption rates were estimated at 1.5 to 2.2% body weight/day for walleye and 1.1 to 3.5% body weight/ day for white crappie. Mercury in forage organisms averaged 0.08 µgHg/g and ranged from 0.02 to 0.40 µgHg/g. Calculated average concentrations of methylmercury in fish diets averaged 0.05 µgMeHg/g for walleye and 0.04 µgMeHg/g for white crappie.

Mercury concentrations in walleye and white crappie increased with increasing fish length, and were similar in walleye and white crappie of the same age. This appears to stem from similarities in their food habits and in the amount of methylmercury consumed. The percentage of accumulated methylmercury derived from food was estimated at 41-62% for walleye and 51-73% for white crappie, however the error associated with these estimates is potentially quite large. Under conditions which can reasonably be assumed to occur, food is shown to be a major source of accumulated methylmercury in Tongue River Reservoir fishes, however, analytical difficulties prevented an accurate, quantitative determination of its importance.

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ABSTRACT

Food habits and consumption rates, mercury concentrations in food organisms, and mercury accumulation rates of walleye and white crappie from the Tongue River Reservoir, Montana, were studied in detail in order to estimate mercury uptake from the diet and to compare these estimates to observed mercury accumulation rates. Analysis of stomach contents showed that walleye are predominantly piscivorous, feeding principally on young-of-the-year crappie. Age 0 crappie were also important food items for white crappie, however zooplankton and aquatic insects were prominent in their diets as well. Diet composition of both species varied with fish size and season, and white crappie diets varied with time of day. Annual food consumption rates were estimated at 1.5 to 2.2% body weight/day for walleye and 1.1 to 3.5% body weight/day for white crappie. Mercury in forage organisms averaged 0.08 μgHg/g and ranged from 0.02 to 0.40 μgHg/g. Calculated average concentrations of methylmercury in fish diets averaged 0.05 μgMeHg/g for walleye and 0.04 μgMeHg/g for white crappie.

Mercury concentrations in walleye and white crappie increased with increasing fish length, and were similar in walleye and white crappie of the same age. This appears to stem from similarities in their food habits and in the amount of methylmercury consumed. The percentage of accumulated methylmercury derived from food was estimated at 41-62% for walleye and 51-73% for white crappie, however the error associated with these estimates is potentially quite large. Under conditions which can reasonably be assumed to occur, food is shown to be a major source of accumulated methylmercury in Tongue River Reservoir fishes, however, analytical difficulties prevented an accurate, quantitative determination of its importance.

INTRODUCTION

Mercury is a dangerous environmental contaminant which has been extensively researched because it accumulates in aquatic organisms to concentrations which endanger human consumers. Methylmercury is the form of greatest concern, as it is both the most toxic and the most readily accumulated chemical species (Hannerz 1968; Clarkson 1971). Inorganic mercury is converted to methylmercury by aquatic bacteria under a variety of conditions, making all forms potentially hazardous (Wood et al. 1968; Jensen and Jernelöv 1969). Interestingly, fish can accumulate methylmercury to concentrations that far exceed recommendations for safe human consumption without manifesting adverse effects themselves (McKim et al. 1976).

Laboratory studies demonstrate that fish assimilate methylmercury from water across gill surfaces, and from food via digestive absorption (Hannerz 1968; Lock 1975; Olson et al. 1975); mercury accumulated from both sources is additive (Phillips and Buhler 1978). However, conflicting evidence in the literature concerning the relative importance of these two sources of mercury to fishes in natural waters, leaves unresolved the question of whether or not mercury is magnified through food chains. Methylmercury accumulation from water has not been directly quantified because current analytical techniques are not sensitive enough to detect the low concentrations of methylmercury which occur in most natural waters (Westöö 1975; National Academy of Sciences

1978). The alternative approach, direct quantification of methylmercury accumulated by fish from their food, has proven equally frustrating due to the difficulty of determining methylmercury consumption by fish in natural waters (National Academy of Sciences 1978).

This study was conducted to try to quantify dietary accumulation of methylmercury, under natural conditions, by two species of fish (walleye, Stizostedion vitreum, and white crappie, Pomoxis annularis) occupying different trophic positions in the Tongue River Reservoir and was part of a project to identify and evaluate sources, fates, and cycling of mercury in the Tongue River Reservoir. To estimate mercury uptake from the diet, data were collected on dietary habits, food consumption rates, and mercury concentrations in food organisms.

DESCRIPTION OF STUDY AREA

The Tongue River Reservoir (TRR) is an irrigation and flood control impoundment located in southeastern Montana, approximately 10 km north of the Montana - Wyoming border, near the small town of Decker in Bighorn County (Figure 1). The region is semi-arid and sagebrush communities predominate. The Tongue River originates in the Bighorn Mountains of Wyoming and flows northeast, eventually joining the Yellowstone River near Miles City, Montana. The river receives sewage effluents from Sheridan, Wyoming, upstream from the reservoir. The reservoir itself lies atop the Fort Union coal formation and has two active surface coal mines adjacent to it; a third mine is proposed.

The TRR is a mildly eutrophic, well-mixed, hardwater impoundment (Whalen 1979); selected chemical and physical characteristics of the reservoir are summarized in Table 1. Important sport fishes in the reservoir's warm-water fishery include white crappie, black crappie (Promoxis nigromaculatus) sauger (Stizostedion canadense), northern pike (Esox lucius), and walleye. Aquatic macrophytes (and the macroinvertebrates normally associated with them) are not well established, presumably due to the extreme fluctuations in water level which regularly occur from spring to fall (Whalen 1979). Benthic fauna is also impoverished, however planktonic communities are moderately to highly productive (Leathe, 1980), and probably serve as a base for reservoir food chains.

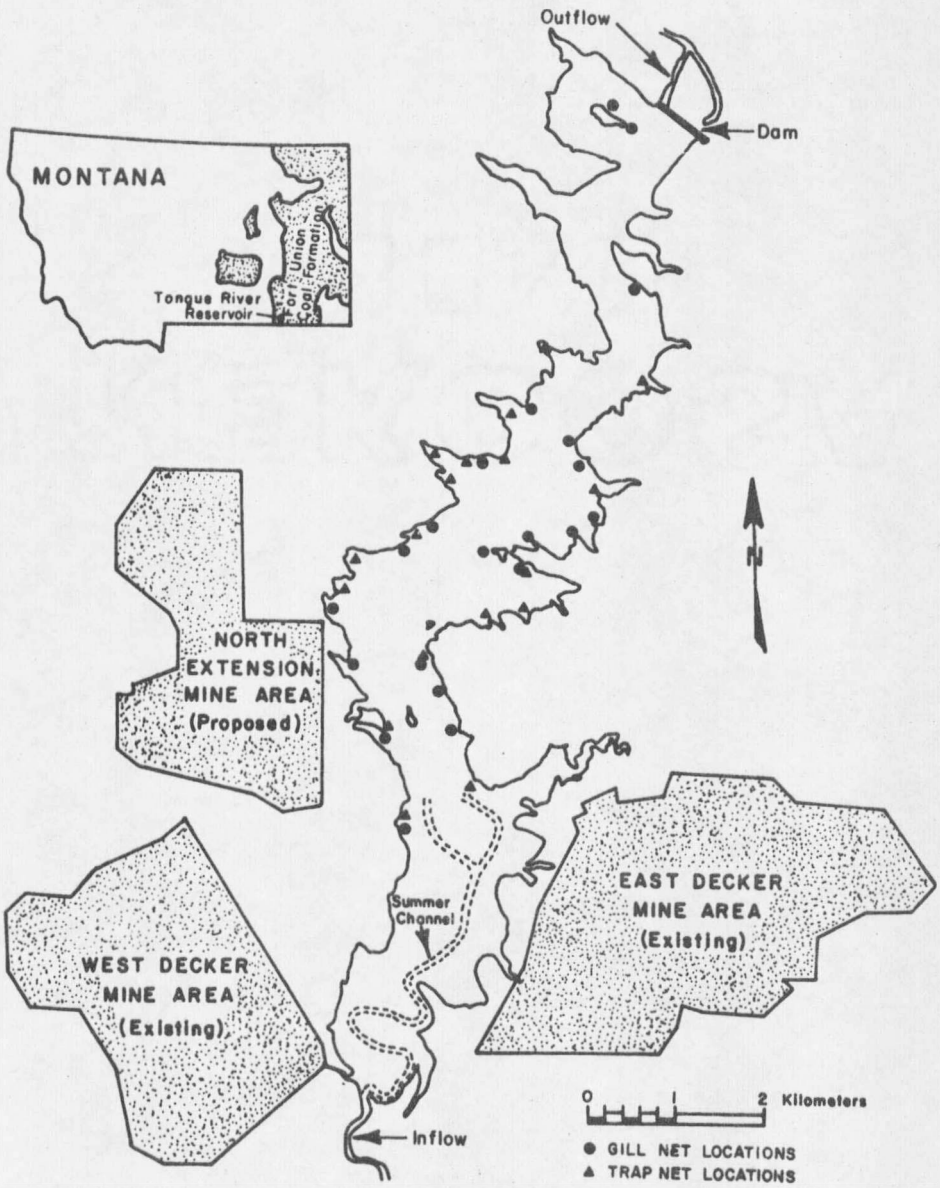

Figure 1. Map of the Tongue River Reservoir showing nearby surface coal mining activity and sampling sites for walleye (using primarily gill nets) and white crappie (using primarily trap net).

Table 1. Some chemical, physical and morphometric characteristics of the Tongue River Reservoir; physical/chemical data collected from November 1975 - November 1976 (Whalen 1979).

Mean depth (m)	5.9
Maximum depth (m)	18.0
Surface area (km^2)	13.0
Volume (m^3)	757×10^5
Depth of outlet (m)	15.2
Temperature (°C)	11.0 (1.2 - 23.9)[a]
Dissolved oxygen (mg/l)	19.3 (0.2 - 19.6)[a]
pH	8.4 (7.5 - 9.0)[a]
Turbidity (JTU)	12.1 (1.3 - 62)[a]
Total alkalinity (me/l)	3.66 (1.56 - 5.62)[a]
Total P (µg/l)	5.1 (1.0 - 260)[a]

[a] Mean and range from three sampling stations.

METHODS

Field Collection

Walleye, white crappie, and their food organisms were collected every other month from ice-off in April through October, 1980. Sampling was confined primarily to the middle third of the reservoir for convenience (Figure 1), as mark-recapture data indicate that both species move freely throughout the reservoir (Riggs 1978; Lenhart pers. comm.).

White crappie were collected at three hour (3-h) intervals using single-lead trap nets. Samples were taken for all times of day, and sets were repeated if the sample size for a given time interval was small. Short sampling intervals allowed observation of daily feeding peaks and provided relatively undigested stomach contents. Walleye were collected using single mesh and "experimental mesh" gill nets which were set in the late afternoon, fished overnight, and worked early the next morning. Identifiable stomach contents were obtained with this schedule, eliminating the need for more frequent sampling. Forage fish were collected using both gill and trap nets while sweep nets and an Ekman dredge were used to collect invertebrates.

An effort was made to capture 30-50 walleye and 60-80 white crappie (six to ten from each time of day) during each of the four sampling periods (April, June, August and October). Fish were selected to cover a wide size range. All fish were sacrificed at collection, weighed to

the nearest ten grams (g), and their total length measured to the nearest millimeter (mm). A muscle sample was taken from the anterior epaxial area and frozen for subsequent individual mercury analysis. The stomach (walleye) or entire gastrointestinal tract (crappie) was removed, preserved in 70% ethanol, and stored for later identification of the contents.

Stomach contents were periodically inspected in the field and predominant food organisms were collected and frozen whole for subsequent mercury analysis and calculation of mercury in diet. For comparison, the frozen stomach and intestinal contents of approximately 80 white crappie (representing all sampling periods except June) were also analyzed for mercury. A few (five to ten) walleye and white crappie were frozen whole to compare mercury concentrations in whole fish to mercury concentrations in muscle.

Mercury Analyses

Mercury analyses were performed by the staff of the Chemistry Station at Montana State University. Total mercury concentrations (μg Hg/g) in fish and invertebrates were determined using a Varian model AA-6 atomic absorption spectrophotometer. Samples were burned in an oxygen combustion chamber and the evolved mercury collected on a hollow gold-plated carbon rod. The tube was then heated in a carbon rod atomizer, thereby releasing the mercury, and the resulting absorption

signal was measured (Siemer and Woodriff 1974). Whole fish were homogenized in a blender with dry ice and an aliquot of the resulting frozen powder was analyzed for total mercury as above. The system was calibrated using freshly mixed standard solutions and tissue samples of known mercury concentration from the U.S. National Bureau of Standards. Blind and known duplicate analyses of samples were also performed. Mean percent deviation was 13.4 (0.03 μgHg/g) for known tissue duplicates, 17.3 (0.01 μgHg/g) for known whole fish duplicates and 31.1 (0.08 μg Hg/g) for blind tissue duplicates. All mercury concentrations are reported on a wet weight basis.

Methylmercury (MeHg) concentration was determined for whole fish as follows: an aliquot of homogenized tissue (prepared as for total mercury) was acidified with hydrochloric acid (forming methylmercuric chloride) and extracted into benzene. Methylmercury was then removed from the benzene by partitioning it into aqueous cysteine; this cysteine layer was acidified and the resulting MeHg salt re-extracted into benzene. MeHg in the final benzene layer was quantified in a gas-liquid chromatograph equipped with an electron capture detector (Watts et al. 1976).

Food Habit Analyses

Volumes of stomach and intestinal (crappie only) contents were measured to the nearest 0.05 cubic centimeter (cc) in the laboratory; white crappie contents were weighed to the nearest 0.01 gram. Fish found in stomachs were identified to species, and their individual lengths and volumes measured when possible. Invertebrates were identified to order or family, depending on state of digestion. Total invertebrate volumes were measured directly for each stomach, however the small volumes of individual orders and families precluded direct measurement. Percent volumes of invertebrate orders and families were therefore estimated visually by distributing the contents evenly over a grid. Percent frequency of occurrence and percent volume were calculated for major diet components by season (sampling period), size (length), and time of day (crappie only). Fish were divided into length categories according to growth rates and length-age class estimates for walleye (Riggs 1978) and white crappie (Elser et al. 1977) from the TRR. Live total lengths of prey fish consumed were estimated from their digested remains, using linear regression equations (Snedecor and Cochran 1967) comparing the total lengths of undigested fish to the lengths of various portions of their bodies (Table 2).

Table 2. Linear regression equations used to estimate live total length (TL) of prey fish eaten from portions of their digested remains. Equations derived from a series of length measurements made on whole fish. $p < 0.001$ for all equations.

Forage species	Regression	r^2
Crappie spp.	TL = 1.30 (standard length) + 1.65	0.99
	TL = 1.67 (trunk & operculum) + 1.39	0.99
	TL = 1.93 (trunk length) + 2.72	0.99
Golden shiner	TL = 1.33 (standard length) - 3.71	0.99
	TL = 1.53 (trunk & operculum) - 2.77	0.99
	TL = 1.69 (trunk length) - 3.21	0.99
Yellow perch	TL = 1.24 (standard length) - 4.68	0.90
	TL = 1.47 (trunk & operculum) + 1.64	0.88
	TL = 1.73 (trunk length) - 3.02	0.89
Combined	TL = 1.19 (standard length) + 6.27	0.94
	TL = 1.41 (trunk & operculum) + 12.83	0.92
	TL = 1.60 (trunk length) + 13.62	0.92

Food Consumption Rates

Walleye. Annual food consumption rates of walleye in the TRR were estimated for each size class from specific growth rates (g/g/day) and metabolic requirements, utilizing the bioenergetics model of Kitchell et al. (1977) as modified by Breck and Kitchell (1978). Metabolic requirements were predicted from average body weights and average reservoir temperatures. Riggs (1978) age and growth data were used to estimate specific growth rates and average body weights. The year was divided into a growing period (May - September) when average monthly reservoir temperatures exceeded 12 C (the physiological threshold for growth of walleye; Kelso 1972), and a non-growing period (October - April) when monthly temperatures were below 12 C. The average temperature for the growing period was 18.2 C over several years, while 4.7 C was average for the non-growing period (Whalen 1979; Leathe 1980; Phillips et al. 1980). Consumption estimates for the two periods were averaged to obtain an annual ration (R). Multiples of the standard metabolic rate of a species, commonly referred to as Winberg I, II and III, were used to estimate resting, average, and maximum metabolic rates (activity levels) of walleye (Winberg 1956; Ware 1975). Possible combinations of these activity levels for growing and non-growing periods gave a range of annual consumption values for use in calculating MeHg uptake from food.

White crappie. Food consumption rates of white crappie were estimated for each sampling period from daily feeding peaks, using the field method described by Nakashima and Leggett (1978); size classes were pooled to improve sample size. For each 3-h sampling interval, the total wet weights of the digestive tract contents (stomach plus intestine) were corrected for the effects of preservation, pooled by sampling period, and expressed as a percentage of the total body weight of the fish. Graphs of these values plotted versus time displayed feeding peaks, which were summed to provide an estimate of 24-h food consumption in that month. Consumption rates for May, July, and September were estimated by extrapolating between calculated values. Maintenance rations based on Kitchell et al.'s (1977) estimates for 100 g yellow perch and mean monthly reservoir temperatures were assumed for November through March. Monthly estimates were averaged to obtain an annual estimate and standard errors were calculated (Snedecor and Cochran 1967), providing a range of consumption values for use in calculating MeHg uptake from food.

Methylmercury in the Diet

Methylmercury concentrations in the diet were calculated for each size class of walleye and white crappie. Total mercury concentrations in food items were measured directly whenever possible. They were converted to methylmercury concentrations by multiplying by the percentage