Ref ID 88302
Rep ID

ENVIRONMENTAL RESEARCH 22, 73–80 (1980)

Relation between Trophic Position and Mercury Accumulation among Fishes from the Tongue River Reservoir, Montana

GLENN R. PHILLIPS, THOMAS E. LENHART, AND RICHARD W. GREGORY

Montana Cooperative Fishery Research Unit,[1] Biology Department, Montana State University, Bozeman, Montana 59717

Received August 6, 1979

Concentrations of total mercury were determined in muscle tissue from northern pike (*Esox lucius*), sauger (*Stizostedion canadense*), walleye (*S. vitreum*), black crappie (*Pomoxis nigromaculatus*), and white crappie (*P. annularis*) collected from the Tongue River Reservoir, Montana, prior to extensive surface coal-mine development in the region. Mercury concentrations in fish flesh increased with fish size and age; larger individuals of all five species exceeded the U.S. Food and Drug Administration's mercury concentration guideline of 0.5 μg/g. The rate of mercury accumulation was faster in the piscivorous species (northern pike, saugers, and walleyes) than in the planktivores (black crappies and white crappies). Differences in mercury uptake rates among the various species appeared to be directly related to the quantity of mercury eaten; results are discussed in relation to published models of mercury accumulation by fishes.

INTRODUCTION

The expansion of energy development, particularly surface coal mining, in the western United States has created a need for information on the effects of these activities on the introduction of metals into natural waters. Preliminary studies have shown that mercury occurs in western coal (Chadwick *et al.*, 1975) and that fish reared in water decanted from a western coal mine accumulate mercury (Phillips and Gregory, 1979). We measured the concentrations of mercury in fishes from the Tongue River Reservoir, Montana, to determine whether a mercury problem existed in the reservoir before large-scale coal mining occurred in the watershed; of particular interest was the relation between trophic position and rate of mercury accumulation among fish species from the reservoir.

Mercury in aquatic environments. Methylmercury is the most toxic and most readily accumulated form of mercury (Clarkson, 1973) and is the predominant mercurial present in fish tissue (Westoo, 1973; Uthe *et al.*, 1973). Further, microorganisms that occur in most natural waters can convert inorganic mercury to methylmercury (Wood *et al.*, 1968; Jensen and Jernelov, 1969). Human poisonings resulting from consumption of fishes or shellfishes contaminated with methylmercury have occurred in several countries (National Academy of Sciences, 1978); because of the hazards of consuming methylmercury, the U.S. Food and Drug Administration (FDA) has established a concentration of 0.5 μg Hg/g as the high-

[1] The Unit is jointly supported by the Montana Department of Fish and Game, the Biology Department at Montana State University, and the U.S. Fish and Wildlife Service.

0013-9351/80/030073-08$02.00/0
Copyright © 1980 by Academic Press, Inc.
All rights of reproduction in any form reserved.

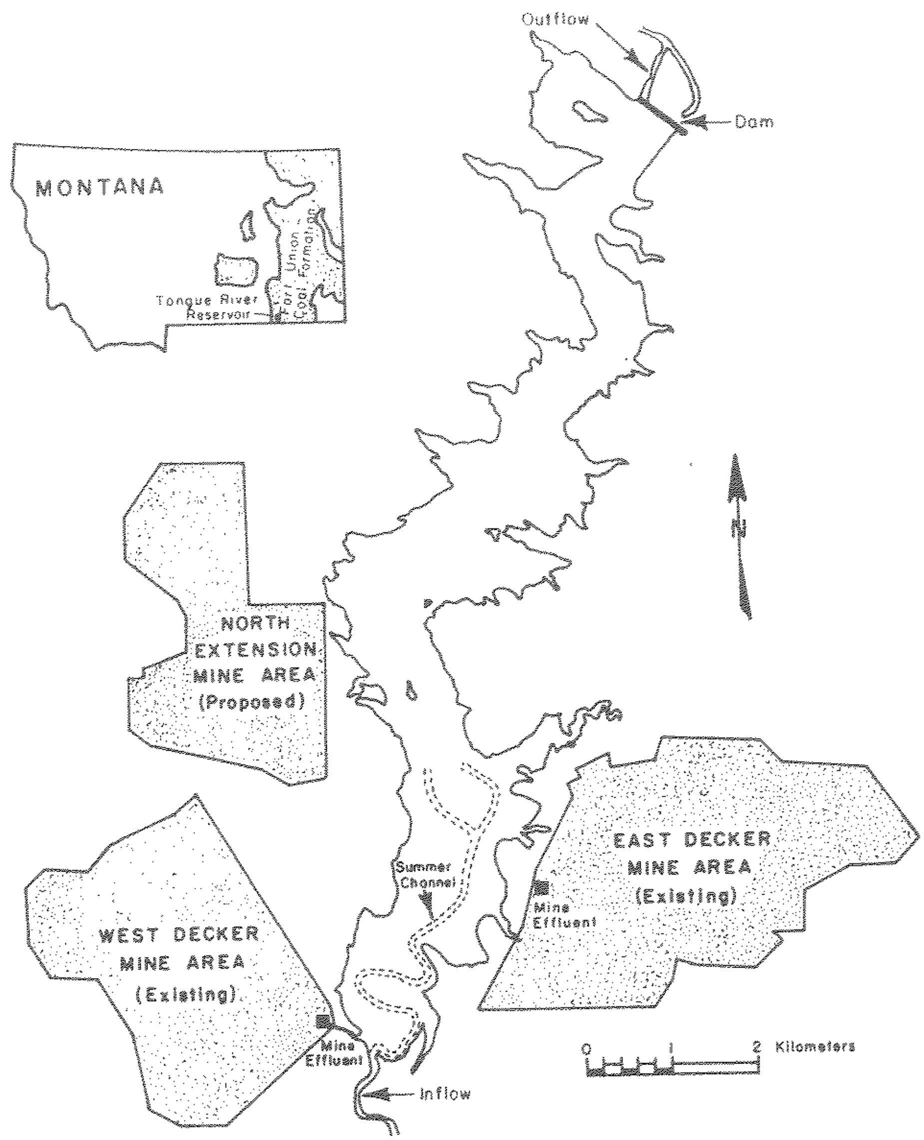


FIG. 1. Tongue River Reservoir, Montana, and nearby surface coal mines.

est allowable level for mercury (assumed to be methylmercury) in food (FDA, 1974). We assumed that most of the mercury in the flesh of Tongue River Reservoir fishes was methylmercury.

Study area. The Tongue River Reservoir is a major agricultural storage impoundment about 10 km north of the Montana–Wyoming border near the town of Decker, Montana (Fig. 1). Water in the reservoir is provided from the Tongue River, which originates on the east slopes of the Bighorn Mountains in northcentral Wyoming. The river moves northeastward through the coal fields of eastern Wyoming and Montana, finally reaching its confluence with the Yellowstone River near Miles City, Montana.

Mining operations on both the east and west sides of the reservoir are currently discharging disturbed groundwater into the Tongue River near the upstream end of the reservoir (Fig. 1); although dilution negates any detectable influence on the water quality of the reservoir (Whalen, 1979), expanded mining could conceivably increment the current rate of mercury dissolution to the reservoir.

The reservoir supports a warm-water fishery that includes black crappie (*Pomoxis nigromaculatus*), white crappie (*P. annularis*), sauger (*Stizostedion canadense*), walleye (*S. vitreum*), and northern pike (*Esox lucius*). These species were chosen for this study because they are frequently caught and consumed by sport fishermen.

MATERIALS AND METHODS

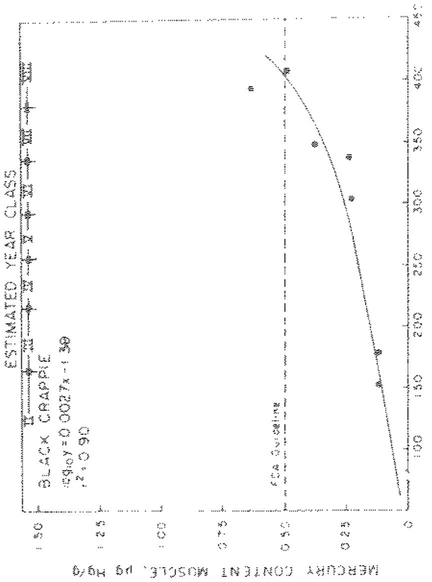
We collected fish from the Tongue River Reservoir during spring and summer 1978, using trap nets or gill nets; nets were set in late afternoon, fished overnight, and lifted the following morning. All fish were weighed and measured at capture; samples were selected to include a wide range of sizes. Northern pike were anesthetized with MS-222 at capture, and a muscle sample (about 0.5 g) was surgically removed from a dorsolateral section of the trunk, adjacent to the spine; the pike were released after surgery. All other species were sacrificed and iced, and a dorsolateral muscle sample was removed from each fish within a few hours. The tissue samples were bagged, frozen, and stored for subsequent mercury analyses.

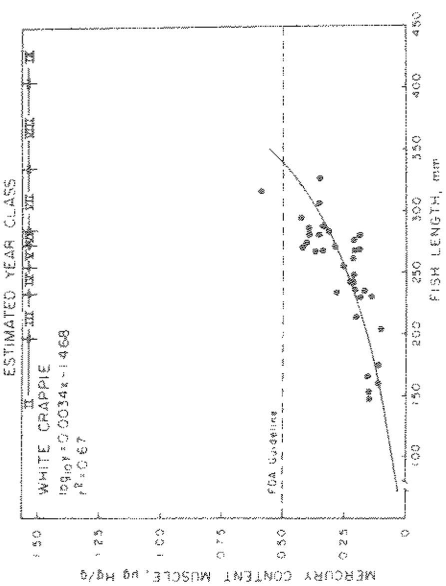
Previous age and growth studies conducted on Tongue River Reservoir fishes provided estimates of age for black and white crappies (Elser *et al.*, 1977) and for walleye and saugers (Riggs, 1978). No age and growth studies of northern pike in the Tongue River Reservoir have been completed; however, ages of pike were estimated from the work of Van Engel (1940), who recorded ages of pike from Wisconsin lakes that were at a latitude similar to that of the Tongue River Reservoir.

Total mercury in fish tissue was determined using a Varian Model AA-6 atomic absorption spectrophotometer. Samples were combusted in oxygen (no extraction required) and the evolved mercury was concentrated on a gold-plated carbon rod atomizer tube. The gold tube was heated and the mercury released was quantified in an absorption cell (Siemer and Woodriff, 1974). Every fifth sample was calibrated against tissue samples of known mercury content obtained from the U.S. National Bureau of Standards. Precision was estimated at ± 0.01 μg Hg/g based on the standard deviation of repeated analyses of the same sample. All mercury concentrations are reported in terms of wet weight.

RESULTS AND DISCUSSION

Mercury concentrations in muscle tissue from all five species of Tongue River Reservoir fishes increased with fish length (Fig. 2). Data are best described exponentially by regressions of the form $\log Y = a + bx$, where $b > 0$; linear regressions resulted in poorer correlations. According to these regressions, the average lengths (mm) at which different species of fish began to exceed the FDA guideline (0.5 μg Hg/g) were female northern pike, 850; male northern pike, 775; male northern pike and female northern pike combined, 806; walleye, 637; sauger, 545; black crappie, 403; and white crappie, 343. The trend toward increasing mercury content with fish size has been noted by others (e.g., Bache *et al.*, 1971;


ESTIMATED YEAR CLASS
BLACK CRAPPIE
log10 Y = 0.0027x - 1.30
r² = 0.90
FDA Guideline
FISH LENGTH, mm
MERCURY CONTENT MUSCLE, µg Hg/g


ESTIMATED YEAR CLASS
WHITE CRAPPIE
log10 Y = 0.0034x - 1.468
r² = 0.67
FDA Guideline
FISH LENGTH, mm
MERCURY CONTENT MUSCLE, µg Hg/g

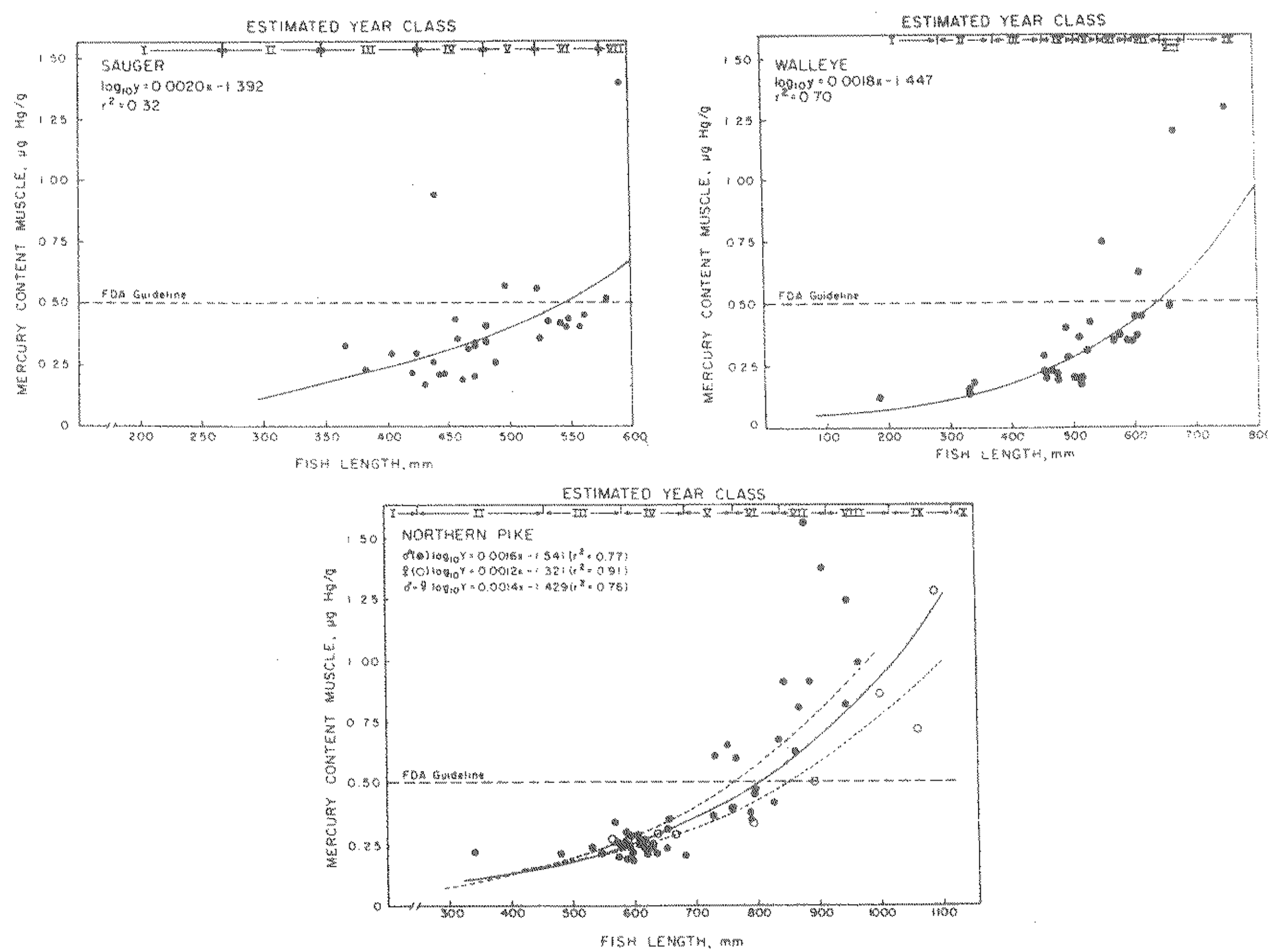


FIG. 2. Relation between total fish length and total mercury concentration in flesh for five fishes from the Tongue River Reservoir (values determined for both male and female northern pike); estimated age intervals are shown along the upper border.

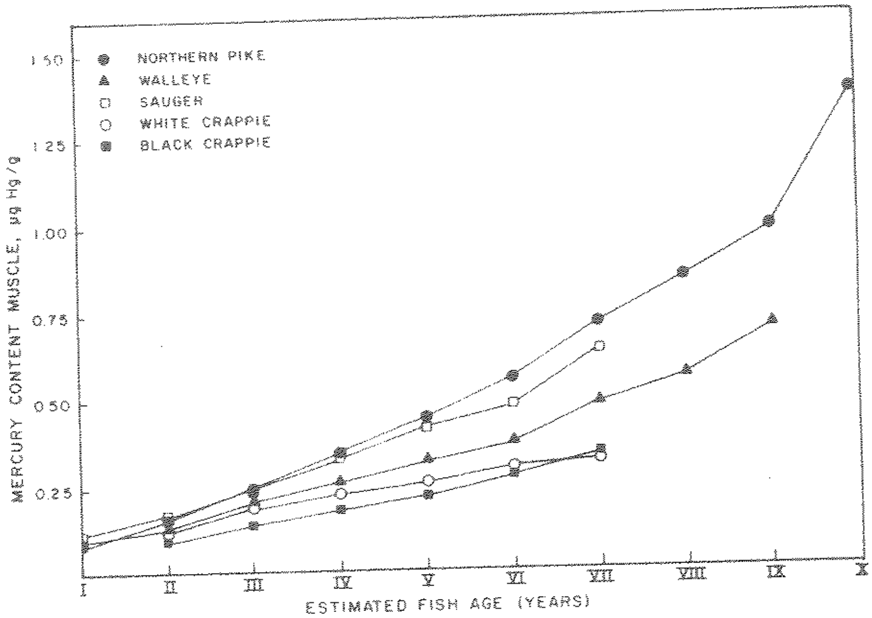


FIG. 3. Relation between estimated age of Tongue River Reservoir fishes and total mercury concentration in the flesh; age estimates were from Elser *et al.* (1977), Riggs (1978), and Van Engel (1940).

Fagerstrom *et al.*, 1974; Scott, 1974; Potter *et al.*, 1975) and is primarily a result of the long biological half-time of methylmercury in fishes (Jarvenpaa *et al.*, 1970; Giblin and Massaro, 1972); fish retain previously assimilated mercury while continuing to accumulate more.

Male northern pike contained higher mercury concentrations than did females of similar length (Fig. 2). This trend was a result of the slower growth of males relative to females (Johnels *et al.*, 1967; Olsson and Jensen, 1975).

Mercury concentrations in some individuals of all the species analyzed exceeded the FDA guideline. Maximum mercury concentrations (µg Hg/g) observed were as follows: northern pike, 1.53; sauger, 1.40; walleye, 1.30; black crappie, 0.64; and white crappie, 0.60. Mercury concentrations in northern pike were particularly high: 29% of the pike analyzed exceeded the FDA guideline. A hazardous situation could develop if expanded coal mining increases mercury concentrations in the reservoir. Current mine discharges should be monitored for mercury so that the situation can be evaluated before expansion occurs.

A comparison of the ages of Tongue River Reservoir fishes with their mercury content (Fig. 3) shows that northern pike and saugers accumulated mercury nearly twice as fast as did the two species of crappie; the rate for walleyes was intermediate. Ages (years) at which fish began to exceed the FDA guideline were VI for northern pike and saugers, VII for walleyes, and VIII for the two crappie species. Northern pike, saugers, and walleyes are highly piscivorous whereas crappies, in the Tongue River Reservoir, feed almost exclusively on zooplankton. Because forage fish contain much higher concentrations of methylmercury than do zooplankton feeders (Jernelov and Lann, 1971; Cox *et al.*, 1975), pike, walleye, and sauger consume more methylmercury than black or white crappie. Moreover, pike are larger than walleyes or saugers at a given age and are thus capable of feeding on larger, and therefore more heavily contaminated forage fish. Various authors have shown that northern pike often attain higher concentrations of mercury than other fish species in the same environment (Lockhart *et al.*, 1972; Fagerstrom and Asell, 1973; Jernelov *et al.*, 1975; Olsson and Jensen, 1975).

Although we did not quantify either component of mercury uptake, we did show that piscivorous fish species from the Tongue River Reservoir accumulate mercury faster than do planktivores. This result strongly suggests that piscivorous fishes derive at least part of their body burden of mercury from their diet. Norstrom *et al.* (1976) estimated that Ottawa River (Canada) yellow perch (*Perca flavescens*) derived about 60% of their total methylmercury burden from their diet; they assumed that the fish assimilated 80% of the methylmercury they ingested and 12% of that passing over the gills. Conversely, Fagerstrom and Asell (1973) attributed most of the methylmercury in northern pike from swedish lakes to uptake from water; they assumed that the fish assimilated 15% of the methylmercury in the diet and 100% of that (in water) passing over the respiratory surfaces. Recent laboratory studies have demonstrated that rainbow trout (*Salmo gairdneri*) assimilated 10–12% of the methylmercury passing over their gills (Phillips and Buhler, 1978) and that northern pike accumulated 15–20% of the methylmercury they ingested (Phillips, 1978); in the later experiment, dietary methylmercury was fed to northern pike in the form of young-of-the-year carp that had accumulated mercury while in a natural environment.

We believe that Norstrom *et al.* (1976) are correct to use 12% for efficiency of respiratory methylmercury assimilation and that Fagerstrom and Asell (1973) have correctly used a 14% efficiency for assimilation of dietary methylmercury. However, incorrect coefficients have been incorporated into both of the above models to describe the second component of methylmercury uptake. We conclude that planktivores derive most of their methylmercury body burden from water but that piscivores receive a significant amount from both diet and water.

ACKNOWLEDGMENTS

We thank L. Hageman and L. Torma for performing the mercury analyses. This research was supported by the U.S. Fish and Wildlife Service, National Fishery Research Laboratory, Columbia, Missouri, Project 28.2.

REFERENCES

Bache, C. A., Gutenmann, W. H., and Lisk, D. V. (1971). Residues of total mercury and methylmercury salts in lake trout as a function of age. *Science* 172, 951–952.

Chadwick, R. A., Rice, R. C., Bennett, C. M., and Woodriff, R. A. (1975). Sulfur and trace elements in the Rosebud and McKay coal seams, Colstrip field, Montana. *In* "Energy Resources of Montana," pp. 167–175. Geological Society, 22nd annual publication, Billings, Montana.

Clarkson, T. W. (1973). The pharmacodynamics of mercury and its compounds with emphasis on the short-chain alkylmercurials. *In* "Mercury in the Western Environment" (D. R. Buhler, Ed.), pp. 332–353. Continuing Education Publications, Oregon State University, Corvallis.

Cox, M. F., Holm, H. W., Kania, H. J., and Knight, R. L. (1975). Methylmercury and total mercury concentrations in selected stream biota. *In* "Trace Substances in Environmental Health" (D. D. Hemphill, Ed.), Vol. 9, pp. 151–155. Univ. of Missouri Press, Columbia.

Elser, A. R., McFarland, R. C., and Schwehr, D. (1977). "The Effects of Altered Streamflow on Fish of the Yellowstone and Tongue Rivers, Montana." Technical Report No. 8, Water Research Division, Montana Dept. Natural Resources.

Fagerstrom, T., and Asell, B. (1973). Methylmercury accumulation in an aquatic food chain. A model and some implications for research. *Ambio* 2(5), 164–171.

Fagerstrom, T., Asell, B., and Jernelov, A. (1974). Model for accumulation of methylmercury in northern pike (*Esox lucius*). *Oikos* 25, 14–20.

Giblin, F. J., and Massaro, E. J. (1972). Pharmaco-dynamics of methylmercury in the rainbow trout (*Salmo gairdneri*): Tissue uptake, distribution and excretion. *Toxicol. Appl. Pharmacol.* 24, 81–91.

Jarvenpaa, T., Tillander, M., and Miettinen, J. K. (1970). Methylmercury: Half-time of elimination in flounder, pike and eel. *Suom. Kemistil.* 43, 439–442.

Jensen, S., and Jernelov, A. (1969). Biological methylation of mercury in aquatic organisms. *Nature (London)* 223, 753–754.

Jernelov, A., Landner, L., and Larsson, T. (1975). Swedish perspectives on mercury pollution. *J. Water Pollut. Contr. Fed.* 47, 810–822.

Jernelov, A., and Lann, H. (1971). Mercury accumulation in food chains. *Oikos* 22, 403–406.

Johnels, A. G., Westermark, T., Berg, W., Persson, P. I., and Sjostrand, B. (1967). Pike (*Esox lucius* L.) and some other aquatic organisms in Sweden as indicators of mercury contamination in the environment. *Oikos* 18, 323–333.

Lockhart, W. L., Uthe, J. F., Kenney, A. R., and Mehrle, P. M. (1972). Methylmercury in northern pike (*Esox lucius*): Distribution, elimination and some bio-chemical characteristics of contaminated fish. *J. Fish Res. Bd. Canada.* 29, 1519–1523.

National Academy of Sciences. (1978). "An Assessment of Mercury in the Environment." National Academy of Science, Washington, D.C.

Norstrom, R. J., McKinnon, A. E., and deFreitas, A. S. W. (1976). A bioenergetic based model for pollutant accumulation by fish. Simulation of PCB and methylmercury residue levels in Ottawa River yellow perch (*Perca flavescens*). *J. Fish. Res. Bd. Canada.* 33, 248–267.

Olsson, M., and Jensen, S. (1975). Pike as the test organism for mercury, DDT and PCB pollution. A study of the contamination in the Stockholm Archipelago. *Fish. Bd. Swed. Inst. Freshwater Res. Drottningholm Rep.* 54, 83–106.

Phillips, G. R. (1978). "The Potential for Long-Term Mercury Contamination of the Tongue River Reservoir Resulting from Surface Coal Mining and Determination of an Accurate Coefficient Describing Mercury Accumulation from Food." Final Report, U.S. Fish and Wildlife Service, Fort Collins, Colorado.

Phillips, G. R., and Buhler, D. R. (1978). The relative contributions of methylmercury from food or water to rainbow trout (*Salmo gairdneri*) in a controlled laboratory environment. *Trans. Amer. Fish. Soc.* 107, 853–861.

Phillips, G. R., and Gregory, R. W. (1979). The accumulation of trace metals by northern pike (*Esox lucius*) reared in surface coal mine decant water. *Proc. Montana Acad. Sci.*, in press.

Potter, L., Kidd, D., and Standiford, D. (1975). Mercury levels in Lake Powell; bioamplification of mercury in a man-made desert reservoir. *Environ. Sci. Technol.* 9, 41–46.

Riggs, V. L. (1978). "Age and Growth of Walleye and Sauger in the Tongue River Reservoir." M. S. Thesis, Montana State University, Bozeman.

Scott, D. P. (1974). Mercury concentration in white muscle in relation to age, growth, and condition in four species of fishes from Clay Lake, Ontario. *J. Fish Res. Bd. Canada.* 31, 1723–1729.

Siemer, D. D., and Woodriff, R. (1974). Application of the carbon rod atomizer to the determination of mercury in the gaseous products of oxygen combustion of solid samples. *Anal. Chem.* 46, 597–598.

U. S. Food and Drug Administration. (1974). Action level for mercury in fish and shellfish. *Fed. Regis.* 39 (236), 42738–42740.

Uthe, J. F., Atton, F. M., and Royer, L. M. (1973). Uptake of mercury by caged rainbow trout (*Salmo gairdneri*) in the South Saskatchewan River. *J. Fish Res. Bd. Canada.* 30, 643–650.

Van Engel, W. A. (1940). The rate of growth of the northern pike (*Esox lucius*) Linnaeus, in Wisconsin waters. *Copeia* 1940 (3), 177–188.

Westoo, G. (1973). Methylmercury as a percentage of total mercury in flesh and viscera of salmon and sea trout of various ages. *Science* 181, 567–568.

Whalen, S. C. (1979). "The Chemical Limnology and Limnetic Primary Production of the Tongue River Reservoir, Montana." M. S. Thesis, Montana State University, Bozeman.

Wood, J. M., Kennedy, F. S., and Rosen, C. G. (1968). Synthesis of methyl-mercury compounds by extracts of methanogenic bacterium. *Nature* (London) 200, 173–174.