Menominee River Area of Concern

This document features excerpts from the Michigan Department of Environmental Quality (MDEQ) Staff Report: *Status of Fish Contaminant Levels in the Lower Menominee River Area of Concern* released in March 2017 and the *Stage 2 Remedial Action Plan for the Lower Menominee River* released in December 2011. If you have questions about either document, please contact the MDEQ Office of the Great Lakes' Area of Concern program at 517-284-5035.

Overview of Areas of Concern (AOCs)

In the 1980s, the United States and Canadian governments identified 43 places in the Great Lakes region that had severe, long-term environmental problems. These places are called *Areas of Concern* or *AOCs*. Michigan originally had 14 AOCs located in both the upper and lower peninsulas. Two have been remediated and removed from the list. Now there are only 12 remaining, including the Lower Menominee River Area of Concern shared by the states of Wisconsin and Michigan.

People in federal, state, and local governments are working together to address the problems in all of these areas. Locally, the Lower Menominee River Citizens Advisory Committee (CAC) addresses these environmental problems with the support of partners from the state governments of Michigan and Wisconsin, as well as the U.S. Environmental Protection Agency.

Beneficial Use Impairments (BUIs)

These environmental problems are called *beneficial use impairments* or *BUIs.* There are 14 categories of BUIs named in the U.S.-Canadian Great Lakes Water Quality Agreement. However, a place does not have to have all 14 problems to be called an AOC. The Lower Menominee River AOC originally had six BUIs, now only five are remaining.

Each BUI has goals that need to be met in order to be removed from the AOC's list of problems. Once all BUIs are removed from the list, the AOC is considered to be no longer impaired and can be *delisted,* or removed from the list of AOCs.

The Goal: Delisting & a Healthy Environment

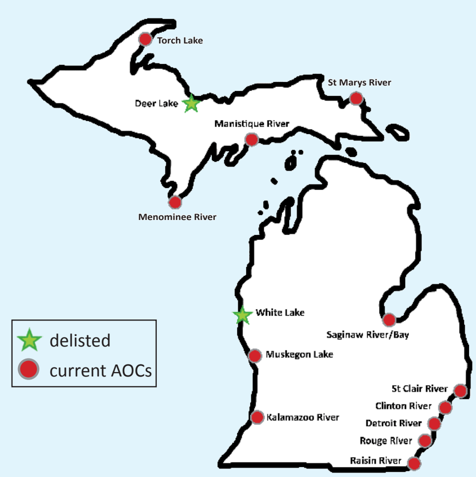
Once all of the assigned BUIs have been removed from an AOC, the CAC and Michigan Department of Environmental Quality, and the Wisconsin Department of Natural Resources submit a petition to the U.S. Environmental Protection Agency requesting it be removed from the list of AOCs. This is called "delisting." Two of Michigan's 14 original AOCs were delisted in 2014. Other sites in both states, including the Lower Menominee River AOC, are closer to delisting thanks to the dedication of the local, state, and federal stakeholders working to improve our environment, along with funding from the U.S. Environmental Protection Agency and the Great Lakes Restoration Initiative.

The Lower Menominee River's BUIs:

- Restrictions on Fish and Wildlife Consumption
- Degraded Fish and Wildlife Populations
- Loss of Fish and Wildlife Habitat
- Degradation of Benthos
- Restrictions on Dredging Activities
- Beach Closings *(Removed March 2011)*

Additional BUIs not affecting this area:

- Restrictions on Drinking Water Consumption or Taste and Odor Problems
- Tainting of Fish and Wildlife Flavor
- Fish Tumors or Other Deformities
- Bird or Animal Deformities or Reproductive Problems
- Degradation of Phytoplankton and Zooplankton Populations
- Degradation of Aesthetics
- Eutrophication or Undesirable Algae
- Added Costs to Agriculture or Industry



2017 Review on the Status of Fish Contaminant Levels in the Lower Menominee River

Assessing the Fish Consumption BUI in the Lower Menominee River AOC is challenging given that the AOC extends into areas that are likely influenced by sources beyond the scope of the Lower Menominee River AOC.

The focus of this white paper prepared by Michelle Bruneau of the Michigan Department of Health and Human Services at the behest of the Menominee River AOC Coordinators at the MDEQ and WDNR is to summarize the MDEQ Staff Report that follows this document, which compares fish contaminant levels in the AOC with those in a control site, which is one of the three options in the restoration targets.

The Menominee River flows into Green Bay. Green Bay has many direct source contaminant inputs, as well as tributaries that are far more contaminated than the Menominee River, including the Wisconsin's Lower Green Bay and Fox River AOC. Fish are able to move from Green Bay into the Menominee River AOC, unobstructed until they reach the Menominee Dam. The section of the river between the Menominee Dam and the upper limits of the AOC, the Park Mill/Upper Scott Dam - an area otherwise known as the Lower Scott Flowage - is the section of the AOC that most likely reflects the true status of the AOC's Fish Consumption BUI. This is because although the area downstream of the Menominee Dam is still part of the AOC, fish collected here do not present an accurate snapshot of the current status of the Fish Consumption BUI given the likely influence of contaminated areas outside of the AOC.

The Park Mill/Upper Scott Dam serves as a barrier preventing fish from traveling upstream of the AOC. Therefore, comparing fish from the upstream portion of the Menominee River and the selected primary reference site of Little Bay de Noc, to the fish from the Lower Scott Flowage, will provide the best assessment of the AOC's Fish Consumption BUI. Little Bay de Noc was selected as the primary reference site for the Lower Menominee River AOC because the regional inputs are going to be similar to those around the Lower Menominee River AOC, but the bay was not historically influenced by direct contaminant inputs like the Menominee River, and fish species are going to be similar in both locations.

In 2011, the Michigan Department of Health and Human Services (MDHHS) was provided funding from the U.S. EPA through the Great Lakes Restoration Initiative to partner with the Michigan Department of Environmental Quality (MDEQ) and the local AOC Public Advisory Councils to assess the status of the Fish Consumption BUIs in five of Michigan's then fourteen AOCs.

The MDEQ, in partnership with the Wisconsin Department of Natural Resources (WDNR) and MDHHS, collected fish from the AOC and the agreed upon reference site, Little Bay de Noc in 2012 and 2014. The fish were analyzed and the ***MDEQ Staff Report: Status of Fish Contaminant Levels in the Lower Menominee Area of Concern*** (draft attached to this document) detailing this work was produced by Joseph Bohr, MDEQ Water Resources Division in 2017.

The following white paper summarizes the 2017 MDEQ Staff Report and other pertinent information that can be used by the MDEQ Office of the Great Lakes AOC Program, the Lower Menominee River Citizens' Advisory Committee, and the Wisconsin Department of Natural Resources to assess the current status of the Fish Consumption BUI.

It should be noted that WDNR has additional data points for the Menominee River AOC that were not included in the attached MDEQ Staff Report, and therefore not accounted for in this White Paper for three reasons:

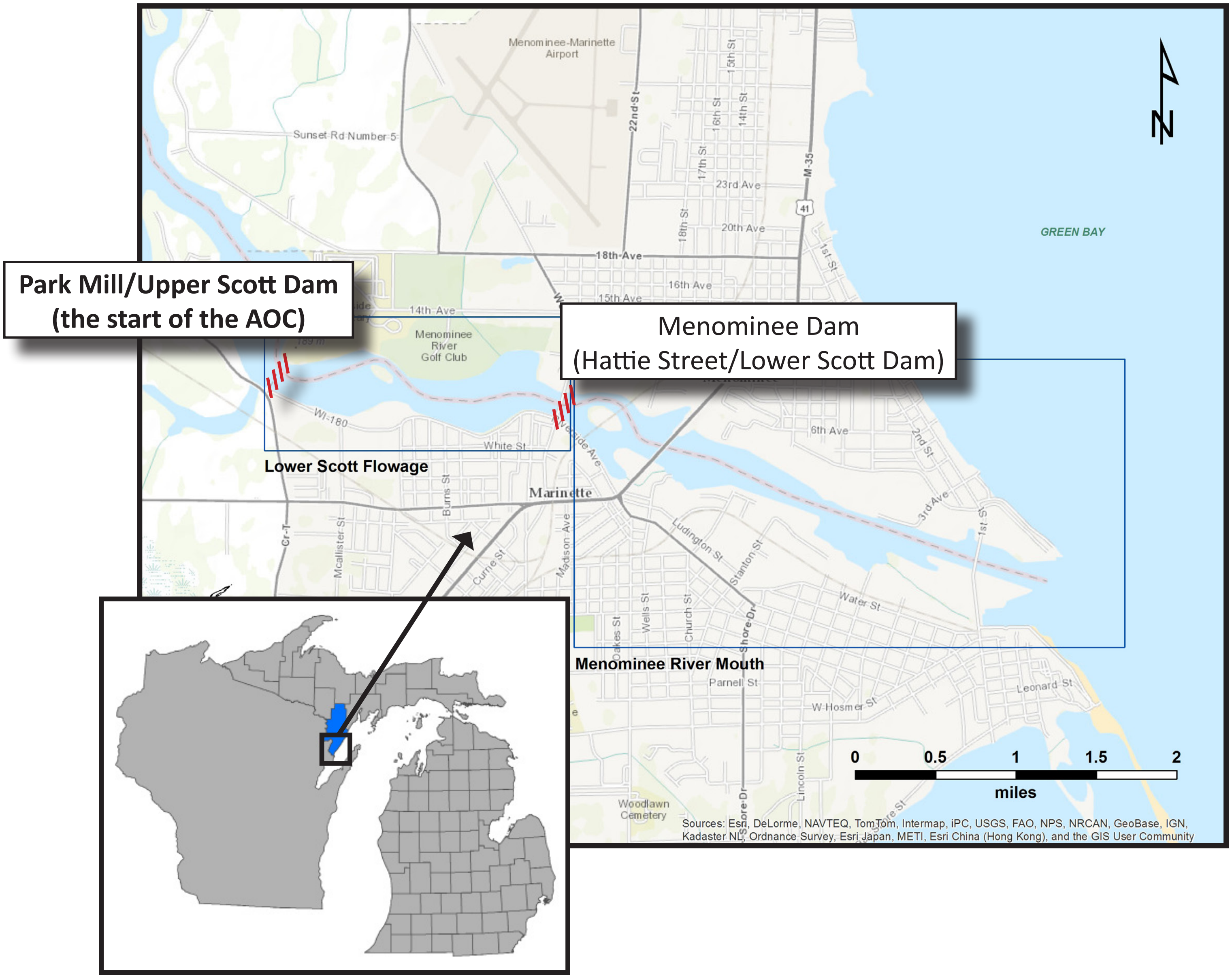
- Wisconsin's Lower Scott Flowage data were not included in the MDEQ analysis because they were too old to provide for accurate across-site comparisons
- MDEQ and MDHHS run carp and pike as skin-off fillets, unlike Wisconsin
- The MDHHS Laboratory runs analysis of PCBs as congeners instead of aroclors.

To learn more about the Michigan Fish Consumption program and methods:
http://www.michigan.gov/documents/mdch/MFCAP_Guidance_Document_500546_7.pdf

To learn more about the Wisconsin Fish Consumption program and methods:
Request the *Fisheries Management Handbook Chapter 530 Section B, titled Fish Consumption Advisory Determination* from the WDNR. Not available online.

About the Lower Menominee River Area of Concern (AOC)

The Lower Menominee River AOC includes the lower three miles (4.8 km) of the river from the Park Mill Dam (aka Upper Scott Dam) downstream to the river mouth and approximately 3.1 miles (5 km) north and south of the mouth along the adjacent shoreline of Green Bay. It includes the Lower Scott Flowage, which is an impoundment formed by the Menominee Dam (aka Lower Scott Dam and Hattie Street Dam), Green Island, and Seagull Bar. The AOC and its watershed is shared between Michigan and Wisconsin.



Restrictions on Fish Consumption Beneficial Use Impairment

According to the Stage 2 Remedial Action Plan (RAP) for the Lower Menominee AOC (2011), this beneficial use is considered impaired due to mercury and PCBs. Per the Stage 2 RAP, the restoration targets for this AOC are as follows:

- Sources of PCBs, mercury, and dioxins within the AOC have been controlled or eliminated; and
- Waters within the Lower Menominee River AOC are no longer listed as impaired due to PCB or dioxin fish consumption advisories in the most recent Impaired Waters (303(d)) list for either state; **OR**
- Fish tissue contaminants causing advisories in the AOC are the same or lower than those in the associated Great Lake or appropriate control site.

PCBs

In 2006, the US EPA completed the ***Results of the Lake Michigan Mass Balance Project: Polychlorinated Biphenyls Modeling Report (December 2006)*** (http://1.usa.gov/1QHagE6). This study looked at all of the major tributaries that lead into Lake Michigan and calculated the amount of PCBs they add to the lake. This study showed that the Menominee River only adds a small amount of the total PCBs going into the lake. In fact, it was determined that the Fox River adds 20 times MORE PCBs than the Menominee; however, work is underway to reduce the amount of PCBs in the Lower Fox River.

According to PCB analysis conducted by the MDEQ and MDHHS in 2012 [Table 6 from the attached MDEQ Staff Report], PCB concentrations in carp from both the area downstream of the Menominee Dam and Little Bay de Noc were significantly higher than concentrations in carp from Lower Scott Flowage. PCB concentrations in northern pike, rock bass, and smallmouth bass were also the same or higher in the reference site compared to the AOC.

Table 6. Median total PCB and median lipid-normalized total PCB concentrations in fish collected from the Lower Scott Flowage (LSF), Menominee River downstream of the Menominee Dam (DMD), and Little Bay De Noc (LBDN).

Species	Median Total PCB (mg/kg)			Median Lipid-Normalized Total PCB (mg/kg)		
	LSF	DMD	LBDN	LSF	DMD	LBDN
Carp	0.04*	1.83*	0.67*	0.02*	0.29*	0.12*
Northern Pike	--	0.02*	0.002*	--	0.10*	0.01*
Rock Bass	0.002	--	0.002	0.004	--	0.008
Smallmouth Bass	0.002*	0.05*	0.008*	0.02*	0.13*	0.02*

Source: Table 6 - MDEQ Staff Report: Status of Fish Contaminant Levels in the Lower Menominee River Area of Concern, 2017
*significantly different

Also, when referencing the ***MDHHS 2015 Eat Safe Fish Guide - Upper Peninsula***, fish have consumption guidelines driven by PCBs not only in the Lower Scott Flowage, but also in adjacent areas below the Menominee Dam and throughout Green Bay, as well as above the Upper Scott Dam, which is the upper limits of the AOC.

This demonstrates that Menominee River fish are likely influenced by PCB inputs not only downstream of the AOC, but also upstream. And in fact, the section of the river which is essentially the heart of the AOC - the Lower Scott Flowage - has only one fish species (carp) that includes PCBs as a Chemical of Concern in the ***2015 Eat Safe Fish Guide*** compared to four fish species above (carp, largemouth bass, smallmouth bass, and suckers) and five fish species below (black crappie, carp, largemouth bass, smallmouth bass, and white crappie). In addition, suckers are listed for PCBs below and above the Lower Scott Flowage, and only for mercury within the Lower Scott Flowage.

Summary:

- **There are no apparent direct sources of PCBs in the Lower Menominee River AOC.**
- **Median totals of PCBs in fish from the Lower Scott Flowage are lower or the same as fish from Little Bay de Noc.**

MDHHS 2015 Eat Safe Fish Guidelines for the Menominee River

Upstream of the AOC

Menominee River
(between the Twin Falls Dam in Dickinson Co. and Upper Scott [Park Mill] Dam; including the Big & Little Quinnesec Falls Impoundments in Dickinson Co., and the Chalk Hill Impoundment, White Rapids Impoundment, Grand Rapids Impoundment, and the Upper Scott Flowage in Menominee Co.)

Type of Fish	Chemicals of Concern	Size of Fish (length in inches)	MI Servings per Month*
Carp	PCBs	Any	Limited▲
Largemouth Bass	PCBs	Any	1 2x
Northern Pike	Mercury	Any	1
Rock Bass	Mercury	Any	4
Smallmouth Bass	PCBs	Any	1 2x
Suckers	PCBs & Mercury	Under 18”	4
	Mercury	Over 18”	1
Walleye	Mercury	Any	1

Lower Scott Flowage

Menominee River
(between the Upper Scott [Park Mill] Dam and the Menominee Dam)

Type of Fish	Chemicals of Concern	Size of Fish (length in inches)	MI Servings per Month*
Carp	PCBs & Mercury	Any	2
Rock Bass	Mercury	Any	2
Suckers	Mercury	Any	6 Per Year
Walleye	Mercury	Under 20”	1
		Over 20”	6 Per Year

Downstream of Menominee Dam

Menominee River
(between the Menominee Dam and Green Bay)

Type of Fish	Chemicals of Concern	Size of Fish (length in inches)	MI Servings per Month*
Black Crappie	Mercury	Under 9”	8
	PCBs & Mercury	Over 9”	4
Bluegill	Mercury	Any	8
Carp	PCBs	Any	Do Not Eat▲
Largemouth Bass	PCBs & Mercury	Under 18”	2
	Mercury	Over 18”	1
Northern Pike	Mercury	Any	1
Smallmouth Bass	PCBs & Mercury	Under 18”	2
	Mercury	Over 18”	1
Sunfish	Mercury	Any	8
White Crappie	Mercury	Under 9”	8
	PCBs & Mercury	Over 9”	4
Yellow Perch	Mercury	Any	4

When fishing the river downstream of the Menominee Dam, please use the Green Bay guidelines on page 20 for species not listed above.

Source: MDHHS' 2015 Eat Safe Fish Guide

Mercury

Unfortunately, mercury is a worldwide problem - not one just limited to the Menominee River. The majority of fish consumption guidelines in Michigan's Upper Peninsula are caused by mercury. Of note, when comparing mercury levels in Lower Peninsula and Upper Peninsula fish, Upper Peninsula fish tend to have higher concentrations of mercury at smaller sizes than their Lower Peninsula counterparts. However, this is most likely due to slower fish growth rates due to lower water temperatures and a limited nutrient base in Upper Peninsula waterbodies.

In addition, watershed characteristics, including the number of wetlands and higher sulfur levels in these northern areas tend to lead to increased methylation rates. These environmental factors, rather than exceptionally higher levels of mercury in the lakes and rivers, are likely what lead to the elevated mercury levels in Upper Peninsula fish.

To learn more, read: ***The Growing Degree-Day and Fish Size-at-Age: the Overlooked Metric*** **at** http://sites.google.com/site/abneuheimer/Neuheimer_Taggart_2007.pdf **and MDEQ's Water Investigation: Groundwater in Menominee County (1963)** at http://www.michigan.gov/documents/deq/GIMDL-WI02I_216279_7.PDF.

According to studies cited by the International Joint Commission, concentrations of mercury in top predator fish are likely atmospherically driven and likely due to increased global mercury emissions affecting the Great Lakes Basin. To learn more, read ***Atmospheric Deposition of Mercury in the Great Lakes Basin*** found at https://www.epa.gov/sites/production/files/2015-08/documents/lmmbhg.pdf.

Another source examining mercury deposition in the Great Lakes region is the article titled: ***Use of Stable Isotope Signatures to Determine Mercury Sources in the Great Lakes*** found at: http://pubs.acs.org/doi/pdf/10.1021/acs.estlett.5b00277. This article demonstrates that overall, more mercury collects in the northern Lake Michigan basin than the southern portion of the basin, which further demonstrates that the mercury inputs into the Menominee River are more regional in nature, than localized within the AOC.

Michigan's Mercury Consumption Guideline Comparisons					
	MI Servings Per Month				
Species	**Statewide Guidelines**	**Lake Michigan**	**Green Bay**	**Menominee River - DMD**	**Menominee River - LSF**
Black/White Crappie	4	N/A	N/A	Under 9" - 8 Over 9" - 4	N/A
Bluegill/Sunfish	8	N/A	N/A	8	N/A
Large- and Small-mouth Bass	Under 18" - 2 Over 18" - 1	N/A	Under 18" - 2 Over 18" - 1	1	Under 18" - 1 Over 18" - 6 Per Year
Northern Pike	Under 30" - 2 Over 30" - 1	N/A	1	1	N/A
Yellow Perch	4	Under 10" - 4/8 (PCBs) Over 10" - 4	N/A	4	N/A

In fact, when comparing fish consumption guidelines driven by mercury in the Lower Menominee Area of Concern, most consumption guidelines in the area are the same or are better than the Michigan Statewide Safe Fish Guidelines which account for atmospheric deposition input of mercury into Michigan's waterways.

To learn more, read the ***MDHHS 2015 Eat Safe Fish Guide - Upper Peninsula***.

Based on fish contamination data collected by MDEQ and MDHHS in 2012 assessing mercury, the Lower Scott Flowage of the Menominee River does show higher levels of mercury than the reference site in all species of fish tested: carp, rock bass, and smallmouth bass. However, this data alone does not provide an accurate portrait of the current status of the AOC.

Per the US EPA's Lake Michigan Mass Balance Study conducted in 2004, the Menominee River received a top scoring of 1 on the Index of Watershed Indicator. This best quality rating was assigned to just two of Lake Michigan's tributaries, the Menominee and the Manistique Rivers. A score of one represents "better quality, low vulnerability" in the river system.

In addition, according to the report, the lowest total mercury concentrations were observed in the Muskegon, Pere Marquette, Manistique, and Menominee Rivers. However, dissolved methylmercury concentrations in the Menominee River were significantly higher than in the Muskegon, Fox, Grand, and Grand Calumet Rivers. This leads one to conclude that it isn't necessarily an uncontrolled direct source of mercury to the Menominee River that results in higher mercury levels in fish, but rather, the natural environment within the river is actually conducive to methylation. Methylmercury is the type of mercury that is found in fish. This unfortunate mercury to methylmercury conversion efficiency is likely what leads to the slightly higher rates of mercury in fish tissue in the Menominee River despite the lower overall measurements of mercury in the river system.

Table 8. Median total mercury in fish collected from the Lower Scott Flowage (LSF), Menominee River downstream of the Menominee Dam (DMD), and Little Bay De Noc (LBDN).

Species	Median Total Mercury (mg/kg)		
	LSF	DMD	LBDN
Carp	0.44*	0.20*	0.29*
Northern Pike	--	0.22	0.49
Rock Bass	0.16	--	0.08
Smallmouth Bass	0.50	0.33	0.28

Source: Table 8 - MDEQ Staff Report: Status of Fish Contaminant Levels in the Lower Menominee River Area of Concern, 2017

To learn more, read the US EPA's ***Lake Michigan Mass Balance Study: Mercury Data Report (February 2004)*** found at https://www.epa.gov/sites/production/files/2015-08/documents/lmmbhg.pdf.

SUMMARY:

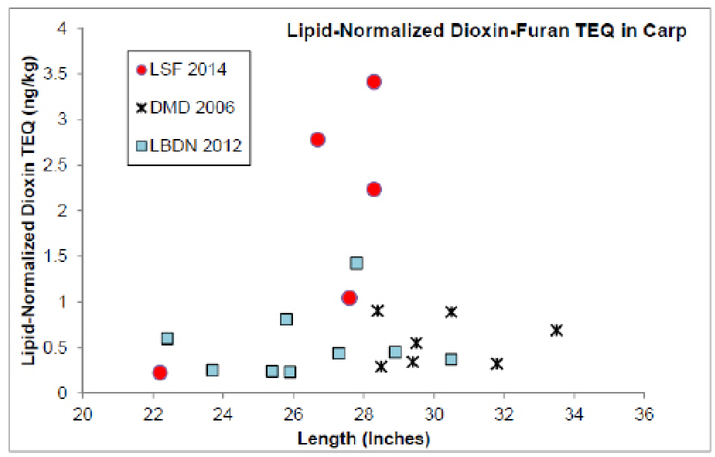
- **There are no apparent direct sources of mercury in the Lower Menominee River AOC.**
- **Median totals of mercury in fish from the Lower Scott Flowage are higher than fish from Little Bay de Noc; however, it is likely due to environmental influences beyond the scope of the AOC program.**

Dioxins

To assess this contaminant, carp were collected and analyzed from multiple locations within the Menominee River, Green Bay, and Little Bay de Noc. Carp were used because they generally present the worst case scenario for chlorinated contaminants like PCBs and dioxins due to their feeding habits and other biological factors.

To determine appropriate fish consumption guidelines, MDEQ and MDHHS calculate amounts of dioxins using toxic equivalency factors, also known as TEQ. The TEQ is a calculation that generally includes dioxin, furans, and dioxin-like PCBs. TEQ is used in Michigan to determine fish consumption guidelines because furans and dioxin-like PCBs tend to act the same as dioxins in the body after they are eaten. It's important to note that WDNR's fish consumption program does not do this. Another key difference between Michigan and Wisconsin's fish consumption program is Wisconsin runs aroclors, and not congeners like Michigan. Therefore, consumption advice for the same waterbody is sometimes different between states due to the inclusion of TEQ in MDHHS's guidelines.

When calculating for fish consumption guidelines, MDEQ and MDHHS use non-lipid normalized data (because guidelines are not calculated using comparisons) and set guidelines based on the 95% Upper Confidence Limit or regression analysis, whichever is most approriate. However, for the assessment of the Lower Menominee AOC Fish Consumption BUI, the MDEQ Staff Report utilizes both non-lipid normalized, as well as lipid normalized data, to allow for a more apples-to-apples statistical comparison. *Lipid normalized* means the contaminant results were divided by the amount of fat in each of the fish. Statistical methods of adjusting for differences in fat content were also used. This was done to ensure like comparisons between fish and sites. This is important because dioxins collect in the fat of a fish, so a fatter carp will carry more contaminants, even if the waterbody is not highly contaminated.



Source: Figure 23 - MDEQ Staff Report: Status of Fish Contaminant Levels in the Lower Menominee River Area of Concern, 2017

The lipid-normalized dioxin TEQ concentrations in carp from the Lower Scott Flowage were greater than TEQ in carp from Little Bay de Noc, and the amounts were significantly different. However, lipid-normalized dioxin TEQ levels from within the AOC were not statistically different than TEQ levels in the Chalk Hill Flowage, which is upstream of the AOC [Figure 23 from the MDEQ Staff Report, 2017].

In addition, when comparing non-lipid normalized data between the Chalk Hill Flowage and the Lower Scott Flowage, the mean dioxin TEQ concentration in the Chalk Hill Flowage is nearly double than what is found in Lower Scott Flowage fish. The Lower Scott Flowage fish also show the lowest mean concentrations of dioxin TEQ of all sites, although the differences are not significantly different [Table 12 from the MDEQ Staff Report, 2017].

Table 12. The 95% UCL on the mean dioxin TEQ concentration and projected consumption advice due to dioxin TEQ, based only on the most recent results for carp collected from the Chalk Hill Flowage (CHF), the Lower Scott Flowage (LSF), Menominee River downstream of the Menominee Dam (DMD), Green Bay (GB), and Little Bay De Noc (LBDN).

95% UCL (ppt)					Meals per Month				
CHF	LSF	DMD	GB	LBDN	CHF	LSF	DMD	GB	LBDN
7.7	3.9	11.4	5.6	4.7	0.5	1	0.5	1	1

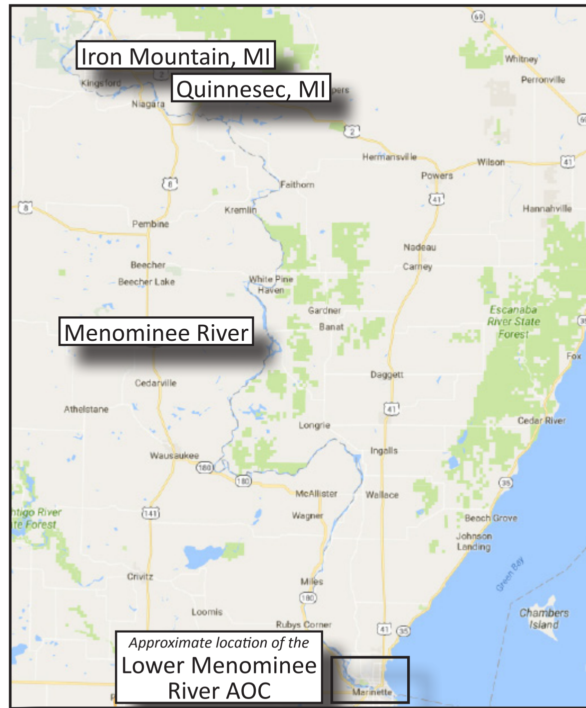
Note: *Meals per Month presented here do not represent the final MDHHS determinations*

Source: Table 12 - MDEQ Staff Report: Status of Fish Contaminant Levels in the Lower Menominee River Area of Concern, 2017

*no significant differences

These two analyses demonstrate that dioxins upstream of the AOC are likely carried downstream into the Lower Scott Flowage and below the Menominee Dam. Similar to the other two chemicals cited in the Lower Menominee River AOC Fish Consumption BUI removal criteria, a direct source of dioxins does not seem to be present within the AOC based on fish contaminant analysis.

Dioxin-like PCBs are primarily associated with the Lower Green Bay and Fox River AOC. Additional upstream contamination also likely stems from historical release of waste by-products from the Champion International Paper - Quinnesec Mill, a source outside of the boundaries of the Lower Menominee River AOC. All of these locations are outside the boundaries of the Menominee River AOC. Because of this, MDEQ opted to exclude dioxin-like PCBs from the calculations above because dioxins and furans have historically been found only in areas far upstream of the AOC. Additional potential sources of these dioxins and furans include paper mill operations in the Kingsford and Iron Mountain areas.



SUMMARY:

- **There are no apparent direct sources of dioxins in the Lower Menominee River AOC.**
- **Lipid-normalized dioxin TEQ in carp from the Lower Scott Flowage are higher than carp from Little Bay de Noc. However, the fish are likely influenced by sources upstream of the AOC.**

Resources

MDEQ Staff Report: Status of Fish Contaminant Levels in the Lower Menominee Area of Concern (attached)

Stage 2 Remedial Action Plan for the Lower Menominee AOC (2011)
http://www.michigan.gov/documents/deq/deq-ogl-aoc-MenomineeStage2RAP_378187_7.pdf

US EPA's Results of the Lake Michigan Mass Balance Project: Polychlorinated Biphenyls Modeling Report (December 2006) https://www.epa.gov/sites/production/files/2015-08/documents/lmmbpcb.pdf

MDHHS 2015 Eat Safe Fish Guide - Upper Peninsula
http://www.michigan.gov/documents/mdch/MDCH_EAT_SAFE_FISH_GUIDE_-_UPPER_PENINSULA_WEB_455361_7.pdf

International Joint Commission's Atmospheric Deposition of Mercury in the Great Lakes Basin
http://bit.ly/1XW2jAI

US EPA's Lake Michigan Mass Balance Study: Mercury Data Report (February 2004)
https://www.epa.gov/sites/production/files/2015-08/documents/lmmbhg.pdf

The Growing Degree-Day and Fish Size-at-Age: the Overlooked Metric
http://sites.google.com/site/abneuheimer/Neuheimer_Taggart_2007.pdf

MDEQ's Water Investigation: Groundwater in Menominee County (1963)
http://www.michigan.gov/documents/deq/GIMDL-WI02I_216279_7.PDF

MDEQ Impaired Waters (303(d))
http://www.michigan.gov/deq/0,4561,7-135-3306_71085_7257-12711--,00.html

About this Document

This White Paper was prepared by Michelle Bruneau, Project Manager for the Assessing Michigan's Beneficial Use of Sport-Caught Fish project at MDHHS in May 2016 and revised in March 2017 and provided to the state and local stakeholders working to remove the BUIs on the Menominee River AOC.

REVISED MARCH 8, 2017
MI/DEQ/WRD-16/005

MICHIGAN DEPARTMENT OF ENVIRONMENTAL QUALITY
WATER RESOURCES DIVISION
MARCH 2016

STAFF REPORT

STATUS OF FISH CONTAMINANT LEVELS IN THE LOWER MENOMINEE RIVER AREA OF CONCERN

INTRODUCTION

The Lower Menominee River Area of Concern (MR-AOC) includes the lower three miles (4.8 km) of the river from the Park Mill (Wisconsin) Dam (aka Upper Scott Dam) downstream to the river mouth and approximately 3.1 miles (5 km) north and south of the mouth along the adjacent shoreline of Green Bay (GB). The Lower Scott Flowage (LSF), an impoundment formed by the Menominee Dam (aka Lower Scott Dam and Hattie Street Dam), is included in the AOC (Figure 1). The AOC watershed is shared between Michigan and Wisconsin.

Both Michigan and Wisconsin have issued consumption advisories for certain species of fish from the MR-AOC. Those advisories date back to 1976 (Zander, 1995) and are primarily due to elevated levels of polychlorinated biphenyls (PCBs). The MR-AOC is relatively close to the Lower GB and Fox River AOC. A large part of the problem in that AOC is due to historic discharges of PCB from numerous paper mills along the lower Fox River, and the MR-AOC may be impacted to some degree by that legacy contamination. The Lake Michigan Mass Balance Project (United States Environmental Protection Agency (U.S. EPA), 2006) estimated PCB loadings by major tributaries to the lake and compared PCB concentrations in Lake Michigan sediments. Based on that study it is believed that the Menominee River is a minor source of PCBs to GB, contributing roughly 20 times less than the Fox River. The mass balance study also estimated that the PCB loading from the Menominee River is only slightly higher than loadings from the Muskegon, Pere Marquette, and Manistique Rivers. A water quality study conducted on the Menominee River in 2011 found no evidence of a significant PCB source within the MR-AOC (Bohr, 2012).

Mercury is also a contaminant of concern and is a primary cause of fish consumption advisories covering the full length of the Menominee River. The source of mercury is most likely air-borne emissions, primarily from regional and global fossil fuel combustion, with subsequent atmospheric deposition throughout the watershed.

The pesticide DDT has a history of extensive use worldwide. The compound or its degradation products are present in measurable quantities in nearly all fish sampled from Michigan waters, including the Menominee River; if DDT was the only contaminant of concern it would cause a fish consumption advisory for the Menominee River downstream of the Menominee Dam. The source of DDT to the Menominee River watershed is likely a combination of atmospheric deposition and runoff from agricultural fields treated with the pesticide prior to its being banned in 1972.

Dioxins and furans are by-products of paper pulp bleaching, waste incineration, and the production of chlorinated chemicals. They have been measured in fish tissue samples from the Menominee River upstream of the Park Mill Dam, downstream of the Menominee Dam (DMD), and in fish from GB and Little Bay De Noc (LBDN). Currently, dioxins would cause fish consumption advisories in the upper Menominee River and in the MR-AOC if it was the only contaminant of concern.

Fish move freely between GB and the Menominee River up to the first dam, and it is thought that the primary source of PCBs and perhaps other contamination lies outside of the MR-AOC (Zander, 1995). Fish in the LSF are isolated from GB and the Menominee River downstream of the Menominee Dam. One goal of this project is to determine if the MR-AOC is a source of the contaminants causing fish consumption advisories in the AOC by comparing contaminant concentrations in fish from the LSF with concentrations in fish from DMD and LBDN. The latter site is considered to be a reference site in that the area is sufficiently far from any AOC, but should be subject to the same regional climate and atmospheric contaminant inputs as the MR-AOC.

SUMMARY

1. Three species of fish were collected from the MR-AOC and LBDN from 2012 through 2014 and analyzed for mercury, PCBs, and chlorinated pesticides. Rock bass collected in 2008 from LBDN were compared to the same species collected from LSF in 2012.
2. Dioxin toxic equivalence (TEQ) was measured in carp collected from LSF and LBDN in 2014 and 2012, respectively. The results were compared to TEQ measurements in carp collected from DMD in 2006, GB in 2000, and upstream of the MR-AOC in 1991 and 1996.
3. Carp and smallmouth bass were collected in the LSF, DMD, and LBDN. Total PCB concentrations in both species were lowest in the LSF and highest in the DMD. The differences were statistically significant for both species.
4. Carp, northern pike, and smallmouth bass were collected from both DMD and LBDN. Total PCB concentrations in all three species were higher in the samples from DMD compared to LBDN, and the differences were statistically significant. The fish consumption guidance based on those results also differed for all three species.
5. Mercury concentrations in fish collected from upstream of the Menominee Dam were consistently higher than in fish of the same species collected from DMD or from LBDN.
6. Total DDT would be a secondary cause of fish consumption advisories for carp from both DMD and LBDN. Concentrations were slightly higher in carp from DMD than from LBDN but the projected consumption guidance was the same for both areas. Total DDT concentrations were low in all other fish populations sampled for this project and would not cause fish consumption advisories for those species.
7. Dioxin TEQ concentrations in carp from LSF were higher than measured in LBDN and GB. Dioxin TEQ concentrations in carp from DMD were not significantly different than in carp from LBDN. Sources of dioxins are most likely upstream of the MR-AOC.
8. The results of this project, in combination with previous studies, supports the hypothesis that PCBs and dioxins measured in fish collected from the MR-AOC are primarily from sources outside of the AOC.

METHODS

Carp (*Cyprinus carpio*) and smallmouth bass (*Micropterus dolomieu*) were the primary target species and were collected in both areas of the MR-AOC (LSF and DMD) and in LBDN, providing the best overall between site comparisons (Table 1). Carp were selected as a target species because they tend to have high PCB burdens relative to other species in a given water body, they are relatively ubiquitous, and results from previous sampling are available. Smallmouth bass were selected because they are a popular sport fish and have good site fidelity.

Northern pike (*Esox lucius*) and rock bass (*Ambloplites rupestris*) were collected at varying sites and provide additional between-site comparisons. Both species are popular with anglers and have good site fidelity.

Fish from the MR-AOC were collected by the Wisconsin Department of Natural Resources (WiDNR) primarily in 2012. Collections of sufficient numbers of carp and smallmouth bass were problematic and necessitated additional effort in 2013 and 2014. Fish from LBDN were collected by the Michigan Department of Natural Resources (MDNR) in 2012 and 2014. Rock bass collected from LBDN in 2008 were used for comparisons with fish collected from LSF in 2012. In addition, mercury concentrations in smallmouth bass collected in 2014 by We Energies from Menominee River impoundments to meet hydroelectric facility licensing requirements were used for comparison with fish collected from LSF.

Table 1. Number of fish samples collected from the Lower Menominee River AOC and Little Bay De Noc and analyzed by the MDHHS Laboratory (years of collection in parentheses). Little Bay De Noc samples provided by MDNR, all others provided by the WiDNR.

Species	Lower Scott Flowage	Menominee River d/s Menominee Dam	Little Bay De Noc
Carp	11	10	9
	(2012, '13, '14)	(2012)	(2012)
Smallmouth Bass	10	10	10
	(2012, '13)	(2012, '13)	(2012)
Northern Pike	0	9	10
		(2012)	(2014)
Rock Bass	10		14
	(2012)		(2008)

The fish were processed as standard edible portions in accordance with the MDEQ, Water Resources Division, Fish Contaminant Monitoring Fish Collection Procedure WRD-SWAS-004. Total length was measured to the nearest millimeter and converted to inches for reporting. Length data are presented in Appendix A1. Total weight was measured to the nearest 10 grams and gender was recorded. Standard edible portions are untrimmed, skin-on fillets for rock bass and smallmouth bass, and untrimmed, skin-off fillets for carp and northern pike. Each sample was individually wrapped in aluminum foil, appropriately labeled, and frozen until preparation for analysis. A total of 65 fillet samples from the MR-AOC, 10 from CHF, and 53 from LBDN were analyzed (Table 1).

Table 2. Standard suite of contaminants quantified in fish tissue samples for the MDEQ Fish Contaminant Monitoring Program.

2,4'-DDD	*gamma*-Chlordane
2,4'-DDT	*trans*-Nonachlor
4,4'-DDD	*alpha*-Chlordane
4,4'-DDE	*cis*-Nonachlor
4,4'-DDT	Hexachlorobenzene
Aldrin	Mercury
Dieldrin	Mirex
gamma-BHC (Lindane)	Octachlorostyrene
Heptachlor	PBB (FF-1, BP-6)
Heptachlor Epoxide	Pentachlorostyrene
Heptachlorostyrene	Terphenyl
Hexachlorostyrene	Toxaphene
Oxychlordane	
Total PCB (as congeners; Aroclors prior to 2000)	

Since 2000, the MDHHS Laboratory has measured PCB concentrations using the congener method; total PCB concentration was estimated by summing the concentrations of PCB congeners. Individual congeners below the quantification level were assigned a concentration equal to 0 for the purpose of calculating a total PCB concentration. Also, congener analyses that did not meet retention time criteria or were subject to analytical interference were assigned a concentration equal to 0 for the purpose of calculating a total PCB concentration. All fillet and whole fish samples were analyzed for a standard suite of contaminants including total mercury, organochlorinated pesticides (Table 2), and PCB congeners (Table 3) by the Michigan Department of Health and Human Services (MDHHS) Analytical Chemistry Laboratory.

Table 3. PCB structure and corresponding identification number of congeners assayed in fish tissue samples.

Structure	BZ#	Structure	BZ#	Structure
TRICHLOROBIPHENYLS		PENTACHLOROBIPHENYLS		HEPTACHLOROBIPHENYLS
2,2',4	82	2,2',3,3',4	170	2,2',3,3',4,4',5
2,2',5	84	2,2',3,3',6	171	2,2',3,3',4,4',6
	87	2,2',3,4,5'	172	2,2',3,3',4,5,5'
2,3,4'	90	2,2',3,4',5	174	2,2',3,3',4,5,6'
2,3',4	91	2,2',3,4',6	175	2,2',3,3',4,5',6
2,3',5	92	2,2',3,5,5'	177	2,2',3,3',4',5,6
2,4,4'	95	2,2',3,5',6	178	2,2',3,3',5,5',6
2,4',5	97	2,2',3',4,5	179	2,2',3,3',5,6,6'
2,4',6	99	2,2',4,4',5	180	2,2',3,4,4',5,5'
2',3,4	100	2,2',4,4',6	182	2,2',3,4,4',5,6'
3,4,4'	101	2,2',4,5,5'	183	2,2',3,4,4',5',6
	105	2,3,3',4,4'	185	2,2',3,4,5,5',6
TETRACHLOROBIPHENYLS	110	2,3,3',4',6	187	2,2',3,4',5,5',6
2,2',3,3'	118	2,3',4,4',5	190	2,3,3',4,4',5,6
2,2',3,4'	126	3,3',4,4',5	193	2,3,3',4',5,5',6
2,2',3,5'				
2,2',3,6		HEXACHLOROBIPHENYLS		OCTACHLOROBIPHENYLS
2,2',4,4'	128	2,2',3,3',4,4'	194	2,2',3,3',4,4',5,5'
2,2',4,5'	130	2,2',3,3',4,5'	195	2,2',3,3',4,4',5,6
2,2',5,5'	132	2,2',3,3',4,6'	196	2,2',3,3',4,4',5,6'
2,3,3',4'	135	2,2',3,3',5,6'	198	2,2',3,3',4,5,5',6
2,3,4,4'	136	2,2',3,3',6,6'	199	2,2',3,3',4,5,6,6'
2,3',4',5	137	2,2',3,4,4',5	201	2,2',3,3',4,5,5',6'
2,3,4',6	138	2,2',3,4,4',5'	203	2,2',3,4,4',5,5',6
2,3',4,4'	141	2,2',3,4,5,5'	205	2,3,3',4,4',5,5',6
2,3',4',5	144	2,2',3,4,5',6		
2,3',4',6	146	2,2',3,4',5,5'		NONACHLOROBIPHENYLS
2,4,4',5	149	2,2',3,4',5',6	206	2,2',3,3',4,4',5,5',6
3,3',4,4'	151	2,2',3,5,5',6		
	153	2,2',4,4',5,5'		
	156	2,3,3',4,4',5		
	157	2,3,3',4,4',5'		
	158	2,3,3',4,4',6		
	163	2,3,3',4',5,6		
	167	2,3',4,4',5,5'		

BZ# = identification numbers adopted by the International Union of Pure and Applied Chemists (IUPAC)

Total DDT concentrations were calculated by summing concentrations of the para, para' and ortho, para' forms of DDT, dichlorodiphenyldichloroethylene (DDE), and 1,1-bis(4-chlorophenyl)-2,2-dichloroethane (DDD). Individual chemicals below the quantification level were assigned a concentration equal to 0 for the purpose of calculating a total DDT concentration. If all six components were below the quantification level, then the total DDT concentration was reported as less than the lowest quantification level of the metabolites.

Dioxin, dibenzofuran (furan), and dioxin-like PCB congener concentrations were measured in carp collected from LSF and LBDN (Tables 4a and 4b). In addition, dioxin and furan results are available for carp collected in 2006 from DMD. Total 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) TEQ was calculated for those samples using toxic equivalency factors developed by the World Health Organization (Van den Berg et al., 2006). The concentrations of individual dioxin, furan, and dioxin-like PCB congeners in a fish sample were multiplied by chemical-specific toxic equivalency factors and the resulting products summed to calculate a TCDD TEQ concentration. Individual congener concentrations less than the detection level were assigned a value of 0 for the purpose of calculating the dioxin TEQ. Dioxin TEQ was measured in carp collected from CHF in 1991 and 1996 (n=12), from LSF in 2014 (n=5), from DMD in 2006 (n=7), from GB in 2000 (n=10), and from LBDN in 2012 (n=9).

The complete dataset is available electronically (by request) or through the Fish Contaminant Monitoring Program Web site (www.deq.state.mi.us/fcmp).

The MDHHS, Division of Environmental Health, develops fish consumption advice following protocols described in the *Michigan Fish Consumption Advisory Program Guidance Document*. That document along with links to supporting documentation and other related reports is available online at http://www.michigan.gov/eatsafefish (Reports & Science button). The guidance was used in this report to predict the likely fish consumption advice based only on the most recent analytical results. Specifically, the projected advice was determined by comparing the 95 percent upper confidence limit (95% UCL) on the mean concentration in legal-size fish for each species/site/contaminant combination with the appropriate MDHHS screening value for that contaminant. The screening values developed by the MDHHS are presented in Appendix B. It is important to note that the projected consumption advice reported here may not be the final advice put forth by the MDHHS; the MDHHS bases consumption guidance on the most current analytical results in combination with previous data for the water body as well as knowledge of legacy or ongoing contamination issues.

The MDHHS fish consumption guidance is presented as a recommended number of meals per month of a given species. The meal categories range from 16 meals per month to a “Do Not Eat” category; the latter category is reserved for those species and water bodies where the estimated contaminant concentration in a single meal would exceed the annual safe level of exposure. In addition the MDHHS has designated a “Limited” category; healthy adults may eat 1 or 2 meals per year of fish in this category but it is recommended that women of childbearing age, young children, and adults with a chronic health condition not eat these fish.

Contaminant loads in fish are sometimes positively correlated with the age of the fish, and fish length is generally used as a surrogate for age. In addition, chlorinated contaminants such as PCBs, DDT, and dioxins tend to accumulate preferentially in lipids. Since the length range and lipid content of fish can vary from site to site, a simple comparison of contaminant concentrations has the potential to be biased. To compensate for the potential bias, statistical comparisons were conducted using a Generalized Linear Model (GLM) with lipid content, gender, and fish length as covariates for the chlorinated contaminant concentrations, and fish length and gender as covariates for mercury concentrations. Contaminant concentrations were transformed using the natural log in order to meet assumptions of the GLM.

In addition, chlorinated contaminant results were lipid normalized by dividing the contaminant concentration by the lipid content and compared using the Kruskal-Wallis (KW) and Mann-Whitney statistical tests, the nonparametric equivalent of Analysis of Variance, and the t-test, respectively.

Statistical tests were considered significant at $p \leq 0.05$. The software package Minitab 15 was used to perform the statistical tests.

Table 4a. Chlorinated dibenzo-p-dioxin (CDD) and chlorinated dibenzofuran (CDF) congeners quantified in fish tissue samples.

CDD	Quantification Limit (ppt)	TEF*
2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD)	1.0	1
1,2,3,7,8-Pentachlorodibenzo-p-dioxin (PCDD)	1.0	1
1,2,3,4,7,8-Hexachlorodibenzo-p-dioxin (HxCDD)	1.0	0.1
1,2,3,6,7,8-HxCDD	1.0	0.1
1,2,3,7,8,9-HxCDD	1.0	0.1
1,2,3,4,6,7,8-Heptachlorodibenzo-p-dioxin (HpCDD)	1.0	0.01
1,2,3,4,6,7,8,9,-Octachlorodibenzo-p-dioxin (OCDD)	1.0	0.003
CDF		
2,3,7,8-Tetrachlorodibenzofuran (TCDF)	1.0 ppt	0.1
1,2,3,7,8-Pentachlorodibenzofuran (PCDF)	1.0 ppt	0.03
2,3,4,7,8-PCDF	1.0 ppt	0.3
1,2,3,4,7,8-Hexachlorodibenzofuran (HxCDF)	1.0 ppt	0.1
1,2,3,6,7,8-HxCDF	1.0 ppt	0.1
1,2,3,7,8,9-HxCDF	1.0 ppt	0.1
2,3,4,6,7,8-HxCDF	1.0 ppt	0.1
1,2,3,4,6,7,8-Heptachlorodibenzofuran (HpCDF)	1.0 ppt	0.01
1,2,3,4,7,8,9-HpCDF	1.0 ppt	0.01
1,2,3,4,6,7,8,9-Octachlorodibenzofuran (OCDF)	1.0 ppt	0.0003

Table 4b. Coplanar PCB congeners analyzed for Michigan's Fish Contaminant Monitoring Program.

BZ#	Structure	Quantification Limit (ppt)	TEF*
	TETRACHLOROBIPHENYLS		
77	3,3'4,4'	50	0.0001
81	3,4,4',5	50	0.0003
	PENTACHLOROBIPHENYLS		
105	2,3,3',4,4'	50	0.00003
114	2,3,4,4',5	50	0.00003
118	2,3',4,4',5	50	0.00003
123	2',3,4,4',5	50	0.00003
126	3,3',4,4',5	50	0.1
	HEXACHLOROBIPHENYLS		
156	2,3,3',4,4',5	50	0.00003
157	2,3,3',4,4',5'	50	0.00003
167	2,3',4,4',5,5'	50	0.00003
169	3,3',4,4',5,5'	50	0.03
	HEPTACHLOROBIPHENYLS		
189	2,3,3',4,4',5,5'	50	0.00003

* - World Health Organization 2,3,7,8 TCDD Toxic Equivalency Factors (Van den Berg et al., 2006)

RESULTS AND DISCUSSION

The following discussion includes between-site comparisons of results for total PCBs, mercury, total DDT, and dioxin. Elevated levels of PCBs, mercury, or both have led to the need for consumption advisories for certain species of fish taken from the MR-AOC since the early 1990s. While DDT has not caused advisories for MR-AOC fish, it is either known or likely to be present at concentrations high enough to cause advisories under the revised MDHHS advisory protocol now in use.

PCBs

PCBs were quantified in all fish collected from the DMD, and in all carp regardless of sampling site (Table 5). Otherwise, rates of quantification varied somewhat by species and sampling site. The highest PCB concentrations were measured in carp, regardless of sampling site; concentrations in northern pike, rock bass, and smallmouth bass were considerably lower (Table 6; Appendix A2). This pattern of concentrations between species is typical of other water bodies where these species coexist.

Table 5. Percentage of fish samples with quantifiable levels of total PCBs from the Lower Scott Flowage (LSF), Menominee River downstream of the Menominee Dam (DMD), and Little Bay De Noc (LBDN).

Species	LSF	DMD	LBDN
Carp	100	100	100
Northern Pike	--	100	70
Rock Bass	60	--	40
Smallmouth Bass	90	100	100

Table 6. Median total PCB and median lipid-normalized total PCB concentrations in fish collected from the Lower Scott Flowage (LSF), Menominee River downstream of the Menominee Dam (DMD), and Little Bay De Noc (LBDN).

Species	Median Total PCB (mg/kg)			Median Lipid-Normalized Total PCB (mg/kg)		
	LSF	DMD	LBDN	LSF	DMD	LBDN
Carp	0.04	1.83	0.67	0.02	0.29	0.12
Northern Pike	--	0.02	0.002	--	0.10	0.01
Rock Bass	0.002	--	0.002	0.004	--	0.008
Smallmouth Bass	0.002	0.05	0.008	0.02	0.13	0.02

There was no significant relationship between fish length and total PCB concentrations in carp from any of the three sampling sites in 2012, and the size range of carp collected at all sites was similar (Figure 2; Appendix A1). Gender was not a significant factor in the carp total PCB GLM. There was a strong correlation between lipid content and total PCB concentrations ($r=0.6$; $p<0.001$). The median total PCB and median lipid-normalized total PCB concentrations in carp from DMD were higher than in carp from LBDN (Table 6; Figure 3). Those differences were not statistically significant, although a larger sample size would probably indicate statistical significance. PCB concentrations in carp from both DMD and LBDN were significantly higher than concentrations in carp from LSF. These relationships were verified using the GLM. The projected consumption advice based on PCBs for carp from DMD and LBDN differs substantially from advice for carp from LSF (Table 7).

The northern pike collected from DMD and LBDN did not provide a good comparison due to the difference in lengths of the fish collected (Appendix A1). The northern pike from DMD were mostly clustered between 22 and 25 inches, while those from LBDN were fairly evenly spaced between 24 and 35 inches in length (Figure 4). Both total PCB and lipid-normalized PCB concentrations in the northern pike from DMD are higher than in northern pike from LBDN (Table 6; Figure 5), and the differences were statistically significant. Analysis using the GLM also indicated a significant difference between PCB concentrations in northern pike from the two areas. Gender was not a significant factor in the northern pike total PCB GLM. In addition, the projected consumption advice based on PCBs for northern pike from DMD is substantially more restrictive than for pike from LBDN (Table 7).

Table 7. The 95% UCL on the mean total PCB concentration and projected consumption advice due to total PCBs, based only on the most recent results for fish collected from the Lower Scott Flowage (LSF), Menominee River downstream of the Menominee Dam (DMD), and Little Bay De Noc (LBDN).

Species	95% UCL (ppm)			Meals per Month		
	LSF	DMD	LBDN	LSF	DMD	LBDN
Carp	0.12	2.85	2.06	1	DNE	Limited
Northern Pike	--	0.16	0.01	--	1	16
Rock Bass	0.01	--	0.003	16	--	16
Smallmouth Bass	0.07	0.09	0.02	2	2	12

DNE = Do Not Eat; MDHHS recommends that no one ever eat the fish in this category

Limited = Healthy adults may safely eat one or two meals per year of fish in this category. MDHHS recommends that women of childbearing age, young children, or adults with a chronic health condition should not eat these fish.

Note: *Meals per Month presented here do not represent the final MDHHS determinations*

Rock bass were collected from LSF in 2012 and from LBDN in 2008. Total PCB concentrations in rock bass from the two sites were not significantly different. Lipid-normalized total PCB concentrations in LSF rock bass were higher than in LBDN rock bass, although there was not a strong correlation between total PCBs and lipid content. The difference was due to an unusually high concentration measured in one fish from LSF (Figures 6 and 7). Gender was not a significant factor in the rock bass total PCB GLM. The projected consumption advice based on PCBs for rock bass from LSF is the same as for rock bass from LBDN (Table 7).

There was no significant relationship between fish length and total PCB concentrations in smallmouth bass from any of the three sites sampled in 2012 and 2013. Lipid content and total PCB concentrations were not strongly correlated in smallmouth bass. Gender was not a significant factor in the smallmouth bass total PCB GLM. Total PCB and lipid-normalized total PCB concentrations in smallmouth bass from DMD were higher than in both LSF and LBDN (Table 6; Figures 8 and 9), and the differences were statistically significant based on the KW tests. Total PCB concentrations in smallmouth bass from LSF were not different from bass from LBDN. The relationships were verified using the GLM. Overall, based on graphical interpretation and statistical analysis it appears that smallmouth bass from DMD have slightly higher concentrations of PCBs than those fish from LSF and LBDN. In addition, the projected consumption advice based on PCBs for smallmouth bass from the MR-AOC (both LSF and DMD) was more restrictive than for smallmouth bass from LBDN (Table 7).

Mercury

Total mercury was quantified in all samples from all sampling sites. The species having the highest median mercury concentration varied by sampling site (Table 8; Appendix A3). The interspecies pattern of mercury concentrations is unusual; generally a top predator (e.g., northern pike or smallmouth bass) has significantly higher mercury concentrations compared to species lower in the food web, but the median concentration in redhorse sucker from LSF was higher than in smallmouth bass from the same water body.

Table 8. Median total mercury in fish collected from the Lower Scott Flowage (LSF), Menominee River downstream of the Menominee Dam (DMD), and Little Bay De Noc (LBDN).

Species	Median Total Mercury (mg/kg)		
	LSF	DMD	LBDN
Carp	0.44	0.20	0.29
Northern Pike	--	0.22	0.49
Rock Bass	0.16	--	0.08
Smallmouth Bass	0.50	0.33	0.28

There was no significant relationship between fish length and total mercury in carp from any of the three sites sampled in 2012 (Figure 10). Gender was not a significant factor in the carp total mercury GLM. The highest mercury concentrations in carp were measured in samples taken from LSF (Table 8; Figure 11); the concentrations in all three sites were significantly different from each other, both using the KW and GLM statistical methods. The most restrictive projected consumption advice for carp is for fish from LSF while the least restrictive advice for carp is for fish from DMD (Table 9). This, along with results for other species, suggests that the mercury concentration in carp from the MR-AOC is not strongly related to mercury sources within the AOC. It might also indicate that the carp collected from DMD may have spent time in GB, outside of the Menominee River.

Table 9. The 95% UCL on the mean total mercury concentration and projected consumption advice due to mercury, based only on the most recent results for fish collected from the Lower Scott Flowage (LSF), Menominee River downstream of the Menominee Dam (DMD), and Little Bay De Noc (LBDN).

Species	95% UCL (ppm)			Meals per Month		
	LSF	DMD	LBDN	LSF	DMD	LBDN
Carp	0.57	0.25	0.38	1	4	2
Northern Pike	--	0.47	0.55	--	2	1
Rock Bass	0.24	--	0.11	4	--	8
Smallmouth Bass	0.69	0.42	0.36	1	2	2

Note: *Meals per Month presented here do not represent the final MDHHS determinations*

The northern pike samples do not provide an adequate between site comparison since the length ranges of fish collected from DMD and LBDN are not similar (Figures 12 and 13). However, if we assume northern pike from the two areas either intermingle or are exposed to similar levels of mercury we can combine the datasets and evaluate the relationship between fish length and mercury concentration. A regression of mercury concentration on fish length using the combined dataset produced a line with a statistically significant slope (Figure 12). Using the GLM with fish length as a covariate indicates that mercury concentrations in northern pike from DMD are higher than in those fish from LBDN. Gender was not a significant factor in the northern pike total mercury GLM. If advice for consumption of northern pike were based only on the mercury results for these sample sets, the advice for DMD would be less restrictive than for LBDN (Table 9).

Mercury concentrations in rock bass from LSF were significantly higher than in rock bass from LBDN (Figures 14 and 15). Mercury concentrations were positively correlated to fish length in both rock bass populations, and regressions of mercury concentration on fish length were significant for both populations. Gender was not a significant factor in the rock bass total mercury GLM. The projected consumption advice based only on these mercury results is more restrictive for rock bass from LSF as compared to LBDN (Table 9).

Both KW and GLM statistical methods indicate that mercury concentrations in smallmouth bass from DMD and LBDN were similar, and concentrations in smallmouth bass from LSF were significantly higher than in those fish from the other two sites (Figures 16 and 17). Mercury concentrations were weakly positively correlated with fish length in all three smallmouth bass populations. Gender was not a significant factor in the smallmouth bass total mercury GLM. The projected consumption advice based only on these mercury results is equivalent for smallmouth bass from DMD and LBDN and most restrictive for fish from LSF (Table 9).

Concentrations measured in the LSF are not unusual compared to other impoundments upstream on the Menominee River; smallmouth bass from LSF had mercury levels equivalent to concentrations in smallmouth bass from Big Quinnesec Flowage and slightly higher than levels in the White Rapids Flowage (Figure 18).

DDT

Total DDT was quantified in nearly all carp samples regardless of sampling site, but spatial differences were apparent for the other species sampled (Table 10; Appendix A4). Based on the rates of detection and the 95% UCL (Table 11) DDT concentrations are lowest in fish from LSF; concentrations in fish from DMD and LBDN are roughly equivalent.

Table 10. Percentage of fish samples with quantifiable levels of total DDT from the Lower Scott Flowage (LSF), Menominee River downstream of the Menominee Dam (DMD), and Little Bay De Noc (LBDN).

Species	LSF	DMD	LBDN
Carp	91	100	100
Northern Pike	--	80	40
Rock Bass	0	--	7
Smallmouth Bass	10	100	100

There was no significant relationship between fish length and total DDT in carp from any of the three sites sampled in 2012 (Figure 19), but there was a strong positive correlation between lipid content and total DDT concentrations (r=0.70; p<0.001). Lipid normalized total DDT concentrations in carp from DMD did not differ from concentrations in carp from LBDN, but carp from LSF had significantly lower concentrations than fish from the other two sites. The projected consumption advice based on these total DDT results for carp from DMD and LBDN differs substantially from advice for carp from LSF (Table 11).

There was no significant relationship between fish length or lipid content and total DDT concentrations in northern pike collected from DMD or LBDN (Figure 20). Based on these results, total DDT would not cause a fish consumption advisory for northern pike from either site that is more restrictive than 16 meals per month (Table 11).

Total DDT was not quantified in any of the rock bass collected from LSF and in only 1 of 14 rock bass collected from LBDN (Table 10). Based on the results, total DDT would not cause a fish consumption advisory for rock bass from either site more restrictive than 16 meals per month (Table 11).

Table 11. The 95% UCL on the mean total DDT concentration and projected consumption advice due to total DDT, based only on the most recent results for fish collected from the Lower Scott Flowage (LSF), Menominee River downstream of the Menominee Dam (DMD), and Little Bay De Noc (LBDN).

Species	95% UCL (ppm)			Meals per Month		
	LSF	DMD	LBDN	LSF	DMD	LBDN
Carp	0.004	0.45	0.28	16	4	4
Northern Pike	--	0.01	0.003	--	16	16
Rock Bass	0.001	--	0.001	16	--	16
Smallmouth Bass	0.001	0.008	0.004	16	16	16

Note: *Meals per Month presented here do not represent the final MDHHS determinations*

Total DDT was quantified in all smallmouth bass samples from both DMD and LBDN, but in only 1 of 10 smallmouth bass collected from LSF (Table 10). There was a positive correlation between total DDT and fish length (r=0.5; p=0.03) and between total DDT and lipid content (r=0.6; p=0.006) for smallmouth bass collected at DMD and LBDN (Figure 21). Both total DDT and lipid normalized concentrations in smallmouth bass from DMD were higher than in those fish from LBDN, and the differences were statistically significant. Based on these results total DDT would not cause a fish consumption advisory for smallmouth bass from either site that was more restrictive than 16 meals per month (Table 11).

Dioxin TEQ

Since dioxins and furans may have sources independent of PCB sources, TCDD TEQ was calculated without dioxin-like PCB congeners. The dioxin-like PCB concentrations were assayed only in the carp from LSF and LBDN, and were not used for between-site comparisons. The complete set of 7 dioxin, 10 furan, and 12 dioxin-like PCB congeners are used by the MDHHS to develop fish consumption advice whenever those results are available.

Quantifiable concentrations of 2,3,7,8 TCDD TEQs were measured in all carp analyzed to-date from the CHF, LSF, DMD, GB, and LBDN. Lipid content was strongly correlated with TEQ across all samples (r=0.8; p<0.001), but fish length was only correlated with TEQ for the GB samples (r=0.7; p=0.02). Dioxin TEQ concentrations were highest in DMD and lowest in LSF (Table 12; Figure 22), but differences were not statistically different. Lipid normalized TEQ concentrations in carp were highest in LSF, CHF, and DMD (Figure 23); the concentrations at those sites were not significantly different but those concentrations were significantly different than the lipid normalized TEQ concentrations in carp from GB. Lipid-normalized TEQ concentrations in LSF carp were higher than in both LBDN and GB, and the difference was statistically different.

Table 12. The 95% UCL on the mean dioxin TEQ concentration and projected consumption advice due to dioxin TEQ, based only on the most recent results for carp collected from the Chalk Hill Flowage (CHF), the Lower Scott Flowage (LSF), Menominee River downstream of the Menominee Dam (DMD), Green Bay (GB), and Little Bay De Noc (LBDN).

95% UCL (ppt)					Meals per Month				
CHF	LSF	DMD	GB	LBDN	CHF	LSF	DMD	GB	LBDN
7.7	3.9	11.4	5.6	4.7	0.5	1	0.5	1	1

Note: *Meals per Month presented here do not represent the final MDHHS determinations*

Historically, dioxin TEQ was also assayed in a limited number of walleye from the Menominee River, including three samples from the Badwater Impoundment (upstream of Iron Mountain) collected in 1992 and four samples from the CHF collected in 1991. No quantifiable concentrations were measured in the walleye samples from the Badwater Impoundment, while all four samples from the CHF had low but quantifiable concentrations. Although the small sample size prevents a definitive comparison, the results suggest a dioxin source downstream of the Badwater Impoundment and upstream of the MR-AOC.

Lastly, 2,3,7,8 TCDD was assayed in walleye collected in 1989 from the upper Menominee River upstream and downstream of the Champion International Paper – Quinnesec Mill (Taft, 1991). Dioxin was not detected in the fish collected upstream of the mill, but measurable quantities were found in the fish collected downstream. This suggests that the paper mill was a possible dioxin source and provides further evidence that there have been sources upstream of the MR-AOC.

SYNOPSIS

Total PCB concentrations in fish from DMD were consistently higher than the concentrations in the same species from LBDN and from the Menominee River upstream of the Menominee Dam. This pattern held for lipid-normalized total PCB concentrations as well. These results support the hypothesis that PCB contamination in GB is a likely source of contamination in the MR-AOC.

Total mercury concentrations in fish from the LSF were consistently higher than in fish from DMD and LBDN. It is unlikely that elevated mercury levels in the LSF are due to mercury sources within the MR-AOC; rather, higher concentrations in the LSF are most likely due to favorable conditions for mercury methylation within the LSF or the Menominee River watershed in general.

Total DDT concentrations were low in all fish populations sampled, and were lowest in fish from LSF. There are no known or likely point sources for DDT within the MR-AOC, with atmospheric deposition and agricultural runoff being the most likely inputs to the Menominee River watershed.

Previous sampling indicated that legacy paper mill discharges from upstream of the AOC are a likely source of the dioxin contamination observed in fish collected in LSF and probably contribute to dioxin contamination in fish from the DMD.

The MDHHS issues consumption guidance based on the contaminant(s) causing the most restrictive advice. Based on this evaluation, PCBs are the primary cause of advisories for carp and northern pike caught in the DMD (Table 13). Mercury would be the primary contaminant causing advisories for rock bass and smallmouth bass caught in the LSF. Total PCBs and mercury would together be primary causes of consumption advice for carp from the LSF and for smallmouth bass from DMD. It is important to reiterate that the projected consumption advice reported here may not be the final advice put forth by the MDHHS; the MDHHS bases consumption guidance on the most current analytical results in combination with previous data for the water body as well as knowledge of legacy or ongoing contamination issues.

Table 13. Projected consumption advice based on samples collected in 2010, 2012, and 2013, and contaminants causing the advice for fish collected from the Chalk Hill Flowage (CHF), the Lower Scott Flowage (LSF), the Menominee River downstream of the Menominee Dam (DMD), and Little Bay De Noc (LBDN).

Species		Sampling Site			
		CHF	LSF	DMD	LBDN
Carp	Meals/Month	1	1	DNE	Limited
	Cause	TEQ	PCBs, TEQ & Mercury	PCBs	PCBs
Northern Pike	Meals/Month	--	--	1	1
	Cause	--	--	PCBs	Mercury
Rock Bass	Meals/Month	--	4	--	8
	Cause	--	Mercury	--	Mercury
Smallmouth Bass	Meals/Month	--	1	2	2
	Cause	--	Mercury	PCBs & Mercury	Mercury

DNE = Do Not Eat; MDHHS recommends that no one ever eat the fish in this category.
Limited = Healthy adults may safely eat one or two meals per year of fish in this category. MDHHS recommends that women of childbearing age, young children, or adults with a chronic health condition should not eat these fish.
Note: *Meals per Month presented here do not represent the final MDHHS determination.*

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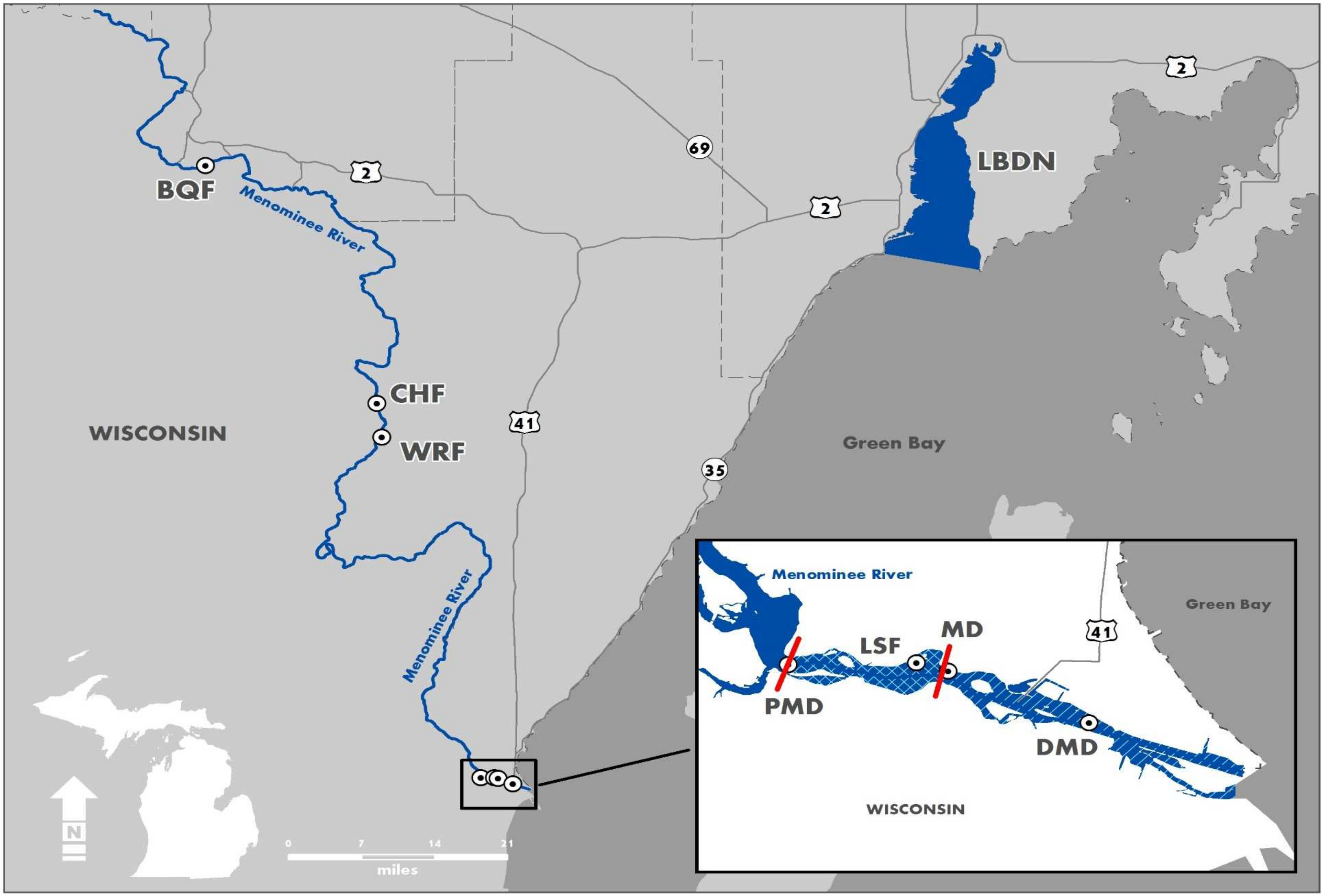

Figure 1. Map of Menominee River AOC (crosshatched in inset) indicating locations of the Park Mill Dam (PMD) and Menominee Dam (MD), and fish collection locations at Big Quinnesec Flowage (BQF), White Rapids Flowage (WRF), Chalk Hill Flowage (CHF), Lower Scott Flowage (LSF), Menominee River downstream of the Menominee Dam (DMD), and Little Bay De Noc (LBDN).

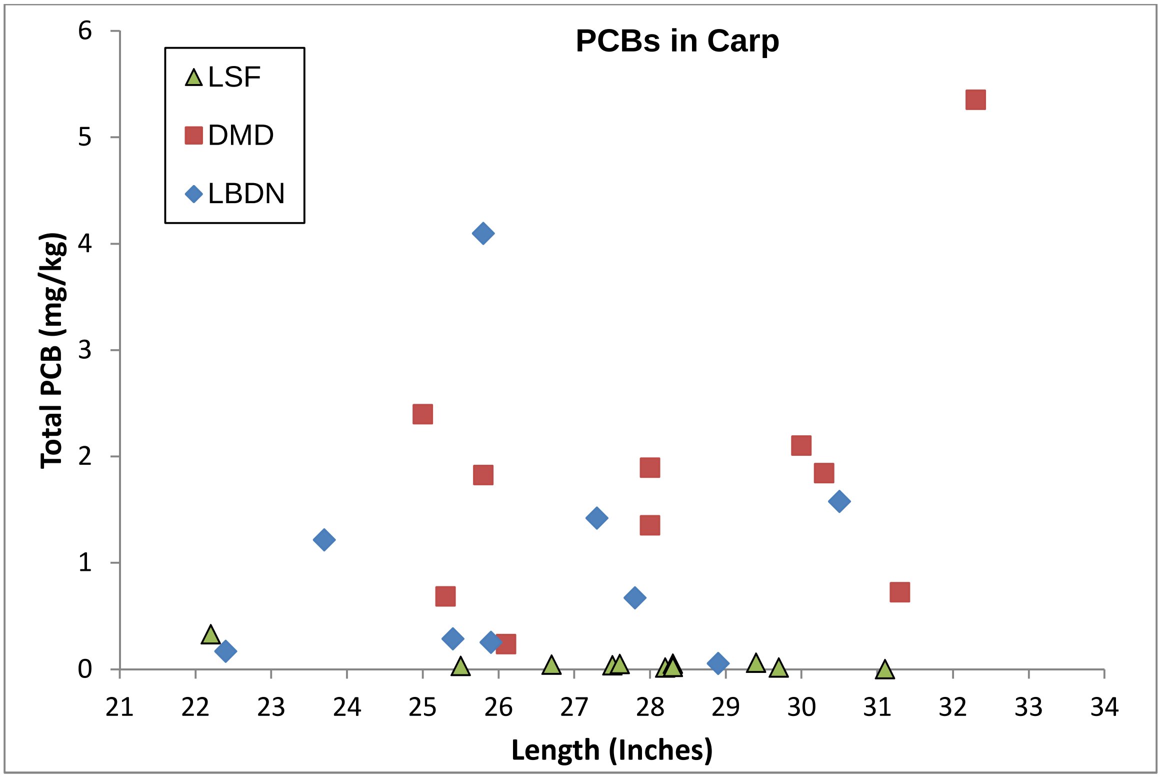

Figure 2. Length versus total PCB concentration in carp collected from Lower Scott Flowage (LSF), the Menominee River downstream of the Menominee Dam (DMD), and Little Bay De Noc (LBDN).

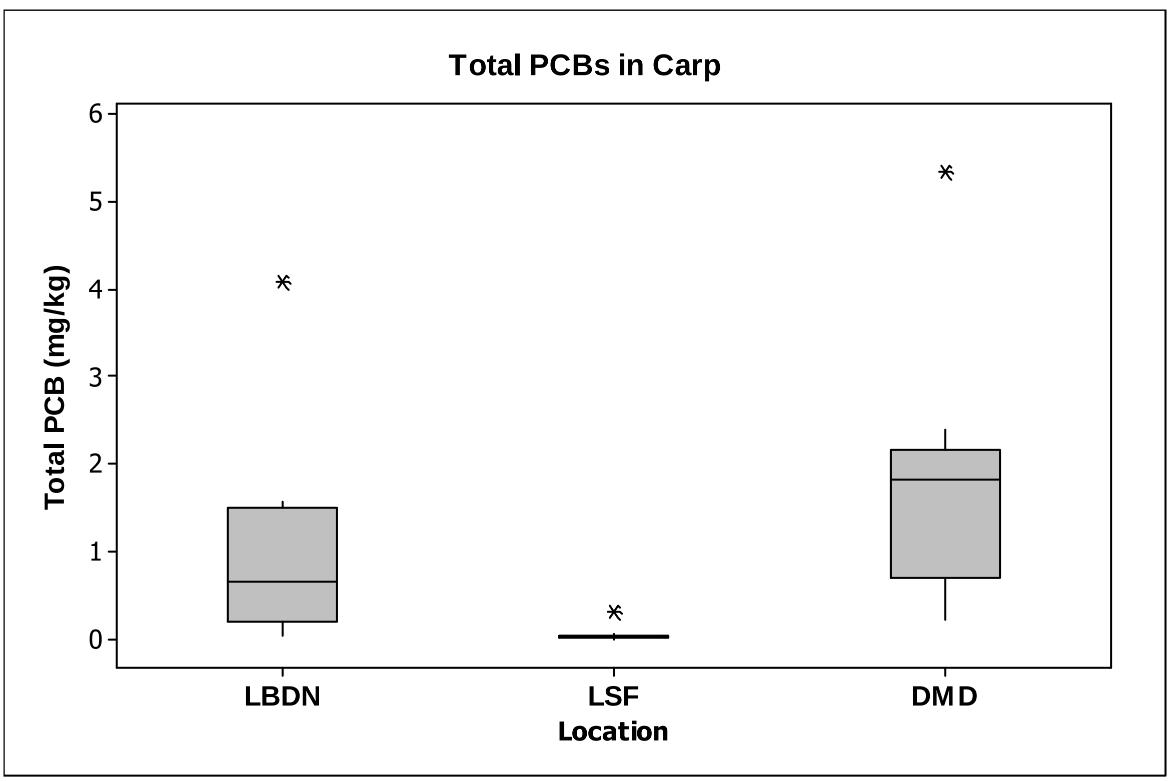

Figure 3. Boxplots of total PCB concentrations in fillets of carp from Little Bay De Noc (LBDN), Lower Scott Flowage (LSF), and the Menominee River downstream of the Menominee Dam (DMD).

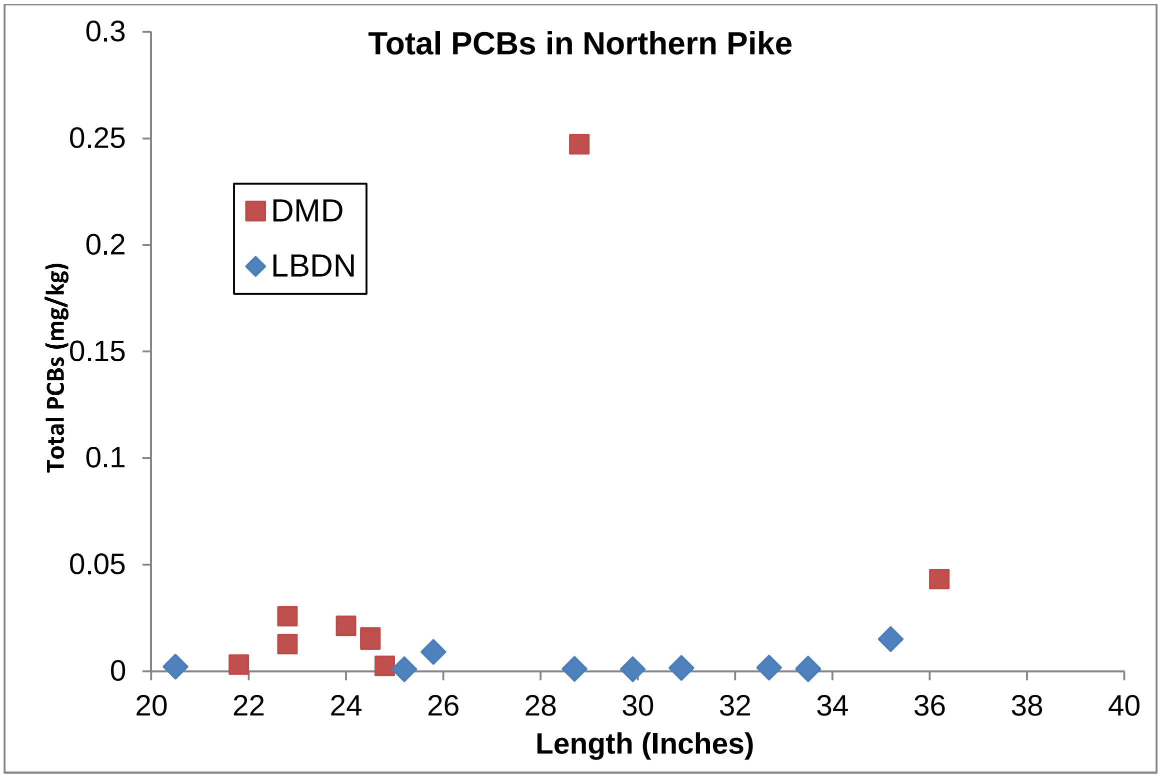

Figure 4. Length versus total PCB concentration in northern pike collected from the Menominee River downstream of the Menominee Dam (DMD), and Little Bay De Noc (LBDN).

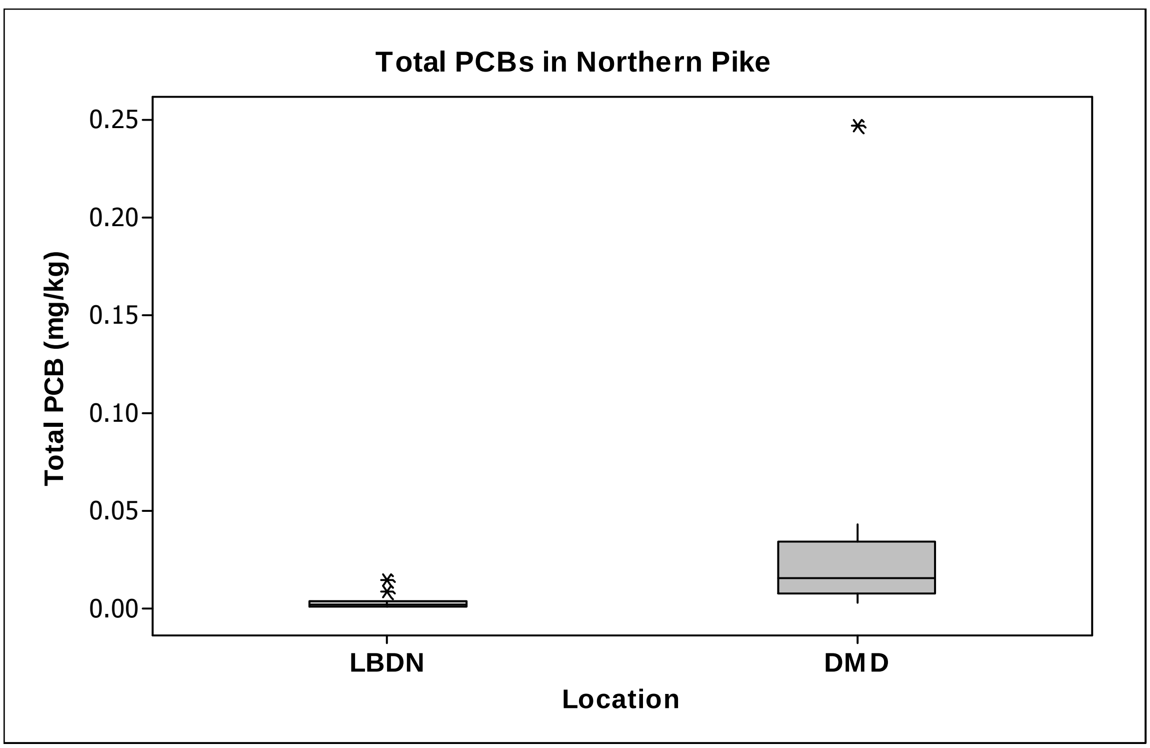

Figure 5. Boxplots of total PCB concentrations in fillets of northern pike from Little Bay De Noc (LBDN) and the Menominee River downstream of the Menominee Dam (DMD).

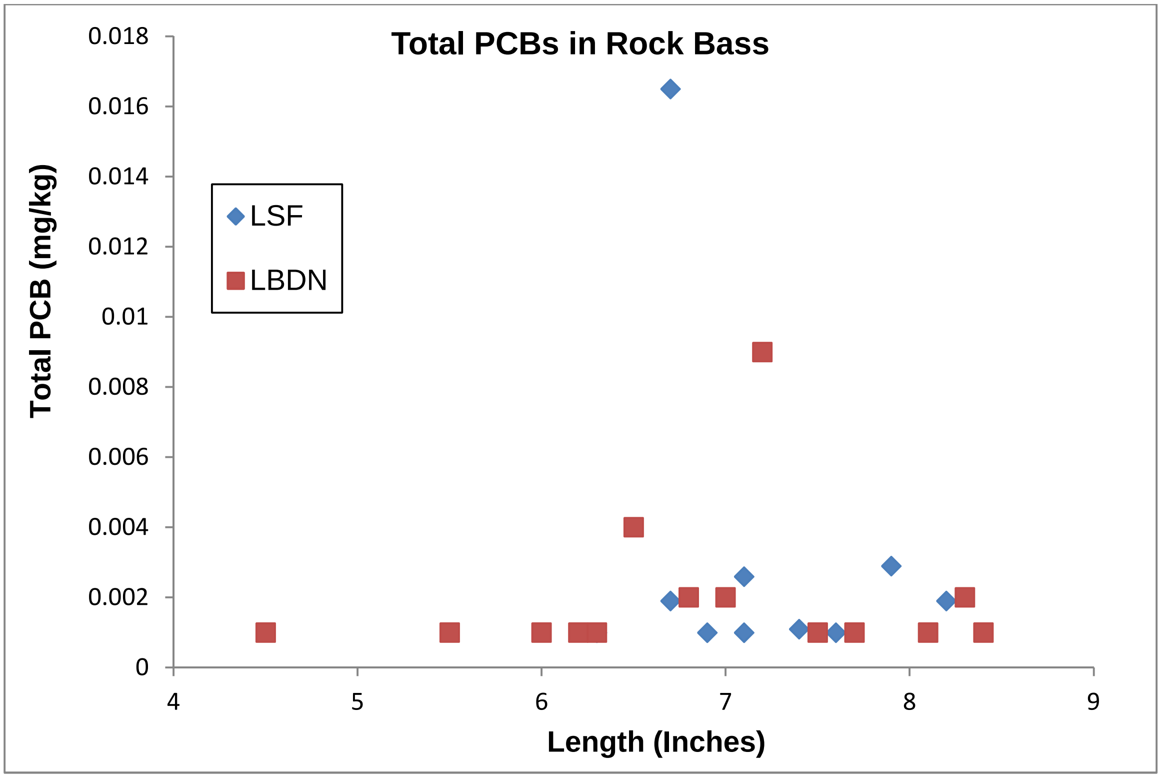

Figure 6. Length versus total PCB concentration in rock bass collected from Lower Scott Flowage (LSF) and Little Bay De Noc (LBDN).

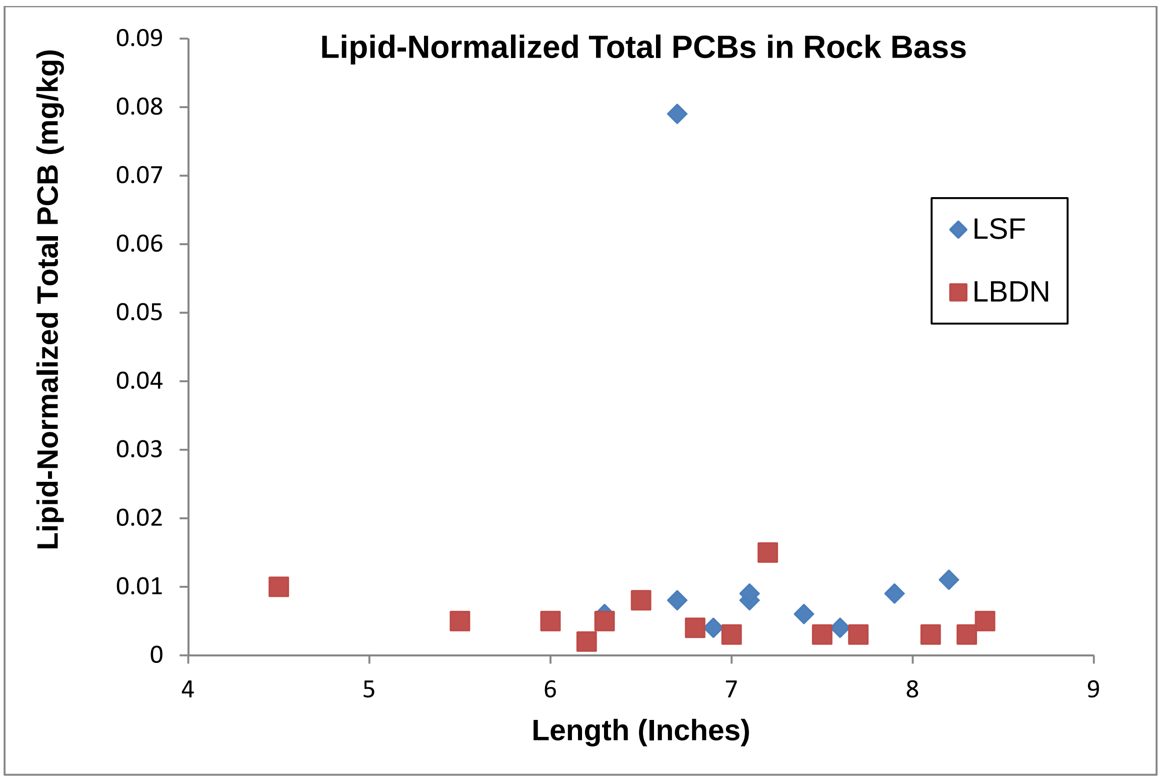

Figure 7. Length versus lipid-normalized total PCB concentration in rock bass collected from Lower Scott Flowage (LSF) and Little Bay De Noc (LBDN).

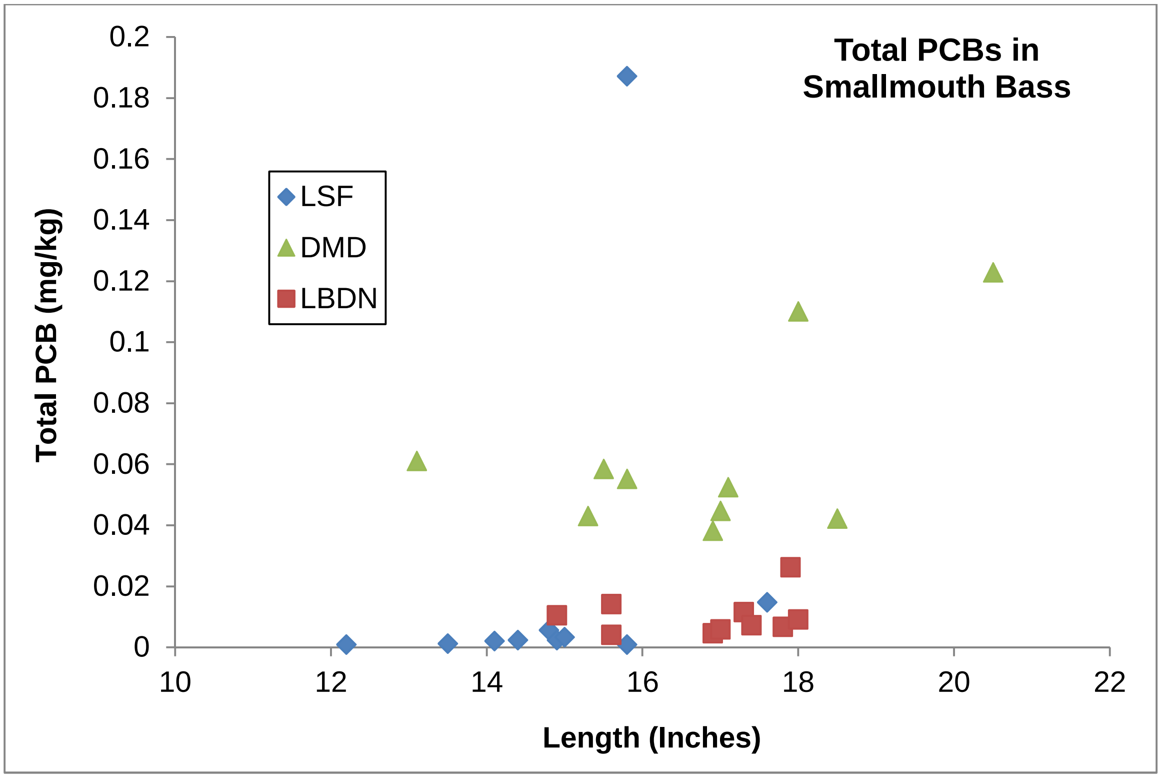

Figure 8. Length versus total PCB concentration in smallmouth bass collected from Lower Scott Flowage (LSF), Menominee River downstream of the Menominee Dam (DMD), and Little Bay De Noc (LBDN).

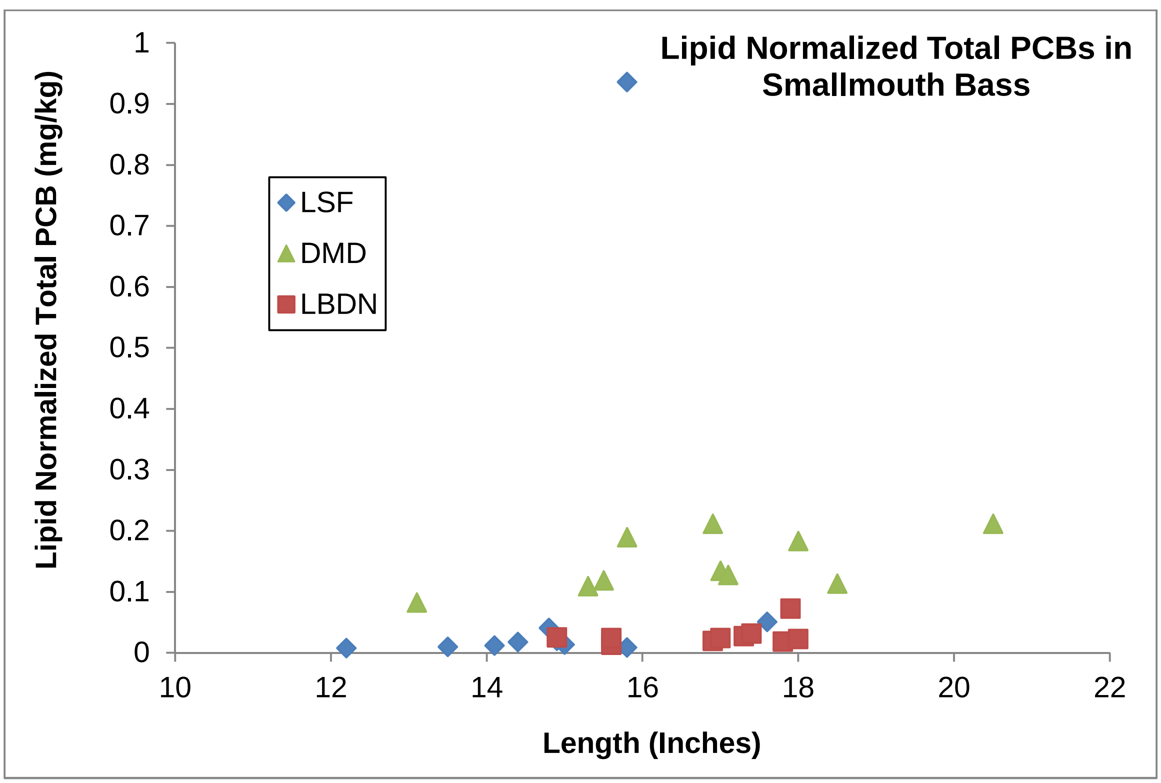

Figure 9. Length versus lipid-normalized total PCB concentration in smallmouth bass collected from Lower Scott Flowage (LSF), Menominee River downstream of the Menominee Dam (DMD), and Little Bay De Noc (LBDN).

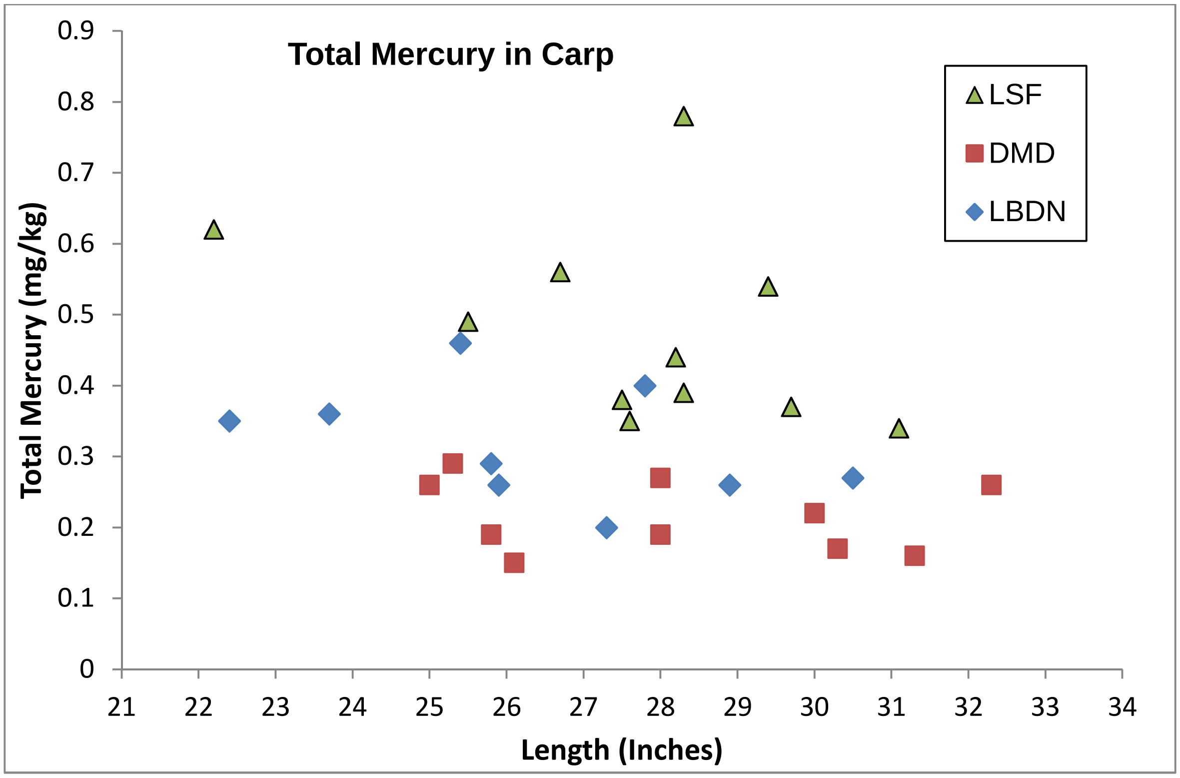

Figure 10. Length versus total mercury concentration in carp collected from Lower Scott Flowage (LSF), Menominee River downstream of the Menominee Dam (DMD), and Little Bay De Noc (LBDN).

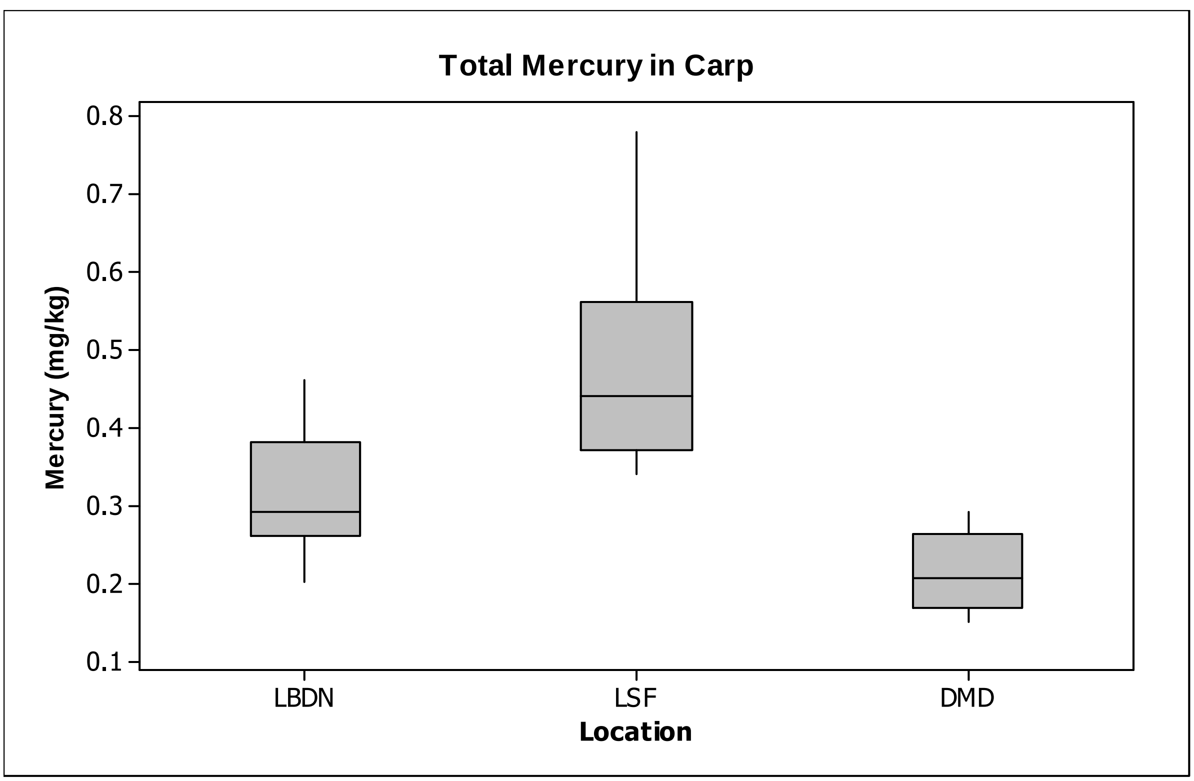

Figure 11. Boxplots of total mercury concentrations in fillets of carp from Little Bay De Noc (LBDN), Lower Scott Flowage (LSF), and the Menominee River downstream of the Menominee Dam (DMD).

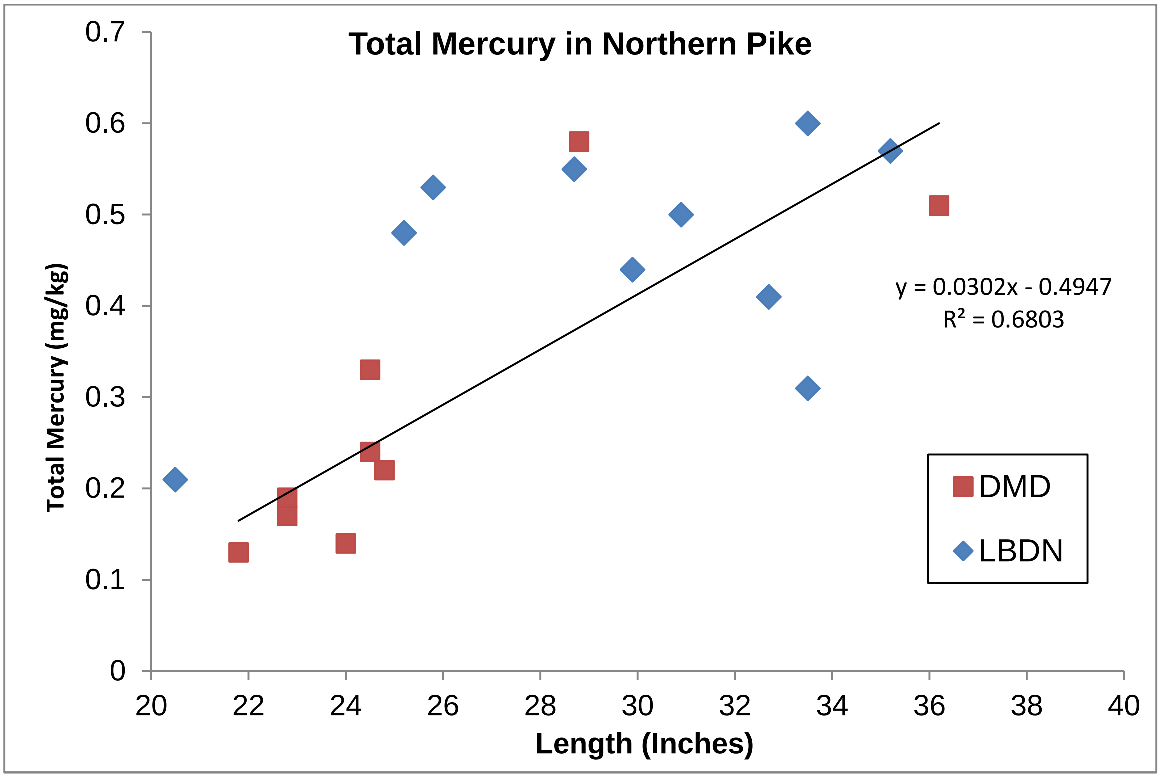

Figure 12. Length versus total mercury concentration in northern pike collected from the Menominee River downstream of the Menominee Dam (DMD) and Little Bay De Noc (LBDN).

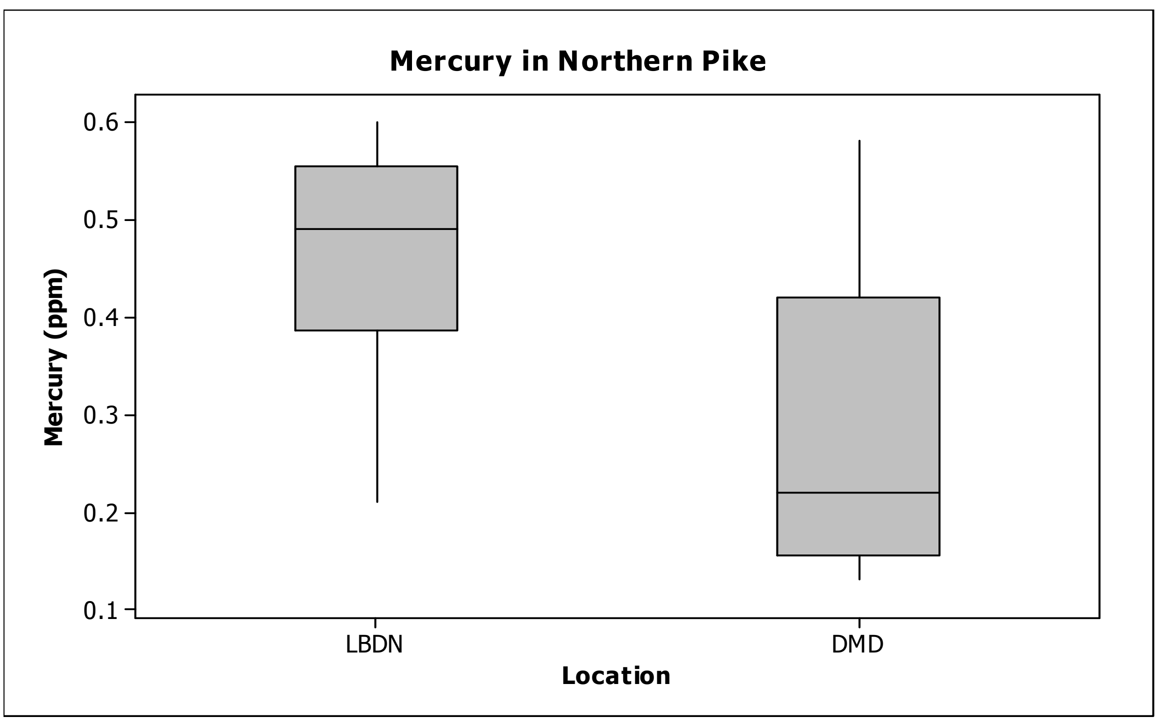

Figure 13. Boxplots of total mercury concentrations in fillets of northern pike from Little Bay De Noc (LBDN) and the Menominee River downstream of the Menominee Dam (DMD).

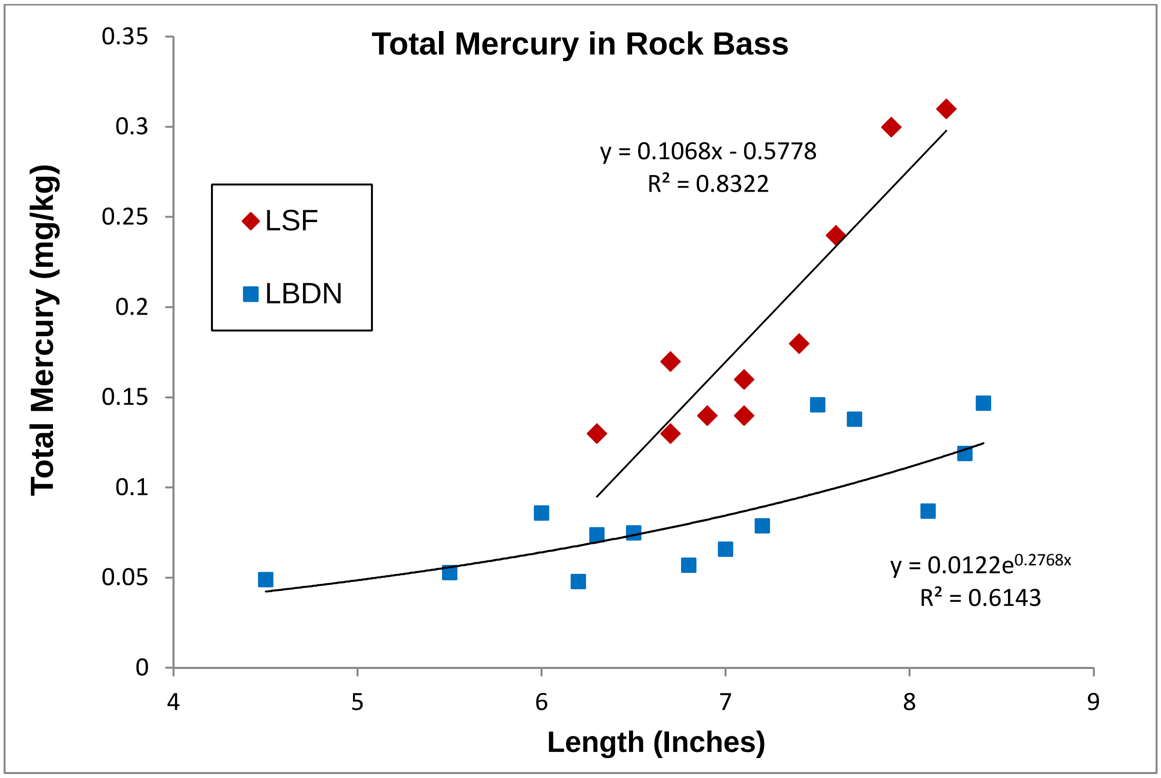

Figure 14. Length versus total mercury concentration in rock bass collected from the Lower Scott Flowage (LSF) and Little Bay De Noc (LBDN).

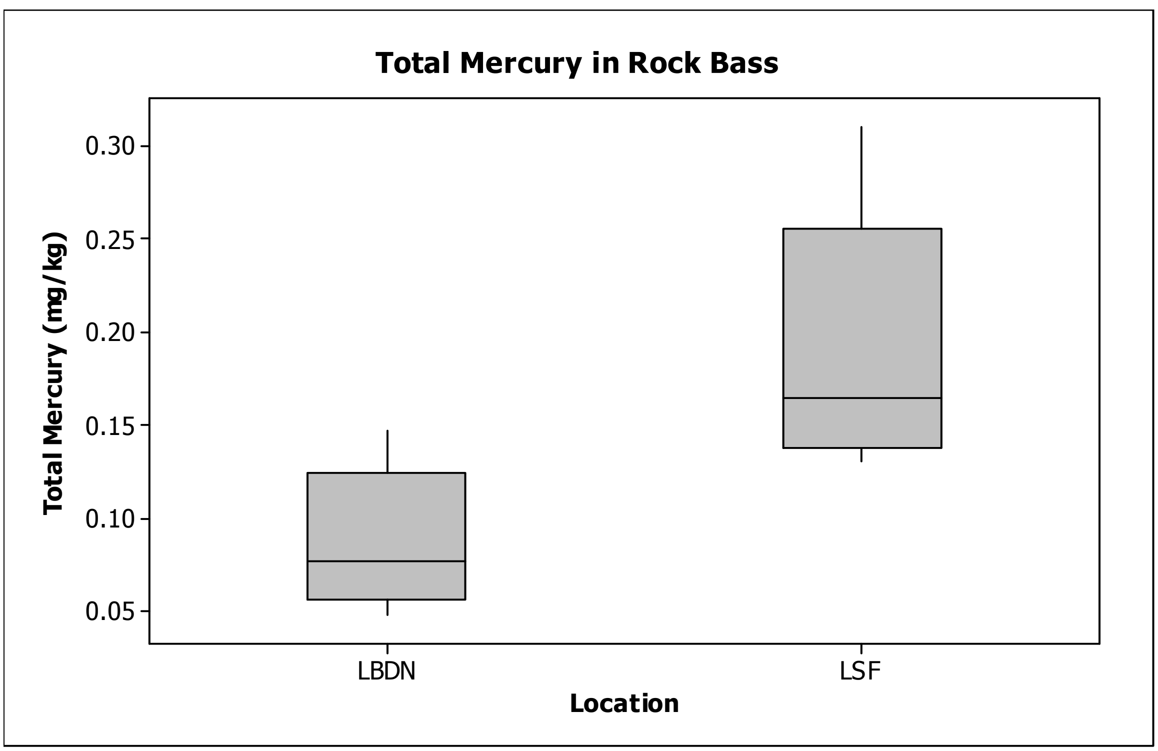

Figure 15. Boxplots of total mercury concentrations in fillets of rock bass from Little Bay De Noc (LBDN) and the Lower Scott Flowage (LSF).

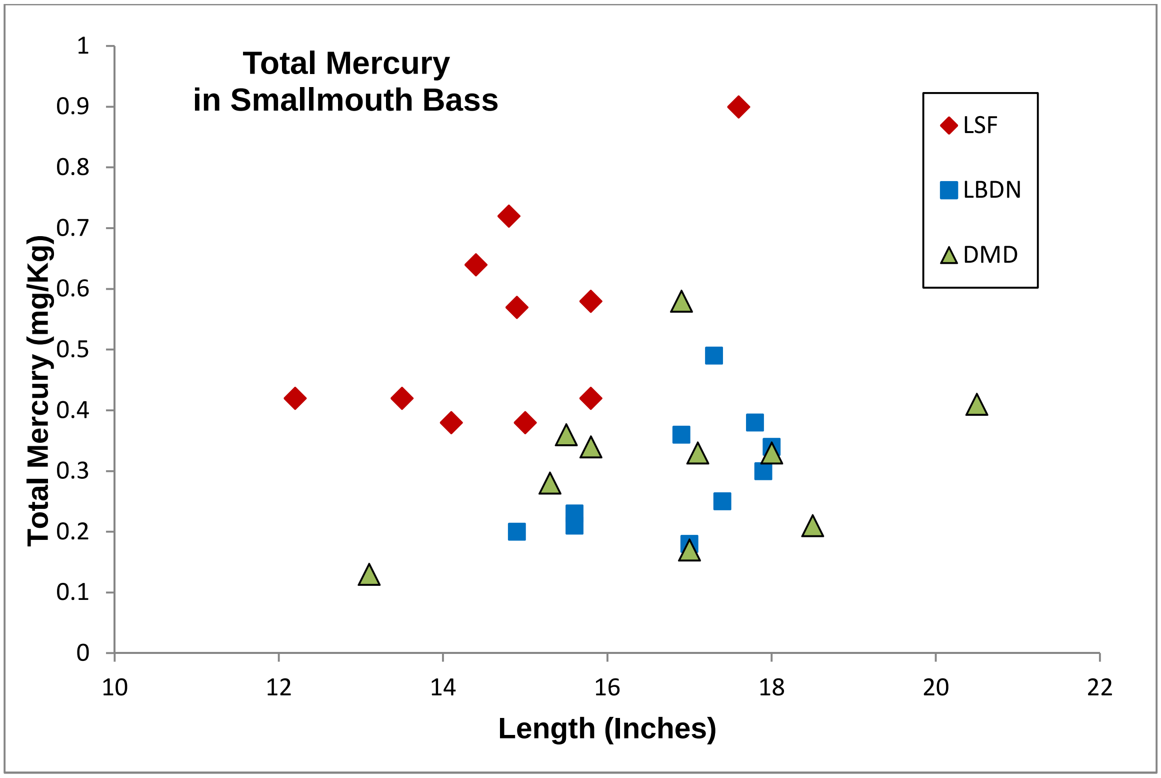

Figure 16. Length versus total mercury concentration in smallmouth bass collected from Lower Scott Flowage (LSF), Menominee River downstream of the Menominee Dam (DMD), and Little Bay De Noc (LBDN).

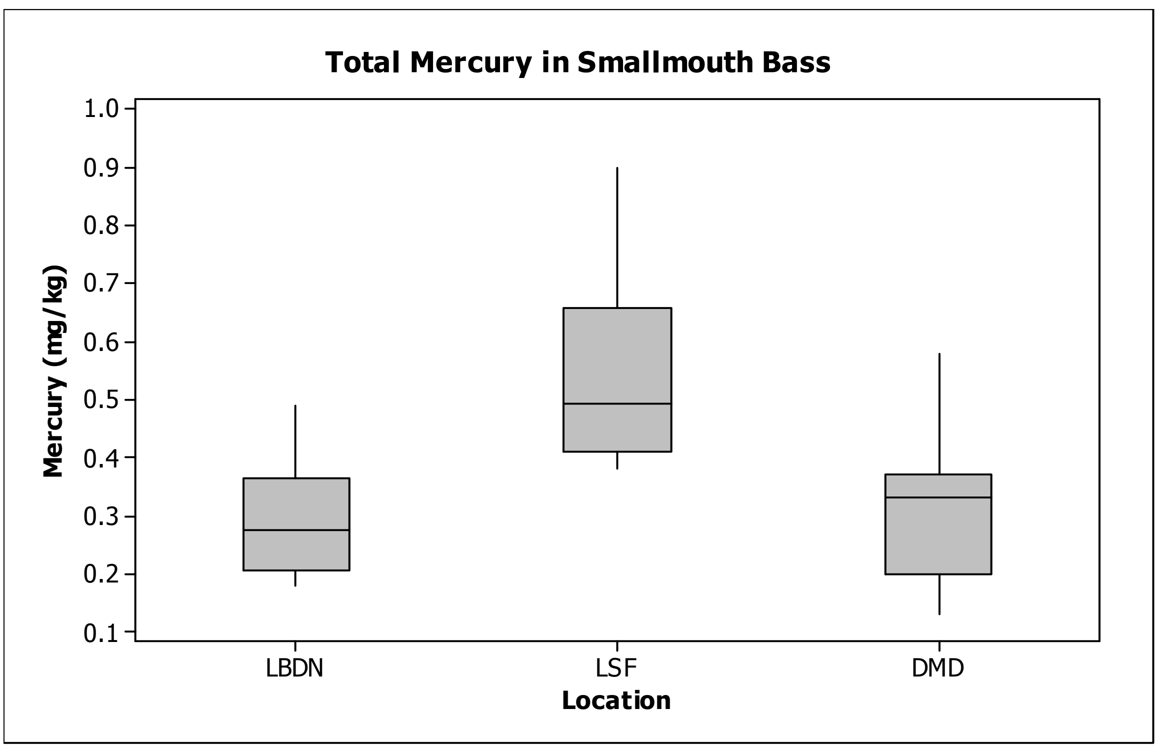

Figure 17. Boxplots of total mercury concentrations in fillets of smallmouth bass from Little Bay De Noc (LBDN), Lower Scott Flowage (LSF), and the Menominee River downstream of the Menominee Dam (DMD).

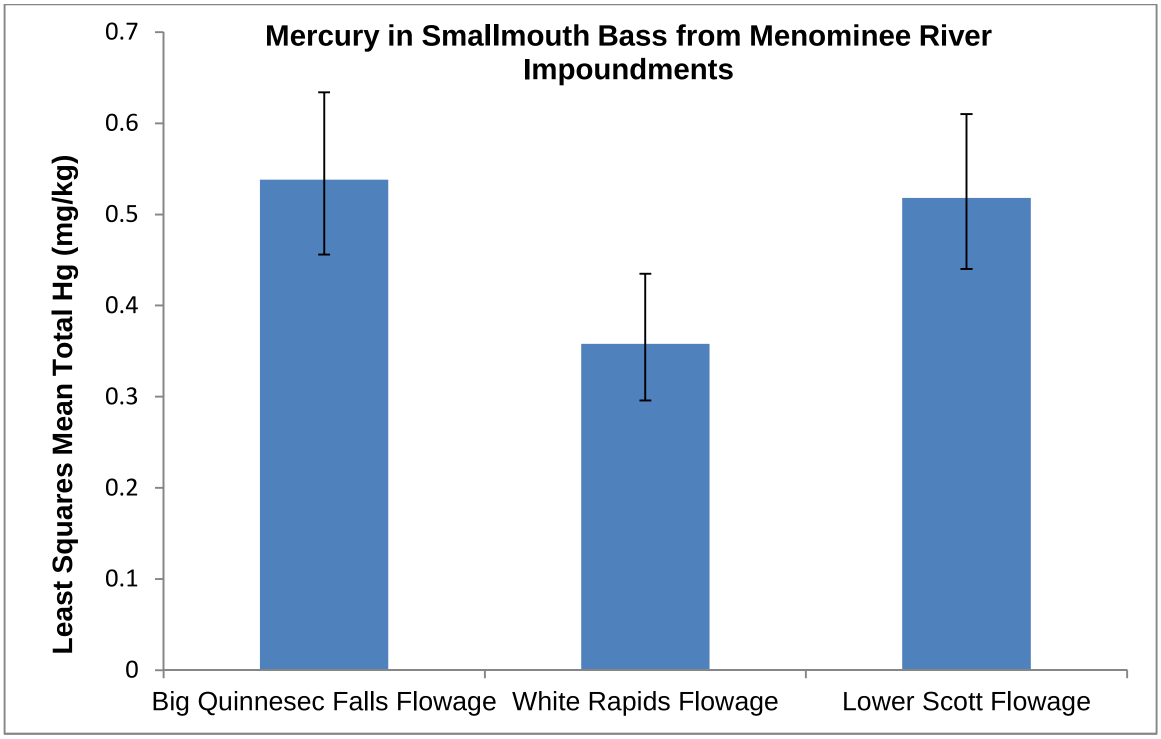

Figure 18. Least squares mean total mercury concentrations in smallmouth bass collected from three impoundments of the Menominee River in 2013 and 2014.

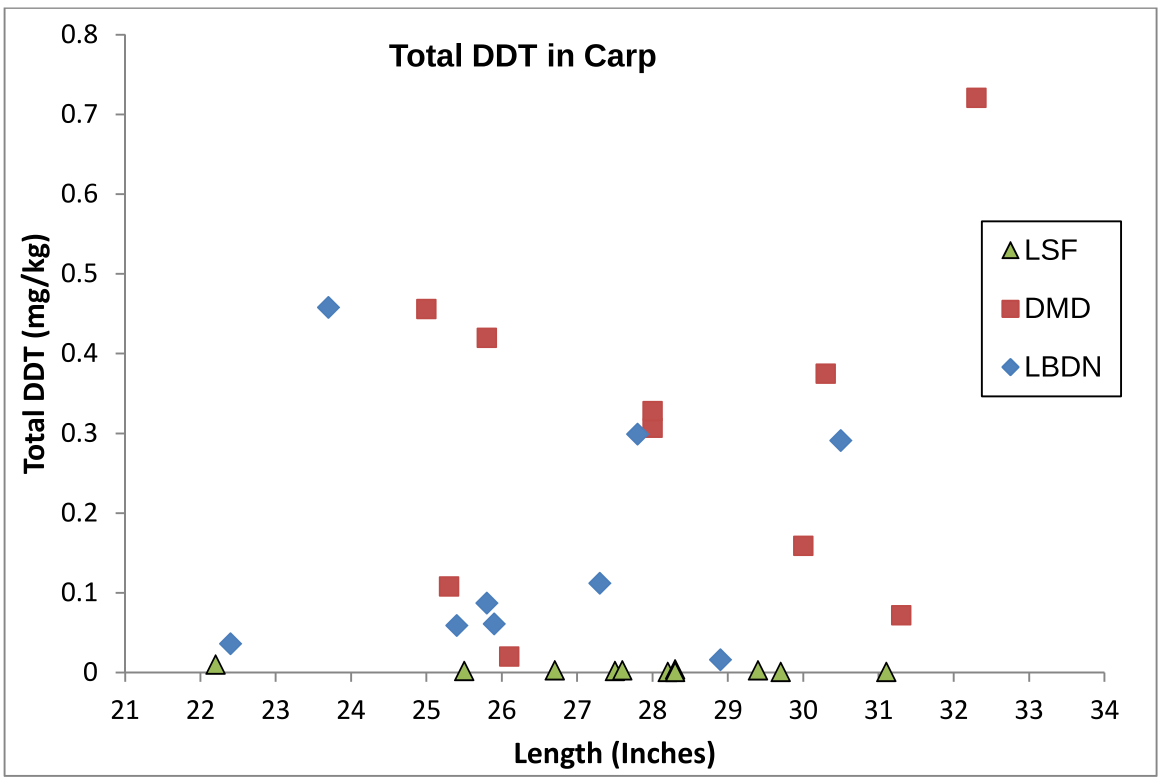

Figure 19. Length versus total DDT concentration in carp collected from Lower Scott Flowage (LSF), Menominee River downstream of the Menominee Dam (DMD), and Little Bay De Noc (LBDN).

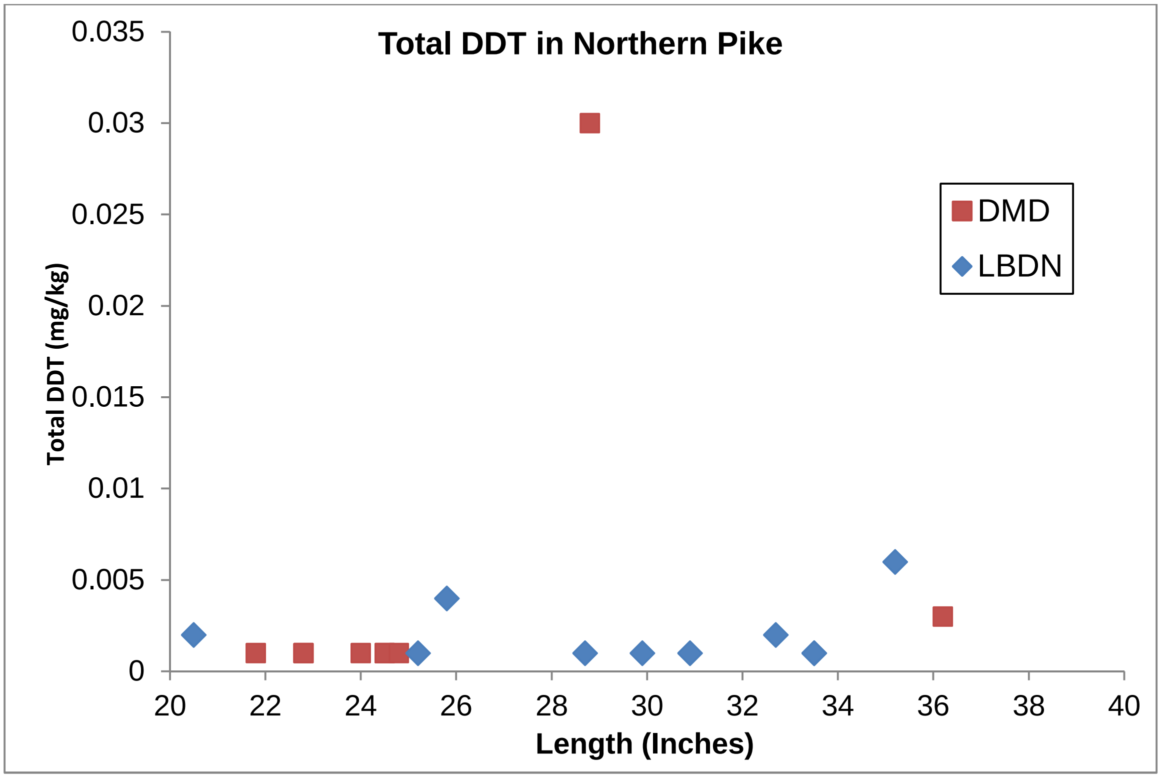

Figure 20. Length versus total DDT concentration in carp collected from Lower Scott Flowage (LSF), Menominee River downstream of the Menominee Dam (DMD), and Little Bay De Noc (LBDN).

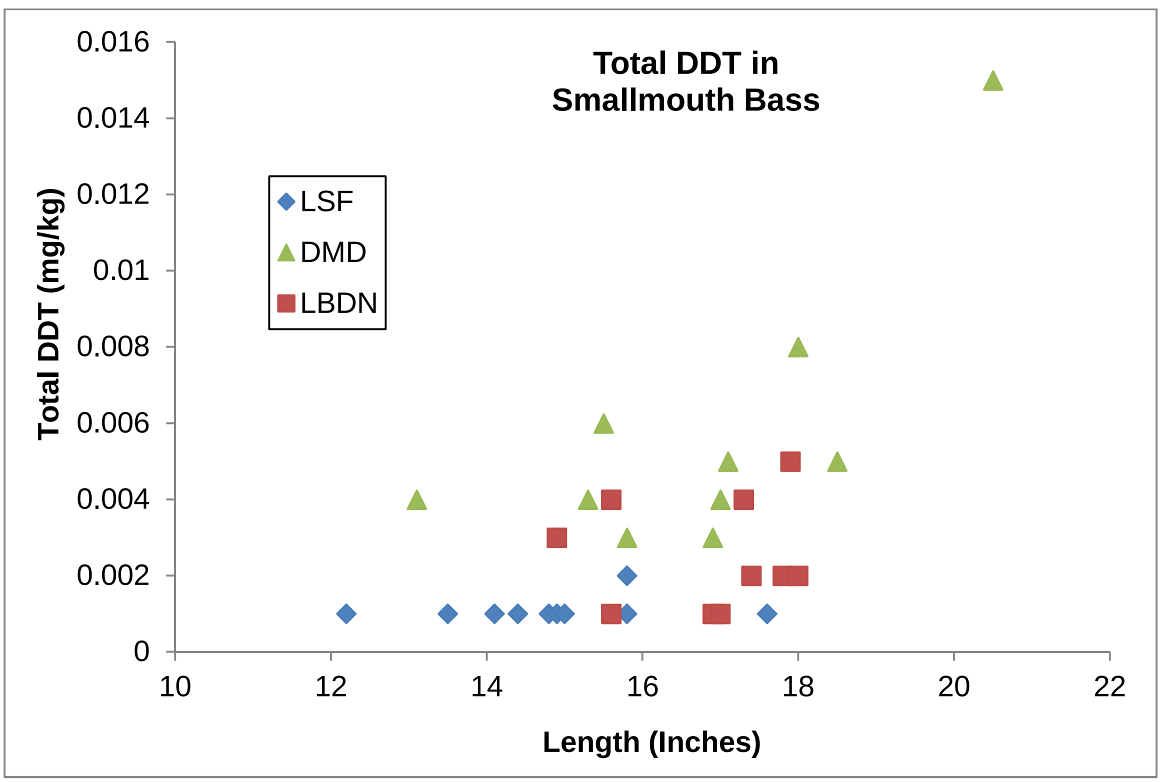

Figure 21. Length versus total DDT concentration in smallmouth bass collected from Lower Scott Flowage (LSF), Menominee River downstream of the Menominee Dam (DMD), and Little Bay De Noc (LBDN).

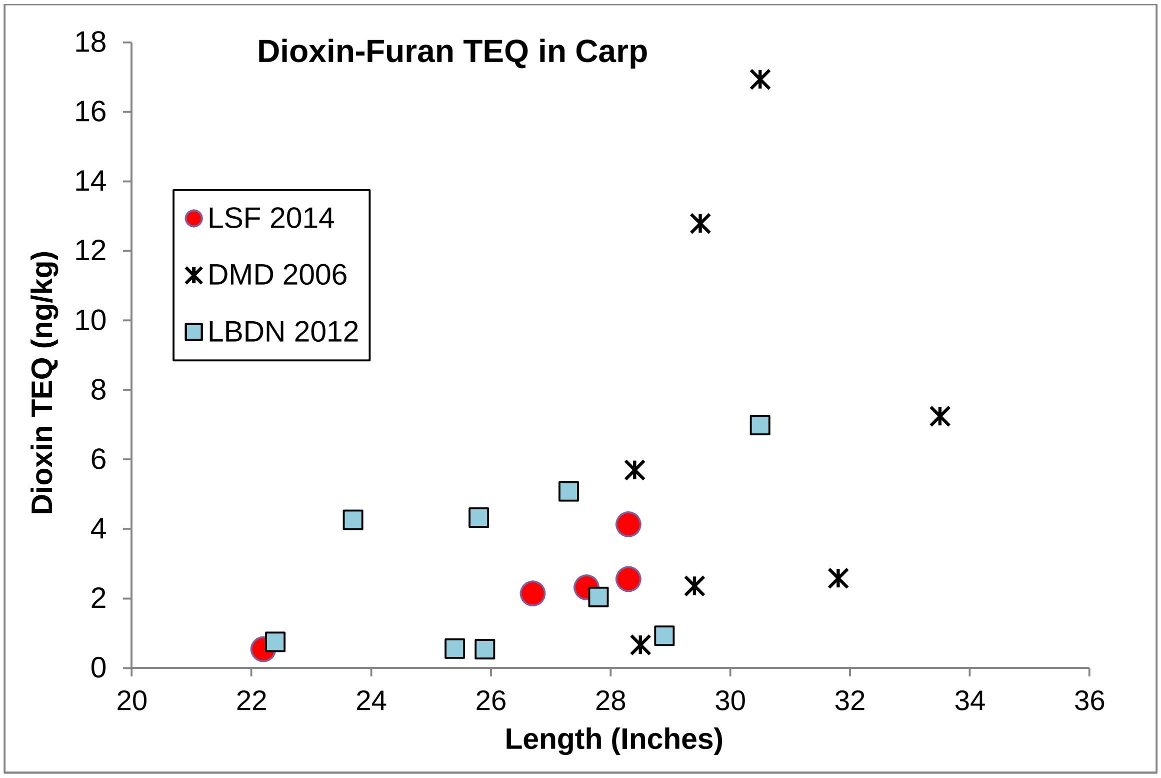

Figure 22. Length versus dioxin TEQ concentration in carp collected from Lower Scott Flowage in 2014 (LSF 2014), Menominee River downstream of the Menominee Dam in 2006 (DMD 2006), and the Little Bay De Noc in 2012 (LBDN 2012).

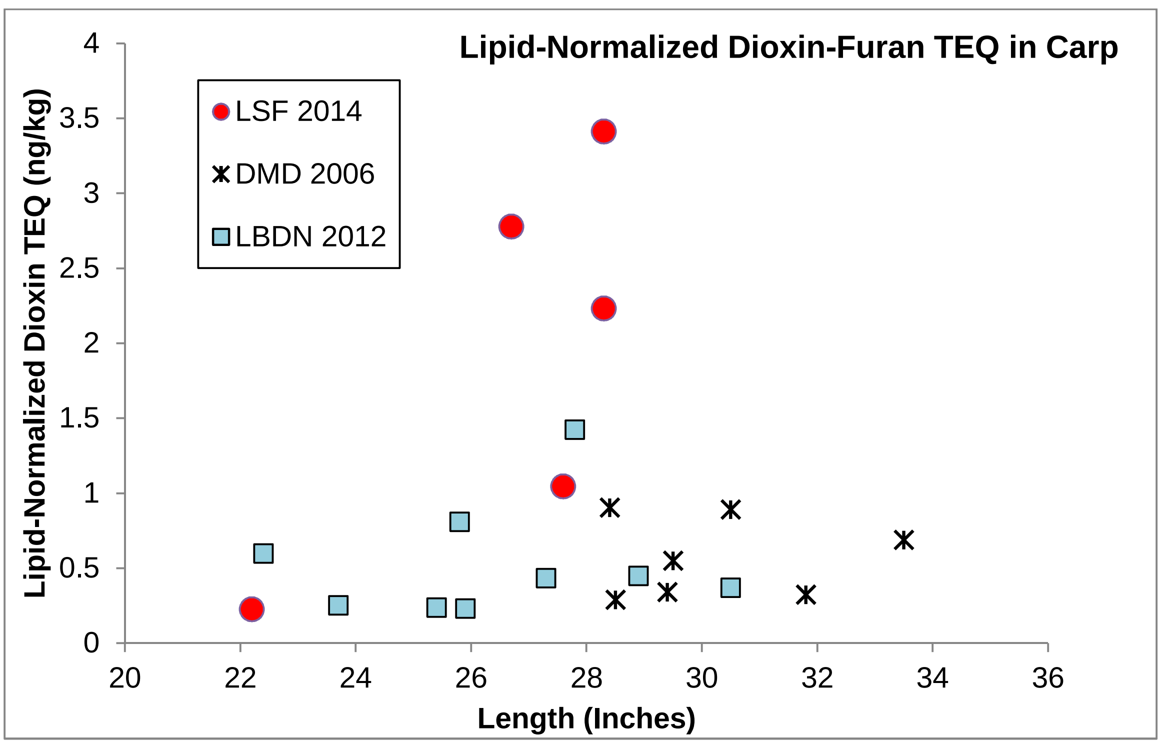

Figure 23. Length versus lipid-normalized dioxin TEQ concentration in carp collected from Lower Scott Flowage in 2014 (LSF 2014), Menominee River downstream of the Menominee Dam in 2006 (DMD 2006), and the Little Bay De Noc in 2012 (LBDN 2012).

Appendix A1.

Summary statistics for lengths of fish samples collected from the Lower Scott Flowage (LSF), Menominee River downstream of the Menominee Dam (DMD), Little Bay De Noc (LBDN), and Chalk Hill Flowage (CHF).

Species	Length (Inches)						
	Site	Median	Mean	St Dev	Min	Max	N
Carp	LSF	28.2	27.7	2.4	22.2	31.1	11
	DMD	28.0	28.2	2.6	25.0	32.3	10
	LBDN	25.9	26.4	2.5	22.4	30.5	9
Northern Pike	DMD	24.5	25.6	4.4	21.8	36.2	9
	LBDN	30.4	29.6	4.6	20.5	35.2	10
Redhorse Sucker	LSF	20.5	20.2	0.6	19.4	20.9	5
	LBDN	22.9	22.7	1.8	20.2	25.4	10
	CHF	21.3	19.9	3.6	12.4	23.0	10
Rock Bass	LSF	7.1	7.2	0.6	6.3	8.2	10
	LBDN	6.9	6.8	1.1	4.5	8.4	14
Smallmouth Bass	LSF	14.9	14.8	1.5	12.2	17.6	10
	DMD	17.0	16.8	2.0	13.1	20.5	10
	LBDN	17.2	16.8	1.1	14.9	18.0	10

Appendix A2.

Summary statistics for total PCB concentrations fish samples collected from the Lower Scott Flowage (LSF), Menominee River downstream of the Menominee Dam (DMD), Little Bay De Noc (LBDN), and Chalk Hill Flowage (CHF).

Species	Total PCB Concentration (mg/kg)						
	Site	Median	Mean	St Dev	Min	Max	N
Carp	LSF	0.04	0.06	0.09	0.003	0.33	11
	DMD	1.83	1.84	1.42	0.24	5.35	10
	LBDN	0.67	1.08	1.27	0.06	4.10	9
Northern Pike	DMD	0.02	0.04	0.08	0.003	0.25	9
	LBDN	0.002	0.004	0.005	0.001	0.015	10
Redhorse Sucker	LSF	0.006	0.009	0.006	0.004	0.02	5
	LBDN	0.03	0.05	0.04	0.006	0.13	10
	CHF	0.002	0.008	0.01	0.001	0.03	10
Rock Bass	LSF	0.002	0.003	0.005	0.001	0.31	10
	LBDN	0.001	0.002	0.002	0.001	0.15	14
Smallmouth Bass	LSF	0.002	0.02	0.06	0.001	0.19	10
	DMD	0.054	0.06	0.03	0.038	0.12	10
	LBDN	0.008	0.01	0.01	0.004	0.03	10

Appendix A3.

Summary statistics for total mercury concentrations fish samples collected from the Lower Scott Flowage (LSF), Menominee River downstream of the Menominee Dam (DMD), Little Bay De Noc (LBDN), and Chalk Hill Flowage (CHF).

Species	Total Mercury Concentration (mg/kg)						
	Site	Median	Mean	St Dev	Min	Max	N
Carp	LSF	0.44	0.48	0.14	0.34	0.78	11
	DMD	0.20	0.22	0.05	0.15	0.29	10
	LBDN	0.29	0.32	0.08	0.20	0.46	9
Northern Pike	DMD	0.22	0.28	0.16	0.13	0.58	9
	LBDN	0.49	0.46	0.12	0.21	0.60	10
Redhorse Sucker	LSF	0.81	0.77	0.33	0.27	1.10	5
	LBDN	0.28	0.37	0.27	0.09	0.85	10
	CHF	0.82	0.71	0.32	0.11	1.10	10
Rock Bass	LSF	0.16	0.19	0.07	0.13	0.31	10
	LBDN	0.08	0.09	0.04	0.05	0.15	14
Smallmouth Bass	LSF	0.50	0.54	0.17	0.38	0.90	10
	DMD	0.33	0.31	0.13	0.13	0.58	10
	LBDN	0.28	0.29	0.10	0.18	0.49	10

Appendix A4.

Summary statistics for total DDT concentrations fish samples collected from the Lower Scott Flowage (LSF), Menominee River downstream of the Menominee Dam (DMD), Little Bay De Noc (LBDN), and Chalk Hill Flowage (CHF).

Species	Total DDT Concentration (mg/kg)						
	Site	Median	Mean	St Dev	Min	Max	N
Carp	LSF	0.002	0.003	0.003	0.001	0.010	11
	DMD	0.318	0.297	0.213	0.020	0.721	10
	LBDN	0.087	0.158	0.154	0.016	0.458	9
Northern Pike	DMD	0.001	0.004	0.010	0.001	0.030	9
	LBDN	0.001	0.002	0.002	0.001	0.006	10
Redhorse Sucker	LSF	0.001	0.001	0.000	0.001	0.001	5
	LBDN	0.010	0.016	0.015	0.002	0.050	10
	CHF	0.001	0.001	0.000	0.001	0.001	10
Rock Bass	LSF	0.001	0.001	0.000	0.001	0.001	10
	LBDN	0.001	0.001	0.000	0.001	0.002	14
Smallmouth Bass	LSF	0.001	0.001	0.000	0.001	0.002	10
	DMD	0.005	0.006	0.004	0.003	0.015	10
	LBDN	0.002	0.003	0.001	0.001	0.005	10

Appendix B. Michigan Department of Health and Human Services Fish Consumption Screening Values for DDT plus metabolites, dioxin-like chemicals, mercury, PCBs, PFOS, selenium, and toxaphene.

Meal Category	**DDT, DDE, DDD**	**Dioxins/Furans & co-planar PCBs**	**Mercury**	**PCBs**
meals per month	*μg/g (ppm)*	*pg TEQ/g (ppt-TEQ)*	*μg/g (ppm)*	*μg/g (ppm)*
16	≤ 0.11	≤ 0.5	≤ 0.07	≤ 0.01
12	>0.11 to 0.15	>0.5 to 0.6	>0.07 to 0.09	>0.01 to 0.02
8	>0.15 to 0.23	>0.6 to 0.9	>0.09 to 0.13	>0.02 to 0.03
4	>0.23 to 0.45	>0.9 to 1.9	>0.13 to 0.27	>0.03 to 0.05
2	>0.45 to 0.91	>1.9 to 3.7	>0.27 to 0.53	>0.05 to 0.11
1	>0.91 to 1.8	>3.7 to 7.5	>0.53 to 1.1	>0.11 to 0.21
6 meals per year	>1.8 to 3.7	>7.5 to 15	>1.1 to 2.2	>0.21 to 0.43
Limited	>3.7 to 20	>15 to 90	NA	>0.43 to 2.7
Do Not Eat	>20	>90	>2.2	>2.7

Meal Category	**PFOS (provisional)**	**Selenium**	**Total "Apparent" Toxaphene**	**Toxaphene Parlars 26, 50, 62 (Σ3PC26,50,62)**
meals per month	*μg/g (ppm)*	*μg/g (ppm)*	*μg/g (ppm)*	*μg/g (ppm)*
16	≤ 0.009	≤ 2.3	≤ 0.02	≤ 0.001
12	>0.009 to 0.013	>2.3 to 3.1	>0.02 to 0.03	>0.001 to 0.002
8	>0.013 to 0.019	>3.1 to 4.6	>0.03 to 0.05	>0.002 to 0.003
4	>0.019 to 0.038	>4.6 to 9.2	>0.05 to 0.09	>0.003 to 0.006
2	>0.038 to 0.075	>9.2 to 17	>0.09 to 0.18	>0.006 to 0.011
1	>0.075 to 0.15	NA	>0.18 to 0.36	>0.011 to 0.023
6 meals per year	>0.15 to 0.3	NA	>0.36 to 0.73	>0.023 to 0.046
Limited	NA	NA	>0.73 to 4.5	>0.046 to 0.28
Do Not Eat	>0.3	>17	>4.5	>0.28