



Mercury-Based Consumption Advice for Wisconsin Ceded Territory Muskellunge

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Introduction

For several years, GLIFWC has been collecting and analyzing data to develop mercury-based fish consumption advice for maashkinoozhe or muskellunge (*Esox masquinongy*). A memo was produced in 2016 on this topic. The following is an update of that memo to include the most up to date data collected by GLIFWC and the states of Minnesota, Wisconsin, and Michigan and to describe the development of muskellunge mercury maps to be incorporated into outreach materials that will communicate safe consumption advice to community members of GLIFWC's member tribes. The vast majority of available information is within the 1837 and 1842 Treaty Ceded Territories of Wisconsin. Thus, this region is the focus of this report.

Muskellunge are harvested by GLIFWC member tribes within the Ceded Territories. It is the second most harvested fish species, after walleye. Between 1985 and 2018, tribal members harvested 7,997 muskellunge during the spring spearing season in Wisconsin, with annual totals ranging from 55 to 343 fish throughout this time period (Hmielewski, 2019).

Muskellunge are the largest harvested fish in inland waters within the treaty Ceded Territories. They can become very large, with the Wisconsin state record weighing in at just under 70 pounds and 64 inches (61 kilograms and 161 centimeters) from the Chippewa Flowage in Sawyer County (1949). These fish may live to the age of 20 years or more. They are highly piscivorous, residing at the top of the aquatic food web. As a result of their trophic status, longevity, and size, muskellunge have an increased potential to bioaccumulate environmental contaminants, including mercury.

There is a scarcity of published literature documenting mercury levels in muskellunge. A search of peer reviewed literature identified only three studies that included such information. Flaherty *et al.* (2003), in an assessment of mercury exposure through fish consumption by Wisconsin ice anglers, cited a mean muskellunge mercury concentration of 0.28µg/g. The mercury data were supplied by the Wisconsin Department of Natural Resources, but there is no information regarding the number of samples, tissue type, fish size, harvest location, or other summary statistics (e.g. range or standard error of mercury concentrations). Kamman *et al.* (2003) reported a mean muskellunge mercury concentration of 0.98µg/g for fish averaging 79.4cm (31.3 inches). This value represented the mean of 18 fillets (skin on versus off not specified) and was the highest level reported for the 13 freshwater species included in the study. The mercury data were provided by various state and provincial governments in northeastern North America, encompassing a region that extended east to, but did not include, the Great Lakes Region. Finally, Rypel (2010) compiled mercury data for fish in 32 Wisconsin lakes from the U.S. EPA national mercury database (<http://www.epa.gov/waterscience/fish/mercurydata.html>). The mean muskellunge mercury concentration was 0.845µg/g (range: 0.041-2.200µg/g), which encompassed data from 32 lakes and represented fish with a mean length of 85.4cm (33.6 inches).

Muskellunge Records Available in the Mercury Databases

GLIFWC and its member tribes have been interested in expanding the GLIFWC mercury database to include additional muskellunge records due to this species' potential for accumulating significant concentrations of mercury, its importance to the tribes for subsistence, and the scarcity of existing muskellunge mercury data both within the existing database and within the published scientific literature. Efforts by GLIFWC's Inland Fisheries staff to increase muskellunge sampling for GLIFWC's Mercury Program have resulted in the collection and mercury testing by GLIFWC of 226 additional muskellunge between 2011 and 2019. Skin-off fillets were tested for total mercury by the Lake Superior Research Institute (LSRI) at the University of Wisconsin – Superior. In total, GLIFWC has generated 320 of the 552 (58%) available muskellunge mercury records available within the Ceded Territories. The remainder were collected by state (MI, MN, WI) agencies, with the exception of four muskellunge collected by the Lac du Flambeau Band of Lake Superior Chippewa. These are a combination of both skin-on and skin-off fillets. The vast majority of available Ceded Territory mercury records, 525 of 552 (95%), are from the Wisconsin Ceded Territory (Table 1).

Table 1. Number of records available in the fish mercury databases for muskellunge collected within the Ceded Territories of Michigan, Minnesota, and Wisconsin

	Total number of muskellunge mercury records	Number of Records Generated by GLIFWC	Number of lakes with muskellunge mercury records	Number of lakes with sample size of n≥4*
All Ceded Territories	552	320	126	47
MI Ceded Territories	5	0	2	0
MN Ceded Territories	22	0	4	2
WI Ceded Territories	525	320	120	45

* This is the minimum sample size required to develop lake-specific consumption advice according to GLIFWC's methodology (Madsen *et al.*, 2008).

Selecting a Normalization Length for Determining Fish Consumption Advice

Because mercury concentration increases with increasing fish length, mercury concentrations of muskellunge must be normalized to a fish of a pre-selected length in order to determine a single safe consumption rate. A number of factors were taken into account when selecting the length at which muskellunge fish consumption advice would be generated, including: size of fish with available mercury data, size of fish harvested by GLIFWC member tribes during the spring spearing season, percent of harvest that advice is protective of at a given length, state and tribal size limits for harvest, and reference lengths for existing state consumption advisories.

The mean length of all 552 muskellunge records in the mercury database is 36.0 inches (91.4 cm) and median length is 36.3 inches (92.2 cm). Lengths range from 14.1 to 54.0 inches (35.8 to 137.1 cm) (Figure 1).

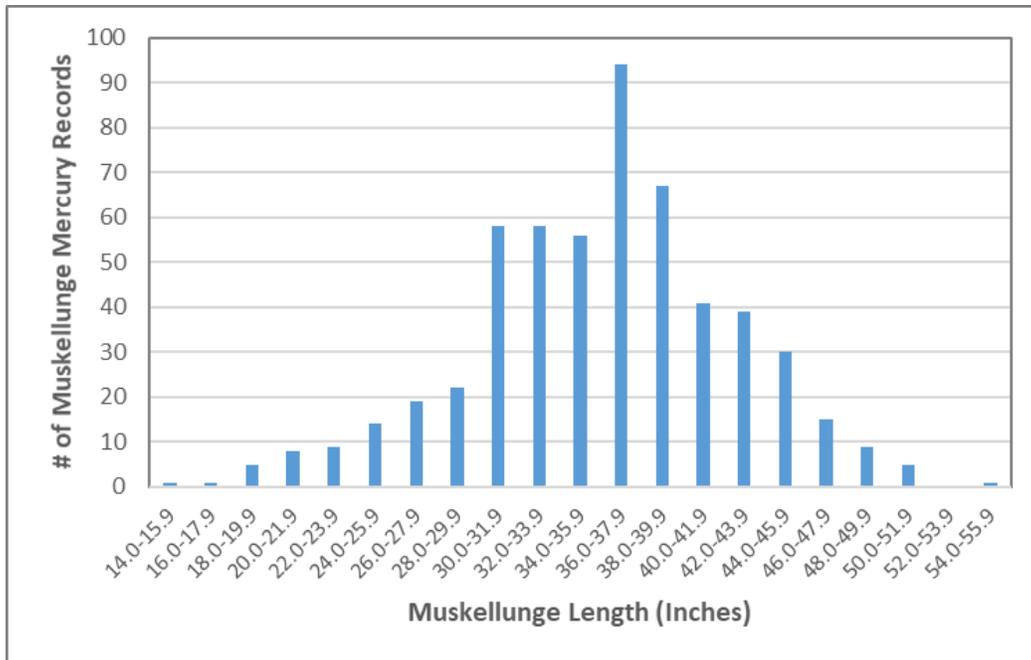


Figure 1. Size distribution of muskellunge in the mercury databases

Fish length has been recorded for 7,947 of the 7,997 (99.3%) muskellunge speared by GLIFWC member tribes between 1985 and 2018 in Wisconsin during the spring spearing and netting season. The mean length was 38.0 inches (96.5 cm) for this entire time period, with a range of 13 to 57 inches (33 to 145 cm) (Hmielewski, 2019). Annual averages have been similar, ranging from 35.4 to 39.9 inches (89.9 to 101.3 cm). The length-frequency distribution for muskellunge harvested by GLIFWC member tribes during spring 2018, the most current year available, as well as for the entire period from 1985-2018 is very similar to the size distribution of the muskellunge in the mercury database (Figure 2).

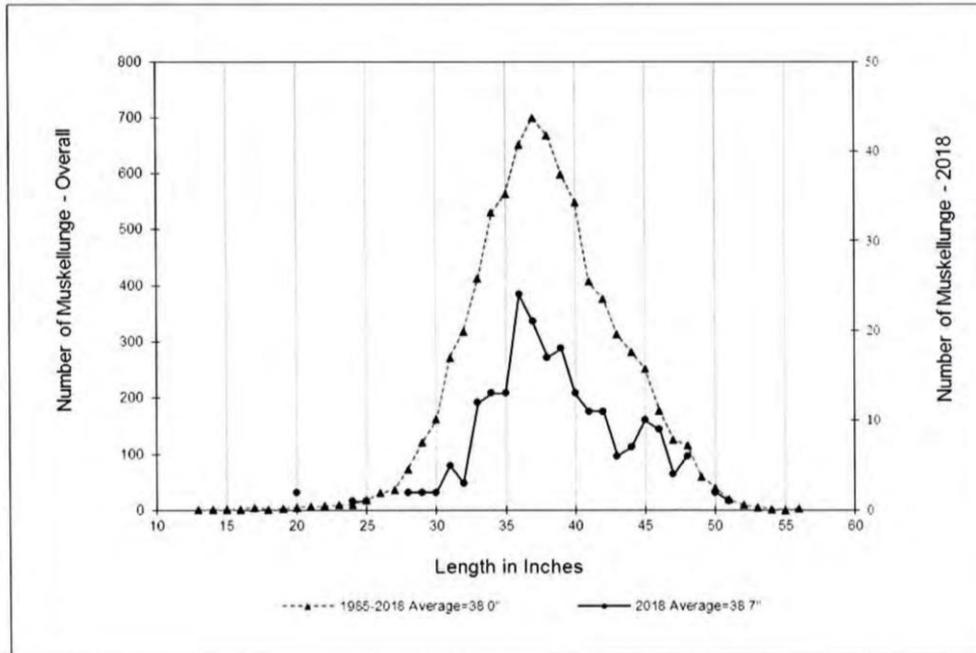


Figure 2. Length-frequency of muskellunge speared by GLIFWC member tribes in Wisconsin during spring 2018 and during the 34-year period from 1985-2018 (Hmielewski, 2019)

When developing fish consumption advice for walleye, a reference length of 20 inches (51 cm) is used. For the 34-year period from 1985-2018, 94.0% of walleye harvested during the spring spearing and netting season in Wisconsin were under 20 inches (51 cm). Therefore, the fish consumption advice for walleye communicated by GLIFWC’s Mercury Maps is protective for 94.0% of the fish typically harvested. In order to meet a similarly protective percentage for muskellunge, length frequencies for the same time period were analyzed. Of the muskellunge harvested by the tribes during each spring season from 1985-2018, 92.6% were under 46 inches (117 cm).

According to the GLIFWC Wisconsin Model Code, under a tribal spearing permit the first muskellunge may be of any size, thereafter at least ½ of the catch must be at least 32 inches (81 cm). The Wisconsin Department of Natural Resources (WDNR) currently manages muskellunge as a trophy fish by establishing high minimum length requirements and low daily bag limits for fishers, promoting the increased presence of larger individuals within the population. The minimum legal size for Wisconsin state anglers is 40 inches (102 cm). The state angler minimum legal sizes in Michigan and Minnesota are 42 and 54 inches (107 and 137 cm), respectively. None of these three states indicate a reference size for their consumption advice of muskellunge, likely because all fish harvested must be very large (40 to 54 inches or 102 to 137 cm, depending on the state), so the size range of fish consumed by state anglers is small.

Considering all of the information above, it was decided to explore the safe fish consumption advice for muskellunge at two reference lengths. The following lengths were chosen:

- 38 inches (97 cm): This length is representative of the average muskellunge harvested by GLIFWC member tribes over a 34-year period (1985-2018). Since 38 inches (97 cm) is the approximate median length of muskellunge harvested, the advice generated at this normalization length would be protective of ~50% of tribally harvested muskellunge.
- 46 inches (117 cm): Advice developed for this length muskellunge is protective for 93% of the muskellunge harvested by GLIFWC member tribes. Thus, it is similarly protective as the walleye consumption advice displayed on GLIFWC's Mercury Maps.

Selecting a Geographic Unit for Developing Fish Consumption Advice

GLIFWC's Mercury Maps, which communicate walleye fish consumption advice, are lake-specific, meaning each of approximately 500 lakes is analyzed individually and appropriate safe fish consumption generated for each lake. The mercury data for muskellunge are much more limited than that available for walleye. Of the 126 lakes within the Ceded Territories that have muskellunge mercury data available, 47 (37%) have a sufficient number of samples ($n \geq 4$) to generate lake specific advice. This represents a small percentage of the lakes available for muskellunge harvest to the tribes. For example, in 2018 tribal muskellunge quotas were established for 307 lakes in Wisconsin, and muskellunge were harvested from 71 (23%) of those lakes. But, the lakes for which sufficient data are available to develop lake-specific consumption advice disproportionately represent the lakes where harvest most often takes place. Although muskellunge quotas were established for 307 Wisconsin lakes in 2018, 57% of the muskellunge harvested were taken from the 47 Wisconsin lakes for which lake-specific muskellunge consumption advice was developed here.

Lake specific advice was generated when sufficient data were available. In addition, due to the large number of potential harvest lakes with insufficient data for generating lake-specific advice, general Ceded Territory-wide advice was generated by combining all available muskellunge mercury data.

Generation of Fish Consumption Advice for Muskellunge

Mercury concentrations of muskellunge (skin-on and skin-off fillets) in the database ranged from 0.067 to 3.06 $\mu\text{g/g}$ (ppm), with an average of 0.72 $\mu\text{g/g}$ and a median of 0.59 $\mu\text{g/g}$. Mercury concentration generally increased with increasing fish length (Figure 3).

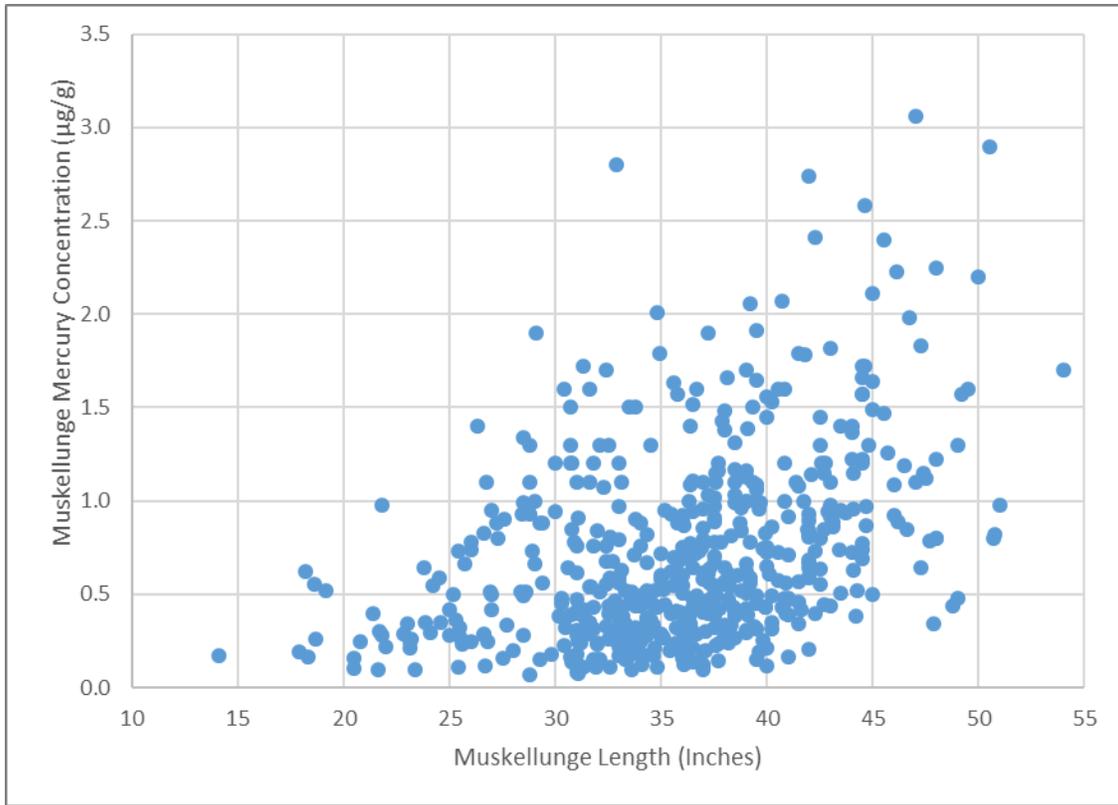


Figure 3. Muskellunge length versus mercury concentration for all samples in the mercury databases (MI, MN, and WI; n=552)

An analysis similar to that used to assign color codes to inland lakes for the walleye Mercury Maps was performed for muskellunge (Table 2). The one major modification was that fish mercury was normalized to a 38-inch (97 cm) and a 46-inch (117 cm) muskellunge, rather than the 20-inch (51 cm) length typically applied to walleye. Details of the methods used to develop the walleye consumption advice and Mercury Maps can be found in GLIFWC Administrative Report 18-10 (Moses, 2018).

Table 2. Consumption recommendations for muskellunge up to 38 and 46 inches (97 and 117 cm) for the sensitive¹ and general² populations

State	County	Lake	Safe Number of Meals per Month: 38" Musky		Safe Number of Meals per Month: 46" Musky	
			General Population	Sensitive Population	General Population	Sensitive Population
ALL	ALL	ALL	2	0	2	0
MN	Cook	Crescent L	4	1	2	1
MN	Lake	Dumbbell L	2	0	1	0
WI	Ashland	English L	1	0	1	0
WI	Ashland	Moquah L	1	0	0	0
WI	Ashland	Potter L	1	0	1	0
WI	Ashland	Spider L	1	0	0	0
WI	Ashland	Spillerberg L	1	0	1	0
WI	Bayfield	Namekagon L	2	0	1	0
WI	Burnett	McKenzie L	4	1	2	0
WI	Oneida	Booth L	4	1	1	0
WI	Oneida	Buckskin L	2	0	2	0
WI	Oneida	Clear L	1	0	1	0
WI	Oneida	Minocqua L	2	1	2	0
WI	Oneida	Pelican L	2	0	1	0
WI	Oneida	Squirrel L	4	1	2	0
WI	Oneida	Tomahawk L	4	1	2	1
WI	Polk	Bone L	4	2	4	1
WI	Polk	Deer L	2	0	2	0
WI	Sawyer	Callahan L	2	0	2	0
WI	Sawyer	Grindstone L	2	1	2	0
WI	Sawyer	L Chippewa	4	1	2	1
WI	Sawyer	L Winter	2	0	1	0
WI	Sawyer	Lac Courte Oreilles	4	1	2	0
WI	Sawyer	Round L	4	1	2	0
WI	Sawyer	Sand L	2	0	1	0
WI	Sawyer	Sissabagama L	2	1	1	0
WI	Sawyer	Tiger Cat FL	2	0	1	0
WI	Vilas	Ballard L	1	0	1	0
WI	Vilas	Big Arbor Vitae L	8	2	4	1
WI	Vilas	Big L (Boulder JCT)	2	0	2	0
WI	Vilas	Big Muskellunge L	4	1	2	0
WI	Vilas	Big St Germain L	4	1	4	1
WI	Vilas	Brandy L	2	1	1	0
WI	Vilas	Clear L	2	0	1	0

Table 2 Continued....

Table 2 Continued....

State	County	Lake	Safe Number of Meals per Month: 38" Musky		Safe Number of Meals per Month: 46" Musky	
			General Population	Sensitive Population	General Population	Sensitive Population
WI	Vilas	Irving L	1	0	1	0
WI	Vilas	Johnson L	2	0	1	0
WI	Vilas	Kentuck L	2	1	2	0
WI	Vilas	Little Arbor Vitae L	8	2	4	2
WI	Vilas	Little John L	8	4	4	1
WI	Vilas	Little St Germain L	8	2	4	2
WI	Vilas	N Twin L	4	1	2	1
WI	Vilas	Plum L	2	0	2	0
WI	Vilas	Trout L	4	1	2	0
WI	Vilas	Upper Gresham L	2	0	1	0
WI	Vilas	White Sand L	2	0	2	0
WI	Vilas	Wildcat L	4	1	2	1
WI	Washburn	Shell L	2	0	1	0

¹ **Sensitive Population:** women of childbearing age and children under 15.

² **General Population:** women beyond child bearing age and men 15 and older.

Overall, the mercury-based consumption advice for muskellunge is more restrictive than for walleye, though in general the same overall trends are seen among the lakes (e.g., which lakes have fish with higher or lower mercury). This was expected because mercury biomagnifies within food webs and muskellunge occupy a higher trophic level than walleye. When all muskellunge mercury data from Ceded Territory inland waters are combined, the consumption advice for both a 38" and 46" (97 and 117 cm) muskellunge is 2 meals per month for the general population and "do not eat" for the sensitive population. But, this advice can be refined for the 47 lakes for which sufficient data are available to develop lake specific advice. An analysis of the number of lakes falling in to each of the five advice categories for the consumption of a 38" or 46" (97 or 117 cm) muskellunge by the general and sensitive populations shows that the most frequent advice categories are "do not eat" for the sensitive population and 2 meals/month for the general population (Table 3).

Table 3. Number of lakes (out of 47 lakes with consumption advice developed) per consumption advice category for 38” and 46” (97 and 117 cm) muskellunge

	38” Muskellunge		46” Muskellunge	
	General Population	Sensitive Population	General Population	Sensitive Population
8 meals/month	4 (9%)	0 (0%)	0 (0%)	0 (0%)
4 meals/month	14 (30%)	1 (2%)	6 (13%)	0 (0%)
2 meals/month	21 (45%)	4 (9%)	20 (43%)	2 (4%)
1 meal/month	8 (17%)	19 (40%)	19 (40%)	9 (19%)
Do not eat	0 (0%)	23 (49%)	2 (4%)	36 (77%)

Comparison with Existing State Fish Consumption Advisories for Muskellunge

The general statewide fish consumption guidelines for muskellunge are:

- Wisconsin: General Population – 1 meal per month. Sensitive Population – Do not eat.
- Minnesota: General Population – 4 meals per month. Sensitive Population – Do not eat.
- Michigan: General and Sensitive Populations – 1 meal per month.

None of the lakes for which lake-specific fish consumption advice was developed in this memo had lake-specific advice issued by the states for muskellunge that differed from the general statewide advice. The Ceded Territory-wide muskellunge consumption advice developed here (2 meals/month for the general population and “do not eat” for the sensitive population) falls within the range of advice issued by the states that range from 1-4 meals/month for the general population and 0-1 meals/month for the sensitive population. A small number of lakes for which lake-specific advice was generated in this report, resulted in less restrictive consumption advice than that issued by the states, allowing up to 8/meals per month for the general population and 2 or 4 meals/month for the sensitive population, depending on the size of the muskellunge. Further, our lake specific analysis demonstrates that there may be certain lakes for which advice that is more restrictive than the state may be warranted, with some lakes having advice of “do not eat”, even for the general population.

Development of a Muskellunge Mercury Map

The information presented in Table 2 was used to generate a series of muskellunge mercury maps similar to those GLIFWC issues for walleye. The maps provide lake-specific, color-coded, mercury based consumption advice for muskellunge. The geographical range of the maps was limited to the Wisconsin Ceded Territory since this represented >95% of the data available. The maps were split into an eastern and western region to provide a better display and easier identification of lakes and their advice categories. There are 4 maps for each region (for a total of 8 maps) depicting advice for the sensitive and general populations at each of the two reference

lengths (38 and 46 inches or 97 and 117 cm). The maps (Figures 4-11) will next be developed into outreach materials that can be shared with tribal members as part of GLIFWC’s Mercury Outreach Program. The maps were produced by GLIFWC Environmental Specialist, Esteban Chiriboga.

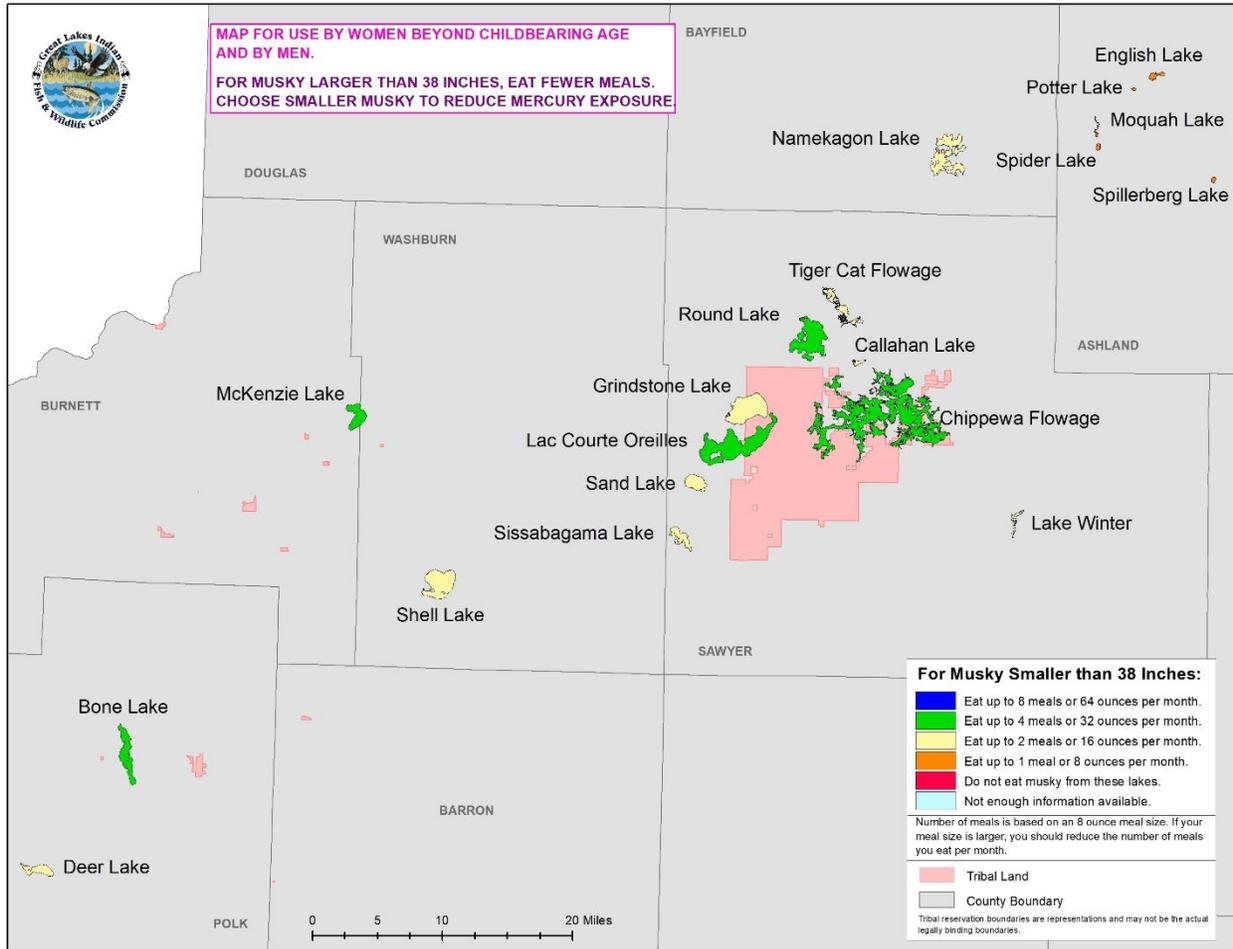


Figure 4. Muskellunge mercury map for the western Ceded Territory of Wisconsin depicting safe consumption categories for the general population for a 38” (97 cm) muskellunge

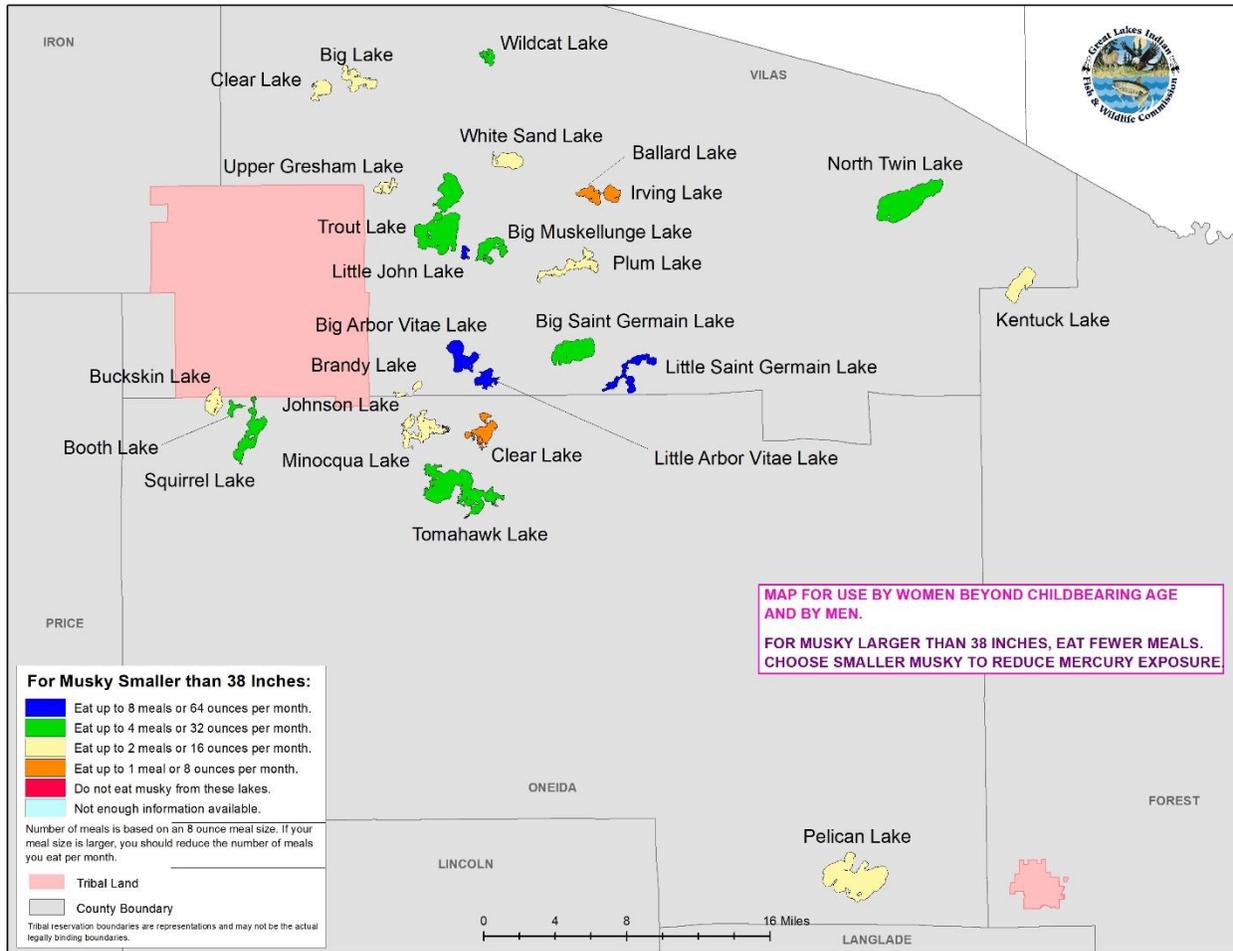


Figure 5. Muskellunge mercury map for the eastern Ceded Territory of Wisconsin depicting safe consumption categories for the general population for a 38” (97 cm) muskellunge

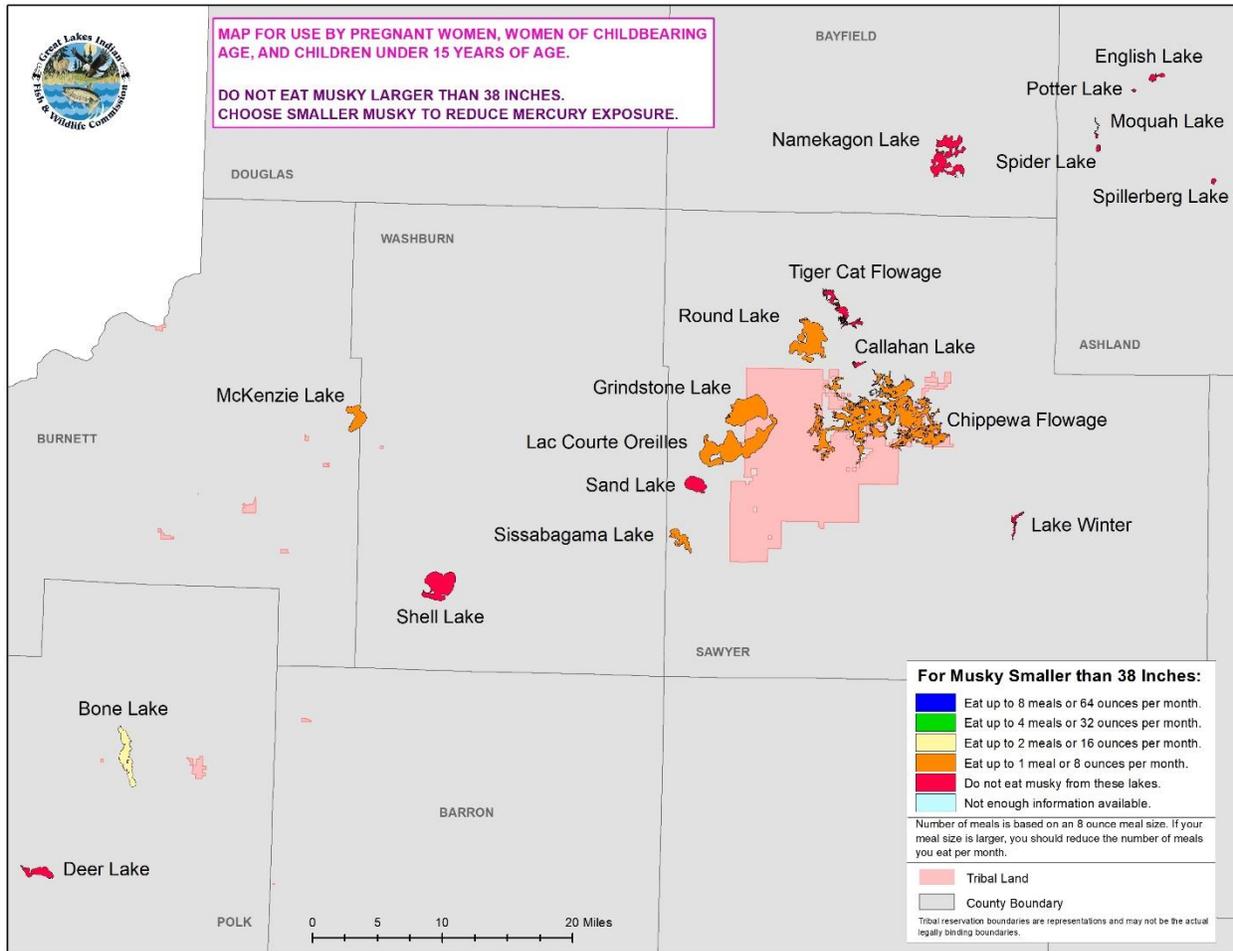


Figure 6. Muskellunge mercury map for the western Ceded Territory of Wisconsin depicting safe consumption categories for the sensitive population for a 38” (97 cm) muskellunge

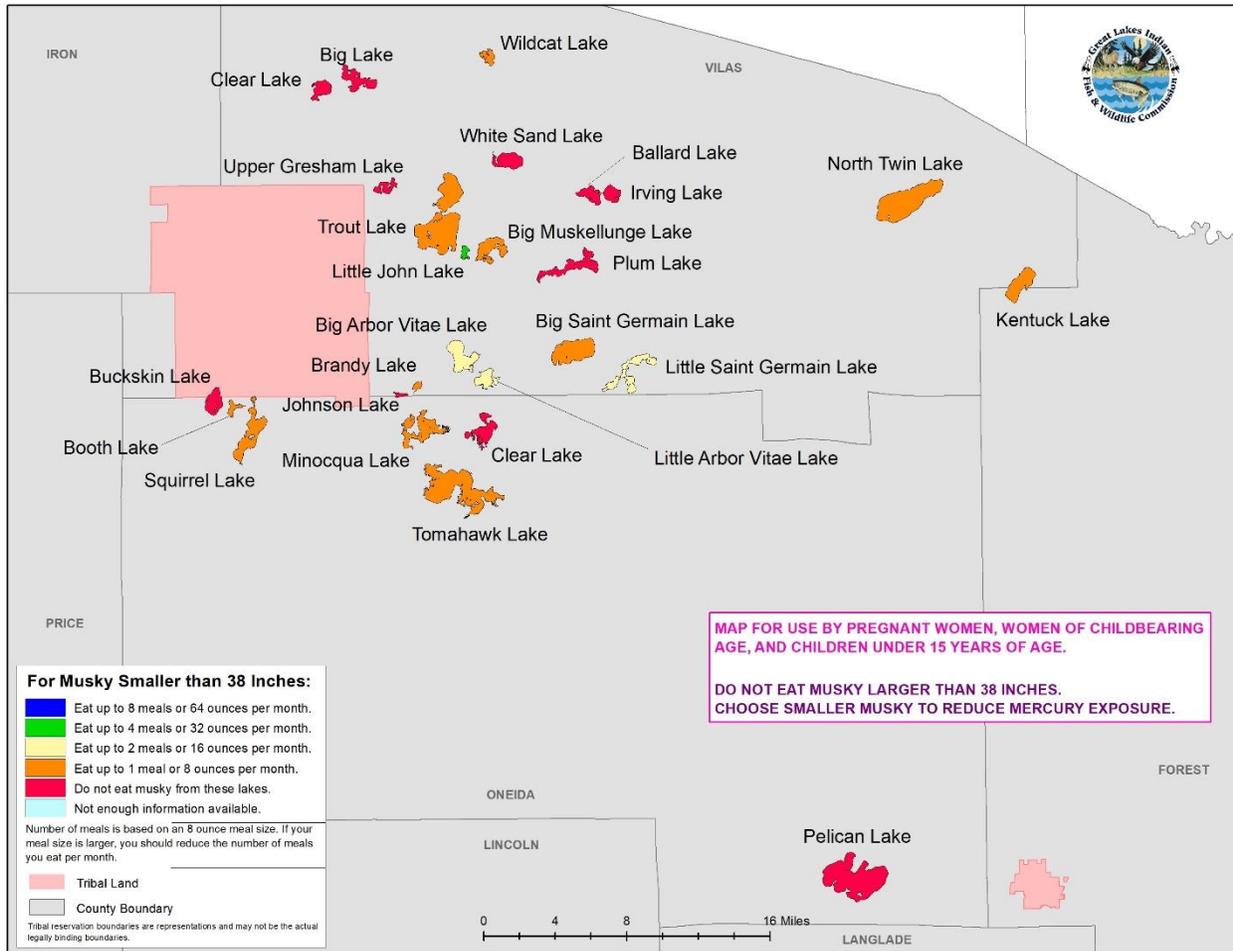


Figure 7. Muskellunge mercury map for the eastern Ceded Territory of Wisconsin depicting safe consumption categories for the sensitive population for a 38” (97 cm) muskellunge

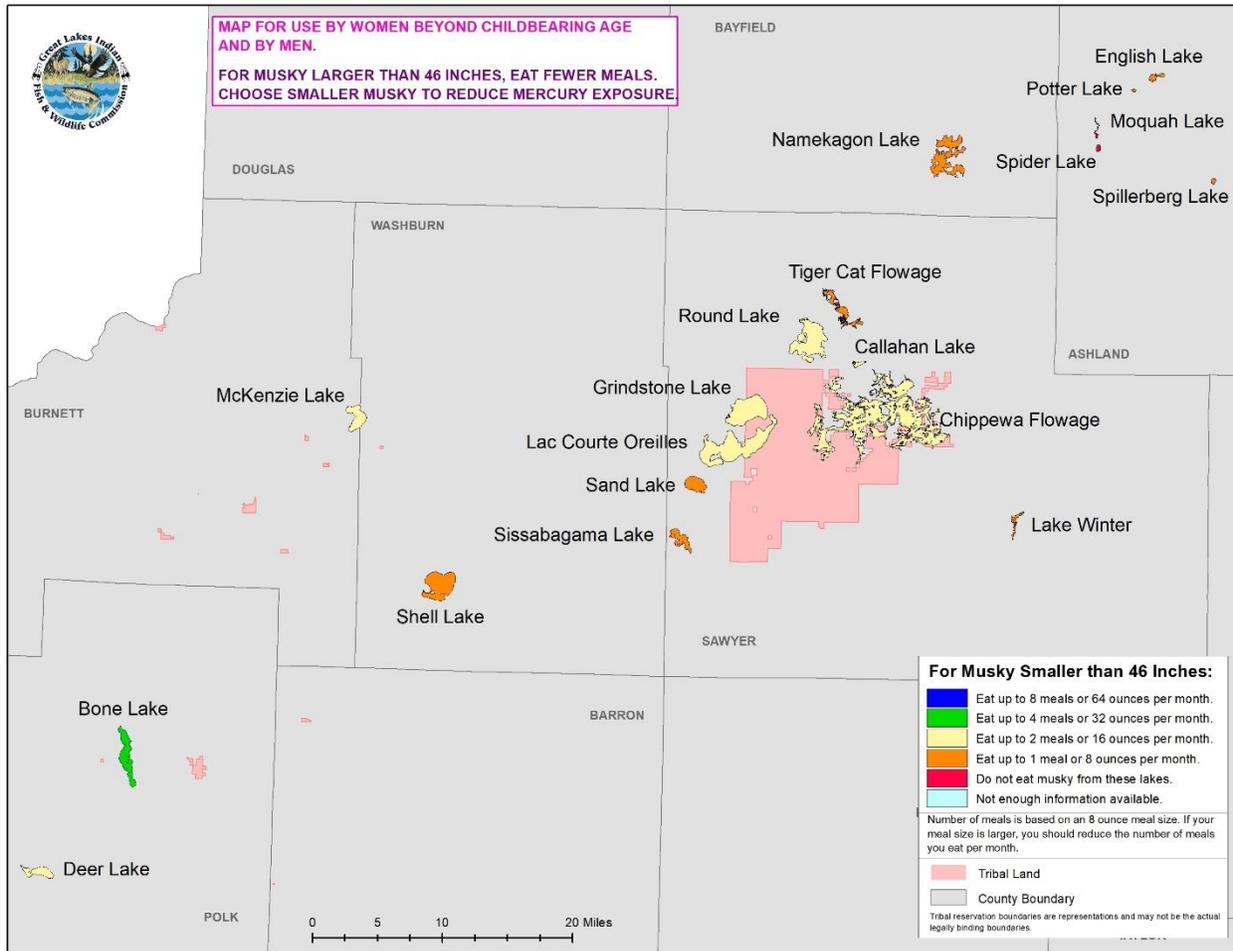


Figure 8. Muskellunge mercury map for the western Ceded Territory of Wisconsin depicting safe consumption categories for the general population for a 46” (117 cm) muskellunge

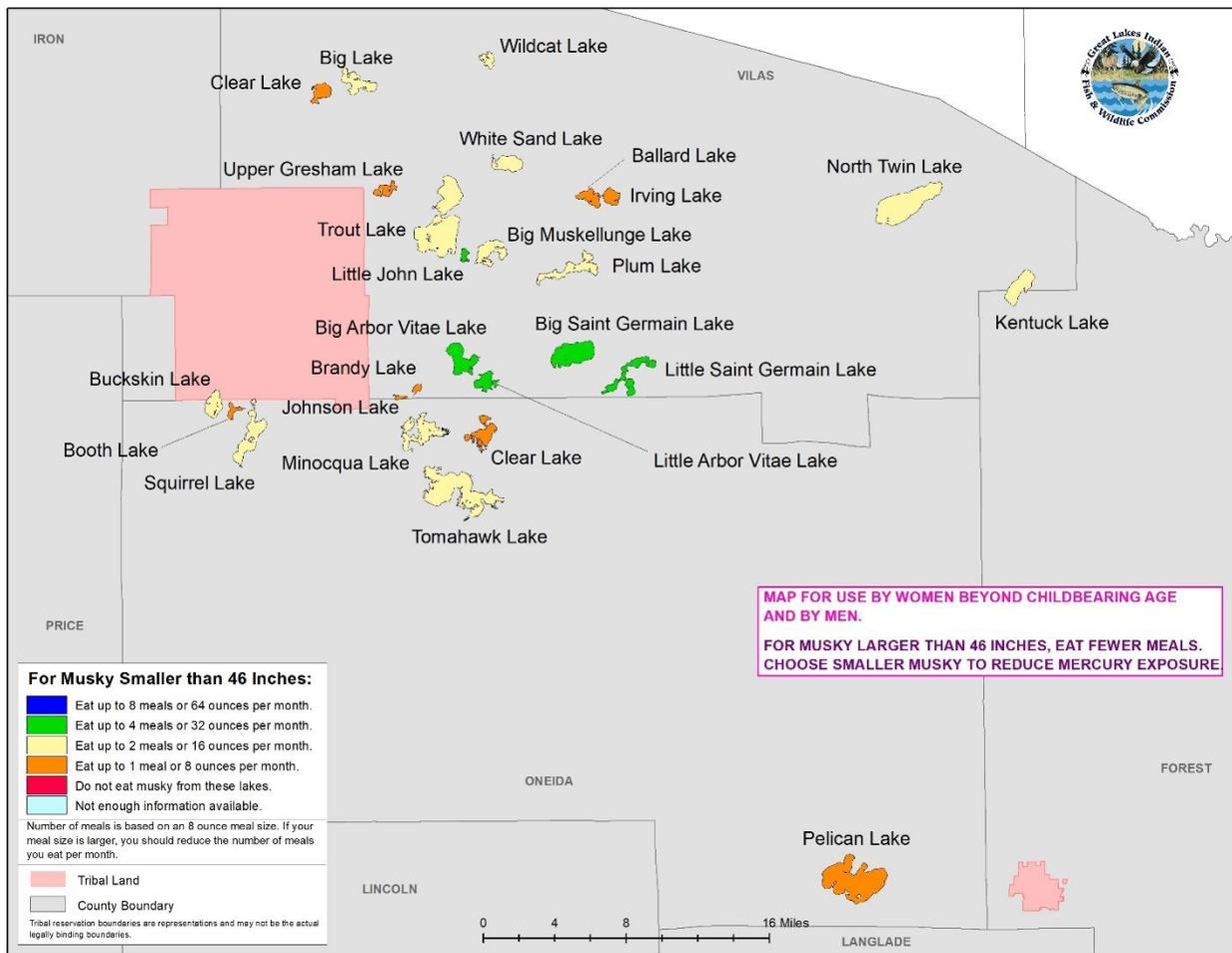


Figure 9. Muskellunge mercury map for the eastern Ceded Territory of Wisconsin depicting safe consumption categories for the general population for a 46” (117 cm) muskellunge

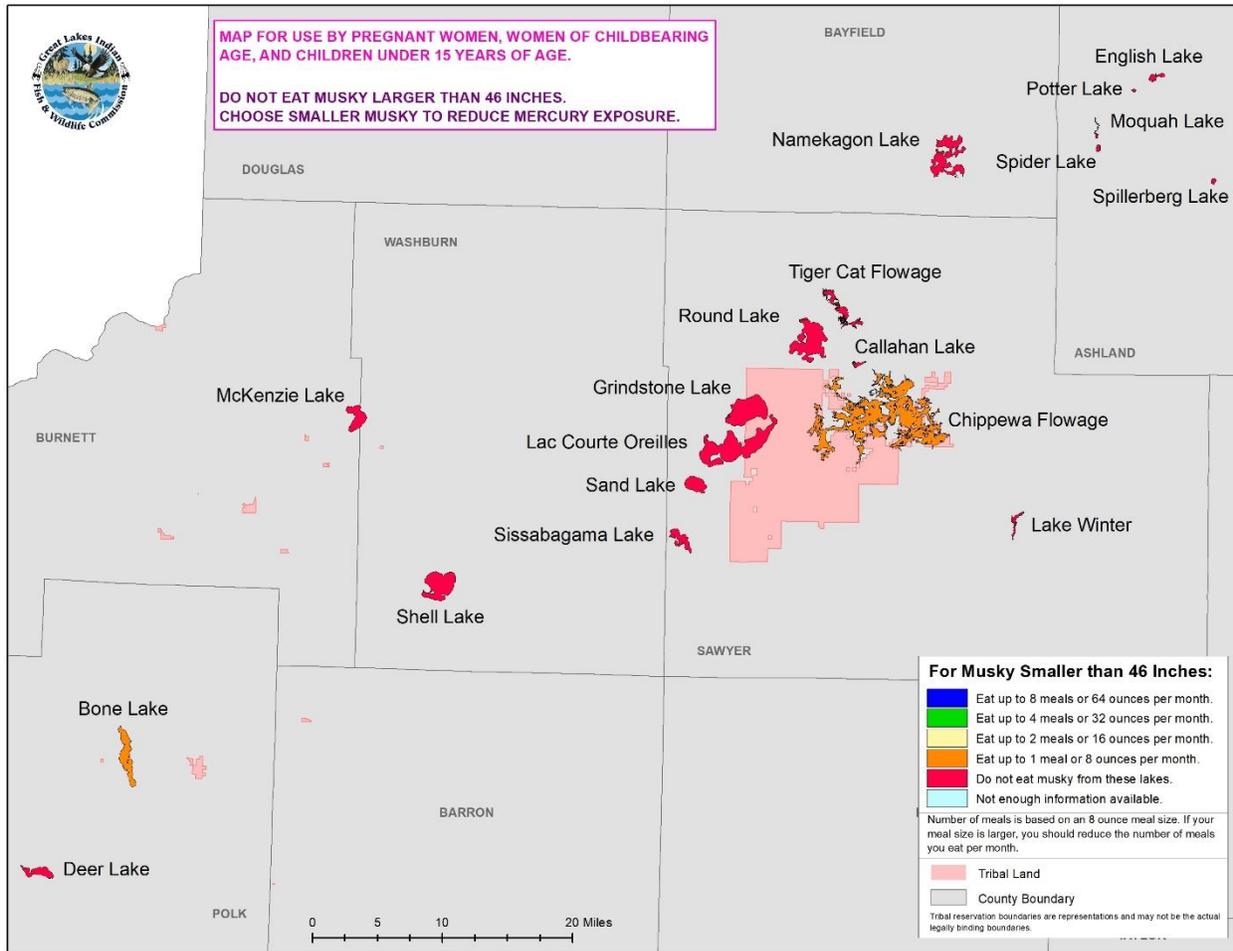


Figure 10. Muskellunge mercury map for the western Ceded Territory of Wisconsin depicting safe consumption categories for the sensitive population for a 46” (117 cm) muskellunge

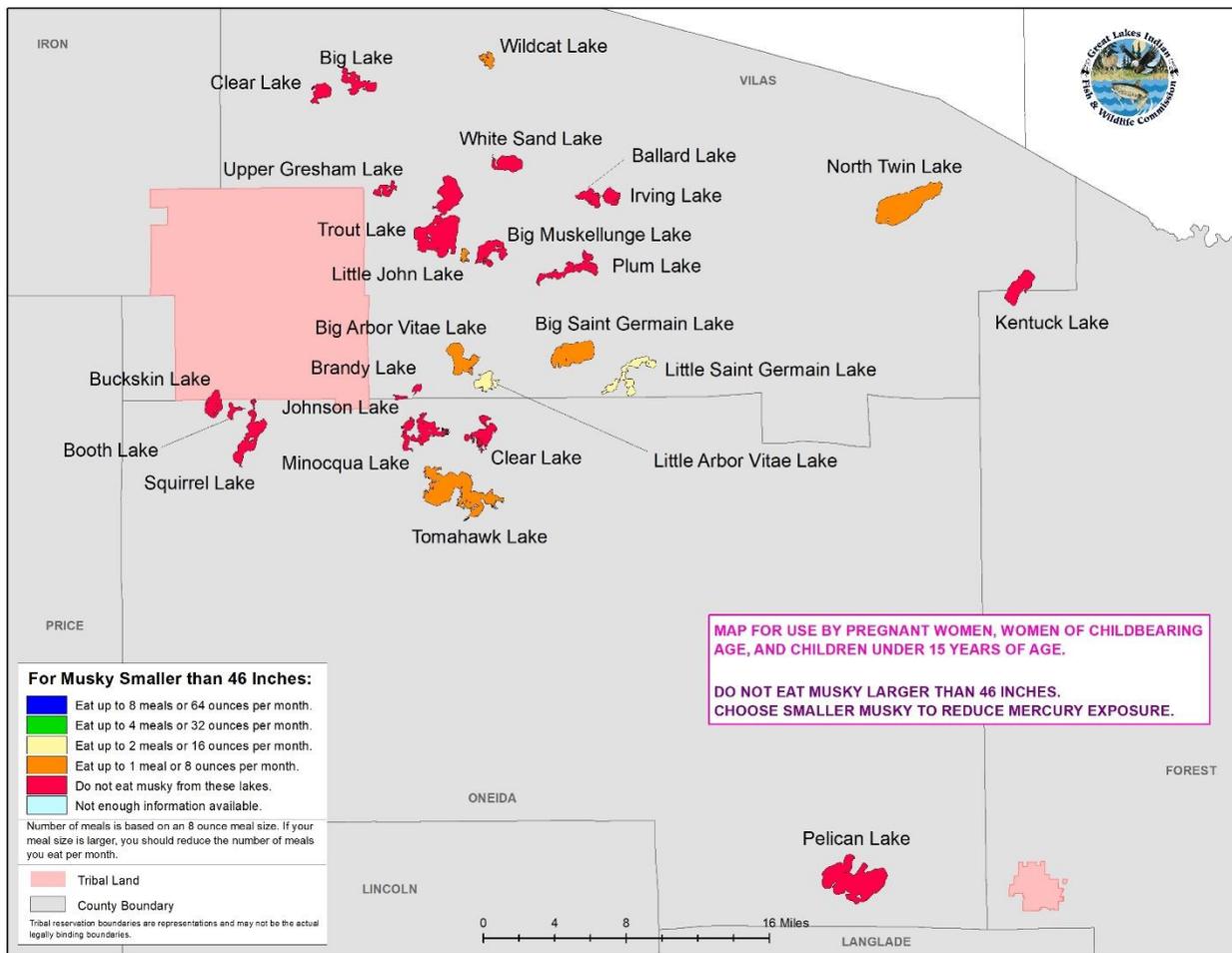


Figure 11. Muskellunge mercury map for the eastern Ceded Territory of Wisconsin depicting safe consumption categories for the sensitive population for a 46” (117 cm) muskellunge

Future Plans

Future priorities for muskellunge include 1) collecting additional mercury data to fill in data gaps and provide lake-specific advice for additional lakes, and 2) using the maps presented here to develop outreach materials that can be distributed to GLIFWC’s member tribes.

The top nine harvest lakes for which there was not sufficient information for generating lake-specific advice are:

1. Lost Land Lake (Sawyer)
2. Bearskin Lake (Oneida)
3. Upper Buckatabon Lake (Vilas)
4. Lac Vieux Desert (Vilas)
5. Lake Laura (Vilas)
6. Star Lake (Vilas)
7. Yellow Lake (Burnett)

8. Cedar Lake (St Croix)
9. Turtle-Flambeau Flowage (Iron)

These are the only remaining lakes with >10 muskellunge harvested by the tribes during the spring spearing season in Wisconsin in the last 5 years (2015-2019). 15% of muskellunge were harvested from these lakes in these years. They should be priority targets for future mercury testing of muskellunge.

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