Final Project Report

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Fund: GLRI
Focus Area: Focus Area 1- Toxic Substances and Areas of Concern
Project Title: Assessment of Risk to the Keweenaw Bay Indian Community from Cumulative Toxicity of Chemical Contaminants in Lake Superior, Torch Lake, and Portage Lake Fish

1. Introduction

1a. Rationale

Toxic, bioaccumulative contaminants present threats to the availability and safety of traditional food sources and therefore infringe on the treaty rights of many tribal communities. Contamination of fish by toxic atmosphere-surface exchangeable pollutants or "ASEPs" is a transboundary, cross-scale, global problem with long-term impacts on ecosystem and human health (Perlinger et al. 2016) Fishing communities share a disproportionate burden from toxic contaminants (Basu et al. 2013; Boucher et al. 2014; Cassady 2007; Donatuto et al. 2011; O'Neill 2007; Ranco 2001; Turyk et al. 2012). Fish production represents a prominent ecosystem service (Steinman et al. 2017; Sterner et al. 2020) and a nutritious food supply (Rideout and Kosatsky 2017; Williams et al. 2017) to KBIC and many other Indigenous communities. Among the eleven member-tribes served by GLIFWC, the average fish consumption rate is 10-fold higher than the U.S. average (O'Neill 2004). For tribal communities, the value of small inland and Great Lake (GL) fisheries is heightened due to community reliance on the resource for subsistence and income, and also for cultural heritage and traditions. Toxicants disrupt cultural practices, and prevent the transmission of generational cultural knowledge (Gagnon 2016; Hoover 2013; NEJAC and Council) 2002; O'Neill 2007; Ranco et al. 2007). Thus contaminants impair Indigenous community ecological and cultural health and transgenerational education, in addition to potentially impairing human health .

It is widely recognized that the cumulative toxicity of mixtures of environmental contaminants may exceed the toxicity of the individual contaminants (Altenburger et al. 2015; Androutsopoulos et al. 2013; Hernandez et al. 2013). Even in the absence of common molecular mechanisms for toxicity, one contaminant may activate or inhibit receptors and transporters for other contaminants (Nicklisch et al. 2016) or interfere with the degradation of other contaminants (Cedergreen 2014). Due to our limited understanding of mechanisms for mixture toxicity (Altenburger et al. 2015) and the infrequency of synergistic reactions (Cedergreen, 2014), it has been argued that chemical additivity (CA) is the simplest, most appropriate model to estimate cumulative toxicity (Backhaus and Faust 2012; Gandhi et al. 2017; Kortenkamp et al. 2009). Direct evidence of additive toxicity of mercury and polychlorinated biphenyl (PCB) compounds, as well as of PCBs and polychlorinated dioxins and furans has been obtained in experimental studies (Costa et al. 2007; Goldoni et al. 2008; Van den Berg et al. 2006), and epidemiological studies offer further evidence (Boucher et al. 2010; Boucher et al. 2016; Boucher et al. 2014; Stewart et al. 2003). KBIC is working with MTU and GLIFWC in existing projects as well as this project to determine the distribution of cumulative toxicity of contaminants in fish throughout the study region and to develop strategies for maximizing health benefits to tribal and fish communities.

Historically, fish contaminant concentrations have been monitored in few locations within the study area. The U.S. EPA has monitored contaminant concentrations in Lake Trout at two sites (Apostle Islands [management unit (MU) WI2], Copper Harbor [MI3]) since the 1980s as part of the Great Lakes Fish Monitoring and Surveillance Program. Those monitoring stations show a steady decline in fish PCB concentrations, but a leveling of mercury concentrations (e.g., Urban et al. 2020). The State of Michigan has measured contaminants in fish from Keweenaw Bay every five years since 1991, but those data do not show a decline in PCB concentrations (Urban et al. 2020; Urban et al. 2016). The Great Lakes Fish and Wildlife Commission (GLIFWC) has measured mercury in a variety of fish species throughout the study area since 2011 (Moses 2020). As part of the National Coastal Condition Assessment (NCCA), the U.S. EPA began measuring contaminants in coastal fish in the Great Lakes in 2010. Results from 2010 (U.S.EPA 2015) showed large spatial variability in contaminant concentrations with very high fish mercury and PCB concentrations north of the Keweenaw Peninsula, and much lower concentrations (5-fold for mercury and 10- to 20-fold for PCBs) in Keweenaw Bay (Fig. 1). Concentrations of PCBs in Lake Superior MUs MI2 and MI3 were 10- to 20-fold higher than those in MI4 and MI5 and as high as those measured 30 years previously (Urban et al. 2020).

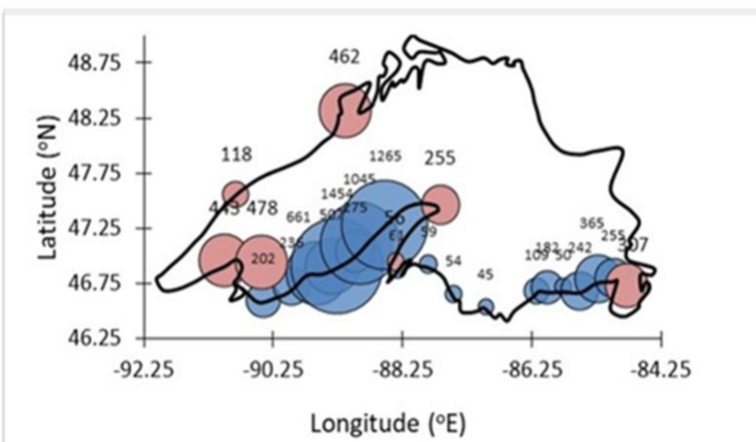

Figure 1. Spatial distribution of PCB concentrations (ng/g ww) in lake trout in Lake Superior in 2009/2010. Circle sizes are proportional to concentrations; values of concentrations are printed directly above each circle. Blue circles indicate sampling locations in the NCCA, and pink circles denote the seven sampling stations of five other agencies (Minnesota DNR, Wisconsin DNR, EPA GLFMSP, EPA NCCA, MI DEQ, and ECCC). Most striking are the high concentrations north of the Keweenaw Peninsula and the much lower concentrations between Keweenaw Bay and Munising (Urban et al. 2020).

If the spatial pattern of mercury and PCBs in fish shown in Figure 1 is representative of a long-term pattern, it would be of considerable significance to KBIC. Not only would consumption of fish from MI2 and MI3 pose considerably higher health risk than fish from elsewhere in the lake, but it also would imply that populations of Lake Trout are unique to each locale and do not intermingle throughout the lake. It would also imply that Lake Trout spawning on Buffalo Reef in Keweenaw Bay are of greater value because of the lower contaminant concentrations and associated health risks; the cost of failure to protect this reef would be higher than previously estimated (Fletcher and Cousins 2019). The higher concentrations of contaminants in MI2 and MI3 might result from older, larger fish, slower growing fish, the length of the food web, or the diet of fish in this area. In this project the concentration of contaminants in archived fish from MI3 and MI4 were measured to determine if these fish samples show the same large difference as reported by the NCCA and to determine if this spatial pattern has persisted over time.

1b. Objectives

The **overarching goal** of this work is to **better understand the risk posed to tribes by contaminants in fish** such that they can make informed resource management decisions. The **first objective** of this project is **to determine the spatial distribution of the two major contaminants in fish, PCBs and mercury, along with the distribution of toxic risk posed by the contaminants singly and in combination within the study region** defined above. The **second objective is to perform a preliminary evaluation of factors (local sources, food web structure, fish diet and growth rates) contributing to any spatial patterns** observed in contaminant distributions. The **final objective is to communicate the findings to tribal members** and to initiate discussion of possible responses of KBIC to the research findings.

2. Summary of work performed

The work was organized into tasks required to meet each of the project objectives. In the section below, we provide details on the work performed in each task.

2a. Task list with work performed

Objective 1

Task 1. Select and obtain archived fish samples from GLIFWC.

GLIFWC provided a list of archived Lake Superior fish samples that had been collected as part of their mercury monitoring program (Moses 2020). From the 482 archived Lake Superior fish, a subset of 142 (20 Cisco, 81 Lake Trout, 28 Lake Whitefish, 13 Walleye) were identified and obtained from GLIFWC for possible analysis; this subset included fish caught from MI2 to MI5. Because of time and financial constraints, this subset was further culled for fish caught only in management units MI3 and MI4. The final set of fish analyzed for PCBs (26 Lake Trout), stable isotope ratios (15 Lake Whitefish, 22 Lake Trout, 19 Cisco) and lipid content (6 Lake Whitefish, 58 Lake Trout, 20 Cisco) are summarized in Table 1 below.

Table 1. Characteristics of fish samples analyzed.

Fish Pkey	Species	LS Mngmt Unit	LS Mngmt Unit Specific	Year	Length	Sex	Age	Weight	Lipid	SIA	Contaminants
					(cm)		(yr)	(g)			
518	CISCO	MI-3	COPPER HARBOR	2013	45.7	F	9	880	Y	Y	
519	CISCO	MI-3	COPPER HARBOR	2013	51.8	F	5	1365	Y	Y	
520	CISCO	MI-3	COPPER HARBOR	2013	43.2	M	12	621	Y	Y	
523	CISCO	MI-3	COPPER HARBOR	2013	50.3	F	11	1252	Y	Y	
533	CISCO	MI-3	COPPER HARBOR	2013	46.7	F	6	903	Y	Y	
535	CISCO	MI-3	COPPER HARBOR	2013	46.7	F	10	798	Y	Y	
536	CISCO	MI-3	COPPER HARBOR	2013	46.0	F	7	862	Y	Y	
537	CISCO	MI-3	COPPER HARBOR	2013	42.4	M	9	717	Y	Y	
538	CISCO	MI-3	COPPER HARBOR	2013	43.9	M	5	798	Y	Y	
534	CISCO	MI-3	COPPER HARBOR	2013	43.4	F	6	794	Y		
477	CISCO	MI-4	KEWEENAW BAY	2011	41.9	M	25	590	Y	Y	
478	CISCO	MI-4	KEWEENAW BAY	2011	39.4	F	13	499	Y	Y	
479	CISCO	MI-4	KEWEENAW BAY	2011	36.1	F	7	440	Y	Y	
480	CISCO	MI-4	KEWEENAW BAY	2011	36.3	M	7	458	Y	Y	
481	CISCO	MI-4	KEWEENAW BAY	2011	38.1	F	8	503	Y	Y	
482	CISCO	MI-4	KEWEENAW BAY	2011	42.9	F	17	671	Y	Y	
484	CISCO	MI-4	KEWEENAW BAY	2011	37.1	F	16	336	Y	Y	
486	CISCO	MI-4	KEWEENAW BAY	2011	34.8	M	10	381	Y	Y	
489	CISCO	MI-4	KEWEENAW BAY	2011	37.6	F	7	395	Y	Y	
8,631	CISCO	MI-4	KEWEENAW BAY	2011	33.3	F	6	299	Y	Y	
526	LAKE TROUT	MI-3	COPPER HARBOR	2013	57.9	M	7	1352	Y	Y	Y
527	LAKE TROUT	MI-3	COPPER HARBOR	2013	57.9	M	11	1474	Y	Y	Y
528	LAKE TROUT	MI-3	COPPER HARBOR	2013	62.7	M	8	1764	Y	Y	Y
529	LAKE TROUT	MI-3	COPPER HARBOR	2013	67.8	M	8	2250	Y	Y	Y
532	LAKE TROUT	MI-3	COPPER HARBOR	2013	89.7	M	15	7362	Y	Y	Y
524	LAKE TROUT	MI-3	COPPER HARBOR	2013	56.4	M	7	1397	Y	Y	
525	LAKE TROUT	MI-3	COPPER HARBOR	2013	57.9	M	7	1805	Y	Y	
530	LAKE TROUT	MI-3	COPPER HARBOR	2013	74.4	F	13	3180	Y	Y	
531	LAKE TROUT	MI-3	COPPER HARBOR	2013	87.9	M	11	5244	Y	Y	
10,162	LAKE TROUT	MI-3	COPPER HARBOR	2019	67.8	M		2320	Y		Y
10,163	LAKE TROUT	MI-3	COPPER HARBOR	2019	71.1	M		2910	Y		Y
10,164	LAKE TROUT	MI-3	COPPER HARBOR	2019	69.1	M		2650	Y		Y
10,165	LAKE TROUT	MI-3	COPPER HARBOR	2019	67.6	M		2320	Y		Y
10,166	LAKE TROUT	MI-3	COPPER HARBOR	2019	81.5	F		4770	Y		Y
10,167	LAKE TROUT	MI-3	COPPER HARBOR	2019	64.3	M		2470	Y		Y
10,168	LAKE TROUT	MI-3	COPPER HARBOR	2019	61.2	M		1990	Y		Y

557	LAKE TROUT	MI-3	COPPER HARBOR	2015	67.8	F	12	2921	Y		
558	LAKE TROUT	MI-3	COPPER HARBOR	2015	64.0	F	17	2431	Y		
559	LAKE TROUT	MI-3	COPPER HARBOR	2015	66.8	M	5	2350	Y		
560	LAKE TROUT	MI-3	COPPER HARBOR	2015	66.0	M	12	2381	Y		
561	LAKE TROUT	MI-3	COPPER HARBOR	2015	65.5	M	9	2499	Y		
515	LAKE TROUT	MI-3	EAGLE R SHOAL	2013	64.0	M	7	2096	Y	Y	Y
514	LAKE TROUT	MI-3	MONEY BAY	2013	74.9	M	12	3375	Y	Y	
540	LAKE TROUT	MI-4	BETSY JETTY	2015	56.1	M		1388	Y		
542	LAKE TROUT	MI-4	BETSY JETTY	2015	61.0	M	15	1919	Y		
543	LAKE TROUT	MI-4	BETSY JETTY	2015	75.9	M	19	4359	Y		
545	LAKE TROUT	MI-4	BETSY JETTY	2015	74.7	M		3878	Y		
548	LAKE TROUT	MI-4	BETSY JETTY	2015	71.1	M	17	3561	Y		
549	LAKE TROUT	MI-4	BETSY JETTY	2015	82.8	F		5502	Y		
551	LAKE TROUT	MI-4	BETSY JETTY	2015	63.2	M	13	2422	Y		
552	LAKE TROUT	MI-4	BETSY JETTY	2015	67.3	F	16	2781	Y		
555	LAKE TROUT	MI-4	BETSY JETTY	2015	56.9	M	13	1370	Y		
10,194	LAKE TROUT	MI-4	BUFFALO REEF	2019	91.2	F		6050	Y		Y
10,196	LAKE TROUT	MI-4	BUFFALO REEF	2019	77.5	F		3900	Y		Y
10,197	LAKE TROUT	MI-4	BUFFALO REEF	2019	61.7	F		1830	Y		Y
10,198	LAKE TROUT	MI-4	BUFFALO REEF	2019	58.4	F		1500	Y		Y
10,201	LAKE TROUT	MI-4	BUFFALO REEF	2019	88.9	M		6380	Y		Y
10,203	LAKE TROUT	MI-4	BUFFALO REEF	2019	71.1	F		3020	Y		Y
10,204	LAKE TROUT	MI-4	BUFFALO REEF	2019	66.0	F		2360	Y		Y
10,206	LAKE TROUT	MI-4	BUFFALO REEF	2019	69.9	F		2600	Y		Y
10,211	LAKE TROUT	MI-4	BUFFALO REEF	2019	64.8	F		1880	Y		Y
562	LAKE TROUT	MI-4	BUFFALO REEF	2015	61.2	F		1792	Y		
563	LAKE TROUT	MI-4	BUFFALO REEF	2015	65.5	F		2318	Y		
10,208	LAKE TROUT	MI-4	BUFFALO REEF	2019	67.6	F		2670	Y		
10,209	LAKE TROUT	MI-4	BUFFALO REEF	2019	69.3	F		3230	Y		
10,212	LAKE TROUT	MI-4	BUFFALO REEF	2019	66.3	M		2690	Y		
10,213	LAKE TROUT	MI-4	BUFFALO REEF	2019	79.5	M		4280	Y		
608	LAKE TROUT	MI-4	HURON ISLANDS	2013	80.0	F		5017	Y	Y	

609	LAKE TROUT	MI-4	HURON ISLANDS	2013	74.7	F		2640	Y	Y	
610	LAKE TROUT	MI-4	HURON ISLANDS	2013	74.4	F	8	3751	Y	Y	
613	LAKE TROUT	MI-4	HURON ISLANDS	2013	66.3	F		4241	Y	Y	
3	LAKE TROUT	MI-4	MID-KEWEENAW BAY	2013	61.7	F	8	1873	Y	Y	Y
4	LAKE TROUT	MI-4	MID-KEWEENAW BAY	2013	53.6	M		1474	Y	Y	Y
5	LAKE TROUT	MI-4	MID-KEWEENAW BAY	2013	63.2	M	8	2272	Y	Y	Y
12	LAKE TROUT	MI-4	MID-KEWEENAW BAY	2013	48.5	M	7	1157	Y	Y	Y
10	LAKE TROUT	MI-4	MID-KEWEENAW BAY	2013	58.2	M	8	1633	Y	Y	
13	LAKE TROUT	MI-4	MID-KEWEENAW BAY	2013	53.1	M	8	1352	Y	Y	
14	LAKE TROUT	MI-4	MID-KEWEENAW BAY	2013	52.3	M	8	1193	Y	Y	
495	LAKE WHITEFISH	MI-3	EAGLE RIVER	2013	48.5	M		1025		Y	
496	LAKE WHITEFISH	MI-3	EAGLE RIVER	2013	49.0	M		1057		Y	
501	LAKE WHITEFISH	MI-3	EAGLE RIVER	2013	57.2	F		1030		Y	
504	LAKE WHITEFISH	MI-3	EAGLE RIVER	2013	53.8	M		1288		Y	
505	LAKE WHITEFISH	MI-3	EAGLE RIVER	2013	45.7	M		1188		Y	
510	LAKE WHITEFISH	MI-3	EAGLE RIVER	2013	52.1	M		1293		Y	
465	LAKE WHITEFISH	MI-4	BUFFALO REEF	2011	71.1	M	12	3393	Y	Y	
466	LAKE WHITEFISH	MI-4	BUFFALO REEF	2011	52.8	M	13	1334	Y	Y	
470	LAKE WHITEFISH	MI-4	BUFFALO REEF	2011	58.9	M	13	1814	Y	Y	
472	LAKE WHITEFISH	MI-4	BUFFALO REEF	2011	67.3	M	8	2576	Y	Y	
473	LAKE WHITEFISH	MI-4	BUFFALO REEF	2011	59.7	M	13	2000	Y	Y	
475	LAKE WHITEFISH	MI-4	BUFFALO REEF	2011	52.6	M	12	1397	Y	Y	
464	LAKE WHITEFISH	MI-4	BUFFALO REEF	2011	60.2	M	10	1891		Y	
467	LAKE WHITEFISH	MI-4	BUFFALO REEF	2011	57.2	M	11	1610		Y	
473	LAKE WHITEFISH	MI-4	BUFFALO REEF	2011	59.7	M	13	2000		Y	

Task 2. Analyze fish samples for PCB concentrations.

Prior to analyzing fish samples, a series of quality control analyses were performed; results are summarized in the next section of the report. A total of four batches of fish samples (26 total fish, all lean lake trout) were analyzed for PCBs. Each batch contained two blanks, one standard reference material (SRM) sample (SRM 1946 Lake Superior Lake Trout), eight fish samples and one duplicate of one of the fish samples. Methods for extraction and analyses are described in the Quality Assurance Project Plan (QAPP), which is available on request.

Task 3. Compare contaminant concentrations in skin-on and skin-off fillets to enable conversion of concentrations in skin-off fillets to concentrations in skin-on fillets.

A total of 36 fish (lake trout, lake whitefish, walleye) were collected from MI3 and MI4 by GLIFWC and KBIC in spring 2022. These fish were filleted by GLIFWC or KBIC personnel, and one fillet from each fish was skinned. The fillets were delivered frozen to Michigan Tech. Fillets were thawed and homogenized (Waring blender), and then stored frozen until analysis. These fish samples were analyzed only for lipid content following the method of Folch et al. (1957).

Task 4. Based on PCB concentrations and mercury concentrations, calculate risk (hazard quotients, indices) for individual and combined contaminants.

In this project, PCBs were measured only in skin-off fillets as provided by GLIFWC, and the assessments of risk were made only for skin-off fillets. We followed the methods of Madsen et al. (2009) to be consistent with consumption advisories promulgated by GLIFWC. This study considered three classes of compounds: methylmercury, dioxin-like and non-dioxin-like PCBs. In calculating recommended fish consumption rates based on the reference doses listed below, we used a body weight of 70 kg. Recommended consumption limits were calculated for two fish sizes: 800 and 610 mm. Following Madsen et al., we used 1-sided upper 75% confidence bounds for the general population and 1-sided upper 75% prediction bounds for the sensitive population. As did Madsen et al., we used different reference doses for the general and sensitive populations as summarized in Table 2 below.

Task 5. Evaluate spatial patterns by mapping concentrations and risk and compare with previous measurements.

Fish PCB concentrations were collected from multiple agencies including Michigan Dept. Environment, Great Lakes, and Energy (EGLE), U.S. EPA GLENDA database with Great Lakes Fish Contaminant Monitoring Program measurements, and National Coastal Condition Assessment results (2010, 2015 and 2020). Data from these sources were uploaded into ArcGIS and mapped together with measurements from this study.

Objective 2

Task 6. Analyze a subset of the fish samples for stable isotope ratios to determine the trophic position of fish species.

Approximately 55 archived fish tissue samples from GLIFWC were selected for analysis of stable isotopes as summarized in Table 1. One-gram samples were dried in an oven at 60ºC for 48 hours; samples were weighed before and after drying to calculate water content. Aliquots (0.5-1 mg) of dried fish tissue were placed into tin capsules that were then crimped and sealed. Samples were analyzed on an elemental analyzer coupled with an isotope-ratio mass spectrometer in the LEAF laboratory at Michigan Tech.

Task 7. Analyze the fish samples for lipid content.

A total of 83 fish samples from the GLIFWC archive were selected for analysis of lipid content. Samples were extracted with methanol-acetone following the methods of Folch et al. (1957).

One sample was analyzed with each batch of samples processes to ensure comparability between batches and to determine the precision of analysis.

Task 8. Evaluate whether spatial differences (MI3 vs. MI4) in fish trophic positions (stable isotopes), fish conditions (lipid content, condition factor, growth rates), or contaminant sources (congener distributions) explain differences in contaminant concentrations.

Approximately equal numbers of fish from MI3 and MI4 management units were analyzed for contaminants, stable isotopes, and lipids. Otolith-based ages were made available by GLIFWC for some of the fish which enable us to compare age-at-length curves for the two lake management units.

<u>Objective 3</u>

Task 9. Utilizing appropriate means, communicate the results to the Tribal community and discuss among all partners possible management responses.

The following activities were carried out in Task 9: regular meetings of Tribal and academic project partners, leadership in the 2023 Zeba tribal landscape community partner meeting, co-creation of panel boards located at Sandpoint on the KBIC's reservation, presentations at the International Association for Great Lakes Research (IAGLR) 2023 and 2024 conferences, participation in the June 2024 KBIC Kid's Fishing Day, participation in the summer 2024 KBIC Pow-wow, and co-creation of a safe fishing brochure customized for the KBIC.

Regular meetings of project partners. To facilitate project research activities among the Tribal and academic project partners, meetings were held approximately monthly. These meetings kept communication lines open and advanced the meeting of project objectives.

April 2023 Zeba tribal landscape community partner meeting. A partner meeting was held at the community hall in Zeba, Michigan on April 20, 2023. The goal of this meeting was to exchange knowledge of the importance of fish to the KBIC and discuss concerns about human-fish relations. The meeting consisted of four presentations in the morning and three afternoon breakout sessions. The meeting was attended by 10 tribal and government members, 5 academic members, and 11 students. The meeting program and selected photos are included in Appendix C. Gagnon co-organized and co-facilitated the meeting and gave a morning presentation. Urban and Perlinger gave presentations. Advisees of Gagnon, Urban, and Perlinger also participated; some served as discussion facilitators.

Sandpoint panel. Through collaborations among the Great Lakes Indian Fish and Wildlife Commission (GLIFWC), Michigan Technological University, KBIC, Michigan SeaGrant, the U.S. EPA, and the Michigan Department of Environment, Great Lakes, and Energy (MI EGLE), panels for boards were created by Gagnon, Urban, Perlinger, and GLIFWC project partner Ackley for posting at the KBIC's restoration site Sandpoint, which is located on the western shore of Keweenaw Bay. Sandpoint was and continues to be impacted by copper mining, being inundated with heavy metal laden stamp sand byproducts of rock milling operations and near-shore transport from up-current dumping. It is being restored through capping and planting of metal-tolerant plants. The panels incorporated this project's PCB analysis results, demonstrated the benefits of Lake Superior fish consumption, compared concentrations of PCBs found in lake trout collected in MI2 and MI3 with MI4 lake trout concentrations, and provided recommendations for safe fish consumption. Pdfs of the panels are included in Appendix C. The boards where the panels will be posted have been installed, and the panels themselves will soon be posted.

IAGLR 2024 presentation. Urban and Perlinger presented at the IAGLR conference in May 2024 in Windsor, Ontario. The presentation, entitled "Convergence Research or Lessons from Geese", explored how research with/by/as Tribal communities can be carried out in a good way by building and maintaining relationships.

Participation in the June 2024 KBIC Kid's Fishing Day. Urban, Perlinger, and Gagnon participated in this annual KBIC celebration of fishing. They held a booth where two posters that were contextualized for the event were shared.

Participation in the July 2024 KBIC Pow-wow. Urban, Perlinger, and Gagnon also participated in this pow-wow together with KBIC Natural Resources Department (NRD) staff. They presented two posters contextualized for the event and held a raffle at a booth.

Safe fishing brochure customized for the KBIC. Together with GLIFWC project partner Ackley and KBIC NRD project partners, this brochure is currently in development.

3. **Results**

3a. <u>Quality assurance summary</u>

The quality of the data was for the most part high. The limit of detection (LOD) is determined by comparing the deviations from the mean of seven replicate injections of a method blank spiked with target analyte to deviations from the mean of seven replicate injections of an unspiked method blank. The greater of these is the limit of detection. See the Quality Assurance Project Plan (QAPP) for details. The median limit of detection (LOD) of the 200 compounds was 0.2 ng/g. 75% of the compounds exhibited LODs < 0.24 ng/g, and 95% of the compounds exhibited LODs < 0.40 ng/g.

Measurement precision was determined by first computing the standard deviation (SD) of 3 duplicates, and then computing the relative standard deviation as the ratio of the SD to the mean. 75% of the samples had RSDs of 18% or less, and 90% of the samples had RSDs of 32% or less.

Surrogate standard recoveries provide a means to assess the ability of the sample processing procedure to extract and retain the target analytes. Four C-13 labeled PCBs of known concentration were spiked into fish samples before extraction. The ratio of the mass of compound measured to the spike mass provides the measure of recovery. The acceptability criteria for surrogate standard recoveries in the QAPP is that recovery be > 50% and less than 150%. The average recoveries of all four surrogate standards were within these limits (Appendix A.3). Few recoveries were < 50%. 15 and 14 of the two larger C-13 labeled standard PCBs, congeners 189 and 209, respectively, had recoveries > 150%. Recoveries of these standards also exhibited higher RSDs. The cause of the high and variable recoveries of these two surrogate compounds is under investigation.

Recoveries of Standard Reference Material (SRM) 1946 Lake Superior Lake Trout were determined by processing and analyzing these samples with each batch of fish samples, giving five samples in total. Recovery is computed as the ratio of the measured concentration (ng/g) to the value reported by the National Institute of Standards and Technology (NIST). All measurements of averages were greater than the LODs of the analytes. The average recovery of all samples for all analytes was 81%. Of 39 analytes that were present at concentrations greater than the detection limit, four had recoveries greater than the upper limiting criterion of 140%, and fifteen had recoveries less than the lower limiting criterion of 60%. The lower recoveries are being investigated. They may be the result of the internal standard spiking procedure employed.

3b. <u>Lipid content results</u>

Lipid content was compared in paired skin-on/skin-off fillets for Lake Trout (n = 10), Lake Whitefish (n = 14), and Walleye (n = 12). The relative standard deviation (RSD) in the measurement of lipid content of a skin-off lake trout sample with each sample batch was 12.5% indicating highly reproducible measurements. Based on t-test results, summarized in Table B.2 (Appendix) below, skin-on fillets had statistically significant higher lipid content for lake trout (1.1x) whereas lake whitefish had significantly lower lipid content (0.85x). In other words, skin-on fillet lipid content was 14% less than skin-off fillet lipid content.

Statistically equivalent lipid contents in skin-on and skin-off fillets were found in walleye. The average lipid content of walleye is lower as compared to that of lake trout and lake whitefish (Appendix Table B.2). As Zhang et al. (2013) also found for rainbow trout as compared to brown trout, Chinook salmon, and coho salmon, this low lipid content fish did not possess significantly different concentrations of lipids in skin-on vs. skin-off fillets.

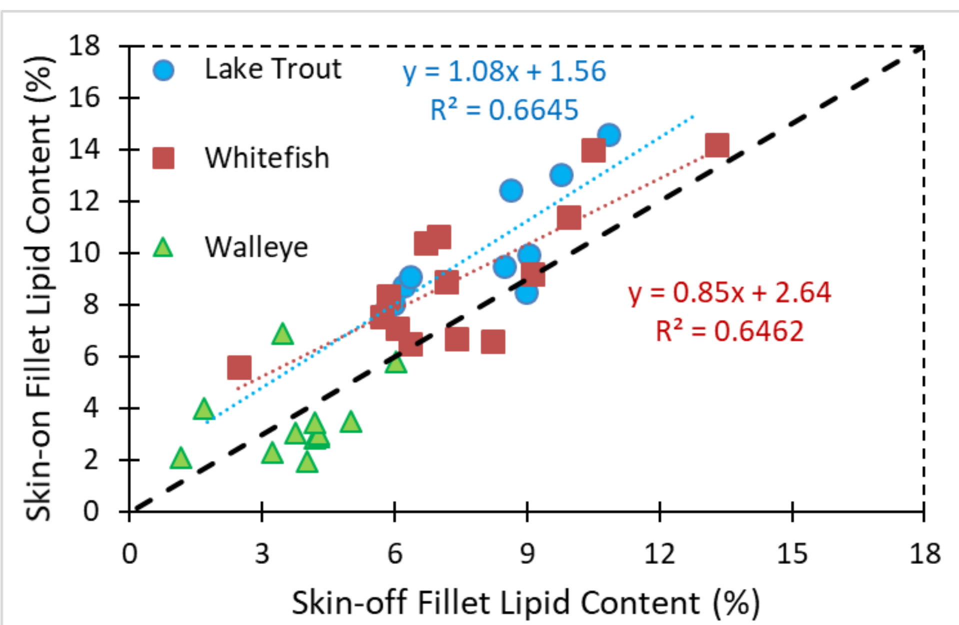

Figure 2. Comparison of lipid content of skin-on and skin-off fillets of lean lake trout, lake whitefish, and walleye. The black diagonal has a slope of 1.0. The lake trout have a slope (1.08) greater than one indicating higher lipid content in skin-on fillets. In contrast, the whitefish have a slope (0.85) less than 1 indicating higher lipid content in skin-off fillets. Walleye show no significant difference in lipid content between skin-on and skin-off fillets. Data are tabulated in Appendix B2.

Lipid content also was measured in 84 archived fish samples (see Table 1) as part of the effort to explain differences in contaminant concentrations in management units MI3 and MI4. A higher lipid content might indicate higher availability of food resources. Of the total samples analyzed there were 23 lake trout samples from MI3 and 28 from MI8. One-way ANOVA was used to confirm that there were no significant differences in lipid content between the different years of samples (2013, 2015, 2019). Results from all three years were pooled and the data were log transformed to achieve normal distributions. T-tests (two-sample, equal variance) indicated that lipid content was not significantly different in MI3 (9.91 $\pm$ 2.3%) and MI4 (8.3 $\pm$ 1.1%).

3c. Stable isotope results

Stable isotopes were measured on 22 lake trout muscle samples (11 each from MI3, MI4), 16 lake whitefish samples (eight from each management unit), and 19 Cisco samples (10 and 9 from MI4 and MI3, respectively). Results (Fig. 3) show that the trophic positions, shown by the $\delta^{15}N$ of each fish species appear to be identical in both management units. However, all three fish species exhibit wider ranges of $\delta^{13}C$ in MI4 than in MI3. Furthermore, the spread of $\delta^{13}C$ from Cisco to lake trout is also much wider. Results suggest that fish in Keweenaw Bay are feeding on a broader variety of food than are those in MI3. The broader variety may indicate food from a broader range of water depths or a broader range of food types (i.e., different organisms). By themselves, the stable isotopes do not indicate if there is a greater availability of food resources in Keweenaw Bay, but they do indicate that more types of food are being utilized.

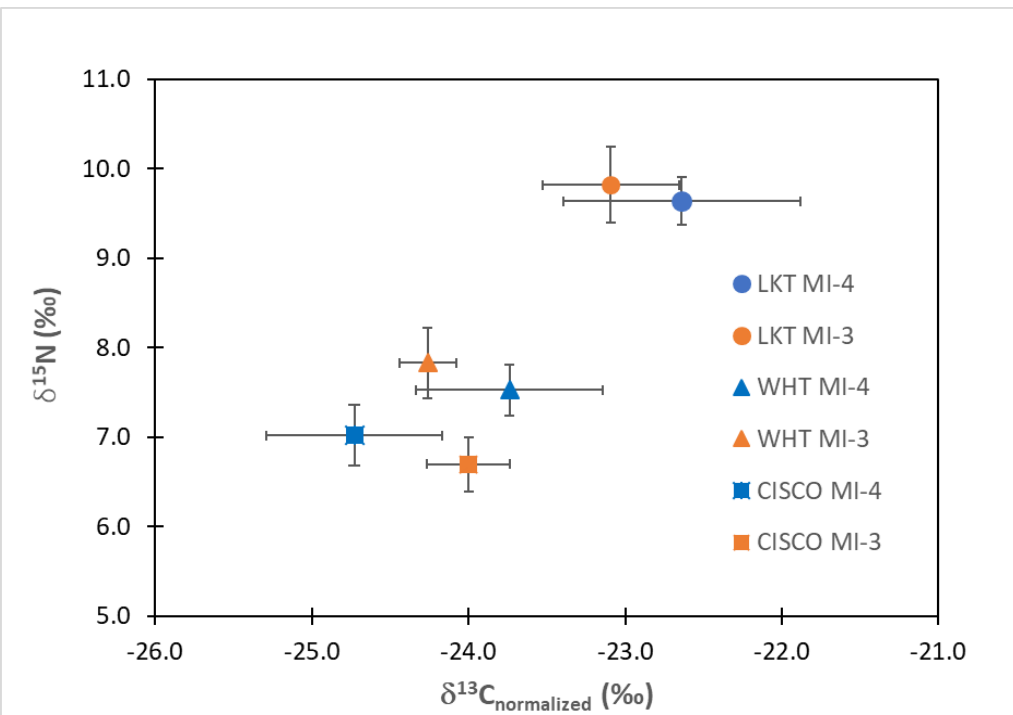

Figure 3. Comparison of MI3 and MI4 stable isotope ratios in muscle tissue from samples of Cisco, lake whitefish, and lean lake trout. Samples were taken from frozen fish fillet homogenates archived by GLIFWC. Shown are the means and standard deviations for the three fish species in each management unit.

3d. PCB results

Concentrations of PCBs in lake trout fillets ranged from 23 to 576 ng/g wet wt. The median value of the 26 samples was 46 ng/g. These values suggest that concentrations of PCBs in Lake Superior have decreased from 1980s values of 200-2000 ng/g (Urban et al. 2020). At the fish consumption rate of the average U.S. person (18 g/d), the concentrations measured in this study would allow consumption of 1 meal/week of lake trout using the reference dose espoused by the EPA. However, at a "desired" fish consumption rate of 260 g/d, the rate of consumption by KBIC members (Asher Consulting and Ad Hoc Analytics 2016), the median PCB concentration would still imply that KBIC members could not safely consume Lake Superior fish at their desired rate. Target concentrations of non-dioxin-like PCBs for the general population at the desired fish consumption rate would be 460 ng/g (in some fish below the measured concentrations ranging from 105 to 625 ng/g), but the target value for the sensitive population is 5 ng/g. At the observed rate of decline (half-life of about 12 years), it will require about 38 years for the concentration to decrease from our median value to the target value. Of more concern are the dioxin-like PCBs, for which the target concentrations are 0.62 (general population) and 0.27 pg-TEQ/g (sensitive population). A much longer time will be required to reach those concentrations.

Measured PCB concentrations increase exponentially with fish length (Fig. 4). Although the increases in length and weight of adult fish slow down and ultimately stop, bioaccumulation and increasing contaminant concentrations continue throughout the life of a fish. We performed regressions separately for the MI3 and MI4 fish because they exhibit distinctly different trends. Concentrations of PCBs are lower in fish of all sizes from MI4 than in fish from MI3.

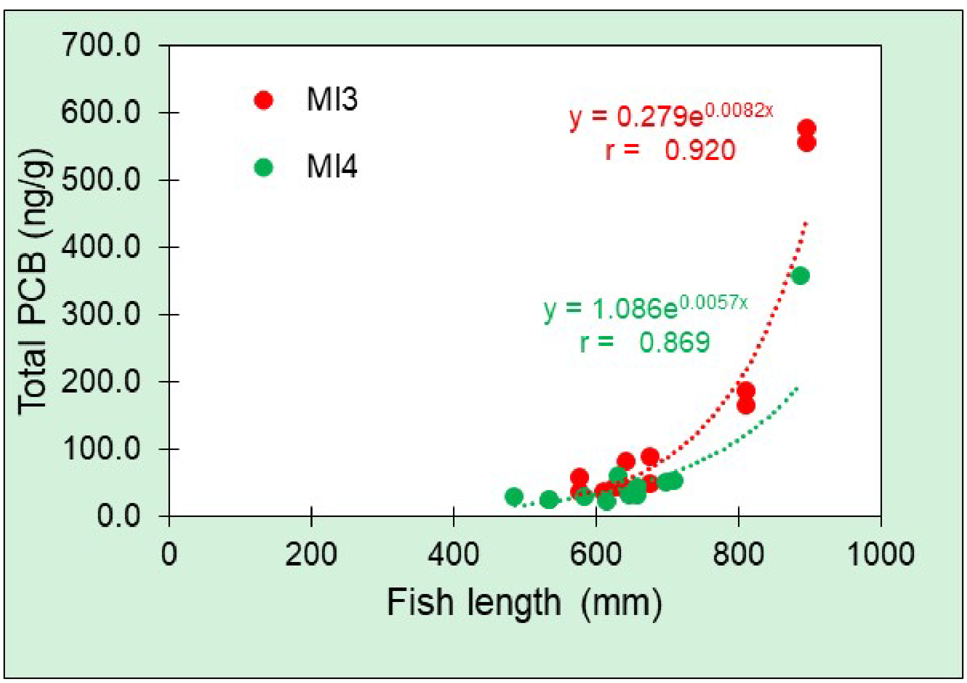

Figure 4. Comparison of lake trout PCB concentrations in MI3 and MI4. Even in smaller fish (< 700 mm), PCB concentrations were lower in lake trout from MI4 than in those from MI3. The difference between the two populations increases with the size of fish.

3e. Hazard indices and fish consumption guidance calculations

Fish consumption guidelines were calculated following the general procedures of Madsen et al. (2009) with some exceptions. Theoretically, age rather than length should be linearly related to bioaccumulated contaminant concentrations when the contaminant half-life in the fish is much over a year. Reported half-lives for methylmercury in fish range from 1-3 years (Amlund et al. 2007; Tollefson and Cordle 1986; Van Walleghem et al. 2013; Van Walleghem et al. 2007). Furthermore, the correlation coefficient between fish length and fish mercury concentration (0.83) is slightly lower than the correlation coefficient (0.86, n = 60) between ln(fish length) and ln(fish mercury) in this study. Accordingly, we used the regression of natural logs to predict the Hg concentration in fish of 610 mm (24 in) and 900 mm (35 in); the smaller size was the median lake trout size of those analyzed for PCBs, and 900 mm was the 90^{th} percentile of those analyzed. Following Madsen et al., we use a 1-sided 75% confidence bound of the predicted concentration for the general population, and a 1-sided 75% prediction bound for sensitive populations (children under age 15 and women of child-bearing age). We solved for the consumption rate (CR, meal/month) at the fish size-specific contaminant concentration (C, $\mu g/kg_{fish}$); at this consumption rate, the daily intake would equal the reference dose (RfD, µg/kg-day):

$$CR\left(\frac{meal}{month}\right) = \frac{RfD\left(\frac{\mu g}{kg-d}\right)\cdot BW(kg)\cdot T_{avg}\left(\frac{d}{month}\right)}{MS\left(\frac{g}{meal}\right)\cdot C\left(\frac{\mu g}{g}\right)} \quad (1)$$

Here MS is meal size (g fish per meal), BW is body weight (70 kg), and T_{avg} is the days per month (30.4). We utilized an up-to-date compilation (Shaw 2022) of reference doses for mercury, non-dioxin-like (NDL) PCBs, and dioxin-like (DL) PCBs. The reference doses selected are summarized in the table below. As did Madsen et al., we apply the lower reference dose for the sensitive population and the higher dose for the general population.

Table 2. Reference doses of compound classes for general and sensitive populations (Shaw 2022).

Compound Class	Population	Toxicity Endpoint	Reference Dose	Reference
Methylmercury	General		0.3 µg/kg-d	
	Sensitive	Cardiovascular and neurologic effects	0.1 µg/kg-d	MDCH 2009
Dioxin-like PCBs	General	Reproductive effects	0.7 pgTEQ/kg-d	MDCH 2013
	Sensitive	Reproductive effects	0.3 pg TEQ/kg-d	EFSA 2018
Non-dioxin-like PCBs	General	Neurologic effects	1.7 µg/kg-d	MDCH 2012
	Sensitive	Immunological effects	0.02 µg/kg-d	EPA 1996

These analyses enable us to say what rate of fish consumption would not cause ingestion of more than the reference dose of any particular contaminant. A hazard quotient may be calculated for each contaminant as the ratio of the size-specific contaminant concentration in fish to the threshold concentration for the appropriate population (general or sensitive). The threshold concentration is calculated as the reference dose times the body weight divided by the fish consumption rate. Hazard quotients for multiple contaminants may be added to quantify the Hazard Index (HI) or cumulative risk from all contaminants in a fish. An HI value of one would mean the fish contains contaminants at the maximum concentration deemed safe; an HI value of 20 would indicate that the total risk from all contaminants is 20 times greater than the level considered safe.

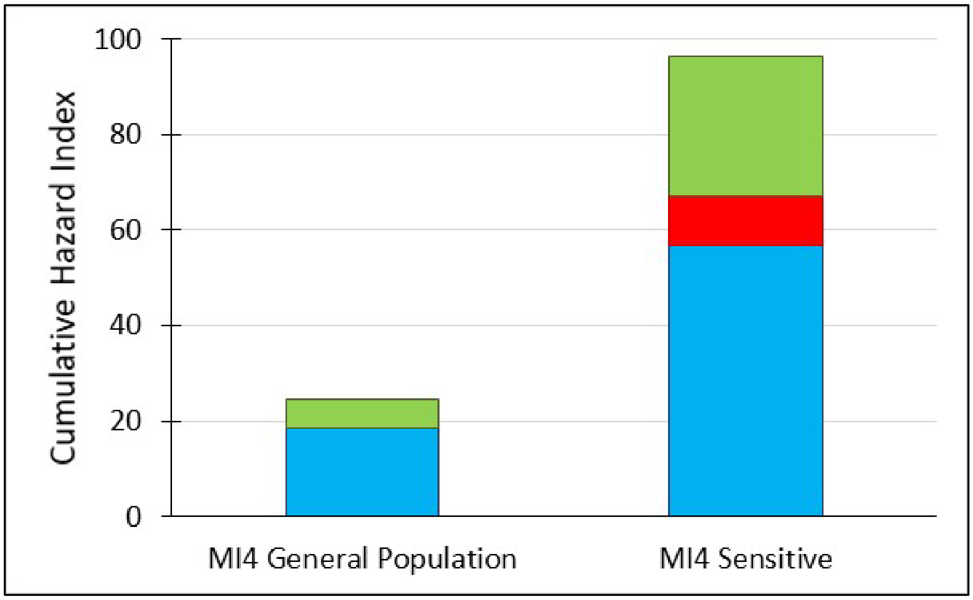

Figure 5. Comparison of hazard index for the general and sensitive populations consuming 610-mm lake trout from MI4. The blue bar is the hazard quotient (HQ) for dioxin-like PCBs, the red is for non-dioxin-like PCBs, and the green bar is for methylmercury.

In Figure 5 it is apparent that dioxin-like PCBs cause the greatest threat to human health of the three contaminant groups considered; methylmercury represents ~25% of the total risk to health for the sensitive population. The sensitive population is at a much greater risk than the general population both because a lower bar is set for the probability of harm (75% prediction interval below the "safe" level) and because this population is assumed to be more susceptible to harm via the health end point for the lower reference dose.

The top panel in Figure 6 shows that there is little difference between the number of meals per month that can be safely consumed of fish from MI3 and from MI4. Although contaminant concentrations are higher in MI3, the difference is small, especially for small fish. In both locations, the largest risk is from dioxin-like PCBs followed by methylmercury in the fish. The lower panel demonstrates the large impact of fish size on risk; large fish (800 mm) are about four times as hazardous as "small" (610-mm) fish.

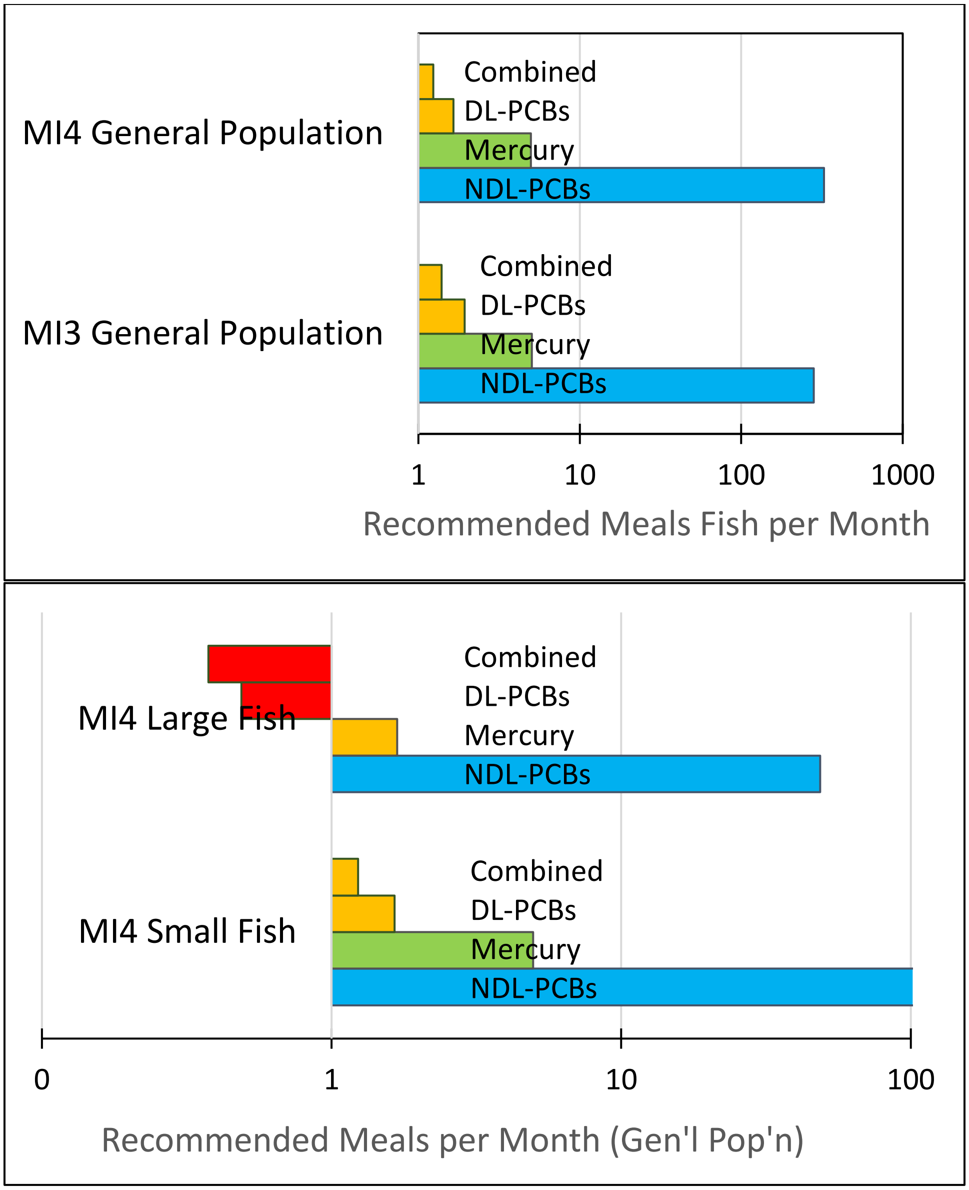

Figure 6. Recommended fish consumption rates as a function of personal susceptibility (sensitive vs. general population – top panel) and fish size (800 mm vs. 610 mm).

4. Discussion

4a. Are contaminant concentrations higher in MI3 than in MI4?

Our assessment of agency data as well as of our own analyses is that concentrations of contaminants are higher in lean Lake Trout on the western side of the Keweenaw Peninsula (MI3) than they are on the eastern side (MI4). Historical fish contaminant measurements by state (EGLE), federal (EPA Great Lakes Fish Surveillance and Monitoring Program - GLFSMP, Great Lakes Human Health Fish Tissue Study - GLHHFTS, National Coastal Condition Assessment- NCCA), and Tribal (Great Lakes Indian Fish and Wildlife Commission - GLIFWC) data were compiled for assessing the geographic patterns (Fig. 7). PCB measurements by the agencies appear to show a preponderance of high PCB concentrations in lean lake trout along the northern shoreline of the Keweenaw Peninsula. The map shows that, while large fish anywhere in the lake have high PCB concentrations, only along the northern side of the Keweenaw Peninsula do medium-size (~700 mm) fish also have consistently high concentrations. This map includes fish concentrations measured over the period 2000-2020.

These findings are corroborated by our measurements shown in Figure 4. At all fish sizes, concentrations of PCBs were higher in fish from MI3 than in fish from MI4. A t-test for samples in the size range of 400-750 mm indicates a significantly higher ($p < 0.05$) concentration for MI3 fish. Slopes of the regression lines are statistically distinct at the 90% confidence level. The fish analyzed in this study were caught in the period 2013-2019 so the difference shown in Figure 6 does persist over the decade 2010-2020.

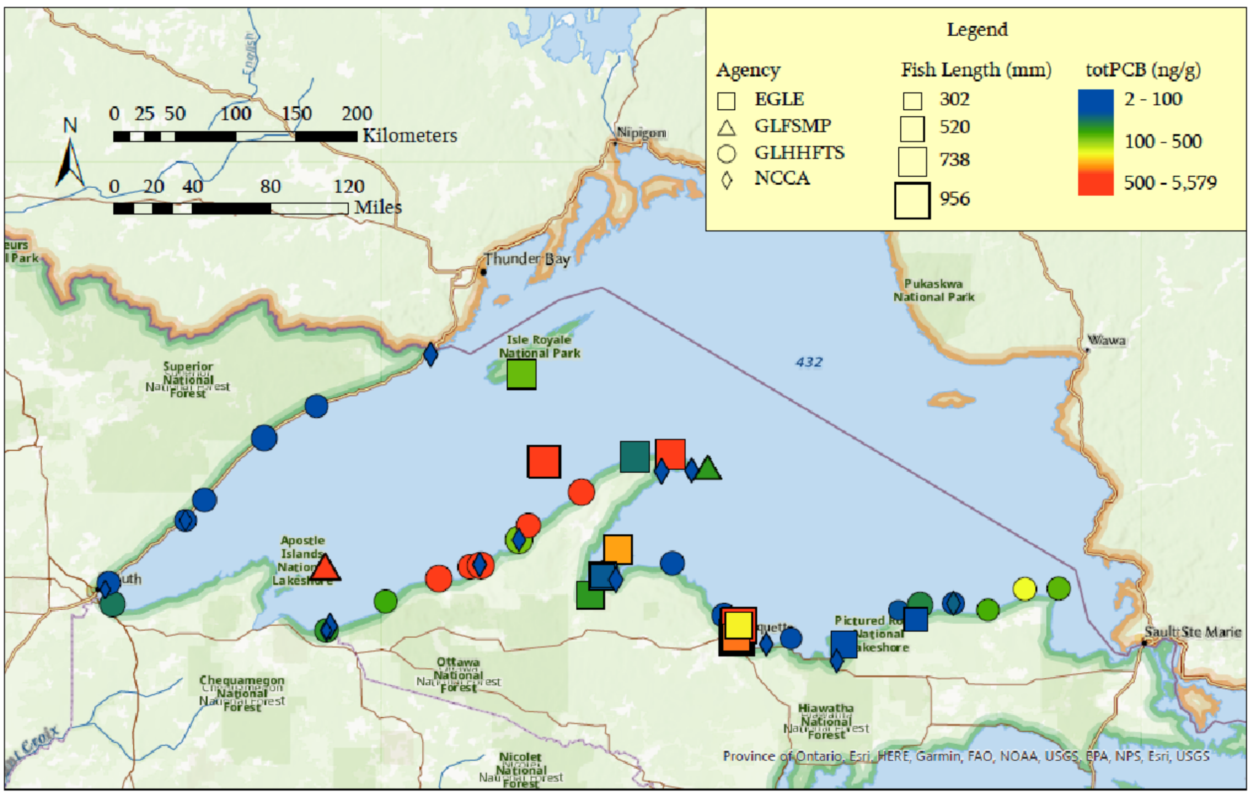

Figure 7. Distribution of PCB concentrations in lean lake trout. Data are segregated according to agency source and fish size. The map shows a localized preponderance of high concentrations (red) along the northern shore of the Keweenaw Peninsula.

Although PCB concentrations are different on the two sides of the peninsula, this does not translate into a large difference in the recommended fish consumption rates of fish from MI3 and MI4 (Fig. 6). The recommended consumption rate for the sensitive population in MI3 and MI4 is less than one meal per month. The estimate of total toxicity shown in Figure 6 is driven primarily by dioxin-like PCBs, a particularly toxic subclass that represents only a small fraction of total PCBs. Because the recommended consumption rate calculated for dioxin-like PCBs is much less than that calculated for methylmercury, it is important that GLIFWC, KBIC and other tribes either monitor PCBs in Lake Superior or post consumption guidelines based on state agency monitoring.

4b. Evaluation of hypotheses for higher concentrations

Although the spatial differences in PCB concentrations do not have large implications for fish consumption guidance, they do point to spatial differences in internal processes within the lake. The two hypotheses that we sought to evaluate were that (1) spatial differences in PCB concentrations were driven by differences in food web structure, and (2) the differences are driven by resource availability. Hypothesis one would be implicated if top predator fish in MI3 had a higher trophic position (as indicated by $\delta^{15}N$) than those fish in MI4 or if the food web in MI3 was supported by a larger consumption of benthic macroinvertebrates than in MI4. Our measurements of stable isotope ratios showed very little difference in $\delta^{15}N$ for Cisco, lake whitefish and lake trout between MI3 and MI4. These results suggest that hypothesis does not explain the spatial difference in measured PCB concentrations. Furthermore, recent comparison of dietary difference between the two management units revealed that lean lake trout in MI4 consume more benthic invertebrates than those in MI3 (Edwards 2023).

Our measurements of $\delta^{13}C$, however, do show a consistent difference in carbon sources for the two management units. The spread of $\delta^{13}C$ was much greater for each individual fish species (Cisco, lake whitefish, lean lake trout) as well as for the food chain extending from Cisco through lake trout. We do not yet know the cause of this greater variety in food sources in MI4, and we suggest that it warrants further study. More refined diet analysis (e.g., using e-DNA) might be capable of showing species differences in organisms consumed in MI4 as compared to MI3. There has not been a study of the variation of ^{13}C with water depth in benthic macroinvertebrates in Keweenaw Bay as has been done for the other side of the Keweenaw Peninsula (Sierszen et al. 2014).

This study did not find indications of greater resource availability in MI4. Neither lipid contents nor condition factors (not shown in this report) were higher in MI4 than MI3. Thus it would appear to be qualitative difference in resources rather than resource abundance that may be causing observed spatial patterns in PCBs.

4c. Possible management responses to research findings

We did not measure PCB concentrations in paired skin-on and skin-off fillets of any fish species, and therefore we cannot compare our results with skin-on PCB concentrations measured by the U.S. EPA and the State of Michigan. Zhang et al. (2013) concluded that lipid distribution within a fish body is the most influential factor in determining the distributions of lipophilic organic contaminants such as PCBs. In this way, lipid content serves as an indicator for PCB concentration - the higher the lipid content the higher the PCB content and vice versa.

Importantly, in lake whitefish, the slope of the line of lipid content of skin-on fillets vs. lipid content of skin-off fillets was less than 1, which means that skin-on fillets contain less lipid and by inference, lower PCB concentrations than skin-off fillets. This finding leads to the recommendation that people should consume whitefish fillets with the skin left on.

Skin removal has been found to increase mercury content, because fish skin contains less mercury than the other parts of fish fillets. The reason for this chemical behavior is specific to mercury, which mainly accumulates in fish muscles in methylmercury form by bonding with sulfur-bearing amino acids (Dellinger et al. 1995; as cited by Zhang et al. (2013)).

As found by Zhang et al. (2013), studies have shown inconsistent results on the reduction of organic contaminants by removing fish skin and flesh. The authors found that removing skin significantly reduced concentrations of legacy organic contaminants found in brown trout, Chinook salmon, and coho salmon, but the reduction was insignificant in rainbow trout. They also concluded that although skin removal tends to increase mercury concentrations in brown trout, coho salmon and rainbow trout, the total intake of mercury for a given meal size will be lower for the skin-off fillet compared to the corresponding skin-on fillet. Because, when you account for removing the mass of skin there is lower fish mass and the mass of PCB consumed is then less (i.e., a lower mass of fish (g) × PCB concentration (ng/g) gives a lower PCB mass consumed), the authors concluded that trimming skin from fish fillet before consumption is helpful in reducing exposure to toxic contaminants.

5. Conclusions

We conclude with recommendations for the KBIC drawn from this study:

1. Harvest small fish;
2. In Lake Superior it is important to monitor fish PCBs or to post consumption guidelines based on state agency monitoring;
3. Before consuming lake trout remove the skin;
4. Avoid eating large lake trout caught to the west of the Peninsula;

Basis for Recommendation 1: As the analysis shown in Figure 5 demonstrates, PCB concentrations increase exponentially with fish size. Eating small fish exposes people to lower PCB concentrations.

Basis for Recommendation 2: The estimate of total toxicity shown in Figure 6 is driven primarily by dioxin-like PCBs, a particularly toxic subclass that represents only a small fraction of total PCBs. Because the recommended consumption rate calculated for dioxin-like PCBs is much less than that calculated for methylmercury, it is important that GLIFWC, KBIC and other tribes either monitor PCBs in Lake Superior or post consumption guidelines based on state agency monitoring.

Basis for Recommendation 3: Removing the skin will decrease PCB concentrations in lake trout (Figure 2). Others have concluded, based on mercury measurements alone, that removing the skin increases methylmercury concentrations, and therefore recommended not removing the skin. GLIFWC follows this practice in their walleye Hg monitoring program (Moses 2020). However, because PCBs contribute more to the total toxicity than does mercury(Figure 5), and also because a lower mass of fish resulting from skin removal causes less total PCBs to be consumed, we recommend removing the skin prior to consumption of lake trout. In the case of whitefish, the skin-on/skin-off results in Figure 2 indicate that removing the skin will increase PCB concentrations. However, because skin removal results in a lower weight of the fillet which, in turn, results in lower total PCBs consumed, removing the skin may decrease the total mass of PCBs consumed. A basis for a final recommendation can be formulated by estimating the weights of these contradicting factors in determining PCB concentrations. These calculations could also take into account the greater toxicity of the dioxin-like PCBs relative to total PCBs. Whether or not removing the skin of whitefish prior to consumption decreases toxicity cannot be concluded at this time. In the case of walleye, the toxicity of total PCBs is equivalent in skin-on and skin-off fillets. Consideration could be given to making the recommendations easier to follow. One recommendation (to remove skin) would be easier to communicate, remember, and put into practice.

Basis for Recommendation 4: As Figures 4 and 6 demonstrate, only a very small quantity of large lake trout from the western side of the Peninsula can be safely consumed. We recommend that the grandmother fish from the western side of the peninsula be released if caught.

Recommendations for Future Work:

This work also leaves some unanswered science questions that have implications for human activities and our understanding of our underwater kin. We do not know why fish in Keweenaw Bay eat a wider variety of food, and nor do we know what constitutes that wider variety of food. Techniques more sensitive than gut content analysis (e.g., e-DNA analysis of gut contents) might help to clarify what is being eaten. Once we know what is being eaten, we can better frame a study of why a greater variety of food is eaten. Only once we know the pressures on fish that cause the behavior can we design management practices that maximize benefits to fish. It also is possible that the different diet of MI4 fish relative to MI3 fish renders one population richer in desirable constituents such as omega-3 fatty acids. A deeper understanding of the ecosystem should help us to improve relationships between humans and fish.

This study did not answer the question of why MI3 fish have higher PCB contents. A next step in answering that question would be to measure PCBs throughout the food web to understand the major sources of PCBs to each fish population.

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Appendix

Appendix A. Quality Control

Appendix B. Results of Analyses

Appendix C. Objective 3 Research Supporting Documents

Appendix A. Quality Control

A.1 Limit of Detection – The limit of detection (LOD) is determined by comparing the deviations from the mean of 7 replicate injections of a method blank spiked with target analyte to deviations from the mean of 7 replicate injections of an unspiked method blank. The greater of these is the limit of detection. See the Quality Assurance Project Plan (QAPP) for details.

Table A.1 Limit of Detection (ng/g)

Congener	LOD	Congener	LOD	Congener	LOD	Congener	LOD	Congener	LOD
PCB001	0.12	PCB051	0.09	PCB104	0.18	PCB154	0.24	PCB200	0.08
PCB002	0.28	PCB052/073	0.24	PCB105/127	0.13	PCB155	0.03	PCB201	0.29
PCB003	0.18	PCB053	0.14	PCB109/107	0.25	PCB156	0.11	PCB202	0.00
PCB004/010	0.17	PCB054	0.06	PCB110	0.29	PCB157	0.12	PCB203/196	0.20
PCB005	0.14	PCB055	0.08	PCB112	0.20	PCB159	0.18	PCB204	0.07
PCB006	0.16	PCB056/060	0.24	PCB113	0.22	PCB160/158	0.18	PCB205	0.18
PCB008	0.25	PCB058	0.05	PCB114	0.19	PCB161	0.07	PCB206	0.13
PCB009/007	0.16	PCB059	0.26	PCB115	0.29	PCB162	0.03	PCB207	0.05
PCB011	0.31	PCB061	0.09	PCB117	0.38	PCB164/163/138	0.13	PCB208	0.06
PCB012/013	0.32	PCB063	0.05	PCB118/106	0.17	PCB165/142	0.12	PCB209	0.08
PCB014	0.17	PCB064/068/041	0.29	PCB119	0.16	PCB166	0.06	PCB83/108	0.27
PCB015	0.35	PCB065/62	0.15	PCB120	0.31	PCB167	0.09	o,p'-DDT	0.20
PCB017	0.29	PCB066	0.23	PCB121	0.24	PCB169	0.22	o,p'-DDE	0.14
PCB018	0.15	PCB067	0.11	PCB122	0.19	PCB170	0.62	o,p'-DDD	0.15
PCB019	0.16	PCB069	0.27	PCB123	0.16	PCB171	0.07	p,p'-DDT	0.20
PCB021/020/033	0.30	PCB070	0.32	PCB124	0.31	PCB172/192	0.10	p,p'-DDE	1.18
PCB022	0.25	PCB071	0.15	PCB125/111	0.24	PCB173	0.22	p,p'-DDD	0.07
PCB023	0.20	PCB072	0.21	PCB126	0.11	PCB174	0.01	cis-Chlordane	0.07
PCB025	0.20	PCB074	0.14	PCB128	0.07	PCB175	0.11	trans-Chlordane	0.42
PCB026	0.18	PCB076/080	0.36	PCB129	0.07	PCB176	0.04	cis-Nonachlor	0.19
PCB027/024	0.25	PCB077	0.13	PCB130	0.08	PCB177	0.06	trans-Nonachlor	0.32
PCB028	0.32	PCB078	0.35	PCB131	0.09	PCB178	0.05	Oxychlordane	0.03
PCB029	0.17	PCB079	0.19	PCB132/168	0.11	PCB179	0.03	Aldrin	0.09
PCB030	0.15	PCB081	0.26	PCB133	0.32	PCB180	0.19	Endrin	0.03
PCB031	0.27	PCB082	0.13	PCB134	0.19	PCB181	0.15	Endrin aldehyde	0.05
PCB032/016	0.20	PCB084	0.16	PCB135/144	0.22	PCB182/187	0.15	Endrin ketone	0.05
PCB034	0.19	PCB086	0.11	PCB136	0.03	PCB183	0.07	Dieldrin	0.20
PCB035	0.31	PCB087/116/85	0.28	PCB137	0.04	PCB184	0.02	a-BHC	0.17
PCB036	0.28	PCB088	0.15	PCB139/149	0.10	PCB185	0.03	b-BHC	0.18
PCB037	0.44	PCB091	0.02	PCB140	0.04	PCB186	0.02	g-BHC (lindane)	0.20
PCB038	0.24	PCB092	0.23	PCB141	0.02	PCB188	0.03	d-BHC	0.18
PCB039	0.28	PCB093/095	0.13	PCB143	0.07	PCB189	0.33	Endosulfan I (alpha isomer)	0.24
PCB040/57	0.34	PCB094	0.04	PCB145	0.26	PCB190	0.21	Endosulfan II (beta isomer)	0.08
PCB042	0.39	PCB096	0.14	PCB146	0.14	PCB191	0.07	Endosulfan sulfate	0.03
PCB043/049	0.19	PCB097	0.16	PCB147	0.02	PCB193	0.09	Heptachlor epoxide	0.05
PCB044	0.21	PCB098/102	0.20	PCB148	0.23	PCB194	0.10	Methoxychlor	47.31
PCB045	0.18	PCB099	0.18	PCB150	0.03	PCB195	0.08	Mirex	0.03
PCB046	0.17	PCB100	0.08	PCB151	0.20	PCB197	0.00	Hexachlorobenzene	6.90
PCB047/075/048	0.29	PCB101/90/089	0.29	PCB152	0.20	PCB198	0.06	Pentachloroanisole	0.21
PCB050	0.12	PCB103	0.29	PCB153	0.40	PCB199	0.18	Tetradifon	0.13

A.2 Measurement Precision

Measurement precision was determined by first computing the standard deviation (SD) of 3 duplicates using the following equation:

$$SD = \sqrt{\frac{\sum\left(0.5(x_1 - x_2)\right)^2}{n-1}} \quad \text{(A-1)}$$

where x_1 and x_2 are the concentrations of the analyte in replicates 1 and 2 and n = 3 pairs. The relative standard deviation (RSD), computed as

$$RSD = \frac{SD}{mean} \times 100\% \quad \text{(A-2)}$$

75% of the samples had RSDs of 18% or less, and 90% of the samples had RSDs of 32% or less. The following table contains RSDs of the 3 duplicates.

Table A.2. Concentrations (ng/g) of duplicate lake trout samples and associated RSDs.

Name	B1403F10289	B1410DUP10289	B1504F13	B1511DUP13	B1608F12739	B1609DUP12739	RSD (%)
a-BHC	0.22	0.23	0.42	0.35	0.34	0.43	7%
cis-Chlordane	1.88	1.86	0.44	0.37	2.93	3.55	14%
cis-Nonachlor	14.90	12.68	1.78	1.63	21.66	24.65	2%
Dieldrin	6.13	6.81	4.19	4.26	5.72	6.72	15%
Endosulfan II	0.97	0.89	0.20	0.21	0.88	0.70	18%
Endrin	0.90	1.00	0.05	0.03	0.19	0.16	5%
Endrin ketone	0.96	0.84	0.77	0.80	1.11	1.30	6%
Heptachlor epoxic	0.99	1.13	0.88	0.77	0.81	0.87	5%
Mirex	0.65	0.60	0.09	0.10	2.63	2.12	26%
Oxychlordane	0.65	0.73	0.62	0.88	1.81	2.27	34%
p,p'-DDD	1.61	1.43	0.18	0.22	3.16	3.85	16%
p,p'-DDE	36.57	33.33	7.31	3.25	153.17	169.95	7%
p,p'-DDT	6.72	5.94	0.81	0.96	7.68	7.61	7%
PCB061	0.48	0.45	0.36	0.31	3.21	1.28	99%
PCB086	0.78	0.68	0.16	0.13	1.66	1.53	15%
PCB091	0.12	0.10	0.03	0.02	0.45	0.36	29%
PCB099	2.41	2.06	0.47	0.46	9.01	8.71	9%
PCB105/127	1.05	0.82	0.20	0.20	3.62	3.66	6%
PCB110	1.65	1.48	0.37	0.37	4.90	5.38	7%
PCB118/106	3.42	2.45	0.31	0.56	11.74	12.11	3%
PCB123	0.25	0.21	1.07	0.19	3.36	3.38	32%
PCB128	2.61	2.06	0.26	0.25	7.01	7.63	1%
PCB130	1.48	1.27	0.19	0.18	3.06	2.92	12%
PCB132/168	0.24	0.21	1.53	1.63	23.64	56.34	118%
PCB137	0.78	0.67	0.09	0.09	2.55	2.54	5%
PCB139/149	1.57	1.27	0.20	0.18	3.24	2.96	19%
PCB141	1.57	1.40	0.13	0.11	5.38	5.38	4%
PCB146	5.63	4.74	0.64	0.62	15.00	15.26	5%
PCB147	0.29	0.22	0.04	0.03	0.85	0.78	21%
PCB153	25.98	20.87	3.12	2.99	83.39	96.54	10%
PCB156	1.56	1.37	0.23	0.19	0.36	4.75	148%
PCB160/158	0.43	0.38	1.36	1.28	35.02	33.83	6%
PCB162	0.33	0.27	0.04	0.04	0.91	0.94	3%
PCB164/163/138	7.32	5.92	0.86	0.84	22.07	21.40	11%
PCB165/142	2.13	1.80	0.30	0.29	6.57	6.57	6%
PCB167	2.60	2.04	0.26	0.25	7.12	5.84	31%
PCB171	0.86	0.74	0.11	0.09	3.11	3.24	0%
PCB174	1.36	1.08	0.17	0.16	2.85	2.81	12%
PCB175	0.21	0.16	1.39	1.33	29.71	28.83	5%
PCB177	2.90	2.33	0.31	0.26	7.46	7.53	8%
PCB178	1.57	1.37	0.17	0.17	4.29	4.81	8%
PCB180	10.89	9.72	1.12	1.13	42.71	50.54	17%
PCB182/187	3.91	3.20	0.48	0.47	3.65	13.82	111%
PCB183	2.12	1.82	0.25	0.25	8.73	9.34	4%
PCB193	0.99	0.92	0.11	0.11	35.41	3.80	230%
PCB197	0.18	0.16	0.01	0.01	0.62	0.78	23%
PCB199	2.64	2.39	0.21	0.21	9.12	8.52	11%
PCB202	0.83	0.72	0.07	0.06	2.54	2.68	1%
trans-Nonachlor	20.80	20.08	2.80	2.70	36.84	42.11	11%

A.3 Surrogate Standard Recoveries

The following table provides recoveries of surrogate standards in 40 fish samples. The acceptability criteria for surrogate standard recoveries in the QAPP is that recovery be > 50% and less than 150%. The average recoveries of all four surrogate standards were within these limits. Few recoveries were < 50%. A larger number of the two larger C-13 labeled standard PCBs 189 and 209 had recoveries > 150%. Recoveries of these standards also exhibited higher RSDs.

Table A.3. Surrogate Standard Recovery Statistics

Surrogate Standard	**PCB015 (13C)**	**PCB155 (13C)**	**PCB189 (13C)**	**PCB209 (13C)**
Average Recovery (%)	70%	62%	150%	114%
Standard Deviation (%)	31%	15%	96%	77%
Relative Standard Deviation (%)	45%	25%	64%	67%
Minimum	17%	19%	21%	17%
Maximum	186%	95%	351%	296%
Number < 50%	9	8	2	6
Number > 150%	1	0	15	14
Total Number	40	40	40	40

A.4 Standard Reference Material Recovery

Standard Reference Material (SRM) 1946 Lake Superior Lake Trout was purchased from the National Institute of Standards and Technology (NIST). This material is characterized in an exhaustive manner for chemical constituents including PCBs and organochlorine pesticides, as reflected in the NIST certificate of analysis (CoA). The 1946 SRM was measured 5 times, and the average was compared to the NIST CoA value. All measurements of averages were greater than the LOD of the analyte. The average recovery of all samples for all analytes was 81%. Of 39 analytes that were present at concentrations greater than the detection limit, 4 had recoveries greater than the upper limiting criterion of 140%, and 15 had recoveries less than the lower limiting criterion of 60%.

Table A.4. Standard Reference Material 1946 L. Superior Lake Trout Recoveries.

Compound	NIST Meas'd. Conc. (ug/kg)	95% CI (ug/kg)	Avg Meas'd. Conc. (ug/kg)	95% CI (ug/kg)	This Study/NIST
PCB 44	4.66	0.86	2.83	0.40	61%
PCB 49	3.8	0.39	1.27	0.39	33%
PCB 52	8.1	1	1.92	0.47	24%
PCB 66	10.8	1.9	7.42	1.61	69%
PCB 70	14.9	0.6	10.49	2.27	70%
PCB 74	4.83	0.51	3.41	0.77	71%
PCB 77	0.327	0.025	0.94	0.21	287%
PCB 87	9.4	1.4	2.72	0.53	29%
PCB 95	11.4	1.3	4.05	0.90	36%
PCB 99	25.6	2.3	20.81	4.17	81%
PCB 101	34.6	2.6	14.63	9.14	42%
PCB 105	19.9	0.9	6.50	5.23	33%
PCB 110	22.8	2	17.64	3.44	77%
PCB 118	52.1	1	19.48	14.87	37%
PCB 126	0.38	0.017	1.19	0.45	312%
PCB 128	22.8	1.9	9.69	2.09	43%
PCB 138	115	13	35.98	3.27	31%
PCB 146	30.1	3.5	22.51	3.05	75%
PCB 149	26.3	1.3	8.47	0.87	32%
PCB 153	170	9	126.98	14.28	75%
PCB 156	9.52	0.51	5.47	5.81	57%
PCB 169	0.106	0.014	0.16	0.03	156%
PCB 170	25.2	2.2	19.71	3.56	78%
PCB 180	74.4	4	68.86	12.68	93%
PCB 183	21.9	2.5	14.61	2.72	67%
PCB 187	55.2	2.1	15.73	2.46	29%
PCB 194	13	1.3	8.76	0.81	67%
PCB 195	5.3	0.45	3.20	0.55	60%
PCB 206	5.4	0.43	2.92	0.90	54%
PCB 209	1.3	0.21	0.68	0.42	52%
Oxychlordane	18.9	1.5	15.09	13.91	80%
cis-Chlordane	32.5	1.8	23.91	7.36	74%
trans-Chlordane	8.36	0.91	4.92	5.09	59%
cis-Nonachlor	59.1	3.6	60.31	8.25	102%
trans-Nonachlor	99.6	7.6	84.31	91.42	85%
p,p'-DDE	373	48	448.56	89.59	120%
o,p'-DDD	2.2	0.25	2.76	0.91	126%
p,p'-DDD	17.7	2.8	19.56	7.89	110%
p,p'-DDT	37.2	3.5	71.08	9.61	191%

Appendix B. Results of Analyses

B.1 Toxics Concentrations – available upon request as a Microsoft Excel file

B.2 Skin-on vs. Skin-off Lake Trout Lipid Content Comparison

Table B.2. Comparison of skin-off to skin-on paired walleye fillet lipid content.

Species	Skin-off % lipid	Skin-on % lipid	Skin-off Avg (%)	Skin-on Avg (%)	n	Slope	Intercept	r^2	p-value
Lake Trout			8.2	10.4	10	1.08	1.04	0.7579	0.0007
	11.0	14.3							
	6.4	9.1							
	10.9	14.6							
	9.8	13.0							
	6.2	8.8							
	5.8	7.7							
	8.5	9.5							
	6.0	8.1							
	9.0	10.0							
	9.0	8.5							
Lake Whitefish			7.6	9.0	14	0.85	2.48	0.6778	0.0051
	7.0	9.2							
	6.7	10.4							
	5.9	8.4							
	2.5	5.6							
	10.5	14.0							
	7.2	8.9							
	7.4	6.7							
	9.1	9.2							
	9.9	11.4							
	13.3	14.2							
	8.2	6.6							
	5.7	7.5							
	6.1	7.1							
	6.3	6.5							
Walleye			3.8	3.5	12	0.33	2.23	0.0851	0.5444
	1.7	4.0							
	4.3	3.0							
	6.0	5.8							
	4.2	3.4							
	4.3	2.9							
	3.7	3.0							
	3.5	6.9							
	4.0	1.9							
	1.2	2.1							
	4.2	2.8							
	3.2	2.3							
	5.0	3.5							

B.3 Moisture, Lipid, and Stable Isotope Content

Table B.3. % Lipid, % Moisture, and Stable Isotope Content of Lake Trout Samples. Empty cells indicate that the data has not yet been obtained.

MTU code	GLIFWC Fish Identifier	MU	% Lipid	% Moisture	$\delta^{13}C$ lipid-normalized (‰)	$\delta^{15}N$ (‰)
B1403F10289	CPH 10289	MI3	11.1			
B1404F10385	CPH 10385	MI3	11.1			
B1405F10374	CPH 10374	MI3	8.68			
B1406F11500	BFR 11500	MI3	16.32			
B1407F10383	BFR 10383	MI4	10			
B1408F10237	BFR 10237	MI4	8.47			
B1409F10235	BFR 10235	MI4	7.35			
B1410DUP10289	CPH 10289	MI4	9.25			
B1502F25	KWN-25	MI4	3.9	78.80%	-23.06	9.1
B1503F13	KWN-13	MI4	4.98	77.60%	-24.36	9.0
B1504F21	KWN-21	MI4	6.37	74.40%	-23.99	9.4
B1505F16	KWN-16	MI4	6.43	79.70%	-21.57	9.9
B1506F12748	CPH-12748	MI3	8.14	75.00%	-24.60	9.2
B1507F12740	CPH-12740	MI3	6.18	75.40%	-24.28	10.1
B1508F6871	CPH-6871	MI3	8.37	73.70%		
B1509F12738	CPH-12738	MI3	6.29	76.10%	-23.77	10.0
B1510DUP13	KWN-13	MI4	4.98	77.60%	-24.36	9.0
B1602F10243	BFR-10243	MI4	6.11			
B1603F10237	BFR-10237	MI4	7.35			
B1604F13998	BFR-13998	MI4	6.35			
B1605F10385	CPH-10385	MI3	8.68			
B1606F10276	CPH-10276	MI3	7.54			
B1607F12743	ERS-12743	MI3	6.89	74.40%	-23.97	9.1
B1608F12739	CPH-12739	MI3	4.59	74.40%		
B1609F5	HIS-5	MI4	4	64.90%		
B1610F12739dup	CPH-12739	MI3	4.59	74.40%		

Appendix C. Objective 3 Research Supporting Documents

C.1 April 20, 2023 Zeba Community Partner Meeting Program

Hosted by
Keweenaw Bay Indian Community Natural Resources Department, Michigan Tech, and Great Lakes Indian Fish and Wildlife Commission

Tribal Landscape System Community Partners Meeting

Thursday April 20, 2023
9:00am-3:00pm
Zeba Community Hall
16141 Zeba Road, Zeba, MI 49946

Lunch and Refreshments Provided by
Kat and Sam Catering
Sponsored by 8th Fire Consulting, LLC.

Tribal Landscape System

Project Overview

This project brings together natural and social sciences researchers and tribal community partners in the Upper Peninsula of Michigan to **better understand toxic contamination and climate-related changes** across the water-rich landscape.

The team aims to **map** the extent of the region's mercury and organic toxics, e.g., polychlorinated biphenyl (PCB) compounds, contamination and fatty acid nutrients in fish in inland lakes, and concurrently, map tribal harvesting practices, valued resources, and climate-related changes across the landscape to categorize lakes and specific practices as low, moderate, or high risk.

The project team will also explore particular **management and outreach** scenarios in order to minimize contamination risk, respond to climate-related consequences, and support human-environment relationships that promote the health and wellbeing of the UP environment and its communities.

Finally, the project team's engagement in **bridging Western and Indigenous sciences** and expertise will be assessed to identify successes and challenges, and to contribute to the growing scholarship in university and Indigenous community partnerships.

What is the KBIC Tribal Landscape System?

The tribal landscape system (TLS) is a broad yet specific term we use to describe the soil, rock, and minerals that make up the **lands** we live within, the **waters** that criss-cross and richly inundate parts of the land, the **winds** and air that fill our lungs and blow through the trees, and the **many beings** inhabiting the lands, waters, and airways throughout the Keweenaw and the surrounding Ojibwa homelands.

In particular, the tribal landscape system is the many multi-directional and **constellation of relationships** between the land, water, wind, and living systems at any given time and between time(s). The system also consists of a **history** that informs the present day and will continue to inform the future - the dynamic geologic processes and events reflecting Earth's deep time, as well as **diverse human ideas and values** such as political borders, trade and economy, treaty law, and conceptions of property, ownership, natural resources, and more.

Scan the QR code to find more information about the Tribal Landscape System research project

Great Lake Research Center
Michigan Technological University

NSF AWARD #2009258 - CNH2-S: Convergence Research: Bridging Knowledge Systems and Expertise for Understanding the Dynamics of a Contaminated Tribal Landscape System.

Agenda for the Day

8:45 Doors Open

Coffee and Light Refreshments

9:00 Welcome and Introductions

9:15 Knowledge Exchange

- **Synthesizing Keweenaw Bay Indian Community Knowledge and Practice for Socio-Cultural Mapping-** *Valoree Gagnon*
- **Values, Ethics, and Practices of Keweenaw Bay Indian Community Landscape Relations-***Erika Vye*
- **Ecosystem Health-** *Noel Urban, Judith Perlinger, Enid Partika, Libia Hazra, Azmat Naseem, and Molly Greene*
- **What's in the Fish We Eat?-** *Judith Perlinger, Noel Urban, Enid Partika, Azmat Naseem, Libia Hazra*

10:45 Refreshment Break

11:00 Breakout Session 1

Fish for Seven Generations (*Valoree Gagnon*)

11:30 Share Out

12:00 Lunch

Soup and Sandwiches by Kat and Sam Catering (*8th Fire Consulting*, LLC.)

1:00 Breakout Session 2

Tribal Landscape System Mapping (*Erika Vye, Robert Hazen, Daniel Lizzadro-McPherson*)

1:30 Refreshment Break

1:35 Breakout Session 3

Tribal Landscape System Diagram (*Valoree Gagnon*)

1:50 Refreshment Break

2:00 Share Out

2:45 Closing

NOTES

Worksheet: Breakout Session 1

Fish for Seven Generations

In what ways are fish important to you, your family, and your community?

Are there climate related changes you are observing and experiencing from season to season?

Please note other concerns that you have about fish.

NOTES

Worksheet: Breakout Session 2

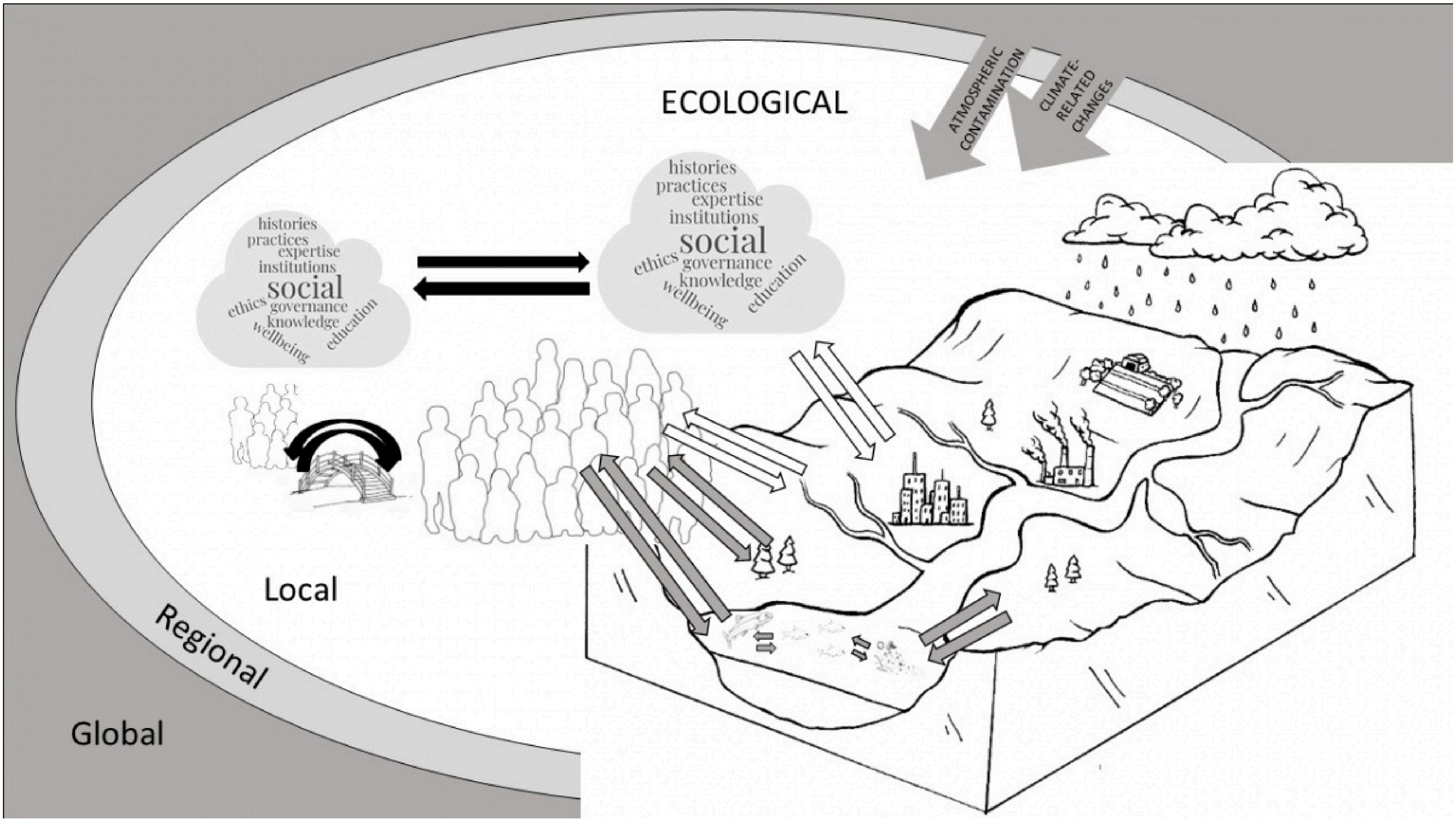
Tribal Landscape System Mapping

What landscape practices do you engage in? How do these relationships shift across seasons?

What are priority areas and places to protect? What changes to land and water are you seeing?

Draw, sketch, or note on the map what might be missing.

Working Model of Tribal Landscape System



TLS Diagram Description

KBIC Tribal Landscape System

Here, the tribal landscape system is the social and ecological system embedded within regional and global environments. The **social system** includes political and economic structures, the KBIC and its institutions, governance structures, histories, and knowledges, as well as kinship structures, Ojibwa practices, and culturally-important foods and foodways.

The TLS **ecological system** components include the area landscape of climate, watersheds, fish, and life webs. The KBIC are also connected to the same social and ecological relationships that anyone living in the Keweenaw (or elsewhere) are a part of and yet they are, at the same time, distinct.

Current Description

The tribal landscape system (TLS) **bridges the boundaries of ecological and social sciences** by including Indigenous science expertise and knowledge, demonstrating the "two-eyed" seeing approach to research and new discoveries (black arrows, with the non-Indigenous team members and their thoughts to the rear). The goal is to elucidate TLS linkages that are relevant to both Western and Indigenous ways of knowing.

Illustrated here, our working model of the tribal landscape system seeks to capture **multidirectional dynamics and interactions** of a social-ecological system that is perturbed by external forces of **atmospheric contaminant deposition and climate-related changes**. To understand how these influence and interact within the TLS, the project will characterize the ecological components of the TLS. The team will collect data to understand how **differences in watershed characteristics and food webs** result in lakes exhibiting different trophic magnification and contaminant mixtures (gray arrows).

To characterize how external perturbations impact the **human** biophysical components, the team will collect data on **fish harvesting and consumption** (gray arrows), and other landscape **practices** (lower white arrows). Analyses of these data will be used to clarify how the human social components interact reciprocally with the biophysical system (upper white arrows), through resource management (e.g., location of harvest, the magnitude of harvest, and stocking) and other governance and outreach mechanisms.

In turn, the team will evaluate how these actions affect both the **extent of contaminant biomagnification** and **potential exposure** (gray arrows), and the tribal knowledge of and kinship with the environment (upper white arrows). For example, the characterization of fish accounts for their role as part of the food web, in supporting tribal fisheries, and as a cultural keystone species. Changes in one component - e.g., contamination or degraded ecosystems - influences and affects the system as a whole.

Worksheet: Breakout Session 3

Tribal Landscape Diagram

What connections do you see? How do these relationships shift across seasons?

What are priority practices in the landscape?

Draw, sketch, or note on the map what might be missing.

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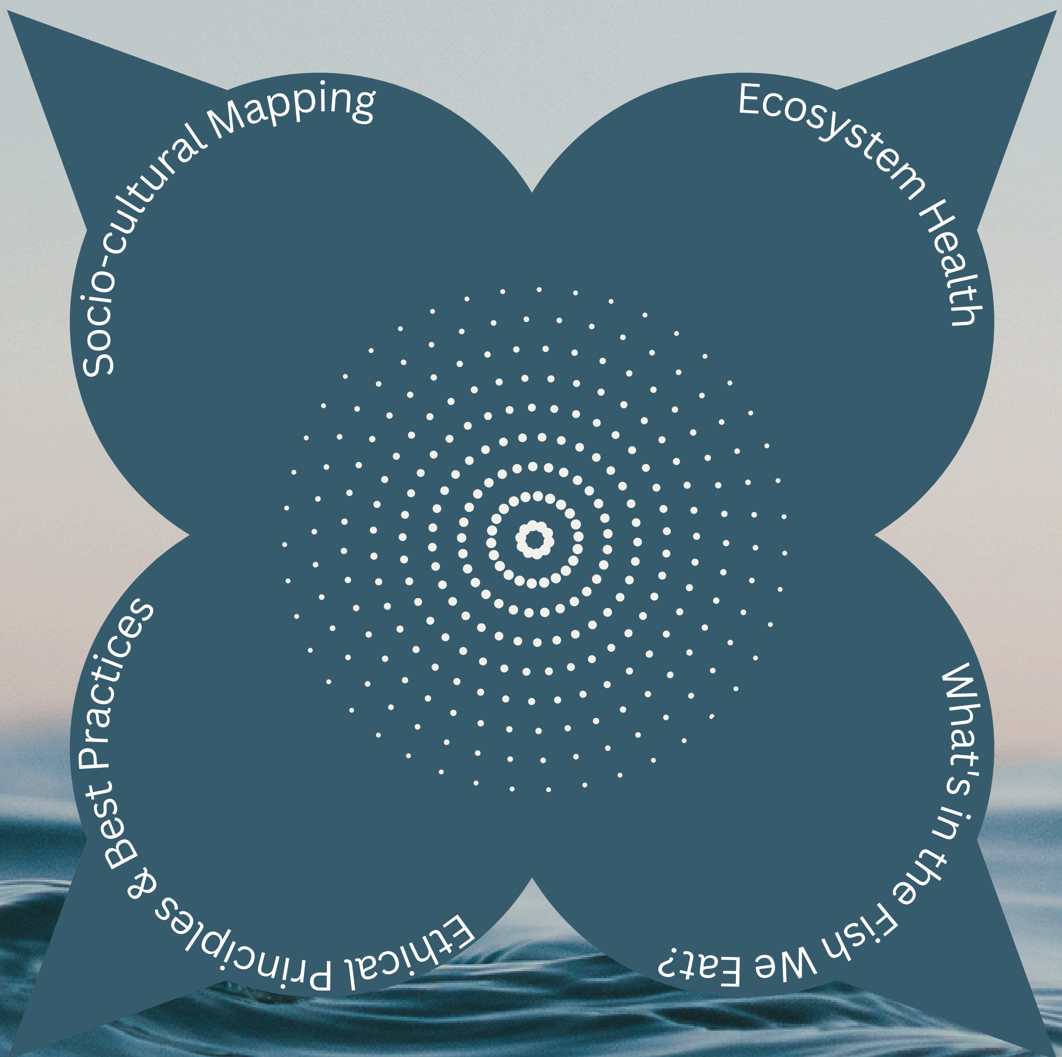
Chi miigwech for attending the Tribal Landscape System community partners meeting



TLS Community Partners Meeting Survey

Miigwech for attending our community partners meeting and sharing your voice and perspectives on our work. Your contributions are valuable to the work that we are doing! Please consider responding to the questions below to help our team improve for future community meetings and workshops. If you would like to complete this survey online, please scan the QR code to the side:

Where did you hear about today's meeting?

What was your favorite part of today's meeting?

What could have made your experience better today?

What did you hear about today that you would like to learn more about?

Do you have any suggestions for our next community meeting?

Additional comments, suggestions, or feedback:

C.2 Photos of April 20, 2023 Zeba Community Partner Meeting Program

C.3 Sandpoint Panels

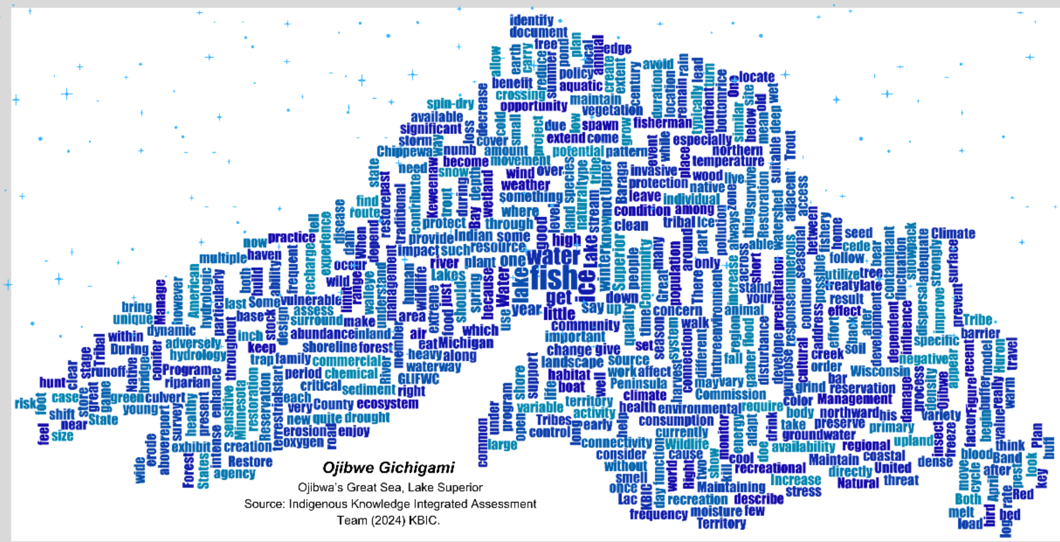
ENDAZHI-WIIKWEDONG, GIBIMINIZHA'WAANAANIG GIIGOONYAG

"In the Keweenaw, we follow the fish"

AKI GAYE BIMAADIZIWIN DAZHI-WIIKWEDONG

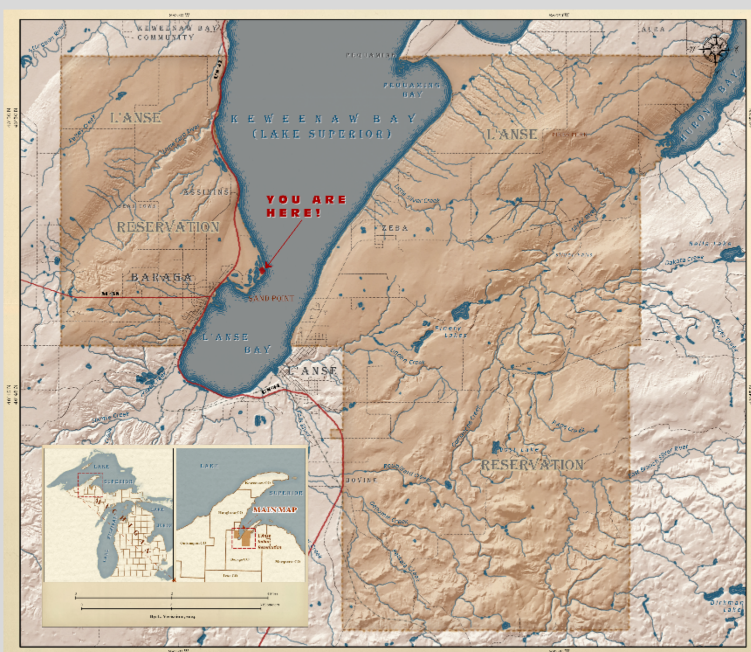
"Land and Life in Keweenaw Bay"

The Keweenaw Bay landscape is rich with waters and forests of many kinds where both human and more-than-humans are interconnected with seasons and climate cycles. Lives and livelihoods rely on respectful interactions, reciprocal practices, shared responsibilities and a reverence for each other.



Ojibwe Gichigami
Ojibwa's Great Sea, Lake Superior
Source: Indigenous Knowledge Integrated Assessment Team (2024) KBIC.

Who We Are



We are the Keweenaw Bay Indian Community (KBIC) Lake Superior Band of Ojibwa, dedicated to the long-term protection of natural resources and the preservation of Ojibwa culture. This commitment has contributed to our survival and resiliency for many generations.

We belong to the Three Fires Confederation, the peoples known as the Anishinaabeg. We are one of the largest Indigenous groups in the Americas with nearly 150 different bands living throughout present-day United States and Canada.

We are signatories to the Treaty of 1842, and established under the Treaty of 1854, the heart of KBIC is the L'Anse Indian Reservation, spanning 59,000 mostly forested acres, with extensive water resources, including 23 miles of Lake Superior shoreline, over 200 miles of streams and rivers, and nearly 5,000 acres of lakes and wetlands. In the U.S., Treaties are decreed to be the Supreme Law of the Land by the Constitution (Article VI, Clause 2). In 1936, we became the first federally recognized tribe in Michigan; we also currently retain the largest land base in the State.

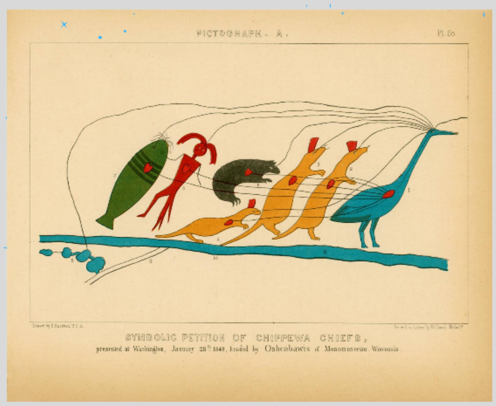
AANDAKIIWAN. AANJIWEBAD. GIBIMINIZHA'WAANAANIG.

"The season changes. The weather changes. We follow the fish."

For nearly two millennia, Ojibwa peoples have traversed the seasonal landscape following fish pathways within Lake Superior's deep waters, in Keweenaw Bay, and many inland lakes, streams, rivers, and creeks.

The First Treaty

According to Anishinaabeg teachings, passed from one generation to the next, the First Treaty with Gichi Manidoo (the Creator) includes reciprocal obligations with all orders of creation in perpetuity. Also known as Sacred Law, The Great Laws of Nature, and the original instructions, the First Treaty obligates each order of creation, all created from rock, water, fire, and wind – the physical world of sun, stars, moon and earth; the water and sky beings, plant and animal beings, and human beings – to care for one another and honor each other's autonomy. The Great Laws govern placement, movement, powers, rhythm, and continuity: all things live and work by these laws. ("Ojibway Heritage" Basil Johnston 1976)



"Symbolic Petition of Chippewa Chiefs"
(Wisconsin Historical Society 1851)

Ziigwang
(in the/when it is spring)

Ziigwan fishing is a time for spearing and netting across Ojibwa homelands. As the beginning of all seasons, in the spring we follow fish such as the Ogaa (Walleye), Giigoozens (Smelt), Namegoshens (Steelhead/Rainbow Trout), Maazhimegozi (Salmon), Odazhegomoo (Rock Bass), Noosa'owesi (Smallmouth Bass), Ashigan (Largemouth Bass), Namebin (Sucker) and Name (Sturgeon).

Niibing
(in the/when it is summer)

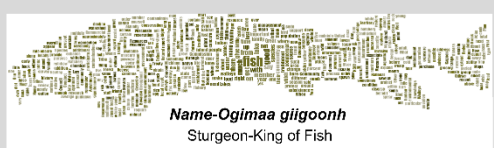
Niibin fishing uses netting practices, and hook and line, in many of the Keweenaw Peninsula's waterways and within Lake Superior. We follow fish pathways in the summer such as Namegos (Lake Trout), Adikameg (Whitefish), Ginoozhe (Northern Pike), Maashkinoozhe (Muskellunge, also known as muskie), Odazhegomoo (Rock Bass), Ashigan (Largemouth Bass) and Agwadaashi (Sunfish, also means bluegill and crappie).

Dagwaaging
(in the/when it is fall)

Dagwaagin provides fishing opportunities for netting, spearing, and angling across the watery landscape. Our people have been known to follow many fish in the fall, including Maazhamegosens (Brook Trout), Namegos (Brown Trout), Namegoshens (Steelhead/Rainbow Trout), Maazhimegozi (Salmon, coho and chinook), Maashkinoozhe (Muskellunge, also known as muskie), Okewis (Cisco or Herring), Ginoozhe (Northern Pike), and Noosa'owesi (Smallmouth Bass).

Biboong
(in the/when it is winter)

Biboon fishing takes place through the ice in waters big and small. Some of the fish followed by the people in the winter include Namegos (Lake trout), Ginoozhe (Northern Pike), Adikameg (Whitefish), Asaawens (Perch) and Mizay (Burbot or Eelpout).



INCREASING UNDERSTANDING OF LAKE SUPERIOR FISH COMMUNITIES

Lake Superior and Its Inhabitants

Gitchigami (Lake Superior) has the largest surface area of any freshwater lake in the world. It was formed when glaciers retreated about 10,000 years ago. The food web in the lake (Figure 1) captures energy from the sun and passes it from algae to zooplankton to small fish to large fish. Bottom dwellers (Diporeia, Mysis) capture settling food and recycle it back into the food web.

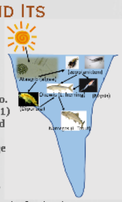


***Figure 1**. Simplified L. Superior food web.*

Our Relationships with Lake Superior Fish

Relationships between the Tribe and the environment have existed since time immemorial; each and every family today is linked to fishing in some way. As their ancestors did before them, subsistence fishermen continue harvesting for their families and community members as well as providing for both ceremonial and communal feasts. Fishing is the strand of the cultural core that ties history to present day to future; it is a vital part of the foundation for cultural beliefs and values, traditional lifeways, and individual identity.

Conditions are Changing

Earth is always changing. Rapid change makes it difficult to adapt. Changes include:

Invasive species - There are about 98 non-native species in L. Superior; 18% of fish species are non-native. Invasive species cause ~20% of all extinctions. Are invasives good or bad?

Excess nutrients - Inputs of phosphorus doubled in early 20th century before declining to present level. Nitrate increased 5-fold since 1900. Nutrient concentrations influence which species thrive.

Over-fishing - Fish populations fluctuated widely over the last century. Lake trout, herring, and white fish plummeted in 1950s from over-fishing and sea lampreys. By 1990s lake trout had recovered.

Altered landscape – The watershed of Lake Superior is 97% natural, only 2% developed and 1% agricultural. Nonetheless, rivers bring large inputs (e.g., salt, wastewater) and cause change locally and throughout lake.

Climate change - Warmer water, reduced ice cover, altered habitat boundaries, increased susceptibility to invasive species, and reduced reproductive success (e.g., lake herring) are some effects of changing climate.

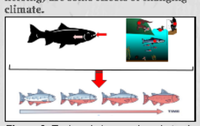


***Figure 3**. Toxic substances do not stay in water but absorb to organisms, a process called bioconcentration. Small organisms (algae and benthic invertebrates, Fig. 1) are consumed by small fish that are consumed by larger fish. that are then consumed by top predators (ducks. mink, otters, humans). The larger animals concentrate the chemicals, a process called biomagnification. Together, bioconcentration and biomagnification are referred to as bioaccumulation.*

Health Benefits of Fish Consumption

In addition to providing social and cultural health benefits, fish provide numerous biophysical health benefits. Fish have anti-oxidation, anti-inflammation, and wound healing properties in addition to protecting nerves, the heart and liver. Some fish proteins help to defend against viral and bacterial infections and prevent protein-calorie malnutrition. Fish oil constituents such as Omega-3 and -6 fatty acids promote healthy minds (Fig. 2).

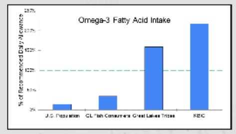


***Figure 2**. KBIC members obtain abundant healthy Omega-3 fatty acids.*

Why Are There Toxic Chemicals in L. Superior Fish?

Toxic contaminants are another change caused by humans. These toxics often accumulate in fish and may pose health risks when fish are eaten (Fig. 3).

Toxic chemicals such as polychlorinated biphenyl compounds (PCBs) and mercury are deposited into Lake Superior from the sky. Although Lake Superior is remote from large cities, its large surface makes it a good collector of chemicals from the air. Other contaminants are discharged in wastewater to the lake. The levels of the pollutants in Lake Superior water are very low. However, many toxic chemicals bioaccumulate in the food web and reach high concentrations in fish (Fig. 3). Consuming toxic substances in fish can harm the health of winged, four- and two-legged animals.

Safe Fish Consumption

Where fish are caught (Fig. 4), the size of fish, (Fig. 5) and the type of fish all affect the safety of eating fish. Small fish are safer to eat than large fish, Keweenaw Bay is safer than west of the Keweenaw, and herring and whitefish are safer than lake trout.

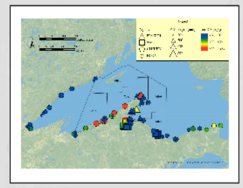


***Figure 4**. PCB concentrations in lake trout vary from place to place. Concentrations are highest on the western side of the Keweenaw Peninsula and are lower from Keweenaw Bay to Grand Island. Differences in the food webs in MI2/MI3 and MI4 cause the different PCB concentrations.*

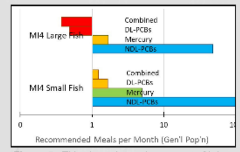


***Figure 5.** This chart shows the amount of lake trout from Keweenaw Bay that can be safely consumed by the general population. The top set of four bars is for large trout (> 24 inches), the bottom set is for small (< 24 inches) fish. The different bars show consumption guidelines based on different chemicals or all contaminants combined (top bar). Bar colors indicate safety levels from unsafe (red) to safe (blue).*

How Can We Improve Our Relationships with L. Superior Fish?

For ourselves, we can

- Choose locations to fish with low contaminant concentrations
- Eat smaller-sized fish
- Eat low on the food web
- Prepare fish to minimize contaminants
  - Remove skin and fatty areas
  - Avoid blackening fish

For the lake ecosystem, we can

- Act to reduce climate change
- Reduce pollution by, e.g., improving the treatment of wastewater to remove toxic substances such as microplastics and per- and polyfluoroalkyl substances (PFAS)
- Demand and support legislation and policy requiring best management practices for water- and airshed protection

MIIGWECH TO ALL OUR COLLABORATORS

Great Lakes RESTORATION

Great Lakes Indian Fish & Wildlife Commission

Michigan Tech

Keweenaw Bay Indian Community

Sea Grant MICHIGAN

United States Environmental Protection Agency

EGLE MICHIGAN DEPARTMENT OF ENVIRONMENT, GREAT LAKES, AND ENERGY