White Paper
Study of Fish Contaminants in Lakes in the Keweenaw Bay Indian Community Fishing Territory

U.S. EPA Environmental Justice or Other Appropriate Programs

Evelyn Ravindran[1], Dione Price[1], Gene Mensch[1], Bill Mattes[2], Sara Moses[2], Esteban Chiriboga[2], Noel R. Urban[3], Judith A. Perlinger[3], Valoree S. Gagnon[3]

1. Keweenaw Bay Indian Community, Natural Resources Dept.
2. Great Lakes Fish and Wildlife Commission
3. Michigan Technological University

Overview

The Keweenaw Bay Indian Community (KBIC) is the successor in interest of the L'Anse and Ontonagon Bands of Lake Superior Chippewa Indians, and signatories to the 1842 Treaty with the Chippewa (7 Stat. 591) and the 1854 Treaty with the Chippewa (10 Stat. 1109). Our community has long relied on subsistence harvesting throughout the landscape, and the fish harvest is particularly central to our harvesting lifeways. However, we are also aware that fish are contaminated with harmful bioaccumulative toxicants, and at this time, there are substantial lacks in fish contaminant data, cumulative toxicity impacts to human health, and outreach materials to guide safe cultural fishing practices in our community. In working with our research partners, we understand that there is an urgent need to estimate the cumulative toxicity of contaminants in fish throughout the study region and to evaluate statistical predictors of cumulative toxicity. Such research can provide decision-making guidance for KBIC, informing environmental policy, management strategies and educational initiatives, all of which supports the health and wellbeing of our fish-reliant community. In order to address these priorities, KBIC requests funding assistance from the Environmental Protection Agency to support this research with Michigan Technological University ("Michigan Tech") and the Great Lakes Indian Fish and Wildlife Commission (GLIFWC). In what follows, we provide the study's rationale and describe a potential workplan.

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 many Indigenous communities. Among the eleven member-tribes served by the Great Lakes Indian Fish and Wildlife Commission (GLIFWC), the average fish consumption rate is 10-fold higher than the U.S. average (O'Neill, 2004). For tribal communities, the value of inland and Great Lake (GL) fisheries is heightened due to community reliance 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 ecological, cultural, and educational health metrics for Indigenous communities. For all these reasons, many fish-reliant communities cannot or will not adhere to advisory recommendations. Threats to the availability and safety for consumption of fish negatively impact the health and wellbeing of the 100+ Indigenous nations within the GL region currently served by 36 tribal and inter-tribal governmental entities in the

U.S. **Redressing the burden of fish contamination is a pressing societal need** because many tribes as well as the general population of the Great Lakes region consume contaminants (via fish) at rates above accepted human health criteria (O'Neill, 2004) and lack the information required to maintain a safe fish-reliant diet.

A large number of chemicals, including legacy as well as new and emerging chemicals of concern, bioaccumulate to unhealthy levels in fish. For nearly five decades, monitoring of fish contaminants has shown chemical compounds at concentrations unsafe for GL area residents (GLIFWC, 2016; U.S.EPA, 2017). Many emerging contaminants have been found in fish, and many others likely remain to be analyzed (Crimmins et al., 2018; Deere et al., 2020; Fernando et al., 2018; Moore et al., 2018); however, the cumulative or mixture toxicity of all contaminants is unknown (Davis et al., 2016; Elliott et al., 2018; Gandhi et al., 2017; Hernandez et al., 2013). A significant challenge faced by fish-reliant communities is that toxic contamination is largely invisible (Gagnon et al., 2018). Nonetheless, multiple studies have documented an increase in contaminant exposure associated with consumption of GL fish (Christensen et al., 2016; Hanrahan et al., 1999; Humphrey et al., 2000). Human cohort studies have documented developmental impacts from fish contaminants at consumption rates existing in the GL region (Han et al., 2016; Jacobson and Jacobson, 1996a, b; Jacobson et al., 1984). In response, government agencies rely on fish consumption advisories or guidelines, advisory "recommendations" to limit consumption or to avoid particular water bodies and fish species (GLIFWC, 2016; MDCH, 2012; U.S.EPA, 2017). Currently, more than 80% of advisories in the

U.S. relate to mercury and polychlorinated biphenyl (PCB) contamination. All five Great Lakes have fish consumption advisories for PCBs, and three have advisories for mercury.

GL states account for more than half of the nation's total advisories (EPA, 2013), and all GL states have state-wide mercury advisories for fresh-caught fish (EPA, 2013; MDCH, 2012). For these reasons, an initial, small-scale project could focus on mercury and PCB contamination of fish, but we acknowledge the need for study of the larger mixture of contaminants of concern. Our research partners at MTU have the analytical capacity to examine numerous contaminants in both targeted and non-targeted strategies as funding permits.

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 PCBs, 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). We suggest that there is an urgent need to estimate the cumulative toxicity of contaminants in fish throughout the study region and to evaluate statistical predictors of cumulative toxicity.

Measurements of fish contaminants are sparse in remote, rural locations. There are approximately 5,000 lakes in Michigan's Upper Peninsula larger than one hectare and approximately 350 state-maintained boat access sites, but only 75 lakes with measurements of walleye mercury concentrations (Perlinger et al., 2018) and only 16 with measurements of walleye PCB concentrations (Shaw and Urban, 2020; Sokol, 2015); contaminant concentrations in other fish species are even more sparse (Evers et al., 2011). More sparse yet are measurements of the myriad contaminants of emerging concern (CEC) (Davis et al., 2016; Deere et al., 2020; Elliott et al., 2018; Elliott and VanderMeulen, 2017; Moore et al., 2018). An NSF- funded collaborative project between KBIC and Michigan Tech that will start in 2021 will measure PCBs in a few more Michigan lakes; with additional funding, that project could also perform nontargeted analyses for CECs. Because resources are never adequate to measure fish contaminants in all lakes of interest, it is desirable to have means of predicting contaminant concentrations for lakes lacking such measurements. Empirical, multi-variate statistical models for the entire UP have previously been developed that relate measurements of contaminant concentrations in walleye (76 for Hg, 16 for PCBs) to characteristics of the lakes and watersheds (Priyadarshini, 2018; Sokol, 2015). However, data for more lakes are required to strengthen these models.

Static measurements of fish contaminant concentrations can provide guidance on where it is safest to harvest fish (e.g., DeWeese et al., 2009), but do not provide guidance on other management options. Simultaneous modeling of fish contaminant concentrations and community or population dynamics can guide management by predicting impacts of management actions on fish populations as well as contaminant concentrations. Such modeling can be done at multiple levels of effort and complexity. In the simplest approach, statistical relationships between lake characteristics and fish contaminants can be used in conjunction with statistical models of fish diet, growth and bioaccumulation (Lepak et al., 2012a; Lepak et al., 2012b) to evaluate the potential impacts of fish management strategies on contaminant concentrations in top predator species. A slightly more involved approach is to combine known historical and predicted future trajectories of contaminant deposition with simple models of contaminant cycling linked with fish bioaccumulation factors (BAFs) (Brown et al., 2007; Khan, 2018; Knightes, 2008). At the highest level of complexity, contaminant mass balance models can be combined with food web models (e.g., EcoSim with EcoPath) (McGill et al., 2017; Walters and Christensen, 2018) to predict contaminant concentrations throughout the food web. The existing Ecosim with Ecopath model for Lake Superior (Kitchell et al., 2000) needs to be updated with the wealth of information gathered over the past 20 years.

A variety of metrics (e.g., natural capital, ecosystem services, habitat equivalency, risk, resiliency) may be used to assess impacts of environmental decisions and hence to guide resource management (Costanza et al., 1997; Costanza et al., 2014). However, these metrics can vary with the spatial scale considered as well as the stakeholders considered (Hein et al., 2006), involve tradeoffs among ecosystem services (Nelson et al., 2009), and often fail to adequately incorporate cultural and social values into the valuation (e.g., Chan et al., 2012a; Chan et al.,

2012b; Costanza et al., 2017; Hein et al., 2006). For fish contamination, health risk is often the metric used to guide decision making or consumption advisories (e.g., MDCH, 2012), but that approach ignores issues of food sovereignty, available alternatives, health benefits of fish consumption, and impairments to cultural values and practices (Gagnon et al., 2018). Indigenous Health Indicators (IHI) were developed to circumvent some of these shortcomings (Donatuto et al., 2016). Metrics selected for this study should be meaningful to both the tribes and to EPA.

Workplan

The objectives of the proposed project are: 1) to develop an understanding of the concentrations of individual (mercury, PCB) and combined contaminants in fish that will allow quantitative prediction of concentrations in any area lakes; 2) to develop a model of the relationships between the population size and age structure of fish communities and the associated contaminant concentrations; and 3) to use these tools to develop (a) outreach mechanisms (maps, phone apps) to inform our tribal members of fish safety in any area lake as well as (b) strategies whereby we might manage resources on tribal lands to maximize indicator metrics within the tribal-landscape system. We propose to demonstrate a strategy involving tribally-directed research and outreach locally in Michigan’s Upper Peninsula. We suggest that this strategy could subsequently be applied with the more than 100 tribal communities across the GL region. Below we briefly outline a sequence of tasks to accomplish these objectives.

Tasks:

1. Develop/Choose an appropriate set of metrics to guide decisions regarding resource stewardship and education programs: KBIC has familiarity with a variety of metrics having previously worked with Indigenous Health Indicators (Abt Associates Inc., 2020), ecosystem service valuation (Fletcher and Cousins, 2019), and the culturally sensitive risk-based maps prepared by GLIFWC for mercury in fish (DeWeese et al., 2009). As a community, we will select the metrics most appropriate to the current project.

2. Assess the current status of the selected indicator metrics for regional lakes that have importance/significance to KBIC related to fish:

> 2a. Identify a lake set in which fish harvesting is important to KBIC: KBIC already has identified 27 lakes of particular interest for fish harvest; of these, 16 have had some measurements of mercury in walleye, and four have had some measurements of PCBs in walleye.
>
> 2b. Enlarge the database on fish contaminant concentrations and fish communities in regional lakes: We propose to obtain whole fish samples from our community fishers and to analyze these for both mercury and PCBs. For the lakes in which mercury has been measured but PCBs have not, we propose to obtain archived walleye tissue from the Great Lakes Indian Fish and Wildlife Commission (GLIFWC), and to measure PCBs in those samples.
>
> 2c. Develop statistical, predictive models of fish contaminant concentrations as a function of lake and watershed characteristics as described above. Using existing data, we will develop similar models for different spatial extents and to evaluate the error of model predictions as a function of spatial scales. The scales we propose to use include the six- county area fished by the KBIC and the 1842 Ceded Territory. In this project we will also develop similar models for the combined toxicity of the two contaminants. Because
>
> each contaminant responds to different driving variables in the statistical models, the combined toxicity model may not mirror either of the individual contaminant models.

3. Use models of fish community dynamics and contaminant concentrations to investigate the impact of potential management actions on the chosen indicator metrics: We propose to apply three levels of complexity to determine which approach yields satisfactory predictions with the least effort. Model runs with and without implementation of management actions will be used to evaluate the potential magnitude of impact of management strategies. Again, all models will predict both individual contaminant concentrations as well as the cumulative toxicity of the two contaminants in multiple fish species. The outcomes of the modeling will be used to evaluate effects of alternative resource management strategies (harvesting, stocking, etc) on the indicator metrics to identify favorable options.

4. Create community-directed outreach materials to enable fishers to view the lake-specific metrics across the tribal-landscape system: Outreach materials might take the form of printed materials, online-accessible maps, online story maps, phone apps, or dial-up information. Maps can be created using GIS and posted on KBIC and GLIFWC websites alongside explanatory materials. These maps would be patterned after the GLIFWC mercury maps (https://www.glifwc.org/Mercury/index.html). KBIC and GLIFWC will direct the creation of desired outreach formats (mobile apps, story maps) and materials, and research partners will support the development of community-directed formats and materials as appropriate.

References:

7 Stat., 591. Treaty with the Chippewa. Proclamation, Mar. 23, 1843. Washington, D.C.: Government Printing Office; 1842.

10 Stat., 1109. Treaty with the Chippewa. Proclamation, Jan. 29, 1855. Washington, D.C.: Government Printing Office; 1854.

Abt Associates Inc., 2020. Lake Superior Manoomin Cultural and Ecosystem Characterization Study, Draft Report, draft ed. National Oceanic and Atmospheric Administration, Boulder, CO, p. 100.

Altenburger, R., Ait-Aissa, S., Antczak, P., Backhaus, T., Barcelo, D., Seiler, T.B., Brion, F., Busch, W., Chipman, K., de Alda, M.L., de Aragao Umbuzeiro, G., Escher, B.I., Falciani, F., Faust, M., Focks, A., Hilscherova, K., Hollender, J., Hollert, H., Jager, F., Jahnke, A., Kortenkamp, A., Krauss, M., Lemkine, G.F., Munthe, J., Neumann, S., Schymanski, E.L., Scrimshaw, M., Segner, H., Slobodnik, J., Smedes, F., Kughathas, S., Teodorovic, I., Tindall, A.J., Tollefsen, K.E., Walz, K.H., Williams, T.D., Van den Brink, P.J., van Gils, J., Vrana, B., Zhang, X., Brack, W., 2015. Future water quality monitoring--adapting tools to deal with mixtures of pollutants in water resource management. Sci Total Environ 512- 513, 540-551.

Androutsopoulos, V.P., Hernandez, A.F., LIesivuori, J., Tsatsakis, A.M., 2013. A mechanistic overview of health associated effects of low levels of organochlorine and organophosphorous pesticides. Toxicology 307, 89-94.

Backhaus, T., Faust, M., 2012. Predictive Environmental Risk Assessment of Chemical Mixtures: A Conceptual Framework. Environmental Science & Technology 46, 2564- 2573.

Basu, N., Cryderman, D., Miller, F., Johnston, S., Rogers, C., Plain, W., 2013. Multiple chemical exposure assessment at Aamjiwnaang. McGill Environmental Health Sciences Lab Occasional Report 1.

Boucher, O., Bastien, C.H., Saint-Amour, D., Dewailly, E., Ayotte, P., Jacobson, J.L., Jacobson, S.W., Muckle, G., 2010. Prenatal exposure to methylmercury and PCBs affects distinct stages of information processing: An event-related potential study with Inuit children.
Neurotoxicology 31, 373-384.

Boucher, O., Muckle, G., Ayotte, P., Dewailly, E., Jacobson, S.W., Jacobson, J.L., 2016. Altered fine motor function at school age in Inuit children exposed to PCBs, methylmercury, and lead. Environment International 95, 144-151.

Boucher, O., Muckle, G., Jacobson, J.L., Carter, R.C., Kaplan-Estrin, M., Ayotte, P., Dewailly, E., Jacobson, S.W., 2014. Domain-Specific Effects of Prenatal Exposure to PCBs, Mercury, and Lead on Infant Cognition: Results from the Environmental Contaminants and Child Development Study in Nunavik. Environmental Health Perspectives 122, 310- 316.

Brown, S., Saito, L., Knightes, C., Gustin, M., 2007. Calibration and evaluation of a mercury model for a western stream and constructed wetland. Water Air and Soil Pollution 182, 275-290.
Cassady, J., 2007. A tundra of sickness: the uneasy relationship between toxic waste, TEK, and cultural survival. Arctic Anthropol 44, 87-97.
Cedergreen, N., 2014. Quantifying Synergy: A Systematic Review of Mixture Toxicity Studies within Environmental Toxicology. Plos One 9.
Chan, K.M.A., Guerry, A.D., Balvanera, P., Klain, S., Satterfield, T., Basurto, X., Bostrom, A., Chuenpagdee, R., Gould, R., Halpern, B.S., Hannahs, N., Levine, J., Norton, B., Ruckelshaus, M., Russell, R., Tam, J., Woodside, U., 2012a. Where are Cultural and Social in Ecosystem Services? A Framework for Constructive Engagement. Bioscience 62, 744-756.
Chan, K.M.A., Satterfield, T., Goldstein, J., 2012b. Rethinking ecosystem services to better address and navigate cultural values. Ecological Economics 74, 8-18.
Christensen, K.Y., Raymond, M.R., Thompson, B.A., Anderson, H.A., 2016. Fish Consumption, Levels of Nutrients and Contaminants, and Endocrine-Related Health Outcomes Among Older Male Anglers in Wisconsin. Journal of Occupational and Environmental Medicine 58, 668-675.
Costa, L.G., Fattori, V., Giordano, G., Vitalone, A., 2007. An in vitro approach to assess the toxicity of certain food contaminants: Methylmercury and polychlorinated biphenyls. Toxicology 237, 65-76.
Costanza, R., dArge, R., deGroot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., Oneill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., vandenBelt, M., 1997. The value of the world's ecosystem services and natural capital. Nature 387, 253-260.
Costanza, R., de Groot, R., Braat, L., Kubiszewski, I., Fioramonti, L., Sutton, P., Farber, S., Grasso, M., 2017. Twenty years of ecosystem services: How far have we come and how far do we still need to go? Ecosystem Services 28, 1-16.
Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S.J., Kubiszewski, I., Farber, S., Turner, R.K., 2014. Changes in the global value of ecosystem services. Global Environmental Change-Human and Policy Dimensions 26, 152-158.
Crimmins, B.S., McCarty, H.B., Fernando, S., Milligan, M.S., Pagano, J.J., Holsen, T.M., Hopke, P.K., 2018. Commentary: Integrating non-targeted and targeted chemical screening in Great Lakes fish monitoring programs. Journal of Great Lakes Research 44, 1127-1135.
Davis, J.M., Ekman, D.R., Teng, Q., Ankley, G.T., Berninger, J.P., Cavallin, J.E., Jensen, K.M., Kahl, M.D., Schroeder, A.L., Villeneuve, D.L., Jorgenson, Z.G., Lee, K.E., Collette, T.W., 2016. Linking field-based metabolomics and chemical analyses to prioritize contaminants of emerging concern in the Great Lakes basin. Environmental Toxicology and Chemistry 35, 2493-2502.
Deere, J.R., Moore, S., Ferrey, M., Jankowski, M.D., Primus, A., Convertino, M., Servadio, J.L., Phelps, N.B.D., Hamilton, M.C., Chenaux-Ibrahim, Y., Travis, D.A., Wolf, T.M., 2020. Occurrence of contaminants of emerging concern in aquatic ecosystems utilized by Minnesota tribal communities. Science of the Total Environment 724.
DeWeese, A.D., Kmiecik, N.E., Chiriboga, E.D., Foran, J.A., 2009. Efficacy of Risk-Based, Culturally Sensitive Ogaa (Walleye) Consumption Advice for Anishinaabe Tribal Members in the Great Lakes Region. Risk Analysis 29, 729-742.
Donatuto, J., Campbell, L., Gregory, R., 2016. Developing Responsive Indicators of Indigenous Community Health. International Journal of Environmental Research and

Public Health 13, 16.
Donatuto, J.L., Satterfield, T.A., Gregory, R., 2011. Poisoning the body to nourish the soul: Prioritising health risks and impacts in a Native American community. Health, Risk & Society 13, 103-127.
Elliott, S.M., Brigham, M.E., Kiesling, R.L., Schoenfuss, H.L., Jorgenson, Z.G., 2018. Environmentally Relevant Chemical Mixtures of Concern in Waters of United States Tributaries to the Great Lakes. Integrated Environmental Assessment and Management 14, 509-518.
Elliott, S.M., VanderMeulen, D.D., 2017. A regional assessment of chemicals of concern in surface waters of four Midwestern United States national parks. Science of the Total Environment 579, 1726-1735.
EPA, U.S., 2013. 2011 National Listing of Fish Advisories. U.S. Environmental Protection Agency, Washington, D.C., p. 8.
Evers, D., Wiener, J., Driscoll, C., Gay, D., Basu, N., Monson, B., Lambert, K., Morrison, H., Morgan, J., Williams, K., 2011. Great Lakes mercury connections: the extent and effects of mercury pollution in the Great Lakes region, Gorham, ME.
Fernando, S., Renaguli, R., Milligan, M.S., Pagano, J.J., Hopke, P.K., Holsen, T.M., Crimmins, B.S., 2018. Comprehensive Analysis of the Great Lakes Top Predator Fish for Novel Halogenated Organic Contaminants by GCxGC-HR-ToF Mass Spectrometry.
Environmental Science & Technology 52, 2909-2917.
Fletcher, A., Cousins, K., 2019. Ecosystem Services Valuation of the Keweenaw Peninsula. Earth Economics, Tacoma, WA, p. 28.
Gagnon, V.S., 2016. Ojibwe Gichigami (Ojibwa's Great Sea): An intersecting history of treaty rights, tribal fish harvesting, and toxic risk in Keweenaw Bay. Water History 8, 365-384.
Gagnon, V.S., Gorman, H.S., Norman, E.S., 2018. Eliminating Fish Consumption Advisories in the Great Lakes Region: A Policy Brief, Houghton, MI.
Gandhi, N., Drouillard, K.G., Arhonditsis, G.B., Gewurtz, S.B., Bhavsar, S.P., 2017. Are Fish Consumption Advisories for the Great Lakes Adequately Protective against Chemical Mixtures? Environmental Health Perspectives 125, 586-593.
GLIFWC, G.L.I.F.a.W.C., 2016. Guidance for Safe Consumption of Walleye from Inland Lakes within the Ceded Territories of Wisconsin, Michigan, and Minnesota. Great Lakes Indian Fish and Wildlife Commission, Odanah, WI.
Goldoni, M., Caglieri, A., Poli, D., Vettori, M.V., Ceccatelli, S., Mutti, A., 2008. Methylmercury at low doses modulates the toxicity of PCB153 on PC12 neuronal cell line in asynchronous combination experiments. Food and Chemical Toxicology 46, 808-811.
Han, L., Hsu, W.W., Todem, D., Osuch, J., Hungerink, A., Karmaus, W., 2016. In utero exposure to polychlorinated biphenyls is associated with decreased fecundability in daughters of Michigan female fisheaters: a cohort study. Environmental Health 15, 13.
Hanrahan, L.P., Falk, C., Anderson, H.A., Draheim, L., Kanarek, M.S., Olson, J., Great Lakes, C., 1999. Serum PCB and DDE levels of frequent Great Lakes sport fish consumers - A first look. Environmental Research 80, S26-S37.
Hein, L., van Koppen, K., de Groot, R.S., van Ierland, E.C., 2006. Spatial scales, stakeholders and the valuation of ecosystem services. Ecological Economics 57, 209-228.
Hernandez, A.F., Parron, T., Tsatsakis, A.M., Requena, M., Alarcon, R., Lopez-Guarnido, O., 2013. Toxic effects of pesticide mixtures at a molecular level: Their relevance to human health. Toxicology 307, 136-145.
Hoover, E., 2013. Cultural and health implications of fish advisories in a Native

American community. Ecol Process 2.
Humphrey, H.E.B., Gardiner, J.C., Pandya, J.R., Sweeney, A.M., Gasior, D.M., McCaffrey, R.J., Schantz, S.L., 2000. PCB congener profile in the serum of humans consuming Great Lakes fish. Environmental Health Perspectives 108, 167-172.
Jacobson, J.L., Jacobson, S.W., 1996a. Dose-response in perinatal exposure to polychlorinated biphenyls (PCBs): the Michigan and North Carolina cohort studies. Toxicol Ind Health 12, 435-445.
Jacobson, J.L., Jacobson, S.W., 1996b. Intellectual impairment in children exposed to polychlorinated biphenyls in utero. New England Journal of Medicine 335, 783-789.
Jacobson, J.L., Jacobson, S.W., Fein, G.G., Schwartz, P.M., Dowler, J.K., 1984. Prenatal exposure to an environmental toxin: a test of the multiple effects model. Develop. Psychol. 20, 523-532.
Khan, T., 2018. Evaluation, Improvement, and Application of Models of Environmental Fate and Transport of Atmosphere-Surface Exchangeable Pollutants (ASEPs), Civil & Environmental Engineering. Michigan Technological University, Houghton, MI, p. 195.
Kitchell, J.F., Cox, S.P., Harvey, C.J., Johnson, T.B., Mason, D.M., Schoen, K.K., Aydin, K., Bronte, C.R., Ebener, M.P., Hansen, M., Hoff, M.H., Schram, S.T., Schreiner, D.R., Walters, C.J., 2000. Sustainability of the Lake Superior fish community: Interactions in a food web context. Ecosystems 3, 545-560.
Knightes, C.D., 2008. Development and test application of a screening-level mercury fate model and tool for evaluating wildlife exposure risk for surface waters with mercury-contaminated sediments (SERAFM). Environmental Modelling & Software 23, 495-510.
Kortenkamp, A., Backhaus, T., Faust, M., 2009. State of the Art Report on Mixture Toxicity. European Union, Brussels, p. 391.
Lepak, J.M., Hooten, M.B., Johnson, B.M., 2012a. The influence of external subsidies on diet, growth and Hg concentrations of freshwater sport fish: implications for management and fish consumption advisories. Ecotoxicology 21, 1878-1888.
Lepak, J.M., Kinzli, K.D., Fetherman, E.R., Pate, W.M., Hansen, A.G., Gardunio, E.I., Cathcart, C.N., Stacy, W.L., Underwood, Z.E., Brandt, M.M., Myrick, C.A., Johnson, B.M., 2012b. Manipulation of growth to reduce mercury concentrations in sport fish on a whole-system scale. Canadian Journal of Fisheries and Aquatic Sciences 69, 122-135.
McGill, L.M., Gerig, B.S., Chaloner, D.T., Lamberti, G.A., 2017. An ecosystem model for evaluating the effects of introduced Pacific salmon on contaminant burdens of stream- resident fish. Ecological Modelling 355, 39-48.
MDCH, M.D.o.C.H., 2012. Technical Support Document for a Polychlorinated Biphenyl Reference Dose (RfD) as a Basis for Fish Consumption Screening Values (FCSVs). Michigan Dept. Community Health, Lansing, MI, p. 107.
Moore, S., Wolf, T., Ferrey, M., Jankowski, M., Deere, J., Convertino, M., Phelps, N., Primus, A., Travis, D., 2018. Chemicals of emerging concern in waters, sediments, and subsistence fish used by the Grand Portage Band of Chippewa, Partners In Action Conference “New Horizons, Honored Past”. Bureau of Indian Affairs, Milwaukee, WI.
NEJAC, Council), N.E.J.A., 2002. Fish Consumption and Environmental Justice: a report developed from the National Environmental Justice Advisory Council Meeting of December 3-6, 2001. Environmental Protection Agency, Washington, D.C.
Nelson, E., Mendoza, G., Regetz, J., Polasky, S., Tallis, H., Cameron, D.R., Chan, K.M.A., Daily, G.C., Goldstein, J., Kareiva, P.M., Lonsdorf, E., Naidoo, R., Ricketts, T.H.,

Shaw, M.R., 2009. Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. Frontiers in Ecology and the Environment 7, 4-11.
Nicklisch, S.C., Rees, S.D., McGrath, A.P., Gokirmak, T., Bonito, L.T., Vermeer, L.M., Cregger, C., Loewen, G., Sandin, S., Chang, G., Hamdoun, A., 2016. Global marine pollutants inhibit P-glycoprotein: environmental levels, inhibitory effects, and cocrystal structure.
Sci Adv 2, e1600001.
O'Neill, C.A., 2004. Mercury, risk, and justice. Environmental Law Reporter: News & Analysis 34, 11070-11115.
O'Neill, C.A., 2007. Protecting the tribal harvest: The right to catch and consume fish. Journal of Environmental Law and Litigation 22, 131-152.
Perlinger, J.A., Gorman, H.S., Norman, E.S., Obrist, D., Selin, N.E., Urban, N.R., Wu, S., 2016. Measurement and Modeling of Atmosphere-Surface Exchangeable Pollutants (ASEPs) To Better Understand their Environmental Cycling and Planetary Boundaries. Environ. Sci. Technol. 50, 8932-8934.
Perlinger, J.A., Urban, N.R., Giang, A., Selin, N.E., Hendricks, A.N., Zhang, H., Kumar, A., Wu, S., Gagnon, V.S., Gorman, H.S., Norman, E.S., 2018. Responses of deposition and bioaccumulation in the Great Lakes region to policy and other large-scale drivers of mercury emissions. Environ. Sci.: Processes Impacts 20, 195 - 209.
Priyadarshini, M., 2018. Factors Contributing to Elevated Concentrations of Mercury and PCBs in Fish in the Inland Lakes of Michigan’s Upper Peninsula and Lake Superior, Civil & Environmental Engineering Dept. Michigan Technological University, Houghton, MI, p. 120.
Ranco, D., 2001. Environment risk, fish consumption, and American Indians: exploring the logic of genocide. Bad Subjects 55, 9-12.
Ranco, D., Suagee, D., Antipode, J., 2007. Tribal sovereignty and the problem of difference in environmental regulation: Observations on “measured separatism” in Indian country. Antipode 39, 691-707.
Rideout, K., Kosatsky, T., 2017. Fish for Dinner? Balancing Risks, Benefits, and Values in Formulating Food Consumption Advice. Risk Analysis 37, 2041-2052.
Shaw, E.L., Urban, N.R., 2020. Twenty-eight years of monitoring fish tissue PCBs, what can we learn? Env. Sci. Policy in review.
Sokol, E., 2015. An Assessment of Polychlorinated Biphenyl Contamination in Fish from the Inland and Great Lakes of Michigan, Civil and Environmental Engineering. Michigan Technological University, Houghton, MI, p. 182.
Steinman, A.D., Cardinale, B.J., Munns, W.R., Ogdahl, M.E., Allan, J.D., Angadi, T., Bartlett, S., Brauman, K., Byappanahalli, M., Doss, M., Dupont, D., Johns, A., Kashian, D., Lupi, F., McIntyre, P., Miller, T., Moore, M., Muenich, R.L., Poudel, R., Price, J., Provencher, B., Rea, A., Read, J., Renzetti, S., Sohngen, B., Washburn, E., 2017. Ecosystem services in the Great Lakes. Journal of Great Lakes Research 43, 161-168.
Sterner, R.W., Keeler, B., Polasky, S., Poudel, R., Rhude, K., Rogers, M., 2020. Ecosystem services of Earth's largest freshwater lakes. Ecosystem Services 41, 11.
Stewart, P.W., Reihman, J., Lonky, E.I., Darvill, T.J., Pagano, J., 2003. Cognitive development in preschool children prenatally exposed to PCBs and MeHg. Neurotoxicology and Teratology 25, 11-22.
Turyk, M.E., Bhavsar, S.P., Bowerman, W., Boysen, E., Clark, M., Diamond, M., Mergler, D., Pantazopoulos, P., Schantz, S., Carpenter, D.O., 2012. Risks and Benefits of Consumption of Great Lakes Fish. Environmental Health Perspectives 120, 11-18.

U.S.EPA, U.S.E.P.A., 2017. Choose Fish and Shellfish Wisely. U.S. EPA, Washington, D.C.

Van den Berg, M., Birnbaum, L.S., Denison, M., De Vito, M., Farland, W., Feeley, M., Fiedler, H., Hakansson, H., Hanberg, A., Haws, L., Rose, M., Safe, S., Schrenk, D., Tohyama, C., Tritscher, A., Tuomisto, J., Tysklind, M., Walker, N., Peterson, R.E., 2006. The 2005 World Health Organization reevaluation of human and mammalian toxic equivalency factors for dioxins and dioxin-like compounds. Toxicological Sciences 93, 223-241.

Walters, W.J., Christensen, V., 2018. Ecotracer: analyzing concentration of contaminants and radioisotopes in an aquatic spatial-dynamic food web model. Journal of Environmental Radioactivity 181, 118-127.

Williams, M.C.W., Murphy, E.W., McCarty, H.B., Snyder, B.D., Schrank, C.S., McCann, P.J., Crimmins, B.S., 2017. Variation in the essential fatty acids EPA and DHA in fillets of fish from the Great Lakes region. Journal of Great Lakes Research 43, 150-160.