VALUING THE ECONOMIC AND CULTURAL IMPACTS OF INLAND FISHERIES: CASE STUDY OF THE LAEK WHITEFISH (*COREGONUS CLUPEAFORMIS)* COMMERCIAL FISHERY IN MICHIGAN STATE WATERS OF LAKE MICHIGAN, USA

By

So-Jung Youn

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

Fisheries and Wildlife – Doctor of Philosophy
Environmental Science and Policy – Dual Major

2023

ABSTRACT

Inland fisheries provide many ecosystem services to human communities, especially for food and livelihood security. The benefits from inland fisheries, however, are often undervalued or overlooked by decision-makers (e.g. resource managers, funding agencies, government heads), especially when compared to other uses (e.g. agriculture, transportation, municipal use, hydropower) of freshwater resources. This undervaluation of inland fisheries is particularly prevalent in the United States, where freshwater is generally prioritized for other uses. It is necessary to ensure inland fisheries have a voice in water use and allocation discussions by guaranteeing that the benefits provided by inland fisheries are properly evaluated and readily accessible by the people who utilize these fisheries and concurrently raising public awareness of the ecosystem contributions provided by inland fisheries.

This dissertation explores the valuation of economic and cultural impacts provided by a long-standing inland fishery in Lake Michigan (United States): the commercial Lake Whitefish (*Coregonus clupeaformis*) fishery. Lake Whitefish have a regional cultural role (e.g. tribal traditions, history of freshwater fish consumption), play a role in local economies (e.g. commercial fisheries, employment in fishing-related livelihoods) and are a source of food and nutrients (e.g. protein) for local and regional communities. In addition to supporting a commercial fishery, Lake Whitefish also contribute to subsistence fisheries for tribal communities residing in the Great Lakes region.

The Lake Whitefish fisheries were chosen as a case study because these fisheries characterize a well-developed, commercial, wild-capture freshwater fishery in a developed economy. The supply chain for these fisheries is established, relatively easy to trace, and incorporates multiple aspects of fishery-related businesses (e.g. fish capture, processing, and sale). The established supply chain also makes it possible to incorporate and strengthen a value chain (e.g. the process of activities by which value is added to a product) onto the existing supply chain.

The goal of this dissertation is to examine the economic and cultural values of the Lake Whitefish commercial fishery in the Lake Michigan region. In order to meet this goal, there are four objectives: review the contributions of Lake Whitefish to the diet and economy of Michigan communities; elucidate the value chain for the commercial Lake Whitefish fishery; assess which aspects of Lake Whitefish consumers prefer; and determine the cultural values that Lake

Whitefish hold for people in Michigan. The conclusions and recommendations of this dissertation will focus on possible strategies and policies to sustain inland fisheries and the food and livelihood contributions of these resources to human communities.

ACKNOWLEDGEMENTS

I am grateful to my advisor, Dr. William Taylor, and my committee members, Drs. Heather Triezenberg, David Ortega, and Felicia Wu, for their guidance and support during my PhD. I would also like to thank the members of the Fisheries and Wildlife department, particularly my Center for Systems Integration and Sustainability colleagues and the members of the Taylor lab, for their encouragement and support throughout this process. Thank-you also to Dr. Mary Bremigan and Ms. Jill Cruth for supporting me during the completion of my dissertation. I also owe thanks to Dr. Nancy Leonard for her mentoring and support and to Drs. Devin Bartley and Simon Funge-Smith for helping facilitate my internship at the Food and Agriculture Organization of the United Nations. Finally, I am very grateful for the continued support and encouragement of my family and friends.

Funding for this project was provided by: the National Climate Change and Wildlife Science Center at the United States Geological Survey, Michigan State University Graduate School, Michigan State University Fisheries and Wildlife department, the Fisheries and Wildlife Graduate Student Organization, the Equal Opportunity Section of the American Fisheries Society, the American Institute of Fishery Research Biologists, and Michigan Sea Grant Extension.

TABLE OF CONTENTS

INTRODUCTION

Ecosystem Services Provided by Inland Fisheries

Freshwater fish and fisheries provide ecological, social, economic, and cultural benefits to human communities (Lynch et al. 2016, Youn et al. 2016, Olden et al. 2020). Sometimes these benefits are associated with an industry (e.g. food and livelihoods from commercial fishing, license and equipment sales for recreational fishing), which means that there is an explicit monetary value (e.g. market value) attached to these benefits. More often, however, the benefits from freshwater fisheries are not explicitly quantified in market transactions, which makes these non-market values more difficult to identify and quantify, and thus makes valuation more difficult (Gupta et al. 2015, FAO 2018). Examples include the spiritual value of fish (e.g. Lake Whitefish and Lake Trout to Anishinaabe communities, Golden Mahseer to Bhutan) and the existence value of species (e.g. Lake Sturgeon and Arctic Grayling to northern Michigan communities). Compounding this valuation problem is lack of data on how people, especially non-fishers, generally perceive and use freshwater fish and fisheries resources (e.g. consumption at restaurants, existence values, aquarium attractions). As a result, the impacts of freshwater fisheries, especially in terms of sociocultural benefits, can be difficult to enumerate and measure. Some of these sociocultural benefits include the contribution of fish species to a person's sense of belonging to, or identification with, a particular area (i.e. sense of place) and the contribution of commercial fisheries to the development of a town or community. As a result, these difficulties make it more challenging to create fisheries policies that support and maintain the full range of benefits that inland fisheries provide to human communities.

One way to better identify the ecosystem services from inland fisheries is to divide these services into economic services, sociocultural services, and ecological services (Table 1; adapted from Lynch et al. (2016)). While some values can overlap between categories (e.g. to an individual angler, recreationally harvested fish can provide recreation, food, and emotional well-being), this framework offers a starting point for identifying and categorizing services provided by fisheries.

Lake Whitefish Fisheries in Lake Michigan as a Case Study of Freshwater Fishery Ecosystem Services

While once considered abundant in the upper Great Lakes, Lake Whitefish populations (based on yield data) have fluctuated vastly over the past 50 years (Baldwin et al. 2000; MDNR 2017). Yields declined to all-time lows during the 1960s and 1970s (less than 1,000,000 kg per year), increased during the 1980s and 1990s (peaking at 6,586,855 kg in 1993), then again began decreasing from the mid-1990s to present (1,556,909 kg in 2016; Figure 1). These fluctuations in Lake Whitefish population abundances have been attributed to negative interactions with introduced species (predominantly Dreissenid mussels and sea lamprey *Petromyzon marinus*) and degradation of water quality and fish habitat due to increasing human population densities and natural resource use in the Great Lakes region (Nalepa et al. 2009). *Diporeia*, a preferred food source by Lake Whitefish, have decreased in abundance as Dreissenid mussel populations have increased in the Great Lakes (Nalepa et al. 2009). Although the reasons why are unclear, one hypothesis suggests that Dreissenids may outcompete *Diporeia* for food, resulting in decreased *Diporeia* survival and thus decreased *Diporeia* available for consumption by Lake Whitefish (Rennie et al. 2009). The decreased availability of *Diporeia* resulted in Lake Whitefish consuming greater amounts of alternate food sources (e.g. molluscs) that contain fewer nutrients (e.g. omega-3 fatty acids) than *Diporeia* (Pothoven and Madenjian 2008). Increased human population densities in the Great Lakes region (and the resulting urbanization and transportation/shipping), as well as greater conversion of land to human use (e.g. agriculture, development), may have degraded water quality and habitat for Lake Whitefish, in particular degrading the quality and availability of near-shore spawning habitat (Ebener et al. 2008).

Of the fish ecosystem services described in Lynch et al. (2016), many are provided by Lake Whitefish to Michigan's coastal human communities. Lake Whitefish are often cited as a socioeconomically important fish species in the Laurentian Great Lakes region (Ebener et al. 2008, Brenden et al. 2010, Lynch et al. 2015, Dellinger and Ripley 2016). Lake Whitefish support longstanding commercial fisheries in the upper Great Lakes (Lake Huron, Michigan, Superior; Ebener et al. 2008) and are an integral part of the history and sense-of-place of many coastal human communities along the Great Lakes. As a commercial fishery, Lake Whitefish are a food source to tribal and non-tribal communities in the Great Lakes basin. These commercial

fisheries also make Lake Whitefish a cultural symbol to fishing families and coastal fishing towns (historical and current) along the Lake Michigan coast, reflecting the importance of the fish and fishery in the histories of these families and towns. The role of Lake Whitefish as a "First Food" and traditional food source for Anishinaabe communities in the Great Lakes basin means Lake Whitefish are also both a food source and cultural symbol for tribal communities in the region. Additionally, Lake Whitefish served a historical role as a food source for early European settlers to the Great Lakes region and commercialization of Lake Whitefish helped spur settlement and development of the Great Lakes region by these settlers. In modern times, while the food contribution of Lake Whitefish to the Great Lakes has diminished, due to decreased abundance of Lake Whitefish and changing human diet patterns (especially the shift toward pre-packaged and convenience foods), Lake Whitefish are still a traditional food source for tribal communities and a sought-after commodity by tourists to coastal communities in the Great Lakes region, especially around the upper Great Lakes (Ebener et al. 2008).

Despite general acknowledgement among Great Lakes scientists and fisheries managers regarding the ecosystem roles and contributions of Lake Whitefish, there have been few studies identifying and/or quantifying the social and economic contributions of Lake Whitefish to this region. As a result, ascertaining and measuring the ways Lake Whitefish contribute value to human communities in the Great Lakes region remains an important area for ongoing research. Holistic identification of the ways in which Lake Whitefish contribute to health and well-being of human communities along the Great Lakes will provide policymakers with more detailed information of the tradeoffs made between alternative uses of Great Lakes water resources and their potential impacts to local communities. Additionally, more detailed valuation of specific socioeconomic contributions of Lake Whitefish will assist policymakers in identifying potential impacts of commercial fishery disruptions on specific areas (e.g. livelihoods, human diets) and design policies to reduce these impacts.

Dissertation Goals and Objectives

A literature review of peer-reviewed papers on Lake Whitefish in the Laurentian Great Lakes, as well as semi-structured interviews with fisheries managers and Lake Whitefish researchers, revealed several hypothesized sociocultural and economic values of Lake Whitefish in the Great Lakes. Currently these values are considered hypothetical because few peer-reviewed studies have been conducted to determine whether or not, and in what ways, these

values are held by Great Lakes residents. Additionally, there is a lack of systematically collected evidence supporting the existence and/or magnitude of these hypothesized values. For ease of discussion, these values can be divided into economic, sociocultural, and ecosystem categories (Table 1), recognizing that some values do overlap between categories (e.g. food, recreation).

Economic Values

There are commercial fisheries for Lake Whitefish, both state-licensed and tribal/First Nation fisheries, all around the Great Lakes region. In addition to being a part of modern day coastal economies, Lake Whitefish commercial fisheries were also historically important to the economy and food security of most of the Great Lakes states and their coastal communities, including Michigan (Chiarappa and Szylvian 2003). In addition to the commercial fisheries, Lake Whitefish also contribute to the tourist economies of coastal communities along the Great Lakes. In Michigan, for example, many visitors to towns "up North" look for Lake Whitefish dishes at local restaurants and purchase Lake Whitefish products to take home with them (Amber Petersen, fish retailer, personal communication). Additionally, with the increasing popularity of local markets (farmers' markets) in Michigan and elsewhere, and increases in fishers' efforts to market their products, there has been an increase in fish vendors at these markets (2020 Michigan Fish Producers Annual Meeting). In addition to their economic value, people's enjoyment of Lake Whitefish, and the role of Lake Whitefish as a popular tourist commodity, also carries significant sociocultural values.

Sociocultural Values

Lake Whitefish are a native, recognizable fish species of the Laurentian Great Lakes. In addition to supporting (historically and currently) livelihoods and food and nutrient availability for human communities in the region, Lake Whitefish are a "first food" and thus culturally important to Anishinaabe communities. As a result, in addition to the food security benefits they provide, Lake Whitefish are also a source of important nutrients (e.g. omega-3 fatty acids) to human communities in the Great Lakes region. Additionally, human desires to promote and re-establish "native" fish communities in the Great Lakes entail efforts to conserve and re-establish Lake Whitefish populations in this region. In tandem with these sociocultural values, Lake Whitefish are widely studied in the Great lakes. Many of the research and monitoring programs center on various aspects of Lake Whitefish ecology, such as spawning and recruitment of these fish into the commercial fishery (GLFT report 2018). These programs, and the associated

funding and human effort involved in implementing these programs, are generally focused on understanding why Lake Whitefish populations in the upper Great Lakes are decreasing and how these declines might be reversed. Although few studies (Chiarappa and Szylvian 2003, Dellinger et al. 2014) have been conducted on these sociocultural values of Lake Whitefish, the existence of, and continued support for, these research and management programs demonstrate the sociocultural importance that Lake Whitefish have to the Great Lakes region.

Ecosystem Values

Lake Whitefish are an important component of the Great Lakes ecosystem. The body condition of Lake Whitefish (e.g. fat content, parasite/contaminant burden) can serve as an indicator for lake water quality and overall lake ecosystem health (Pothoven et al. 2001; Pietrock & Hursky 2011). In particular, the contaminant level of Lake Whitefish could serve, by proxy, as a baseline indicator for PBT (persistent, bioaccumulative, and toxic) contaminant levels in piscivorous fish species (e.g. lake trout *Salvelinus namaycush*; Gerstenberger and Dellinger 2002), contaminant levels of these species will be higher than levels in Lake Whitefish. Because Lake Whitefish are also consumed by humans, the contaminant (e.g. mercury, PCB) loads in Lake Whitefish also have human health implications (Dellinger et al. 2014). The levels of these contaminants in Lake Whitefish, among other fish species, serve as the basis for creation of general (e.g. non-species specific) fish consumption advisories for areas around the Great lakes (Gerstenberger and Dellinger 2002, Neff et al. 2014). These fish consumption advisories are intended to serve as a guideline for safe amounts of fish to consume, based on where the fish were harvested and current contaminant levels per portion of fish (Imm et al. 2005). In addition to their body condition, Lake Whitefish are affected by environmental conditions in the lakes (e.g. changing climate, competition with invasive species) and can serve as an indicator of potential food web changes and other ecosystem impacts due to these changing environmental conditions (Pothoven et al. 2001, Nalepa et al. 2009). Warming winters and lower levels/durations of lake ice cover, for example, are thought to be one reason for declining Lake Whitefish populations, as Lake Whitefish rely on ice cover to protect their eggs during the winter, before they hatch in the spring (Lynch et al. 2015).

Dissertation Format

This dissertation is composed of 3 chapters, in addition to this introduction and a concluding synthesis section. The goal of this dissertation is to determine the socioeconomic

contributions made by Great Lakes Lake Whitefish to human coastal communities in Michigan. These contributions will focus on 3 broad areas, focused on socioeconomic ecosystem services: diet (Chapter 1), livelihoods (Chapter 2), and economy (Chapter 3). Diet is broadly defined as both nutrient contribution (i.e. nutrients available within Lake Whitefish for human consumption) and consumption (i.e. human intake of Lake Whitefish). Livelihood is defined as actors in the Lake Whitefish supply chain in Michigan, with a focus on Michigan's state-licensed commercial fishers (due to prior connections with this community and their willingness to participate in this study). For the purposes of this dissertation, the economic contributions will focus on attributes of Lake Whitefish products that are sought by consumers at local Michigan markets and the price premiums consumers are willing to pay for these attributes. Because these attributes, and the premiums that consumers are willing to pay, may change given availability of Lake Whitefish and other factors affecting consumer demand for Lake Whitefish (e.g. availability of or preference for other fish species), the results of this economic study are a reflection of consumer preferences during the specific year in which the field experiment was conducted and, as such, do not provide data on changes in consumer preferences or willingness to pay over time. Through these chapters, this dissertation illustrates 3 different socioeconomic contributions Lake Whitefish make to human coastal communities in Michigan and provides a baseline for future studies of Great Lakes Lake Whitefish valuation.

FIGURES

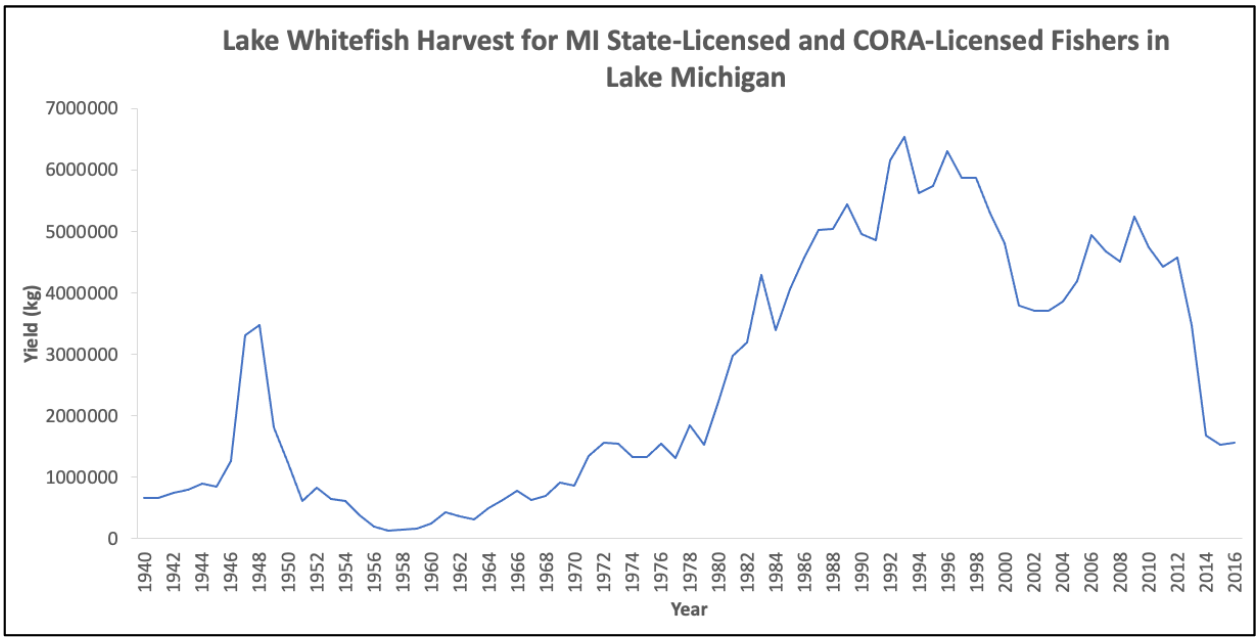

Figure 1. Yields of commercial Lake Whitefish (state-licensed and tribal) for Michigan waters of Lake Michigan from 1940 - 2016. Based on data from Baldwin et al. (2000) and the Michigan Department of Natural Resources (MDNR; MDNR 2017).

TABLES

Table 1. Services provided by inland fish and their fisheries, divided into 3 primary categories: economic services, sociocultural services, and ecosystem services. Table adapted from Lynch et al. (2016).

Economic Services
Livelihoods
Recreation
Commercial activities
Sociocultural Services
Heritage, spiritual, and aesthetic values
Human health and well-being, including nutrition
Food source
Ecological Services
Ecosystem structure and functions
Indicators of aquatic system health, productivity, and contaminant levels

REFERENCES

Brenden, T. O., M. P. Ebener, T. M. Sutton, M. L. Jones, M. T. Arts, T. B. Johnson, M. A. Koops, G. M. Wright, and M. Faisal. 2010. Assessing the health of Lake Whitefish populations in the Laurentian Great Lakes: Lessons learned and research recommendations. *Journal of Great Lakes Research, 36*(SUPPL. 1), 135 – 139.

Chiarappa, M. J., and K. M. Szylvian. 2003. Fish for all: An oral history of multiple claims and divided sentiment on Lake Michigan. Michigan State University Press, East Lansing, Michigan.

Dellinger, J. A., M. D. Moths, M. J. Dellinger, and M. P. Ripley. 2014. Contaminant Trends in Freshwater Fish from the Laurentian Great Lakes: A 20-Year Analysis. *Human and Ecological Risk Assessment, 20*(2), 461 – 478.

Dellinger, M. J., and M. P. Ripley. 2016. Mercury risks versus nutritional benefits of tribal commercial fish harvests in the Upper Laurentian Great Lakes. *Human and Ecological Risk Assessment, 22*(4), 1036 – 1049.

Ebener, M. P., R. E. Kinnunen, P. J. Schneeberger, L. C. Mohr, J. A. Hoyle, and P. Peeters. 2008. Management of Commercial Fisheries for Lake Whitefish in the Laurentian Great Lakes of North America. *International Governance of Fisheries Ecosystems: Learning from the Past, Finding Solutions for the Future*, 99 – 143.

FAO. 2018. The State of World FIsheries and Aquaculture. Rome.

Gerstenberger, S. L., and J. Dellinger. 2002. PCBS, mercury, and organochlorine concentrations in lake trout, walleye, and whitefish from selected tribal fisheries in the upper great lakes region. *Environmental Toxicology, 17*(6), 513 – 519.

Gupta, N., A. Kanagavel, P. Dandekar, N. Dahanukar, K. Sivakumar, V. B. Mathur, and R. Raghavan. 2015. God's fishes: religion, culture and freshwater fish conservation in India. *Oryx, 50*(2), 1 – 6.

Imm, P., L. Knobeloch, H. A. Anderson, L. Sport, and F. Consortium. 2005. Fish Consumption and Advisory Awareness in the Great Lakes Basin. *Environmental Health Perspectives, 113*(10), 1325 – 1329.

Lynch, A. J., S. J. Cooke, A. M. Deines, S. D. Bower, D. B. Bunnell, I. G. Cowx, V. M. Nguyen, J. Nohner, K. Phouthavong, B. Riley, M. W. Rogers, W. W. Taylor, W. Woelmer, S. Youn, and T. Douglas Beard Jr. 2016. The social, economic, and environmental importance of inland fishes and fisheries. *Environmental Reviews, 7*(February), 1 – 7.

Lynch, A. J., E. Varela-Acevedo, and W. W. Taylor. 2015. The need for decision-support tools for a changing climate: Application to inland fisheries management. *Fisheries Management and Ecology, 22*(1), 14 – 24.

Nalepa, T. F., D. L. Fanslow, and G. A. Lang. 2009. Transformation of the offshore benthic community in Lake Michigan : recent shift from the native amphipod Diporeia spp. to the invasive mussel Dreissena rostriformis bugensis. *Freshwater Biology, 54*(3), 466 – 479.

Neff, M. R., S. P. Bhavsar, F. J. Ni, D. O. Carpenter, K. Drouillard, A. T. Fisk, and M. T. Arts. 2014. Risk-benefit of consuming Lake Erie fish. *Environmental Research, 134*, 57–65.

Olden, J. D., J. R. S. Vitule, J. Cucherousset, and M. J. Kennard. 2020. There's more to Fish than Just Food: Exploring the Diverse Ways that Fish Contribute to Human Society. *Fisheries*, 1 – 12.

Pothoven, S. A., and C. P. Madenjian. 2008. Changes in consumption by alewives and Lake Whitefish after dreissenid mussel invasions in Lake Michigan and Huron. *North American Journal of Fisheries Management, 28*(1), 308 – 320.

Pothoven, S. A., T. F. Nalepa, P. J. Schneeberger, and S. B. Brandt. 2001. Changes in Diet and Body Condition of Lake Whitefish in Southern Lake Michigan Associated with Changes in Benthos. *North American Journal of Fisheries Management, 21*(4), 876 – 883.

Youn, S., E. H. Allison, C. Fuentevilla, S. Funge-Smith, H. Triezenberg, M. Parker, S. Thilsted, P. Onyango, W. Akpalu, G. Holtgrieve, M. J. Good, and S. Muise. 2016. The Underappreciated Livelihood Contributions of Inland Fisheries and the Societal Consequences of Their Neglect, 107 – 120.

CHAPTER 1: DIETARY CONTRIBUTIONS PROVIDED BY LAKE WHITEFISH (*COREGONUS CLUPEAFORMIS)* TO COASTAL HUMAN COMMUNITIES IN NORTHERN MICHIGAN, USA

Introduction

Freshwater fish are often acknowledged as an important food and nutrient source, especially for people in developing countries, but their contributions to food and nutrition security in developed countries, particularly in terms of direct human consumption, are less frequently studied (Lynch et al. 2016). Previous studies on human fish consumption have shown that consumers in developed countries tend to prefer and consume marine species (e.g. tuna, shrimp, Pacific salmon) rather than freshwater species, regardless of whether consumers live in a coastal or inland area (US EPA 2014). Human consumption estimates of fish are incomplete or outdated in many areas of the world (Youn et al. 2016), likely due to the intensive time, personnel, and monetary resources needed to conduct household consumption studies and the inaccuracies possible in recall consumption surveys (e.g. incorrect recall of consumption frequency or amount) (Dellinger 2004a). As a result, the food and nutrients available via fish consumption are often inaccurate or unknown for many fish species, both freshwater and marine. Some studies, however, indicate that freshwater fish may serve as an important food source for particular communities (e.g. indigenous peoples, recreational anglers, and commercial fishers) in developed countries, in particular ethnic minorities, immigrants, and urban anglers. For these communities, freshwater fish could be a more accessible (cheaper and/or readily available) or culturally-linked food source, so members of these communities may be more likely, and prefer, to consume freshwater fish than non-members (Kalkirtz et al. 2008, Lauber et al. 2017).

Lake Whitefish (*Coregonus clupeaformis*) historically were an important food source for human communities of the upper Laurentian Great Lakes region (Lakes Michigan, Huron, and Superior; Figure 2; Chiarappa and Szylvian 2003). Archaeological records indicated that Lake Whitefish were a staple food of indigenous peoples in this region by at least 800 A.D. (Kinietz 1965, Cleland 1982). When European settlers came to the region in the early 1600s, Lake Whitefish also became a popular food source for this population, due to their sweet taste and relative ease of harvest, and thus were the primary target for the commercial fisheries that developed in the Great Lakes during the late 1700s (Kinietz 1965). In the present day, Lake Whitefish are considered a "first food" (e.g. important cultural food source) by Anishinaabe communities in the upper Great Lakes region. Lake Whitefish today continue to support a commercial fishery in this region, though yields have greatly fluctuated over the past several decades due to invasive species (sea lamprey, *Dreissenid* mussels) and changes in habitat quality

and availability (Ebener et al. 2008). Historically, and continuing to the present day, commercial and subsistence harvests of Lake Whitefish provided an important source of food and livelihoods for Great Lakes communities. The collapse of the Great Lakes Lake Whitefish commercial fisheries in the 1960s (Figure 3), however, in addition to changing habitats (e.g. reduced ice cover in winter, warming water temperatures) and negative interactions with invasive species (e.g. sea lamprey and *Dreissenids*) led to the subsequent failure of Lake Whitefish stocks to rebuild to previously reported population levels (Brenden et al. 2010). As a result, Lake Whitefish fisheries in the upper Great Lakes region have generally become greatly diminished and the subsequent relatively low yields of Lake Whitefish from these waters have, in turn, led to fewer fish harvested for the human communities that rely on Lake Whitefish for food and livelihoods.

Goal of Chapter

Studies of Lake Whitefish generally acknowledge the socioeconomic and cultural importance of these fish to the Great Lakes region, but generally do not detail how and why Lake Whitefish were and are important to the human communities of this region (Lynch et al. 2015, Pothoven 2020). Diet is one dimension that can be used to evaluate the contributions, and thus the importance, of Lake Whitefish to human communities. In this chapter, "diet" is broadly defined as both nutrition and the cultural issues surrounding food (e.g. harvest of fish, preparation of fish for consumption, and consumption of fish), following the definition of "diet" used by the Food and Agriculture Organization of the United Nations (FAO; Eme et al. 2019).

In order to ascertain this information for upper Great Lakes Lake Whitefish, a literature review of published papers on Lake Whitefish in the Great Lakes region was conducted to determine the dietary contributions of Lake Whitefish to the people living in the coastal upper Laurentian Great Lakes region, where commercial and tribal Lake Whitefish fisheries are currently still in operation. In addition to peer-reviewed published papers, "gray literature" were also reviewed. Sources of this "gray" literature include reports from the Great Lakes Fisheries Trust (GLFT) and Great Lakes Fishery Commission (GLFC), reports from federal and state government agencies and fisheries managers, written materials provided by Sea Grant or university Extension agents within the study locations, student theses and dissertations, and popular (e.g. newspaper, magazine, internet) articles on Lake Whitefish in the Great Lakes region.

Although this dissertation chapter primarily draws on published literature and reports as data sources, this chapter delivers a unique scholarship contribution by connecting the research thread on consumption of Lake Whitefish in Michigan with existing research on nutrients in Lake Whitefish. This chapter also brings together a holistic view of the food and nutrition benefits provided by Lake Whitefish by examining three freshwater fish-consuming populations in Michigan: Anishinaabe communities, commercial fishers, and tourists to Michigan's coastal communities.

Lake Whitefish Contributions to Individual and Community Human Diets

Nutrients in Lake Whitefish

Fish are increasingly being promoted as a healthy food source in the developed world, especially due to the presence of omega-3 fatty acids (particularly docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA)) in several fish species (Jahns 2016). Although it was once thought that only marine fish contained omega-3s, the omega-3 benefits present in freshwater fish are increasingly recognized for their nutritional value to human diets (Moths et al. 2013). Coldwater species (both marine and freshwater), such as Lake Whitefish, tend to have increased levels of omega-3 fatty acids, compared to tropical fish species, due to the generally higher fat content of coldwater species (Belinksy et al. 1996; Moths et al. 2013). Lake Whitefish are also a source of high amounts of protein (per amount of meat consumed) and, in some cases, more accessible (in terms of price and/or retail location) than beef (Ebener et al. 2008). Other essential nutrients generally found in Great Lakes Lake Whitefish are selenium, iron, and calcium (Dellinger et al. 2018b). Freshwater fish are also generally a more efficient source of omega-3 fatty acids and selenium than terrestrial meat sources (Pantazopoulos et al. 2013). Per portion size, freshwater fish tend to contain more of these nutrients than do terrestrial meat sources (Youn et al. 2014). Freshwater fish also are generally less expensive and more widely available than terrestrial meat sources.

Individual Lake Whitefish differ in their exact nutrient content, however, due to the size of the fish, location of harvest, and time of harvest (e.g. season) (Neff et al. 2014, Dellinger et al. 2018a). Harvest locations impact nutrient content because different areas provide different nutrients, due to differences in habitat characteristics. For example, areas with greater nutrient

availability (e.g. selenium) can support greater diversity of food sources (e.g. macrophytes Lake Whitefish), thus increasing the quantity and variety of nutrients found within Lake Whitefish (Dellinger et al. 2018b). Time of harvest also affects nutrient content of these fish because the internal nutrient composition of Lake Whitefish varies depending on the time of year (Belinsky et al. 1996, Gerstenberger and Dellinger 2002). In the summer and fall, as Lake Whitefish are getting ready to spawn, the fish build up their reserves of omega-3 fatty acids, resulting in greater amounts of omega-3s into their eggs. After spawning, however, these reserves are depleted. Thus, Lake Whitefish harvested shortly before the spawning season are generally a greater source of omega-3 fatty acids than Lake Whitefish harvested shortly after the spawning season and thus can provide more omega-3 fatty acids for human consumption (Dellinger et al. 2018a).

Additionally, ecological changes within the lake could further impact the nutritional content of Lake Whitefish. For instance, Pantazopoulos et al. (2013) found that the reduction of *Diporeia* (species of zooplankton and historically the preferred food source of Lake Whitefish) in Lake Whitefish diets (concurrent with the *Dreissenid* (zebra and quagga mussels) invasion in the Great Lakes) could have led to the reduced omega-3 content in Lake Whitefish. Because *Diporeia* may be a more energy-rich food source for Lake Whitefish, compared to the aquatic insects or mollusks that Lake Whitefish currently predominantly feed on, decreased consumption of *Diporeia* has been implicated as a primary reason for the noted decrease in omega-3 content in Lake Whitefish that occurred (Pothoven 2005). As such, decreased availability of a fatty and nutritious food source (*Diporeia*) likely has had negative impacts on the growth and body condition of Lake Whitefish, which in turns reduces the nutritional value to human consumption of Lake Whitefish.

Human Consumers of Lake Whitefish in the Great Lakes Region

Consumption of fish in the United States is generally relatively low (4.44 oz/week in 2013) compared to the 8 oz/week suggested by the US Food and Drug Administration (FDA) to obtain the recommended 250 mg of eicosapentaenoic acoid (EPA) and docosahexaenoic acid (DHA; 2 types of omega-3 fatty acids) per day (Jahns 2016). A variety of potential factors have been suggested for this relatively low consumption rate, including difficulty in accessing fresh fish products, unfamiliarity with how to prepare and eat fish, and consumer dislike of "fishy" smells and taste (Jahns 2016). Fish consumption in the Great Lakes region is generally higher than the rest of the United States (38 meals/year on average, per person, in the Great Lakes

region; compared to 32 meals/year for the United States), but consumption still tends to be below the 104 meals/year recommended by the FDA (Imm et al. 2005) for adequate intake of EPA and DHA. Additionally, fish consumption is not equal among all members of the Great Lakes population (residents of the states, tribes and provinces surrounding the upper Great Lakes; Figure 2).

Non-fishers in the United States tend to consume the least amount of fish (primarily tuna, salmon and tilapia) while recreational fishers (particularly charter captains) tend to consume the most amount of fish (primarily sport-caught fish; Hanrahan et al. 1999; Imm et al. 2005). No studies of fish consumption among (state-licensed) commercial fishers or the commercial fishing communities in the Great Lakes region were found. Another population of interest is the Anishinaabe, located along the upper Great Lakes, for whom Lake Whitefish is a culturally important, and preferred, food source (Gerstenberger and Dellinger 2002). A final group of Lake Whitefish consumers that should be noted are summer tourists to Michigan's coastal towns. Many of these tourists enjoy consuming Lake Whitefish as part of their vacation and seek out Lake Whitefish meals at restaurants and/or purchase Lake Whitefish fillets and other products from local businesses (Johnson and Schroeder 2012, Broadway et al. 2019). Again, however, no studies of fish consumption among Michigan tourists were found.

Because Lake Whitefish are generally currently not widely harvested recreationally there is very little information on the consumption of Lake Whitefish (or other non-sport fish species) by recreational anglers in the Great Lakes region. Additionally, most studies of fish consumption in the Great Lakes region tend to focus on groups with increased affinity for fish (e.g. recreational fishers), although the lack of studies on consumption among commercial fishers and tourists to Michigan's coastal towns are notable gaps. Another notable gap is the lack of studies on consumption of Lake Whitefish among Great Lakes residents (as a whole) or non-fishing residents of the Great Lakes region (in particular). Due to these gaps, the majority of the following review of Lake Whitefish consumption will focus on consumption by the Anishinaabe, who are also the focus of the majority of the literature available for Lake Whitefish consumption (and fish consumption in general) in the Great Lakes region.

Most studies of Lake Whitefish consumption in the Great Lakes region focus on consumption by Anishinaabe communities (Table 3; Dellinger et al. 2018a; Fediuk et al. 2002). A search of Google Scholar, using the keywords "Lake Whitefish" and "consumption", was

unable to find any studies related to Lake Whitefish consumption (or fish consumption in general) of commercial fishers in the Great Lakers or tourists to Michigan. All studies that were identified focused either on tribal communities, charter captains, or recreational anglers. Consumption studies (general fish consumption for the Great Lakes, as no consumption studies specifically for Lake Whitefish were identified) among licensed charter captains and sport fishers indicate that these groups consume more fish than non-fishing populations (Imm et al. 2005; Hovinga et al. 1993; Hanrahan et al. 1999; Faulk et al. 1999). Thus, commercial Lake Whitefish fishers may also tend to consume more fish than the non-fishing population, due to easier access (e.g. cost and/or availability) to fish.

Role of Lake Whitefish in Anishinaabe Diets

The Anishinaabe (also known as Ojibwe, Ojibway, or Chippewa) live along the shores of the upper Great Lakes. In the United States, the Anishinaabe are recognized as an independent nation and, via treaties with individual states as well as the United States of America federal government, retain fishing and management rights for portions of the upper Great Lakes (Figure 2). Despite their heritage as a fishing culture and historically high fish consumption, fish consumption among the Anishinaabe is currently relatively low (about 2 oz per week in 2015) compared to the 6 – 8 oz per week recommended by the FDA (Dellinger et al. 2018a). In Michigan, the tribal commercial fisheries in the upper Great Lakes are regulated by the Chippewa Ottawa Resource Authority (CORA, formerly the Inter-Tribal Fisheries and Assessment Program), which represents the fisheries interests of five Anishinaabe tribes in Michigan (Dellinger et al. 2018a). CORA licenses and monitors two culturally and traditionally important subsistence fisheries in this region: lake trout (*Salvelinus namaycush*) and Lake Whitefish. Both species are considered "first foods" by the Anishinaabe and retain culturally important roles for the Anishinaabe. In consumption studies conducted by Dellinger and Ripley (2016), lake trout were preferentially consumed over Lake Whitefish by tribal members. While lake trout generally contained higher levels of omega-3 fatty acids than Lake Whitefish, lake trout generally also had higher contaminant levels of mercury and PCBs, due to their more piscivorous diet (Gerstenberger and Dellinger 2002). Thus, despite their lower omega-3 content, Lake Whitefish might be a healthier choice than the community-preferred Lake Trout, due to the lower levels of contaminants in Lake Whitefish.

Nutrients in Lake Whitefish

Studies of nutrient composition of Lake Whitefish in the Great Lakes basin are relatively scarce. Many of the studies that do exist are relatively outdated (from the 1980s or earlier). Because of the many ecosystem changes that occurred in the Great Lakes since the 1980s (particularly the invasion of Dreissenid mussels and the reduction of *Diporeia* populations), the nutrient content of current Lake Whitefish may be different from the nutrient content estimates given in these past studies. Nutrient content in current Lake Whitefish is presumably lower, given the relatively poor body condition of present-day Lake Whitefish compared to Lake Whitefish in the late 1970s and earlier (Pothoven et al. 2001). Sampling protocols for determining nutrient composition of Lake Whitefish also varied between studies, making it difficult to compare results between different geographic areas and/or time periods. Different sampling protocols, particularly differences in sex and age of fish sampled, parts (e.g. fillet, whole fish, fish guts) of fish sampled, and timing (e.g. season and time of day) can result in very different estimates of the nutrients present in the fish. Some studies determine nutrient content based on the whitefish fillet with the skin on (to be consistent with sampling protocols with fish consumption advisories) while other studies determine nutrient content using a whitefish fillet with the skin off (to be consistent with the way whitefish are commonly eaten among the Anishinaabe). Nutrients present in Lake Whitefish are: protein, vitamin B-12, vitamin D, omega-3 fatty acids, omega-6 fatty acids, calcium, copper, iron, zinc, and selenium (Table 2). Several of these nutrients are discussed in-depth in the following sections. These nutrients were chosen based on their contribution to human health and prevalence of being mentioned in the human nutrition literature.

Protein

Protein content estimates for Lake Whitefish were only available for Lake Whitefish caught in Canadian waters of the Great Lakes and Canadian inland lakes. The USDA Food Products Database (USDA 2018) lists protein content of Lake Whitefish as 14.52g per 100g of fish (slightly lower than grass-fed ground beef, 19.42 g/100g; USDA 2018), but the method used for this protein content determination is unlisted. Protein content of Lake Whitefish caught from tribal fishing areas in Quebec ranged from 14 – 16.2g/100g (Belinsky et al. 1996) for fresh raw fish (fillet only). These values are slightly lower than values found by Kuhnlein et al. (18 g/100g for raw fish; 1994) for a whitefish population in a relatively pristine habitat in the Northwest

Territories (Canada) and the 19g/100g for raw whitefish fillet listed in the Canadian Nutrient File (Health Canada 2015).

Omega-3 Fatty Acids

Omega-3 fatty acids were the nutrient of most interest for the majority of papers reporting nutrient content of Lake Whitefish in the Great Lakes region. Much of this interest is due to the protective qualities of omega-3s against certain chronic diseases mediated by inflammation, such as heart disease (Belinksky et al. 1996). Although misconceptions regarding the lack of freshwater sources of omega-3 fatty acids have somewhat limited demand for Great Lakes fish, evidence from the past 20 years supporting Great Lakes fish as a source of omega-3s and other important nutrients (e.g. selenium) has renewed interest in Great Lakes fish consumption, particularly among Anishinaabe communities (Dellinger et al. 2014). Pantazopoulos et al. (2013) found omega-3 fatty acid content for Lake Whitefish fillets in Lakes Erie, Huron, and Superior to range from average 15,100 mg per 100g of fish (Table 4) while Neff et al. (2014) found a value of 961 mg/100g for the Canadian province of Ontario's waters of Lake Erie, which is similar to the values for omega-3 content of Lake Superior whitefish (Dellinger et al. 2018a; Dellinger et al. 2014). In general, Lake Whitefish from Lake Michigan had the lowest omega-3 content and Lake Whitefish from Lake Superior had the highest omega-3 content, with whitefish from Lake Huron generally in between these two lakes. This result may be due to the relatively stable ecosystem (e.g. higher *Diporeia* populations and fewer invasive Dreissenid mussels) of Lake Superior compared to the more heavily impacted ecosystem (e.g. almost no *Diporeia* and heavy invasion by Dreissenids) of Lake Michigan. The greater availability of *Diporeia* in more stable ecosystems, and the greater content of omega-3 fatty acids in *Diporeia* as compared to other Lake Whitefish food sources, may result in the higher omega-3 content of Lake Whitefish from relatively stable ecosystems, compared to lower omega-3 content of Lake Whitefish from more heavily impacted ecosystems.

Vitamin D

Vitamin D plays several important roles in the human body, such as facilitating bone growth (along with calcium) and helping regulate the immune system. Humans cannot synthesize Vitamin D and must derive all of their Vitamin D requirements from animal sources, such as the oily livers of certain fish species. Few studies reported the vitamin D content of Lake Whitefish, perhaps because fish are generally not a major source of Vitamin D for human

communities in developed countries. The only available values of Vitamin D content for Lake Whitefish came from the Canadian Nutrient File (2015) database, which listed vitamin D content for a variety of Lake Whitefish products. Vitamin D content ranged from 4.5 micrograms/100g for raw and baked whitefish to 37.3 micrograms/100g for smoked dried whitefish. The database did not indicate, however, how these values were determined. Additionally, the values listed in this database may not reflect values solely for Lake Whitefish, as there are several fish species commonly referred to as "whitefish" in Canada, but most of these fish are either not the *C. clupeaformis* species that is of interest in this paper or are *C. clupeaformis* from Canadian inland lakes, which tend to have a different flavor (and presumably nutrient content, due to the different ecosystem structure and food source composition) than Lake Whitefish found in the Great Lakes (Ebener et al. 2008).

Selenium

Several studies (Health Canada 2015; Dellinger et al. 2018b; Hursky and Pietrock 2012) listed selenium content for Lake Whitefish in the upper Great Lakes. Selenium is of interest to human health because selenium could mitigate the effects of persistent bioaccumulative toxic (PBT) chemicals commonly found in Great Lakes fish, such as methyl mercury (Dellinger et al. 2018b). Additionally, selenium is an important micronutrient for human health due to the role of selenium in producing antioxidant enzymes. The link between selenium and mercury is still being investigated, however, and it is unclear what amount of selenium in whitefish would be needed to counteract mercury levels in these fish. Additionally, more studies of selenium content in Lake Whitefish are needed since the selenium content of freshwater fish is dependent on the selenium content of local soils (Pantazopoulos et al. 2013). Thus, the selenium content of a Lake Whitefish in Lake Michigan may be very different from the selenium content of a whitefish in Lake Superior. Even within the same lake, the selenium content of individual whitefish could differ significantly for populations (e.g. stocks) that spend the majority of their time in different habitats/areas within the lake.

Consumption of Lake Whitefish

In the literature, data on consumption of Lake Whitefish from the Great Lakes focused exclusively on tribal (predominantly Anishinaabe) consumption of Lake Whitefish. Consumption estimates tended to focus on tribal communities harvesting fish from the upper Great Lakes region or inland lakes in northern Canada, rather than consumption within specific states or

provinces. Additionally, consumption studies tended to focus on the risks (from PBTs, predominantly PCBs and methylmercury) of consuming Lake Whitefish, since fish consumption is the main human exposure route for both of these contaminants in the Great Lakes region (Dellinger et al. 2018b). Given the importance of fish, including Lake Whitefish, to Anishinaabe culture, balancing the benefits versus the risks of consuming Great Lakes fish is a growing area of study (Gerstenberger and Dellinger 2002). These studies tend to focus on nutrient benefits vs. toxin risk consumption, and do not address consumer preferences for fish products (or other animal source foods) and factors influencing accessibility and purchasing of fish products.

Parts of Fish Consumed

In general, only the fillet of the Lake Whitefish is consumed by people in the Great Lakes region. Although fish consumption advisories generally quantify contaminant burdens using fillets with the skin on, consumers generally tend to eat whitefish fillets with the skin off (Dellinger et al. 2014), which can reduce measured levels for some contaminants. Whitefish are eaten in a variety of formats (e.g. smoked, dried, baked, cooked fillet, pate/spread; Health Canada 2015, USDA 2018). In some tribal communities (e.g. Canadian Northwest Territories) the eggs, esophagus, and head of Lake Whitefish are also consumed (Kuhnlein et al. 1994). There is no mention in the literature of the bones of Lake Whitefish being consumed. Legally caught Lake Whitefish tend to be somewhat large (43 – 56 cm; Ebener et al. 2008), which makes it more difficult to consume the bones, since the bones of larger fish do not readily dissolve in soups and are otherwise difficult to break down for easy human consumption.

Differences in Nutrient Intake Based on Fish Part Consumed

Different parts of Lake Whitefish (e.g. fillet, egg, head) contain different nutrients, so nutrient intake will vary with the part of the fish that is consumed (Table 2. Methods of fish preparation and consumption can also significantly impact nutrient availability and thus the nutrient intake available for human consumption (Gerstenberger and Dellinger 2002). In general, eggs tend to be richer in micronutrients (e.g. calcium, copper, iron, zinc) than comparable amounts (e.g. 100g of edible fish) of fillet (Belinsky et al. 1996; Kuhnlein et al. 1994). However, due to the greater amount of eggs needed to be eaten in order to realize these nutrient intakes (e.g. it may be more likely to eat 100g of fillet than 100g of eggs), and thus Lake Whitefish eggs may not be substitutable (in terms of micronutrients) for Lake Whitefish fillets. Additionally, fillets are generally a more nutritious source of protein and omega-3 fatty acids than are Lake

Whitefish eggs (Belinsky et al. 1996; Kuhnlein et al. 1994). Eggs were included, however, since Lake Whitefish eggs are sometimes consumed by tribal communities.

Anishinaabe Consumption of Lake Whitefish

Although Lake Whitefish are identified as an important part of Anishinaabe culture and a desirable traditional food source, current Anishinaabe consumption of Lake Whitefish tends to be lower than the FDA-recommended 6oz/week (170.1g/week) of seafood consumption, perhaps due to "westernization" of the diet in recent times (Dellinger and Ripley 2016). Estimates of Anishinaabe fish consumption based on weighing consumed fish portions ranged from 29.4g/week (based on weighing consumed portions; Dellinger 2004) to 78.4g/week (Dellinger and Ripley 2016). Consumption estimates based on participant recall are much higher (434g/week; Dellinger 2004). All fish consumption statistics presented here include all wild-caught fish species consumed by the Anishinaabe (e.g. lake trout, whitefish, and walleye). Consumption estimates of solely Lake Whitefish were unfortunately not available as fish consumption estimates tended to be reported in aggregate (e.g. all fish species, all traditional fish species, or Lake Whitefish and lake trout).

These consumption estimates may also be unreliable due to the participant recall methodology used to generate them. Numerous studies have shown that, during recall studies, participants tend to overestimate the amount of fish they have actually consumed, leading to substantial overestimation of consumption (Dellinger 2004; Dellinger and Ripley 2016; Jahns 2016). Additionally, due to the human seasonality of Lake Whitefish consumption, the timing of recall studies can influence consumption estimates that are obtained. Studies taking place during the fishing season could result in overestimation of whitefish consumption, while studies taking place during the off-season (e.g. late fall, winter) could underestimate consumption. Comparing consumption and recall estimates to fish harvest data could help contextualize these estimates and indicate whether or not recall estimates are realistic.

Some studies indicate that other traditional (e.g. lake trout, walleye) or more readily accessible (farmed salmon) fish species are preferred by the Anishinaabe, instead of Lake Whitefish (Gerstenberger and Dellinger 2002; Dellinger et al. 2018b). Because the only source of Lake Whitefish is the local (Great Lakes) wild-capture commercial and subsistence fisheries, availability of Lake Whitefish is highly seasonal and concentrated during the fishing season from late spring to mid fall. Consumers may prefer fish sources that are more easily accessible

throughout the year (e.g. farmed fish species are relatively cheaply available at grocery stores year-round). Additionally, consumers may prefer lake trout (or other animal products) for their taste or attributes other than availability (e.g.: perceived quality of fish). Recent increases, however, in consumer interest in Lake Whitefish products (Ebener et al. 2008b) and eating locally harvested foods, as well as a growing recreational fishery for Lake Whitefish (Kinnunen 2016), may reverse these trends, perhaps making fish more prominent in these consumers' diet.

Consumption preferences for Lake Whitefish could also be decreasing for other reasons. Recent EPA, and other agency, announcements specifically targeted at fish-consuming subpopulations (e.g. female anglers; children; women of childbearing age) were warned of the contaminant risks of consuming Great Lakes fish and may have led to a further reduction in Lake Whitefish consumption among Anishinaabe communities in the upper Great Lakes (Dellinger and Ripley 2016). Efforts to contextualize these risks and incorporate the importance of traditional foods to the Anishinaabe, however, have resulted in a revised consumption advisory that may increase tribal communities' perception of the safety of consuming Lake Whitefish (Dellinger et al. 2019).

Effects of Lake Whitefish Consumption on Great Lakes Human Health

Despite the health benefits (especially from omega-3 fatty acids) of consuming Great Lakes fish (especially lake trout and Lake Whitefish), consumption of these fishes is relatively low in the Great Lakes region, compared to recommended fish consumption guidelines. One reason may be due to concerns over PBTs that used to be prevalent in Great Lakes fish, especially lake trout, walleye, and Lake Whitefish (Gerstenberger et al. 1997, Dellinger and Ripley 2016). Concerns about contaminants and fish consumption advisories regarding those contaminants have generally reduced people's demand for Great Lakes fish (Dellinger et al. 2014, Dellinger and Ripley 2016). PBTs, especially PCBs and mercury, are legacy contaminants that polluted water sources due to past industrial activities in the Great Lakes basin (Gerstenberger and Dellinger 2002). These contaminants bioaccumulate, meaning that amounts of these chemicals become concentrated in fish that eat at higher trophic levels (e.g. fish that eat other fish). Because Lake Whitefish are not principally piscivorous (e.g. are not fish-eating), Lake Whitefish do not bioaccumulate these contaminants as readily as other Great Lakes fish

species which tend toward piscivory (e.g. lake trout). Additionally, the levels of many of these contaminants in the Great Lakes have been decreasing due to environmental/pollution reduction legislation passed in the United States in the 1970s (Moths et al. 2013). Further, fish preparation methods can mitigate risk. Because PCBs accumulate in fish's fat tissues, PCB exposure can be reduced by consuming smaller fish, trimming fat from the fish prior to consumption, and using cooking techniques that reduce fat from remaining in the fillet (Gerstenberger and Dellinger 2002). Mercury exposure is more difficult to reduce via cooking methods as mercury tends to be associated with the fish muscle (e.g. fillet; Gewurtz et al. 2011). Because Lake Whitefish are not piscivorous, however, mercury levels in Lake Whitefish are of lower concern than levels in other Great Lakes fish, such as lake trout and walleye (Gerstenberger and Dellinger 2002). Due to the lack of data available for general Great Lakes consumption of Lake Whitefish, the majority of this paper's discussion will focus on the nutrient and diets impacts of Lake Whitefish consumption on Anishinaabe communities in the upper Great Lakes region.

Effects on Health of Anishinaabe Communities

Over the past several decades, Anishinaabe diets have generally been shifting away from traditional diets toward nontraditional ("westernized) diets and food sources (Lynn et al. 2013). Part of this shift is due to the easier accessibility (both effort and cost) of nontraditional foods (e.g. supermarket food items) compared to traditional food sources, in addition to cultural loss of knowledge regarding traditional food sources and methods of preparation and reduced availability of traditional food sources (Dellinger et al. 2014). Consequently, the proportion of traditional foods, including Lake Whitefish, in Anishinaabe diets has been declining. Because the Anishinaabe still consume higher amounts of fish than the non-tribal Great Lakes population, many studies have focused on the contaminant risks of Great Lakes fish consumption (particularly lake trout and Lake Whitefish; Dellinger 2004b, Dellinger and Ripley 2016). These studies, however, need to be contextualized within the cultural practices of the Anishinaabe as well as the benefits (e.g. omega-3 content) of fish consumption (Dellinger et al. 2019). Much of the data needed to create these risk-benefit analyses, however, is currently unavailable or incomplete (Dellinger et al. 2018b; Turyk et al. 2012; Wang et al. 1990), partly due to the difficulty and expense of collecting these data.

Another point of debate in the literature is the health impacts of traditional vs. westernized diets for indigenous communities. Some studies (Lynn et al. 2013; Moths et al.

2013) indicate that increased consumption of Lake Whitefish and other traditional food sources can decrease the risk of chronic diseases, particularly Type-2 diabetes and heart disease. Other studies (Marushka et al. 2017; Philibert et al. 2009), however, show an increased risk of diabetes and other chronic diseases with increased consumption of traditional fish (e.g. lake trout and Lake Whitefish). This increased risk may be due to the increased risk of PBT contaminant exposure associated with increased Great Lakes fish consumption, although some risks can be mitigated through fish preparation and cooking processes. As levels of these contaminants continue to decrease in Great Lakes fish, it is important to reevaluate the link between fish consumption and chronic disease risk in indigenous populations, since indigenous groups suffer higher rates of Type-2 diabetes and other chronic diseases, compared to non-indigenous communities (Marushka et al. 2017).

Conclusion

Consumption of Lake Whitefish (and thus nutrient intake from Lake Whitefish) is likely relatively low among Great Lakes human populations (Imm et al. 2005; Jahns 2016). This conclusion is drawn based on a review of published information regarding Lake Whitefish consumption, nutrient content, and health impacts on human populations in the Great Lakes region, as well as assuming that human consumption patterns of lake trout, and studies of fish consumption by Great Lakes recreational anglers, would be similar and applicable to human consumption of Lake Whitefish. Lack of existing data specifically on Lake Whitefish consumption does not necessarily mean, however, lack of importance. Because of the traditional cultural importance of Lake Whitefish to Anishinaabe communities, prior research efforts may have focused on the health and nutrition roles of Lake Whitefish in Anishinaabe communities. Additionally, Anishinaabe communities are fairly well-defined and accessible, compared to non-tribal communities, because many Anishinaabe live on reservations in northern Michigan and Wisconsin with treaty-protected rights to fishing. Accessing non-tribal, fish-dependent communities is more difficult because there is no readily available way of directly defining and contacting these populations.

There is growing evidence that some non-tribal populations around the upper Great Lakes (e.g. commercial fishers, tourists to Michigan's coastal towns) may also preferentially consume Lake Whitefish. For both populations, consumption of Lake Whitefish is likely seasonal. Consumption is likely highest during the summer months, when both commercial harvests and

the summer tourism season are at their peaks, and lowest in the winter, when there are no harvests of Lake Whitefish and coastal tourism is minimal (Ebener et al. 2008, Broadway et al. 2019). Increasing interest in "culinary/food tourism" for Lake Whitefish (Johnson and Schroeder 2012, Broadway et al. 2019) also points to the greater dietary role Lake Whitefish could contribute to Michigan's summer tourists. These initial studies highlight Lake Whitefish consumption as a mechanism for drawing tourists, and thus additional revenue, to local communities and tourist attractions. This mechanism works, in part, because tourists view consumption of locally harvested Lake Whitefish as a draw to visit these coastal communities (Johnson and Schroeder 2012). The likely seasonal nature of consumption, and the brief time period most tourists spend in a given town, however, may indicate that both overall consumption, and thus health and dietary impact, of Lake Whitefish is quite low for tourists.

Assuming that consumption patterns for the Great Lakes region are also applicable to Michigan, due to the sociocultural and environmental similarities among the Great Lakes states, Lake Whitefish consumption in Michigan may also be low. For Anishinaabe communities in the upper Great Lakes region (particularly the Upper Peninsula and northern Lower Peninsula of Michigan), however, the consumption of Lake Whitefish is likely greater. Lake Whitefish is a culturally valued traditional food source for the Anishinaabe and consumption of Lake Whitefish is generally higher in Anishinaabe communities (compared to non-indigenous Great Lakes communities). The health impacts of Lake Whitefish for Anishinaabe communities, however, are uncertain. Exposure to PBTs can have negative health impacts, but consumption of the omega-3 fatty acids (and potentially selenium) present in Lake Whitefish could mitigate risks of heart disease, PBT exposure, Type-2 diabetes, as well as other chronic diseases. The evidence for the health impacts (both positive and negative) of Lake Whitefish on Anishinaabe communities is mixed, however, and further confounded by the general shift in Anishinaabe diets to a nontraditional ("westernized") diet instead of their traditional diets. The increasing presence of per-and polyfluoroalkyl substances (PFAS), including PFOA and PFOS, in freshwater fish also presents a growing dietary concern (Barbo et al. 2023). PFAS are a class of synthetic chemical compounds that are used in many industrial and household products and tend to be highly environmentally persistent (Ruffle et al. 2020). Ingestion is considered to be the most significant route of PFAS intake in humans, and health effects from long-term exposure include liver, thyroid, reproductive, developmental, and immune toxicity (ATSDR, 2018). Elevated levels of

PFAS have been found in Lake Whitefish from the Great Lakes (Ruffle et al. 2020), however Smelt (*Osmerus mordax*) are currently the only Great Lakes fish with a PFAS advisory in effect (House, 2023). Overall, however, Lake Whitefish do not constitute a large portion of the overall diet for Michigan communities (low consumption of Lake Whitefish compared to other food sources). Because the consumption of Lake Whitefish is relatively small, the diet impacts are also likely to be small.

The diet impacts illustrated in this chapter could elucidate potential impacts from the COVID-19 pandemic, and resultant business closure and supply chain disruptions, in 2020 and 2021 on consumption of Lake Whitefish in human communities in Michigan. While commercial fisheries were deemed an essential business and allowed to continue their operations, the near-total closure of local restaurants and sharp decrease in summer tourism meant that fishers had very few options for selling their harvest (Williams 2020). The decrease in retail opportunities likely resulted in a further decrease in Lake Whitefish consumption in Michigan communities during this time. In order to make some income, fishers likely increased their direct-sale efforts to consumers and also provided more value-added Lake Whitefish products (e.g. smoked fish, dip) in an effort to increase sales (Kremer 2022). Additionally, the difficulty in accessing COVID-19 relief funds (e.g. 2021 Coronavirus Response and Relief Supplementation Appropriations Act, 2020 Coronavirus Aid, Reflect, and Economic Security Act) by commercial fishers added to the many difficulties fishers faced during these years (Spratt 2021).

This review also gives an indication regarding impacts of continued changes in Lake Whitefish populations, due to a variety of factors, on the diets of human communities in Michigan. These factors include climate change, which could contribute to a decrease in the abundance of Lake Whitefish populations, as well as continued changes in diet among human communities, particularly the shift toward a more "westernized" diet and preference for terrestrial sources of animal protein and potential rise in food tourism among visitors to Michigan's coastal communities. Decreased ice cover during the winters, increasingly becoming more frequent as the climate warms, could correspond to a decrease in Lake Whitefish populations by reducing Lake Whitefish egg survival during the winter months (Lynch et al. 2015). Warmer water temperatures could also lead to increased frequency of invasive species (Stachowicz et al. 2002) competing with Lake Whitefish, either for food or as parasites, further reducing Lake Whitefish populations. These factors would negatively impact Lake Whitefish

populations, further decreasing the availability of Lake Whitefish available for human consumption and potentially reducing accessibility of Lake Whitefish in certain areas of the Great Lakes region, particularly inland communities.

Through a review of the available literature on consumption of Lake Whitefish in three key populations around Michigan's coast (Anishinaabe tribal communities, commercial fishers, and tourists to Michigan's coastal towns), this chapter provides a broad overview of the consumption and dietary impacts of Lake Whitefish on human communities in Michigan. While overall consumption is likely low in all three populations, the seasonality of Lake Whitefish consumption (due to restrictions in the harvest season and Lake Whitefish availability) indicates that a summer-only analysis of Lake Whitefish consumption could provide additional insight into the dietary impacts of Lake Whitefish. Additionally, this chapter provided an outline of the impacts of changing Lake Whitefish fisheries could have on the diet of these three groups.

FIGURES

Figure 2. Map of Laurentian Great Lakes. The upper Great Lakes are Lakes Superior, Michigan, and Huron. Image courtesy of the US Army Corps of Engineers.

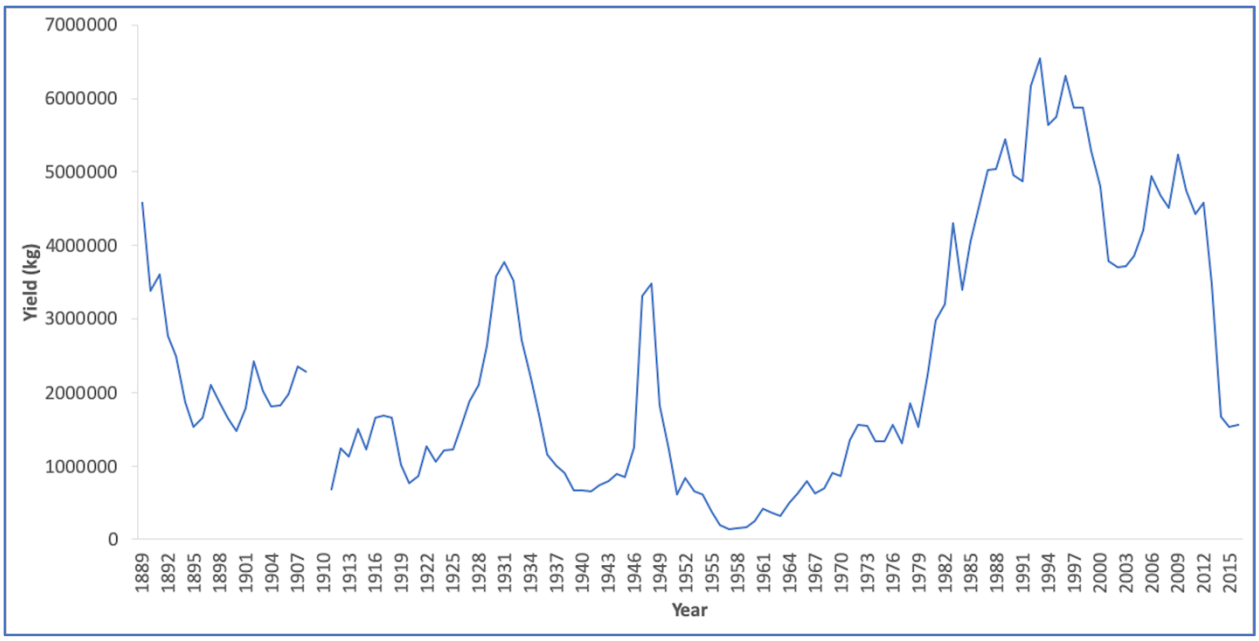

Figure 3. Yields of Lake Whitefish from Michigan waters of Lake Michigan by Michigan state-licensed fishers and Chippewa Ottawa Resource Authority (CORA) licensed fishers. Data were obtained from Baldwin et al. (2000), the Michigan Department of Natural Resources (MDNR), and CORA.

TABLES

Table 2. Nutrients available in Lake Whitefish.

Reference	Fish Part	Total Protein (g/100g)	Total Fat* (g/100g)	Total Carbohydrate (g/100g)	Vitamin B-12 (g/100g)	Vitamin D (micrograms per 100 g of edible fish)	Omega-3 Fatty Acids (g/100g) Unsaturated	Omega-6 Fatty Acids (g/100g) Unsaturated	n-6/n-3 Ratio	Calcium (g/100g)	Copper (g/100g)	Iron (g/100g)	Zinc (g/100g)	Selenium (ppm)	How Composition Determined	Fish Harvest Location
Belinsky et al. 1996	Flesh; fresh raw fish	15 +/- 2.85	0.7 +/- 0.39	3.2			0.4 +/- 0.09	0.3 +/- 0.10	0.75	7 +/- 2.94	0.03 +/- 0.011	0.23 +/- 0.040	0.4 +/- 0.057		5 adult females harvested during autumn	Caniapiscau (Quebec)
	Flesh; fresh raw fish	15 +/-2.06	1.1 +/- 0.48	4.1			0.6 +/- 0.09	0.5 +/- 0.10	0.83	5 +/- 1.02	0.03 +/- 0.011	0.3 +/- 0.12	0.6 +/- 0.20		5 adult females harvested during autumn	Lac Temoin (Quebec)
	Flesh; fresh raw fish	14 +/- 2.14	0.8 +/- 0.65	3.9			0.4 +/- 0.13	0.4 +/- 0.08	1	5 +/- 2.1	0.02 +/- 0.006	0.2 +/- 0.02	0.4 +/- 0.11		5 adult females harvested during autumn	Vermeulle (Quebec)
	Flesh; fresh raw fish	16.2	1.7	5.2			0.53	0.39	0.74	7.6	0.03	0.28	0.55		5 adult females harvested during autumn	Wemindji (Quebec)
	Eggs	11.9	7.0	15.7			0.21	0.66	3.14	38.2	0.2	0.31	2.3		Composite sample of 5 adult females harvested during autumn	Caniapiscau (Quebec)
	Eggs	10.9	8.3	16.7			0.47	1.9	4.04	33.2	0.12	0.44	4.3		Composite sample of 4 adult females harvested during autumn	Lac Temoin (Quebec)

* Levels of total fat are variable within fish and vary with the age, sex, and reproductive status of the fish being sampled. Often, these characteristics are not mentioned in studies of lake whitefish nutrient composition (Belinsky et al. 1996).

Table 3. Aggregation of fish consumption estimates currently available for the upper Great Lakes region.

Reference*	Fish meal/yr	Fish g/week	Fish g/day	Notes
Dellinger 2004	95		62	Ojibwe for upper Great Lakes; all fish species (mostly lake trout and whitefish) - based on participant recall weeks/months later
	104		60	Ojibwe for Lake Superior; all fish species (mostly lake trout and whitefish) - based on participant recall weeks/months later
	12		4.2	Ojibwe for upper Great Lakes - predominantly ate whitefish and perch (peaked in late summer) - based on participants consumption of walleye (weighed consumed portions) from 1997 - 2002
	34		11.2	Ojibwe for Lake Superior; all fish species (mostly lake trout and whitefish) - small amount of whitefish in March and summer - based on participants consumption of walleye (weighed consumed portions) from 1997 - 2002
Dellinger & Ripley 2016		78.4		Anishinaabe of upper Great Lakes (all fish species; traditional and nontraditional sources) - Previously reported to eat 420 g/week of fish --> Reduction may be due to EPA and other reports estimating that Anishinaabe subsistence practices place them at greater health risk from contaminants - Tribal people tend to overestimate fish consumption - Estimated and actual consumption values come from Dellinger 2004
Dellinger et al. 2018a		2 oz per week		Anishinaabe of upper Great Lakes (all fish species; traditional and nontraditional sources) - US EPA and USDA recommended fish intake is 6 oz per week
Gerstenberger et al. 1997	29			Ojibwa near Lake Superior - 75% of harvested WF and LT came from Lake Superior - Of study participants, most frequently eaten fish were LT (37%), wallleye (27.2%), and WF (27.2%) - Fish from Lake Superior were eaten 1x per month (or less) by 64.1% of sampled population (28.1% ate 1x per week and 6.7% ate 2x per week) - Highest fish consumption occurred in spring and early summer - 29 fish meals/year are for all fish species, not just WF (ranged from 0 - 150 fish meals/year)
Marushka et al. 2017			6.7	First Nations in Boreal Shield/Subarctic Ecozone (Ontario) - Averaged 0.14 ng/kg/day of DDE, 0.13 ng/kg/day of PCBs, and 0.11 g/day of n-3 FAs (EPA + DHA) based on this whitefish consumption
			2.03	First Nations in Boreal Shield/ Northeast Ecozone (Ontario) - Averaged 0.12 ng/kg/day of DDE, 0.24 ng/kg/day of PCBs, and 0.03 g/day of n-3 FAs (EPA + DHA) based on this whitefish consumption
			3.4	First Nations in Hudson Plains/Subarctic Ecozone (Ontario) - Averaged 0.10 ng/kg/day of DDE, 0.14 ng/kg/day of PCBs, and 0.05 g/day of n-3 FAs (EPA + DHA) based on this whitefish consumption
			1.4	First Nations in Mixed-wood Plain/Northeast Ecozone (Ontario) - Averaged 0.07 ng/kg/day of DDE, 0.17 ng/kg/day of PCBs, and 0.02 g/day of n-3 FAs (EPA + DHA) based on this whitefish consumption

* No studies listed the specific fish parts consumed.

Table 4. Comparison of nutrients between Lake Whitefish, wild Coho Salmon, and wild Lake Trout. Nutrient data for Coho Salmon come from FoodData Central (USDA 2019). Protein content for Lake Trout is from Fortune Fish Company and Vitamin D content of Lake Trout is from the James Bay region (Quebec, Canada). All three fish species are frequently harvested from Lake Michigan.

Nutrient	Lake Whitefish	Coho Salmon	Lake Trout
Protein	14.52g per 100g of fish[1]	21.62g per 100g of fish	592.5g per 100g of fish[4]
Omega-3 Fatty Acids	15100mg per 100g of fish[2]	1992mg per 100g of fish	22000mg per 100g of fish[2]
Vitamin D	4.5µg per 100g of fish[3]	9µg per 100g of fish	2.84.5µg per 100g of fish[5]

[1]USDA 2019, [2]Pantazopoulos et al. 2013, [3]Canadian Nutrient File 2015, [4]Fortune Fish Company, [5]Blanchet et al. 2004

REFERENCES

Agency for Toxic Substances and Disease Registry (ATSDR). 2018. Toxicological profile for perfluoroalkyls.

Barbo, N., T. Stoiber, O. V. Naidenko, and D. Q. Andrews. 2023. Locally caught freshwater fish across the United States are likely a significant source of exposure to PFOS and other perfluorinated compounds. *Environmental Research, 220*, 115 – 165.

Belinksy, D. L., H. V. Kuhnlein, F. Yeboah, A. F. Penn, and H. M. Chan. 1996. Composition of fish consumed by the James Bay Cree. *Journal of Food Composition and Analysis, 9*, 148 – 162.

Blanchet, C., E. Dewailly, M. Lucas, L. Atikesse, C. Godin, L. Leclerc, E. Robinson, S. Babo, M. Plante, J. Dessau, G. Lemay, and J. Pelletier. 2004. The northern fish nutrition guide – James Bay region. https://www.hydroquebec.com/data/developpement-durable/pdf/northern_fish_nutrition_guide_james_bay_en.pdf

Brenden, T. O., M. P. Ebener, T. M. Sutton, M. L. Jones, M. T. Arts, T. B. Johnson, M. A. Koops, G. M. Wright, and M. Faisal. 2010. Assessing the health of Lake Whitefish populations in the Laurentian Great Lakes: Lessons learned and research recommendations. *Journal of Great Lakes Research 36*(SUPPL. 1), 135–139.

Broadway, M., L. Antunes, and J. Broadway. 2019. Food tourism in a marginal agricultural region: The case of Michigan's Upper Peninsula. *Journal of Gastronomy and Tourism, 4*(1), 1- 12.

Chiarappa, M. J., and K. M. Szylvian. 2003. Fish for all: An oral history of multiple claims and divided sentiment on Lake Michigan. Michigan State University Press, East Lansing, Michigan.

Cleland, C. E. 1982. The Inland Shore Fishery of the Northern Great Lakes: Its Development and Importance in Prehistory. *American Antiquity 47*(4), 761 – 784.

Dellinger, J. A. 2004. Exposure assessment and initial intervention regarding fish consumption of tribal members of the Upper Great Lakes region in the United States. *Environmental Research, 95*, 325 – 340.

Dellinger, J. A., M. D. Moths, M. J. Dellinger, and M. P. Ripley. 2014. Contaminant trends in freshwater fish from the Laurentian Great Lakes: A 20-year analysis. *Human and Ecological Risk Assessment: An International Journal, 20*(2), 461 – 478.

Dellinger, M. J. and M. P. Ripley. 2016. Mercury risks versus nutritional benefits of tribal commercial fish harvests in the Upper Laurentian Great Lakes. *Human and Ecological Risk Assessment: An International Journal, 22*(4), 1036 – 1049.

Dellinger, M. J., J. T. Olson, B. J. Holub, and M. P. Ripley. 2018a. Fatty acids in ten species of fish commonly consumed by the Anishinaabe of the upper Great Lakes. *Journal of Great Lakes Research, 44,* 521 – 526.

Dellinger, M. J., J. T. Olson, B. J. Holub, and M. P. Ripley. 2018b. Mercury, polychlorinated biphenyls, selenium, and fatty acids in tribal fish harvests of the Upper Great Lakes. *Risk Analysis, 38*(10), 2029 – 2040.

Dellinger, M. J., M. Lyons, R. Clark, J. Olson, N. Pingatore, and M. Ripley. 2019. Culturally adapted mobile technology improves environmental health literacy in Laurentian, Great Lakes Native Americans (Anishinaabeg). *Journal of Great Lakes Research 45*(5):969–975.

Johnson, L. and B. Schroeder. 2012. Sustainable coastal tourism development in Northeast Michigan. Michigan Sea Grant. Ann Arbor, MI. http://www.discovernortheastmichigan.org/downloads/sustainablecoastaltourism_101012.pdf

Ebener, M. P., R. E. Kinnunen, P. J. Schneeberger, L. C. Mohr, J. A. Hoyle, and P. Peeters. 2008. Management of commercial fisheries for Lake Whitefish in the Laurentian Great Lakes of North America. Pages 99 – 143 *in* Schechter, M. G., N. J. Leonard, and W. W. Taylor. *International Governance of Fisheries Ecosystems.* American Fisheries Society, Bethesda, MD.

FAO. 2018. The State of World FIsheries and Aquaculture. Rome.

Fortune Fish Company. n.d. Lake Trout nutritional information. https://www.fortunefishco.net/Assets/ffg-trout-lake-sm.pdf

Gerstenberger, S. L. and J. A. Dellinger. 2002. PCBs, mercury, and organochlorine concentrations in lake trout, walleye, and whitefish from selected tribal fisheries in the upper Great Lakes region. *Environmental Toxicology, 17,* 513 – 519.

Gerstenberger, S. L., D. R. Tavris, D. R., L. K. Hansen, J. Pratt-Shelley, and J. A. Dellinger. 1997. Concentrations of blood and hair mercury and serum PCBs in an Ojibwa population that consumes Great Lakes region fish. *Journal of Toxicology: Clinical Toxicology, 35*(4), 377 – 386.

Gewurtz, S. B., S. P. Bhavsar, and R. Fletcher. 2011. Influence of fish size and sex on mercury/PCB concentration: Importance for fish consumption advisories. *Environmental International, 37,* 425 – 434.

Hanrahan, L. P., C. Falk, H. A. Anderson, L. Draheim, M. S. Kanarek, J. Olson, and the Great Lakes Consortium. 1999. Serum PCB and DDE levels of frequent Great Lakes sport fish consumers – A first look. *Environmental Research Section A, 80,* S26 – S37.

Health Canada. 2015. Canadian Nutrient File (CNF) Database. https://food-nutrition.canada.ca/cnf-fce/index-eng.jsp

House, K. 2023. Lakes Michigan and Huron join list of lakes with PFAS-tainted smelt. *Bridge Michigan*. https://www.bridgemi.com/michigan-environment-watch/lakes-michigan-and-huron-join-list-lakes-pfas-tainted-smelt

Hursky, O. and M. Pietrock. 2012. Chemical contaminants and parasites: Assessment of human health risks associated with consumption of whitefish (*Coregonus clupeaformis*) from two boreal lakes in northern Saskatchewan, Canada. *Science of the Total Environment, 424*, 97 – 103.

Imm, P., L. Knobeloch, H. A. Anderson, and the Great Lakes Sport Fish Consortium. 2005. Fish consumption and advisory awareness in the Great Lakes Basin. *Environmental Health Perspectives, 113*(10), 1325 – 1329.

Jahns, L. 2016. Chapter 1: Fish intake in the United States. *In* Raatz, S. K. and D. M. Bibus (eds). *Fish and fish oil in health and disease prevention.* Academic Press- Elsevier.

Kalkirtz, V., M. Martinez, and A. Teague. 2008. Environmental Justice and Fish Consumption Advisories on the Detroit River Area of Concern. Master's Thesis. University of Michigan, Ann Arbor, MI.

Karahadian, C. and R. C. Lindsay. 1989. Composition of n-3 oils from some Great Lakes freshwater fish. *Journal of Food Composition and Analysis, 2,* 13 – 21.

Kinietz, W. V. 1965. The Indians of the western Great Lakes, 1615 – 1760. *Ann Arbor Paperback,* University of Michigan Press, Ann Arbor, MI.

Kinnunen, R. E. 2016. Recreational fishers also target Lake Whitefish in the Great Lakes. https://www.canr.msu.edu/news/recreational_fishers_target_lake_whitefish_in_the_great_lakes_kinnunen16.

Kremer, R. 2022. State commercial fishing industry adapting to changing ecosystems, COVID-19 pandemic. Wisconsin Public Radio. https://www.wpr.org/state-commercial-fishing-industry-adapting-changing-ecosystems-covid-19-pandemic.

Kuhnlein, H. V., D. Appavoo, N. Morrison, R. Soueida, and P. Pierrot. 1994. Use and nutrient composition of traditional Sahtú (Hareskin) Dene/Métis foods. *Journal of Food Composition and Analysis, 7,* 144 – 157.

Lauber, T. B., N. A. Connelly, J. Niederdeppe, and B. A. Knuth. 2017. Urban anglers in the Great Lakes region: Fish consumption patterns , influences, and responses to advisory messages. *Science of the Total Environment, 590–591,* 495 – 501.

Love, D. C., P. Pinto, J. Olson, J. P. Fry, and P. M. Clay. 2017. Fisheries, food, and health in the

USA : the importance of aligning fisheries and health policies. *Agriculture & Food Security 6*(16), 1 – 15.

Lynch, A. J., S. J. Cooke, A. M. Deines, S. D. Bower, D. B. Bunnell, I. G. Cowx, V. M. Nguyen, J. Nohner, K. Phouthavong, B. Riley, M. W. Rogers, W. W. Taylor, W. Woelmer, S. Youn, and T. Douglas Beard, Jr. 2016. The social, economic, and environmental importance of inland fishes and fisheries. *Environmental Reviews 7*(February), 1 – 7.

Lynch, A. J., E. Varela-Acevedo, and W. W. Taylor. 2015. The need for decision-support tools for a changing climate: Application to inland fisheries management. *Fisheries Management and Ecology 22*(1), 14 – 24.

Lynn, K., J. Daigle, J. Hoffman, F. Lake, N. Michelle, D. Ranco, C. Viles, G. Voggesser, and P. Williams. 2013. The impacts of climate change on tribal traditional foods. *Climate Change, 120,* 545 – 556.

Marushka, L., M. Batal, W. David, H. Schwartz, A. Ing, K. Fediuk, D. Sharp, A. Black, C. Tikhonov, and H. M. Chan. 2017. Association between fish consumption, dietary omega-3 fatty acids, and persistent organic pollutants intake, and type 2 diabetes in 18 First Nations in Ontario, Canada. *Environmental Research, 156,* 725 – 737.

Moths, M. D., J. A. Dellinger, B. Holub, M. P. Ripley, J. E. McGraw, and R. E. Kinnunen. 2013. Omega-3 fatty acids in fish from the Laurentian Great Lakes tribal fisheries. *Human and Ecological Risk Assessment: An International Journal, 19*(6), 1628 – 1643.

Neff, M. R., S. P. Bhavsar, F. J. Ni, D. O. Carpenter, K. Drouillard, A. T. Fisk, and M. T. Arts. 2014. Risk-benefit of consuming Lake Erie fish. *Environmental Research, 134,* 57 – 65.

Pantazopoulos, P., J. M. Sawyer, M. E. Turyk, M. Diamond, S. P. Bhavsar, D. Mergler, S. Schantz, N. Ratnayake, and D. O. Carpenter. 2013. Fatty acids in Great Lakes lake trout and whitefish. *Journal of Great Lakes Research, 39,* 120 – 127.

Philibert, A., H. Schwartz, H, and D. Mergler. 2009. An exploratory study of diabetes in a First Nation community with respect to serum concentrations of p,p'-DDE and PCBs and fish consumption. *Environmental Research and Public Health, 6,* 3179 – 3189.

Pothoven, S. A. 2005. Changes in Lake Whitefish Diet in Lake Michigan , 1998-2001. Pages 127–142 *in* L. C. Mohr and T. F. Nalepa, editors. *Proceedings of a workshop on the dynamics of Lake Whitefish (Coregonus clupeaformis) and the amphipod Diporeia spp. in the Great Lakes*. Great Lakes Fish. Comm. Tech.

Pothoven, S. A. 2020. The influence of ontogeny and prey abundance on feeding ecology of age-0 Lake Whitefish (Coregonus clupeaformis) in southeastern Lake Michigan. *Ecology of Freshwater Fish, 29*(1), 103 – 111.

Pothoven, S. A., T. F. Nalepa, P. J. Schneeberger, and S. B. Brandt. 2001. Changes in diet and body condition of Lake Whitefish in southern Lake Michigan associated with changes in benthos. *North American Journal of Fisheries Management, 21,* 876 – 883.

Ruffle, B., U. Vedagiri, D. Bogdan, M. Maier, C. Schwach, and C. Murphy-Hagan. 2020. Perfluoroalkyl substances in U.S. market basket fish and shellfish. *Environmental Research, 190,* 109932

Spratt, D. 2021. Federal relief: Great Lakes fisheries finally get a cut of COVID-19 relief funds. *Great Lakes Now*. https://www.greatlakesnow.org/2021/01/great-lakes-fisheries-federal-covid-19-relief-funds/

Stachowicz, J. J., J. R. Terwin, R. B. Whitlatch, and R. W. Osman. 2002. Linking climate change and biological invasions: Ocean warming facilitates nonindigenous species invasions. *Proceedings of the National Academy of Sciences of the United States of America, 99*(24), 15497 – 15500.

Turyk, M. E., S. P. Bhavsar, W. Bowerman, E. Boysen, M. Clark, M. Diamond, D. Mergler, P. Pantazopoulos, S. Schantz, and D. O. Carpenter. 2012. Risks and benefits of consumption of Great Lakes fish. *Environmental Health Perspectives, 120*(1), 11 – 18.

USDA. 2018. USDA Food Composition Database. https://ndb.nal.usda.gov/ndb/.

US EPA. 2014. Estimated fish consumption rates for the U.S. population and selected subpopulations (NHANES 2003-2010). Washington, D.C.

Wang, Y. J., L. A. Miller, M. Perren, and P. B. Addis. 1990. Omega-3 fatty acids in Lake Superior fish. *Journal of Food Science, 55*(1), 71 – 74.

Williams, K. 2020. Commercial fishing is critical infrastructure – will it survive COVID-19? *Manistee News Advocate*, https://www.manisteenews.com/local-news/article/Commercial-fishing-is-critical-infrastructure-15369951.php

Youn, S., E. H. Allison, C. Fuentevilla, S. Funge-Smith, H. Triezenberg, M. Parker, S. Thilsted, P. Onyango, W. Akpalu, G. Holtgrieve, M. J. Good, and S. Muise. 2016. The Underappreciated Livelihood Contributions of Inland Fisheries and the Societal Consequences of Their Neglect. *Freshwater, Fish and the Future: Proceedings of the Global Cross-Sectoral Conference,* 107 – 120.

Youn, S., W. W. Taylor, A. J. Lynch, I. G. Cowx, T. Douglas Beard Jr., D. Bartley, and F. Wu. 2014. Inland capture fishery contributions to global food security and threats to their future. *Global Food Security 3*(3–4), 142 – 148.

CHAPTER 2: DETERMINING AND DESCRIBING THE VALUE CHAIN OF THE COMMERCIAL LAKE WHITEFISH (*COREGONUS CLUPEAFORMIS*) FISHERIES IN MICHGIAN WATERS OF LAKE MICHIGAN

Introduction

Since the late 1990s the abundance of Lake Whitefish populations in the upper Laurentian Great Lakes (Michigan, Huron, Superior) have been steadily decreasing (Baldwin et al. 2000). Part of this decrease has been attributed to overfishing, increased intra-specific competition with invasive *Dreissenid* mussels (which negatively altered the Great Lakes food webs), and habitat degradation (e.g. declines in spawning habitat area and quality) due to increasing human population density, natural resource use, and land-use changes in the Great Lakes basin (Nalepa et al. 2009). Additionally, declining ice cover on the lakes during the winters (amount of ice cover and delays in when ice cover forms) and warming lake temperatures, both associated with climate change, are thought to have decreased survival of Lake Whitefish eggs and juveniles during the winter and spring, further contributing to a decline in the abundance, and thus harvest, of Lake Whitefish populations in Lakes Michigan and Huron (Lynch et al. 2015).

Commercial harvests of Lake Whitefish in the Great Lakes have also been decreasing, largely due to declining Lake Whitefish population abundances. As a result, commercial fishers have had increasing difficulty in harvesting enough fish to support their livelihoods and there is a growing lack of Lake Whitefish to satisfy customer demand (Gorenflo and Wright, 2018). Additionally, while Lake Whitefish is often considered a premium food product (Cox et al. 2011), dockside value for Lake Whitefish tends to be relatively low and has not increased in spite of recent decreases in Lake Whitefish harvests (average $2.09 per pound in 2013; Michigan DNR 2016). In order to increase their own profits and economic well-being, some fishers are directly selling the whitefish that they harvest, usually at specialty fish stores or farmers' markets. Doing so increases profits via bypassing wholesalers and allowing fishers to directly connect with customers. Actors in the Lake Whitefish supply chain have also tested methods of increasing the value of Lake Whitefish harvests to consumers, such as creating sustainability or brand labels and introduction of new products (e.g. whitefish dip, whitefish sausage), in an effort to increase the revenue generated by dwindling commercial harvests.

One such effort was the labeling of Lake Whitefish under the "Legend of the Lakes" brand (http://www.greatlakesfisheriestrail.org/collection.asp?ait=jv&jid=18), whose development was led by Michigan Sea Grant in concert with state-licensed commercial fishers and Michigan government representatives. The Legends of the Lakes was a marketing program

created in partnership with commercial fishers in Michigan and Michigan State University's Product Center for Agriculture and Natural Resources, along with other partners (https://www.michiganseagrant.org/downloads/upwellings/upwellings-Feb09.pdf). The steering committee also hired a market research firm that helped bring the various actors in the Lake Whitefish commercial industry together in order to identify the needs of the industry as a whole in order to promote the value and sustainability of the industry. Based on this process, the *Legends of the Lakes* brand, and accompanying packaging and marketing strategies, were developed and launched. Although initially successful in raising awareness of Great Lakes Lake Whitefish among consumers and increasing the price supply chain actors received for their products, the *Legends of the Lakes* brand faded after a few years, mostly due to key actors (especially two of the biggest processors) retiring or otherwise leaving the industry (Ron Kinnunen, retired MI Sea Grant extension educator, personal communication). Actors have now shifted their efforts towards individual or smaller-scale efforts (such as individual storefronts and stalls at farmers' markets) to increase the value of Lake Whitefish products, rather than continuing a coordinated industry-wide effort.

Governance of the Lake Whitefish Fisheries

Governance of Lake Whitefish commercial fisheries in the Great Lakes region involves interactions between state (United States), provincial (Canada), federal, and tribal authorities (Ebener et al. 2008). In Michigan, some of the Lake Whitefish commercial fisheries are managed by the state of Michigan (primarily by the Michigan Department of Natural Resources; MDNR) while other commercial fisheries are managed by tribal authorities (e.g., Chippewa Ottawa Resource Authority; CORA). The division and management of these fisheries is based on the 2000 Consent Decree for the 1836 Treaty Waters (Figure 4; Hudson and Ziegler 2014). The 2000 Consent Decree was valid for 20 years and is currently being renegotiated, to be in effect for another 20 years. Division of the 1836 Treaty Waters between state and tribal waters (for fish harvesting and management purposes), regulations for these waters, gear restrictions, spawning closures, and harvest limits are all decided in this Consent Decree (Case No. 2:73 CV 26 2000). The Consent Decree focuses on several fish species in these waters, but places particular emphasis on lake trout and Lake Whitefish.

Due to the governance structure for Lake Whitefish in the 1836 Treaty Waters, commercial fisheries in this region are regulated by the state of Michigan (primarily through the

Michigan Department of Natural Resources; DNR) and tribal authorities (Chiarappa and Szylvian 2003). As a result, there are both state-licensed commercial fishers and tribal-licensed commercial fishers for Lake Whitefish. Each group has different commercial fishing regulations (e.g. gear used, license requirements, harvest limits), which are based on the 2000 Consent Decree and regulations by their respective governing authority (e.g. MDNR or CORA).

Goals and Objectives

This study focused on Michigan state-licensed commercial fisheries due to prior connections with state-licensed commercial fishers via their interactions with Michigan Sea Grant and interactions at Michigan Fish Producer Association (MFPA) annual meetings. The MFPA is composed mostly of commercial fishers and works to develop and promote the commercial fishing industry in Michigan (mfpa.us). The goals of this research were threefold: 1) Identify the current (2019) actors in the Michigan Lake Whitefish supply chain, 2) Trace the path of Lake Whitefish from harvest to consumption (i.e., the Lake Whitefish supply chain), and 3) Describe the strengths and challenges that supply chain actors believe will impact the future of the Michigan Lake Whitefish commercial fishery. By pulling together these three areas of information, this study fills a knowledge gap on the structure and composition of Michigan's Lake Whitefish commercial fishery. Additionally, this study provides updated information on the socioeconomic aspects of the commercial fishery since the adoption of the 2000 Consent Decree, which has previously not been available in the literature.

Methods

In summer and fall of 2019, I conducted In-depth, semi-structured interviews with Michigan state-licensed commercial fishers and key informants knowledgeable about the Lake Whitefish supply chain (IRB Study 00002654). Interview questions focused on participants' experiences in the Lake Whitefish commercial fishery, including changes in the fishery over the past 10 years, and participants' perspectives on how the fishery would, or needs to, change over the next 10 years in order to remain economically and ecologically viable (Appendix I). Information provided by interviewees was confidential. Interview participants were recruited via contacting current and former commercial fishers who have worked with Michigan Sea Grant extension educators and reaching out to attendees at the annual Michigan Fish Producers Association (MFPA) meetings. Additional interview participants were identified using the snowball sampling method (Patton 2014, Bevilacqua et al. 2019).

All interviews were recorded and later transcribed and coded using the MAXQDA2020 software program. Data were analyzed using inductive codes drawn from the research goals and common themes identified in the interviews (Patton 2014). Codes were developed for each of the research goals. For goal 1 (fishery participants), the "actor" code was supplemented with more specific subcodes for each type of actor mentioned by interviewees (e.g. "fisher", "retailer", "supplier"). For goal 2 (Lake Whitefish supply chain), a code was used for each stage of the life cycle (e.g. "harvest", "processing", "wholesale", "own store", "local market"). For goal 3 (future of the fishery), each "challenge" and "opportunity" identified by interviewees was assigned an overall "challenge" or "opportunity" code. The "challenge" and "opportunity" codes were supplemented with sub-codes as similar themes arose across interviews (e.g. "declining fish" was a frequently mentioned challenge, while "local demand" was a frequently mentioned opportunity).

Interview participants were asked to provide information on their participation in the Lake Whitefish commercial fishery (in what capacity, how long, etc.), including other actors (e.g. suppliers, customers) they interact with. Interviewees were also asked to share information regarding what characteristics of Lake Whitefish they look for when purchasing or selling fish products and how they market their products. Finally, interviewees were asked to describe how the fishery had changed, in their personal experience, over the past decade and how they believed the fishery would change over the next decade, including potential opportunities and challenges they foresaw for the continued viability of the commercial Lake Whitefish fishery in Michigan. The full interview guide is available in Appendix 1. Interviewee names, as well as other identifying information the interviews, have been changed or omitted in this paper to preserve the confidentiality of interviewees.

Data gathered from these interviews were supplemented with anthropological accounts of commercial fishing in the Great Lakes region (e.g. *Fish for All* (Chiarappa and Szylvian 2003)), presentations given at the annual Michigan Fish Producers Association meetings and attendees' comments/questions on those presentations, newspaper articles about the Lake Whitefish commercial fishery, and radio and podcast interviews given by Michigan state-licensed commercial fishers on their livelihoods. These additional data sources provided context regarding the Lake Whitefish commercial fishery in the larger Great Lakes region and allowed for insights from commercial fishers (and other supply chain actors) who were unavailable to be

interviewed. Some of these supplemental data sources also provided longer-term background information regarding changes in the Lake Whitefish commercial fishery over the past fifty years.

Results

Based on the interviews, two overarching themes were identified: current status of the fishery and the uncertain future of the fishery. The first theme (current status of the fishery) addressed research questions related to the structure and form of the Lake Whitefish supply chain. The second theme (uncertain future of the fishery) also touches on the Lake Whitefish supply chain but encompasses a value-added component, as this theme also encompassed interviewees' ideas to innovate and develop products and businesses to maintain the value of the fishery and sustain the Lake Whitefish commercial fishery into the next decade.

Current Status of the Lake Whitefish Commercial Fishery

Actors and Structure of the Lake Whitefish Supply Chain

All of the interviewees expressed that the fishery was very different now than it had been a decade ago, and many of them believed that these changes (particularly changes in consumer demand and retail opportunities) would continue into the future (Figure 5). From close to 60 commercial Lake Whitefish fishers a few decades ago, there are currently only 13 state-licensed commercial fishers in Michigan. Many of these fishers are older and belong to multi-generational commercial fishing families. In addition to their license for Lake Whitefish, some of these fishers also own licenses for other commercially harvested species in the Great Lakes.

The fishery itself has also been consolidating as actors (e.g., commercial fishers, processors) have retired from the fishery or left for other reasons, such as the difficulty of financially supporting themselves and their families solely through commercial fishing. These challenges are generally due to the inherently difficult nature of commercial fishing itself (long hours, variable harvests, unpredictable working conditions, relatively low pay) as well as the continuing declines in harvests. Several interviewees mentioned the sharp decrease in processors in Michigan, as many processors have retired or sold their business because they were unable to source enough Lake Whitefish to either fulfill demand or keep their processing facilities running cost-effectively. As the fishery has consolidated, fishers find themselves becoming involved in additional steps of the supply chain, especially taking on more processing and retail activities, in order to continue selling their products.

Additionally, while Lake Whitefish used to be sold throughout the eastern United States, the majority of the Lake Whitefish harvest now stays within the Great Lakes coastal communities in which fishers are located. Thus, the current Lake Whitefish supply chain has generally become much shorter, more localized, and has fewer actors involved (Figure 6). These changes in the supply chain have led to changing business models, most notably fishers shifting toward selling to local restaurants in Michigan's coastal communities, rather than wholesalers that then sell Lake Whitefish outside of Michigan. Importantly, while these changes have had negative effects, there have also been positive effects for fishers, such as greater connections to their customers (developing stronger ties to consumers and increasing the loyalty of returning customers), resulting in increased retail opportunities.

In order to augment the revenue generated by their harvests, commercial fishers are experimenting with a variety of processing methods and retail opportunities, particularly direct sale opportunities such as personal storefronts (either online or at a physical retail location) and sales at Michigan farmers' markets. There is also an increased interest in other efforts to increase market reach and consumer interest in Great Lakes Lake Whitefish. Several talks at the past several Michigan Fish Producers Association meetings, for example, covered methods for fishers to directly market their fish in their local communities and served as a forum for fishers to connect with agricultural groups in Michigan dedicated to promoting local Michigan food and food producers. Other fishers are grouping together in order to collectively pay for trucks and other infrastructure needed to transport and sell their harvests to urban areas of Michigan and to wholesalers in Chicago.

In addition to selling to wholesalers, many fishers are turning to selling their harvest (either their whole harvest or some portion of it) themselves. These retail avenues are generally via direct retail in their fishers' own store or through farmers' markets in Michigan. Many fishers have also shifted to selling their Lake Whitefish to local restaurants, especially during the summer tourism season, and some fishers have also experimented with online avenues for selling their harvests. Most interviewees said that, over the past decade, demand for Lake Whitefish during the summer has greatly increased, especially as tourism has also increased, and that they either were not able to keep up with the demand for Lake Whitefish or would easily be able to sell more Lake Whitefish if they were able to harvest more (either due to an increase in quotas or greater abundance of Lake Whitefish).

Future of the Lake Whitefish Fishery

During the interviews, participants were asked to share their thoughts on the future of the fishery and changes they believed needed to occur, if any, in order to ensure the viability of the Lake Whitefish commercial fishery through the next decade. These responses were categorized into perceived strengths and perceived challenges to the Lake Whitefish commercial fishery. These strengths and challenges are self-identified by the interviewees and reflect their individual perspectives on the current status of the fishery and potential opportunities and obstacles each individual saw as likely occurring in the future.

Changes in the Lake Whitefish Value Chain

Many interviewees mentioned difficulties in selling and marketing Lake Whitefish for a viable price. Much of this difficulty was due to increasing competition from Lake Whitefish imported from inland lakes in Canada, which is generally more abundant and cheaper than Great Lakes Lake Whitefish. Some interviewees expressed concern that increasing importation of inland Lake Whitefish was decreasing consumer value for Lake Whitefish in general. A previous study (Ebener et al. 2008) and initial trials during the development of the *Legends of the Lakes* found consumers preferred the taste of Great Lakes Lake Whitefish (as opposed to Lake Whitefish from inland lakes in Canada), noting that Great Lakes Lake Whitefish tasted sweeter and fresher. Interviewees believed that inland whitefish was inferior in quality and taste to Lake Whitefish harvested from the Great Lakes, due to differences in handling procedures post-harvest (e.g. how soon fish were put on ice and to what extent), harvest gear used (e.g. trap nets vs gill nets), and prey species consumed in inland lakes vs. the Great Lakes. Because consumers are generally unaware of the different origins of Lake Whitefish, and the potential differences in taste and quality between Lake Whitefish from different sources, these consumers may believe that all Lake Whitefish do not taste good, rather than realizing that the difference in taste could be due to the harvest location of the Lake Whitefish. All interviewees also shared that their customers have frequently told them that they would no longer buy fish from grocery stores, and would only buy their fish from the interviewee, because the fish taste better and fresher than any fish they have bought in other retail locations.

Another change in the Lake Whitefish commercial fishery during the past decade was the development of additional products and processing of Lake Whitefish. In contrast to the minimal processing (if any) that they used to do, most fishers now perform additional processing (scaling,

deboning, filleting) on their fish before it is sold. Some fishers (particularly those with their own retail outlet) also further process their Lake Whitefish and transform it into different products, such as smoked Lake Whitefish, whitefish sausage, and whitefish dip. These additional processing procedures generally seems to serve 2 functions. First, the more the fish is processed, the more the fishers can charge for the "improved" product (easier to consume these products "as is", so less work and knowledge is needed by consumers). Secondly, some interviewees said that this additional processing gave them a competitive edge when selling to wholesalers, as this additional processing resulted in wholesalers viewing these more processed products as higher quality and additional processing could signal that the fisher took additional steps to ensure the freshness and high quality of their products. Second, new Lake Whitefish products could enable fishers to reach new market segments. When talking to their customers, fishers found that many customers were initially reluctant to purchase fish because they were either unsure how to prepare/cook fish or did not like the taste of fish. The additional processing the fishers provided, however, combined with cooking tips shared by the fishers, helped participants overcome their initial reluctance to cooking fish. Additionally, products like whitefish sausage and whitefish dip appealed to customers because these products were already familiar to customers (due to similarity to existing food products), were easy to prepare and eat, and often did not have the fishy taste many customers disliked.

Perceived Strengths

Most interviewees believed that the Lake Whitefish commercial fishery would continue to exist in some form, especially in Lake Superior, even as commercial fishing is becoming an increasingly difficult livelihood in the upper Great Lakes. This belief seemed to stem from the connection that most commercial fishers have to their livelihood, particularly the multi-generational nature of most commercial fishing operations and the sense of self-identity that commercial fishing contributes to these individuals. Most commercial fishers said that they loved their jobs and had been involved in the industry from a very young age, often getting their first experiences by working for relatives in the commercial fishing industry. Many interviewees also hoped that their children, or other relatives, would carry-on their fishing operations after they retired, although many also expressed doubts about the willingness of their children to become commercial fishers. Interviewees were generally optimistic that commercial fishing would continue to exist on the Great Lakes (perhaps as a specialty fishery), however, pointing out the

contributions of the commercial fishery to the cultural history of the Great Lakes and the importance of keeping alive an important part of Michigan history.

Interviewees were optimistic about consumer demand for Lake Whitefish and believed that demand will continue to grow, especially during the summer tourism season. Most fishers had seen an increase in demand for Lake Whitefish from their restaurant customers, who also reported an increase in tourist demand for Lake Whitefish during the summer months. This demand has been increasing over the past decade and several interviewees said that they could not keep up with the increase in demand (due to an inability to harvest enough Lake Whitefish to meet this demand). Several fishers shared that, especially during the late summer months, they seldom have extra fish to sell because their customer demand (both local restaurants as well as repeat customers to their own fish houses) exceeded the fish they are able to harvest (due to lack of available fish). Additionally, many interviewees said that customers expressed a preference for Great Lakes Lake Whitefish, especially once these customers had had a chance to try Great Lakes Lake Whitefish and received information regarding the health and cultural values Lake Whitefish, and the commercial fishery, provided to Michigan communities. Following from these interactions, most interviewees believed that addressing the lack of consumer awareness of the superior taste of Great Lakes Lake Whitefish and lack of consumer education regarding the positives of Great Lakes fish and fisheries would go a long way toward increasing consumers' value for Great Lakes Lake Whitefish and greatly increasing the number of customers for their businesses.

In addition to selling their harvest to wholesalers and local restaurants, many fishers also have their own retail operations. These operations, which include their own fish house, online storefronts, and/or farmers' markets (https://www.youtube.com/watch?v=5kBdfDw1_D8), are another way for supply chain actors to increase their customer base and form connections with local community members. Farmers' markets in particular are a convenient option for fishers because farmers' markets tend to be locally situated, provide retail infrastructure and an already established customer base, and are usually not as expensive as creating one's own retail outlet. Several interviewees also mentioned that selling at a farmers' market was also a good way to gauge the demand for fish in a given area, before making the decision on whether or not to expand more permanent retail options in that area.

Perceived Challenges

Although interviewees were optimistic about continued consumer demand for Lake Whitefish products, all interviewees expressed concerns about being able to meet that demand. All interviewees mentioned recently declining harvests as a concern, although they disagreed on the long-time outlook. Some interviewees believed that the current declines were not a big problem, because their experiences in the fishery have shown that Lake Whitefish abundance is variable and cyclic. Thus, these participants believed that, while the abundance of Lake Whitefish populations are currently low, the populations will increase in the near future and harvests would again increase. Other participants were more worried, believing that there was little chance of Lake Whitefish populations increasing in the near future. These participants were concerned that decreases in population abundance would continue to occur (due to continued decreases in *Diporeia* and increased abundance of lake trout), posing long-term challenges for the viability of the commercial fishery as lower populations could lead to lower harvest quotas and perhaps even closures of the commercial fishery.

One of the main challenges identified by interviewees is that the state-licensed commercial fishery in Michigan is a single-species fishery. In other words, state-licensed commercial fishers are only allowed to harvest Lake Whitefish. Any other fish that happen to be captured in their nets, such as *Salvinus namaycush* lake trout, cannot be kept and must be immediately released upon capture. In addition to limiting their harvest potential, restrictions on harvest species also impacts fishers' commercial opportunities. Several participants shared that the single-species fishery regulations limited their ability to sell their catch to many grocery stores, which otherwise could be a steady, valuable sources of revenue. These participants said that major grocery stores, such as Meijer and Kroger, would not buy from state-licensed commercial fishers because these fishers were unable to supply both the volume and the variety of fish species (e.g. Lake Whitefish, lake trout, walleye, lake perch) demanded by these retail outlets on a consistent basis. This limitation was also exacerbated by interviewees' fears over competition from inland Lake Whitefish from Canada, which is the primary source of Lake Whitefish sold to major grocery chains.

Another challenge mentioned by interviewees, was the increasing tension between recreational and commercial fishing interests. As commercial fish stocks have declined and recreational fisheries have developed in the Great Lakes region, there has been a perceived loss

of political power for the commercial fisheries (Talhelm 1988). Several interviewees echoed this view, saying that it seemed like the DNR did not care about commercial fisheries (which are mostly Lake Whitefish fisheries) and wanted to eliminate commercial fishing, in favor of further development of recreational fisheries (due to the perceived greater economic value of recreational fisheries). This view was further emphasized by the inability of commercial fishers to expand beyond Lake Whitefish, such as being able to sell the lake trout that were incidentally caught in their nets). Interviewees also expressed frustration with the lack of data regarding valuation of the commercial fishery overall. While dockside value of Lake Whitefish harvests is recorded by the DNR, it is generally acknowledged that the value of the commercial fishery (including other jobs related to the fishery itself) is much greater than just the dockside value of the harvest. This expanded valuation would include the values of Lake Whitefish products that are sold, as well as tourism, retail, and restaurant businesses dependent on selling Lake Whitefish and the livelihoods and communities these businesses support. In a hearing for the Michigan Senate Committee on Natural Resources (June 11, 2020), one witness estimated that the economic value of the commercial fishery is about 10 times the dockside value. The basis for this estimate is unclear, however, as there are very few studies on the overall economic value of the commercial fishery in the Great Lakes, particularly the economic multipliers generated by commercial fishing activities, including the increase in value as Lake Whitefish travel up through the supply chain. In order to convince policymakers, and others, of the contributions that the commercial fishery makes to Michigan's communities and coastal economies, interviewees mentioned the need for studies that estimate economic values of the commercial fishery and its activities. These estimated values, and the studies supporting them, will also strengthen the case for supporting commercial fisheries as important economic components of Michigan's coastal communities and finding synergies between Michigan's commercial and recreational fisheries.

Discussion

This study is a "first look" at state-licensed commercial Lake Whitefish fishers' perceptions of the status of the Lake Whitefish commercial fishery in Michigan waters of the upper great lakes, how the fishery has changed in the past decade, and how it will continue to change in the future. Drawing on the experience of key informants and current and former commercial fishers, this study outlined the current value chain for the Lake Whitefish commercial fishery and serves as a baseline for future work on how the commercial fishery will

continue to change, including due to the COVID-19 pandemic. Additionally, this study illustrates changes in the commercial fishery from a socioeconomic perspective, rather than the ecological impacts perspective often taken in the literature. This socioeconomic perspective provides a stepping stone to more explicitly exploring the linkages between ecological changes in Lake Michigan (e.g. invasive species, changing weather patterns, declining Lake Whitefish populations) and impacts on the human and community side of Lake Michigan's commercial fisheries.

Many of the challenges discussed by the fishers focus on maintaining the economic viability of the commercial fishery, including identifying and communicating the overall value of the commercial Lake Whitefish fishery to Michigan. One important next step is to identify the economic multipliers and values associated with this important commercial fishery. Another important next step is to determine how fluctuating Lake Whitefish abundances impact the commercial fishery, particularly in relation to consumer demand and valuation for Lake Whitefish. For example, does decreased Lake Whitefish abundance increase consumer demand for Lake Whitefish and, in turn, allow suppliers to charge higher prices for Lake Whitefish? Put another way, what is the relationship between Lake Whitefish abundance and consumer valuation of Lake Whitefish, and what is the maximum price consumers are willing to pay for Lake Whitefish products, under market (grocery store or local market) conditions? Additionally, how does the availability of other fish species (e.g. salmon, lake trout, walleye) affect consumer valuation of Lake Whitefish? These research gaps are important to address concerns of Lake Whitefish supply chain actors regarding the future of the Lake Whitefish commercial fishery and enabling actors to better respond to future challenges impacting the fishery. Answering these questions would assist actors in the Lake Whitefish supply chain, and Lake Whitefish mangers, to increase the profitability and sustainability of the Lake Whitefish commercial fisheries.

Identifying Economic Multipliers for the Commercial Fishery

Most of the available data on the economics of the Lake Whitefish commercial fishery in the Great Lakes only track dockside value of the Lake Whitefish harvest, collected by the Michigan DNR alongside commercial harvest. While this information is important, dockside price is only a small portion of the total economic value of the commercial fishery. Dockside value (around $2-3 per pound; MDNR 2006) is often much lower than the retail value of Lake Whitefish (around $8 – 12 per pound, depending on the retailer; Michigan DNR 2022). Between

harvest and retail to the end-consumer, there are many activities involved that add value to the Lake Whitefish product. Information on these downstream activities of the supply chain, however, are scarce or nonexistent, partly because some of this information could be considered proprietary business information. While this study identified some value-added activities, it is not a comprehensive list of all possible value-added activities. Additionally, other complementary research, such as market studies of consumer preferences for various Lake Whitefish products, can better identify and refine potential consumer markets for Lake Whitefish, as well as potential value-added opportunities that could be explored by supply chain actors. This further research could provide detail on the most feasible and cost-effective methods for value-addition to Lake Whitefish, whether that is through some form of consumer education (e.g. reviving the *Legends of the Lakes* or a similar label to highlight Great Lakes Lake Whitefish) or modification of existing Lake Whitefish products.

More research on the value chain for Lake Whitefish, and how the value of the Lake Whitefish products changes at each step of the value chain, would also help clarify some of the economic multipliers associated with the Lake Whitefish commercial fishery. For example, market studies of which Lake Whitefish products consumers prefer, and their willingness-to-pay for these different products, would provide valuable information to supply chain actors. Understanding these changes in value would provide a better idea of the characteristics of Lake Whitefish that increase consumer preference for Lake Whitefish products and how much customers are willing to pay in order to have their product choices include those characteristics. Additionally, systems for tracking sale of Lake Whitefish, beyond dockside value, would provide information on where Lake Whitefish goes after it is harvested (e.g. how local, regional, or larger-scale is the commercial fishery) and the value generated at a retail level by Lake Whitefish (e.g. what is the retail value for Lake Whitefish in Michigan).The aggregate retail value of Lake Whitefish, including the contribution that sales of Lake Whitefish at fish houses and restaurants make to local economies, helps provide a more comprehensive value of the Lake Whitefish commercial fishery.

For a more comprehensive identification of the contributions of Lake Whitefish, it is also useful to know the contributions that Lake Whitefish make to livelihoods, both directly in the commercial fishery as well as in associated industries (e.g. restaurants, tourism). The contributions that Lake Whitefish make to the tourism industry, in particular, are important to

identify since increased summer tourism appears to be a major driver of increased demand for Lake Whitefish, according to interviewees. Neighboring areas, for example Door County, Wisconsin, have seen an increase in "culinary tourism" (a component of the local food movement) and leveraged this aspect of tourism as a community development strategy (Green and Dougherty 2009). Both quantitative and qualitative data are needed to provide a more holistic view of the economic contributions of Lake Whitefish and associated commercial fisheries. Qualitative data include tourists' perceptions of Lake Whitefish (e.g. do tourists seek out opportunities to consume Lake Whitefish, their motivations for doing so, the non-market values that Lake Whitefish provide to coastal communities). Quantitative data include sales of Lake Whitefish (e.g. how much do sales of Lake Whitefish contribute to the community's economy, what proportion of restaurant sales are comprised of Lake Whitefish dishes, does availability of Lake Whitefish draw tourists to certain locations rather than others). Other important information needed to estimate the economic contributions of the commercial fishery includes assessing the livelihood contributions of the commercial fishery. These livelihood contributions include employment the commercial fishery provides to those directly related in harvest and processing of Lake Whitefish. There are multiple associated industries related to the commercial fishing industry, such as retail workers, restaurants, tourism. The contributions of the Lake Whitefish commercial fishery to the viability of these industries is often overlooked, however, because the links between Lake Whitefish and these industries can be subtle and difficult to separate from other, potentially confounding, factors. Overlooking these contributions exacerbates the undervaluation of the commercial fishery overall.

Connecting Ecological Changes to Consumer Demand

Another research gap that remains is how the ecological changes in Lake Whitefish populations will impact commercial fisheries and customer demand and valuation for Lake Whitefish in the future. The supply of Lake Whitefish fluctuates throughout the year, due to Lake Whitefish ecology, weather conditions and safety issues on the Great Lakes, and regulations controlling the harvest season (officially April - December). Demand tends to be higher in the summer months, which coincides with the busiest harvest times for the commercial fishery. Due to decreasing availability of fish, however, many fishers stop going out in the late fall, as the costs of going fishing tend to exceed the revenue generated from the harvest. Thus, while demand and supply of Lake Whitefish tend to overlap, there is a large portion of the year

where there is still demand for Lake Whitefish but supply becomes much more limited. Options for increasing supply, and sale, of Great Lakes Lake Whitefish during the off-season months, particularly to businesses not dependent on summer tourism, would help fishers expand their market and gain additional revenue, especially at a time of the year when they may not have other sources of income.

Another concern is the impacts of consistently decreasing Lake Whitefish abundance on long-term customer demand for Lake Whitefish. The relationships between fluctuating Lake Whitefish abundance, demand for Lake Whitefish, and price of Lake Whitefish are currently unknown. While decreased supply of Great Lakes Lake Whitefish may lead to price and demand increases in the short-term, consistent low supplies of Great Lakes Lake Whitefish could lead to consumers shifting demand away from Great Lakes Lake Whitefish and toward other, cheaper or more accessible sources of Lake Whitefish (from inland lakes in Canada) or to other accessible fish species entirely. Thus, in order to ascertain the long-term future and sustainability of the commercial state-licensed Lake Whitefish fishery, the impacts of ecological changes in Lake Whitefish populations on demand for Lake Whitefish are important to identify, evaluate, and sustainably manage this resource and associated fisheries.

Resiliency of the Fishery in the Face of COVID-19 and Changing Regulations

In addition to the challenges facing Lake Whitefish commercial fisheries discussed in this study, 2020 brought further acute obstacles to commercial fishers. These obstacles include the COVID-19 pandemic and efforts to update Michigan's fishing regulations.

Impacts from the COVID-19 Pandemic

As with many other industries, commercial fishing was heavily impacted by the COVID-19 pandemic. While Governor Whitmer designated commercial fishing as critical infrastructure, allowing the harvesting season to continue, fishers encountered severe difficulties in selling their catch (Williams 2020). The issue was that fishers sell the majority of their catch at local retail outlets and restaurants, which usually experience a sharp increase in demand during the summer from tourists to Michigan's coastal towns. Restrictions and closures of restaurants and other food service establishments, as well as limited opportunities for tourism activities due to the shutdowns, meant that fishers had nearly nowhere to sell their harvest in 2020 (Jescovitch and Nelson 2021). These issues impacted, not just commercial fishers, but local communities who directly and indirectly are involved in the commercial fisheries (e.g., fuel providers, retail

operators, fish processors) (Spratt 2021). Despite the problems faced by Great Lakes commercial fishers, Great Lakes states were completely left out of the $300 million set aside for commercial fisheries and charter boats in the March 2020 COVID relief package passed by Congress (Krupp 2020). As commercial fishers struggled to survive in 2020, the Coronavirus Response and Relief Supplemental Act of 2021, passed by Congress on December 27, 2020, included $15 million allocated to "non-tribal commercial, aquaculture, processor, and charter fishery participants" in Great Lakes states (Jescovitch and Nelson 2021). While welcome relief, fishers struggled to navigate the process of applying for, and accessing, these funds. Additionally, funds took months to reach fishers (Spratt 2021). These issues exacerbated the challenges faced by Great Lakes commercial fishers, the majority of whom are small-businesses that were already struggling to survive and develop alternative sources of revenue before the pandemic.

Efforts to Update Michigan's Commercial Fishing Regulations

In Michigan, the Michigan Department of Natural Resources (DNR) administers and enforces state commercial fishing regulations. The last legislative update for commercial fishing occurred in the 1960s. Since then, each DNR Director has managed commercial fisheries by issuing fisheries orders, which allow the DNR to respond to changes in the fishery within a more timely manner than going through legislation. Starting in approximately 2016, the DNR began working with the Michigan legislature to update Michigan's commercial fishing legislation (Jescovitch 2021). These efforts resulted in House Bills (HB) 4567, 4568, and 4569, which were passed by the Michigan House of Representatives in February 2020 and subsequently referred to the Michigan Senate's Committee on Natural Resources. After receiving testimonies on the bills from commercial fishers, the DNR, recreational fishing groups, and Tribal representatives, the Committee suggested several amendments for each bill. In December 2020, the DNR opposed these Senate amendments, citing a need for more time to review and understand the implications of these amendments (Jescovitch 2021). As the Committee did not meet again in 2020, the bills did not move forward. Since bills cannot be carried over from one legislative session to the next in Michigan, new bills were needed to be introduced during the 2021-2022 legislative session.

HB 4567, 4568, and 4569 proposed to raise fines, mandated submission of GPS coordinates for placement of commercial nets, mandated daily harvest reporting by commercial fishers, increased license prices for commercial fishers, and shortened the commercial fishing season for Lake Whitefish (Hardy 2022). While the bills were meant to modernize Michigan's

fishing regulations, commercial fishers argued that the bills would effectively shut down Michigan's commercial fisheries by making it too expensive to continue fishing and further restricting harvests of an already restricted fishery. Regulators and recreational fishing groups, however, supported the bills, arguing that these changes were needed in order to protect Lake Michigan's continually declining fish populations for all users (House 2021).

Since the bills were not passed, on November 12, 2020, the DNR Director signed Fisheries Order 243.21, which required renewal for 2020. The Fisheries Order stated that the DNR would no longer annually renew certain provisions within Fisheries Order 243, due to lack of authority to implement these provisions, and that passing the proposed HBs would have resolved this gap in authority (Jescovitch 2021). Additionally, starting on January 8, 2021, Fisheries Order 243.21 shortened the Lake Whitefish season for Lake Michigan (closing the fishery in October, rather than November) and restricted fishing in water between 80 – 150 feet in depth (French 2021). MFPA sued, claiming that the order effectively ended commercial fishing, since October is one of the most productive months for harvest and that Lake Whitefish, preferring colder water, were rarely found in water shallower than 80 feet (Krupp 2021).

In February 2021, the DNR sent out an updated Fisheries Order that reversed the contentious regulations in Fisheries Order 243.21 (Hardy 2022). Senate Bill 251, introduced in March 2021 and signed by Governor Whitmer in March 2022, solidified some of these protections for Michigan's commercial fisheries (LaCombe 2022). Most importantly, Senate Bill 251 solidifies regulations for commercial fishing in Michigan, ending the annual Fisheries Order system by the DNR that was previously in place. Despite this victory, commercial fishers continue to anticipate issues with the DNR and recreational fishing groups (Veenstra 2022).

FIGURES

Figure 4. Map showing the 1836 Treaty Waters (light purple) in the Great Lakes region. Image from https://www.bridgemi.com/michigan-environment-watch/all-eyes-grand-traverse-bay-deadline-looms-tribal-fishing-decree.

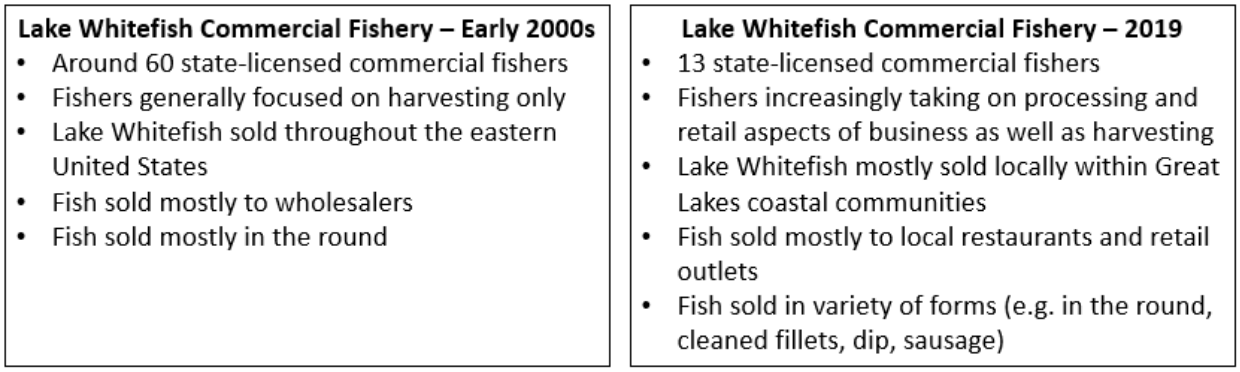

Figure 5. Overview of changes in the Lake Whitefish commercial fishery between early 2000s to present day.

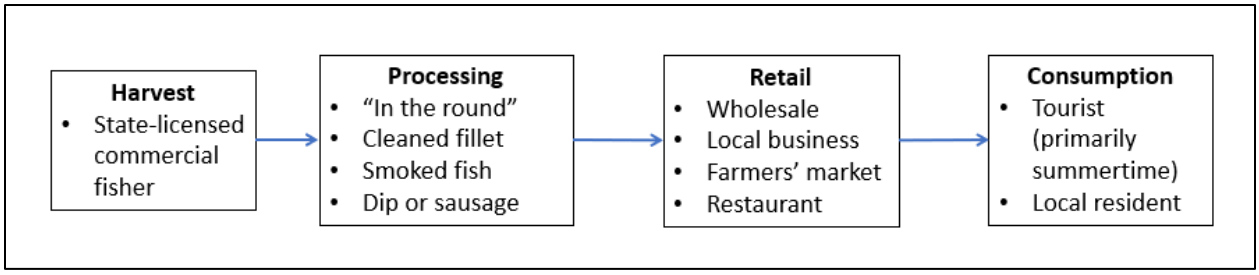

Figure 6. Conceptual overview of the current Lake Whitefish commercial fishery value chain for Michigan waters of Lake Michigan.

REFERENCES

Baldwin, N. A., R. W. Saalfeld, M. R. Dochoda, H. J. Buettner, and R. L. Eshenroder. 2000. Commercial fish production in the Great Lakes 1867 - 2000.

Bevilacqua, A. H. V., R. Angelini, J. Steenbeek, V. Christensen, and A. R. Carvalho. 2019. Following the Fish: The Role of Subsistence in a Fish-based Value Chain. *Ecological Economics, 159*(January), 326 – 334.

Chiarappa, M. J., and K. M. Szylvian. 2003. Fish for all: An oral history of multiple claims and divided sentiment on Lake Michigan. Michigan State University Press, East Lansing, Michigan.

Cox, D. N., G. Evans, and H. J. Lease. 2011. The influence of product attributes, consumer attitudes and characteristics on the acceptance of: (1) Novel bread and milk, and dietary supplements and (2) fish and novel meats as dietary vehicles of long chain omega 3 fatty acids. *Food Quality and Preference, 22*(2), 205 – 212.

Ebener, M. P., R. E. Kinnunen, P. J. Schneeberger, L. C. Mohr, J. A. Hoyle, and P. Peeters. 2008. Management of Commercial Fisheries for Lake Whitefish in the Laurentian Great Lakes of North America. *International Governance of Fisheries Ecosystems: Learning from the Past, Finding Solutions for the Future*, 99–143.

French, C. 2021. Great Lakes fishing companies say Mcihigan DNR order 'pretty much puts us out of business'. *MLive*. https://www.mlive.com/news/saginaw-bay-city/2021/01/great-lakes-fishing-companies-say-michigan-dnr-order-pretty-much-puts-us-out-of-business.html

Gorenflo, T., and S. Wright. 2018. Whitefish decline in the 1836 Treaty-ceded waters of Lakes Huron and Michigan: Impacts on the tribal commercial fishery. Whitefish Research Workshop, East Lansing, MI. http://www.glfc.org/pubs/clc/whitefish/2018%20Whitefish%20Wkshp%20Decline%20in%201836%20Waters.pdf

Green, G. P. and M. L. Dougherty. 2009. Localizing linkages for food and tourism: Culinary tourism as a community development strategy. *Community Development, 39*(3), 148 - 158.

Hardy, M. 2022. Michigan commercial fishing law - Governor Whitmer signs bill to contrain DNR rulemaking. *Thumbwind*. https://thumbwind.com/2022/03/30/michigan-commercial-fishing-law/?expand_article=1

House, K. 2021. A big fight in Lansing over fishing rules on the Great Lakes. *Great Lakes Now. https://www.greatlakesnow.org/2021/04/michigan-fishing-rules-dnr-great-lakes/*

Hudson, J. C., and S. S. Ziegler. 2014. Environment, Culture, and The Great Lakes Fisheries.

Geographical Review, 104(4), 391 – 413.

Jescovitch, L. N. 2021. Many circumstances during 2020 affected Michigan's commercial fishing industry. *MSU Extension: Michigan Sea Grant.* https://www.canr.msu.edu/news/many-circumstances-during-2020-affected-michigan-s-commercial-fishing-industry-msg21-jescovitch21

Jescovitch, L. N. and E. Nelson. 2021. 2020 status of the industry: Michigan's commercial fishing and fish processing businesses. *MSU Extension: Michigan Sea Grant.* https://www.canr.msu.edu/news/2020-status-of-the-industry-michigan-s-commercial-fishing-and-fish-processing-businesses-msg21-jescovitch21-nelson21

Krupp, L. 2020. Congress gave $300 million to help fisheries. The Great Lakes got zero. *Michigan Radio*. https://www.michiganradio.org/economy/2020-09-22/congress-gave-300-million-to-help-fisheries-the-great-lakes-got-zero

Krupp, L. 2021. Commercial fishermen sue Michigan over new restrictions. *National Public Radio. https://www.npr.org/2021/01/12/956145769/commercial-fishermen-sue-michigan-over-new-restrictions*

LaCombe, A. 2022. Whitmer signs McBroom's commercial fishing reform bill. *TV6 - Upper Michigan's Source.* https://www.uppermichiganssource.com/2022/03/15/whitmer-signs-mcbrooms-commercial-fishing-reform-bill/

Lynch, A. J., E. Varela-Acevedo, and W. W. Taylor. 2015. The need for decision-support tools for a changing climate: Application to inland fisheries management. *Fisheries Management and Ecology, 22*(1), 14 – 24.

Michigan DNR. 2016. 2015 State - Licensed Commercial Fishing Data for Michigan. Lansing, Michigan.

Michigan DNR. 2022. History of state-licensed Great Lakes commercial fishing. Accessed February 15, 2022. https://www.michigan.gov/dnr/0,4570,7-350-79136_79236_80538_80541-424724--,00.html

Nalepa, T. F., D. L. Fanslow, and G. A. Lang. 2009. Transformation of the offshore benthic community in Lake Michigan : recent shift from the native amphipod Diporeia spp. to the invasive mussel Dreissena rostriformis bugensis. *Freshwater Biology, 54*(3), 466 – 479.

Patton, M. Q. 2014. Qualitative Research and Evaluation Methods 4th Edition. SAGE Publications.

Spratt, D. 2021. Federal relief: Great Lakes fisheries finally get a cut of COVID-19 relief funds. *Great Lakes Now*. https://www.greatlakesnow.org/2021/01/great-lakes-fisheries-federal-covid-19-relief-funds/

Talhelm, D. R. 1988. The International Great Lakes Sport Fishery of 1980. Ann Arbor, MI.

United States v. Michigan. Case No. 2:73 CV 26. 2000. 2000 Great Lakes Consent Decree (2):28.

Veenstra, C. 2022. Commercial fisheries enjoy protection from newly signed bill. *Huron Daily Tribune.* https://www.michiganstthumb.com/news/article/Senate-Bill-protecting-commercial-fisheries-17023762.php#:~:text=Senate%20Bill%20251%20was%20signed,story%20that%20began%20in%202019

Williams, K. 2020. Commercial fishing in Michigan is critical infrastructure; will it survive COVID-19? *Great Lakes Echo*. https://greatlakesecho.org/2020/05/18/commercial-fishing-in-michigan-is-critical-infrastructure-will-it-survive-covid-19/

APPENDIX 1. INTERVIEW QUESTIONS

1. What is a typical work day like for you?
    a. How often do you work?
    b. What activities do you do during your work?
    c. How do these work activities change throughout the week?
2. Who are your suppliers for your Lake Whitefish? Where do you get Lake Whitefish from?
    a. [For fishers only] Where (which lake) was the fish harvested from?
        i. Who harvests the fish?
    b. How many suppliers do you work with?
    c. What is your relationship like with your suppliers?
        i. Do you frequently buy from the same supplier(s)?
            1. [If yes] Why? [lowest price, exclusive contract, etc.]
        ii. How did these relationships form?
        iii. How have your suppliers changed over the past 10 years?
            1. How has your relationship(s) with your suppliers changed?
            2. How has the number of suppliers changed?
    d. What factors do you consider when purchasing Lake Whitefish?
        i. What characteristics of Lake Whitefish are important for your business?
        ii. How do you define "quality" for Lake Whitefish?
            1. How has this definition changed over the past 10 years?
3. Once you obtain the whitefish, what do you do with them?
    a. How are the fish processed?
        i. What is the final product(s) sold by your business?
    b. Who is the intended customer(s)?
        i. Where are these customers located?
    c. Who are your competitors?
        i. What attributes/services differentiate your products from your competitors?
4. Who do you sell your Lake Whitefish products to?
    a. Could you define your customer base?

        i. Who are your biggest customers?
        ii. How has your customer base changed in the past 10 years?
    b. What characteristics of Lake Whitefish are important to your customers?
        i. How would your customers define a "high quality" product?
        ii. How have the characteristics of a "high quality" product changed over the past 10 years?
    c. Why are your customers interested in Lake Whitefish?
        i. For what purpose are your customers purchasing your products?
5. What is your business's brand?
    a. How do you maintain your brand?
    b. How has your brand evolved?
6. How long have you been involved with the Lake Whitefish fishery?
    a. What were your experiences with Lake Whitefish before your current job?
    b. Did you have any fishery experience (Lake Whitefish or otherwise) before your current job?
        i. [If yes] Can you elaborate on these experiences?
7. How has the fishery changed since you started working in the fishery?
    a. How has your business changed?
    b. What caused these changes?
8. What do you think the fishery will look like 10 years from now?
    a. Why do you think these changes (both positive and negative changes) will occur?
9. What changes would you like to see in the fishery?
    a. Why would you like to see these changes made?
    b. What would be the impact of these changes?
    c. What are some barriers to making these changes?

APPENDIX 2. QUESTION-CONCEPT MATRIX FOR INTERVIEW QUESTIONS

Table 5. Question-concept matrix of relationship between themes, concepts, and interview questions.

Theme	Concept	Question
Supply Chain	Supply Chain Actors	• Could you describe your job to me? • Who harvests the fish you use? • Who are your competitors?
	(Downstream) Sale of Lake Whitefish	• Who is/are your intended market(s)? • Who do you sell your products to? • What is the final product(s) sold by your business?
	(Upstream) Acquisition of Lake Whitefish	• Where do you get your Lake Whitefish from? • How did you form relationships with your suppliers? • What factors do you consider when purchasing fish?
Value Chain	Value-Added Activities	• Once you obtain the whitefish, what do you do with them? • What is the final product for your business? • What attributes/services differentiate your products from your competitors? • What characteristics of Lake Whitefish are important to your customers?
	Personal Brand	• What is your business's brand? • How do you maintain your business's brand? • How has your brand evolved?
Lake Whitefish Commercial Fishery	Historical Lake Whitefish Fishery	• How has the fishery changed since you started working in the fishery?
	Changes in the Lake Whitefish Fishery	• How has the fishery/your business changed since you started working in the fishery? • What do you think the fishery will look like in the next 10 years?
	Current Status of Fishery	• How long have you been involved with the fishery?
	Desired Changes to the Fishery	• What changes would you like to see in the fishery? Why?

CHAPTER 3: PREFERENCES FOR LOCALLY HARVESTED LAKE WHITEFISH (*COREGONUS CLUPEAFORMIS*) AMONG CUSTOMERS AT LOCAL FOOD MARKETS IN MICHIGAN

Introduction

Lake Whitefish (*Coregonus clupeaformis*) are an important part of the cultural, economic, and ecological communities of the Laurentian Great Lakes region. Historically, and continuing to the present day, commercial harvests of Lake Whitefish provided food and livelihoods for Great Lakes communities (Cleland 1982). Today, tourists and residents alike seek out local fish houses and restaurants in order to consume Lake Whitefish fillets, smoked whitefish dip, and other Lake Whitefish products (Ebener et al. 2008). Ecologically, Lake Whitefish abundance in the upper Great Lakes (Lakes Michigan, Huron, and Superior) has fluctuated over the past 50 years, reaching high population abundances during the 1990s, then declining through the present time (Baldwin et al. 2000). Interactions with invasive species (e.g. sea lamprey *Petromyzon marinus*, zebra mussels *Dreissena polymorpha*, and quagga mussels *D. rostriformis*), coupled with climate changes in the Great Lakes (e.g. decrease in fall/winter ice cover, increase in storms) and overfishing likely contributed to the decreases in Lake Whitefish abundance in the upper Great Lakes (Lynch et al. 2015).

While the ecological drivers and impacts of fluctuating Lake Whitefish abundances have been studied intensely over the past decades (Brenden et al. 2010; Fera et al. 2015; Gobin et al. 2016; Rennie et al. 2009), there is much less information available on the sociocultural impacts of changes in Lake Whitefish population abundance. Recent declines in Lake Whitefish abundance may have affected people's values for Lake Whitefish. As Lake Whitefish become less available, for example, people may be willing to pay more in order to consume Lake Whitefish products. It is also possible, however, that decreasing Lake Whitefish abundance decreases people's value for Lake Whitefish because people choose to substitute Lake Whitefish with other fish species or food products. In this study, we evaluate consumer willingness-to-pay for various Lake Whitefish products, which serves as a baseline measure of people's values for Lake Whitefish during a time of decreasing Lake Whitefish abundance.

There are several attributes of Lake Whitefish products that can influence consumer values for these products. These characteristics include the product form, harvest location of fish, who harvested the fish, and fish harvest method (Sawyer et al. 1988; Sogn-grundvag et al. 2014; Vanhonacker et al. 2013). Fish can be sold as a frozen fillet or a fresh fillet, or in a further processed form (Hébert 2010), such as fish sausage, smoked fish, or fish dip. In terms of harvest location, Lake Whitefish commercially sold in the Great Lakes region is harvested from either

the Great Lakes or an inland lake in Canada (Ebener et al. 2008). Additionally, commercial Lake Whitefish in the Great Lakes region can be harvested by a local state-licensed fisher, a tribal fisher, or imported into the Great Lakes region from Canada. Following state and tribal regulations, Lake Whitefish can only be harvested using trap nets or gill nets. While tribal fishers can use trap nets or gill nets, Michigan state-licensed commercial fishers can only harvest Lake Whitefish using trap nets (Ebener et al. 2008). Product form, harvest location, and harvest method are all product characteristics that can influence consumer perception of the freshness, and thus the quality, of the fish products available to them (Vanhonacker et al. 2013). Other attributes, such as who harvested the fish and the harvest location are attributes that can be important to consumers who value supporting a local industry or consuming "local foods" (Bevilacqua et al. 2019). Additionally, harvest location and harvest method can also influence consumers' perception of the sustainability of fish products, which may also influence their perception of the quality of those products (Nielsen et al. 2002). Consumers may be willing to pay more for products that they perceive as higher quality, especially if those products possess attribute(s) important to consumers (Verbeke et al. 2007).

Despite the numerous studies conducted on consumer preferences regarding fish products (Birch and Lawley 2012; Bronnmann and Asche 2016; Nielsen et al. 2002), there is a gap in the literature on Lake Whitefish from the Laurentian Great Lakes. How do consumers define a "high quality" whitefish product? What do consumers know about the whitefish products available to them? Which characteristics of Lake Whitefish do consumers care about? Does providing information to consumers about Lake Whitefish harvesting methods influence consumers' preferences for various attributes of Lake Whitefish? From both a fisheries management and a business perspective, it is important to understand what attributes of whitefish products consumers consider important and are willing to pay a premium for (Bronnmann and Asche 2016; Larsen et al. 2013).

In this paper, we identify drivers of consumer demand for Lake Whitefish products, which serves as a first step for identifying how changes in Lake Whitefish population abundance affect consumers' value for Lake Whitefish products. By identifying the factors that affect consumers' willingness-to-pay (WTP) for various Lake Whitefish products, we are better able to identify the attributes of Lake Whitefish products that consumers value. Our study is unique in that it focuses on a freshwater species of cultural and commercial importance, whereas most

existing studies on consumer preferences for fish products (such as Carlucci et al. 2015, Claret et al. 2012, Gaviglio et al. 2014, Rickertsen et al. 2017) focus on marine fish species. We also add to the literature by investigating the role that information on harvesting methods plays in changing consumer demand for various fish product attributes.

Lake Whitefish Fisheries in the Great Lakes

Lake Whitefish Populations in the Laurentian Great Lakes

Lake Whitefish are a cold-water species indigenous to the Laurentian Great Lakes and waterbodies of northern North America (Ebener et al. 2008). They are typically found in water relatively close to the shoreline (15 – 55m) and feed on benthic macroinvertebrates (e.g. small invertebrates that live on the bottom of the lake, such as *Diporeia* spp.). Due to habitat degradation, influx of invasive species, and increased exploitation (e.g. commercial and subsistence fishing) Lake Whitefish populations in the Laurentian Great Lakes were severely reduced by 1900 and the fishery largely collapsed during 1955 – 1970 (Hudson and Ziegler 2014). Over the past 50 years, yields of Lake Whitefish have fluctuated, declining to all-time lows in the 1960s and 1970s then increasing again in the 1980s (Baldwin et al. 2000). During the past decade, Lake Whitefish populations have again been declining. Although commercial fisheries for Lake Whitefish still exist, Lake Whitefish populations in the Great Lakes have not yet returned to the peak population sizes seen during the 1880s (Baldwin et al. 2000). Additionally, the number of fishers in the commercial Lake Whitefish fishery, and the profits gained from the fishery, have tended to remain stagnant or decrease over the past 20 years (Ebener et al. 2008).

Declines in Lake Whitefish have been mainly attributed to overfishing, interactions with invasive species (e.g. sea lamprey and Dreissenid mussels), and degradation of water quality and habitat (Brenden et al. 2010; Nalepa et al. 2009). These factors may have contributed to drastic changes in the food web of Lake Michigan, resulting in less food available for Lake Whitefish (Fera et al. 2015). In particular, due to the loss of the native amphipod Diporeia (from competition for algae between Diporeia and Dreissenid mussles), Lake Whitefish have switched to suboptimal food sources and forage over broader geographic areas (Pothoven and Madenjian 2008; Rennie et al. 2012). During the mid-1900s, sea lamprey wounding of Lake Whitefish was another source of mortality for Lake Whitefish (Brenden et al. 2010; Mcleod et al. 2011; Spangler et al. 1980). Successful efforts to control sea lamprey populations mitigated the impact

of sea lamprey on Lake Whitefish populations (Brenden et al. 2010), but may have contributed to declining Lake Whitefish populations in the 1960s and 1970s, before such control efforts were widely established. Another factor potentially contributing to the declines in Lake Whitefish abundance is climatic changes in the Great Lakes (e.g. decreases in fall/winter ice cover and increase in storms) (Lynch et al. 2015; Rennie et al. 2009). Lake Whitefish rely on ice cover during the fall and winter to protect their eggs, which hatch in the spring (Lynch et al. 2015). Decreased ice cover during the fall and winter seasons, coupled with an increase in storms, may lead to greater disturbance of Lake Whitefish eggs and thus greater mortality of the eggs and fewer larvae hatching in the spring (Ebener et al. 2008). These climatic changes may also lead to a temporal mismatch between Lake Whitefish larvae emergence from eggs and peak availability of food sources in the spring (Brenden et al. 2010; Lynch et al. 2015). This mismatch may then also contribute to greater larval mortality of Lake Whitefish, as there is less food available for larval whitefish to consume.

The Lake Whitefish Commercial Fishery in the Laurentian Great Lakes

Lake Whitefish support an important commercial fishery in Lake Michigan. Lake Whitefish fisheries in Michigan are divided between state-licensed fisheries (regulated by the Michigan Department of Natural Resources; DNR) and tribal fisheries (governed by individual tribes) (Brenden et al. 2010; Ebener et al. 2008). While state-licensed fisheries can only harvest Lake Whitefish for commercial purposes, tribal fishers can harvest Lake Whitefish for both subsistence and commercial use (Ebener et al. 2008). The total amount of fish each group can harvest, as well as the locations (e.g. management zone) each group is allowed to fish, is governed by the 2000 Great Lakes Consent Decree, which is renegotiated between the tribes and the State of Michigan every 20 years (*2000 Great Lakes Consent Decree* 2000; Hudson and Ziegler 2014).

In 2015, the state-licensed commercial harvest of Lake Whitefish from Lake Michigan was 766,941 round pounds with a total dockside value of $1,625,915 (Michigan DNR 2016). Much of this harvest likely stays within Michigan and is sold to local restaurants and fish shops (Ebener et al. 2008). Currently there are 13 commercial fishers licensed by the state of Michigan (Malewitz 2019). These fishers, many of whom are third or fourth-generation fishing families, harvest Lake Whitefish mostly from Lake Michigan and Lake Superior. While the commercial

fishery is currently small, it represents an important historical and cultural facet of Michigan's history (Chiarappa and Szylvian 2003; Hudson and Ziegler 2014).

Due to current Michigan Department of Natural Resources (DNR) regulations, all state-licensed commercial fishers are required to use trap nets to harvest Lake Whitefish (Ebener et al. 2008). Trap nets are expensive to obtain, require larger boats, and take up a larger area of the lake bottom (Chiarappa and Szylvian 2003). Tribal fishers, on the other hand, are able to use either trap nets or gill nets to harvest Lake Whitefish. Due to their lower cost and relatively greater ease of use, most tribal fishers prefer to use gill nets (Chiarappa and Szylvian 2003). Additionally, the smaller footprint of gill nets means that more gill nets can be set in a given area (e.g. multiple gill nets can be set in the same area needed to set one trap net). Additionally, gill nets can be used in a wider variety of locations, while trap nets require large areas of relatively clear lake bottom (e.g. no rocks or other substrate) in order to be used most effectively (Zhao and Morbey 2017). Despite the monetary benefits of gill nets (e.g. gill nets are generally cheaper than trap nets and more gill nets can be set in a given area), the DNR advocates use of trap nets because they are thought to be more environmentally sustainable than gill nets (Chiarappa and Szylvian 2003). Due to their design, fish harvested in trap nets stay alive longer, so any bycatch (e.g. non-target fish species) caught in trap nets can be released alive and relatively unharmed. Bycatch in gill nets, on the other hand, face higher mortality rates, especially if nets are not lifted frequently (Ebener et al. 2008).

Increasing costs of fishery operation, coupled with declining harvests and lower dockside prices, has led commercial fishers to seek avenues for generating increased value from their declining catch (Ebener et al. 2008; Pohl 2012). One way this has occurred is through the development of new products, such as whitefish sausage and smoked whitefish dip (Chiarappa and Szylvian 2003). These products appeal to consumers who normally avoid consuming fish fillets, thus expanding the consumer market for commercial fishers (Birch and Lawley 2012; Vanhonacker et al. 2013). Another attempt to increase the value of Lake Whitefish products is through the creation of the *Legends of the Lakes* brand, which sought to establish Great Lakes harvested Lake Whitefish as a premium product (Kinnunen 2012). Due to limited marketing and retirement of key fish processors, however, *Legends of the Lakes* was not successful (Kinnunen et al. 2017). As a result, commercial fishers are looking for other ways of raising consumer awareness, and appreciation, of Great Lakes Lake Whitefish.

The efforts of commercial fishers to raise awareness of Great Lakes Lake Whitefish, and the cultural value of the commercial fishery, are especially crucial given recent efforts to decrease the commercial fishery in Michigan. In summer 2019, three bills were introduced to the Michigan legislature regarding commercial fishing (Malewitz 2019). These bills proposed increasing commercial fishing license fees (from $200 per year currently to $1400 per year), exponentially increasing fines for fishing regulation infractions, tightening reporting requirements for commercial harvests, and increasing requirements for how fishers tend their nets (in order to mitigate conflicts with charter fishing boats). These bills, which are heavily backed by recreational angling groups, would make it extremely difficult for current commercial fishers to stay in business, many of whom are already struggling to keep their fishing businesses viable (Malewitz 2019). After failing to pass in the Michigan Senate, the Michigan DNR implemented several Fisheries Orders that, in effect, implemented the measures in the failed Senate bills. After public outcry, these Fisheries Orders were repealed in January 2021.

Attributes of Lake Whitefish Products

Despite widespread recognition that fish are a healthy food source, consumption of fish products in the United States is generally low (US EPA 2014). Consumption of fish in the United States is about half the amount recommended by the US Food and Drug Administration (4.44 oz per week in 2013, compared to recommended amount of 8oz per week; Jahns 2016). Barriers to fish consumption include consumer dislike of the taste, uncertainty regarding how to prepare fish and identify high quality fish, and difficulties in accessing fish products (Birch and Lawley 2012). Another characteristic that affects consumer purchasing decisions regarding fish products is the perceived environmental sustainability of the fish product, with consumers generally preferring to purchase fish that are sustainably harvested (Bronnmann and Asche 2016; Claret et al. 2012).

There are a variety of attributes that consumers could consider when judging the quality of a fish product. One attribute is the form of the product: fresh vs. frozen (Leek et al. 2000). Studies of consumers in Australia and Norway (Birch and Lawley 2012) have found that consumers tend to view fresh (ie: not-frozen) fillets as higher quality, and thus prefer to purchase fresh fillets when possible (Peavey et al. 1994). The perception of fresh fish as being of higher quality can be confounded, however, by fish that are sold as “fresh” (e.g. thawed fish) but were previously frozen. While many studies found that consumers prefer fresh fish to frozen fish, the

definition of "fresh" can vary widely among potential consumers (McManus et al. 2014). Additionally, without being provided additional information, consumers may prefer "chilled" fish (e.g. fish that was previously frozen and sold thawed). With information, however, consumers expressed a preference for fresh fish over frozen fish (Altintzoglou et al. 2012).

There is also a perception, in general, that local fish (e.g. fish harvested in local waters) are fresher (and thus higher quality) than fish that were harvested from more remote locations (Nielsen et al. 2002). Additionally, with increasing interest in consuming "local foods", locally harvested fish may also be seen as more desirable by virtue of being more environmentally sustainable, due to lower transportation costs and emission, and being a cultural, locally available food resource (Green and Dougherty 2009; Bronnmann and Asche 2017). Another attribute that consumers could consider is the harvest method used, which may impact the environmental sustainability of the fish product. "Eco-labelling" schemes (e.g. Monterey Bay's "Seafood Watch" program, Marine Stewardship Council (MSC) certification), which indicate that certain products are more environmentally sustainable than others, have become more prominent in recent decades (Brécard et al. 2009). Many of these schemes, however, focus on marine species. Freshwater fish and fisheries are often overlooked and eco-label criteria are often ill-adapted for the realities and operations of many freshwater fisheries (Cooke et al. 2011). A major component of being deemed "sustainable" by these labels is the impact of the harvest method used to capture the species of interest. In order to be considered "environmentally sustainable", the harvest method needs to have minimal impact on the target species as well as reduce, as much as possible, impacts on non-target species (e.g. bycatch) and the surrounding habitat (Jacquet and Pauly 2007).

Methods

Study and Field Experiment Design

We partnered with a local Michigan fish vendor to elicit consumer preferences of fish product attributes in a natural market setting. A Becker-DeGroot-Marschak (BDM) mechanism was incorporated as part of a field experiment to elicit consumer willingness to pay values for various whitefish products (IRB Study 00002923). The field experiment was executed in partnership with a fisher vendor who operates at 2 farmers' markets in Michigan, during summer of 2019. The fish vendor sells a variety of fish fillets, fish dips, and smoked fish and sells a mix of locally harvested Lake Whitefish and fish sourced from other areas of the United States.

The BDM mechanism is a procedure used in experimental economics to measure willingness to pay (Becker et al. 1964). In a BDM, the respondent formulates a bid for the product being studied under specific game rules that incentivize real valuations. As such the bid is compared to a "market" price, which is randomly generated and drawn from a pre-specified distribution (unknown to the consumer). If the respondent's bid is greater than the market price, he/she pays the market price and receives the product. If the respondent's bid is lower than the market price, no transaction occurs. The BDM mechanism is useful because, unlike experimental auctions, a BDM can be conducted in the field with a single participant, rather than requiring a group of people to participate (Lusk and Shogren 2007). Because the BDM can be conducted with one participant at a time, it is less difficult to recruit participants during the farmers' market hours. Additionally, this solo experience may be more reflective of consumers' "real-world" shopping experiences and incorporates consumers' shopping heuristics and home-grown values for the products being studied. The use of the BDM, however, has some limitations that researchers should be aware of. In particular, respondent unfamiliarity with the BDM structure may result in participants formulating bids that are not reflective of their true willingness to pay for the products being studied. Horowitz (2006), for example, showed that when participants are uncertain about how much they will be asked to pay, they may rely on the distribution of prices to formulate a bid. Additionally, Cason and Plott (2014) have shown that participants may confuse the second-price auction incentives of the BDM with a first-price auction, leading to bids that do not reflect participants' true value for the product.

Based on a review of the literature and input from local commercial fishers, three attributes were identified as potentially influencing consumers' WTP for Lake Whitefish sold at local Michigan markets. These three attributes were product form (fresh vs. frozen), harvest location of the fish (Michigan waters vs. Canadian waters), and fish harvest method (trap net vs. gill net). Because of consumers' perception that fresh fish are higher quality than frozen fish (Kreider et al. 1993), we expect that consumers are willing to pay a higher price for fresh fish (hypothsis 1 (H1), McManus et al. 2014). Additionally, we hypothesize that consumers are willing to pay more for locally caught (i.e., harvested in Michigan waters) fish (hypothesis 2, H2) because of consumers' preference for supporting local Michigan fisheries and their perception that local fish are higher quality than imported fish. Consumer preferences for supporting local commercial fishers and purchasing local fish products, even at a higher price for

fish products, is supported by increasing interest in, and proliferation of, community-supported fisheries (CSFs) and similar models that connect consumers with local fishers (Brinson et al. 2011). Finally, fishers believed that consumers are willing to pay a premium for Lake Whitefish harvested using trap nets, due to the perception that fish harvested using these nets are higher quality than fish harvested using gill nets (Ebener et al. 2008). Additionally, there may be a perception, from both fishers and consumers, that trap nets are more environmentally sustainable than gill nets (Ebener et al. 2008). Reflecting these perceptions, our third hypothesis (H3) was that consumes, after receiving information (via the information treatment) on the different harvest methods for Lake Whitefish (trap nets vs. gill nets) would be willing to pay a premium for fish harvested using trap nets. These three attributes also informed the perception and belief questions that were asked during the experiment (Table 6).

Our study focused on ten Lake Whitefish products that were differentiated by these three key product characteristics. For example, two of the products were a fresh Lake Whitefish fillet and a frozen Lake Whitefish fillet, with no additional information (differentiating product attribute was product form). The other Lake Whitefish products used were: fresh fillet harvested from Lake Michigan, frozen fillet harvested from Lake Michigan, fresh fillet harvested from Canada, frozen fillet harvested from Canada, fresh fillet harvested using a trap net, frozen fillet harvested using a trap net, fresh fillet harvested using a gill net, and frozen fillet harvested using a gill net. The full experimental procedures are described in detail in Appendix 1.

Our study design required participants to formulate bids for the products both before and after an information treatment. This information treatment (Appendix 2) consisted of an explanation of what a gill net and a trap net are and some of the potential impacts each harvest method has on fish product quality and environmental sustainability (e.g. habitat destruction and bycatch). Participants were asked their willingness to pay (WTP) for each of the ten Lake Whitefish products being studied before being given the information on harvest method. After formulating these initial WTP values (bids), participants then read the harvest method information and asked to reassess their bids for the same products. The information treatment was developed to determine whether providing participants with information that illustrated the pros and cons of each harvest method, particularly in relation to fish quality and sustainability, changed participants' WTP for the fish products.

Data

Data were collected via a field experiment on the western coast of Michigan (two coastal towns along Lake Michigan) during the summer of 2019. The market locations drew a mix of local residents and tourists and offer a wide range of fresh produce, meat products, and other items for sale. The markets take place throughout the year, although fish is only available until the end of August. Both markets also take place during the morning and early afternoon, one on a weekday and one on a weekend. Because one market is smaller than the other, the larger market (Market 1) draws many more visitors each week than does the smaller market (Market 2).

Descriptive statistics for our sample (n = 137) are presented in Table 6. The sample was approximately 59% female and the average age was 56 years. The majority of participants (86%) held a college degree, with 39% obtaining postgraduate education. The average household size was three people and average household income was between $60,000 to $80,000 per year. In most respects, the sample reflects the towns where the markets were located. Additionally, the sample is reflective of fish consumption and purchasing demographics found in previous studies. Women more commonly visit local markets and are more often the ones who purchase food for their household (Byker et al., 2012). Additionally, customers of local markets tend to be older, on average, than the average US population (Conner et al., 2009). For fish, specifically, many studies (Kitano and Yamamoto 2020; Verbeke et al. 2007; Verbeke and Vackier 2005) have found that fish consumption increases with age and that women are more likely to purchase fish than men. Studies have also shown that, although fish consumption increases with household size, presence of children in the household tends to decrease fish consumption (Carlucci et al. 2015; Kitano and Yamamoto 2020; Verbeke and Vackier 2005). The higher average household income of our sample, relative to the U.S. population, is also reasonable given that fish products are often more expensive than other protein sources (Carlucci et al. 2015; Verbeke and Vackier 2005) and customers of local markets tend to have higher than average incomes (Colasanti et al. 2010; Conner et al. 2009).

In addition to basic sociodemographic characteristics, our survey also included consumption variables and knowledge and beliefs related to commercial fishing in the Great Lakes region (Table 7). Most participants (76.6%) reported consuming fish either weekly or biweekly during the summer months. About 20% of participants reported their consumption of

fish to be around once a month during the summer. A small proportion of participants (2.9%) reported high fish consumption of once per day during the summer.

Participant responses to knowledge and belief questions were measured on a 5-point Likert scale, ranging from "Strongly Disagree" to "Strongly Agree". Several of these variables (prefer to eat local fish, harvest location information, and fresh fish are higher quality) centered around participant beliefs regarding locally harvested fish. Previous studies have indicated that customers at local markets are willing to pay premiums for locally made/grown products (Byker et al. 2012). Additionally, studies of consumer perceptions for fish products have repeatedly shown that consumers tend to perceive locally harvested fish to be higher quality and thus are willing to pay a premium for local fish (Carlucci et al. 2015; McManus et al. 2014; Morales and Higuchi 2020). Participants were also asked their perception of the quality of fresh vs frozen fish because previous consumer preference studies generally find that consumers prefer fresh fish to frozen fish, both in terms of perceived quality and taste (Altintzoglou et al. 2012; McManus et al. 2014; Sveinsdóttir et al. 2009; Vanhonacker et al. 2013). The next set of belief questions (familiar with Lake Whitefish harvest gear, gill nets produce lower quality fish) centered around participants' perceptions of the two gear types (trap net vs gill net) generally used to harvest Lake Whitefish. These variables were chosen because previous studies have found that consumers may prefer, and be willing to pay a premium for, seafood harvested using gear that they believe produces higher quality fish (Ebener et al. 2008; Nielsen et al. 2002) and is more environmentally sustainable (Bronnmann and Asche 2017; Uchida et al. 2013; Wessells 2002). The next variable (gill nets are environmentally sustainable) served as a counterpoint to the previous attitudinal variables regarding environmental sustainability of Lake Whitefish harvest gear. Because gill nets are less environmentally sustainable than trap nets (Ebener et al. 2008; Raby et al. 2011; Zhao and Morbey 2017), participant responses for this variable should match their response to the previous attitudinal variables regarding environmental sustainability of harvest gear. The last two attitudinal variables (commercial fishing is important to Lake Michigan, Lake Whitefish are culturally important) focus on participant perceptions of the cultural value of Lake Whitefish and the associated commercial fishery to Michigan. Studies of direct-marketing ventures for fish products (e.g. community-supported fisheries; Brinson et al. 2011) and anecdotes from Michigan commercial fishers (Ebener et al. 2008) suggest that some consumers see value in preserving and promoting historical industries (e.g. commercial fishing)

and native fish species (e.g. Lake Whitefish). Consumers who see value in these aspects of the commercial fishery may be more likely to pay a premium for locally harvested Lake Whitefish products.

Model

Consumer WTP for Lake Whitefish product characteristics were modelled using 3 specifications. These specifications ranged from a parsimonious model containing only product attributes (Model 1) to more complex specifications: incorporation of sociodemographic and fish consumption characteristics (Model 2) and addition of participant knowledge and attitudinal factors influencing preferences for product type (Model 3):

$$WTP_{ni} = \alpha + \boldsymbol{x}_n\boldsymbol{\beta} + \boldsymbol{d}_i\boldsymbol{\gamma} + r\rho + (r * \boldsymbol{d}_i)\boldsymbol{\lambda} + \varepsilon_{ni}$$

Where WTP_{ni} is individual *n*'s observed bid for a Lake Whitefish product of type *i*. $\boldsymbol{d}$ is a vector of dummy variables, where d_i = 1 for i in the set {fresh, fresh Michigan, frozen Michigan, fresh Canada, frozen Canada, fresh trap net, frozen trap net, fresh gill net, frozen gill net} if the product bears that label and 0 otherwise(frozen fillet serves as the base product). $\boldsymbol{x}_n$ is a vector of participant characteristics (age, gender, household size, presence of children, household income, highest education, fish consumption frequency, Lake Whitefish consumption frequency, objective knowledge of gill net sustainability, and attitudes toward local fish, harvest gear, and cultural value of commercial fish and fisheries). ε_{ni} is the error term with zero-mean. *r* is a general indicator variable for post-treatment bids ("with information") and $r * \boldsymbol{d}_i$ is a vector of interactions for each bid post-information treatment. The vectors $\beta, \gamma,$ and λ, and α and ρ are all parameters to be estimated.

Results

Summary statistics for participant bids, before and after information treatment, are presented in Table 8. Participants had higher WTP for fresh fillets, compared to frozen fillets with the same attribute types, both before and after the information treatment, supporting H1. Prior to the provision of information, when comparing between fresh and frozen products, participants were willing to pay $2.68 more for the fresh version than the frozen version. After the information treatment, participants were willing to pay $2.34 more for the fresh product than the frozen Lake Whitefish product. The preference for fresh products, over frozen products, is

comparable to other studies of fish consumption preferences, which generally find that consumers prefer fresh fillets (Gvillo et al. 2013; Peavey et al. 1994; Rickertsen et al. 2017).

Participants also had higher WTP for Michigan fillets (both fresh and frozen) than for Canadian fillets, supporting H2. Before the information treatment, participant WTP for fresh Michigan fillets was $2.00 higher for fresh Canadian fillets and $1.37 higher for frozen Michigan fillets (compared to frozen Canadian fillets). These amounts decreased slightly after the information treatment, with participant WTP for fresh Michigan fillets averaging $1.82 higher and frozen Michigan fillets averaging $1.26 higher than the comparable Canadian products. Participant preference for fish harvested in Michigan, as opposed to fish harvested in Canada, support previous studies which find that consumers tend to consider local fish to be higher quality (Brinson et al. 2011; Sveinsdóttir et al. 2009) and that customers of local markets, more specifically, frequent these markets because of a preference for purchasing/supporting local products and businesses (Brinson et al. 2011; Byker et al. 2012).

Average participant WTP was higher for fish harvested using trap nets (both fresh and frozen) than for fish harvested using gill nets, supporting H3. Before the information treatment, participant WTP was $0.48 higher for fresh trap net fillets (compared to fresh gill net fillets) and $0.54 higher for frozen trap net fillets. After the information treatment, these differences in WTP were larger ($4.50 for fresh trap net and $3.91 for frozen trap net). These results may indicate that participants, before the information treatment, were unfamiliar with the different gear types and thus the differences in WTP were relatively small.

The information treatment had a significant effect on bids for frozen fillets (+$0.41), frozen Michigan fillets (+$0.20), fresh trap net fillets (+$2.13), frozen trap net fillets (+$1.86), fresh gill net fillets (-$1.89), and frozen gill net fillets (-$1.51). Receiving information about Lake Whitefish harvest methods (trap nets and gill nets) resulted in participants, in general, increasing their bids for Lake Whitefish harvested using trap nets (about $2.00 on average for fresh and frozen trap net fillets) and decreasing their bids for Lake Whitefish harvested using gill nets (about $1.70 on average for fresh and frozen gill net fillets). The effect of harvest gear information on participant WTP for Lake Whitefish products addresses a gap in the fish preference literature for Lake Whitefish and supports retailers' anecdotal evidence that consumers who learn about the greater environmental sustainability of trap nets are willing to pay more for fish harvested using trap nets.

Model Results

Model results are displayed in Table 9. These results indicated that individuals with greater annual household income generally had substantially higher WTP for Lake Whitefish products. Relative to the low household income group, participants with average household income (between $40,000 - $80,000 annually) were willing to pay $2.06 more and participants with high household income (greater than $80,000 per year) were willing to pay $1.83 more. Individuals who held a college degree or higher were willing to pay approximately $1.85 higher for Lake Whitefish on average, as did individuals who believed they were knowledgeable about Lake Whitefish harvest gears ($0.59 more than the average). Out-of-state residents and families without children also had higher WTP for fish overall than Michigan residents and families with children, respectively. Finally, participants who believed that fresh fish are higher quality, and individuals who believed that gill nets produce lower quality fish, had lower WTP for fish overall than participants who did not hold these beliefs. Coefficients on all other control variables were not statistically significant at conventional levels. Contrary to other studies (e.g. Rickertsen et al. 2017; Carlucci et al. 2015), this study did not find participants' age or gender to significantly affect their WTP for fish.

In model 3, the coefficients for about half of the attributes (fresh, fresh Michigan, frozen Michigan, fresh Canada, frozen gill net) without information were statistically significant at the 1% level. Among these attributes, only frozen gill net had a negative coefficient, indicating that participants were willing to pay a premium for all significant attributes, except for the frozen gill net, over frozen Lake Whitefish. These results indicate that, on average, participants positively value the fresh and Michigan attributes and are willing to pay premiums for these attributes. Previous studies (Claret et al. 2002) have also found that fresh fish (vs. frozen fish) and country of origin, particularly preference for locally harvested fish (in this study, Michigan), are important factors when choosing fish products.

Using the results from model 3, the provision of information had a positive effect of $0.42 on consumer WTP for frozen whitefish fillet. The information treatment increased consumer WTP for fresh fillets by $0.07, no impact on a fresh Michigan fillet, $2.18 for a fresh trap net fillet, and $1.89 for a frozen trap net fillet. The information treatment decreased consumer WTP for a fresh gillnet fillet by $1.87 and $1.50 for a frozen gillnet fillet. Because the information was narrowly focused on the environmental impacts of trap nets and gill nets, the

information treatment may have increased participants' knowledge of (and subsequent value for) trap nets while concurrently decreasing participants' value for fish caught using gill nets. Although the information treatment did mention difference in harvesting gear used between the U.S. and Canada, national differences were not a focal point of the information and do not seem to have influenced participant WTP for the Canada attribute.

Discussion

This study found that participants had higher WTP to pay for fresh fillets (compared to frozen fillets, both before and after information), Michigan fillets (compared to Canadian fillets, before and after information), and trap net fillets (compared to gill net fillets, after information). These results support previous studies, which have generally found that the most important factors for consumers when choosing fish were country of origin, storage conditions (e.g. chilled fresh or frozen), and purchasing price (Claret et al. 2012). Additionally, a review of fish preference studies (Carlucci et al. 2015) found that country of origin is one of the most important product attributes affecting consumer choice. These studies also showed that consumers tend to prefer domestic fish products and viewed domestic fish as being superior to imported fish in terms of quality, safety, and freshness.

Few studies look at the impact of eating habits on fish consumption, as well as how habits of fish consumption are created. There is a frequent perception that fish is expensive, so price is one of the most common barriers to fish consumption. Results from this study, however, indicate that consumers may be willing to pay more for fish that contain attributes consumers prefer (e.g. fresh, local, and harvested using specific gear). Furthermore, for certain products (e.g. fresh fillets, fresh Michigan fillets), average participant WTP was greater than market price for these products at the time of the experiment ($8 - $10 per pound, varies by retailer). By advertising fillets that contain these desired attributes, retailers may be able to increase prices for their products. This ability to increase prices is especially important given that Lake Whitefish population abundances and harvests have been decreasing during the past decade (Brenden et al. 2010), meaning fishers and retailers must continue to earn a living from a decreasing amount of fish. In addition to being important to retailers, this information is also useful for policymakers and fisheries managers. More specifically, participants' preference for locally harvested fillets and fillets harvested using trap nets indicates that there could be monetary value in supporting Michigan's commercial fisheries and encouraging the use of trap nets (as opposed to other

harvest gear). For policymakers concerned with supporting local economies and access to nutritious food, this information indicates that Michigan customers see value in accessing locally-sourced fish products and supporting local industries. These results are similar to previous studies of consumer preference that indicate that consumers prefer fresh locally harvested fish that are perceived to be environmentally sustainable (Carlucci et al. 2015).

Changes in the commercial fishery, and the markets it relies on, since 2020 highlight the need to get this information to policymakers. The widespread restrictions and closures of restaurants and other food service establishments, and the concurrent severe reduction in coastal tourism, during the early part of the COVID-19 pandemic meant that commercial fishers had virtually no outlet in which to sell their catch (Jescovitch and Nelson 2021). As a result, many fishers attempted to pivot their businesses to sell online, or with socially-distanced pickup options, directly to local consumers (people who likely had high WTP for locally sourced fish products). In addition to these closures, the Michigan legislature introduced several bills in early 2020 that increased licensing costs for commercial fishing and restricted the fishing season and locations. After these bills failed to pass, the Michigan Department of Natural Resources issued Fisheries Order 243.21, which essentially imposed these same restrictions on commercial fisheries (Jescovitch 2021). Mobilization of commercial fishers against these regulations, as well as public outcry, led to these regulations being repealed in early 2021 (Veenstra 2022). Political and public support for the reversal of these regulations, in order to maintain the existence of Michigan's commercial fisheries, as well as continued financial support of commercial fishers during the COVID-19 pandemic, highlight the value that these fisheries have to Michigan residents. Furthermore, the supply chain disruptions, and consequent lack of Lake Whitefish available to consumers, caused by these events could raise WTP for Lake Whitefish products in the future (Williams 2020), at least among consumers who value fresh and/or locally-harvested fish products.

Influence of Information Treatment

The information treatment increased participant WTP for all product types, except for fresh Michigan fillets, fresh gill net fillets, and frozen gill net fillets. Mean participant WTP decreased for both gill net fillets (fresh and frozen) and had no effect on WTP for fresh Michigan fillets. These results supported retailers' beliefs that consumers would be willing to pay more for sustainably harvested fish (fish harvested using trap nets). Because all state-licensed commercial

fishers in Michigan (for Lake Whitefish) are required to only use trap nets, these findings indicate that educating consumers about gear types and their environmental impacts could be advantageous for retailers. Based on the information treatment used in this study (Appendix 2), the information provided to consumers need not be lengthy or in-depth. Relatively low-cost methods, such as providing information on a retailer's website or a short flyer available at the retail location, may be sufficient for disseminating this information to potential consumers. If a document containing this information is not readily available, retailers may be able to work with members of the Michigan Fish Producers Association (commercial fishing industry group in Michigan) and educational organizations (e.g. Michigan Sea Grant) to develop a document for retail and online use.

Conclusion

Results from this study indicate that consumers are most willing to pay a premium for the fresh and locally (Michigan) harvested attributes of Lake Whitefish. After receiving information, participants were also willing to pay a premium for fresh and frozen fish harvested using trap nets. Retailers at local Michigan markets (most of whom are commercial fishers) may be able to increase their revenue by highlighting these attributes to consumers and charging a premium for products with these attributes. Given continuing declines in Lake Whitefish abundance and harvests, being able to receive a higher price for Lake Whitefish would help commercial fishers maintain their livelihoods and the viability of the commercial fishery.

In addition to highlighting desired attributes, providing information on the environmental impacts of gill nets (as opposed to the less destructive trap nets) may increase retailers' ability to charge a premium for the harvest method. In addition to providing information on environmental impacts of the different harvest gear, it may also be useful to provide consumers information on differences between Lake Whitefish harvested in the Great Lakes (in this case Michigan waters of Lake Michigan and Superior) and Lake Whitefish harvested from Canadian waters of the Great Lakes and Canadian inland lakes. Doing so may potentially increase consumers' value for the local (Michigan) fish product.

This study is an initial effort to understand consumers' perceptions of various attributes of Lake Whitefish. Given the lack of previous literature on consumer WTP of these attributes for freshwater fish and markets in the United States, this study fills an important research gap. The results are limited, however, because of the focus on a relatively niche fish (Lake Whitefish) and

the study site being limited to local markets in Michigan. While these local markets have been gaining in popularity and abundance across the United States, consumers who frequent these markets tend to be significantly different from the average US population in several key characteristics (e.g. age, education, household income). Thus, these results reflect preferences of a targeted consumer group and are not indicative of broad consumer preferences for various fish product attributes. Further potential limitations of this study also include the relatively small sample size of participants and participants' difficulty in understanding the mechanics of the BDM mechanism, which may have influenced their bids during the experiment.

In addition to retailers, the results of this study may be useful to policymakers and fisheries managers. Consumer WTP a premium for local Lake Whitefish reflects the preference of consumers for supporting local products and local producers. This preference, in turn, indicates the importance of sustaining the Lake Whitefish commercial fishery in Michigan and ensuring the availability of Michigan-harvested Lake Whitefish in Michigan's coastal towns, particularly during the summer months when tourism is high. These values are important fisheries managers to consider when creating or revising fisheries policy, since consumers' willingness to pay a premium for certain attributes of local Lake Whitefish indicates the value this resource, and the associated commercial fishery, has for Michigan communities. Additionally, these values are important for policymakers to consider when making decisions about the accessibility and availability of locally-sourced fish products in Michigan's markets and supporting local businesses and industries.

TABLES

Table 6. Descriptive statistics for study sample. Sample characteristics are in line with 2019 city characteristics for market town locations.

Variable	**Sample**	**Muskegon. MI (2019)[3]**
Average age (years)	56	35
Female (%)	59%	48%
Average household size (total people)	3	2
Households with children (%)	28%	Unavailable
Average household income ($/year) [1]		$49,920
Less than $20,000	10%	
$20,000 - $40,000	10%	
$40,000 – $60,000	12%	
$60,000 - $80,000	12%	
$80,000 - $100,000	7%	
$100,000 - $150,000	31%	
Greater than $150,000	12%	
College education or above (%)	86	12%
Average frequency of fish consumption during the summer		Unavailable
Once per month	20%	
Weekly/Biweekly	77%	
Once per day	3%	
Multiple times per day	0%	
Lake Whitefish within top 3 most commonly consumed fish (%)	47%[2]	
N	137	

[1] Four percent (4.38%) of participants did not report their annual household income.

[2] Just under half of respondents (47.44%) listed Lake Whitefish as one of their top 3 fish species most frequently consumed during the summer.

[3] Muskegon population demographic information drawn from SimplyAnalytics.

Table 7. Descriptive statistics for attitudinal and knowledge variables.

Variable	**Sample**
Prefer to eat local fish (%)	
Strongly disagree/Disagree	0%
Neutral/Unsure	12%
Agree/Strongly agree	88%
Harvest location information influences purchasing (%)	
Strongly disagree/Disagree	4%
Neutral/Unsure	18%
Agree/Strongly agree	77%
Locally harvested fish are higher quality (%)	
Strongly disagree/Disagree	4%
Neutral/Unsure	35%
Agree/Strongly agree	63%
Fresh fish are higher quality (%)	
Strongly disagree/Disagree	6%
Neutral/Unsure	20%
Agree/Strongly agree	74%
Familiar with Lake Whitefish harvest gear (%)	
Strongly disagree/Disagree	55%
Neutral/Unsure	27%
Agree/Strongly agree	18%
Gill nets produce lower quality fish (%)	
Strongly disagree/Disagree	21%
Neutral/Unsure	67%
Agree/Strongly agree	12%
Gill nets are environmentally sustainable (%)	
Strongly disagree/Disagree	21%
Neutral/Unsure	67%
Agree/Strongly agree	12%
Commercial fishing is important to Lake Michigan (%)	
Strongly disagree/Disagree	7%
Neutral/Unsure	26%
Agree/Strongly agree	67%
Lake Whitefish are culturally important (%)	
Strongly disagree/Disagree	0%
Neutral/Unsure	9%
Agree/Strongly agree	91%
N	137

Table 8. Descriptive statistics for bids ($/pound).

	Pre-Information					Post-Information				Impact of Information	Sig. Diff.*
Bids	Mean	St. Dev	Min	Max		Mean	St. Dev	Min	Max		
Frozen Fillet	7.76	4.71	0	25		8.17	4.86	0	28	0.41	***
Fresh Fillet	10.44	4.99	0	30		10.51	5.08	0	30	0.07	
Fresh Michigan	11.41	5.16	0.50	35		11.41	5.15	0.50	35	0.00	
Frozen Michigan	9.14	4.91	0	25		9.34	5.11	0	30	0.20	**
Fresh Canada	9.41	5.21	0	25		9.59	5.43	0	28	0.18	
Frozen Canada	7.77	4.89	0	25		8.08	5.05	0	28	0.31	
Fresh Trap Net	8.50	5.34	0	25		10.63	5.69	0	28	2.13	***
Frozen Trap Net	7.13	4.81	0	25		8.99	5.34	0	28	1.86	***
Fresh Gill Net	8.02	5.55	0	25		6.13	4.80	0	18	-1.89	***
Frozen Gill Net	6.59	5.08	0	25		5.08	4.41	0	16	-1.51	***

*Sig. Diff. indicates there is a statistically significant difference, using robust clustered standard errors and a t-test, in the mean bids for each product type between the pre-information and post-information rounds. Statistical significance is denoted for the 1% ($p<0.01$, ***), 5% ($p<0.05$,**), and 10% ($p<0.1$,*) levels.

Table 9. Regression model – Dependent variable: Bids ($/1 pound).

	Model 1 Only Product Attributes		Model 2 Attributes + Demographics		Model 3 Attributes, Demographics, Attitudinal Variables	
	Coefficient	S.E.[1]	Coefficient	S.E.	Coefficient	S.E.
Constant	7.758***	0.404	9.736***	1.998	9.334***	3.071
Information Treatment	0.413***	0.145	0.422***	0.148	0.422***	0.148
Fresh Fillet	2.679***	0.241	2.687***	0.246	2.687***	0.246
Fresh w/ Info	-0.343***	0.122	-0.351***	0.125	-0.351***	0.125
Fresh Michigan	3.65***	0.310	3.665***	0.317	3.665***	0.318
Fresh Michigan w/ Info	-0.413**	0.188	-0.422**	0.193	-0.422**	0.193
Frozen Michigan	1.384***	0.202	1.392***	0.206	1.392***	0.207
Frozen Michigan w/ Info	-0.212	0.161	-0.217	0.165	-0.217	0.166
Fresh Canada	1.652***	0.322	1.629***	0.329	1.629***	0.330
Fresh Canada w/ Info	-0.232	0.245	-0.237	0.251	-0.237	0.252
Frozen Canada	0.015	0.275	0.031	0.282	0.031	0.282
Frozen Canada w/ Info	-0.110	0.245	-0.112	0.251	-0.112	0.251
Fresh Trap Net	0.738*	0.428	0.702	0.437	0.702	0.438
Fresh Trap w/ Info	1.726***	0.383	1.757***	0.391	1.757***	0.392
Frozen Trap Net	-0.627*	0.376	-0.626*	0.385	-0.626	0.386
Frozen Trap w/ Info	1.449***	0.358	1.474***	0.366	1.474***	0.367
Fresh Gill Net	0.260	0.428	0.251	0.438	0.251	0.439
Fresh Gill w/ Info	-2.300***	0.445	-2.291***	0.453	-2.291***	0.454
Frozen Gill Net	-1.164***	0.363	-1.160***	0.372	-1.160***	0.372
Frozen Gill w/ Info	-1.924***	0.406	-1.915***	0.414	-1.915***	0.414
Female			-0.275	0.717	0.316	0.707
Age			-0.041	0.027	-0.059	0.024
Michigan Resident			-2.957***	0.822	-3.935***	0.771
Average Income			2.856***	1.092	2.059**	0.955
High Income			2.823***	0.932	1.829**	0.843
No Income[2]			-0.865	1.307	-0.988	1.412
College Degree			1.808*	0.981	1.848*	0.945
Household Size			-0.505**	0.213	-0.281	0.235
Child Present			-0.821	0.907	-1.734*	0.937
Biweekly Consumption			0.765	0.906	0.175	0.846
Prefer Local					-0.441	0.415
Harvest Location[3]					0.657	0.422
Local High Quality					0.636	0.424

Table 9 (cont'd).

Fresh High Quality					-0.960**	0.372
Gear Familiarity					0.588**	0.267
Gill Net Low Quality					-1.068***	0.363
Gill Net Sustainable					1.262***	0.395
Commercial Fishing Important					-0.258	0.461
Cultural Importance					0.537	0.461
Root MSE	5.0864		4.6349		4.3033	
R^2	0.0986		0.2593		0.3637	
F-stat	15.77***		12.69***		11.62***	
N	2,740		2,680		2,680	
No. of Clusters	137		134		134	

Statistical significance is denoted for the 1% (p<0.01, ***), 5% (p<0.05,**), and 10% (p<0.1,*) levels.

[1]Robust clustered standard errors.

[2]Respondent did not provide income information.

[3]Fish harvest location influences purchasing decision.

REFERENCES

2000 Great Lakes Consent Decree, 2000.

Altintzoglou, T., B. H. Nøstvold, M. Carlehög, M. Heide, J. Østli, and F. A. Egeness. 2012. The influence of labelling on consumers' evaluations of fresh and thawed cod fillets in England. *Br. Food J., 114*, 1558 – 1570.

Baldwin, N.A., R. W. Saalfeld, M. R. Dochoda, H. J. Buettner, and R. L. Eshenroder, 2000. Commercial fish production in the Great Lakes 1867 - 2000.

Becker, G.M., M. H. DeGroot, and J. Marschak. 1964. Measuring utility by a single-response sequential method. *Behav. Sci., 9*.

Bevilacqua, A.H. V., R. Angelini, J. Steenbeek, V. Christensen, and A. R. Carvalho. 2019. Following the Fish: The Role of Subsistence in a Fish-based Value Chain. *Ecol. Econ., 159*, 326–334.

Birch, D. and M. Lawley. 2012. Buying seafood: Understanding barriers to purchase across consumption segments. *Food Qual. Prefer., 26*, 12–21.

Brécard, D., B. Hlaimi, S. Lucas, Y. Perraudeau, and F. Salladarré. 2009. Determinants of demand for green products: An application to eco-label demand for fish in Europe. *Ecol. Econ., 69*, 115 – 125.

Brenden, T.O., M. P. Ebener, T. M. Sutton, M. L. Jones, M. T. Arts, T. B. Johnson, M. A. Koops, G. M. Wright, and M. Faisal. 2010. Assessing the health of Lake Whitefish populations in the Laurentian Great Lakes: Lessons learned and research recommendations. *J. Great Lakes Res., 36*, 135 – 139.

Brinson, A., M. Y. Lee, and B. Rountree. 2011. Direct marketing strategies: The rise of community supported fishery programs. *Mar. Policy, 35*, 542 – 548.

Bronnmann, J. and F. Asche. 2017. Sustainable Seafood From Aquaculture and Wild Fisheries: Insights From a Discrete Choice Experiment in Germany. *Ecol. Econ., 142*, 113–119.

Bronnmann, J., and F. Asche. 2016. The Value of Product Attributes, Brands and Private Labels: An Analysis of Frozen Seafood in Germany. *J. Agric. Econ., 67*, 231–244.

Byker, C., J. Shanks, S. Misyak, and E. Serrano. 2012. Characterizing Farmers ' Market Shoppers: A Literature Review. *Journal of Hunger and Environmental Nutrition, 7*, 38 – 52.

Carlucci, D., G. Nocella, B. De Devitiis, R. Viscecchia, F. Bimbo, and G. Nardone. 2015. Consumer purchasing behaviour towards fish and seafood products. Patterns and insights from a sample of international studies. *Appetite, 84*, 212 – 227.

Cason, T.N. and C. R. Plott. 2014. Misconceptions and game form recognition: challenges to theories of revealed preference and framing. *J. Polit. Econ., 122,* 1235 – 1270.

Chiarappa, M.J. and K. M. Szylvian. 2003. Fish for all: An oral history of multiple claims and divided sentiment on Lake Michigan. Michigan State University Press, East Lansing, MI.

Claret, A., L. Guerrero, E. Aguirre, L. Rincón, M. D. Hernández, I. Martínez, J. Benito Peleteiro, A. Grau, and C. Rodríguez-Rodríguez. 2012. Consumer preferences for sea fish using conjoint analysis: Exploratory study of the importance of country of origin, obtaining method, storage conditions and purchasing price. *Food Qual. Prefer., 26,* 259 – 266.

Cleland, C.E. 1982. The Inland Shore Fishery of the Northern Great Lakes: Its Development and Importance in Prehistory. *Am. Antiq., 47,* 761 – 784.

Colasanti, K. J. A., D. S. Conner, and S. B. Smalley. 2010. Understanding Barriers to Farmers ' Market Patronage in Michigan Perspectives From Marginalized Populations. *J. Hunger Environ. Nutr., 5,* 316 – 338.

Conner, D.S., S. B. Smalley, K. J. A. Colasanti, and R. Brent. 2009. Increasing Farmers Market Patronage: A Michigan Survey. *J. Food Distrib. Res., 41*.

Cooke, S.J., K. J. Murchie, and A. J. Danylchuk, A.J. 2011. Sustainable "Seafood" Ecolabeling and Awareness Initiatives in the Context of Inland Fisheries: Increasing Food Security and Protecting Ecosystems. *Bioscience, 61*, 911 – 918.

Ebener, M.P., R. E. Kinnunen, P. J. Schneeberger, L. C. Mohr, J. A. Hoyle, and P. Peeters. 2008. Management of Commercial Fisheries for Lake Whitefish in the Laurentian Great Lakes of North America. *Int. Gov. Fish. Ecosyst. Learn. from Past, Find. Solut. Futur.* 99 – 143.

Fera, S.A., M. D. Rennie, and E. S. Dunlop. 2015. Cross-basin analysis of long-term trends in the growth of lake white fish in the Laurentian Great Lakes. *J. Great Lakes Res., 41*, 1138 – 1149.

Gaviglio, A., E. Demartini, C. Mauracher, and A. Pirani. 2014. Consumer perception of different species and presentation forms of fish: An empirical analysis in Italy. *Food Quality and Preference, 36,* 33 – 49.

Gobin, J., N. P. Lester, M. G. Fox, and E. S. Dunlop. 2016. Effects of changes in density-dependent growth and recruitment on sustainable harvest of Lake Whitefish. *J. Great Lakes Res., 42,* 871 – 882.

Green, G. P. and M. L. Dougherty. 2009. Localizing linkages for food and tourism: Culinary tourism as a community development strategy. *Community Development, 39*(3), 148 - 158.

Gvillo, R.M., K. Quagrainie, N. Olynk, and J. Dennis. 2013. Are Midwestern fish retailers

willing to pay more for regionally grown fresh-on-ice fish? *Agricultural Sciences, 4*(6A), 39 – 45.

Hébert, K., 2010. In Pursuit of Singular Salmon: Paradoxes of Sustainability and the Quality Commodity. *Sci. Cult. (Lond). 19*, 553 – 581.

Horowitz, J.K., 2006. The Becker-DeGroot-Marschak mechanism is not necessarily incentive compatible, even for non-random goods. *Econ. Lett., 93*, 6 – 11.

Hudson, J.C., and S. S. Ziegler. 2014. Environment, Culture, and The Great Lakes Fisheries. *Geogr. Rev., 104*, 391 – 413.

Jacquet, J.L., and D. Pauly. 2007. The rise of seafood awareness campaigns in an era of collapsing fisheries. *Mar. Policy, 31*, 308 – 313.

Jahns, L., 2016. Chapter 1 - Fish Intake in the United States A2 *in* Raatz, Susan K., *Fish and Fish Oil in Health and Disease Prevention*.

Jescovitch, L. N. 2021. Many circumstances during 2020 affected Michigan's commercial fishing industry. *MSU Extension: Michigan Sea Grant.* https://www.canr.msu.edu/news/many-circumstances-during-2020-affected-michigan-s-commercial-fishing-industry-msg21-jescovitch21

Jescovitch, L. N. and E. Nelson. 2021. 2020 status of the industry: Michigan's commercial fishing and fish processing businesses. *MSU Extension: Michigan Sea Grant.* https://www.canr.msu.edu/news/2020-status-of-the-industry-michigan-s-commercial-fishing-and-fish-processing-businesses-msg21-jescovitch21-nelson21

Kinnunen, R.E., 2012. Michigan Sea Grant helps Michigan commercial fishers realize economic gains [WWW Document]. Michigan State Univ. Ext. URL https://www.canr.msu.edu/news/michigan_sea_grant_helps_michigan_commercial_fishers_realize_economic_gains

Kinnunen, R.E., C. Pistis, J. D. Schwartz, and C. Y. Swinehart. 2017. Michigan Commercial Fisheries Marketing and Product Development.

Kitano, S., and N. Yamamoto. 2020. The role of consumer knowledge, experience,and heterogeneity in fish consumption: Policy lessons from Japan. *J. Retail. Consum. Serv., 56*, 102 - 151.

Kreider, C.R., J. R. Bacon, U. C. Toensmeyer, and A. J. Groff. 1993. An Analysis of Consumer Perceptions of Fresh Fish and Seafood in the Delmarva Region. *J. Food Distrib. Res., September*, 37–48.

Larsen, T.A., J. A. Young, and G. Sogn-Grundv. 2013. The value of line-caught and other attributes : An exploration of price premiums for chilled fish in UK supermarkets. *Mar.*

Policy, 38, 41 – 44.

Leek, S., S. Maddock, and G. Foxall. 2000. Situational determinants of fish consumption. *Br. Food J., 102*, 18 – 39.

Lusk, J.L. and J. F. Shogren. 2007. Experimental Auctions. *Cambridge Journal of Economics*.

Lynch, A.J., E. Varela-Acevedo, and W. W. Taylor. 2015. The need for decision-support tools for a changing climate: Application to inland fisheries management. *Fish. Manag. Ecol., 22*, 14 – 24.

Malewitz, J. 2019. Michigan fish fight: Bills would squeeze commercial fishers, help anglers. *Bridg. Mag*. https://www.bridgemi.com/michigan-environment-watch/michigan-fish-fight-bills-would-squeeze-commercial-fishers-help-anglers

Mcleod, D. V, R. A. Cottrill, and Y. E. Morbey. 2011. Sea lamprey wounding in Canadian waters of Lake Huron from 2000 to 2009 : Temporal changes differ among regions. *J. Great Lakes Res., 37*, 601 – 608.

McManus, A., W. Hunt, J. Storey, J. McManus, and S. Hilhorst. 2014. Perceptions and preference for fresh seafood in an Australian context. *Int. J. Consum. Stud., 38*, 146 – 152.

Michigan DNR, 2016. 2015 State - Licensed Commercial Fishing Data for Michigan. Lansing, MI.

Morales, L.E. and A. Higuchi. 2020. Should we spend more on fish?—How consumer beliefs about fish influence fish and meat expenditure shares. *J. Sens. Stud., 35*.

Nalepa, T.F., D. L. Fanslow, and G. A. Lang. 2009. Transformation of the offshore benthic community in Lake Michigan : recent shift from the native amphipod Diporeia spp. to the invasive mussel Dreissena rostriformis bugensis. *Freshw. Biol., 54*, 466 – 479.

Nielsen, J., G. Hyldig, and E. Larsen. 2002. "Eating Quality" of fish - A review. *J. Aquat. Food Prod. Technol., 11*, 125 – 141.

Peavey, S., T. Work, and J. Riley. 1994. Consumer attitudes toward fresh and frozen fish. *J. Aquat. Food Prod. Technol., 3*, 71 – 87.

Pohl, S. 2012. reWorking Michigan: Better quality helping the Whitefish industry. WKAR. https://www.wkar.org/newsroom/2012-02-20/reworking-michigan-better-quality-helping-the-whitefishing-industry

Pothoven, S.A. and C. P. Madenjian. 2008. Changes in consumption by alewives and Lake Whitefish after dreissenid mussel invasions in Lake Michigan and Huron. *North Am. J. Fish. Manag., 28*, 308 – 320.

Raby, G.D., A. H. Colotelo, S. J. Cooke, and G. Blouin-Demers. 2011. Freshwater Commercial Bycatch: An Understated Conservation Problem. *Bioscience, 61*, 271 – 280.

Rennie, M.D., W. G. Sprules, and T. B. Johnson. 2009. Factors affecting the growth and condition of Lake Whitefish (Coregonus clupeaformis). *Can. J. Fish. Aquat. Sci., 66*, 2096 – 2108.

Rennie, M.D., T. B. Johnson, and W. G. Sprules. 2012. Energy acquisition and allocation patterns of Lake Whitefish (Coregonus clupeaformis) are modified when dreissenids are present. *Can. J. Fish. Aquat. Sci., 59*, 41 – 59.

Rickertsen, K., F. Alfnes, P. Combris, G. Enderli, S. Issanchou, and J. F. Shogren. 2017. French Consumers' Attitudes and Preferences Toward Wild and Farmed Fish. *Mar. Resour. Econ., 32*, 59 – 81.

Sawyer, F.M., A. V. Cardello, and P. A. Prell, P. 1988. Consumer Evaluation of the Sensory Properties of Fish. *J. Food Sci., 53*, 12 – 18.

Sogn-grundvag, G., T. A. Larsen, and J. A. Young. 2014. Product Differentiation with Credence Attributes and Private Labels : The Case of Whitefish in UK Supermarkets. *J. Agric. Econ., 65*, 368 – 382.

Spangler, G.R., D. S. Robson, and H. A. Regier. 1980. Estimates of Lamprey-Induced Mortality in Whitefish, Coregonus clupeaformis. *Can. J. Fish. Aquat. Sci., 37*, 2146 – 2150.

Sveinsdóttir, K., E. Martinsdóttir, D. Green-Petersen, G. Hyldig, R. Schelvis, and C. Delahunty. 2009. Sensory characteristics of different cod products related to consumer preferences and attitudes. *Food Qual. Prefer., 20*, 120 – 132.

Uchida, H., C. A. Roheim, H. Wakamatsu, and C. M. Anderson. 2013. Do Japanese consumers care about sustainable fisheries ? Evidence from an auction of ecolabelled seafood . *Australian Journal of Agricultural and Resource Economics*, 58(2), 263 – 280.

US EPA. 2014. Estimated fish consumption rates for the U.S. population and selected subpopulations (NHANES 2003-2010) (No. EPA-820-R-14-002). Washington, D.C.

Vanhonacker, F., Z. Pieniak, and W. Verbeke. 2013. European consumer perceptions and barriers for fresh, frozen, preserved and ready-meal fish products. *Br. Food J., 115*, 508 – 525.

Veenstra, C. 2022. Commercial fisheries enjoy protection from newly signed bill. *Huron Daily Tribune.* https://www.michigansthumb.com/news/article/Senate-Bill-protecting-commercial-fisheries-17023762.php#:~:text=Senate%20Bill%20251%20was%20signed,story%20that%20began%20in%202019

Verbeke, W. and I. Vackier. 2005. Individual determinants of fish consumption: Application of the theory of planned behaviour. *Appetite, 44*, 67 – 82.

Verbeke, W., I. Vermeir, and K. Brunsø. 2007. Consumer evaluation of fish quality as basis for fish market segmentation. *Food Qual. Prefer., 18*, 651 – 661.

Wessells, C.R. 2002. The Economics of Information: Markets for Seafood Attributes. *Marine Resource Economics, 17*(2), 153 – 162.

Williams, K. 2020. Commercial fishing in Michigan is critical infrastructure; will it survive COVID-19? *Great Lakes Echo*. https://greatlakesecho.org/2020/05/18/commercial-fishing-in-michigan-is-critical-infrastructure-will-it-survive-covid-19/

Zhao, Y. and Y. E. Morbey. 2017. Estimating the Size Selectivity of Trap Nets using a Gill-Net Selectivity Experiment : Method Development and Application to Lake Whitefish in Lake Huron. *North Am. J. Fish. Manag., 37*, 1341 – 1349. doi:10.1080/02755947.2017.1381206

APPENDIX 1. EXPERIMENTAL PROCEDURES

The BDM experiments were simultaneously conducted by two trained enumerators in a local market setting. The same nine steps were used by each enumerator for each participant. Participants were screened from all consumers at the local market according to the following selection criteria: participants had to be 18 years of age or older and had to purchase fish fillets for themselves or their household. Consumers who exclusively purchased non-fillet fish products or who (either themselves or their household) did not consume fish products were excluded. Participants were informed of the benefits and risks of participation, in conjunction with the nature of the study. If they were willing to participate, consent was obtained. In the second step, consented participants were given a survey eliciting sociodemographic and fish consumption information, opinions regarding fish quality and the commercial fishing industry, and knowledge relative to these topics. Survey question were structured and worded following a pilot phase in order to reduce the likelihood of influencing bid formulation.

Participants were introduced to the BDM mechanism in the third step. Participants were informed that they would be bidding for ten different types of Lake Whitefish products, one of which would be selected at random to be binding. A full explanation of the BDM mechanism was provided, after which participants were given the opportunity to ask any clarification questions regarding the BDM process. In the fourth step. Participants submitted their bids, in terms of price (whole dollar amounts only) per pound of fish, for each of the ten Lake Whitefish products, without any additional information being provided. Many participants were unfamiliar with the harvest gear, for example, but enumerators were instructed not to provide any additional information regarding these gear during this step of the experiment. Before placing their bids, participants had the opportunity to visually examine each product, if they wished to do so. Each fillet was about the same size (roughly one pound each) and participants were instructed to formulate their bids based on one pound of each Lake Whitefish product. All products were presented simultaneously to the participants. In the fifth step participants were provided with information regarding trap nets and gill nets and potential impacts of each method on harvested fish and the surrounding ecosystem (Appendix 2). After reading this information, participants were asked to submit new bids for the same previous 10 Lake Whitefish products, under the context of being more informed about trap nets and gill nets.

In the seventh step, using a multi-sided die, participants determined the binding fish product by rolling a number between one and ten. For the eighth step, a random number generator (via a phone app) was then used to randomly draw a market price between $0 and $20 for the binding fish product. The distribution of prices was not revealed to participants. In the final step, the participant's bid for the selected fish product was compared to the randomly drawn market price. If the participant's bid exceeded the market price, they paid for the selected fish product at the randomly drawn market price and received the fish product. If the randomly drawn market price exceeded the participant's post-treatment bid, no transaction occurred. To conclude each individual session, participants were thanked and debriefed, during which any questions about the study were answered.

Each survey, and the BDM experiment, were conducted in close proximity to the fish vendor's stall at the local markets in order to best ensure the real context of a fish purchase. In order to prevent any anchoring products, however, participants were not able to observe the vendor's listed price for any of the products. This was achieved by the demonstration products listing a price of $0.00 per pound and the vendor hiding their price list for that day's products.

APPENDIX 2. INFORMATION TREATMENT

Lake Whitefish sold in the US are generally harvested from either the Great Lakes (both Canadian and US waters) or inland lakes in Canada. While the fish from these two locations are the same species, the gear used to harvest these fish can vary by jurisdiction. Two common gear used to harvest Lake Whitefish are gill nets and trap nets. Below are illustrative examples of what this gear looks like.

Gill nets catch fish by snagging the gill cover of the fish, when the fish's body becomes wedged into the mesh of the net, or when other parts of the fish (e.g. mouth, teeth, fins) become entangled in the net. Fish caught in gill nets often die before harvest, and thus can have lower flesh quality, depending on how long fish have been dead before harvest occurs.

Lake Whitefish harvested in Michigan waters of Lake Michigan are generally harvested using trap nets. Trap nets reduce bycatch mortality because fish are kept alive in the net until the net is removed from the lake. Because fish captured in trap nets are kept alive until harvest, fish harvested using trap nets are often fresher than fish harvested using gill nets.

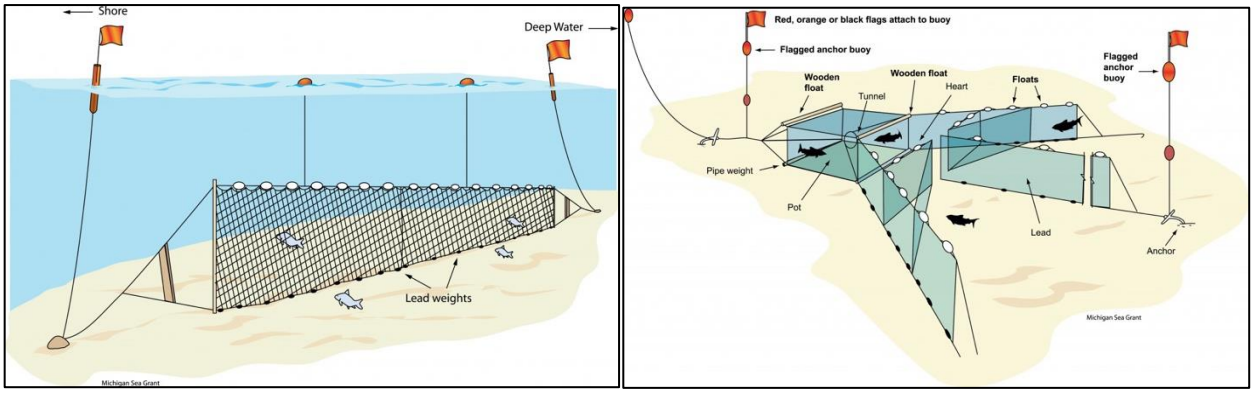

Figure 7. Illustrative example of gill net (left) and trap net (right).

CONCLUSION: WHAT ARE THE CONTRIBUTIONS OF THE LAKE WHITEFISH (*COREGONUS CLUPEAFORMIS*) COMMERCIAL FISHERY IN LAKE MICHIGAN TO MICHIGAN'S HUMAN COMMUNITIES?

Introduction

Freshwater fish and fisheries provide many economic, social, and cultural benefits and values to human communities. Often, these values are difficult to define and/or quantify because they are non-market benefits/values and have no explicit dollar amounts attached to them. Additionally, the impacts of freshwater fisheries can sometimes be difficult to see, especially in terms of sociocultural values and services. As a result, there is a lack of quantifiable, socioeconomic data on how people perceive and use freshwater fish and fisheries.

This dissertation aimed to gather initial data on addressing these data gaps, through a focus on the Lake Whitefish commercial fishery in Michigan waters of Lake Michigan as a case study. At the beginning of this dissertation, three socioeconomic values of inland fisheries to human communities were hypothesized: diet, livelihoods, and economy. Diet was broadly defined as both nutrient contribution (i.e. nutrients available within Lake Whitefish for human consumption) and consumption (i.e. human intake of Lake Whitefish). Livelihood was defined as actors in the Lake Whitefish supply chain in Michigan, with a focus on the state-licensed commercial fishers (due to prior connections with this community and their willingness to contribute to this study). The economic contributions focused on Lake Whitefish as a commodity, specifically price premiums consumers at local Michigan markets are willing to pay for various attributes of Lake Whitefish products.

Lake Whitefish as Food

While historically a commonly consumed food source in the Great Lakes region, the contribution of Lake Whitefish to modern diets is much smaller (Dellinger et al. 2014, Neff et al. 2014). The decrease in Lake Whitefish consumption may be due to a combination of shifting diets (e.g. "westernization" of modern diets) and lack of availability of Lake Whitefish (due to decreasing Lake Whitefish abundances in the Great Lakes) (Dellinger 2004). Although Lake Whitefish are still an important traditional food source for Anishinaabe communities in the Great Lakes region, consumption of Lake Whitefish in these populations have also decreased over the past 50 years (Dellinger et al. 2019). Because Great Lakes Lake Whitefish are overall a healthy food source (high omega-3 fatty acid content and low risk of contamination by persistent bioaccumulative toxins; Gerstenberger and Dellinger 2002, Pantazopoulos et al. 2013, Dellinger et al. 2014), there have been recent efforts to educate potential consumers on the benefits of

eating Lake Whitefish and increasing consumption in order to obtain the human health benefits associated with omega-3 fatty acids (Ebener et al. 2008, Dellinger et al. 2018, 2019). Thus, based on a review of published literature on consumption of Great Lakes Lake Whitefish in the Great Lakes region (focusing on Michigan communities), consumption of Lake Whitefish is likely relatively low among Great Lakes human populations and other fish species (e.g. salmon, tuna) and animal foods are more commonly preferred and consumed (Imm et al. 2005, Jahns 2016).

Lake Whitefish as Livelihood

For this dissertation, the livelihood aspect of the Lake Whitefish commercial fishery was narrowly focused on the Michigan state-licensed commercial fishers. There are many other sectors and communities whose livelihoods depend on, or intersect with, the Lake Whitefish commercial fishery, such as processors, tribal fishers, researchers studying some aspect of Lake Whitefish and/or its associated fisheries, managers, and restaurants (Gerstenberger and Dellinger 2002, Chiarappa and Szylvian 2003, Ebener et al. 2008). These sectors/livelihoods are also important components of the Lake Whitefish commercial fisheries and contribute to, and benefit from, the value of Lake Whitefish in the Laurentian Great Lakes region.

For state-licensed commercial fishers, and the associated supply chain, there have been many changes in the past decade and fishers anticipate more changes, both positive and negative, in the coming decade. The number of state-licensed commercial fishers in Michigan has dramatically decreased, from greater than 60 commercial fishers in the 1980s to currently 13 state-licensed commercial fishers. Many of these fishers belong to multigenerational fishing families and hope that this tradition can be passed down to their children and grandchildren. Additionally, the supply chain itself has become shorter and more localized. Most of the Lake Whitefish harvested by these fishers stays in their local communities, generally sold to restaurants or through their own retail operations. There has been an increase in direct marketing efforts by commercial fishers and a diversification of Lake Whitefish products (e.g. fresh fillet, frozen fillet, smoked fish, whole fish, whitefish dip, whitefish sausage), in order to maintain a viable livelihood in the face of increasing fishing costs and lower abundances of Lake Whitefish in the Great Lakes. Even though the abundance of Lake Whitefish, and consequently the supply, has decreased in the past few decades, demand for Lake Whitefish is growing, especially among summer tourists to Michigan's coastal towns. Thus, while there are some significant challenges

toward maintaining a viable commercial fishery, many fishers retain hope that the fishery will survive and thrive into the future.

Lake Whitefish as Commodity

Few papers have studied consumer preferences regarding Lake Whitefish products in the Great Lakes region, particularly in terms of consumer preferences for specific product attributes and willingness to pay (WTP) for these attributes. A prior attempt to create a brand promoting Great Lakes Lake Whitefish (Legends of the Lakes) identified some of the attributes important to consumers (e.g. fresh, locally harvested). Although it had some initial success, the Legends of the Lakes brand collapsed before it could build up a strong consumer base for locally harvested Great Lakes Lake Whitefish (Ron Kinnunen, Michigan Sea Grant, personal communication).

Thus, this study served as a first step toward identifying Lake Whitefish attributes that consumers preferred and assessing consumer WTP for these attributes. In general, consumers preferred fresh fillets to frozen fillets and preferred locally (Great Lakes) harvested Lake Whitefish to Lake Whitefish harvested in Canadian waters. Once provided with information on the environmental impacts of trap nets and gill nets, consumer WTP significantly increased for Lake Whitefish (both fresh and frozen) harvested using trap nets and significantly declined for Lake Whitefish (both fresh and frozen) harvested using gill nets. The study results from this dissertation research suggest that emphasizing preferred attributes, and providing information on the differential impacts of Lake Whitefish harvesting gear, may help commercial fishers increase their profits via increased consumer WTP for these Lake Whitefish product attributes.

Future of the Lake Whitefish Commercial Fishery

Great Lakes Lake Whitefish populations, and their commercial fisheries, have dramatically changed over the past few decades. Although some of these changes are known (e.g. decreases in Lake Whitefish populations, reduction of commercial fishers and harvests), many changes are unknown. For example, it is unclear how people's attitudes (especially people living in coastal communities and fish consumers in the Great Lakes region) toward Lake Whitefish, and their use/consumption of Lake Whitefish, have changed as Lake Whitefish population abundances have declined. Additionally, the impacts of declining Lake Whitefish populations on Michigan's coastal communities, particularly outside the commercial fishing sector, are largely unknown. If Lake Whitefish populations continue to decrease, as has been the

trend for the past few decades, what will be the impacts to human communities and the Great Lakes ecosystem if Lake Whitefish disappear? Even now, the future of Michigan's commercial fisheries is uncertain.

Legislative Efforts to Update Commercial Fishing Regulations

Several legislative bills (HB 4567, 4568, and 4569) were introduced into the Michigan House of Representatives in early 2000. These bills increased license fees for commercial fishing, increased fines and penalties for certain requirements, and increased regulations around net tending and net location and harvest reporting requirements, among other provisions. While the Michigan Department of Natural Resources (DNR) and other groups in Michigan (e.g. Michigan chapter of Trout Unlimited, Michigan United Conservation Clubs) supported these bills, commercial fishers were adamant that passage of these bills would effectively close commercial fishing in Michigan, as fishers would not be able to meet the new regulations and maintain a viable livelihood. After being passed in the House, the bills were referred to the Michigan Senate Committee on Natural Resources. After several months of testimony from various stakeholders and a work group (led by the Committee Chairperson) to reconcile stakeholders' objections to various provisions in the bills, the DNR opposed all proposed amendments to the bills and the bills "died" in the Senate. As a result, the DNR issued a new Fisheries Order (Fisheries Order 243.21) regarding Michigan's state-licensed commercial fisheries. This fisheries order contained many of the proposed provisions in the house bills and, after outcry from commercial fishers and others, the Fisheries Order was eventually repealed. In March 2022, Governor Whitmer signed into law Senate Bill 251, solidifying some protections for commercial fisheries into law and ending the Fisheries Order system used by the DNR to manage commercial fisheries. Although the passage of this bill closes this issue, commercial fishers anticipate continuing tensions with the DNR and recreational fishing groups over the future of commercial fisheries in the Great Lakes.

Impacts of the COVID-19 Pandemic

Concurrent with this legislative tension, commercial fishers (along with the tourism and restaurant industries) were hard hit by the impacts of the COVID-19 pandemic, particularly the closures implemented during the summer tourism season in order to mitigate the spread of this disease. Although commercial fishers were deemed "essential workers" and could still fish over the summer, the closure of restaurants and retail outlets resulted in severely reduced demand for

fish. Most fishers found that this reduced demand meant that the costs of going out to fish far exceeded the revenue they would received for their harvest (due to reduced demand), which was especially severe given that the closures happened during peak tourism season and thus, the peak retail/profit season for commercial fishers. In order to keep their businesses afloat, many fishers have explored other methods of retail, including direct sale to consumers (with socially-distanced order and pickup methods) and online orders, or have stopped fishing entirely.

Renegotiation of the Consent Decree

A third challenge facing the Lake Whitefish commercial fisheries in 2020 was the renegotiation of the 2000 consent decree. The consent decree is an agreement between five Tribal nations in the Great Lakes region, the U.S. Federal government, and the state of Michigan that guides how, where, how many, and by whom fish can be harvested in parts of the upper Laurentian Great Lakes (U.S. DOJ 2015). First negotiated in 1985, the consent decree was updated in 2000 and set to expire in August 2020 (Case No. 2:73 CV 26 2000). The COVID-19 pandemic, and a disagreement by the Sault Ste. Marie Tribe, delayed the negotiations, extending the consent decree's expiration date to June 30, 2021 (Spratt 2021). Further increasing tensions in the negotiations were the ecological changes in the Great Lakes, resulting in decreasing Lake Whitefish populations (Williams 2022). An agreement was finally reached in late 2022 and is waiting approval by a federal judge (McWhirter 2022). The agreement would extend for 24 years and expands Tribal use of large-mesh gill nets to more areas, although this expansion is accompanied by restrictions on net depth, times of year used, and how much netting is deployed (Flesher 2022). Notably, the Sault St. Marie Tribe refused to join this agreement, citing that the original consent decree was meant to completely expire after 2020 and remove any further regulations of Tribal fishing (McWhirter 2022).

Efforts to Revitalize the Commercial Fisheries

Despite these challenges, there are new initiatives to support the Lake Whitefish commercial fisheries and ensure their continuation into the future. Using a portion of the federal funds allocated to the Great Lakes for COVID-19 relief in 2020, Michigan Sea Grant is working with fish producers on the Mi Fresh Fish educational marketing campaign (Jescovitch 2023). Mi Fresh Fish is a brand that encompasses all Michigan-produced fish (wild-capture and aquaculture). This marketing campaign, via ads and promotion on social media, will reinforce the benefits of eating Michigan fish and spread information about Michigan's commercial fishers

and fish farmers. Another initiative, the Great Lakes Fresh Fish Finder, provides customers with an online map showing local fish-producing businesses and empowering customers to buy locally produced fish and fish products (Celebrating Michigan Fish Producers 2023).

Additionally, Michigan Sea Grant and Wisconsin Sea Grant are jointly developing a framework for a commercial fisheries and fish processing training program (Jescovitch, Moen, Seilheimer, and Adbl-Haleem 2022). This program, utilizing funds from the Young Fishermen's Development Act passed (2022), responds to commercial fishers' concerns about their aging membership and the lack of younger fishers to take over these (often multi-generational) fishing operations once they retire. This framework highlights the need for place-based training opportunities that include region-specific cultural and regulatory contexts and proposes a stakeholder- and rightsholder-driven apprenticeship program to mentor the next generation of the commercial fisheries workforce.

Future Needs and Recommendations for Enhancing the Sustainability of Lake Whitefish in the Upper Laurentian Great Lakes

Although this dissertation studied several types of values related to Great Lakes Lake Whitefish, cultural values were not included. Although they are difficult to identify and quantify, a better understanding of the cultural values of Lake Whitefish is needed in order to have a fuller, more complete, understanding of all the values provided by Great Lakes Lake Whitefish. In particular, it is important to look beyond diet and economic values, as cultural values can be just as important and just as valuable. Some of the cultural values of Lake Whitefish could include the contribution of Lake Whitefish to people/communities' sense of place and the function of Lake Whitefish as a cultural touchstone and component for Great Lakes history, particularly for coastal communities in the region. Methods for defining and measuring these cultural values have been developed for other natural resources systems (Chan et al. 2012, Daniel et al. 2012, Ignatius and Haapasaari 2018) and could be applied to Great Lakes Lake Whitefish.

REFERENCES

Celebrating Michigan fish producers with a bounty of local seafood. 2023. https://www.localdifference.org/blog/celebrating-michigan-fish-producers-with-a-bounty-of-local-seafood/

Chan, K. M. A., A. D. Guerry, P. Balvanera, S. Klain, T. Satterfield, X. Basurto, A. Bostrom, R. Chuenpagdee, R. Gould, B. S. Halpern, N. Hannahs, J. Levine, B. Norton, M. Ruckelshaus, R. Russell, J. Tam, and U. Woodside. 2012. Where are Cultural and Social in Ecosystem Services? A Framework for Constructive Engagement. *BioScience, 62*(8), 744 – 756.

Chiarappa, M. J. and K. M. Szylvian. 2003. Fish for all: An oral history of multiple claims and divided sentiment on Lake Michigan. Michigan State University Press, East Lansing, MI.

Daniel, T. C., A. Muhar, A. Arnberger, O. Aznar, J. W. Boyd, K. M. A. Chan, R. Costanza, T. Elmqvist, C. G. Flint, P. H. Gobster, A. Grêt-Regamey, R. Lave, S. Muhar, M. Penker, R. G. Ribe, T. Schauppenlehner, T. Sikor, I. Soloviy, M. Spierenburg, K. Taczanowska, J. Tam, and A. Von Der Dunk. 2012. Contributions of cultural services to the ecosystem services agenda. *Proceedings of the National Academy of Sciences of the United States of America, 109*(23), 8812 – 8819.

Dellinger, J. A., M. D. Moths, M. J. Dellinger, and M. P. Ripley. 2014. Contaminant Trends in Freshwater Fish from the Laurentian Great Lakes: A 20-Year Analysis. *Human and Ecological Risk Assessment, 20*(2), 461 – 478.

Dellinger, J. a. 2004. Exposure assessment and initial intervention regarding fish consumption of tribal members of the Upper Great Lakes Region in the United States. *Environmental research, 95*(3), 325 – 340.

Dellinger, M. J., M. Lyons, R. Clark, J. Olson, N. Pingatore, and M. Ripley. 2019. Culturally adapted mobile technology improves environmental health literacy in Laurentian, Great Lakes Native Americans (Anishinaabeg). *Journal of Great Lakes Research, 45*(5), 969 – 975.

Dellinger, M. J., J. T. Olson, B. J. Holub, and M. P. Ripley. 2018. Fatty acids in ten species of fish commonly consumed by the Anishinaabe of the upper Great Lakes. *Journal of Great Lakes Research, 44*, 521 – 526.

Ebener, M. P., R. E. Kinnunen, P. J. Schneeberger, L. C. Mohr, J. A. Hoyle, and P. Peeters. 2008. Management of Commercial Fisheries for Lake Whitefish in the Laurentian Great Lakes of North America. *International Governance of Fisheries Ecosystems: Learning from the Past, Finding Solutions for the Future*, 99–143.

Flesher, J. 2022. New Great Lakes fishing deal permits Tribes' use of controversial nets, limits commercial fishing. *USA Today*.

https://www.usatoday.com/story/news/nation/2022/12/13/tribes-great-lakes-fishing-deal-michigan/10887245002/

Gerstenberger, S. L. and J. Dellinger. 2002. PCBS, mercury, and organochlorine concentrations in lake trout, walleye, and whitefish from selected tribal fisheries in the upper great lakes region. *Environmental Toxicology, 17*(6), 513 – 519.

Ignatius, S. and P. Haapasaari. 2018. Justification theory for the analysis of the socio-cultural value of fish and fisheries: The case of Baltic salmon. *Marine Policy, 88*(January 2017), 167 – 173.

Imm, P., L. Knobeloch, and H. A. Anderson. 2005. Fish consumption and advisory awareness in the Great Lakes basin. *Environmental Health Perspectives, 113*(10), 1325 – 1329.

Jahns, L. 2016. Chapter 1 - Fish Intake in the United States. Pages 3–13 *in* Fish and Fish Oil in Health and Disease Prevention. Elsevier Inc.

Jescovitch, L., S. Moen, T. Seilheimer, and F. Abdl-Haleem. 2022. Today's Great Lakes commercial fishing and fish processing industries look to future. *MSU Extension: Michigan Sea Grant.* https://www.canr.msu.edu/news/today-s-great-lakes-commercial-fishing-and-fish-processing-industries-look-to-future-msg22-jescovitch22

Jescovitch, L. 2023. What is Mi Fresh Fish? *Michiagn Sea Grant.* https://www.michiganseagrant.org/blog/2023/04/18/what-is-mi-fresh-fish/

McWhirter, S. 2022. Tribal and state Great Lakes fishing deal sent to federal judge for review. *MLive*. https://www.mlive.com/public-interest/2022/12/tribal-and-state-great-lakes-fishing-deal-sent-to-federal-judge-for-review.html

Moths, M. D., J. A. Dellinger, B. Holub, M. P. Ripley, J. E. McGraw, and R. E. Kinnunen. 2013. Omega-3 fatty acids in fish from the Laurentian Great Lakes tribal fisheries. *Human and Ecological Risk Assessment: An International Journal, 19*(6), 1628 – 1643.

Neff, M. R., S. P. Bhavsar, F. J. Ni, D. O. Carpenter, K. Drouillard, A. T. Fisk, and M. T. Arts. 2014. Risk-benefit of consuming Lake Erie fish. *Environmental Research, 134*, 57 – 65.

Pantazopoulos, P., J. M. Sawyer, M. E. Turyk, M. Diamond, S. P. Bhavsar, D. Mergler, S. Schantz, N. Ratnayake, and D. O. Carpenter. 2013. Fatty acids in Great Lakes lake trout and whitefish. *Journal of Great Lakes Research, 39*(1), 120 – 127.

Spratt, D. 2021. Native rights: Where Great Lakes Tribes can fish and how much is up for debate. *Great Lakes Now*. https://www.greatlakesnow.org/2021/04/native-rights-where-great-lakes-tribes-fish-how-much/

United States v. Michigan. Case No. 2:73 CV 26. 2000. 2000 Great Lakes Consent Decree (2):28.

United States Department of Justice. 2015. U.S. v. Michigan. https://www.justice.gov/enrd/us-v-michigan-1973#:~:text=After%20that%20ruling%2C%20the%20parties,parties%20negotiated%20a%20new%20agreement

Williams, K. 2022. Water test: Rending the Great Lakes food web. *Great Lakes Echo*. https://www.bridgemi.com/michigan-environment-watch/water-test-rending-great-lakes-food-web

Young Fishermen's Development Act, Public Law No: 116-289. (2021). https://www.congress.gov/bill/116th-congress/house-bill/1240