LAKE HURON SALMON FISHERIES VALUATION AND ATLANTIC SALMON POPULATION ASSESSMENT

By

Matthew Zink

A THESIS

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

Fisheries and Wildlife – Master of Science

2022

ABSTRACT

LAKE HURON SALMON FISHERIES VALUATION AND ATLANTIC SALMON POPULATION ASSESSMENT

By

Matthew Zink

Because fishery yield for Lake Huron is currently less than half the lake's specified target level, some agencies with management authority for the lake have considered stocking to enhance recreational fishing opportunities. In 2010, the Michigan Department of Natural Resources (MDNR) expanded stocking of Atlantic salmon in Lake Huron to enhance fishing opportunities. Currently, there is uncertainty about the population this stocking effort has produced or the extent that recreational anglers may value Atlantic salmon versus other salmonids. I surveyed anglers that purchased a 2019 Michigan fishing license to collect salmon fishing trip data for Lake Huron and to ask contingency behavior questions to determine how angler fishing effort might change given changes in expected salmonid catch rates. I additionally fit a statistical catch-at-age model to harvest data from Michigan jurisdictional waters to estimate Atlantic salmon population dynamics and abundance. Based on survey responses, an increase in the catch rate of one fish per 100 hours was estimated to increase the total number of trips to Lake Huron by 13.9 (Chinook salmon), 13.2 (Atlantic salmon), 8.6 (steelhead), 4.5 (coho salmon), and 0.3% (lake trout). This equated to relative values of $38.67, $37.04, $24.40, $12.83, and $0.31 for the species, respectively. The estimated total abundance of Atlantic salmon in 2019 was 392,000 fish, with a peak abundance of approximately 406,000 fish in 2018. Although these results will aid fishery managers evaluate potential stocking options for the lake, I encourage stocking decisions be made collaboratively with input from multiple Lake Huron stakeholder groups.

This thesis is dedicated to my partner Natalie, and my parents.
Thank you for standing by my side.

ACKNOWLEDGEMENTS

I would like to thank my advisors, Drs. Travis Brenden and Simone Valle De Souza, for their help and guidance on this project. I also thank the other members of my graduate committee, Drs. Frank Lupi and Brian Roth, for their contributions and assistance with this project. Randy Claramunt of the Michigan Department of Natural Resources (MDNR) Fish Division initiated this project and was immensely helpful throughout its duration. Tim Cwalinski and Tracy Claramunt from the MDNR Fish Division and Roger Greil from Lake Superior State University provided data and input that greatly benefitted the project. Funding for the project was provided by MDNR Fish Division and the Blue Water Sport Fishing Association. I thank my fellow graduate students and members of the Lake Huron Citizens Advisory Committee for their help in testing the survey instrument. Lastly, I would like to acknowledge Dr. Robert C. Ball and Betty A. Ball for endowing the Robert C. Ball and Betty A. Ball Fisheries and Wildlife Fellowship at Michigan State University, which I was awarded in 2021.

PREFACE

The chapters of this thesis were drafted as standalone papers that will be submitted for publication in peer-reviewed journals. When submitted, all chapters will include one or more co-authors. Consequently, all chapters are written with first person, plural narratives, even though I am listed as the sole author of the thesis. All references are formatted in a style consistent with the Journal of Great Lakes Research.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The fish community of Lake Huron, like most other Great Lakes' fish communities, has changed considerably over time (Bence and Mohr 2008; Ebener 1995; Riley 2013; Riley et al. 2018). Historically, Lake Huron's fish community was dominated by lake trout (*Salvelinus namaycush*), walleye (*Sander vitreus*), and burbot (*Lota lota*) that fed on various coregonid and cottid species (Eshenroder and Burnham-Curtis 1999; Smith 1972). In the late 19th and early 20th centuries, invasion and establishment sea lamprey (*Petromyzon marinus*), along with overfishing and habitat destruction, resulted in severe abundance declines of native piscivores. This in turn contributed to rapid increases in abundance of two invasive planktivorous species, alewife (*Alosa pseudoharengus*) and rainbow smelt (*Osmerus mordax*), to the point where the lake's fish community was soon dominated by these two planktivores (Argyle 1982; Berst and Spangler 1973; Evans and Loftus 1987; Eshenroder 1992; Smith 1970). To reduce abundances of alewife and rainbow smelt, Pacific salmonids (*Oncorhynchus spp.*), chiefly Chinook salmon (*Oncorhynchus tshawytscha*), were introduced and widely stocked by management agencies in the late 1960s and early 1970s. This stocking program successfully reduced invasive planktivore densities and resulted in a fish community dominated largely by Chinook salmon and to a lesser extent other stocked predators, including other Pacific salmonids, lake trout, and walleye, with alewife and rainbow smelt as the principal prey species (Bence and Smith 1999; Tanner and Tody 2002; Roseman and Riley 2009). In 2003, alewife abundance declined severely, which led to concomitant declines in Chinook salmon abundance due to the species being tightly coupled through predation (Bence and Mohr 2008; Brenden et al. 2012; Riley et al. 2007; Roseman and Riley 2009). The decline in alewife abundance promoted the resurgence of several native species, including walleye (Fielder et al. 2007), lake trout (He et al. 2012), and emerald shiner

(*Notropis atherinoides*; Schaeffer et al. 2008). Additionally, abundance of round goby (*Neogobius melanostomous*), an invasive species first detected in Lake Huron in the late 1990s, has increased in recent years (Riley et al. 2020) although it is not known to what extent this increase is related to alewife declines or other fish community changes (e.g., resurgence of native species).

The shifting fish community has directly affected recreational fishing opportunities on Lake Huron. When the lake was dominated by invasive planktivores, recreational fishing opportunities were largely limited to nearshore areas (Bence and Smith 1999; Smith 1970; Tanner and Tody 2002). Although intended to primarily reduce alewife and rainbow smelt abundances, the stocking of Pacific salmonids had the added benefit of enhancing openwater recreational fisheries. Between 1995 and 2003, targeted recreational fishing effort for salmon and trout species in Michigan waters of Lake Huron averaged nearly 1.5 million angler hours with a peak Chinook salmon harvest of more than 150,000 fish [T. Claramunt, Michigan Department of Natural Resources (MDNR), unpublished data]. Since the collapse of alewife, there has been a resurgence in recreational fishing opportunities in nearshore areas of Lake Huron for species like walleye. However, openwater fishing opportunities have declined dramatically as Chinook salmon abundance has declined (Bence and Mohr 2008; Riley and Ebener 2020). Between 2007 and 2019, targeted recreational fishing effort for salmon and trout species in Michigan waters of Lake Huron averaged less than 150,000 angler hours per year with an average annual harvest of 6,000 Chinook salmon per year (T. Claramunt, MDNR, unpublished data).

The overarching fisheries management objective for Lake Huron set by the Lake Huron Committee, which is comprised of representatives from agencies with primary fisheries management jurisdiction on the lake [i.e., MDNR, Ontario Ministry of Northern Development, Mines, Natural Resources, and Forestry (OMNDMNRF), Chippewa-Ottawa Resource Authority (CORA: representing the interests of the five 1836 Native American tribes in Michigan)], is for the lake to have an ecologically balanced, self-sustaining fish community dominated by top predators capable of sustaining combined commercial and recreational fishing yields of 8.9 million kg annually (DesJardine et al. 1995). Between 2011 and 2017, total yield for Lake Huron was estimated at 45% below this target, although even this estimate was believed to possibly be too high because of inaccuracies in recreational fishing yield estimates (Ebener and Riley 2020). Because of severe declines in recreational fishing effort that have occurred since the early 2000s and estimated yield being far below the stated goal for the lake, some agencies with management authority over Lake Huron's fisheries have been interested in enhancing recreational fishing opportunities via stocking (R. Claramunt, MDNR, personal communication). For such a stocking program to be successful, however, the expected realized niche of the stocked species and the status of prey resources in Lake Huron requires consideration. Overall abundance of the Lake Huron prey fish community has been severely depressed since the early 2000s (Bence and Mohr 2008; Riley et al. 2008; Riley and Ebener 2020) due likely to a combination of decreased lake productivity levels and an overabundance of predators (Bence et al. 2016; He et al. 2015; Riley and Dunlop 2016). Consequently, the stocking of a highly specialized piscivore, such as Chinook salmon, is unlikely to be successful due to food resource limitations. Rather, a more viable candidate species would be one that exhibited more generalist feeding and could take advantage of a variety of prey resources, including both fish (e.g., round goby) and invertebrate (e.g., macroinvertebrates, plankton) prey.

In 2010, in response to the need for a more generalist predator in Lake Huron, the MDNR began culturing Atlantic salmon (*Salmo salar*) in state-run hatcheries with the goal of stocking in

Lake Huron to provide new recreational fishing opportunities for the lake's anglers. Although Atlantic salmon are not native to Lake Huron, the species is native to and was once abundant in Lake Ontario prior to its extirpation in the late 19th century from overfishing, poor water quality, and damming of spawning tributaries (Dymond et al. 2019). In the late 1980s, an Atlantic salmon culture program was initiated at Lake Superior State University (LSSU) in Sault Ste. Marie, MI. Yearling Atlantic salmon from this culture program were stocked in the St. Marys River, which is the interconnecting river between Lakes Superior and Huron. This stocking program created a localized recreational fishery for Atlantic salmon in the St. Marys River and northern Lake Huron (Gerig et al. 2019) that is believed to have been relatively unaffected by the fish community changes that have occurred in Lake Huron. Indeed, previous research has supported that Atlantic salmon exhibit generalist feeding at both juvenile and adult life stages (Andreassen et al. 2001; Dixon et al 2019; Johnson et al. 1996), which in theory should improve the species resilience to further fluctuations in the Lake Huron prey fish community. Other characteristics that made Atlantic salmon attractive for enhancing recreational fishing opportunities in Lake Huron were that the species is iteroparous (Dymond et al. 2019) with nonanadromous individuals reaching maximum ages of 14 years (Hutchings et al. 2019). Conversely, Chinook salmon are semelparous and most individuals in Lake Huron spawn by 3 to 5 years of age. Although not growing as large as Chinook salmon, nonanadromous Atlantic salmon have been reported to exceed lengths and weights in excess of 762 mm and 6.4 kg; in Lake Ontario, fish have reached weights of 18 kg (Dymond et al. 2019).

Between 2011 and 2019, the MDNR stocked an average of approximately 100,000 yearling Atlantic salmon annually in Lake Huron, with annual stocking levels ranging from approximately 22,000 to 160,000 fish. Despite stocking for nearly a decade, there is little available information about the population that has resulted from this program. MDNR does conduct an annual openwater creel survey on Lake Huron that generally targets boat recreational fishers. Based on this survey, the return to creel since initiation of the lakewide stocking program, including LSSU stocked fish, has been approximately 1% (R. Claramunt, MDNR, unpublished data). At the initiation of the stocking program, MDNR established a minimum of a 2% return-to-creel target as a benchmark of success, suggesting that the stocking program has not met its intended goal. However, there is recognition that the openwater creel survey may be missing an unknown amount of Atlantic salmon harvest because of when (mid-April to mid-October) and where (primarily openwater, inconsistently covering the St. Mary's River, excluding tributaries and the St. Clair River) it is conducted. As well, there are concerns that anglers that self-report harvest during survey interviews could be underreporting harvest of Atlantic salmon because of difficulties in distinguishing the species from other salmonids [e.g., Chinook salmon, lake trout, steelhead (*Oncorhynchus mykiss*), coho salmon (*Oncorhynchus kisutch*)] present in the lake. Finally, basing the success of the program solely on a return-to-creel target does not account for the possibility of catch-and-release angling for Atlantic salmon by recreational anglers, which according to members of some Lake Huron fishing clubs may be prevalent due to the novelty of the species (R. Claramunt, MDNR, personal communication).

Contemporary openwater recreational fishery harvest of salmon and trout in Lake Huron reflects the dynamic stocking history in the lake. Historically, Chinook salmon composed the majority of openwater recreational harvest in Michigan waters, followed by lake trout, and to a lesser extent Atlantic salmon, coho salmon, and steelhead (T. Claramunt, Michigan DNR, unpublished data). In 2019, lake trout composed the majority of openwater recreational harvest in Michigan waters with Atlantic salmon, Chinook salmon, and steelhead each composing between 7 and 10% of the harvest and brown trout and coho salmon each composing less than 2% of the recreational harvest (T. Claramunt, Michigan DNR, unpublished data). Despite contemporary harvest in Lake Huron being dominated by lake trout, this does not necessarily equate to angler’s preferring to harvest lake trout over other species as behavior is influenced by a multitude of factors, including preference, availability, and accessibility (Thayer and Loftus 1999). Previous research conducted in the Great Lakes has repeatedly found that anglers value catching Chinook salmon more than lake trout (Melstrom and Lupi 2013; Hunt et al. 2021); consequently, recent harvest estimates are likely influenced to a high degree by availability of different salmon and trout species.

Fisheries management can be a challenging endeavor due to policy makers having to account for the needs of a wide range of stakeholders with disparate views. Policy makers must account for biological effects of management decisions, but they also need to account for how stakeholders respond to management decisions as this can dictate whether decisions are successful in meeting their intended goals (Bence and Smith 1999; Thayer and Loftus 2013). According to Bence and Smith (1999), understanding angler behavior may be as important as obtaining reliable information on current status of recreational fisheries and fish stocks when it comes to formulating management decisions. Moreover, it is important to recognize that angler behavior or attitudes towards a particular species can change with time. Consequently, there is a need to periodically re-assess angler behavior, attitudes, and values to ensure major shifts in angler thinking have not occurred (Melstrom and Lupi 2013).

As evidenced by the decision of Michigan DNR to expand Atlantic salmon stocking, Lake Huron fishery managers are searching for ways to expand openwater recreational fishing opportunities that are compatible with the current state of prey resources in the lake.

Uncertainty lingers around angler attitudes towards Atlantic salmon that can influence whether this stocking program will be beneficial. Currently, there are no management tools that address how the anglers value the opportunity to fish for a Lake Huron salmonine. In addition to traditional assessment methods, economic valuation can inform managers as to angler behavior based on the fishery catch rates (Lupi et al. 2020; Melstrom and Lupi 2013).

Against this backdrop, the specific objectives for this thesis were the following:

1) To assess the extent that anglers value opportunities to harvest different salmon and trout species in Lake Huron.
2) To assess the Lake Huron Atlantic salmon population to evaluate its current status (e.g., abundance, exploitation rate) under past stocking levels.

For Objective 1, I conducted an e-mail survey of purchasers of a 2019 Michigan fishing license that took fishing trips to Lake Huron asking about number of trips, the destinations of up to five distinct fishing trip sites, home zip code, mode of transport, number of people in the vehicle, targeted species, whether a boat was towed, and duration of the trip. Survey responses were used to fit a travel cost model to estimate the value of fishing for different species. Additionally, I surveyed anglers how fishing behavior (i.e., number of fishing trips) would change given different changes in expected catch rates for different salmon and trout species that could arise from unspecified management actions. This allowed me to perform a contingent behavior valuation, which is a stated-preference valuation that can reveal the extent that recreational angler prefer to fish for different species based on anticipated behavioral changes in number of trips taken.

For Objective 2, I fit a statistical catch-at-age model to available stocking, harvest, and harvest length composition data from Michigan jurisdictional waters, which allowed me to quantify age-specific abundances and mortality rates. Because of possible inaccuracies in openwater harvest estimates from MDNR creel surveys, the email survey that was described for Objective 1 was used to ask surveyed how much of their reported harvest overlapped with when and where the MDNR creel survey was conducted. Survey respondents were also asked about prevalence of catch-and-release angling; additionally, respondents' ability to correctly distinguish among salmon and trout that are found in Lake Huron was tested by asking them to identify pictures of salmon and trout species that included distinguishing characteristics for the different species. Lastly, for Objective 2 I evaluated condition (i.e., expected weight at given length categories) of Atlantic salmon by fitting allometric growth models to length-weight data to determine how condition had changed as population abundance has ostensibly increased over the duration of the stocking program.

CHAPTER 1: LAKE HURON SALMON FISHERIES VALUATION

INTRODUCTION

Openwater recreational fishing opportunities on Lake Huron in the Laurentian Great Lakes region of North America have changed considerably over time due partly to shifting composition of the lake's fish community. During the early- and mid-20th century, openwater recreational fishing opportunities were limited due to the fish community being heavily dominated by invasive planktivores, namely alewife (*Alosa pseudoharengus*) and rainbow smelt (*Osmerus mordax*) (Smith 1970; Bernst and Spangler 1973; Argyle 1982; Evans and Loftus 1987; Eshenroder 1992). Beginning in the late 1960s, fishery agencies began stocking Pacific salmonids, primarily Chinook salmon (*Oncorhynchus tshawytscha*) but also steelhead (*Oncorhynchus mykiss*) and coho salmon (*Oncorhynchus kisutch*), to reduce planktivorous fish densities and provide openwater recreational fishing opportunities (Bence and Smith 1999). Stocking of Chinook salmon continued through the 1970s, 1980s, and 1990s to maintain predation pressure on alewife and rainbow smelt and support the recreational fisheries that developed around stocking, although stocking levels occasionally were reduced because of perceived imbalances between predator demand and prey production. Other species also were stocked during this time frame to provide additional fishing opportunities and/or promote rehabilitation of native species, including brown trout (*Salmo trutta*), Atlantic salmon (*Salmo salar*), lake trout (*Salvelinus namaycush*), and walleye (*Sander vitreus*). In the early 2000s, alewife population abundance declined precipitously, which led to concomitant declines in Chinook salmon abundance due to the latter being heavily dependent on the former as prey (Bence and Mohr 2008; Brenden et al. 2012; Riley et al. 2007; Roseman and Riley 2009). The decline in Chinook salmon abundance contributed to major reductions in openwater recreational fishing on Lake Huron. From the late 1990s/early 2000s to the late 2000s/early 2010s, annual recreational fishing effort in Michigan openwater water areas of Lake Huron declined by approximately 90% with annual recreational harvest of salmon and trout species declining by approximately 82% (T. Claramunt, Michigan Department of Natural Resources, unpublished data).

Composition of the openwater recreational fishery harvest of salmon and trout in Lake Huron partly reflects the variation in past stocking history and shifts in the fish community. After stocking initiations and through the early 2000s, Chinook salmon composed the majority of openwater recreational harvest in Michigan waters, followed by lake trout, and to a lesser extent Atlantic salmon, coho salmon, and steelhead (T. Claramunt, Michigan DNR, unpublished data). In 2019, lake trout composed the majority of openwater recreational harvest in Michigan waters with Atlantic salmon, Chinook salmon, and steelhead each composing between 7% and 10% of the harvest and brown trout and coho salmon each composing less than 2% of the recreational harvest (T. Claramunt, Michigan DNR, unpublished data). Lake trout dominance of contemporary harvest does not necessarily correlate with angler preference, which is influenced by a multitude of factors, including availability, and accessibility (Thayer and Loftus 1999). Great Lakes anglers traditionally have valued catching Chinook salmon more than lake trout (Melstrom and Lupi 2003; Hunt et al. 2021); thus, recent harvest estimates are likely influenced by the availability (or lack thereof) of different salmon and trout species. The decline in fishing effort in Michigan waters of Lake Huron as the fishery has shifted to a lake trout dominated fishery also suggests differential preference for the species.

The severe declines in recreational fishing effort on Lake Huron have prompted some fishery management agencies to consider stocking as a means to increase fishing opportunities on the lake. However, increased stocking will not necessarily result in higher levels of fishing effort if the species that is stocked is not sufficiently valued by anglers. Successful achievement of management goals stemming from policy decisions is largely dictated by whether stakeholders respond as intended (Bence and Smith 1999; Thayer and Loftus 2012). According to Bence and Smith (1999), understanding angler behavior may be as important as obtaining reliable information on the current status of recreational fisheries and fish stocks when it comes to formulating management policies. Moreover, it is important to recognize that angler behavior or attitudes towards a particular species could change with time; consequently, it can be important to periodically re-assess angler behavior, attitudes, and values (Melstrom and Lupi 2013).

The aim of this research was to assess the extent that recreational anglers in Lake Huron value opportunities to harvest different salmon and trout species to provide information to fishery managers that would be useful for guiding stocking decisions to potentially boost open-water recreational fishing opportunities on the lake. We collected data on salmon fishing trips to Lake Huron with an e-mail survey distributed to purchasers of a 2019 Michigan fishing license. Survey responses were used to fit a travel-cost model to estimate the value of fishing for different salmon and trout species. We additionally conducted a contingent behavior valuation by asking respondents how fishing behavior might change given different scenarios in expected catch rates for different salmon and trout species that might result from a management action such as stocking or alterations in survival rates. This allowed us to fit a random utility model to determine the extent that recreational anglers value opportunities to fish for different species in Lake Huron.

METHODS

Survey description and distribution

We conducted an e-mail survey of online purchasers of a 2019 Michigan fishing license that opted to receive e-mail correspondence from MDNR at the time of license purchase. Consequently, our sample was not a random sample of Lake Huron salmonine anglers but instead consisted of anglers who opted to receive emails from the MDNR, provided a valid email address, and self-selected to participate in the survey. The survey (see Appendix C) was constructed using Qualtrics software (Qualtrics, Provo, UT). Survey questions were primarily designed to collect data from anglers on recreational fishing trips taken to Lake Huron targeting salmonines (i.e., Atlantic salmon, brown trout, Chinook salmon, coho salmon, and lake trout) between April 2019 and March 2020, and contingent behavior data addressing the anticipated number of trips taken to Lake Huron targeting salmon based on hypothetical scenarios of salmon species catch rates. Additional questions were asked to gather information on Atlantic salmon harvest, catch and release angling, and the ability of anglers to distinguish between different Lake Huron salmon and trout species to help with conducting an assessment of the Atlantic salmon population (Chapter 2). Herein, we only report on the results from questions concerning recreational fishing trips to Lake Huron targeting salmonines and contingent behavior data. The Qualtrics software was used to generate unique, single-use links for each email associated with the targeted group; the links were then e-mailed to anglers by the MDNR. A 10% test distribution was released on 24 September 2020. The remaining 90% of the emails were distributed on 28 September 2020. Out of 210,975 possible license purchasers, the survey was ultimately delivered to 209,185 purchasers. Reminder emails were sent on 6 October 2020 and 13 October 2020. The survey was closed on 21 October 2020. Distribution messages were identical and only the subject line changes between distributions (Appendix D). All responses were de-identified and data were aggregated for analysis.

Survey testing

Survey development and testing followed guidelines outlined for revealed and stated preference studies (Lupi et al. 2020; Johnston et al. 2017). We conducted two rounds of individual cognitive interviews consisting of five interviews each. The first round of survey testing involved Michigan State University graduate students and staff. The second round of survey testing involved salmon anglers from the Lake Huron Citizens Advisory Committee that volunteered to test the survey. Because of the Covid-19 pandemic, all cognitive interviews were conducted remotely through video conferencing software. Interviewees were notified their participation was voluntary and they could quit at any time. Next, interviewees shared their screen with the interviewer and proceeded to take the survey as if the interviewer was not present. Upon completion of the survey, the interviewer addressed any noticed difficulties for given questions during survey taking by prompting how the interviewee interpreted the given question. Additionally, each interviewee was taken through a cognitive interview template after completing the survey (Appendix E). Final survey questions were modified accordingly (e.g., some images that were going to be used to assess salmon identification accuracy were deleted due to image quality, questions were deleted about the ability of angler to recall the number of lake trout harvested due to difficulty in recall accuracy because of higher harvest levels).

Salmon preference

Early in the survey, anglers were presented with a Likert-scale question where they selected between five options from strongly agree to strongly disagree to the statement “when fishing in the Great Lakes or its tributaries, I like to catch…”, which would indicate how much they preferred catching Atlantic salmon, brown trout, Chinook salmon, coho salmon, steelhead/rainbow trout, and lake trout (Figure C1). We asked this question to compare the Likert-scale responses of salmon preference versus our contingent behavior analysis of salmon preference for the anglers in our demand model.

Angler self-comparison to MDNR average catch rates

Anglers were presented the MDNR open-water creel 2014 to 2019 average catch rates (in number of fish/100 hours) for Lake Huron salmon and trout to assess if the average catch rates calculated by the MDNR matched the perception of the fishery to anglers (Table A3). Respondents were asked Likert-scale question as to how similar their personal catch rates were to the MDNR average. Their options were five steps between much lower to much higher and the alternative answer “I didn’t target this species”.

Recreational trip data

The questions gathering recreational trip data began with a screening question asking if surveyed anglers had taken a fishing trip to Lake Huron and/or its tributaries during the 2019 fishing season with the main purpose of fishing for a salmonine species. Negative responses were directed to the salmon identification section followed by the demographics section. Surveyed anglers that answered affirmatively to the Lake Huron fishing trip question were asked the number of trips taken with the main purpose of fishing for a salmonine species and were prompted to enter up to five of their most visited fishing sites and the nearest cities to those fishing sites. Surveyed anglers were then asked to report the number of single and multiple day trips taken to each site, and the number of trips taken to all other sites to Lake Huron and/or its tributaries with the main purpose of fishing for salmon. Lastly, surveyed anglers were asked to describe their typical fishing trip targeting salmon on Lake Huron and/or its tributaries, including type of vehicle used to travel to the site, number of passengers above and below 18 years of age, whether or not a boat was used and how or if it was transported (trailered, carried on/in the vehicle, kept at the site), and whether they owned a boat used for fishing Lake Huron and/or its tributaries. The answers to these questions were used to calculate travel cost (see below). We also captured socio-demographic data of surveyed anglers, including age, income, and education, which are essential to determine general characteristics of survey participants and inform about groups behavior and trends in our demand model. (Appendix C).

Site data

To maintain focus on the Lake Huron salmonine fisheries, the only sites identified by surveyed anglers that were considered valid for analyses were those associated with Lake Huron open-water ports or tributaries that were deemed salmon passable. We used Fishwerks (McIntyre et al. 2017) to determine whether sites identified on Lake Huron tributaries were salmon passable. This was done to exclude fishing trip results for anglers that were targeting riverine or land-locked populations of salmon or trout. The northern boundary for Lake Huron was considered Sault Ste. Marie, MI on the St. Mary's River, and the southern boundary was Algonac, MI on the St. Clair River. The valid sites from our survey responses resulted in the identification of 87 unique sites where anglers fished for salmon and trout on Lake Huron. We aggregated those 87 sites into 24 site groupings to help reduce travel-cost model complexity (Table A1, Figure B1); our approach to grouping sites and identifying site group locations mirrored that of English et al. (2018). Site groupings were based on geographic proximity, boundaries for Lake Huron statistical districts, and consistency in the total number of trips to individual sites, avoiding grouping very popular sites with less popular sites. The total number of trips taken within a group were then assumed to have been taken to the sites selected to represent each group (Table A2). The exact location for the 24-site grouping for determining distance traveled by anglers was generally assumed to be the site in the group with the most trips (Table A1). There were two exceptions to this. In selecting a site to represent the group of sites near Saginaw Bay (group 8), the most trips were taken to Saginaw Bay, and with no shoreline launch or city reported, these trips were assumed to originate from Saginaw River due to its proximity to the Bay and access to both northern and southern shorelines. In selecting a site to represent the group of sites in southern Lake Huron include Ontario waters (group 1), the most trips were taken to the site closest to MI (Kettle Point ONT) but given the spread of the sites for this group, a site more east (Grand Bend ONT) was chosen to represent the group.

ECONOMIC METHODS

Travel cost model

A critical component of travel cost modeling is determining the actual cost of individual trips. We estimated the exogenous cost of travel from each origin zip code to each site in the choice set. Even though surveyed anglers did not take trips to all the sites in the choice set, their exogenous cost of travel to these sites was still estimated, as it was necessary for fitting the travel cost model (English et al. 2018; Lupi et al. 2020). Our approach to estimating exogenous travel costs assumed that individuals drove directly to the fishing sites and did not account for any detours or side excursions. The roundtrip cost C for individual *i* traveling to site *j* was calculated as

$$C_{i,j} = \frac{p_d d_{i,j}}{n} + p_t t_{i,j}.$$

where $d_{i,j}$ was roundtrip driving distance, p_d was per mile out-of-pocket driving cost, *n* was party size, $t_{i,j}$ was roundtrip driving time, and p_t was round trip value of time in recreational time. The Georoute module (Weber and Péclat 2016) in STATA (StataCorp, College Station, TX) was used to compute roundtrip driving distance and time from the centroid of each origin zip code to each of the aggregated sites (Weber and Peclat 2017). Our approach for calculating per mile out-of-pocket driving cost followed that of English et al. (2018) and Lupi et al. (2020) and accounted for the typical vehicle used and whether a boat was towed for the trip. Specifically, per mile driving cost was computed using per mile fuel cost, maintenance cost, and depreciation cost for each person's reported typical vehicle type (AAA 2019) plus a towing cost for those anglers that reported they typically trailered boats calculated using existing literature on towing penalties (Thomas et al. 2014; English et al. 2019). The resulting average driving cost was $0.362 per mile. Lastly, for the round trip driving cost per person, the costs per vehicle were divided by average number of adults per vehicle (equal to 2.14). Round trip value of time in recreational time was modeled as one-third of a surveyed angler's income divided by 2000 hours worked per year (Lupi et al. 2020) following previous best practices for recreational demand modeling (English et al. 2018; Lupi et al. 2020).

Contingent behavior data

Contingent behavior questions are stated preference questions intended to elicit a person's expected behavior in response to proposed scenarios; these are often used to understand potential behavioral responses under conditions that have not been observed either in the past or present (Englin and Cameron 1996). Each surveyed angler was presented five contingent behavior questions to gather data on how fishing effort (i.e., number of fishing trips) would change in response to changes in anticipated catch rates for different salmon and trout species. Surveyed anglers were presented the 5-year average catch rate (fish per 100 hours of fishing) for five Lake Huron salmon and trout species calculated from MDNR harvest data (T. Kolb, MDNR, unpublished data) to establish a baseline. For each species (i.e., Atlantic salmon, Chinook salmon, coho salmon, lake trout, and steelhead), the contingent behavior scenarios were drawn from either the current MDNR average catch rate or one of four catch rates chosen to represent meaningful, yet realistic, changes from the 5-year average species catch rates (Table A3). We elected to not include brown trout in the contingent behavior evaluation as the average catch rates for brown trout were considerably lower than for the other species. Increases in catch rates ranged from 1 to 3.5 fish per 100 hours of fishing, whereas decreases in catch ranges from 0.5 to 4.9 fish per 100 hours of fishing. From our five species, each with five catch rates, we created an orthogonal (i.e., statistically independent) array to select five sets of five scenarios to be presented to surveyed anglers. Selected scenarios included both increasing and decreasing catch rates for each species so the resulting model could predict the change in trips for any species catch rate increasing or decreasing and any trade-offs that may result. Scenarios that consisted of all five species catch rates increasing or decreasing were replaced with scenarios where at least one of the five catch rates increased while the other four decreased and vice versa; this replacement was necessary because scenarios with all increasing or decreasing catch rates provided no meaningful information on how angler behavior might change (i.e., surveyed anglers would take more trips if the entire fishery had higher catch rates). The replacement of these scenarios introduced a small amount of correlation (≈10%) between the sets of scenarios. We used the Qualtrics software randomization capabilities to make each set of 5 questions equally likely to be assigned to a surveyed angler. For each scenario presented to surveyed anglers, anglers were asked the number of trips they would take under the scenario presented. In the analysis, only surveyed anglers that provided a valid zip code and took at least one trip targeting salmon to Lake Huron and/or its tributaries were considered in our modeling of the contingent behavior data.

Random Utility Model

We specified our travel cost model as a modified repeated random utility model (RUM) and estimated as a nested logit model in STATA (StataCorp, College Station, TX ; Lupi et al. 2020, Morey et al. 1993). The estimated and calibrated demand models provided the information needed to calculate the per trip value of fishing for salmon on Lake Huron and characterize how angler behavior would change under different fishery conditions (i.e. higher or lower catch rates).

RUM analysis is based on the random utility maximization hypothesis, which assumes that individuals faced with a well-defined choice set will select the alternative that yields the greatest level of utility (McFadden 1974, 1978, 1981). Thus we let U_{jk} represent the conditional utility for individual i in choosing alternative k ($k = 1,\ldots, J$), such that an individual chooses alternative j ($y_{ij} = 1$) if $U_{ij} > U_{ik}$ for all $k \neq j$,

$$y_{ij} = \begin{cases} 1 & \text{if } U_{ij} > U_{ik} \quad \text{for all } k \neq j \\ 0 & \text{Otherwise} \end{cases}$$

The conditional utilities depend on both the individual and the site attributes of the available alternatives. We denoted the factors influencing individual decisions with the function $V_{ij} = V(X_{ij};\tau)$, where X_{ij} is our observable individual/alternative specific attributes, the vector of parameters for estimation τ, and error term $\varepsilon_{ij} = U_{ij} - V_{ij}$. Thus, the probability a specific choice will be made by any individual is,

$$P_{ij} = \Pr\left(y_{ij} \middle| X_{i.}\right) = \Pr\left(U_{ij} > U_{ik} \text{ for all } k \neq j\right) = \Pr\left(\varepsilon_{ik} - \varepsilon_{ij} < V_{ij} - V_{ik} \text{ for all } k \neq j\right).$$

In addition to the 24 aggregate sites described above, the RUM analysis also included a stay-at-home option resulting in a choice set of 25 options with j = 0, 1, 2, …, 24 where j = 0 is the no-trip option. Individuals were modeled as choosing between alternative sites and the stay-at-home option over a series of reporting periods for fishing trips (English et al. 2018; Morey et al 1993). With repeated RUM models, the choice occasions are a conceptual device to capture both total trips as well as individual site choices. It is common to pick a number of choice occasions larger than the maximum number of observed trips in the data to avoid truncations trip data (Freeman et al. 2014). In our case that meant using 110 choice occasions for each individual in our model dataset where either no trip or a trip to 1 of the 24 sites was taken. We assumed the error ε_{ij} for the RUM was identically distributed across all choice occasions, resulting in a log-likelihood function of

$$L_i = \sum_{j=1}^{J} n_{ij} \ln\left(P_{ij}\right) + \left(T_i - \sum_{j=1}^{J} n_{ij}\right) \ln(P_{io}),$$

where n_{ij} is individual i's trips to alternative j summed over their reporting period, T_i is the choice occasions, and P_{io} is the probability no trip was taken on a given choice occasion.

The statistical model was specified as a two-level nested logit model following English et al. (2018) with the stay-at-home option as baseline. The nested logit model allows alternatives within a nest to share a spatially correlated error structure, which is uncorrelated with the errors; in our study, this allows the data to reveal whether sites are better substitutes for one another than for the stay-at-home alternative. If the estimated parameter for the nesting structure is significantly different than one the spatial error correlation is preferred to a model without such error correlation.

In the nested logit demand model, the utility for the stay-at-home option was specified as a function of surveyed angler's demographics. If the parameters for these variables were significant and positive (negative), it indicated that anglers with a large value for that attribute would take fewer (more) trips. In other words, if the parameter corresponding to college education was significantly positive, it meant anglers with college degrees were, on any occasion, more likely to have chosen the stay-at-home option, and hence for the season they took fewer trips. Finally, the utilities for each site were specified to include each person's round trip travel cost to each site, C_{ij}, and a fixed effect to describe the site-specific characteristics of each site, which are often called alternative specific constants in the RUM literature (Murdock 2006).

Contingent Behavior Model

The number of trips anglers would take under different catch scenarios from the contingent behavior data was modeled using standard linear regression methods. The dependent variable was constructed as the percentage change in trips in response to the scenarios change in catch rates from the 5-year average for each species. The coefficient estimates from the contingent behavior model showed the percent change in trips associated with a one fish per 100 hours change in catch rate for a species. The percent changes in trips could then be computed for any combination of possible changes in catch rates. The resulting percent changes could then be used within the demand model to compute the change in economic value to anglers associated with the catch rate change. This was accomplished by using a contraction algorithm to solve for the change in the site fishing utilities that would reproduce the change in fishing behavior from the contingent behavior model (English et al. 2018; Boudreaux 2021). In essence, the contraction map is a type of fixed-point solution algorithm to efficiently identify the change in utilities that will result in the desired change in model outcome (Berry et al. 1995). Therefore, the algorithm iteratively guesses the change in utility that would generate the change in trips predicted using the contingent behavior model, and the solution is the change in utility that equates the two. For a policy illustration, the contraction map was used in five separate scenarios to value a one fish per 100 hours change in the catch rate of each of the species. The model did not have an intercept term to force a change in the percent change of trips taken to depend on a change in a catch rate [i.e., no increase (or decrease) in percent of trips if no change in any catch rate]. Thus, for all scenarios considered in later analyses, changes in trips taken to Lake Huron for the purpose of salmon fishing were attributed to an unknown management (policy) decision resulting in catch rate changes instead of a stochastic change in catch rates.

RESULTS

Of the 209,185 license purchasers that were emailed the survey, usable data were obtained from 821 surveyed anglers and the results of 697 surveyed anglers were used in the RUM analysis, which contained information on 6,121 recreational fishing trips to Lake Huron in 2019 that targeted salmon and trout. Each angler was able to enter their total number of trips for up to five sites, as well as all other trips taken to Lake Huron for the purpose of salmon or trout fishing. At least 60% of anglers in the demand model indicated that they strongly agreed with the statement that they like to catch each of the salmon and trout species that were identified except for lake trout (Figure B2). Lake trout had the greatest percent of responses indicating the anglers strongly disagreed with the statement that they like to catch lake trout at 5.1%. Steelhead, Chinook salmon, and coho salmon were the species that surveyed anglers appeared to most strongly prefer to catch followed by Atlantic salmon, brown trout, and lake trout. The percent of surveyed anglers that indicated they liked to catch each of these species to some degree was 96.1%, 94.7%, 93.6%, 86%, 82.6%, and 71.52%, respectively (Figure B2).

When surveyed anglers were asked to compare their personal catch rates to the 5-year average catch rate calculated from the Michigan DNR openwater creel for Atlantic salmon, Chinook salmon, coho salmon, lake trout, and steelhead, the majority of anglers experienced either similar, lower, or much lower catch rates compared to the 5-year average (Figure B3). A greater percentage of surveyed anglers experienced much lower, or somewhat lower catch rates than the 5-year average for Atlantic salmon (59%), Chinook salmon (59%), and coho salmon (62%) compared to lake trout (40%) and steelhead (43%). Conversely, lake trout and steelhead had the highest proportion of surveyed anglers (24% and 25% respectively) that indicated their catch rates were somewhat higher or much higher than the 5-year average (Figure B3).

For anglers in our model we summarized their demographics used to calculate individual travel cost. The 697 anglers in the model had a mean income of $99,500 (S.E. = 2477.30; 2019 USD). he average age of the individuals in the sample was 52.9 (S.E. = 2.00) years and the average fishing experience was 29.66 (S.E. = 0.30) years. A majority, 60% (S.E. = 0.02), of the anglers were college educated. Lastly, 16% (S.E. = 0.01) of the sample belonged to an angler group and 65% (S.E. = 0. 02) owned a boat used for fishing on Lake Huron.

Travel cost results

Based on the RUM analyses, as travel cost increased, the number of Lake Huron fishing trips decreased. Surveyed anglers with higher incomes were more likely to go on a fishing trip (Table A4), while the results for age and college educations were not significant. The RUM estimates of the relative attractiveness of each site [i.e., alternate-specific constants (ASC)], and the dissimilarity parameter, *tau*, indicated that in response to a change in a site, surveyed anglers were more likely to take a trip to a different site over not taking a trip at all, which suggested a high degree of substitution among sites by anglers (Table A4). The ASC values also represented the relative popularity of each site if considered in the absence of trip cost, with values closer to zero indicating sites are more popular destination for fishing (Table A5). Based on this, the most attractive sites independent of trip costs were Detour and Oscoda, MI. There was a slight geographic trend in site constants, the eleven most desirable fishing sites independent of trip costs price were located north of Oscoda, MI (including Oscoda; Table A5, Figure B1). Using established formulas for predicting trips and deriving the value of a trip from repeated logit RUM models (Haab and McConnell 2002; Freeman et al. 2014), the demand model estimates indicated that a visit to a typical Lake Huron site for the purpose of salmon fishing had an average value of $44 (2019 USD).

Contingent behavior results

Not every angler that provided trip data also provided usable contingent behavior data. As a result, we received 3,210 answers from 665 anglers as to how number of fishing trips would change given changes in Lake Huron catch rates. Based on the contingent behavior analyses, Chinook salmon, Atlantic salmon, and steelhead were estimated to have similar influence on the number of the trips that would be taken to Lake Huron. (Table A6). An increase in catch rate of one fish per 100 hours was estimated to increase the number of total trips taken to Lake Huron by 13.9% (95% CI: 10.9 - 16.8%; Table A6) for Chinook salmon, 13.2% (95% CI: 9.9 -16.5%; Table A6) for Atlantic salmon, and 8.6% (95% CI: 5.6 -11.5; Table A6) for steelhead. Conversely, an increase in the coho salmon catch rate by one fish per 100 hours was estimated to increase the number of total trips taken to Lake Huron by 4.5% (95% CI: 2.4 - 6.6%; Table A6). Based on confidence interval overlap, these results suggest that while coho salmon have a similar influence on number of fishing trips as steelhead, the species is less influential on the number of fishing trips than either Chinook salmon or Atlantic salmon (although see discussion below).

Lake trout had the lowest influence on number of fishing trips. An increase in lake trout catch rate by one fish per 100 hours was estimated to increase the number of trips by 0.3% (95% CI: -0.7 - 1.4%, Table A6), which did not overlap in confidence intervals for any of the other species.

Based on the contracting mapping and the results of the contingency behavior model, the implied value of catching one additional Chinook salmon or Atlantic salmon per 100 hours of fishing was nearly equal at $38.67 for Chinook salmon and $37.04 for Atlantic salmon. For steelhead and coho salmon, the implied value of catching one additional fish per 100 hours of fish was $24.40 and $12.83, respectively. For lake trout, the implied value of catching one additional fish per 100 hours of fish was $0.82 (Table A7).

DISCUSSION

Based on the economic valuation conducted as part of this research, we found that Chinook salmon, Atlantic salmon, steelhead, and coho salmon were more valued by recreational anglers than lake trout. Although Chinook salmon and Atlantic salmon may be similarly valued by recreational anglers as steelhead, based on survey results the former species may be slightly more valued by recreational anglers than coho salmon, although we urge caution in ascribing significance of these results based on the survey methodology (discussed below). Our results are consistent with previous valuation studies that have been conducted for salmonid species in the Great Lakes. Based on angler surveys conducted in 1994 and 1995, Michigan anglers' willingness to pay to catch salmonine species in the Great Lakes were not significantly different for coho salmon, steelhead, or Chinook salmon (Hoehn et al. 1996; Johnston et al. 2006). More recently, Melstrom and Lupi (2013) from Michigan angler surveys conducted in 2008 and 2009 found that anglers' willingness to pay to catch salmon and trout species in the Great Lakes was greatest for Chinook salmon, followed by coho salmon, and steelhead, but differences between species were not statistically significant.

Although Atlantic salmon have been stocked in the St. Mary's River since the late 1980s, the species has not previously been included in surveys assessing angler value for different salmon and trout species in the Great Lakes so we were uncertain as to how anglers might value this species. Based on surveyed angler's responses to how much they liked fishing for different salmon and trout species in the Great Lakes, we would have expected angler's willingness to pay to catch one more Atlantic salmon per 100 hours of fishing would have been greater than lake trout but less than that of Chinook salmon, coho salmon, or steelhead. However, based on the contingency analysis results, surveyed angler's willingness to pay for Atlantic salmon was fairly comparable to that of Chinook salmon and perhaps greater than steelhead. The high value placed on Atlantic salmon despite their relative newness to the system and low overall stocking rate may be partly explained by their reputation as high quality food in both the aquaculture and recreational rod fisheries in the Northeast United States and Northwest Europe (Aprahamian 2010; Breffle and Morey 2000; Kennedy and Crozier 1997; Peirson et al. 2001; Worthington et al 2020).

We urge caution in interpreting our results to be reflective of all Lake Huron salmon and trout anglers. Our survey was not a random sample of anglers, rather it consisted of online purchasers of a 2019 fishing license that opted to receive emails from the MDNR and who self-selected to participate in the survey. Consequently, the responses of surveyed anglers may not truly represent the views (or behaviors) of the at-large population of Lake Huron trout and salmon anglers. The respondents to the contingent survey questions had an average income above the national average and the majority of respondents owned boats, were above the age of fifty, had decades of angling experience, and many were college educated. It is uncertain as to how this compares to the typical Lake Huron trout and salmon anger, but given that offshore salmon and trout fishing in Lake Huron requires specialized vessels, gear, and experience then the demographics of having higher income and angling experience align with the fishery dynamics.

An additional issue with our survey methodology was that the email survey was distributed several months after the close of the 2019 fishing season, meaning the majority of fishing trips that anglers were being asked to recall occurred more than a year prior. While we considered delaying the survey to focus on purchasers of a 2020 Michigan fishing license, we were concerned how the Covid-19 pandemic might affect fishing behavior and how comparable results would be to non-pandemic years. The gap between the survey and the trips reported and the duration of time anglers were asked to recall could result in some recall bias. Typically, the longer the recall period, the lower response accuracy is (Clarke et al 2008; Sudman and Bradborn 1973). Anglers are known to over-report trips the longer the waiting period, thus we calibrated the reported trips from the contingent behavior scenarios to the MDNR open-water creel effort data to prevent over-representing the effort of our surveyed anglers (Osborn and Matlock 2010; Tarrant et al. 1993). Some problems that have been identified the email surveys are that response rates are low and they self-select for respondents that have internet access and email accounts (Taylor 2007; Zahl-Thanem et al. 2021). We elected to conduct an email survey because funding for this project was limited and resources were not available for a mail or in-person survey. Additionally, the methods/randomization implemented in the survey would have been difficult to accomplish in a mail survey.

Our distribution messages were worded to try and minimize non-response bias, and attempted to create a relationship between why anglers did not respond and the questions on the survey (Petrovčič et al. 2016; Phillips et al. 2016). We also accomplished this in part by naming our survey the “Lake Huron Salmon Fisheries Survey”. The data needed for our analysis required respondents to have taken fishing trips targeting salmon on Lake Huron. Therefore, anglers who are not interested in the Lake Huron salmon fishery (i.e. only fish inland panfish), or don’t fish Lake Huron would theoretically be less likely to take the survey based on our messaging and survey title.

The results of our Likert scale question for modeled anglers asking whether they liked to catch each of the five salmon were in slight contradiction with the RUM results. Based on the Likert scale questions, Chinook salmon, coho salmon, and steelhead were the most popular by modeled anglers. However, based on the RUM analyses, Chinook salmon, Atlantic salmon, and steelhead were the most valued when asked about how fishing effort (number of trips) might change based on changes in catch rates. This contradiction could be an indication of the novelty of Atlantic salmon, and once faced with a decision based on catch rates their preference differs from the Likert-scale question. This highlights the utility of an economic valuation over simple Likert scale questions for understanding angler behavior and preference. The valuation provides the framework to address tradeoffs, and address uncertainty in angler behavior. For example, anglers may prefer Chinook salmon over the other salmon and trout, but anglers will take more trips to a fishery with elevated catch rates of Atlantic salmon, coho salmon, and steelhead while Chinook catch rates decrease (or vice versa). Additionally, an economic valuation provides estimates on the degree to which other factors influence trips taken (i.e. income, age, angling experience) and provides uncertainty intervals for these estimates.

For the Lake Huron salmon fishery, sites in the mid to northern half of Lake Huron were more attractive, based on their alternative-specific constants, than the southern half sites if we ignore the price or travel cost. Oscoda, MI was the site furthest south for the 11 most popular fishing sites. This geographic preference indicates that northern Lake Huron is overall preferred by the Lake Huron salmon anglers but for many anglers has associated higher travel costs. Angler preference for sites in northern Lake Huron is likely partly explained by these being the locations where salmon and trout species are most likely to occur in the lake. For example, since 2012 stocking of Chinook salmon by MDNR in Lake Huron has been limited to the lake's northernmost management unit, and most wild reproduction of species such as Chinook salmon and steelhead is believed to be limited to tributaries of Lake Huron's Georgian Bay and North Channel. Some of the sites in the southern half of Lake Huron are around Saginaw Bay, which is not typically considered a location to catch salmon since water temperatures are too warm in the summer for salmon and trout species (R. Claramunt, personal communication).

Management Implications

Current fishery yields for Lake Huron are estimated to be less than half of the target yield established for the lake by representatives from fishery management agencies with jurisdictional authority for the lake. Lake Huron fishery managers are interested in possibly developing new recreational fishing opportunities for the lake through stocking to increase recreational fishing effort and yield. However, any decisions regarding stocking must consider an array of factors that ultimately influence whether stocking will achieve the desired management goal. These factors include the availability of prey resources for the stocked fish, the extent that anglers value the species to be stocked, costs to culture the species to be stocked, expected stocking and post-stocking survival rates, etc.

While the valuation results from the present study suggest that species like Chinook salmon, Atlantic salmon, steelhead, and perhaps coho salmon are equally valued by recreational anglers, attempting to expand recreational fishing opportunities around some of these species is unlikely to be successful. Given the current state of the alewife population in Lake Huron, attempting to expand recreational opportunities by stocking Chinook salmon is unlikely to be successful because of the lack of available prey. Atlantic salmon, steelhead, and coho salmon are each believed to exhibit more generalist feeding than Chinook and may be better suited for taking advantage of available prey resources in Lake Huron, such as invertebrates, round goby (*Neogobius melanostomus*), and other prey fish. Based on our results, increasing recreational fishing opportunities for Atlantic salmon and/or steelhead may be expected to generate more fishing trips to Lake Huron than coho salmon, although as previously pointed out we cannot be certain that our valuation results are representative of the at-large salmon and trout recreational anglers for Lake Huron. With regards to culturing costs, the cost to raise Atlantic salmon to stocking size is approximately 70% greater than the cost to raise steelhead, and 200% greater than the cost to raise coho salmon (E. Eisch, MDNR, unpublished results). Whether these added costs to raise Atlantic salmon is worth perhaps a slightly higher recreational angling value is uncertainty. In terms of differences between stocking and post-stocking survival rates of the different species, little information is currently available as there are no fishery-independent surveys for salmon species in the lake and relying on fishery harvest confounds survival rate estimates with differing vulnerability to angling.

Decisions to expand stocking of Atlantic salmon, coho salmon, or steelhead should also consider that none of these species are native to Lake Huron and there may be conflict with some stakeholder groups regarding expanding stocking of a non-native species, particularly those stakeholders that are focused on restoring Lake Huron to a more native fish community. As a result, we believe that any decision about expanding recreational fishing opportunities through stocking should be preceded by a collaborative decision making process. Collaborative efforts to set new recreational fishing goals for Lake Huron may be more conducive to evaluate the potential benefits and detriments to enhancing recreational fishing opportunities for any of these species.

CHAPTER 2: ATLANTIC SALMON POPULATION ASSESSMENT AND EVALUATION OF FISH CONDITION

INTRODUCTION

The fish community of Lake Huron, like most other Great Lakes' fish communities, has changed considerably over time (Bence and Mohr 2008; Ebener 1995; Riley 2013; Riley et al. 2018). Historically, the community was dominated by lake trout (*Salvelinus namaycush*), walleye (*Sander vitreus*), and burbot (*Lota lota*) that fed on various coregonid and cottid species. (Eshenroder and Burnham-Curtis 1999; Smith 1972). In the late 19th and early 20th centuries, invasion and establishment sea lamprey (*Petromyzon marinus*), along with overfishing and habitat destruction, resulted in severe abundance declines of native piscivores, which in turn contributed to rapid increases in abundance of two invasive planktivorous species, alewife (*Alosa pseudoharengus*) and rainbow smelt (*Osmerus mordax*), to the point where the lake's fish community was soon dominated by these two planktivores (Argyle 1982; Berst and Spangler 1973; Evans and Loftus 1987; Eshenroder 1992; Smith 1970). To reduce abundances of alewife and rainbow smelt, Pacific salmonids (*Oncorhynchus spp.*), chiefly Chinook salmon (*Oncorhynchus tshawytscha*), began being widely stocked by management agencies in the late 1960s and early 1970s. This stocking program successfully reduced invasive planktivore densities and resulted in a fish community dominated largely by Chinook salmon and to a lesser extent other stocked predators, including other Pacific salmonids, lake trout, and walleye, with alewife and rainbow smelt as the principal prey species (Bence and Smith 1999; Tanner and Tody 2002; Roseman and Riley 2009). In 2003, alewife abundance declined severely, which led to concomitant declines in Chinook salmon abundance (Bence and Mohr 2008; Brenden et al. 2012; Riley et al. 2007; Roseman and Riley 2009). The decline in alewife abundance promoted the resurgence of several native species, including walleye (Fielder et al. 2007), lake trout (He et al. 2012), and emerald shiner (*Notropis atherinoides*; Schaeffer et al. 2008). Additionally, the abundance of invasive round goby (*Neogobius melanostomous*) has increased in recent years (Riley et al. 2020), although it is unclear how this increase is related to alewife declines or other fish community changes (e.g., resurgence of native species).

The historical shift in the Lake Huron fish community had direct ramifications for recreational fishing opportunities on the lake. When the lake was dominated by invasive planktivores, recreational fishing opportunities were largely limited to nearshore areas (Bence and Smith 1999; Smith 1970; Tanner and Tody 2002). Although intended to primarily to reduce alewife and rainbow smelt abundances, the stocking of Pacific salmonids had the added benefit of establishing openwater recreational fisheries. Between 1995 and 2003, targeted recreational fishing effort for salmon and trout species in Michigan waters of Lake Huron averaged nearly 1.5 million angler hours with a peak Chinook salmon harvest of more than 150,000 fish (T. Claramunt, Michigan Department of Natural Resources, unpublished data). Since the collapse of alewife, there has been a resurgence in recreational fishing opportunities in nearshore areas of Lake Huron for species like walleye, but pelagic fishing opportunities have declined considerably as Chinook salmon abundance has declined (Bence and Mohr 2008; Riley and Ebener 2020). Between 2007 and 2019, targeted recreational fishing effort for salmon and trout species in Michigan waters of Lake Huron averaged less than 150,000 angler hours per year with an average annual harvest of 6,000 Chinook salmon per year (T. Claramunt, Michigan Department of Natural Resources, unpublished data).

The overarching fisheries management objective for Lake Huron set by the Lake Huron Committee, which is comprised of representatives from agencies with primary fisheries management jurisdiction on the lake [i.e., Michigan Department of Natural Resources (MDNR), Ontario Ministry of Northern Development, Mines, Natural Resources, and Forestry, Chippewa-Ottawa Resource Authority representing the interests of the five 1836 Native American tribes in Michigan)]. The primary objective is for the lake to have an ecologically balanced, self-sustaining fish community dominated by top predators capable of sustaining combined commercial and recreational fishing yields of 8.9 million kg annually (DesJardine et al. 1995). Between 2011 and 2017, total yield for Lake Huron was estimated at 45% below this target, although even this estimate was believed to be too high because of inaccuracies in recreational fishing yield estimates (Ebener and Riley 2020). Because of severe declines in recreational fishing effort that have occurred since the early 2000s and estimated yield being far below the stated goal for the lake, some agencies with management authority over Lake Huron's fisheries have been interested in enhancing recreational fishing opportunities via stocking (R. Claramunt, MDNR, personal observation). For such a stocking program to be successful, however, the expected foraging niche of the candidate species and the status of prey resources in Lake Huron requires consideration. Overall abundance of the Lake Huron prey fish community has been severely depressed since the early 2000s (Bence and Mohr 2008; Riley et al. 2008; Riley and Ebener 2020) due likely to a combination of decreased lake productivity levels and an overabundance of predators (Bence et al. 2016; He et al. 2015; Riley and Dunlop 2016). Consequently, the stocking of a highly-specialized piscivore, such as Chinook salmon, is unlikely to be successful due to food resource limitations. Rather, a more viable candidate species would be one that exhibited more generalist feeding and could take advantage of a variety of prey resources, including both fish (e.g., round goby) and invertebrate (e.g., macroinvertebrates, plankton) prey.

In 2010, in response to the need for a more generalist predator in Lake Huron, the MDNR began culturing Atlantic salmon (*Salmo salar*) in state-run hatcheries to stock in Lake Huron to provide new recreational fishing opportunities for the lake's anglers. Although Atlantic salmon are not native to Lake Huron, the species is native to and was once abundant in Lake Ontario prior to its extirpation in the late 19th century from overfishing, poor water quality, and damming of spawning tributaries (Dymond et al. 2019). In the late 1980s, an Atlantic salmon culture program was initiated at Lake Superior State University (LSSU) in Sault Ste. Marie, MI that stocked fish in the St. Mary's River, which is the interconnecting waterway between Lakes Superior and Huron. This stocking program resulted in a localized recreational fishery for Atlantic salmon in the St. Mary's River and northern Lake Huron (Gerig et al. 2019) that is believed to be relatively unaffected by the fish community changes. Atlantic salmon exhibit generalist feeding at both juvenile and adult life stages (Andreassen et al. 2001; Dixon et al 2019; Johnson et al. 1996), which in theory should improve the species resilience to fluctuations in prey resources. Atlantic salmon are iteroparous and could thereby survive for longer periods in the lake, and the maximum reported age of nonanadromous Atlantic salmon is 14 years (Dymond et al. 2019; Hutchings et al. 2019). Conversely, Chinook salmon are semelparous and most individuals in Lake Huron spawn by 3 to 5 years of age. Finally, while not growing as large as Chinook salmon, nonanadromous Atlantic salmon have been reported to exceed lengths and weights in excess of 762 mm and 6.4 kg and, in Lake Ontario, fish have reached weights of 18 kg (Dymond et al. 2019).

Between 2011 and 2019, the MDNR stocked an average of approximately 100,000 yearling Atlantic salmon annually in Lake Huron, with annual stocking levels ranging from approximately 22,000 to 160,000 fish. Despite stocking having been ongoing for nearly a decade, there is little available information about the population that has resulted from this program. The MDNR does conduct an annual openwater creel survey on Lake Huron that generally targets boat recreational fishers. Based on this survey, the return to creel since initiation of the lakewide stocking program, including LSSU stocked fish, has been approximately 1% (R. Claramunt, unpublished data). At the initiation of the stocking program, MDNR established a minimum of a 2% return-to-creel target as a benchmark of success, suggesting that the stocking program has not met its intended goal. However, there is recognition that the openwater creel survey may be missing an unknown amount of Atlantic salmon harvest because of when (mid-April to mid-October) and where (primarily openwater, inconsistently covering the St. Mary's River, excluding tributaries and the St. Clair River) it is conducted. There are also concerns that anglers that self-reported harvest during survey interviews could misreport harvest of Atlantic salmon because of difficulties in distinguishing the species from other salmonids [e.g., Chinook salmon, lake trout, steelhead (*Oncorhynchus mykiss*), coho salmon (*Oncorhynchus kisutch*)] present in the lake. Finally, basing the success of the program solely on a return-to-creel target does not account for the possibility of catch-and-release angling for Atlantic salmon by recreational anglers, which according to members of some Lake Huron fishing clubs may be prevalent due to the novelty of the species (R. Claramunt, personal observation).

The aim of this study was to assess the Lake Huron Atlantic salmon population to evaluate its current state under past stocking levels. For this assessment, a statistical catch-at-age (SCAA) model was fit to available stocking, harvest, and harvest length composition data from Michigan jurisdictional waters, which allowed us to quantify age-specific abundances and mortality rates. Because of possible inaccuracies in openwater creel harvest estimates, an email survey was distributed to anglers that purchased an online 2019 Michigan fishing license to estimate how much of the reported harvest by survey respondents overlapped spatially and temporally with the MDNR openwater creel survey that is traditionally used to measure Lake Huron fishery harvest. Surveyed anglers were also asked about prevalence of catch-and-release angling and tested as to their ability to correctly distinguish among salmon and trout species that are found in Lake Huron. Lastly, condition (i.e., expected weight at given length categories) of Atlantic salmon was evaluated by fitting allometric growth models to length-weight data to determine how condition had changed as population abundance has ostensibly increased over the duration of the stocking program as a means for assessing whether intra- or inter-specific competition for food resources could be occurring.

METHODS

Study area

Lake Huron is the fifth largest lake by surface area in the world. The lake consists of three relatively discrete water masses: the main basin (including Saginaw Bay), North Channel, and Georgian Bay. The lake receives outflow from Lake Superior via the St. Mary's River and discharges into Lake St. Clair through the St. Clair River. Lake Huron is generally regarded as oligotrophic with the exception of Saginaw Bay and several nearshore areas (Dobiesz et al. 2005). Although MDNR conducts an annual openwater creel survey in its jurisdictional waters, the OMNDMNRF does not regularly conduct creel surveys in its jurisdictional waters (Borgeson et al. 2020). Consequently, our assessment of the Atlantic salmon population was largely limited to Michigan waters of the main basin (see Discussion for consequences of this assumption on study results). Tribal harvest of Atlantic salmon also was not included in the data used in the fitting the SCAA model.

Data Collection

Stocking.—Wild reproduction of Atlantic salmon is not presently believed to be a significant source of recruitment in Lake Huron (R. Claramunt, MDNR, personal observation); consequently, recruitment was assumed to consist solely of stocked fish. Numbers of yearling Atlantic salmon stocked into Lake Huron and the St. Mary's River were obtained from MDNR and LSSU. We included stocking by both MDNR and LSSU because of spatial overlap in where stocking occurs and because reported harvest from the MDNR openwater creel survey could not reliably distinguish between the two groups of fish in all years. As previously mentioned, stocking levels by MDNR ranged from approximately 22,000 to 160,000 yearlings from 2011 to 2019 (Table F1). The MDNR stocks Atlantic salmon at 4 sites: St. Mary's River, Thunder Bay River, Au Sable River, and Lexington Harbor (Figure G1), with stocking levels equally proportioned among the four sites in general, although effective levels may be vary based on region-specific post-stocking survival rates (R. Claramunt, MDNR, personal observation). Since 2013, all Atlantic salmon stocked by MDNR have been tagged with a coded-wire tag (CWT) inserted into fish snouts. Conversely, LSSU stocked between 20,000 and 41,000 Atlantic salmon fingerlings in the St. Mary's River from 2011 to 2019. Atlantic salmon stocked by LSSU are marked with fin clips.

Recreational fishery harvest.—Openwater recreational harvest of Atlantic salmon in Lake Huron was obtained from MDNR (T. Claramunt, MDNR, unpublished data). Annual openwater harvest is estimated by surveying anglers from a selection of major fishing ports in Lake Huron; annual harvest estimates are then expanded to account for harvest from un-surveyed ports using a ratio approach that compares historical harvest at un-surveyed sites to the historical harvest at sites in the same general area to calculate the un-surveyed site's proportional contribution to the harvest of the group of sites. The estimated proportional contribution is then used to calculate harvest for un-surveyed ports.

As indicated previously, there are concerns that the MDNR openwater creel survey may underestimate actual Atlantic salmon harvest because of when and where the survey is conducted. In particular, there is concern that the openwater creel survey may miss harvest occurring in tributary areas late in the calendar year. Consequently, we conducted an email survey of anglers that purchased a Michigan fishing license online in 2019 as a means for estimating what percentage of Atlantic salmon harvest coincided spatially and temporally with the MDNR openwater creel survey (Chapter 1). From the survey we were not interested in the exact number of Atlantic salmon reported as harvested as we did not consider these estimates to be reliable because of recall bias and knowing what fraction of our survey respondents corresponded to total number of anglers. Rather we were simply interested in estimation the proportion of harvest that coincided spatially and temporally with the openwater creel survey as a means for correcting harvest.

The details of the email survey are provided in Chapter 1 of this thesis, but an overview of the survey is described here. The email survey was developed in Qualtrics (Qualtrics, Provo, UT) and was distributed by MDNR to online purchasers of a 2019 Michigan fishing license that opted into receiving email correspondence. A 2019 fishing license covered the time period of April 1, 2019 to March 31, 2020. The survey was delivered to 209,185 of 210,975 possible recipients. A 10% test distribution was released on September 24, 2020. The remaining 90% of the email survey was distributed on September 28, 2020. Reminders to non-respondents were sent on October 6, 2020 and October 13, 2020. Respondents who indicated in the survey they caught an Atlantic salmon in 2019 were asked to report when and where harvest occurred. The spatial categories (Lake Huron open-water, bays, harbors, shore, and piers; Lake Huron tributary; St. Mary's River; Huron-Erie Corridor – St. Clair River, Lake St. Clair, Detroit River; Other Great Lake; Other, please specify) and temporal categories (April-October 2019; November-December 2019; January-March 2020) used in the survey question were intended to determine the percentage of reported harvest that coincided with the MDNR openwater creel survey. Once we calculated the percentage of harvest that coincided spatially and temporally with the openwater creel survey, we corrected the Atlantic salmon harvest estimates to account for harvest that occurred outside these times and areas. For example, if the survey found that 50% of the reported Atlantic salmon harvest by survey respondents coincided spatially and temporally with the openwater creel estimate of harvest, we would double the estimated openwater creel harvest to come up with an estimated annual lakewide harvest. This assumes the openwater creel survey harvest estimate is accurate for the times and areas where it was conducted, but we had little reason to suspect the estimates were not accurate as they have been used to quantify harvest in assessment for other Lake Huron exploited species (e.g., Sitar et al. 1999; Brenden et al. 2012; Fielder and Bence 2014). Even though we only had estimates for 2019, we applied the correction to all annual harvest data (i.e., 2011 to 2019).

Recreational harvest length composition.—Yearly length composition of the recreational harvest was calculated from biological samples collected as part of the MDNR openwater creel program. Although ages of harvested Atlantic salmon were estimated as part of the creel's biological sampling, there were concerns about accuracies of age estimates when contrasted with lengths of sampled fish. As a consequence, we elected to fit our model with recreational harvest length composition and used an age-length transition matrix generated from a von Bertalanffy growth model (described below) to convert predicted age-specific harvest to length-specific harvest (see details below; Quinn and Deriso 1999). Harvest composition length bins were 50 mm wide, and centered at lengths ranging from 300 to 900 mm.

Statistical Catch-at-Age Assessment Model

Abundance at age in the estimated statistical catch-at-age model were for the years 2011 to 2019 and included ages 1 to 7. Definitions of parameters and variables used in equations describing the SCAA model in the main text are presented in Table F2.

Abundance at age of Atlantic salmon at the start of each was projected using an exponential population model

$$N_{y+1,a} = N_{y,a} \cdot \exp\left(-Z_{y,a}\right).$$

We assumed that initial abundance of age-1 Atlantic salmon in each year (i.e., recruitment) was equal to the number of yearling Atlantic salmon stocked that year by MDNR and LSSU multiplied by an immediate post-stocking survival rate

$$N_{y,1} = \gamma \cdot \left(n_y^{LSSU} + n_y^{MDNR}\right).$$

The post-stocking survival rate was estimated through a logistic function

$$\gamma = \frac{\exp(m)}{1+\exp\,(m)}.$$

To help regularize the estimation of the post-stocking survival rate given the lack of an informative data source for this parameter, a penalty (i.e., prior probability distribution) was assigned to *m*. In previous research on steelhead in the Great Lakes, an immediate post-stocking survival rate of 50% has been assumed for stocked yearling fish (Rutherford 1997; Tsehaye et al. 2014). Accordingly, we assigned a normal probability distribution with a mean of 0 and a standard deviation of 0.5 as a penalty for *m*.

Although the MDNR stocking program starting in 2011, the LSSU stocking program was started in the 1980s. Therefore, it was not realistic to assume abundances at ages 2 to 7 for the initial modeled year (2011) were 0. Rather, we projected abundances based on pre-2011 LSSU stocking levels and using the stocking survival rate and age-specific mortality rates for 2011 estimated as part of the SCAA model

$$N_{2011,a} = \gamma \cdot n_{2011-(a-1)}^{LSSU} \cdot \exp\left(-\sum_{i=1}^{a-1} Z_{2011,i}\right), \qquad \text{for } 2 \leq a \leq 7$$

Total instantaneous mortality was partitioned into natural and recreational fishing components

$$Z_{y,a} = M_{y,a} + F_{y,a},$$

Instantaneous natural mortality rates were assumed to be 0.1 for age-1 to age-5 fish and 0.5 and 1.0 for age-6 and age-7 fish, respectively. These assumed mortality rates were based on rates previously assumed for steelhead in the Great Lakes (Rutherford 1997; Tsehaye et al. 2014). Recreational fishing mortality was estimated as the product of an average apical fishing intensity, multiplicative annual fishing intensity deviations, and age-specific selectivities

$$F_{y,a} = s_a \cdot \bar{F} \cdot \exp\left(\tau_y\right).$$

Selectivity was fixed at 1.0 for age-2 Atlantic salmon, whereas selectivities for age-1, age-3, and age-4 fish were estimated as freely varying parameters on a $\log_e$ scale. Selectivities for age-5 and older Atlantic salmon were assumed equal to the age-4 selectivities.

Annual harvest at age of Atlantic salmon from the recreational fishery conditional on the estimated population abundances was calculated using the Baranov catch equation

$$\widehat{H}_{y,a} = \frac{F_{y,a}}{Z_{y,a}} \cdot N_{y,a} \cdot \left(1 - \exp\left(-Z_{y,a}\right)\right),$$

with total annual harvest calculated by summing over ages

$$\widehat{H}_y = \sum_a \widehat{H}_{y,a}.$$

The estimated recreational harvest by length categories was calculating by multiplying harvest at age estimates by an age-length transition matrix

$$\widehat{H}_{y,l} = \widehat{H}_{y,a} \cdot \psi_{a,l}.$$

The length composition of the harvest by year was calculated by dividing length-specific harvests by total harvest

$$\widehat{P}_{y,l} = \frac{\widehat{H}_{y,l}}{\widehat{H}_y}.$$

The age-length transition matrix was generated using parameter estimates from a von Bertalanffy growth model assuming a multiplicative error structure

$$L_i = L_\infty(1 - \exp\left(-K(a_i - t_0)\right)e^{\varepsilon_i}$$

where *i* indexes individuals, L_i is total length (mm), and a is age, L_∞ is the asymptotic fish length parameter, K is the Brody growth coefficient parameter, t_0 is the parameter associated with the theoretical age at which fish length is 0 mm, and ε is a stochastic error term assumed normally distribution with a mean of 0 and standard deviation of s_L. The growth model was fit to age-length data from recaptures of MDNR stocked Atlantic salmon tagged with coded-wire tags, which meant that ages of recaptured fish were known exactly. Because CWT tagging of Atlantic salmon has only occurred since 2013, we fit the growth model using recapture data from 2019 and 2020 to capture the widest possible age range of harvested fish. To help inform the estimation of t_0, we included average stocking length of Atlantic salmon stocked at two Lake Huron sites in 2014, 2019, and 2020 in the age-length dataset. Due to the rapid growth of Atlantic salmon and that harvest occurred throughout the year, we accounted for month of harvest in fish ages rather than treating ages as integers. The growth model was fit in R version 4.0.2 (R Core Team 2021) after log transformation of the growth function using the nls() function from the base stats package (R Core Team 2021). Bootstrapping (number of iterations = 1,000) was used to evaluate uncertainty in the growth model parameter estimates and was conducted using the nlsBoot() function in the nlstools package (Baty et al. 2015).

After fitting the growth model, the age-length transition matrix was derived by assuming the lengths of the fish in each age-class were normally distributed with means equal to predicted lengths at age from the growth model and standard error specific to predicted lengths (Quinn and Deriso 1999). The von Bertalanffy growth model parameters were bias-corrected due to $\log_e$ transformation during model fitting. The month of June was when most Atlantic salmon in Lake Huron were harvested; consequently, the month of June was used as the month for predicted length-at-age for the age-length transition matrix (Quinn and Deriso 1999). For each length category, we calculated the cumulative probability of an Atlantic salmon of a particular age being at least as large as the length-category midpoint. From these cumulative probabilities, we calculated the expected probability of an Atlantic salmon of a particular age being within a particular length category. Using our predicted length-at-age distribution from the Von-Bertalanffy model, we generated the probability of an age 1-7 Atlantic salmon belonging to each length bin.

The Lake Huron Atlantic salmon SCAA model was constructed and implemented in R (version 4.0.2; R Core Team 2020) using the Template Model Builder (TMB) package (Kristensen et al. 2016). The model object, objective functions and gradient, were created by the MakeADFun() function. The nlminb() function in the stats library (R Core Team 2020) was used to numerically search for parameter estimates and minimize the objective functions. Model parameters were estimated by highest posterior density estimation (also referred to as maximum penalized likelihood). A state-space implementation of the SCAA model in which the $\log_e$-scale annual fishing intensity deviations (i.e., process errors) were estimated as random effects was attempted but this model parameterization would not converge on a solution due likely to difficulties in simultaneously estimating standard deviations associated with process and observation errors. The objective function for the SCAA model consisted of the sum of four negative log-likelihood or negative log-prior (penalty) components (Table F3). We assumed lognormal distributions for the annual total recreational fishery harvest and $\log_e$-scale annual fishing intensity deviations (Table F3). A normal distribution was assumed for the penalty of the logistic-scale estimate of post-stocking survival (Table F3). A multinomial distribution was assumed for the recreational harvest length composition. The standard deviation for the lognormal distribution associated with the annual total recreational fishery harvest was estimated as part of the model fitting process. The standard deviation for the lognormal distribution associated with the $\log_e$-scale annual fishing intensity deviations was assumed equal to

$$\sigma_F = \sqrt{\frac{\sigma_H^2}{0.5}}.$$

The multinomial distribution for the recreational harvest length-composition was weighted by an assumed effective sample size of 25.

Despite the short time series of available data, a retrospective analysis was still performed to identify possible systematic biases in model predictions or parameter estimates. The retrospective analysis was performed by refitting the SCAA model after deleting recent years of observations and examining whether terminal year predictions or estimates exhibited systematic biases in parameter estimates or model predictions (Mohn 1999). For the retrospective analysis, we deleted observations as far back as 2016 and evaluated systematic biases in total population abundance and the instantaneous fishing mortality rate for age-2 fish.

Catch and release angling

In addition to asking about when and where Atlantic salmon were harvested in 2019, surveyed anglers were asked about catch and release angling. Anglers who indicated that at least one Atlantic salmon was released were prompted to indicate reasons why fish were released. Available options for answering the question were the following: not legal size, wanted to harvest larger fish, already caught limit, prefer catch and release fishing, did not want to harvest Atlantic salmon, and unsure of species. Respondents could also provide their own reason for practicing catch and release angling. Multiple responses to the question were allowed.

Accuracy in identifying Atlantic salmon

To address concerns about angler's ability to accurately distinguish Atlantic salmon, surveyed anglers were asked to identify pictures of salmon and trout species that were caught in Lake Huron and that included distinguishing characteristics for the different species. The important distinguishing characteristics included the presence or absence of spots on gill plates and the caudal fin and the shape of the caudal fin (Hubbs et al. 2004). Atlantic salmon have spotted gill plates while Chinook and coho salmon do not; conversely, Chinook and coho salmon have spots on their caudal fin while Atlantic salmon do not (Hubbs et al. 2004). To differentiate between Atlantic salmon and lake-phase brown trout, the shape of the caudal fin was the distinguishing characteristic given brown trout have a square caudal fin and Atlantic salmon have a forked caudal fin; additionally, the maxillary of brown trout extend well past the eye while Atlantic salmon maxillaries reach the rear edge of the eye (Hubbs et al. 2004). Steelhead have a distinct pink color, and a square caudal fin that separate them from Atlantic salmon. Lake trout have green coloration with white spots, while Atlantic salmon are silver. After survey testing (testing procedure is described in chapter 1 of this thesis), we used 12 unique photos of Lake Huron salmon and trout: 4 Atlantic salmon, 4 Chinook salmon, 1 coho salmon, and 3 steelhead (Appendix C; Figures C.1-12). Because of our focus on Atlantic salmon, each respondent was asked to identify the same Atlantic salmon photo. Respondents were then asked to identify a random selection of 3 of the 11 remaining photographs. The randomization was implemented in Qualtrics software and designed such that across all surveys the remaining 11 photographs were shown an equal amount of time.

Temporal changes in condition

We assessed temporal changes in condition (i.e., expected weight-at-length) by fitting hierarchical allometric growth models to $\log_e$-transformed length-weight data from biological samples collected through the MDNR openwater creel survey for Lake Huron. The year that length-weight data were collected was included in some models as a potential grouping factor for model coefficients. The allometric growth model with a multiplicative error structure is

$$W_i = \alpha L_i^{\beta} e^{\varepsilon_i},$$

where W_i is an individual's mass (grams), L_i is an individual's length (mm), *a* is the condition parameter, *b* is the curvature parameter, and ε is a stochastic error term assumed normally distribution with a mean of 0 and standard deviation of s_W (Quinn and Deriso 1999). Four model parameterizations were attempted: 1) pooled (i.e., common across years) *a* and *b*, 2) year-specific *a* modeled through a random effect and pooled *b,* 3) year-specific *b* modeled through a random effect and pooled *a,* and 4) year-specific *a* and *b* modeled through random effects. The allometric growth models were fit using the glmmTMB() function from glmmTMB package (version 1.0.2.1; Brooks et al. 2017) in R. The default glmmTMB convergence criteria were used when fitting the models. Akaike Information Criterion (AIC) was used to select which of the four model parameterizations was most supported by available data. The model with the lowest AIC value was used to predict Atlantic salmon weights at the following reference lengths: 546, 600, 680, and 833 mm. The first 3 reference lengths correspond to the 1st quartile, median, and 3rd quartile of observed Atlantic salmon lengths from the biological samples from the MDNR creel data. The largest reference length index was chosen because it was within the range of our observed lengths and corresponds to one of the longer fork lengths (FL; 820 mm) observed by Frechette et al. (2018) looking at condition in spawning sea-run Atlantic salmon. We converted the fork length to total length (TL) for comparison using the equation from previous research relating Atlantic salmon fork length to total length (Wing et al. 1998).

RESULTS

Lake Huron Salmon Fisheries Survey Atlantic salmon harvest

Our survey had complete harvest data from 259 respondents. Based on anglers responses to questions about when and where Atlantic salmon were harvested, we estimate that 42% (SE=3.0%) of total harvest occurred within the spatial and temporal boundaries of the openwater creel. Consequently, the expanded harvest estimates in each year were divided by 0.42 to account for harvest missed by the openwater creel.

Von Bertalanffy Growth Model

Bias-adjusted estimates and bootstrap 95% confidence intervals for the von Bertalanffy growth model fit to CWT length-age data were 730 mm (95% confidence interval: 713 – 747 mm) for asymptotic length, 0.96 (95% confidence interval: 0.89 – 1.04) for the Brody growth coefficient, and 1.14 years (95% confidence interval: 1.11 – 1.16 years) for age at which length equals 0 mm. The residual standard error from the estimated growth model was 0.1039.

Statistical Catch-at-Age Assessment Model

The Lake Huron Atlantic salmon SCAA model successfully converged on a solution. There was close correspondence between observed recreational fishery harvest and the harvest predicted in the SCAA model (Figure G2). Observed and predicted recreational harvest peaked at just less than 6,000 fish in 2012; harvest from 2013 to 2019 exhibited some cyclical patterns but suggested a generally increasing trend (Figure G2). Although predicted mean length at harvest was roughly centered close to observed mean length at harvest, the SCAA model was not able to account for the inter-annual variability that occurred with the observed data (Figure G3). This is likely attributable at least in part to our assuming in the model that selectivity was constant over time, which was necessitated by the short time series of available data, and because of the large variability in growth that was evident in the growth data.

Based on the estimated SCAA model, total abundance of age-1 and older Atlantic salmon generally increased from 2011 to 2019 and appeared to be stabilizing around 400,000 fish under past stocking levels (Figure G4). In 2019, the terminal year of the model, estimated abundance was 392,477 fish (95% confidence interval: 210,975 – 573,980]. The trajectory for population abundance growth from 2012 to 2016 was steeper than it was in later years, which suggested the population had been on track to stabilize at a higher abundance level. The slower population growth rate in later years was a consequence of an approximate 20% reduction in total stocking levels from 2017 to 2019 compared to levels from 2013 to 2016. In terms of composition of the population, between 70 and 90% of the population consisted of individuals age-4 and younger, which could be in part a reflection of the relatively recent expansion of the stocking program, given sufficient time has not allowed for older ages of fish to accumulate in abundance (Table F5).

The estimated immediate post-stocking survival rate for yearling Atlantic salmon was 0.52 with a 95% confidence interval [0.29, 0.75]. As stated in the methods, there is little information in the observed data sources for estimating this parameter, which is why we assumed a penalty for the parameter. The estimated abundances from the SCAA model are likely heavily dependent on what the true post-stocking survival is for MDNR and LSSU stocked fish. Consequently, it is important to recognize that the estimated abundances presented herein are conditional on the estimated post-stocking survival rate.

Estimated recreational selectivities for age-1, age-3, and age-4 and older Atlantic salmon were 0.004 (95% CI: 0.000 – 0.01), 0.8 (95% CI: 0.51 – 1.10), and 4.5e-05 (95% CI: 0.00 – 0.003). Age-2 (i.e., fully selected) instantaneous fishing mortality rates from 2011 to 2019 ranged from approximately 0.02 to 0.21, with peak fishing mortality occurring in 2012. In 2018 and 2019, age-2 instantaneous fishing mortality rates were approximately 0.042.

No retrospective patterns were evident in terminal year total abundance (Figure G4) or terminal year instantaneous fishing mortality rates of age-2 Atlantic salmon (Figure G5). There was some variability in estimates of abundance and age-2 instantaneous fishing mortality rates depending on what years of data were included in the SCAA model, but no systematic biases (i.e., consistent positive or negative biases) were evident.

Prevalence of catch and release angling

Based on survey results, 280 respondents indicated they caught an Atlantic salmon and 244 of those respondents indicated they released an Atlantic salmon during the 2019 fishing season. Of all Atlantic salmon reported caught in our survey, 27.3% (SE = 0.01) were released for any given reason. Of the anglers that reported they released an Atlantic salmon during the 2019 fishing season, 33% indicated they released fish because they prefer catch and release fishing whereas 32% indicated fish were not legal size or were deemed too small. Approximately 14% of anglers indicated they had no interest in harvesting Atlantic salmon and 6% indicated they had already caught their limit. Only 2% of anglers indicated they released a fish because they were not certain about fish species. Approximately 12% of anglers provided other reasons for practicing catch and release angling, which included reasons such as wanting the population to grow, the fish had spawned recently or was getting ready to spawn, they already had enough fish to eat, the fish was foul hooked, and the expressed belief that it was not safe to consume fish. Overall, the prevalence of catch and release fishing (i.e., anglers targeting Atlantic salmon intending to release them) accounted for 9% of all Atlantic salmon reported caught in our survey for the 2019 fishing season.

Accuracy in identifying Atlantic salmon

For the Atlantic salmon photograph that all surveyed anglers were shown, the fish was correctly identified by respondents 18% (SE = 1.0%) of the time. The photograph was most commonly misidentified as a Chinook salmon (21%), followed by lake trout (16%), coho salmon (12%), brown trout (8%), and steelhead (6%). Approximately 10% of respondents indicated they were unsure of the species and 9% of respondents indicated they did not know. Overall, pictures of Atlantic salmon were correctly identified 24% of the time, and were most commonly misidentified as Chinook salmon (14%) followed by lake trout (12%), coho salmon (12%), steelhead (11%), and brown trout (10%). Across all Atlantic salmon photographs, 8% of respondents indicated they were unsure of the species and 7% indicated they did not know the species. When surveyed anglers were shown photos of Chinook salmon, coho salmon, and steelhead, they were misidentified as Atlantic salmon 8, 19, and 3% of the time, respectively.

Condition Analysis

The hierarchical allometric growth model with year-specific *a* and *b* did not converge on a solution likely as a consequence of small sample sizes. The remaining allometric growth model parameterizations did converge on a solution. The model with the lowest AIC value was the parameterization with a pooled *a* and year-specific *b*. The other two models had ΔAIC values of 0.46 and 14.51 for the pooled *b* and year-specific *a* and pooled *a* and *b* models. The two models with AIC values less than 2 units difference were averaged using AIC weights. The averaged model estimates for the *a* parameter on a $\log_e$ scale was -13.958 (95% confidence interval: -14.64 – -13.28]. The population (i.e., year) averaged estimate of β was 3.38 (95% confidence interval: 3.27 – 3.48]. For the pooled *a* and year-specific *b*, year-specific estimates of β ranged from 3.360 to 3.378. The standard deviation for the random-effect associated with β was 0.0064. For the year-specific a and pooled *b*, the year-specific estimates of *a* ranged from -0.62 to 0.51 with associated standard deviation 0.04.

Predicted weights for the four reference length categories based on the best fitting allometric growth model exhibited the same temporal pattern with predicted weights from 2014 to 2017 being somewhat lower than predicted weights from 2011 to 2013 but predicted weights in 2018 and 2019 being higher than previous years (Figure G6). Based on predicted weights for the reference length categories, it did not appear like condition had declined consistently over the length of the stocking program, although there may have been conditions from 2014 to 2017 that led to Atlantic salmon having slightly lower weights at given lengths. For the 546 mm reference length, predicted weights ranged from about 1.4 to 1.6 kg. For the 600 mm reference length, predicted weights ranged from 1.9 to 2.2 kg. For the 680 mm reference length, predicted weights ranged from 2.9 to 3.3 kg. For the 833 mm reference length, predicted weights ranged from 5.8 to 6.6 kg.

DISCUSSION

Our assessment of the Lake Huron Atlantic salmon population suggested that recent stocking by MDNR and LSSU had established a population of approximately 400,000 age-1 and older fish. Recreational fishing exploitation of the population appeared fairly modest, with recent instantaneous recreational fishing mortality estimated at less than 0.05. This level of fishing is comparable to the recreational fishing mortality rate that has been estimated for Lake Huron Chinook salmon both pre- and post-alewife collapse when correcting for realistic levels of wild recruitment and the likelihood of fish migrating to Lake Michigan (T. Brenden, Michigan State University, unpublished data). One notable difference between the assessment results for Lake Huron Atlantic salmon and Chinook salmon was that the fully-selected age to recreational fishing was age-2 for Atlantic salmon whereas for Chinook salmon older age fish (i.e., age-4 and older) are fully selected. For the Atlantic salmon assessment model, when we assumed older age Atlantic salmon were fully selected to recreational fishing, fit to recreational harvest length composition was poor. Although this selectivity result could be linked to assumptions made as part of development of the SCAA model (e.g., assumptions about natural mortality rates), it could also be linked to the relatively recent expansion of the stocking program and fishery in Lake Huron that is not yet being heavily targeted by recreational anglers.

In developing the Lake Huron Atlantic salmon catch-at-age assessment model, a variety of assumptions were made that potentially influenced model estimates and predictions. These assumptions included aspects related to population structure, sources of harvest, as well as model parameterization. First, we assumed that MDNR and LSSU stocking established a single, mixed-population of Atlantic salmon that was then exploited by recreational anglers. We made this assumption because of the spatial overlap in where stocking occurs (i.e., both MDNR and LSSU stock fish in the St. Mary's River) and because the openwater creel harvest estimates cannot reliably differentiate whether a harvested fish was stocked by MDNR or LSSU. An additional assumption that was made was that recruitment to the population consisted of only stocked individuals. Tucker et al. (2014) collected age-0 Atlantic salmon from the St. Mary's River in 2012, which confirmed that spawning was occurring to some extent in the river, but it is not known with certainty whether wild-produced Atlantic salmon are or have been recruiting to the Lake Huron fishery. If wild recruitment is occurring, estimates of abundance and/or mortality may be affected. Out of necessity, we made an assumption as to the post-stocking survival rate of fish stocked by MDNR and LSSU. As indicated previously, we based the prior probability distribution used for the post-stocking survival rate based on assumed stocking survival for steelhead that have been introduced in the Great Lakes (Rutherford 1997; Tsehaye et al. 2014), as biologically this seemed the most comparable species to Atlantic salmon in Lake Huron based on ecology and life history. Whether this post-stocking survival rate is accurate is unknown. As in the case if wild recruitment is occurring, if post-stocking stocking survival rate is higher than what we assumed, population abundance and/or mortality may be different than what we have reported here. There also is the possibility that post-stocking survival of Atlantic salmon could differ depending on the region where fish are stocked due to environmental differences (e.g., water temperatures) or fish community composition among the regions.

In addition to assumptions about sources of recruitment and mixing of MDNR and LSSU stocked fish, it was also necessary to make assumptions about level of harvest. We were unable to account for harvest of Atlantic salmon in Ontario jurisdictional waters because OMNDMNRF does not regularly conduct creel surveys of recreational anglers in Ontario jurisdictional waters. Some harvest of Atlantic salmon in Ontario jurisdictional waters does occur and is believed to be primarily concentrated in the St. Mary's River with some harvest also likely occurring around tributary outlets (D. Gonder, OMNDMNRF , personal communication). Although the extent of this harvest is not known, our estimates of fishing morality rates may be low because of this unaccounted for harvest source. For Chinook salmon, harvest in Ontario waters of Lake Huron has been estimated to be less than 5% of the harvest occurring in Michigan waters (Brenden et al., 2012), which suggests that not including Ontario harvest in our model may not have a large effect. Additionally, prior to 2019, charter businesses operating in Michigan waters of Lake Huron were not required to report Atlantic salmon harvest. In 2019, a total of 118 Atlantic salmon were reported as being harvested by Lake Huron charter operators, whereas the recreational fishery harvest was estimated at around 6,500 fish. Thus, at least in 2019, charter harvest of Atlantic salmon was approximately 2% of recreational harvest, suggesting that not including charter harvest would only have a small effect on assessment results. We also did not account for tribal harvest of Atlantic salmon because estimates of harvest were not available, although like harvest by charter harvest we expect this harvest to be low relative to recreational harvest.

The other assumption related to harvest that may affect assessment model results is the correction that was made to the openwater recreational creel harvest estimate to account for harvest occurring outside the spatial and temporal boundaries of the survey. From our email survey of 2019 Michigan anglers, we estimated that the openwater creel harvest estimate coincided with approximately 42% of the total harvest. The extent that this may vary over time is unknown. As well, because this estimate depended on an angler's ability to accurately recall when and where harvest occurred during the previous fishing season, the estimate may be inaccurate due to recall bias. Despite the potential inaccuracies associated with the survey results, the finding that less than half of the actual Atlantic salmon harvest might be captured by the openwater creel survey may be cause for concern, particularly if a management decision is made to expand stocking to expand recreational fishing opportunities. The extent of the annual creel surveys is inherently limited by budget constraints, although if a decision is made to expand the recreational fishery for Atlantic salmon as a replacement for the Chinook salmon fishery it may be worthwhile for MDNR to reconsider survey design to more accurately monitor fishing effort and harvest.

With respect to model parameterization, major assumptions that were made were time-invariant, age-specific instantaneous natural mortality rates ranging from 0.1 to 1.0, time-invariant age-specific selectivities, and common selectivities for age-4 to age-7 Atlantic salmon. While in theory estimation of natural mortality rates is feasible in SCAA models, the limited availability of data sources for fitting the Lake Huron assessment model required us to make assumptions about natural mortality rates. We based assumed natural mortality rates on values used for steelhead in other Great Lake model applications because as indicated previously this species is ostensibly the most similar to Atlantic salmon in terms of ecology and life-history. We assumed time-invariant age-specific selectivities because there has been little evidence to suggest that Atlantic salmon growth changed appreciably during the evaluated time period to suggest that particular ages of fish may have become more or less vulnerable to angling. We assumed common selectivities for age-4 to age-7 because of the overall low contribution of older aged Atlantic salmon to the recreational fishery. Assuming common selectivities for older fish is relatively common when constructing assessment models for exploited species (Brenden et al. 2011; Fielder and Bence 2014; Linton and Bence 2011; Syslo et al. 2019). As the stocking program matures and there is a larger buildup of older Atlantic salmon, this assumption perhaps could be relaxed.

Additional model parameterization assumptions that were made concerned our choice to use harvest length composition rather than harvest age composition as a data source and with respect to how we generated the age-length transition matrix. As previously stated, we used harvest length compositions because of concerns about accuracies of ages assigned to fish sampled through the MDNR creel program when fish lengths were plotted against age estimates. We were not able to use CWT recoveries as the basis for calculating harvest age compositions because of small sample sizes and because initiation of the CWT tagging program did not coincide with MDNR's stocking of Atlantic salmon. The newness of the CWT tagging program also limited the development of growth models for the Atlantic salmon population so we had little choice other than to assume a single age-length transition matrix that was applicable for all harvest years. In terms of future assessment of the Atlantic salmon population, we encourage MDNR managers and biologists to revisit procedures used to age Atlantic salmon to ensure accuracy of the age estimates. If aging accuracy continues to be an issue, the CWT tagging program should be maintained so as to allow for development of annually varying age-length transition matrices or alternatively changing to a statistical catch at size assessment framework for ongoing assessment.

Our survey results indicated that catch and release angling for Atlantic salmon is occurring on Lake Huron, suggesting that there may be non-consumptive benefits to the stocking program. When MDNR expanded the Atlantic salmon stocking program, the benchmark for evaluating success of the program was based strictly on the return to creel, perhaps in part because harvest is easy to measure through the creel program. From a management perspective, the non-consumptive value of Atlantic salmon to anglers was not included in the overall evaluation of the stocking program's success, although it may be something to be considered. Given the survey distribution method, it is possible that our estimates of catch and release angling may be biased high due to anglers that are most likely to practice this being overrepresented in our sample due to their being perhaps more interested in conservation and fisheries management and thus more likely to respond to an email survey. Additionally, recall bias for these anglers could lead to overreporting of caught Atlantic salmon given the amount of time between the survey distribution and end of the 2019 fishing season (approximately 7 months). Regardless, enough catch and release angling is present that evaluating the fishery as solely harvest based may ignore nearly 10% of the catch for the fishery, and more research should be conducted to gain a more thorough understanding of how this fishery is used by Michigan anglers.

Another concern raised by management was that there is a potential for salmon identification to be misreported to the openwater creel by anglers. Our survey results showed that less than a quarter of the time our respondents could correctly identify an Atlantic salmon. Part of the low number of correct identifications is likely due to the difficulty of identifying salmon from a photo, and identifying fish in the field is perhaps easier. However, to help in developing this recreational fishery, the MDNR should consider exploring methods to provide identification help to anglers which in turn will facilitate managing the recreational salmon fishery by increasing the accuracy of self-reported harvest to the open-water creel. Given that the Atlantic salmon stocking program is evaluated by the openwater creel returns, the difficulty of identifying Atlantic salmon should be considered as a source of underreporting Atlantic salmon harvest to the openwater creel.

The results from evaluation of Atlantic salmon condition suggest that even though there has been an ostensible buildup in population abundance there is little evidence to suggest that fish condition has declined. If there was evidence of declining fish condition, this could be suggestive of the occurrence of intra- or inter-specific competition for limited prey resources. Across all reference lengths, condition was lower from 2014 to 2017 than it was from 2011 to 2013; however, condition in 2018 and 2019 was greater than in any previous year. From the best-performing model, population-averaged and year-specific estimates of β ranged from 3.360 to 3.378, indicating fish became increasingly rotund as length increased. In comparison, Hendry et al. (2003) reported a β parameter estimate of 2.965 when reporting the length-weight relationship for Atlantic salmon in a second-order stream in a Connecticut watershed (Hendry et al. 2003). Although comparison of length-weight relationships across species can be problematic because of species-specific variation in growth, He et al. (2008) reported β parameter estimates of 2.998 (95% credible intervals: 2.920 – 3.114) and 3.116 (95% credible interval: 3.088 – 3.144) for Lake Huron Chinook salmon and lake trout, respectively, from fish collected from the 1970s to early 2000s and that largely preceded the alewife population collapse. One potential issue with the results from our allometric growth modeling may be the relatively recent expansion of the Atlantic salmon population and the resulting limited number of observations of larger individuals. Nonanadromous Atlantic salmon have been reported to live as long as 14 years (Hutchings et al. 2019). Based on data currently available, we do not have a good understanding of what growth might look like for these older individuals if they indeed are capable of living that long in Lake Huron. This limited age/size range of Atlantic salmon for informing the allometric growth modeling could results in biased estimates of growth model coefficients.

One of the underlying reasons for stocking Atlantic salmon in Lake Huron to expand recreational fishing opportunities was that the species exhibits more generalist feeding and therefore might be more adept at finding prey than a highly specialized piscivore such as Chinook salmon. Based on the results from the allometric growth modeling and condition calculations, it appears that at least so far stocked individuals are finding sufficient resources. An ongoing diet study of predators in Lake Huron has found Atlantic salmon diets to be composed of a combination of rainbow smelt, alewife, invertebrates, round goby, and other prey fish (J. Sawecki, Michigan State University, personal communication). Conversely, Chinook salmon diets continue to be heavily dominated by alewife and to a less extent rainbow smelt (J. Sawecki, Michigan State University, personal communication). Although these results are preliminary, it does suggest that Atlantic salmon are exhibiting the generalist feeding strategy that was expected. Gerig et al. (2019) used stable isotope analysis to examine feeding of Chinook salmon and Atlantic salmon in northern Lake Huron and found that the species occupied similar isotopic niche spaces from similar diets or consumption of prey with similar isotopic values. Atlantic salmon niche overlap was greater for smaller Chinook salmon than it was for larger individuals, although interpretation of results was challenged by the fact that Atlantic salmon were collected from the St. Mary's River whereas Chinook salmon were collected from Lake Huron's northern basin. Niche overlap overall between the species was asymmetric, with Atlantic salmon having a 71% niche overlap with Chinook salmon but Chinook salmon having a 27% niche overlap with Atlantic salmon (Gerig et al. 2019). These one-way overlaps suggest that Atlantic salmon forage on the same prey as Chinook salmon, but Chinook salmon do not forage on all the same prey as Atlantic salmon, which further supports the finding that Atlantic salmon are indeed exhibiting generalist feeding. The ability of Atlantic salmon to take advantage of round goby as a prey resource may be the most encouraging finding from preliminary diet studies of Atlantic salmon as that is one of the few prey fish resources that has exhibited signs of expanding in abundance (Riley et al. 2020).

Management Implications

MDNR expanded Atlantic salmon stocking in Lake Huron to expand fishing opportunities for recreational anglers. Based on the results of this research, past stocking levels have established a population of approximately 400,000 fish that to date has been lightly exploited, which could either be related to catchability of the species or alternatively the amount of effort targeting the species. Areas of uncertainty that make it challenging to quantify the exact size of the population and level of exploitation by anglers is uncertainty associated with post-stocking survival rate and extent of harvest in Ontario jurisdictional waters and by charter and tribal fisheries. Charter operators are now required to report Atlantic salmon harvest so information on that aspect of harvest should gradually improve. Follow-up studies concerning post-stocking survival rates and extent of harvest in Ontario jurisdictional waters and by tribal fishers could lead to future refinements of the SCAA model. Allometric growth modeling and condition assessment suggests that individuals composing the population that has resulted from stocking are finding suitable prey resources, thus there is little reason to suspect that intra- or interspecific competition for food resources might be occurring.

The MDNR established a 2% return-to-creel as a threshold for success at initiation of the stocking program. When based solely on estimated harvest from the MDNR openwater creel survey harvest in relation to the number of stocked individuals, the stocking program to date has not met the threshold for success. However, the results of our email survey suggest that the openwater creel survey may capture less than half of actual Atlantic salmon harvest in Michigan jurisdictional waters. Further, our survey results suggest that catch-and-release angling for Atlantic salmon may be prevalent and that anglers may have difficulty accurately differentiating between various salmon and trout species found in Lake Huron. As a result, we urge caution in basing decisions on whether to continue the stocking program based solely on reported return to creel as this does not appear to be an accurate measure as to the extent that recreational anglers value the fishery. Rather, we believe it would be beneficial to judge the Atlantic salmon stocking program based on both consumptive (harvest angling) and non-consumptive (catch-and-release angling) recreational fishing opportunities provided by the program perhaps supplemented with information as to the relative degree that anglers value fishing for different salmon and trout species. Obstacles to adopting this as a metric include the ability to accurately quantify both consumptive and non-consumptive angling harvest, which is complicated by several issues identified herein (i.e., biased harvest estimates from the creel survey, angler's ability to accurately identify between salmon and trout species in Lake Huron, the exact prevalence of catch and release angling) but which potentially could be addressed through modifications to MDNR creel survey design and questions. Based on an economic valuation of salmonid fisheries in Lake Huron (Chapter 1 of this thesis), Chinook salmon, Atlantic salmon, and steelhead are similarly valued by recreational anglers. Of these species, the potential to expand recreational fishing opportunities on Lake Huron is likely limited to either Atlantic salmon or steelhead. Future recreational fishing opportunities for Chinook salmon will likely be limited unless there is a resurgence of the alewife population. Conversely, Atlantic salmon and/or steelhead are likely better suited ecologically to the current fish community of Lake Huron given there more generalist feeding. Given the low exploitation rates that we estimated for Atlantic salmon and the difficulty that anglers had in identifying Atlantic salmon from other salmon and trout species in the lake, it may be worthwhile for management agencies to both promote Atlantic salmon fishing opportunities in Lake Huron and to enact some education opportunities concerning where and when anglers can target Atlantic salmon and how to distinguish them from other species.

APPENDICES

APPENDIX A

Chapter 1 Tables

Table A1. List of 87 valid sites and their aggregated groupings. The latitude and longitude used for modeling efforts were based on a single site within a group. The site used to represent each group geographically is in bold.

Group	Site	Trips
1	Bay Field, Ontario	2
1	**Grand Bend Ont**	5
1	Kettle Point Ont.	20
1	Kincardine Ont.	3
1	Port Franks Ont	5
2	Algonac, MI	5
2	Marine City, MI	6
2	**St. Clair River, MI**	21
2	St Clair, MI	18
3	Point Edwards, ONT	2
3	**Port Huron, MI**	232
3	St. Clair River, Marysville MI	1
4	Lakeport, MI	5
4	Lexington Harbor, MI	418
4	**Port Sanilac, MI**	628
5	Forestville, MI	2
5	**Harbor Beach, MI**	209
5	Port Hope, MI	32
6	**Grind Stone City, MI**	232
6	Port Austin, MI	176
7	Bay Port, MI	6
7	**Caseville, MI**	50
7	Fishing Ports in the thumb, NA	6
7	Pigeon River, MI	13
7	Pigeon, MI	2
7	Streams around thumb of MI	3
8	Bay City, MI	12
8	Essexville, MI	1
8	Linwood, MI	6
8	Pinconning, MI	1
8	Saginaw Bay, MI	26
8	**Saginaw River, MI**	3
8	Saginaw, MI	1
9	**Au Gres, MI**	117
9	Omer, MI	26
9	Rifle River, MI	34

Table A1 (Cont'd)

9	Rifle River, Sterling MI	3
9	Standish, MI	11
9	Sterling, MI	5
9	Twining, MI	3
10	National City, MI	3
10	Rifle River, Skidway Lake MI	4
10	**Rifle River, West Branch MI**	48
10	Rose City, MI	11
10	Selkirk, MI	33
10	West Branch, MI	35
10	Whittemore, MI	14.5
11	East Tawas City, MI	109
11	**Tawas City, MI**	230
12	Foote Site Village, Oscoda, MI	50
12	**Oscoda, MI**	2567.5
13	Black River, MI	18
13	Greenbush, MI	2
13	**Harrisville, MI**	190
14	**Alpena, MI**	321
14	Ossineke, MI	1
14	Rockport, MI	53
14	Thunder Bay River, MI	1
15	**Presque Isle Harbor, MI**	297
15	Thompsons Harbor, MI	9
16	Calcite, MI	2
16	**Rogers City, MI**	457
16	Swan River, MI	3
17	**Hammond Bay Harbor, MI**	64
17	Ocqueoc River, MI	18
18	Bois Blanc Island, MI	1
18	**Cheboygan, MI**	759
19	Mackinac Island, MI	1
19	**Mackinaw City, MI**	68
19	McKinley Township	1
20	Carp River, MI	2
20	Pine River, Mackinaw County MI	1
20	**St Ignace, MI**	89
21	Cedarville, MI	36
21	**Hessel, MI**	78
21	Les Cheneaux Islands, Cedarville MI	18
21	Nunns Creek, Ponchatrain Shores MI	1
21	Port Dolomite, MI	1

Table A1 (Cont'd)

22	**Detour Village, MI**	281
22	Drummond Island, MI	59
23	Pickford, MI	1
23	Soo, MI	8
23	**St Mary's River, MI**	15
24	Sault Rapids, Sault Ste Marie MI	1
24	**Sault Ste. Marie, MI**	173
24	Sugar Island, MI	13

Table A2. The 24 aggregate sites and the total number of trips taken to each site used in our model.

Site ID	Site	Trips
1	Grand Bend Ont	5
2	St Clair River, MI	21
3	Port Huron, MI	232
4	Port Sanilac, MI	628
5	Harbor Beach, MI	209
6	Grind Stone City, MI	232
7	Caseville, MI	50
8	Saginaw River, MI	3
9	Au Gres, MI	117
10	Rifle River, West Branch MI	48
11	Tawas City, MI	230
12	Oscoda, MI	2567.5
13	Harrisville, MI	190
14	Alpena, MI	321
15	Presque Isle Harbor, MI	297
16	Rogers City, MI	457
17	Hammond Bay Harbor, MI	64
18	Cheboygan, MI	759
19	Mackinaw City, MI	68
20	St. Ignace, MI	89
21	Hessel, MI	78
22	Detour Village, MI	281
23	St Mary's River, MI	15
24	Sault Ste. Marie, MI	173

Table A3. Average catch rates of Lake Huron salmon per 100 hours fishing presented to anglers in the Lake Huron Salmon Fisheries Survey.

	Catch Rates				
Species	Minimum	Low	Average	High	Maximum
Atlantic salmon	0.3	0.5	1.0	2.0	4.0
Chinook salmon	1.5	1.7	2.2	3.2	5.2
Coho salmon	0.1	0.3	0.8	1.9	3.9
Lake trout	10.5	12.9	15.4	17.1	18.9
Steelhead/Rainbow trout	0.9	1.1	1.6	2.6	4.7

Table A4. Parameter estimates and 95% confidence intervals from the RUM-consistent nested logit regression. Model estimation results were computed using travel cost per person and specific data on vehicle types and towing and the 2019 AAA cost data by type.

Parameter	Estimate	SE	z	P>|z|	95% CI
Travel Cost (per person)	-0.0037	0.002	-2.25	0.025	[-0.0068, -0.00046]
College Education	0.156	0.134	1.17	0.242	[-0.106, 0.418]
Age	-0.0026	0.005	-0.54	0.587	[-0.012, 0.007]
Income	-3.81E-06	1.50E-06	-2.54	0.011	[-0.0000068, -0.00000087]
tau (dissimilarity)	0.162	0.056			[0.053, 0.271]

‘=

Table A5. Fixed effects for each site in the model and the “don’t go” option. Alternate specific constants (ASC) that are closer to 0 are considered better in the absence of price.

Site	ASC	SE	z	P>|z|	CI
No trip (baseline)	0				
Grand Bend Ont	-3.59	0.38	-9.45	<0.001	[-4.33, -2.84]
St Clair River, MI	-3.54	0.39	-9.09	<0.001	[-4.30, -2.78]
Port Huron, MI	-3.31	0.33	-9.90	<0.001	[-3.96, -2.65]
Port Sanilac, MI	-2.97	0.29	-10.07	<0.001	[-3.55, -2.39]
Harbor Beach, MI	-3.08	0.31	-10.09	<0.001	[-3.68, -2.48]
Grind Stone City, MI	-2.95	0.30	-9.82	<0.001	[-3.55, -2.37]
Caseville, MI	-3.30	0.33	-10.01	<0.001	[-3.95, -2.65]
Saginaw River, MI	-3.48	0.37	-9.50	<0.001	[-4.19, -2.76]
Au Gres, MI	-3.19	0.31	-10.13	<0.001	[-3.81, -2.57]
West Branch Rifle River, MI	-3.16	0.32	-9.85	<0.001	[-3.79, -2.53]
Tawas City, MI	-2.99	0.30	-10.01	<0.001	[-3.58, -2.41]
Oscoda, MI	-2.80	0.30	-9.32	<0.001	[-3.39, -2.21]
Harrisville, MI	-2.94	0.30	-9.69	<0.001	[-3.54, -2.35]
Alpena, MI	-2.81	0.30	-9.30	<0.001	[-3.40, -2.22]
Presque Isle Harbor, MI	-2.83	0.31	-9.22	<0.001	[-3.43, -2.22]
Rogers City, MI	-2.82	0.30	-9.40	<0.001	[-3.40, -2.23]
Hammond Bay Harbor, MI	-3.08	0.31	-9.93	<0.001	[-3.69, -2.48]
Cheboygan, MI	-2.82	0.32	-8.90	<0.001	[-3.45, -2.20]
Mackinaw City, MI	-3.08	0.32	-9.54	<0.001	[-3.71, -2.45]
St Ignace, MI	-3.05	0.31	-9.99	<0.001	[-3.65, -2.45]
Hessel, MI	-2.91	0.31	-9.54	<0.001	[-3.51, -2.32]
Detour Village, MI	-2.71	0.31	-8.70	<0.001	[-3.32, -2.10]
St Mary's River, MI	-3.14	0.32	-9.84	<0.001	[-3.76, -2.51]
Sault Ste Marie, MI	-2.85	0.31	-9.17	<0.001	[-3.46, -2.24]

Table A6. Results of the linear regression analysis of the contingent behavior data. The percent change in total trips taken to Lake Huron for the purpose of catching salmon given a change in catch rate of 1 fish per 100 hours. ATS = Atlantic salmon; CHS = Chinook salmon; COS = Coho salmon; LAT = Lake Trout; RBT = Steelhead/Rainbow Trout.

Species	Estimate	SE	t	P>|t|	CI
CHS	13.86	1.50	9.26	<0.001	[10.92, 16.8]
COS	4.49	1.07	4.19	<0.001	[2.39, 6.6]
RBT	8.55	1.50	5.7	<0.001	[5.6, 11.5]
ATS	13.24	1.68	7.88	<0.001	[9.94, 16.54]
LAT	0.31	0.53	0.59	0.557	[-0.74, 1.36]

Table A7. Implied value (USD) of each Lake Huron Salmon. Generated by increasing each catch rate by 1.0 fish per 100 hours for a single species at a time and using a contraction map to compute change in angler utility that generates the same change of trips as the implied change in trips from the contingent behavior scenarios.

Species	Value (USD)
CHS	$38.67
COS	$12.34
RBT	$24.40
ATS	$37.04
LAT	$0.82

APPENDIX B

Chapter 1 Figures

Figure B1. Plot of the 24 sites around Lake Huron used in our model.

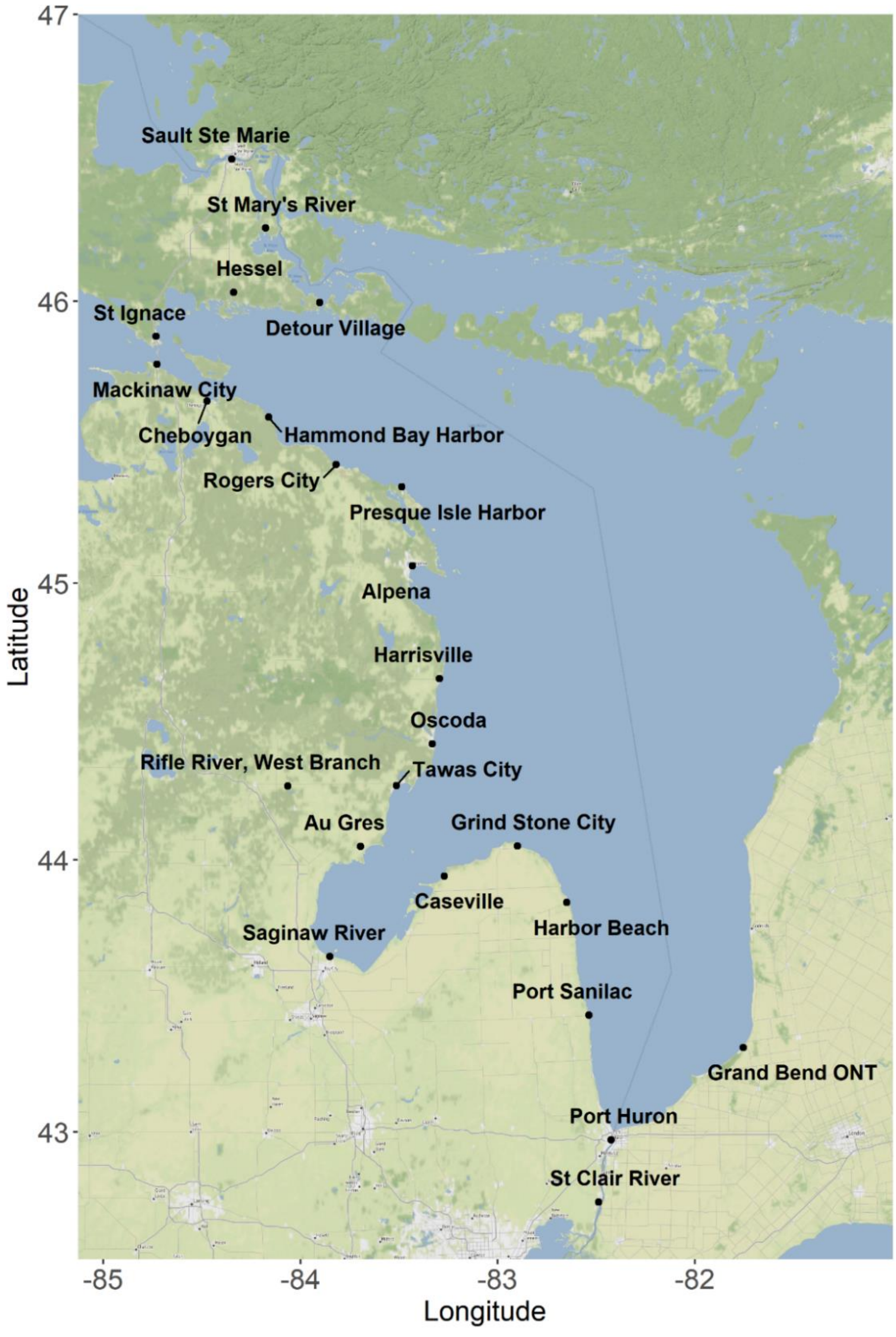


Figure B2. Survey response from Lake Huron Salmon fisheries survey. The Likert-scale question asked, For each of the following salmonid species, please indicate your agreement/disagreement to the following statement. "When fishing in the Great Lakes or its tributaries, I like to catch ...". (ATS = Atlantic salmon; BRT = Brown trout; CHK = Chinook salmon; COH = Coho Salmon, LKT = lake trout; RBT = Steelhead/rainbow trout).

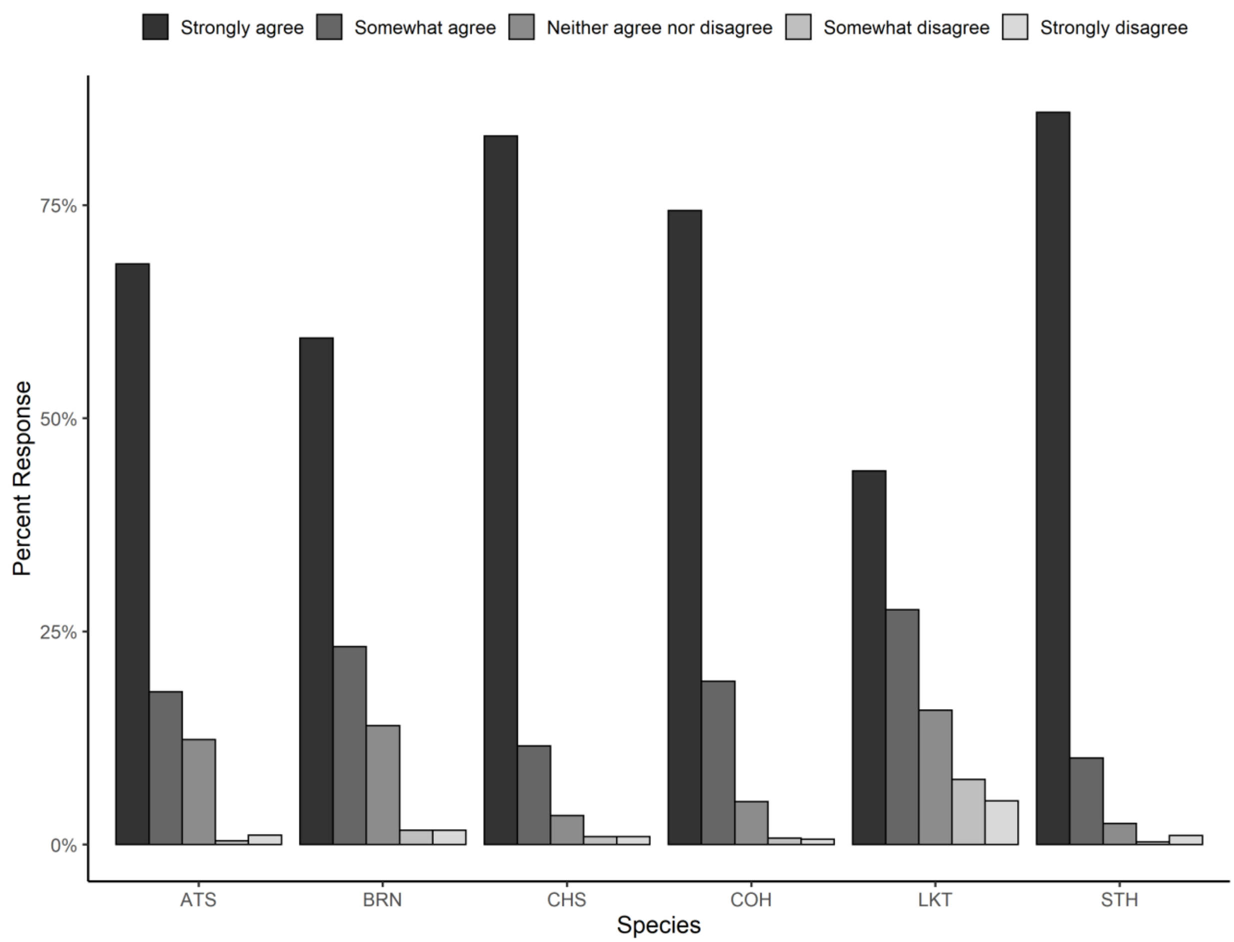
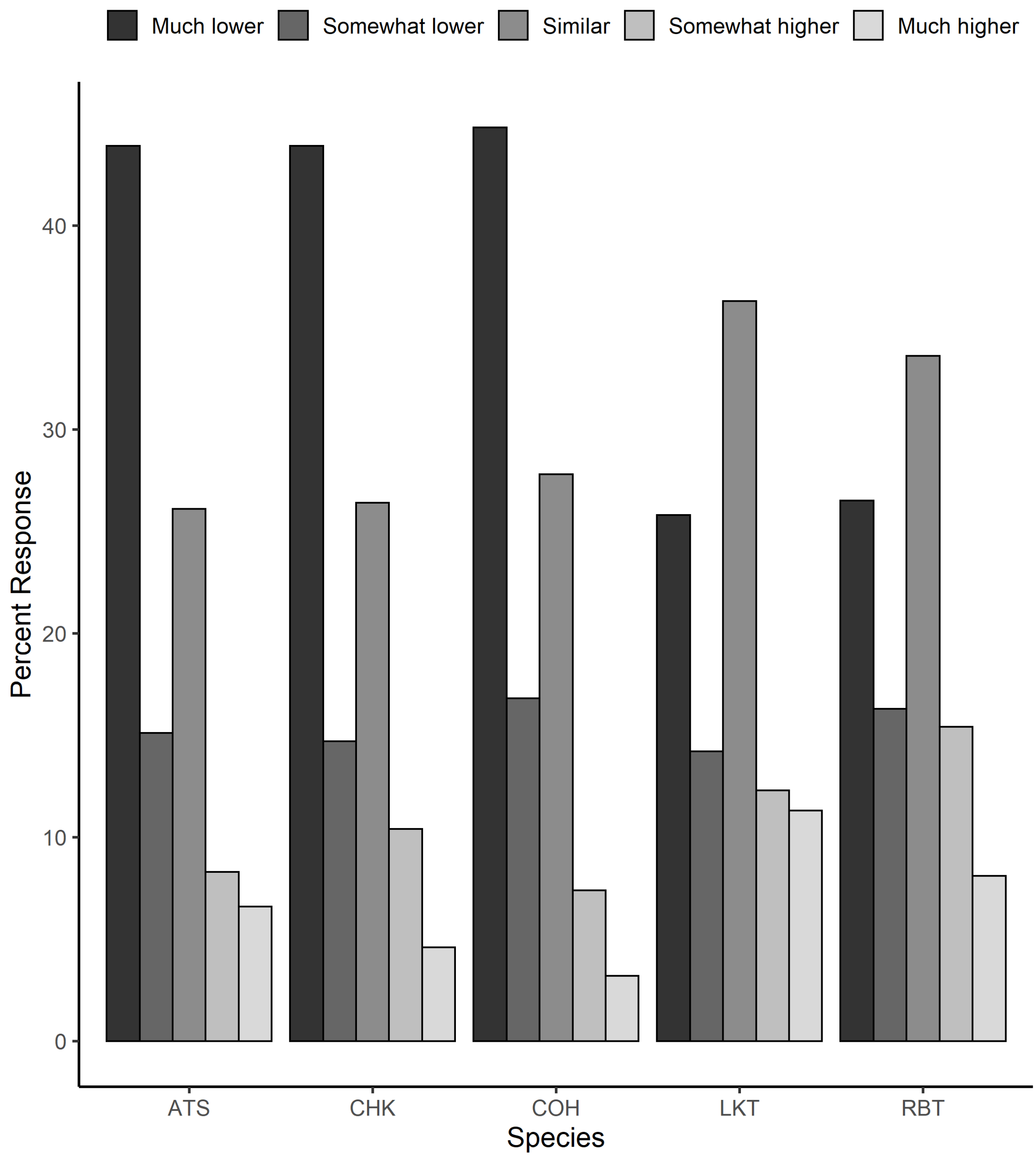


Figure B3. Survey response from the Lake Huron Salmon Fisheries Survey. Anglers were asked whether or not their catch rates were similar, lower, or higher compared to the 5 year average catch rates presented for each salmon or trout. (ATS = Atlantic salmon; CHK = Chinook salmon; COH = Coho Salmon, LKT = lake trout; RBT = Steelhead/rainbow trout).



APPENDIX C

Lake Huron Salmon Fisheries Survey Instrument

The survey below was emailed to Michigan anglers who bought a 2019 Michigan angling license online. Only respondents who indicated they were over 18 years of age were asked to take the survey.

Figure C1. Lake Huron Salmon Fisheries Survey

MICHIGAN STATE UNIVERSITY

Welcome to the Lake Huron salmon fisheries survey

You are being asked to participate in a research survey on fishing in Lake Huron and its tributaries. You must be at least 18 years old to participate. The survey asks questions about your Lake Huron fishing activities and takes about 15 minutes to complete.

Your responses will help Michigan DNR better understand angler preferences and salmon catch/harvest so it can make decisions aimed at improving the Lake Huron fishery.

Participation is voluntary and your responses are confidential. You have the right to say no. You may choose not to answer specific questions or to stop participating at any time.

You indicate your voluntary agreement to participate by beginning this survey.

I consent to survey

Questions or concerns:

If you have concerns or questions about this survey, such as scientific issues, how to do any part of it, or to report an injury, please contact the researcher: Matt Zink, Michigan State University, Quantitative Fisheries Center, East Lansing, MI 48824, zinkmat1@msu.edu, (651) 328-4483.

If you have questions or concerns about your role and rights as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact, anonymously if you wish, the Michigan State University's Human Research Protection Program at 517-355-2180, Fax 517-432-4503, or e-mail irb@msu.edu or regular mail at 207 Olds Hall, MSU, East Lansing, MI 48824.

Figure C1 (Cont'd)

Questions or concerns:

If you have concerns or questions about this survey, such as scientific issues, how to do any part of it, or to report an injury, please contact the researcher: Matt Zink, Michigan State University, Quantitative Fisheries Center, East Lansing, MI 48824, zinkmat1@msu.edu, (651) 328-4483.

If you have questions or concerns about your role and rights as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact, anonymously if you wish, the Michigan State University's Human Research Protection Program at 517-355-2180, Fax 517-432-4503, or e-mail irb@msu.edu or regular mail at 207 Olds Hall, MSU, East Lansing, MI 48824.

→

MICHIGAN STATE UNIVERSITY

Contact Information | Privacy Statement | Site Accessibility
Call MSU: (517) 355-1855 | Visit: msu.edu
MSU is an affirmative-action, equal-opportunity employer. |
Notice of Nondiscrimination
SPARTANS WILL. | © Michigan State University

Figure C1 (Cont'd)

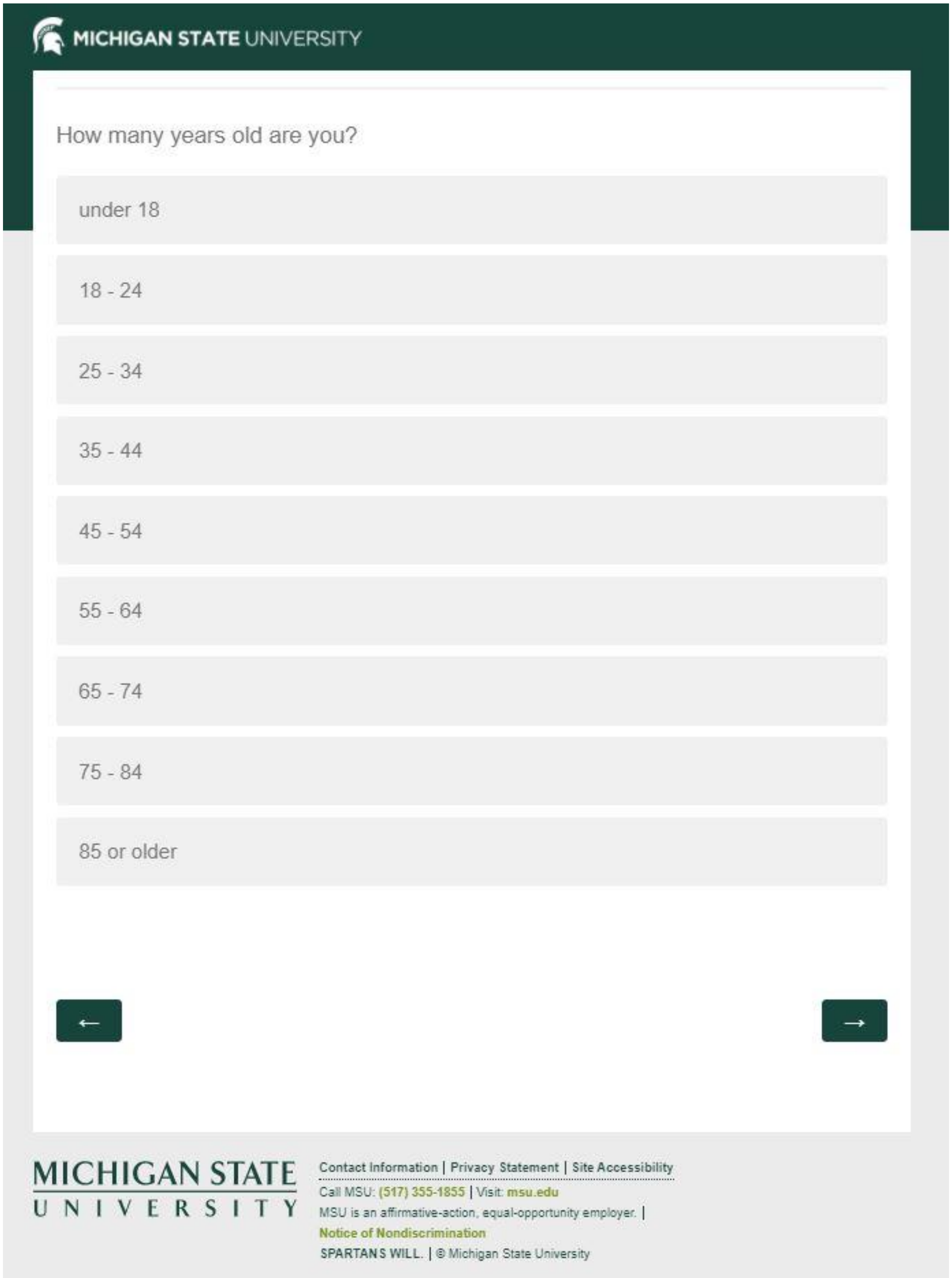
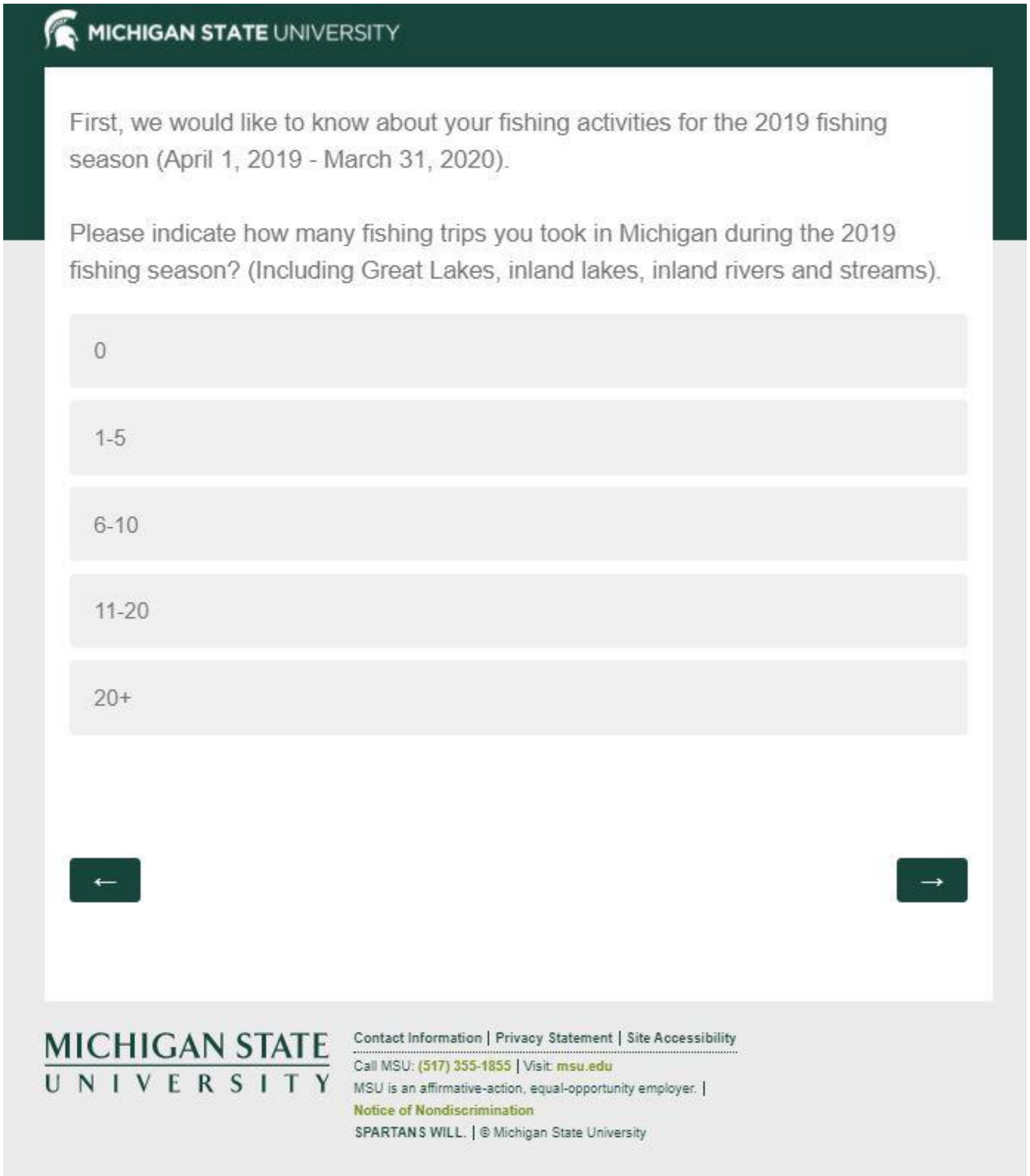


Figure C1 (Cont'd)



MICHIGAN STATE UNIVERSITY

First, we would like to know about your fishing activities for the 2019 fishing season (April 1, 2019 - March 31, 2020).

Please indicate how many fishing trips you took in Michigan during the 2019 fishing season? (Including Great Lakes, inland lakes, inland rivers and streams).

0

1-5

6-10

11-20

20+

←

→

MICHIGAN STATE UNIVERSITY

Contact Information | Privacy Statement | Site Accessibility

Call MSU: (517) 355-1855 | Visit: msu.edu

MSU is an affirmative-action, equal-opportunity employer. |

Notice of Nondiscrimination

SPARTANS WILL. | © Michigan State University

Figure C1 (Cont'd)

MICHIGAN STATE UNIVERSITY

Which, if any, of these trout or salmon did you target and/or catch during the 2019 fishing season (April 1, 2019 - March 31, 2020)? Please select all that apply.

	Caught in 2019	**Targeted** in 2019
Salmonids		
Atlantic salmon	☐	☐
Brown trout	☐	☐
Chinook salmon	☐	☐
Coho salmon	☐	☐
Lake trout	☐	☐
Steelhead/Rainbow trout	☐	☐
Other salmonid ______	☐	☐
None of the above	☐	☐

← →

MICHIGAN STATE UNIVERSITY

Contact Information | Privacy Statement | Site Accessibility

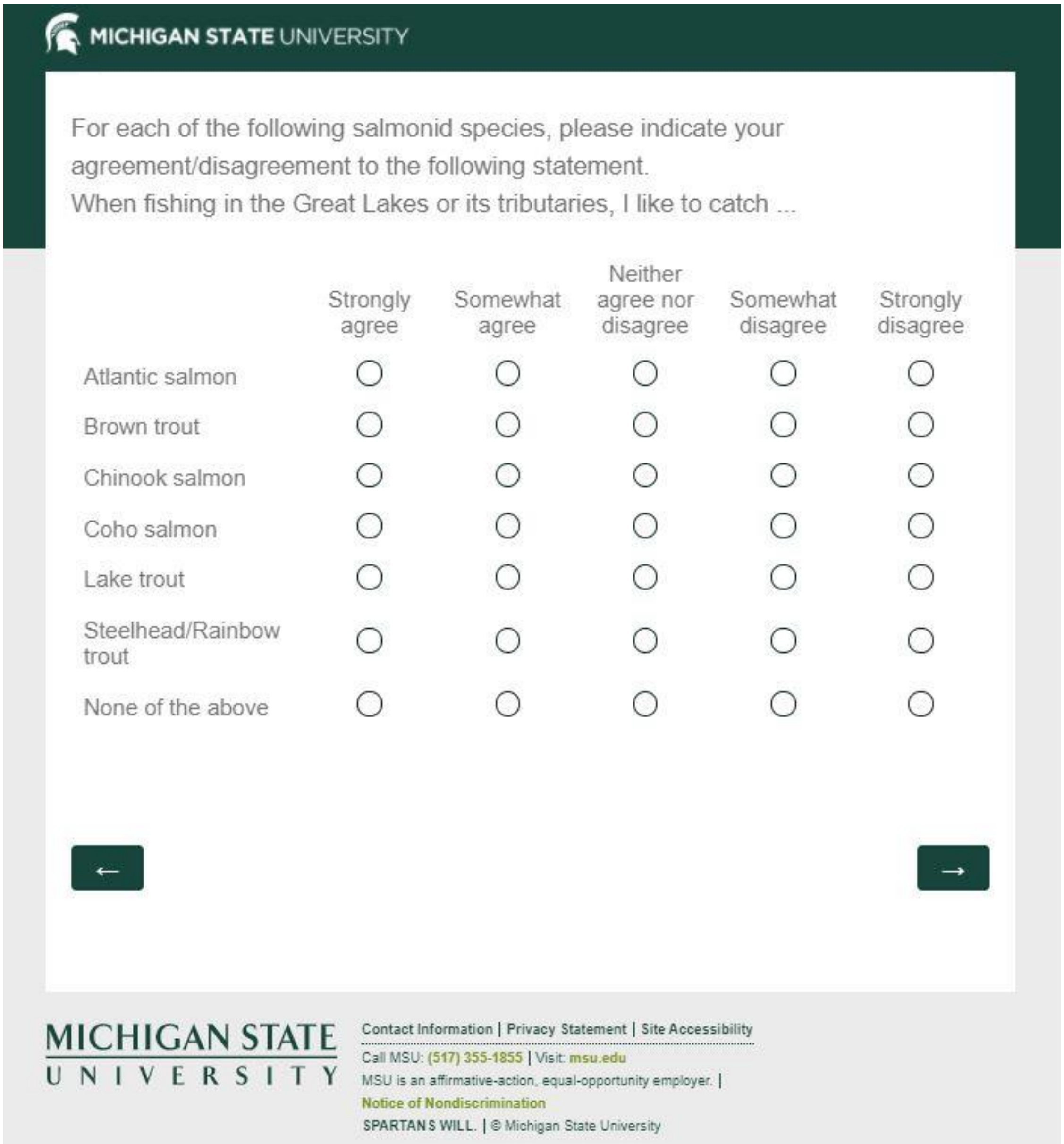
Call MSU: (517) 355-1855 | Visit: msu.edu

MSU is an affirmative-action, equal-opportunity employer. |

Notice of Nondiscrimination

SPARTANS WILL. | © Michigan State University

Figure C1 (Cont'd)



MICHIGAN STATE UNIVERSITY

For each of the following salmonid species, please indicate your agreement/disagreement to the following statement.
When fishing in the Great Lakes or its tributaries, I like to catch ...

	Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree
Atlantic salmon	○	○	○	○	○
Brown trout	○	○	○	○	○
Chinook salmon	○	○	○	○	○
Coho salmon	○	○	○	○	○
Lake trout	○	○	○	○	○
Steelhead/Rainbow trout	○	○	○	○	○
None of the above	○	○	○	○	○

← →

MICHIGAN STATE UNIVERSITY

Contact Information | Privacy Statement | Site Accessibility
Call MSU: (517) 355-1855 | Visit: msu.edu
MSU is an affirmative-action, equal-opportunity employer. |
Notice of Nondiscrimination
SPARTANS WILL. | © Michigan State University

Figure C1 (Cont'd)

MICHIGAN STATE UNIVERSITY

Fishing for salmon on Lake Huron or its tributaries

Key information for this part of the survey:

In this part of the survey, when we ask about fishing for **"salmon"** we mean fishing for any of the following:

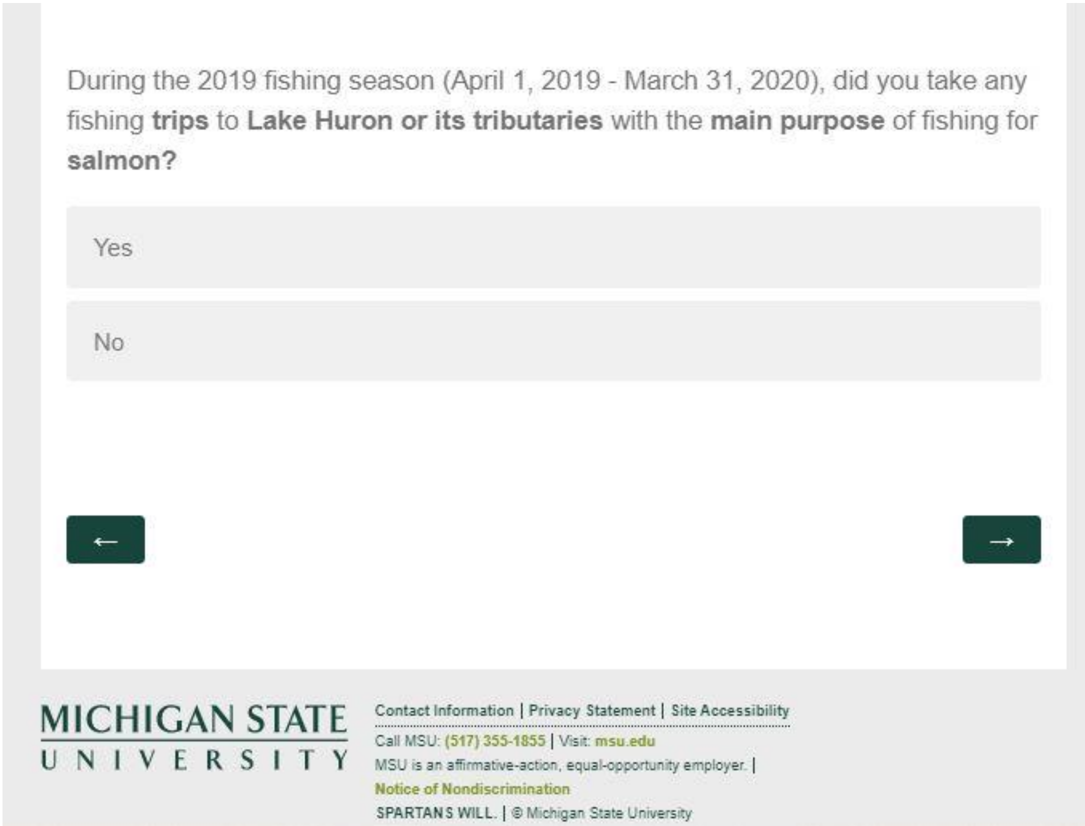
- Atlantic salmon
- Brown trout
- Chinook salmon
- Coho salmon
- Lake trout
- Steelhead/Rainbow trout

When we refer to **Lake Huron or its tributaries** we mean:

- Lake Huron (all ports, bays and open water)
- Tributaries (streams or rivers that flow directly into Lake Huron [e.g., Au Sable River, Thunder Bay River])
- St. Mary's River

Main purpose: In this section we are interested in fishing trips where the "main purpose" was fishing for salmon on Lake Huron or its tributaries. By "main purpose", we mean that the primary reason for taking the trip was to go fishing rather than some other reason for the trip such as visiting relatives or attending a wedding.

Figure C1 (Cont'd)


During the 2019 fishing season (April 1, 2019 - March 31, 2020), did you take any fishing **trips** to **Lake Huron or its tributaries** with the **main purpose** of fishing for **salmon?**

Yes

No

←

→

MICHIGAN STATE UNIVERSITY

Contact Information | Privacy Statement | Site Accessibility

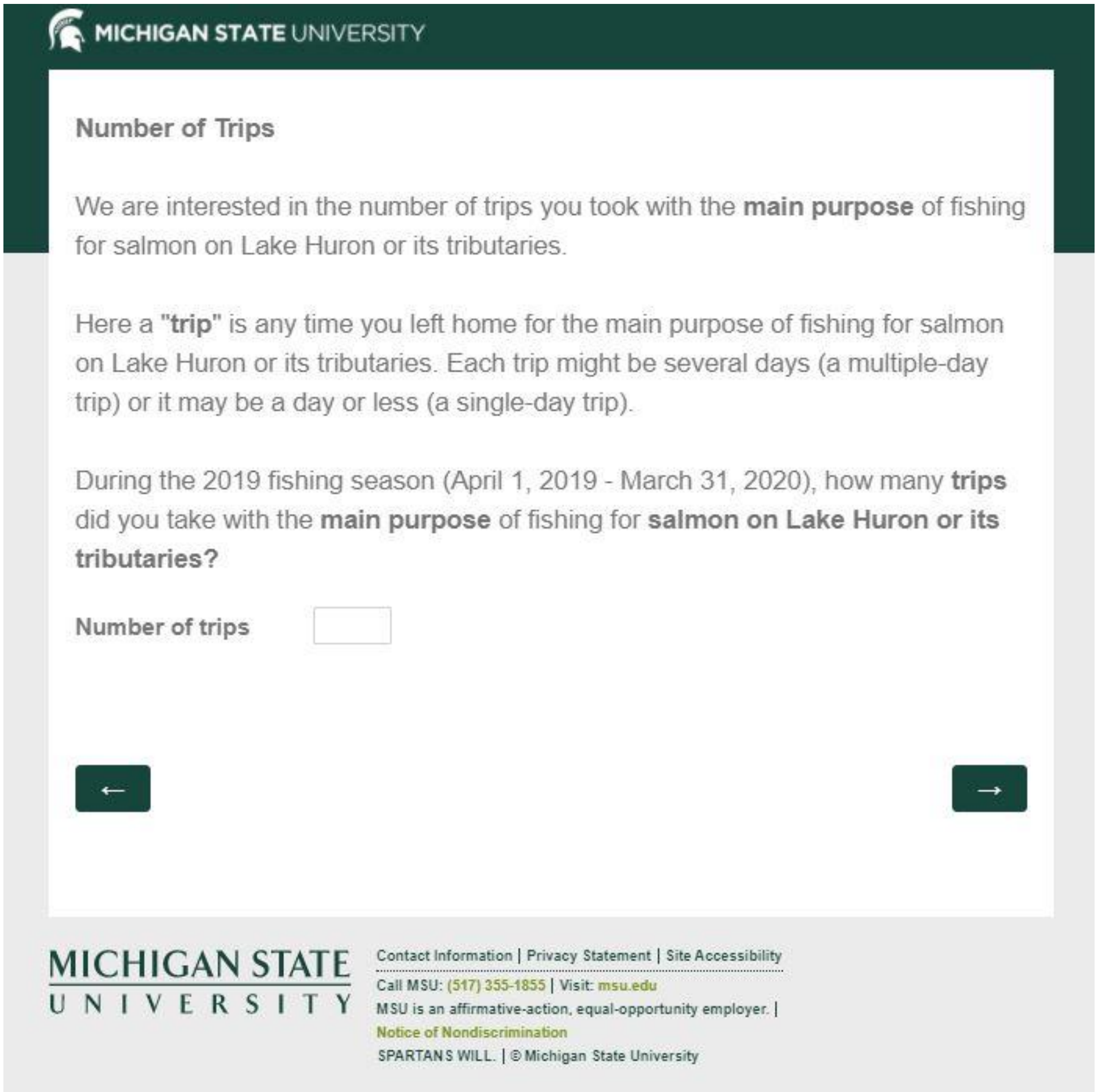
Call MSU: (517) 355-1855 | Visit: msu.edu

MSU is an affirmative-action, equal-opportunity employer. |

Notice of Nondiscrimination

SPARTANS WILL. | © Michigan State University

Figure C1 (Cont'd)



MICHIGAN STATE UNIVERSITY

Number of Trips

We are interested in the number of trips you took with the **main purpose** of fishing for salmon on Lake Huron or its tributaries.

Here a **"trip"** is any time you left home for the main purpose of fishing for salmon on Lake Huron or its tributaries. Each trip might be several days (a multiple-day trip) or it may be a day or less (a single-day trip).

During the 2019 fishing season (April 1, 2019 - March 31, 2020), how many **trips** did you take with the **main purpose** of fishing for **salmon on Lake Huron or its tributaries?**

Number of trips

← →

MICHIGAN STATE UNIVERSITY

Contact Information | Privacy Statement | Site Accessibility
Call MSU: (517) 355-1855 | Visit: msu.edu
MSU is an affirmative-action, equal-opportunity employer. |
Notice of Nondiscrimination
SPARTANS WILL. | © Michigan State University

Figure C1 (Cont'd)

MICHIGAN STATE UNIVERSITY

On your 5 trips fishing for salmon during the 2019 fishing season (April 1, 2019 - March 31, 2020) on Lake Huron or its tributaries, did you always go to the same place to fish?

Yes, I always went to the same place

No, I went to more than one place

← →

MICHIGAN STATE UNIVERSITY

Contact Information | Privacy Statement | Site Accessibility
Call MSU: (517) 355-1855 | Visit: msu.edu
MSU is an affirmative-action, equal-opportunity employer. |
Notice of Nondiscrimination
SPARTANS WILL. | © Michigan State University

MICHIGAN STATE UNIVERSITY

Lake Huron salmon fishing places visited during 2019 fishing season

This question asks about the places you visited on your salmon fishing trips to Lake Huron or its tributaries during the 2019 fishing season (April 1, 2019 - March 31, 2020).

Sometimes people visit more than one site on a trip. For example, if someone launched their boat at two different locations during one trip from home and back, that would be more than one place visited on that trip. If you had any trips where you visited more than one place on that trip, please think about the place where you spent the most time on that trip.

Figure C1 (Cont'd)

What are the **names** and **nearest cities** of the places you went salmon fishing on Lake Huron or its tributaries during the 2019 fishing season?
<u>(If unsure, any brief description will help.) (If you went to fewer places than are shown in the table, leave the extra rows blank.)</u>

	Place Name (Or some description, e.g. city marina)	**Nearest City** (Or some description, e.g. south of Alpena)
Most visited		
2nd most visited		
3rd most visited		
4th most visited		
5th most visited		

← →

MICHIGAN STATE UNIVERSITY

Contact Information | Privacy Statement | Site Accessibility
Call MSU: (517) 355-1855 | Visit: msu.edu
MSU is an affirmative-action, equal-opportunity employer. |
Notice of Nondiscrimination
SPARTANS WILL. | © Michigan State University

Figure C1 (Cont'd)

MICHIGAN STATE UNIVERSITY

This question asks about two kinds of salmon fishing trips.

- Single-day trips: this includes trips were you left your home and spent any part of a day salmon fishing, but you returned home that day or night (i.e., you were not away from home overnight).

Example: Bob left home on 4 separate occasions to fish in Alpena and at the end of each day when Bob was done fishing he returned home. Bob had **4** single-day trips.

- Multiple-day trips: this includes trips where you spent at least one night away from home and salmon fishing was the main purpose of your trip.

Example: Bob left home and spent three days in Alpena and then returned home. Bob did not take any other trips. Bob had **1** multiple-day trip.

Figure C1 (Cont'd)

During the 2019 fishing season (April 1, 2019 - March 31, 2020), how many of your salmon fishing trips to Lake Huron or its tributaries were single-day trips and how many were multiple-day trips?

	Number of Trips that were **Single-Day**	Number of Trips that were **Multiple-Day**
Lexington Harbor, near Lexington	0	0
Thunder Bay Shores Marina, near Alpena	0	0
Au Sable River, near Au Sable	0	0
Drummond Island, near Drummond	0	0
St. Mary's River, near Sault Ste. Marie	0	0
All other places visited	0	0
Total	0	0

← →

MICHIGAN STATE UNIVERSITY

Contact Information | Privacy Statement | Site Accessibility
Call MSU: (517) 355-1855 | Visit: msu.edu
MSU is an affirmative-action, equal-opportunity employer. |
Notice of Nondiscrimination

Figure C1 (Cont'd)

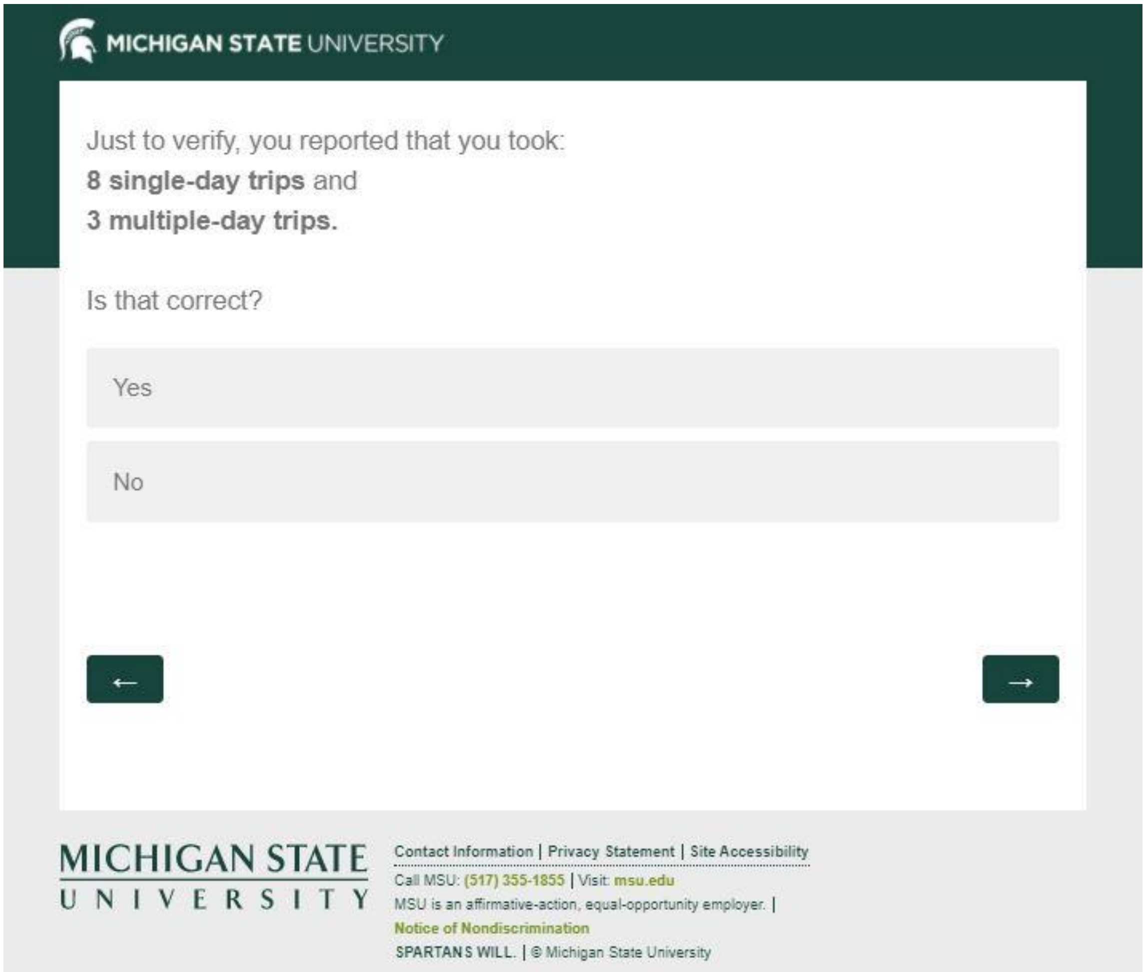


Figure C1 (Cont'd)

MICHIGAN STATE UNIVERSITY

Typical trip questions

The following questions are about a **typical trip** fishing for salmon on Lake Huron or its tributaries. By "typical trip" we mean what you did most often on your trips fishing for salmon on Lake Huron or its tributaries during the 2019 fishing season (April 1, 2019 - March 31, 2020).

On a **typical trip** fishing for salmon on Lake Huron or its tributaries, what type of vehicle did you use?

- Small car
- Medium car
- Large car
- Small SUV
- Medium SUV
- Minivan
- Pick-up truck or large SUV
- Hybrid car
- Electric car
- Other:

Figure C1 (Cont'd)

On a **typical trip** fishing for salmon on Lake Huron or its tributaries, how many people traveled in the **same vehicle** with you?

Myself	1
People 18 years of age or older	0
People younger than 18 years of age	0
Total	1

14. On a **typical trip** fishing for salmon on Lake Huron or its tributaries, did you usually fish from a boat?

Yes

No

← →

MICHIGAN STATE UNIVERSITY

Contact Information | Privacy Statement | Site Accessibility

Call MSU: (517) 355-1855 | Visit: msu.edu

MSU is an affirmative-action, equal-opportunity employer. |

Notice of Nondiscrimination

SPARTANS WILL. | © Michigan State University

Figure C1 (Cont'd)

14. On a **typical trip** fishing for salmon on Lake Huron or its tributaries, did you usually fish from a boat?

Yes

No

Was the boat you fished from during a **typical trip** kept at the place you fished at, trailered, or carried on or in the vehicle?

Kept at the place I fished at

Trailered

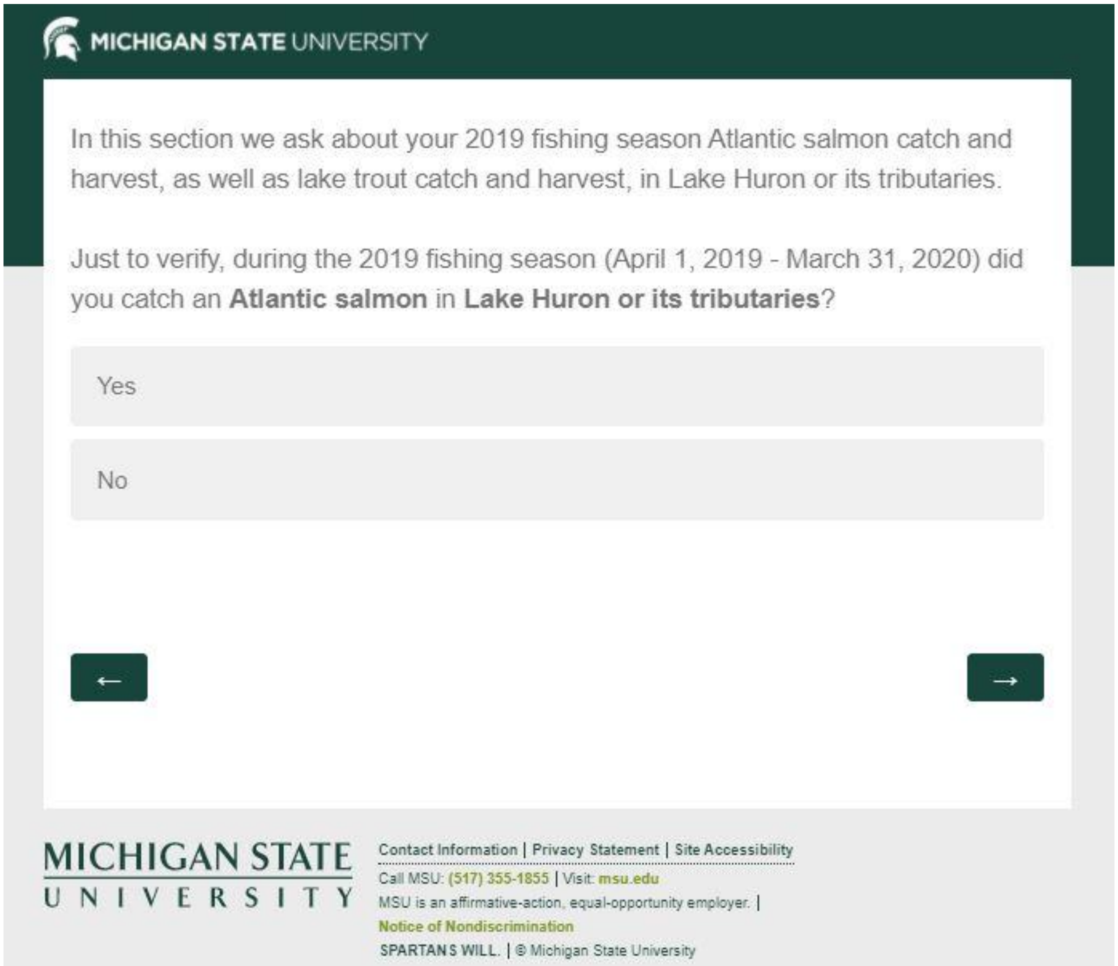
Carried on or in the vehicle

← →

MICHIGAN STATE UNIVERSITY

Contact Information | Privacy Statement | Site Accessibility
Call MSU: (517) 355-1855 | Visit: msu.edu
MSU is an affirmative-action, equal-opportunity employer. |
Notice of Nondiscrimination
SPARTANS WILL. | © Michigan State University

Figure C1 (Cont'd)


MICHIGAN STATE UNIVERSITY

In this section we ask about your 2019 fishing season Atlantic salmon catch and harvest, as well as lake trout catch and harvest, in Lake Huron or its tributaries.

Just to verify, during the 2019 fishing season (April 1, 2019 - March 31, 2020) did you catch an **Atlantic salmon** in **Lake Huron or its tributaries**?

Yes

No

←

→

MICHIGAN STATE UNIVERSITY

Contact Information | Privacy Statement | Site Accessibility

Call MSU: (517) 355-1855 | Visit: msu.edu

MSU is an affirmative-action, equal-opportunity employer. |

Notice of Nondiscrimination

SPARTANS WILL. | © Michigan State University

Figure C1 (Cont'd)

MICHIGAN STATE UNIVERSITY

Of the **Atlantic salmon** that you **harvested** (i.e., caught and kept to eat or mount) during the 2019 fishing season (April 1, 2019 - March 31, 2020), to the best of your recollection please indicate how many of those fish were harvested in the areas and seasons identified below (e.g. Lake Huron - Open water during April to October).

	Number Harvested April-October, 2019	Number Harvested November-December 2019	Number Harvested January-March, 2020	Total
Lake Huron - Open water, bays, harbors, shore, piers	0	0	0	0
Lake Huron - Tributary (e.g., Au Sable River)	0	0	0	0
St. Mary's River	0	0	0	0
Huron-Erie Corridor (Detroit River, Lake St. Clair, St. Clair River	0	0	0	0
Other Great Lake	0	0	0	0
Other, please specify	0	0	0	0

← →

MICHIGAN STATE UNIVERSITY

Contact Information | Privacy Statement | Site Accessibility

Call MSU: (517) 355-1855 | Visit: msu.edu

MSU is an affirmative-action, equal-opportunity employer. |

Notice of Nondiscrimination

Figure C1 (Cont'd)

MICHIGAN STATE UNIVERSITY

Of the 10 **Atlantic salmon** that you **harvested** on Lake Huron, please indicate how these 10 fish were harvested by the modes and seasons identified below (e.g. Lake Huron - personal or rental boat during April to October). Note that the number harvested does NOT include harvest from Lake Huron tributaries, the St. Mary's River, or the Huron-Erie corridor.

	10 fish harvested during April-October, 2019	0 fish harvested during November-December, 2019	0 fish harvested during January-March, 2020	Total
Lake Huron - Shore	0	0	0	0
Lake Huron - Pier, jetty, bridge, or dock	0	0	0	0
Lake Huron - Charter boat	0	0	0	0
Lake Huron - Personal or rental boat	0	0	0	0
Other, location and mode	0	0	0	0

← →

MICHIGAN STATE UNIVERSITY

Contact Information | Privacy Statement | Site Accessibility

Call MSU: (517) 355-1855 | Visit: msu.edu

MSU is an affirmative-action, equal-opportunity employer. |

Notice of Nondiscrimination

SPARTANS WILL. | © Michigan State University

Figure C1 (Cont'd)

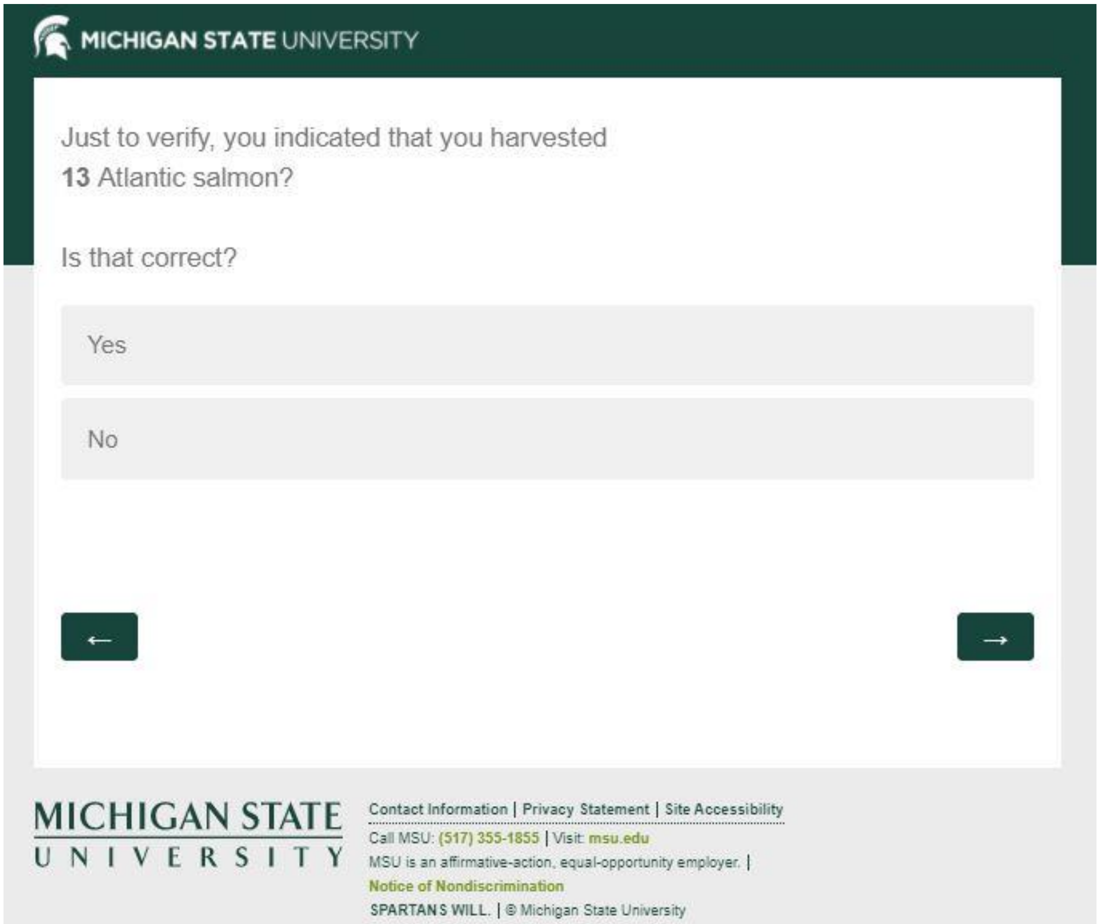


Figure C1 (Cont'd)

MICHIGAN STATE UNIVERSITY

Of the **Atlantic salmon** that you **caught and released** (i.e., returned the fish to the water) in the 2019 fishing season (April 1, 2019 - March 31, 2020), to the best of your recollection please indicate how many of those fish were caught and released in the areas and seasons identified below (e.g. Lake Huron - Open water during April to October).

	Number caught and released April-October, 2019	Number caught and released November-December, 2019	Number caught and released January-March, 2020	Total
Lake Huron - Open water, bays, harbors, shore, piers	0	0	0	0
Lake Huron - Tributary (e.g., Au Sable River)	0	0	0	0
St. Mary's River	0	0	0	0
Huron-Erie Corridor (Detroit River, Lake St. Clair, St. Clair River)	0	0	0	0
Other Great Lake	0	0	0	0
Other, please specify	0	0	0	0

← →

MICHIGAN STATE UNIVERSITY

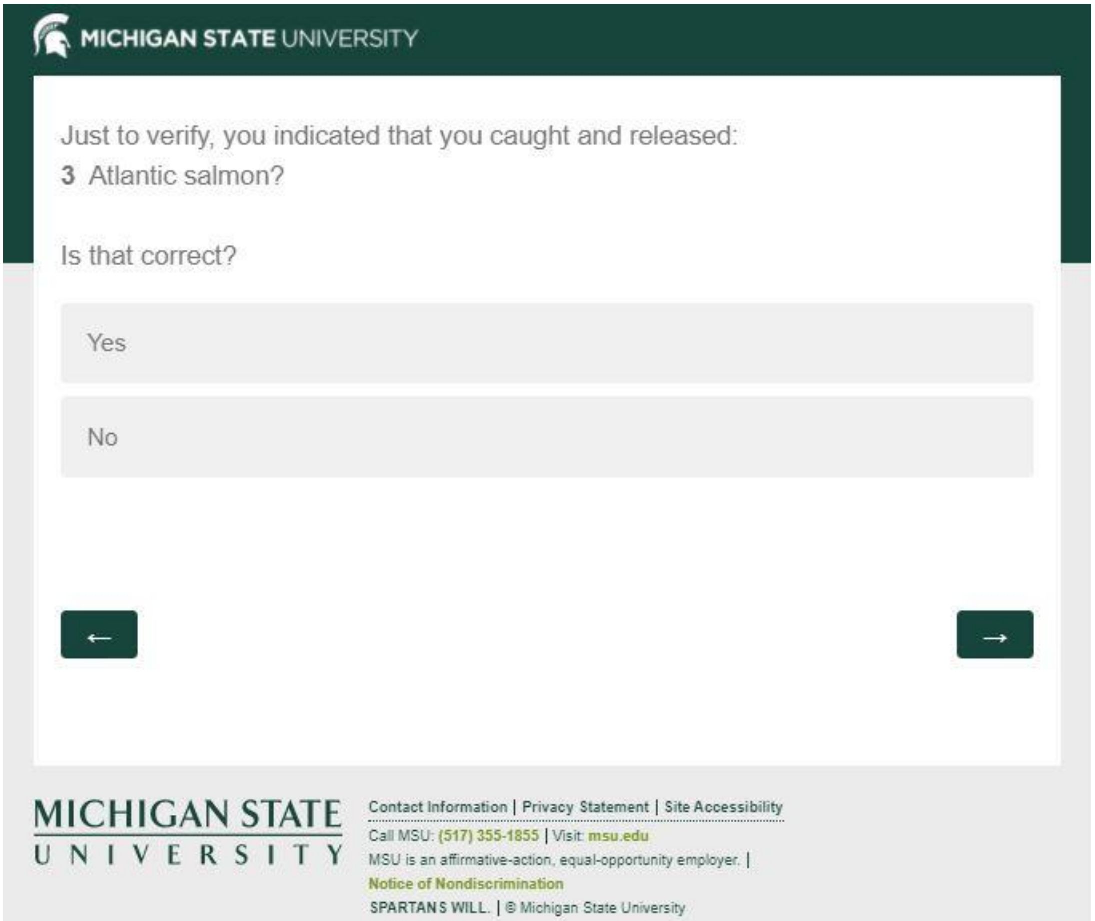
Contact Information | Privacy Statement | Site Accessibility

Call MSU: (517) 355-1855 | Visit: msu.edu

MSU is an affirmative-action, equal-opportunity employer. |

Notice of Nondiscrimination

Figure C1 (Cont'd)



MICHIGAN STATE UNIVERSITY

Just to verify, you indicated that you caught and released:
3 Atlantic salmon?

Is that correct?

Yes

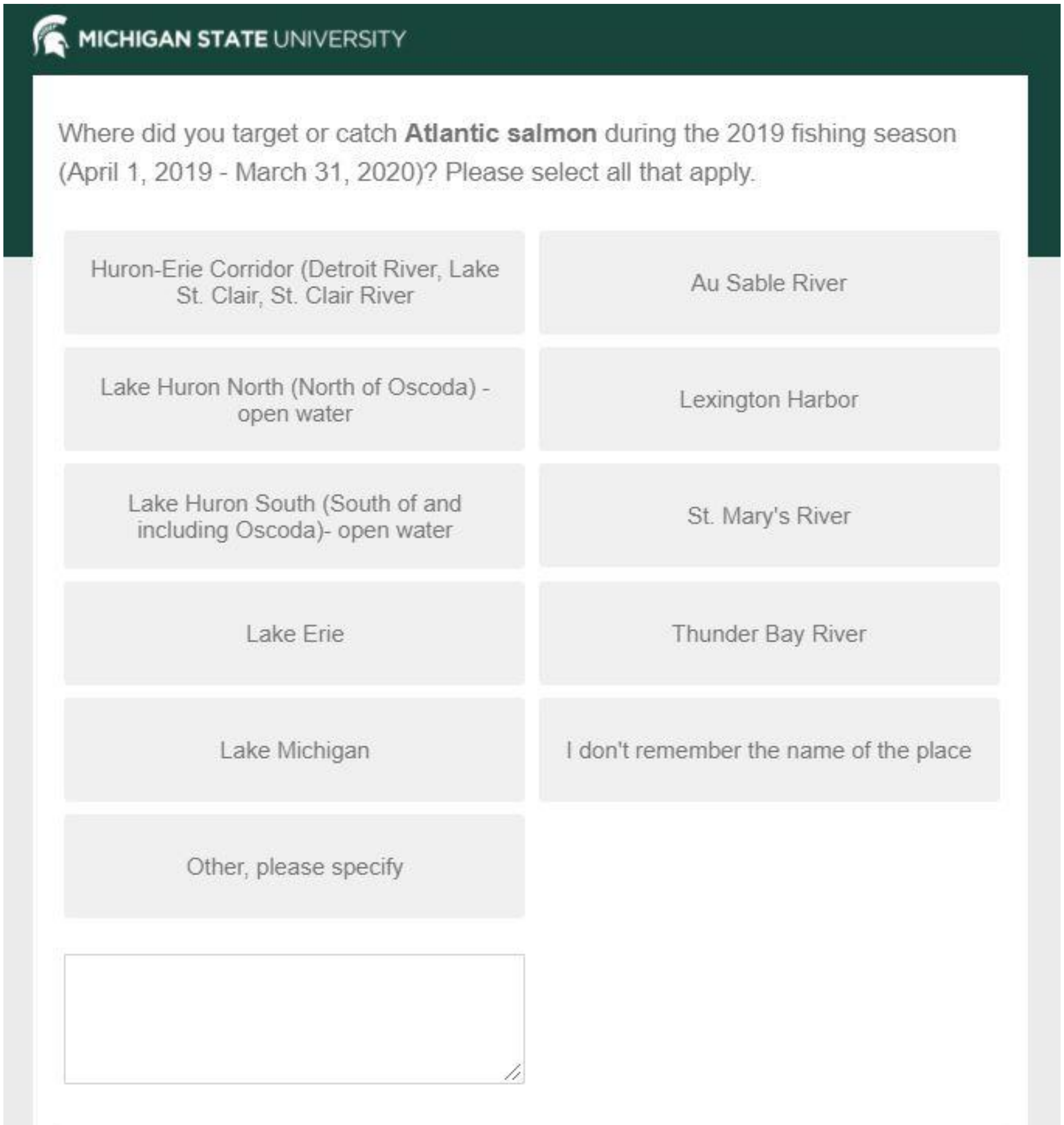
No

← →

MICHIGAN STATE UNIVERSITY

Contact Information | Privacy Statement | Site Accessibility
Call MSU: (517) 355-1855 | Visit: msu.edu
MSU is an affirmative-action, equal-opportunity employer. |
Notice of Nondiscrimination
SPARTANS WILL. | © Michigan State University

Figure C1 (Cont'd)

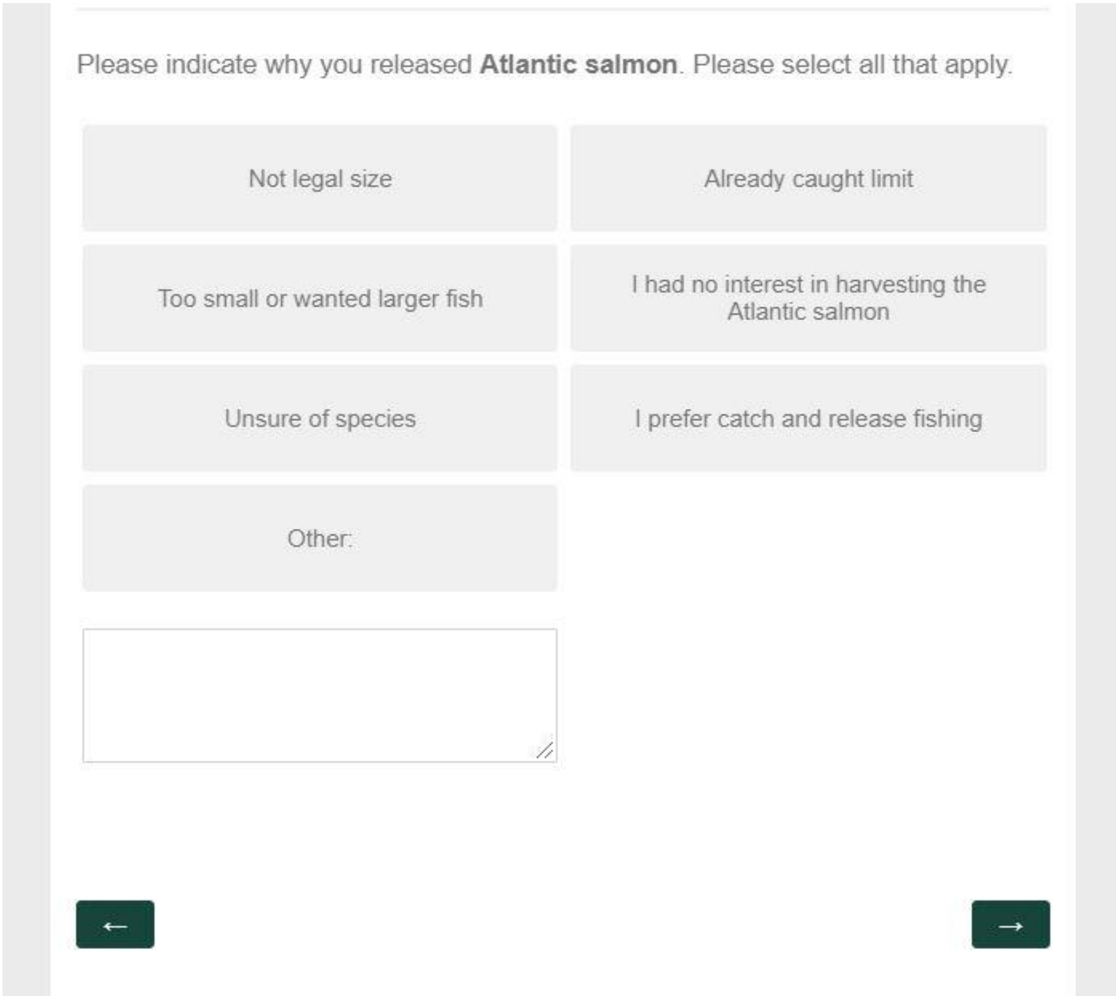


MICHIGAN STATE UNIVERSITY

Where did you target or catch **Atlantic salmon** during the 2019 fishing season (April 1, 2019 - March 31, 2020)? Please select all that apply.

Huron-Erie Corridor (Detroit River, Lake St. Clair, St. Clair River	Au Sable River
Lake Huron North (North of Oscoda) - open water	Lexington Harbor
Lake Huron South (South of and including Oscoda)- open water	St. Mary's River
Lake Erie	Thunder Bay River
Lake Michigan	I don't remember the name of the place
Other, please specify	

Figure C1 (Cont'd)



Please indicate why you released **Atlantic salmon**. Please select all that apply.

Not legal size

Already caught limit

Too small or wanted larger fish

I had no interest in harvesting the Atlantic salmon

Unsure of species

I prefer catch and release fishing

Other:

←

→

Figure C1 (Cont'd)

MICHIGAN STATE UNIVERSITY

For this question, to the best of your recollection how many days did you spend fishing for **any salmon** in Lake Huron and its tributaries during the 2019 fishing season (April 1, 2019 - March 31, 2020)? About how many hours did you fish on average for the days you fished during the 2019 fishing season?

As a reminder, **salmon** include: Atlantic salmon, Brown trout, Coho salmon, Chinook salmon, Lake Trout, and Steelhead/Rainbow trout.

	Average number of hours fished per day	**Total days fished:** April-October, 2019	**Total days fished:** November-December, 2019	**Total days fished:** January-March, 2020
Shore	0	0	0	0
Pier, jetty, bridge, or dock	0	0	0	0
Charter boat	0	0	0	0
Personal or rental boat	0	0	0	0

← →

MICHIGAN STATE UNIVERSITY

Contact Information | Privacy Statement | Site Accessibility

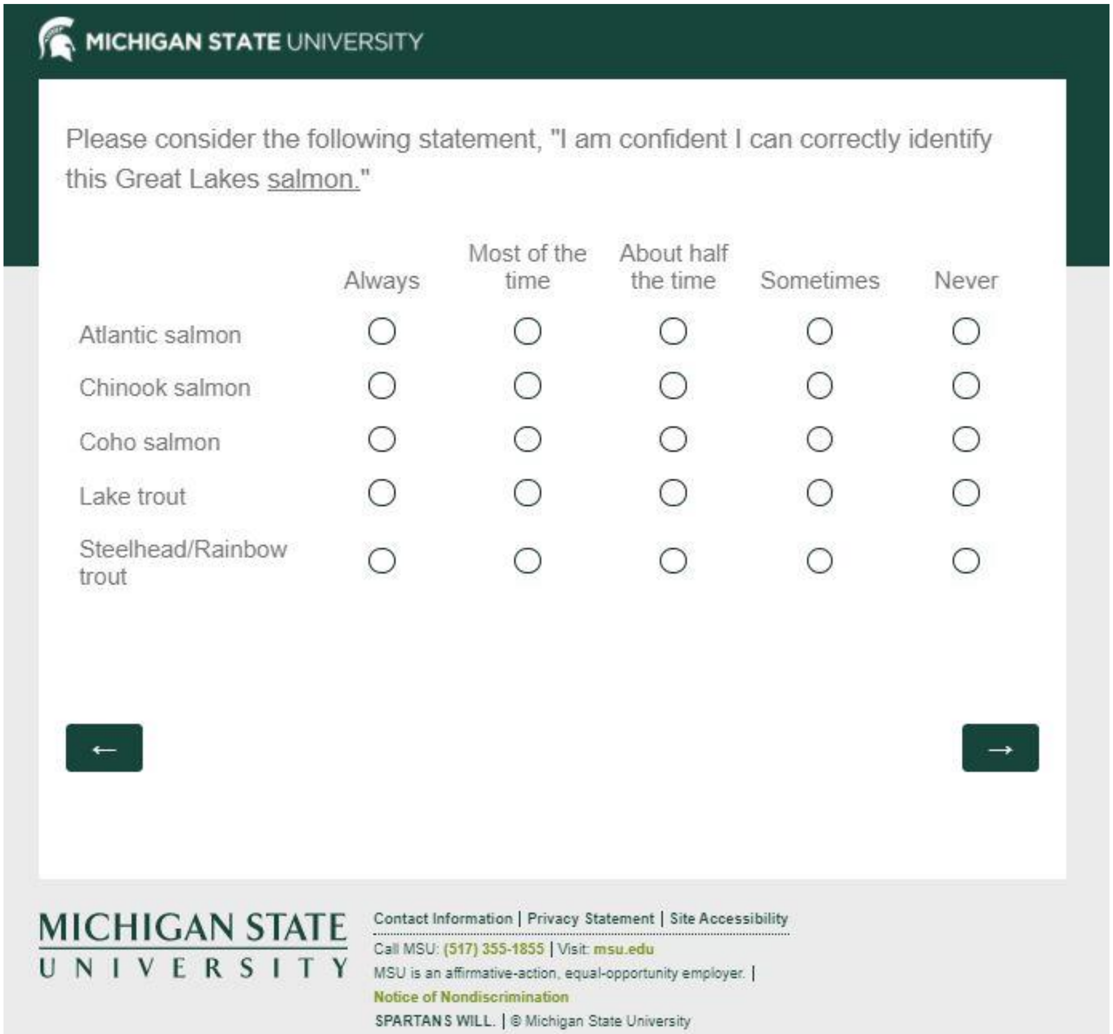
Call MSU: (517) 355-1855 | Visit: msu.edu

MSU is an affirmative-action, equal-opportunity employer. |

Notice of Nondiscrimination

SPARTANS WILL. | © Michigan State University

Figure C1 (Cont'd)



MICHIGAN STATE UNIVERSITY

Please consider the following statement, "I am confident I can correctly identify this Great Lakes salmon."

	Always	Most of the time	About half the time	Sometimes	Never
Atlantic salmon	○	○	○	○	○
Chinook salmon	○	○	○	○	○
Coho salmon	○	○	○	○	○
Lake trout	○	○	○	○	○
Steelhead/Rainbow trout	○	○	○	○	○

← →

MICHIGAN STATE UNIVERSITY

Contact Information | Privacy Statement | Site Accessibility

Call MSU: (517) 355-1855 | Visit: msu.edu

MSU is an affirmative-action, equal-opportunity employer. |

Notice of Nondiscrimination

SPARTANS WILL. | © Michigan State University

Figure C1 (Cont'd)

MICHIGAN STATE UNIVERSITY

Please identify this fish. Choose from the list below.

- Atlantic salmon
- Brook trout
- Brown trout
- Chinook salmon
- Coho salmon
- Lake trout
- Steelhead/Rainbow trout
- Walleye
- Cannot tell from picture
- Unsure

← →

MICHIGAN STATE UNIVERSITY

Contact Information | Privacy Statement | Site Accessibility

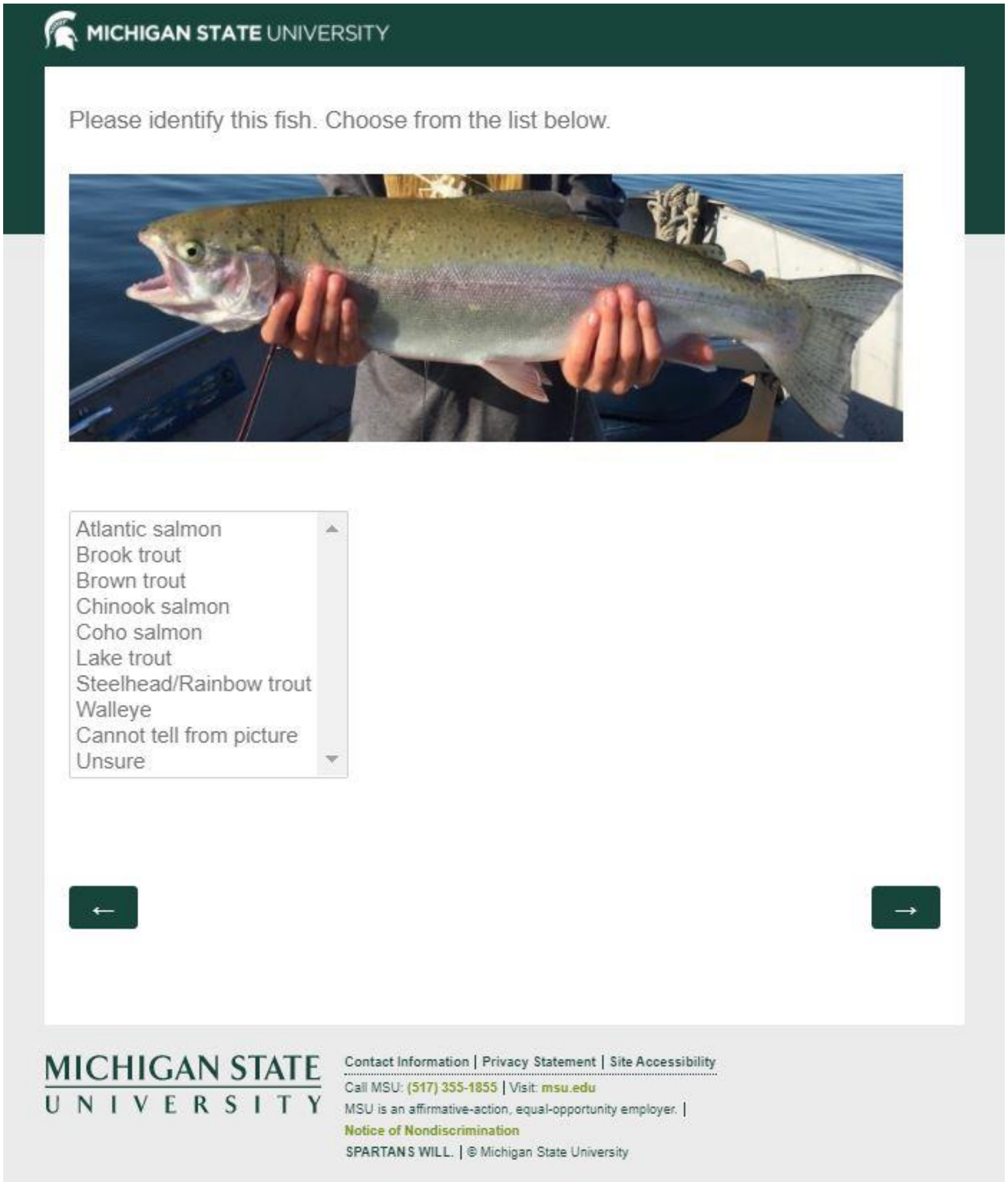
Call MSU: (517) 355-1855 | Visit: msu.edu

MSU is an affirmative-action, equal-opportunity employer. |

Notice of Nondiscrimination

SPARTANS WILL. | © Michigan State University

Figure C1 (Cont'd)



MICHIGAN STATE UNIVERSITY

Please identify this fish. Choose from the list below.

Atlantic salmon
Brook trout
Brown trout
Chinook salmon
Coho salmon
Lake trout
Steelhead/Rainbow trout
Walleye
Cannot tell from picture
Unsure

← →

MICHIGAN STATE UNIVERSITY

Contact Information | Privacy Statement | Site Accessibility
Call MSU: (517) 355-1855 | Visit: msu.edu
MSU is an affirmative-action, equal-opportunity employer. |
Notice of Nondiscrimination
SPARTANS WILL. | © Michigan State University

Figure C1 (Cont'd)

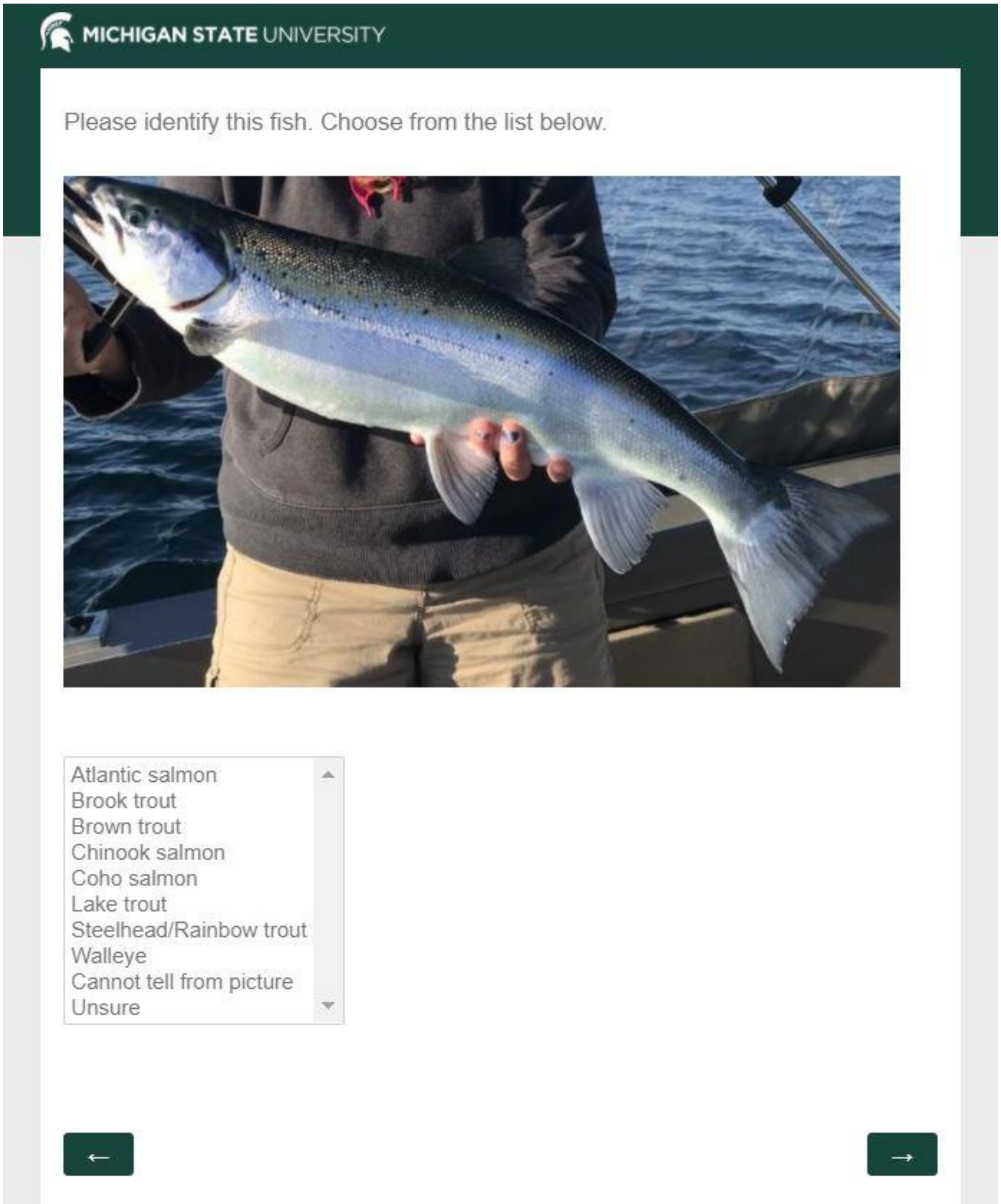


Figure C1 (Cont'd)

MICHIGAN STATE UNIVERSITY

Please identify this fish. Choose from the list below.

Atlantic salmon
Brook trout
Brown trout
Chinook salmon
Coho salmon
Lake trout
Steelhead/Rainbow trout
Walleye
Cannot tell from picture
Unsure

← →

MICHIGAN STATE UNIVERSITY

Contact Information | Privacy Statement | Site Accessibility
Call MSU: (517) 355-1855 | Visit: msu.edu
MSU is an affirmative-action, equal-opportunity employer. |

Figure C1 (Cont'd)

MICHIGAN STATE UNIVERSITY

In this section of the survey we present Michigan DNR open-water creel data for the Lake Huron salmonid fishery. Additionally, we ask about your preference for alternative futures of the Lake Huron salmonid fishery.

Presented in this table are the **5-year average catch rates** in Lake Huron for 5 salmonid species. The presented catch rate is the **number of fish caught per 100 hours of fishing effort**.

Species	5-year (2014-2019) average catch rate (fish caught per 100 hours of fishing)
Atlantic salmon	1.0
Chinook salmon	2.2
Coho salmon	0.8
Lake trout	15.4
Steelhead	1.6

For example, the 5-year average catch rate for Atlantic salmon is 1.0 fish caught per 100 hours of fishing effort whereas the average catch rate for Chinook salmon is 2.2 fish caught per 100 hours of fishing effort.

Figure C1 (Cont'd)

When fishing Lake Huron or its tributaries for one or more of the above salmonids, are your catch rates similar, lower, or higher than the 5-year average(s) for the species you targeted?

	Much lower	Somewhat lower	Similar	Somewhat higher	Much higher	Didn't target this species
Atlantic salmon	○	○	○	○	○	○
Chinook salmon	○	○	○	○	○	○
Coho salmon	○	○	○	○	○	○
Lake trout	○	○	○	○	○	○
Steelhead/Rainbow trout	○	○	○	○	○	○

← →

Figure C1 (Cont'd)

MICHIGAN STATE UNIVERSITY

Average Catch Rates

Fishery conditions can vary over time due to many factors (e.g., weather conditions, status of the population). Even though there is variation, fishery conditions can be described by the average number of fish recreational anglers catch over a time period (catch rates).

For your convenience and use in these next questions, here again are the catch rates for recreational anglers targeting salmonids in the open waters of Lake Huron:

Species	5-year (2014-2019) average catch rate (fish caught per 100 hours of fishing)
Atlantic salmon	1.0
Chinook salmon	2.2
Coho salmon	0.8
Lake trout	15.4
Steelhead	1.6

Reminder of Trips in 2019

You mentioned earlier that you took 5 trips to Lake Huron or its tributaries fishing for salmonids in 2019. These 5 trips occurred under the average catch rates shown above.

Figure C1 (Cont'd)

A Different Scenario

Please consider the following scenario for how conditions could be different compared to average conditions. The scenario is characterized by differences in catch rates to the 5-year average catch rates by species. The scenario does not represent planned management actions or known outcomes. Instead the scenario represents one of many possible outcomes that managers seek to understand how angler behavior might change under different conditions. We are interested in knowing whether this alternative scenario would lead you to take the same number of trips, fewer trips, or more trips. If you would take fewer or more trips, we would like to know how many fewer or more trips would you take.

Species	2014-2019 Avg.	Scenario 1
Atlantic salmon	1.0	0.3
Chinook salmon	2.2	3.2
Coho salmon	0.8	1.9
Lake trout	15.4	12.9
Steelhead	1.6	4.7

Suppose that Scenario 1 described the fishery instead of the average catch rate between 2014 and 2019 when you took 5 trips.

1. How many trips would you take to Lake Huron or its tributaries to fish for salmonids under scenario 1?

Trips under scenario 1

→

Figure C1 (Cont'd)

MICHIGAN STATE UNIVERSITY

Scenario 2 of 5

Now consider another scenario for how conditions might be different than the 2014-2019 average.

Species	2014-2019 Avg.	Scenario 2
Atlantic Salmon	1.0	0.5
Chinook Salmon	2.2	5.2
Coho Salmon	0.8	0.1
Lake Trout	15.4	18.9
Steelhead	1.6	2.6

Suppose that Scenario 2 described the fishery instead of the average catch rate between 2014 and 2019 when you took 5 trips.

2. How many trips would you take to Lake Huron or its tributaries to fish for salmonids under scenario 2?

Trips under scenario 2

←   →

MICHIGAN STATE UNIVERSITY

Contact Information | Privacy Statement | Site Accessibility

Call MSU: (517) 355-1855 | Visit: msu.edu

MSU is an affirmative-action, equal-opportunity employer. |

Notice of Nondiscrimination

Figure C1 (Cont'd)

MICHIGAN STATE UNIVERSITY

Scenario 3 of 5

Now consider another scenario for how conditions might be different than the 2014-2019 average.

Species	2014-2019 Avg.	Scenario 3
Atlantic Salmon	1.0	1.0
Chinook Salmon	2.2	1.5
Coho Salmon	0.8	0.8
Lake Trout	15.4	15.4
Steelhead	1.6	1.6

Suppose that Scenario 3 described the fishery instead of the average catch rate between 2014 and 2019 when you took 5 trips.

3. How many trips would you take to Lake Huron or its tributaries to fish for salmonids under scenario 3?

Trips under scenario 3

← →

MICHIGAN STATE UNIVERSITY

Contact Information | Privacy Statement | Site Accessibility
Call MSU: (517) 355-1855 | Visit: msu.edu
MSU is an affirmative-action, equal-opportunity employer. |
Notice of Nondiscrimination

Figure C1 (Cont'd)

MICHIGAN STATE UNIVERSITY

Scenario 4 of 5

Now consider another scenario for how conditions might be different than the 2014-2019 average.

Species	2014-2019 Avg.	Scenario 4
Atlantic Salmon	1.0	2.0
Chinook Salmon	2.2	1.7
Coho Salmon	0.8	3.9
Lake Trout	15.4	10.5
Steelhead	1.6	1.1

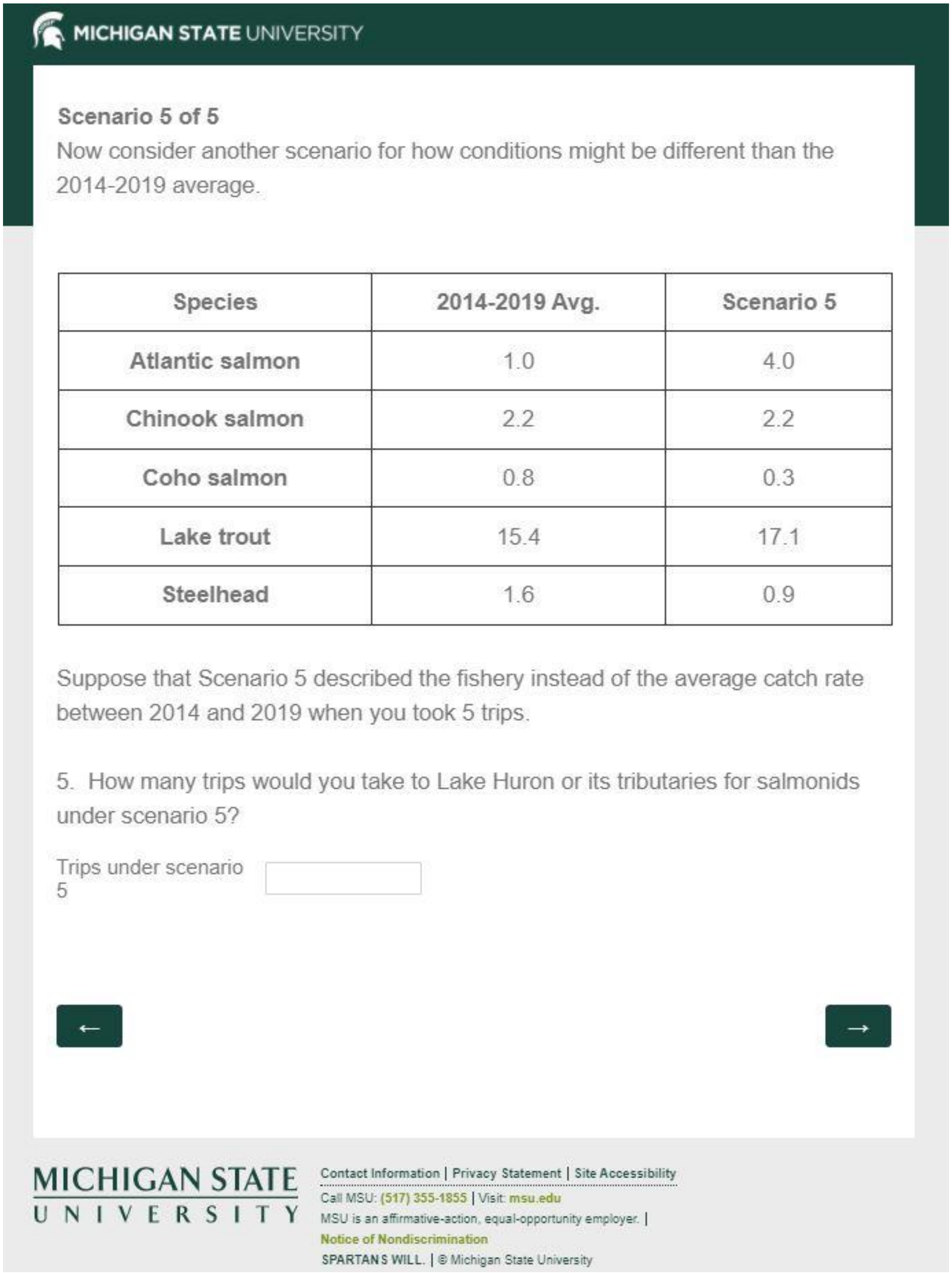
Suppose that Scenario 4 described the fishery instead of the average catch rate between 2014 and 2019 when you took 5 trips.

4. How many trips would you take to Lake Huron or its tributaries to fish for salmonids under scenario 4?

Trips under scenario 4 ______

← →

Figure C1 (Cont'd)



Scenario 5 of 5

Now consider another scenario for how conditions might be different than the 2014-2019 average.

Species	2014-2019 Avg.	Scenario 5
Atlantic salmon	1.0	4.0
Chinook salmon	2.2	2.2
Coho salmon	0.8	0.3
Lake trout	15.4	17.1
Steelhead	1.6	0.9

Suppose that Scenario 5 described the fishery instead of the average catch rate between 2014 and 2019 when you took 5 trips.

5. How many trips would you take to Lake Huron or its tributaries for salmonids under scenario 5?

Trips under scenario 5

← →

MICHIGAN STATE UNIVERSITY

Contact Information | Privacy Statement | Site Accessibility

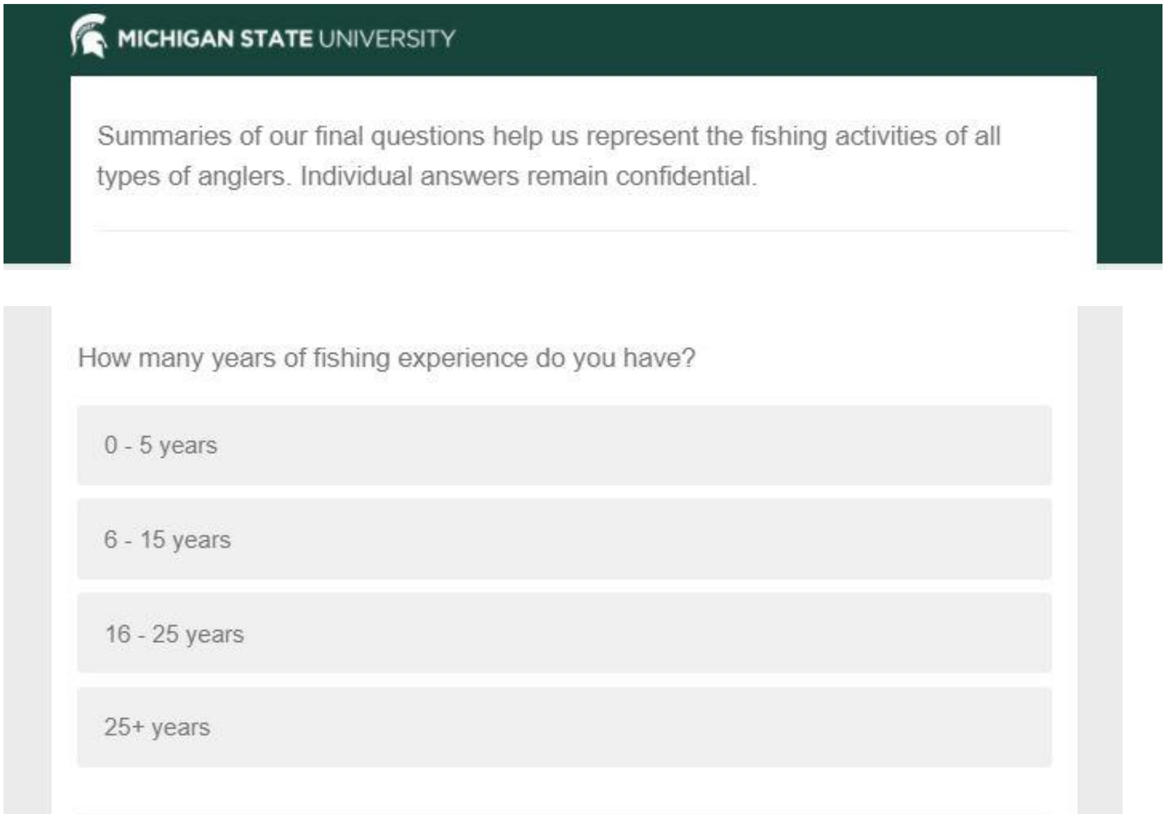
Call MSU: (517) 355-1855 | Visit: msu.edu

MSU is an affirmative-action, equal-opportunity employer. |

Notice of Nondiscrimination

SPARTANS WILL. | © Michigan State University

Figure C1 (Cont'd)



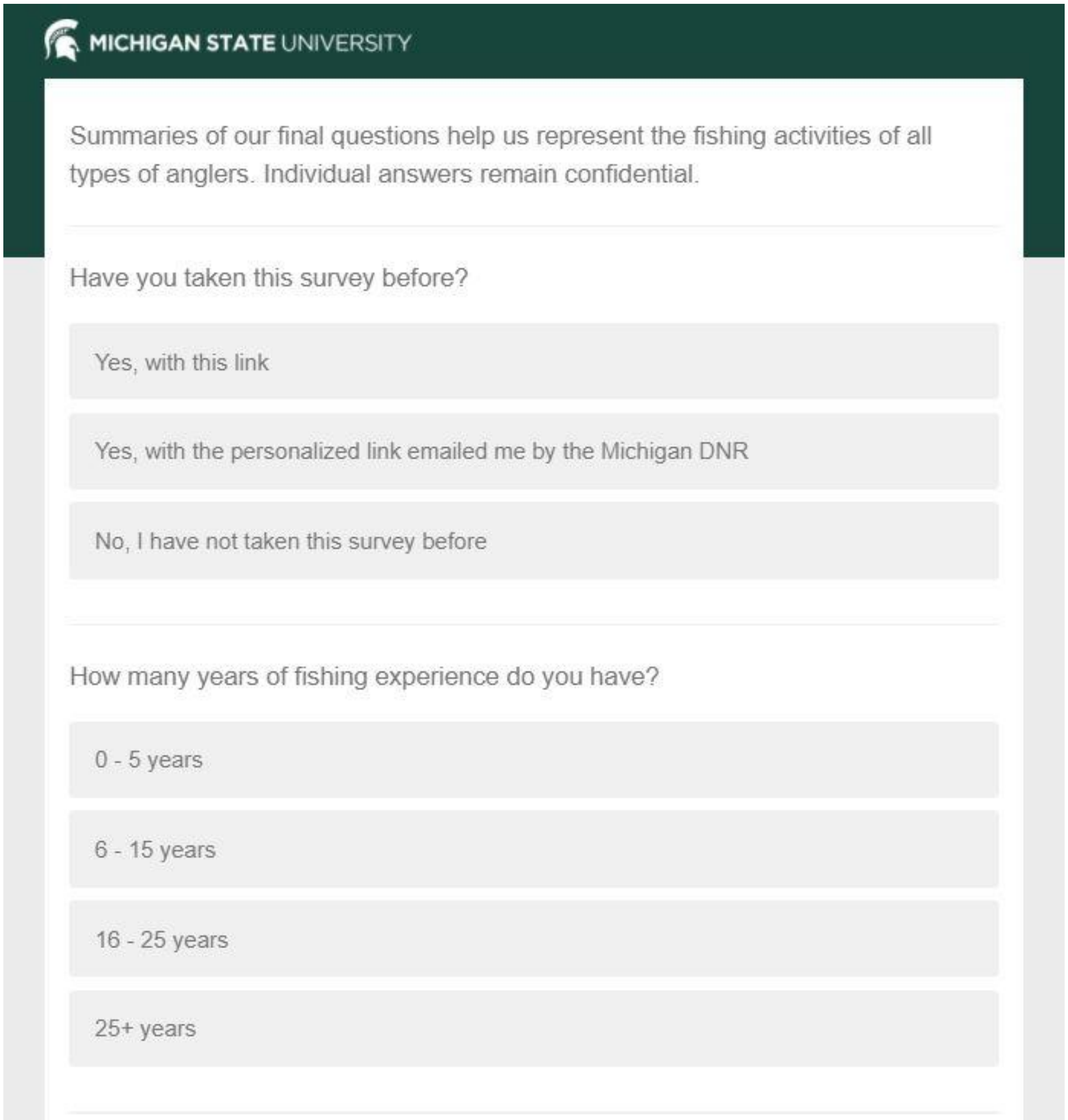
MICHIGAN STATE UNIVERSITY

Summaries of our final questions help us represent the fishing activities of all types of anglers. Individual answers remain confidential.

How many years of fishing experience do you have?

- 0 - 5 years
- 6 - 15 years
- 16 - 25 years
- 25+ years

Figure C1 (Cont'd)



MICHIGAN STATE UNIVERSITY

Summaries of our final questions help us represent the fishing activities of all types of anglers. Individual answers remain confidential.

Have you taken this survey before?

- Yes, with this link
- Yes, with the personalized link emailed me by the Michigan DNR
- No, I have not taken this survey before

How many years of fishing experience do you have?

- 0 - 5 years
- 6 - 15 years
- 16 - 25 years
- 25+ years

Figure C1 (Cont'd)

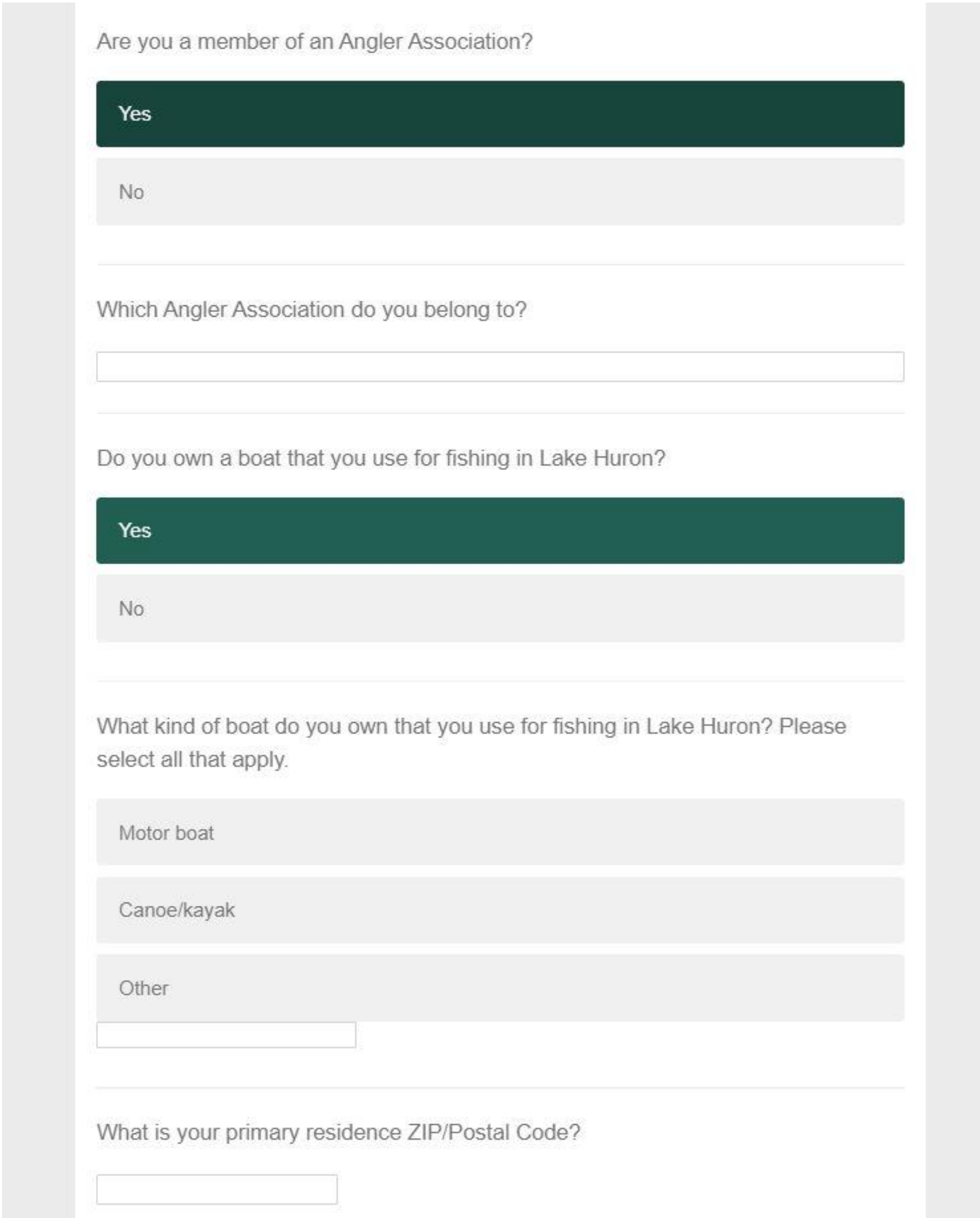
Did you buy a 2019 Michigan fishing license (April 1, 2019 - March 31, 2020 license)?

- Yes
- No

Which license did you buy?

- Resident Annual
- Nonresident Annual
- Senior Annual
- 24-hour
- 72-hour

Figure C1 (Cont'd)



Are you a member of an Angler Association?

- Yes
- No

Which Angler Association do you belong to?

Do you own a boat that you use for fishing in Lake Huron?

- Yes
- No

What kind of boat do you own that you use for fishing in Lake Huron? Please select all that apply.

- Motor boat
- Canoe/kayak
- Other

What is your primary residence ZIP/Postal Code?

Figure C1 (Cont'd)

Please indicate your gender

Female

Male

I prefer to identify as, (please specify)

What is your highest level of education? (Select one)

Less than High School degree

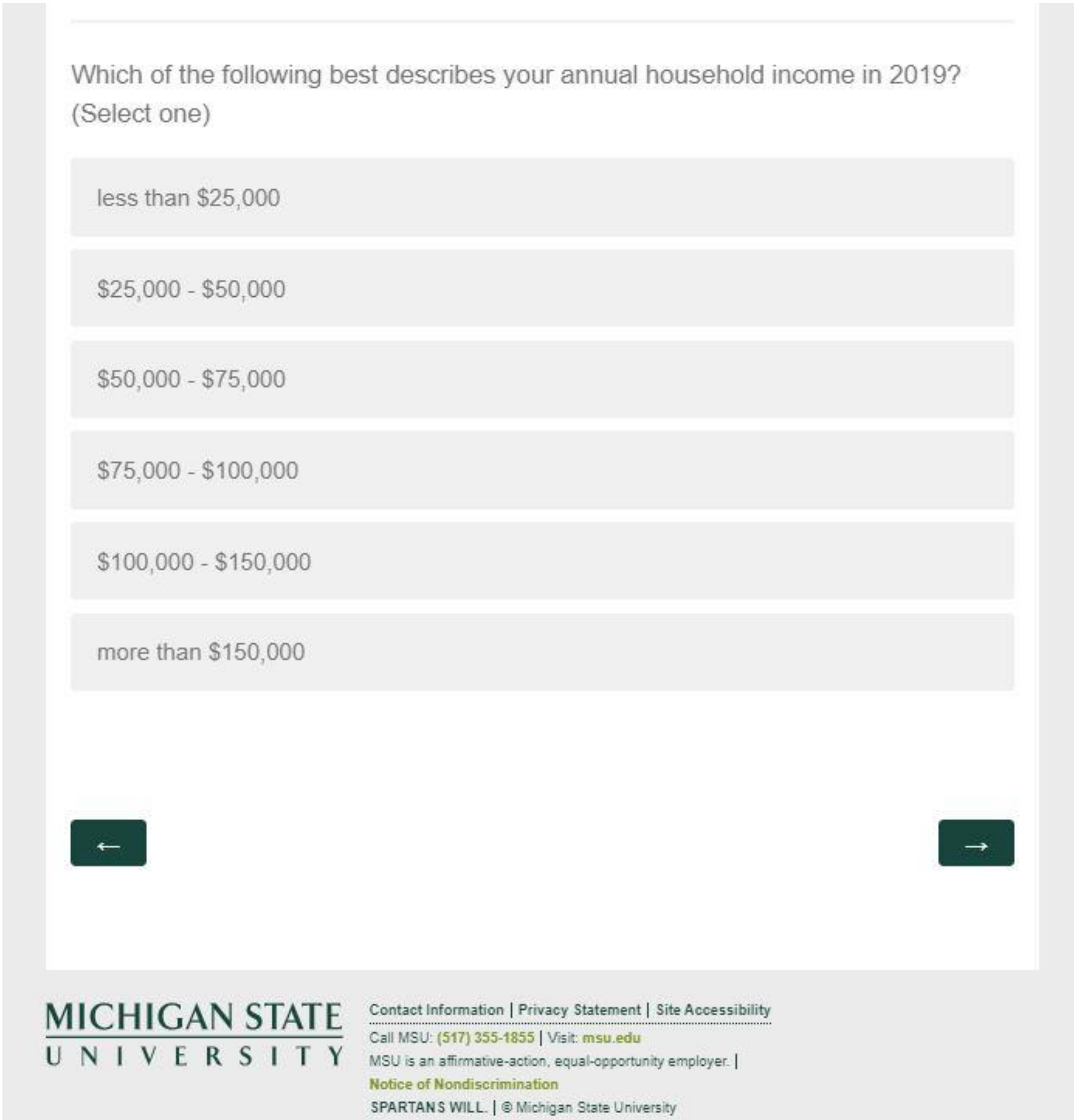
High School degree or GED

Some post High School or some college

Bachelor's Degree

Graduate Degree

Figure C1 (Cont'd)



Which of the following best describes your annual household income in 2019? (Select one)

- less than $25,000
- $25,000 - $50,000
- $50,000 - $75,000
- $75,000 - $100,000
- $100,000 - $150,000
- more than $150,000

← →

MICHIGAN STATE UNIVERSITY

Contact Information | Privacy Statement | Site Accessibility
Call MSU: (517) 355-1855 | Visit: msu.edu
MSU is an affirmative-action, equal-opportunity employer. |
Notice of Nondiscrimination
SPARTANS WILL. | © Michigan State University

Figure C1 (Cont’d)

APPENDIX D

Survey Distribution Messages

Figure D1. Initial email distributing personalized survey links. The email was sent with the subject line, “Lake Huron Salmon Fisheries Survey”.

Lake Huron Salmon Fisheries Survey

Michigan Department of Natural Resources sent this bulletin at 09/28/2020 09:18 AM EDT

Share or view as webpage | Update preferences

MICHIGAN DEPARTMENT OF

NATURAL RESOURCES

We are partnering with Michigan State University to conduct a survey to learn more about Lake Huron’s salmon fisheries. Your answers are important to us.

The information will help us better understand angler uses and preferences for Lake Huron salmon fishing. Your input will aid managers in decision making for the future of Lake Huron’s salmon fisheries.

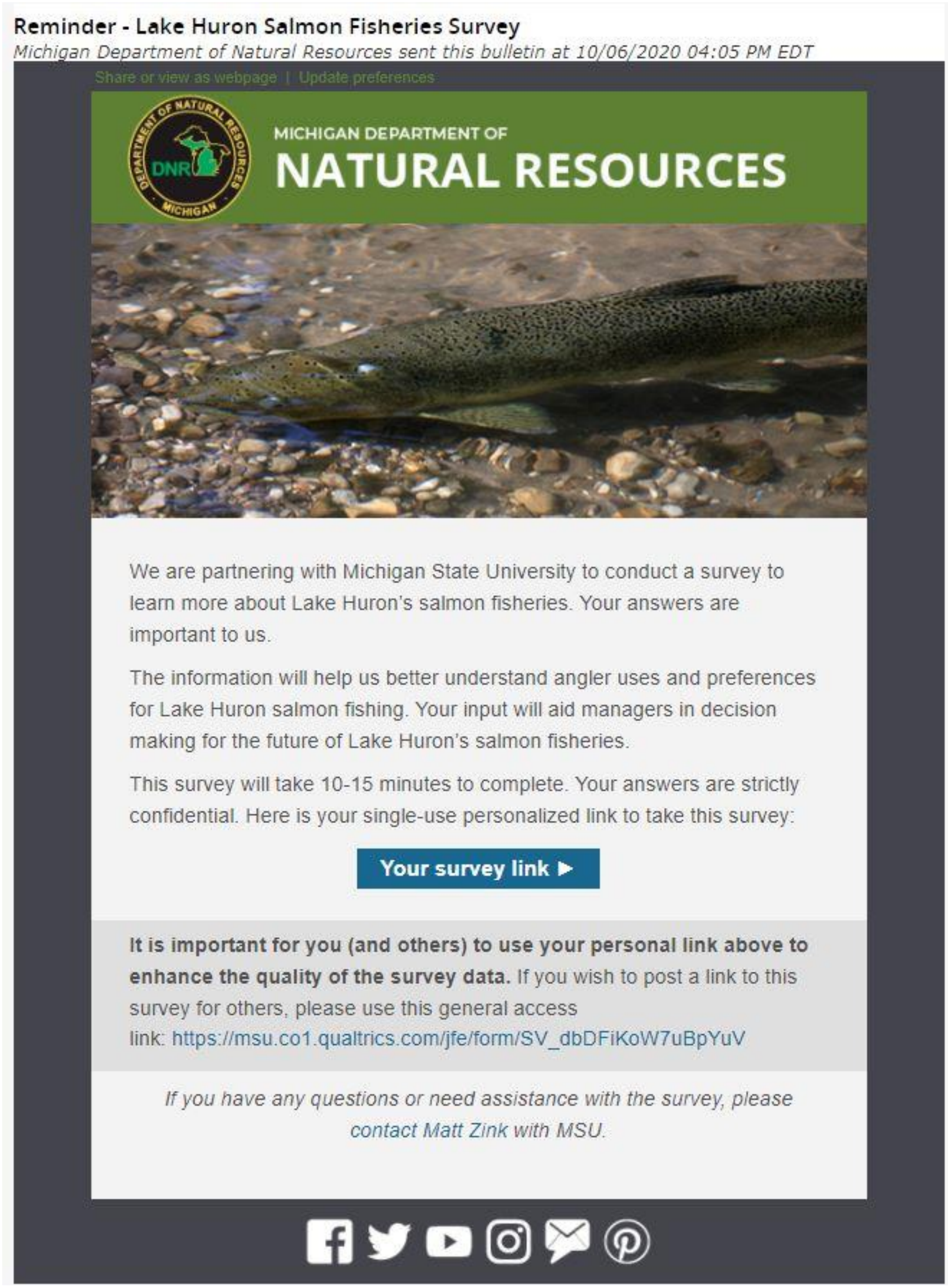
This survey will take 10-15 minutes to complete. Your answers are strictly confidential. Here is your single-use personalized link to take this survey:

Your survey link ▶

It is important for you (and others) to use your personal link above to enhance the quality of the survey data. If you wish to post a link to this survey for others, please use this general access link: https://msu.co1.qualtrics.com/jfe/form/SV_dbDFiKoW7uBpYuV

If you have any questions or need assistance with the survey, please contact Matt Zink with MSU.

Figure D2. First reminder email distributed to people on the distribution list that did not open the initial email. Email was sent with subject line, “Reminder – Lake Huron Salmon Fisheries Survey”.



Reminder - Lake Huron Salmon Fisheries Survey

Michigan Department of Natural Resources sent this bulletin at 10/06/2020 04:05 PM EDT

Share or view as webpage | Update preferences

MICHIGAN DEPARTMENT OF

NATURAL RESOURCES

We are partnering with Michigan State University to conduct a survey to learn more about Lake Huron’s salmon fisheries. Your answers are important to us.

The information will help us better understand angler uses and preferences for Lake Huron salmon fishing. Your input will aid managers in decision making for the future of Lake Huron’s salmon fisheries.

This survey will take 10-15 minutes to complete. Your answers are strictly confidential. Here is your single-use personalized link to take this survey:

Your survey link ▶

It is important for you (and others) to use your personal link above to enhance the quality of the survey data. If you wish to post a link to this survey for others, please use this general access link: https://msu.co1.qualtrics.com/jfe/form/SV_dbDFiKoW7uBpYuV

If you have any questions or need assistance with the survey, please contact Matt Zink with MSU.

Figure D3. Final reminder email distributed to people on the distribution list that did not open the initial email. Email was sent with subject line, "FINAL REMINDER – Lake Huron Salmon Fisheries Survey".

FINAL REMINDER - Lake Huron Salmon Fisheries Survey

Michigan Department of Natural Resources sent this bulletin at 10/13/2020 03:40 PM EDT

Share or view as webpage | Update preferences

MICHIGAN DEPARTMENT OF

NATURAL RESOURCES

We are partnering with Michigan State University to conduct a survey to learn more about Lake Huron's salmon fisheries. Your answers are important to us.

The information will help us better understand angler uses and preferences for Lake Huron salmon fishing. Your input will aid managers in decision making for the future of Lake Huron's salmon fisheries.

This survey will take 10-15 minutes to complete. Your answers are strictly confidential. Here is your single-use personalized link to take this survey:

Your survey link ▶

It is important for you (and others) to use your personal link above to enhance the quality of the survey data. If you wish to post a link to this survey for others, please use this general access link: https://msu.co1.qualtrics.com/jfe/form/SV_dbDFiKoW7uBpYuV

If you have any questions or need assistance with the survey, please contact Matt Zink with MSU.

APPENDIX E

Cognitive Interview Template and Summaries

The following template was used for each individual in each round. The interviewee took the survey over zoom while sharing their screen with the interviewer. Interviewees were notified their response to any question is optional, and they can quit the survey at any time. While the interviewee took the survey, the interviewer muted the mic and shut off video to avoid influencing the interviewee in any way. Respondents were stopped on the last question, and then were given the standard prompts in addition to any difficulties observed during the survey or mentioned by the interviewee.

Cognitive Interview Template – Lake Huron Salmon Fisheries Survey

*Inform tester they do not have to participate, and make sure they are still willing and able to take the survey. State that their responses will remain confidential. Stop before demographics block.

Consent Block

---

1 Consent

2 Embedded data Q

3 Age

4 # of trips

Prompts: Should not need to return to any of these questions unless the tester does something in the interview worthy of coming back.

2019 salmon fishing behavior/preference block

5

6

Prompts: Return if tester struggles, should be pretty easy questions.

Trip block

7

8

9

10

11

12

13

14

15

16

17

18

19

20

21

22

23

24

25

26

27

28

Prompts: Note any questions or hesitations.

Can you talk about what waters you considered as destinations for a fishing trip?

Tell me about your single day trip, how long were you out? How was the fishing

Tell me about your multiple day trips, how many days did you stay out?

ATS Harvest Block

29

30

31

32

33

34

35

36

37

38

39

40

41

Prompts: Nothing really specific, see how they fill out the tables.

Fish ID

42

43

44

45

46

47

48

49

50

51

52

53

54

55

Prompts: Here I actually want to ask grad students if they think these photos are good for anyone to ID.

Angler comments on creel numbers

56

57

Prompts: Prod about percentage ranges and if they were thinking of catch rates correctly

---

Preference scenarios

58

59

60

61

62

63

Prompts:

How did you arrive at X trips?

What made you change your number of trips from the last scenario?

Prod for how they are thinking about catch rates and potential changes in the fishery.

When you were presented the table of catch rates, what did you focus on/what were you thinking as you first read it?

STOP – Work backwards through this document.

Summary of Cognitive Interviews Round 1

Round one of cognitive interviews consisted of four graduate students and a lab manager. Overall the survey was interpreted as intended, however several of the same photos in the Fish ID block of the survey were noted as too difficult to identify. These photos were removed from the survey before the next round of testing.

Summary of Cognitive Interviews Round 2

Round two of cognitive interviews consisted of four people belong to the Lake Huron Citizens' Advisory Committee or Lake Huron angler groups, and one professor of Fish Ecology. The harvest section that asked about lake trout harvest proved very difficult for this round. Recall was poor since the fish was not as important to the interviewees and they indicated they caught too many to remember. Therefore, the harvest block of the survey was edited to only ask about Atlantic salmon harvest and catch and release.

APPENDIX F

Chapter 2 Tables

Table F1. Number of yearling Atlantic salmon stocked per year by MDNR and LSSU from 2011 to 2019.

Year	LSSU	MDNR	Total
2011	31,100	21,742	52,842
2012	35,230	35,120	70,350
2013	35,000	100,865	135,865
2014	40,908	131,387	172,295
2015	29,880	160,472	190,352
2016	36,790	159,853	196,643
2017	28,482	110,746	139,228
2018	34,937	113,409	148,346
2019	19,894	82,242	102,136

Table F2. Description of equation symbols used in the SCAA model and text for age-structured assessment of Lake Huron Atlantic salmon population dynamics.

Symbol	Description
	Indicator variables
a	Age-class (1-7)
y	Year (2011-2019)
l	Length bin (300, 350, …, 900 mm)
	Estimated parameters
s	Recreational fishing selectivities
$\bar{F}$	Average recreational apical fishing intensity
τ	Annual recreational apical fishing intensity deviations
m	Stocking survival (logistic scale)
σ_H	Standard deviation for recreational fishery harvest lognormal log-likelihood component
	Calculated and assumed quantities
N	Population abundance
Z	Instantaneous total mortality
M	Instantaneous natural mortality
F	Instantaneous recreational fishing mortality
γ	Post-stocking survival rate
$\hat{H}$	Predicted recreational fishing harvest
$\hat{P}$	Predicted recreational fishing harvest age composition
σ_F	Standard deviation for fishing intensity deviations lognormal log-prior component
	Data
n^{MDNR}	Number of yearling Atlantic salmon stocked by MDNR
n^{LSSU}	Number of yearling Atlantic salmon stocked by LSSU

Table F2 (Cont'd)

H	Observed recreational fishing harvest
P	Observed recreational fishing harvest length composition
L	Age-length transition matrix

Table F3. Equations and descriptions of the negative log likelihood and penalty components of the Lake Huron Atlantic salmon statistical catch-at-age model.

Equation	Description
$L_H = 9 \cdot log(\sigma_H) + \frac{0.5}{\sigma_H^2} \sum_y \left[log_e(H_y) - log_e(\hat{H}_y) \right]^2$	Recreational fishery harvest
$L_F = 9 \cdot log(\sigma_F) + \frac{0.5}{\sigma_F^2} \sum_y \left[log_e(\tau_y) \right]^2$	Recreational fishing intensity deviations
$L_m = \log(0.5) + \frac{0.5}{0.5^2} (m)^2$	Stocking survival penalty
$L_P = -\sum_y 25 \sum_{a_h} \left(P_{y,l} log_e \hat{P}_{\ y,l} \right)$	Recreational fishery length compositions of harvest

Table F4. Estimates of length-at-age of Lake Huron Atlantic salmon from the Von Bertalanffy growth model.

Age	Predicted Length (mm)	Standard Deviation
1	216.456	22.490
2	536.236	55.715
3	658.304	68.398
4	704.900	73.239
5	722.686	75.087
6	729.476	75.793
7	732.068	76.062

Table F5. Statistical catch-at-age model estimated abundance at age (in thousands of fish) of Atlantic salmon in Lake Huron from 2011 to 2019.

Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7
2011	27.477	12.371	11.218	9.890	6.226	7.028	2.017
2012	36.581	25.855	10.389	9.562	8.949	5.634	4.263
2013	70.648	33.072	18.303	7.971	8.652	8.097	3.417
2014	89.591	63.918	29.095	16.193	7.213	7.829	4.911
2015	98.981	81.050	55.098	25.323	14.652	6.526	4.748
2016	102.252	89.556	72.214	49.242	22.914	13.257	3.958
2017	72.397	92.511	78.847	63.926	44.556	20.733	8.041
2018	77.138	65.503	82.304	70.384	57.843	40.316	12.575
2019	53.109	69.786	56.866	72.044	63.686	52.338	24.453

APPENDIX G

Chapter 2 Figures

Figure G1. Map of Lake Huron showing rivers and harbors where Atlantic salmon are stocked by MDNR and LSSU. The solid line indicates the international border separating Michigan and Ontario jurisdictional waters.

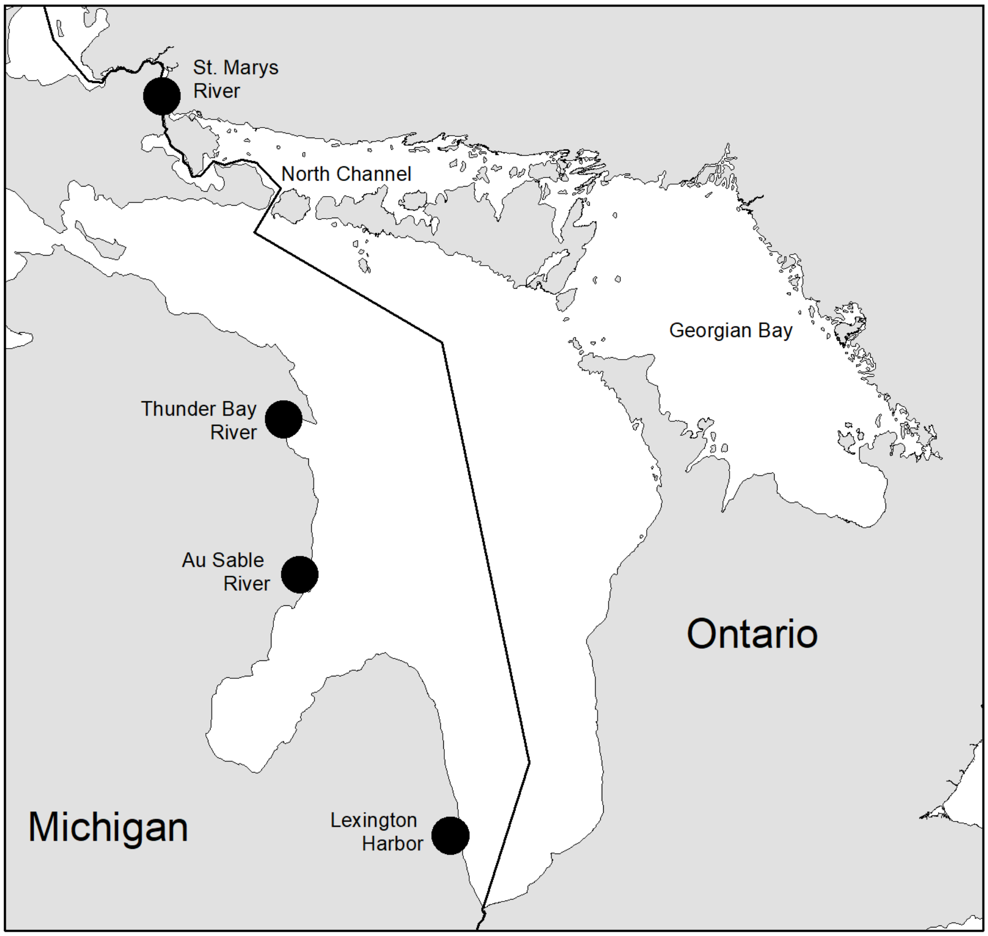


Figure G2. The observed (inverted, open triangle) vs predicted (solid, grey circle) total recreational harvest of Atlantic salmon in Lake Huron were very close or exactly equal. Thus, the points are on top of one another. 95% confidence intervals were very narrow (approximately plus or minus 1 fish from estimate), which is likely due to the fact that recruitment was not estimated in our model.

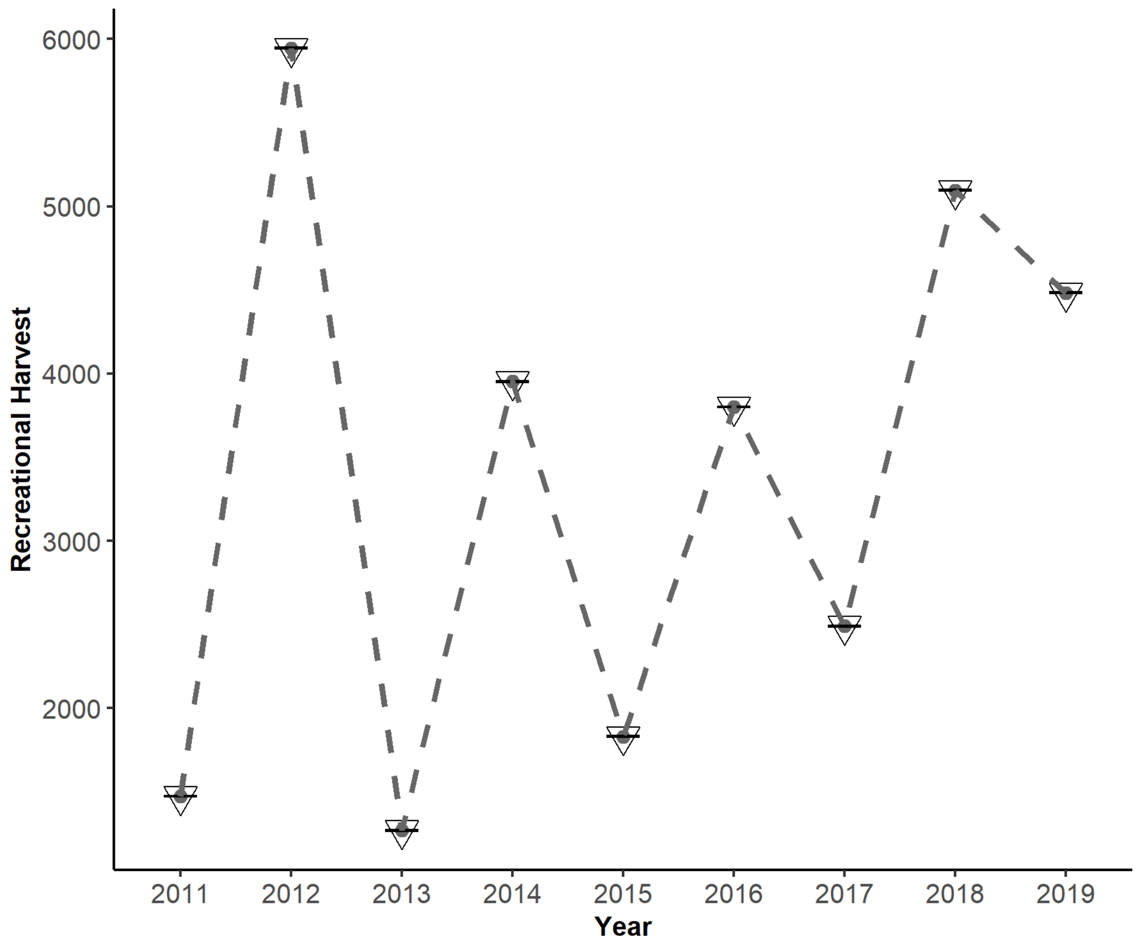


Figure G3. Observed (black line, open circle) vs predicted (grey line, open triangle) mean length (mm) of the harvest for Lake Huron Atlantic salmon.

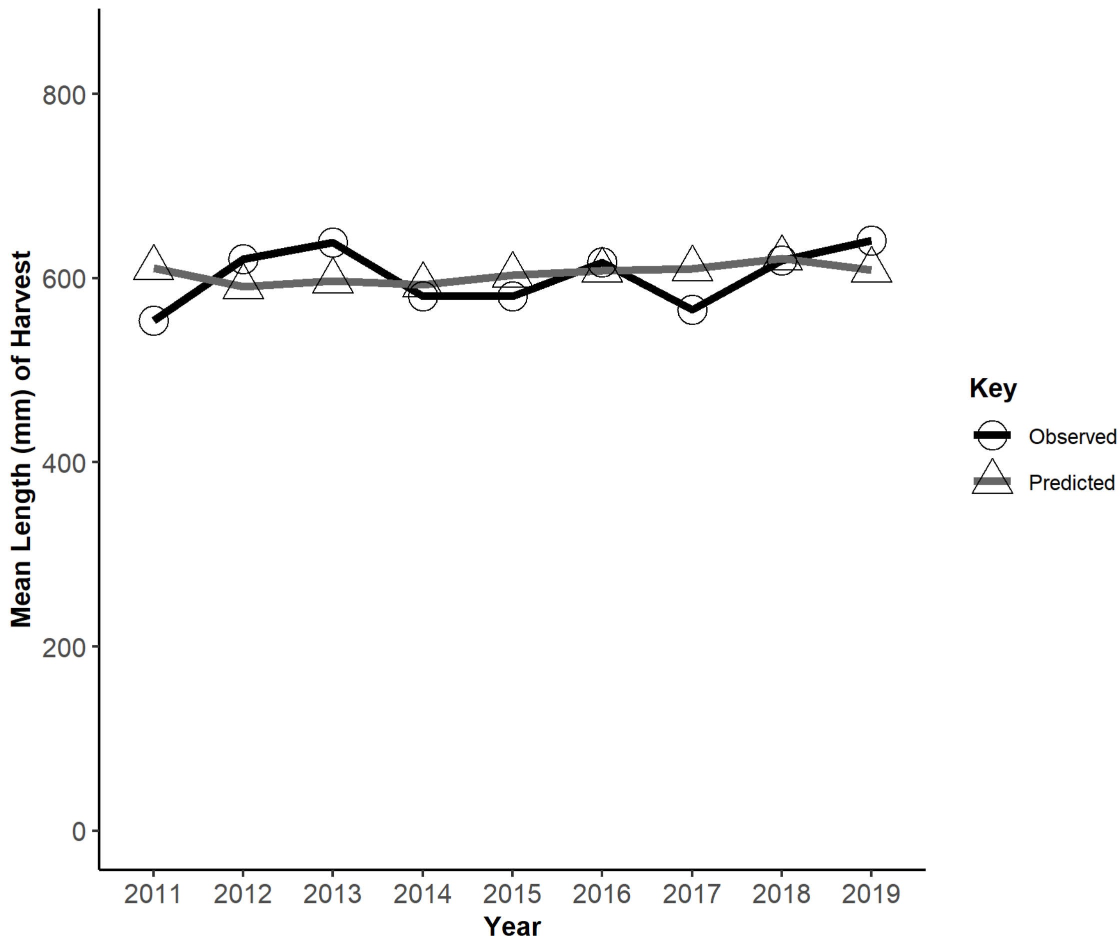


Figure G4. Retrospective analysis of the Lake Huron Atlantic salmon SCAA total abundance predictions. 2015 (dashed, dark grey), 2016 (dot-dash), 2017 (long-dash), 2018 (two-dash), and 2019 (black, solid) with 95% confidence intervals showed no retrospective pattern in terminal year abundances predicted by the SCAA.

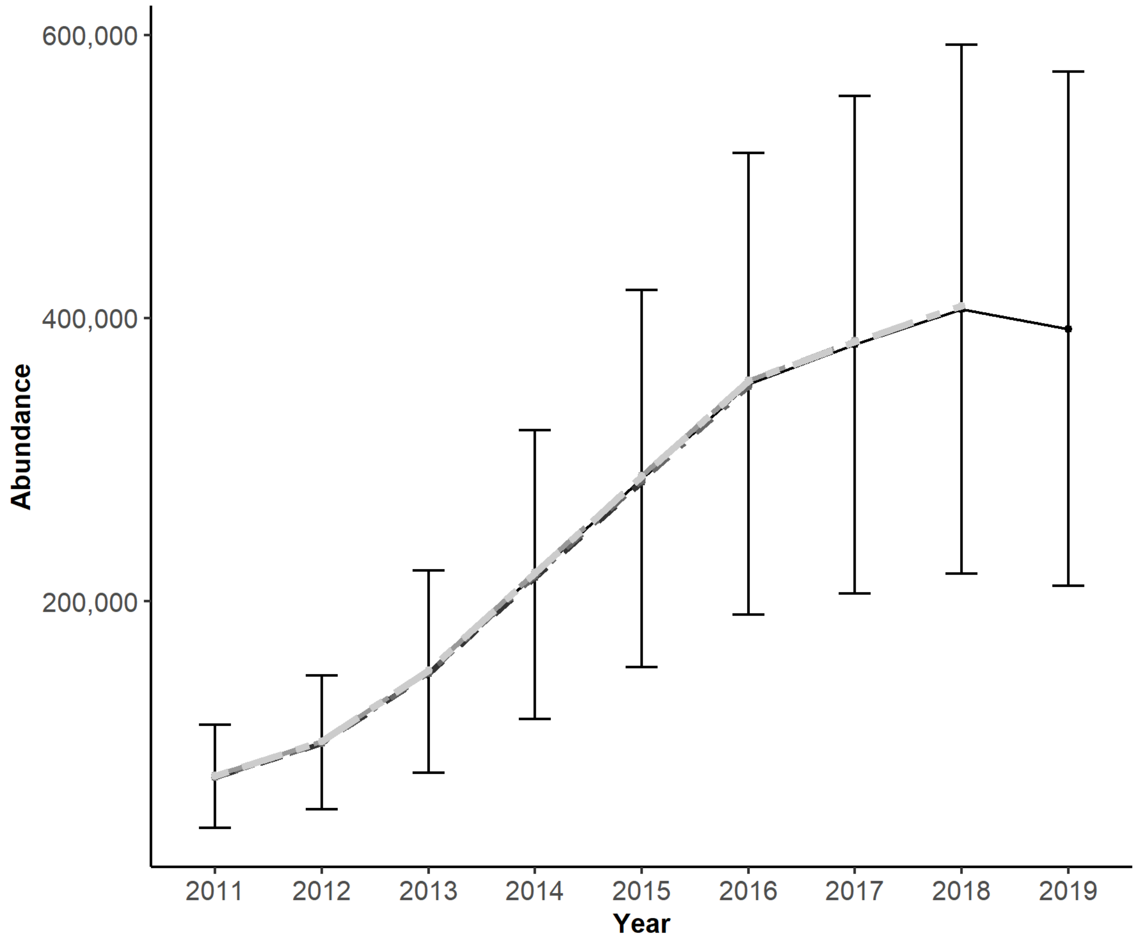


Figure G5. Retrospective analysis of the Lake Huron Atlantic salmon SCAA fully selected age-2 instantaneous fishing mortality rates. 2015 (dashed, dark grey), 2016 (dot-dash), 2017 (long-dash), 2018 (two-dash), and 2019 (black, solid) with 95% confidence intervals showed no retrospective pattern in terminal year fully selected age-2 instantaneous fishing mortality rates.

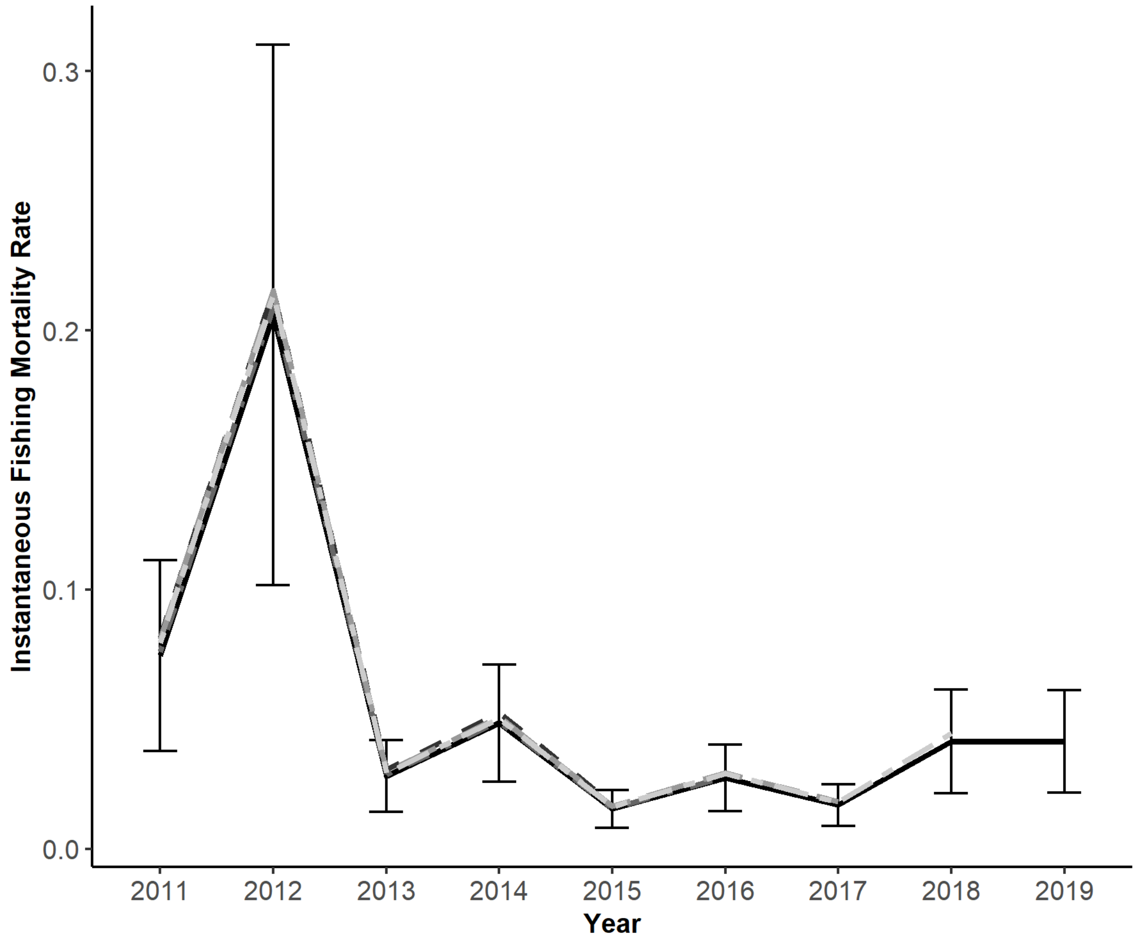
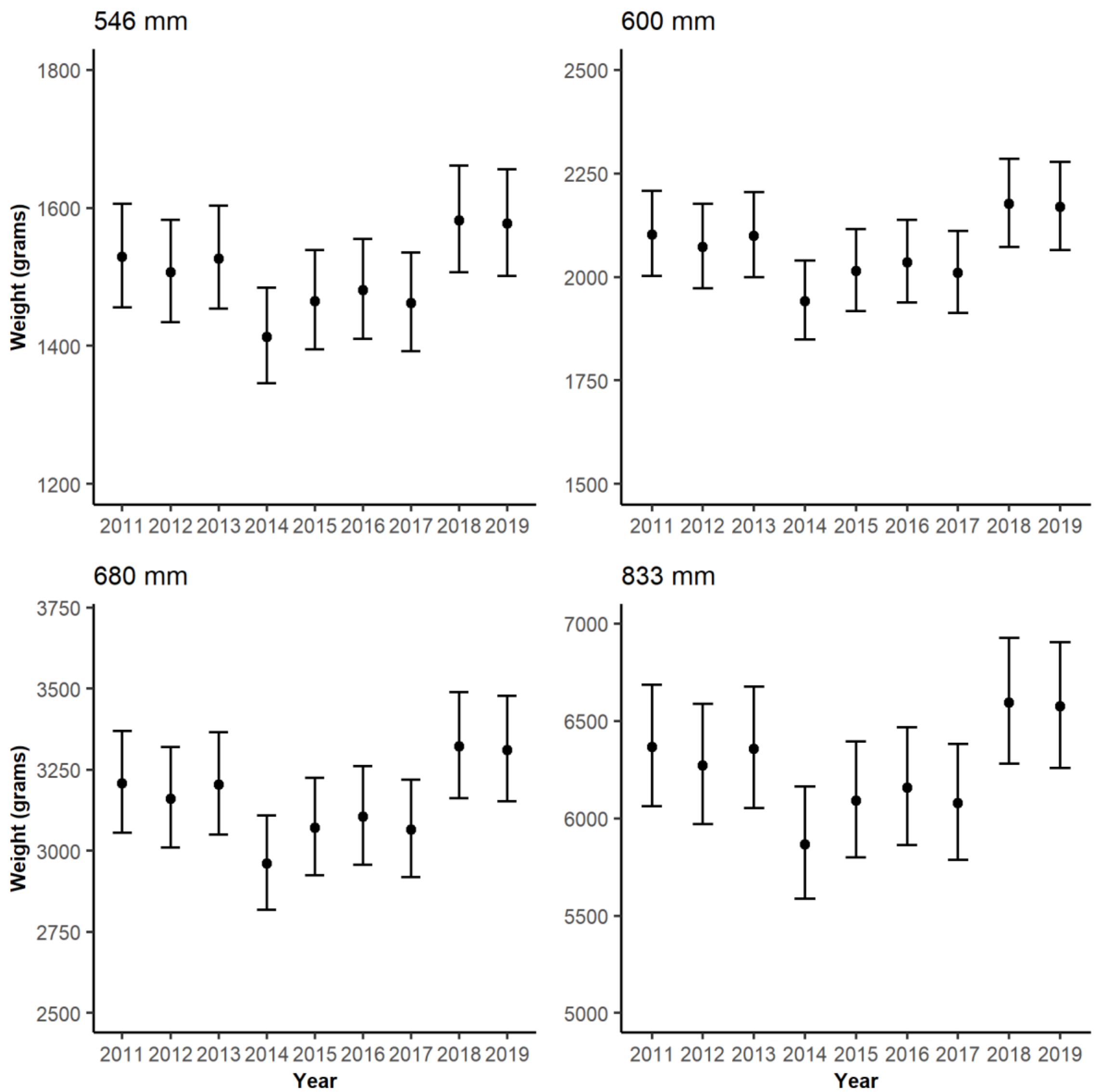


Figure G6. Predicted weight (grams) at four reference lengths (546, 600, 680, and 820 mm) from the weighted AIC averaged hierarchical allometric growth models fit to available length-weight data for Lake Huron Atlantic salmon. Each point estimate has its associated 95% confidence interval.



REFERENCES

REFERENCES

Andreassen, P.M.R., Martineussen, M.B., Hvidsten, N.A., Stefansson, S.O., 2001. Feeding and prey-selection of wild Atlantic salmon post-smolts. J. Fish Biol. 58, 1667-1679.

Aprahamian, M.W., Hickley, P., Shields, B.A., Mawle, G.W., 2010. Examining changes in participation in recreational fisheries in England and Wales. Fish. Manag. Ecol. 17, 93-105.

Argyle, R.L., 1982. Alewives and rainbow smelt in Lake Huron: midwater and bottom aggregations and estimates of standing stocks. Trans. Am. Fish. Soc. 111, 267-285. DOI: 10.1577/1548-8659(1982)111<267:AARSIL>2.0.CO;2.

Bacon, P.J., Palmer, S.C.F., MacLean, J.C., Smith, G.W., Whyte, B.D M., Gurney, W.S.C., Youngson, A.F., 2009. Empirical analyses of the length, weight, and condition of adult Atlantic salmon on return to the Scottish coast between 1963 and 2006. ICES J. Mar. Sci. 66, 844-859.

Baty, F., Ritz, C., Charles, S., Brutsche, M., Flandrois, J., Delignette-Muller, M., 2015. A toolbox for nonlinear regression in R: the package nlstools. J. Stat. Softw. 66, 1-21. doi: 10.18637/jss.v066.i05.

Bence, J.R., Smith, K.D., 1999. An overview of recreational fisheries of the Great Lakes. Great Lakes fisheries policy and management. Michigan State University Press, East Lansing, MI.

Bence, J.R., Mohr, L.C. (EDS.), 2008. The state of Lake Huron in 2004. Great Lakes Fish. Comm. Spec. Pub. 08-01.

Bence, J.R., Madenjian, C.P., He, J.X., Fielder, D.G., Pothoven, S.A., Dobiesz, N.E., Johnson, J.E., Ebener, M.P., Cottrill, R.A., Mohr, L.C., Koproski, S.R., 2016. Reply to comments by Riley and Dunlop on He et al. (2015). Can. J. Fish. Aquat. Sci. 73, 865-868.

Berst, A.H., Spangler, G.R., 1972. Lake Huron: effects of exploitation, introductions, and eutrophication on the salmonid community. J. Fish. Res. Board Can. 29, 877-887.

Berst, A.H., Spangler, G.R., 1973. Lake Huron the ecology of the fish community and man's effects on It. Technical Report 21. Great Lakes Fish. Comm. Retrieved from http://www.glfc.org/pubs/TechReports/Tr21.pdf. Apr 8, 2021.

Breffle, W.S., Morey, E.R., 2000. Investigating preference heterogeneity in a repeated discrete-choice recreation demand model of Atlantic salmon fishing. Mar. Res. Econ. 15, 1-20.

Brenden, T.O., Bence, J.R., Szalai, E.B., 2012. An age-structured integrated assessment of Chinook salmon population dynamics in Lake Huron's main basin since 1968. Trans. Am. Fish. Soc. 141, 919-933.

Bocaniov, S.A., Burton, D.R., Schiff, S.L., Smith, R.E.H., 2013. Impact of tributary DOM and nutrient inputs on the nearshore ecology of a large, oligotrophic lake (Georgian Bay, Lake Huron, Canada). Aquat. Sci. 75, 321-332.

Brooks, M.E., Kristensen,K., Van Benthem, K.J., Magnusson, A., Berg, C.W., Nielsen, A., Skaug, H.J., Mächler, M., Bolker, B.M., 2017. glmmTMB balances speed and flexibility among packages for zero-inflated generalized linear mixed modeling. R J. 9, 378-400.

Butler, J.R., Radford, A., Riddington, G., Laughton, R., 2009. Evaluating an ecosystem service provided by Atlantic salmon, sea trout and other fish species in the River Spey, Scotland: the economic impact of recreational rod fisheries. Fish. Res. 96, 259-266.

Clarke, P.M., Fiebig, D.G., Gerdtham, U.G., 2008. Optimal recall length in survey design. J. Health Econ. 27, 1275-1284.

Connerton, M.J., Lantry, J.R., Walsh, M.G., Weidel, B.C., Hoyle, J.A., Desjardins, M.D., Holden, J.P., Johnson, J.H., Yuille, J., Bowlby, J.N., Prindle, S.E., Lake, C.C., Stewart, T.J., 2017. Offshore pelagic fish community. Pages 67-96 *in* R. O'Gorman, editor. The State of Lake Ontario in 2014, Great Lakes Fish. Comm., Ann Arbor, MI.

DesJardine, R.L., Gorenflo, T.K., Payne, R.N., Schrouder, J.D., 1995. Fish-community objectives for Lake Huron. Great Lakes Fish. Comm. Spec. Pub. 95-1. Ann Arbor, Michigan.

Dixon, H.J., Dempson, J.B., Power, M., 2019. Short-term temporal variation in inshore/offshore feeding and trophic niche of Atlantic salmon *Salmo salar* off West Greenland. Mar. Ecol. Prog. Ser. 610, 191-203. https://doi.org/10.3354/meps12841.

Dobiesz, N.E., McLeish, D.A., Eshenroder, R.L., Bence, J.R., Mohr, L.C., Henderson, B.A., Ebener, M.P., Nalepa, T., Woldt, A.P., Johnson, J.E., Argyle, R.L., Makarewicz, J.C., 2005. Ecology of the Lake Huron fish community 1970-1999. Can. J. Fish. Aquat. Sci. 62, 1432-1451.

Dymond, J.R., MacKay, H.H., Burridge, M.E., Holm, E., Bird, P.W., 2019. The history of the Atlantic salmon in Lake Ontario. Aquat. Ecosyst. Health Manag. 22, 305-315.

English, E., Von Haefen, R.H., Herriges, J., Leggett, C., Lupi, F., McConnell, K., Welsh, M., Domanski, A., Meade, N., 2018. Estimating the value of lost recreation days from the Deepwater Horizon oil spill. J. Environ. Econ. Manag. 91, 26-45.

Ebener, M.P. (ED.)., 1995. The state of Lake Huron in 1992. Great Lakes Fish. Comm. Spec. Pub. 95-2, 140. Ann Arbor, Michigan.

Eshenroder, R.L., 1992. Decline of lake trout in Lake Huron. Trans. Am. Fish. Soc. 121, 548-554. DOI: 10.1577/1548-8659-121.4.548.

Eshenroder, R.L., Payne, N.R., Johnson, J.E., Bowen II, C., Ebener, M.P., 1995. Lake trout rehabilitation in Lake Huron. J. Great Lakes Res. 21 (Supplement 1), 108-127. DOI 10.1016/S0380-1330(95)71086-3.

Eshenroder, R.L., Burnham-Curtis, M.K., 1999. Species succession and sustainability of the Great Lakes fish community. Pages 145-184 *in* W.W. Taylor and C.P. Ferreri, editors. Great Lakes fisheries policy and management: a binational perspective. Michigan State University Press, East Lansing, MI.

Evans, D.O., Loftus, D.H., 1987. Colonization of inland lakes in the Great Lakes region by rainbow smelt, Osmerus mordax: their freshwater niche and effects on indigenous fishes. Can. J. Fish. Aquat. Sci. 44(Suppl. 2), 249-266.

Fielder, D.G., Schaeffer, J.S., Thomas, M.V., 2007. Environmental and ecological conditions surrounding the production of large year classes of walleye (*Sander vitreus*) in Saginaw Bay, Lake Huron. J. Great Lakes Res. 33, 118-132.

Fielder, D.G., Bence, J.R., 2014. Integration of auxiliary information in statistical catch-at-age (SCA) analysis of the Saginaw Bay stock of walleye in Lake Huron. N. Am. J. Fish. Manag. 34, 970-987. DOI:10.1080/02755947.2014.938141.

Fisch, N.C., Bence, J.R., Myers, J.T., Berglund, E.K., Yule, D.L., 2019. A comparison of age- and size-structured assessment models applied to a stock of cisco in Thunder Bay, Ontario. Fish. Res. 209, 86-100.

Friedland, K.D., MacLean, J.C., Hansen, L.P., Peyronnet, A.J., Karlsson, L., Reddin, D.G., Maoiléidigh, N.Ó., McCarthy, J.L., 2009. The recruitment of Atlantic salmon in Europe. ICES J. Mar. Sci. 66, 289-304.

Fournier, D., Archibald, C., 1982. A general theory for analyzing catch at age data (fisheries). Can. J. Fish. Aquat. Sci. 39(8), 1195-1207.

Frechette, D.M., Dugdale, S.J., Dodson, J.J., Bergeron, N.E., 2018. Understanding summertime thermal refuge use by adult Atlantic salmon using remote sensing, river temperature monitoring, and acoustic telemetry. Can. J. Fish. Aquat. Sci. 75, 1999-2010. dx.doi.org/10.1139/cjfas-2017-0422.

Gerig, B.S., Chaloner, D.T. , Cullen, S.A., Greil, R., Kapucinski, K., Moerke, A.H., Lamberti, G.A., 2019. Trophic ecology of salmonine predators in northern Lake Huron with emphasis on Atlantic salmon (*Salmo salar*). J. Great Lakes Res. 45, 160-166. https://doi.org/10.1016/j.jglr.2018.11.003.

Gibson, R.J. 1993. The Atlantic salmon in fresh water: spawning, rearing and production. Rev. Fish Biol. Fish. 3, 39-73.

He, J.X., Bence, J.R., Johnson, J.E., Clapp, D.F., Ebener, M.P., 2008. Modeling variation in mass-length relations and condition indices of lake trout and Chinook salmon in Lake Huron: a hierarchical Bayesian approach. Trans. Am. Fish. Soc. 137, 801-817.

He, J.X., Ebener, M.P., Riley, S.C., Cottrill, A., Kowalski, A., Koproski, S., Mohr, L., Johnson, J.E., 2012. Lake trout status in the main basin of Lake Huron, 1973–2010. N. Am. J. Fish. Manag. 32, 402-412. DOI: 10.1080/02755947.2012.675947.

He, J.X., Bence, J.R., Madenjian, C.P., Pothoven, S.A., Dobiesz, N.E., Fielder, D.G., Johnson, J.E., Ebener, M.P., Cottrill, R.A., Mohr, L.C., Koproski, S.R., 2015. Coupling age-structured stock assessment and fish bioenergetics models: a system of time-varying models for quantifying piscivory patterns during the rapid trophic shift in the main basin of Lake Huron. Can. J. Fish. Aquat. Sci. 72, 7-23.

Hendry, A.P., Letcher, B.H., Gries, G., 2003. Estimating natural selection acting on stream-dwelling Atlantic salmon: implications for the restoration of extirpated populations. Conserv. Biol. Vol 17(3), 795-805.

Hoehn, J. P., Tomasi, T., Lupi, F., Chen, H.Z., 1996. An economic model for valuing recreational angling resources in Michigan. Report to the Michigan Department of Environmental Quality and the Michigan Department of Natural Resources, Michigan State University, East Lansing.

Hubbs, C.K., Lagler, K.F., Smith, G.R., 2004. Fishes of the Great Lakes region, revised edition. University of Michigan Press, Ann Arbor, Michigan.

Hutchings, J.A., Ardren, W.R., Barlaup, B.T., Bergman, E., Clarke, K.D., Greenberg, L.A., Lake, C., Piironen, J., Sirois, P., Sundt-Hansen, L.E., Fraser, D.J., 2019. Life-history variability and conservation status of landlocked Atlantic salmon: an overview. Can. J. Fish. Aquat. Sci. 76, 1697-1708. dx.doi.org/10.1139/cjfas-2018-0413.

Johnson, J.H., McKeon, J.E., Dropkin, D.S., 1996. Comparative diets of hatchery and wild Atlantic salmon smolts in the Merrimack River. N. Am. J. Fish. Manag. 16, 440-444. DOI:10.1577/1548-8675(1996)016<0440:CDOHAW>2.3.CO;2.

Johnston, R.J., Ranson, M.H., Besedin, E.Y., Helm, E.C., 2006. What determines willingness to pay per fish? A meta-analysis of recreational fishing values. Mar. Res. Econ. 21, 1-32.

Johnston, R.J., Boyle, K.J., Adamowicz, W., Bennett, J., Brouwer, R., Cameron, T.A., Hanemann, W.M., Hanley, N., Ryan, M., Scarpa, R. and Tourangeau, R., 2017. Contemporary guidance for stated preference studies. J. Assoc. Environ. Res. Econ. 4, 319-405.

Jones, C.A., Sung, Y.D., 1993. Valuation of environmental quality at Michigan recreational fishing sites: methodological issues and policy applications. EPA Contract No. CR-816247-01-2, Final Report.

Jonsson, N., Jonsson, B., Hansen, L.P., 1998. The relative role of density-dependent and density-independent survival in the life cycle of Atlantic salmon *Salmo salar*. J. Anim. Ecol. 67, 751-762.

Kennedy, G.J.A., Crozier, W.W., 1997. What is the value of a wild salmon smolt, *Salmo salar* L.?. Fish. Manag. Ecol. 4, 103-110.

Kotchen, M.J., Moore, M.R., Lupi, F., Rutherford, E.S., 2006. Environmental constraints on hydropower: an ex post benefit-cost analysis of dam relicensing in Michigan. Land Econ. 82, 384-403.

Kristensen, K., Nielsen, A., Berg, C.W., Skaug, H., Bell, B., 2016. TMB: automatic differentiation and laplace approximation. J. Stat. Softw. 70, 1-21. http://dx.doi.org/10.18637/jss.v070.i05.

Linton, B.C., Bence, J.R., 2011. Catch-at-age assessment in the face of time-varying selectivity. ICES J. Mar. Sci. 68, 611-625.

Lupi, F., Hoehn, J.P., Christie, G.C., 2003. Using an economic model of recreational fishing to evaluate the benefits of sea lamprey (*Petromyzon marinus*) control on the St. Marys River. J. Great Lakes Res. 29, 742-754.

Lupi, F., Phaneuf, D. J., Von Haefen, R. H., 2020. Best practices for implementing recreation demand models. Rev. Environ. Econ. Pol. 14, 302-323.

McFadden, D., 1974. Conditional logit analysis of discrete choice behavior. *In* P. Zarembka, editor. Frontiers of Econometrics, Academic Press, New York.

McFadden, D., 1978. Modeling the choice of residential location. Pages 75-96 *in* A. Karlquist, L. Lundquist, F. Snickbars, J.W. Weibull, editors. Spatial interaction theory and planning models, North-Holland, Amsterdam.

McFadden, D., 1981. Econometric models of probabilistic choice. Pages 198-272 *in* C.F. Manski, D. McFadden, editors. Structural analysis of discrete data: with econometric applications, MIT Press, Cambridge, Massachusetts.

Mohn, R., 1999. The retrospective problem in sequential population analysis: an investigation using cod fishery and simulated data. ICES J. Mar. Sci. 56, 473–488.

Melstrom, R.T., Lupi, F., 2013. Valuing recreational fishing in the Great Lakes. N. Am. J. Fish. Manag. 33, 1184-1193.

Morey, E.R., Rowe, R.D., Watson, M., 1993. A repeated nested-logit model of Atlantic salmon fishing. Am. J. Ag. Econ. 75, 578-592.

Ogle, D.H., J.C. Doll, P. Wheeler, A. Dinno., 2021. FSA: Fisheries Stock Analysis. R package version 0.9.1, https://github.com/droglenc/FSA.

Osborn, M.F., Matlock, G.C., 2010. Recall bias in a sportfishing mail survey. N. Am. J. Fish. Manag. 30, 665-670.

Petrovčič, A., Petrič, G., Manfreda, K.L., 2016. The effect of email invitation elements on response rate in a web survey within an online community. Comput. Hum. Behav. 56, 320-329.

Peirson, G., Tingley, D., Spurgeon, J., Radford, A., 2001. Economic evaluation of inland fisheries in England and Wales. Fish. Manag. Ecol. 8, 415-424.

Phillips, A.W., Reddy, S., Durning, S.J., 2016. Improving response rates and evaluating nonresponse bias in surveys: AMEE Guide No. 102. Medical teacher. 38, 217-228.

Quinn, T.J., Deriso, R.B., 1999. Quantitative Fish Dynamics. Oxford University Press. Oxford, New York.

Rand, P.S., Stewart, D.J., Seelbach, P.W., Jones, M.L., Wedge, L.R., 1993. Modeling steelhead population energetics in Lakes Michigan and Ontario. Trans. Am. Fish. Soc. 122, 977-1001. DOI:10.1577/1548-8659(1993)122<0977:MSPEIL>2.3.CO;2.

Ricker, W.E. 1954. Stock and recruitment. J. Fish. Res. Board Can. 11, 559-623.

Riley, S.C., He, J., Johnson, J.E., O'Brien, T.P., Schaeffer, J.S., 2007. Evidence of widespread natural reproduction by lake trout *Salvelinus namaycush* in the Michigan waters of Lake Huron. J. Great Lakes Res. 33, 917-921.

Riley S.C., Roseman, E.F., Nichols, S.J., O'Brien, T.P., Kiley, C.S., Shaeffer, J.S., 2008. Deepwater demersal fish community collapse in Lake Huron. Trans. Am. Fish. Soc. 137, 1879-1890.

Riley, S.C. [ED.]. 2013. The state of Lake Huron in 2010. Great Lakes Fish. Comm. Spec. Pub. 13-01. Ann Arbor, Michigan.

Riley, S.C., Ebener, M.P. (EDS)., 2020. The state of Lake Huron in 2018. Great Lakes Fish. Comm. Spec. Pub. 2020-01. Ann Arbor, Michigan. http://www.glfc.org/pubs/SpecialPubs/Sp20_01.pdf

Roseman, E.F., Riley, S.C., 2009. Biomass of deepwater demersal forage fishes in Lake Huron, 1994-2007: implications for offshore predators. Aquat. Ecosyst. Health Fish. Manag. 12, 29-36. DOI:10.1080/14634980802711786.

Rutherford E., 1997. Evaluation of natural reproduction, stocking rates, and fishing regulations for steelhead *Oncorhyncus mykiss*, chinook salmon *O. tschawytscha*, and coho salmon in Lake Michigan. Federal Aid in sportfish restoration, Project F-35-R-22, Final Report. Michigan Department of Natural Resources, Ann Arbor, Mich.

Schaeffer, J.S., Warner, D.M., O'Brien, T.P., 2008. Resurgence of emerald shiners *Notropis atherinoides* in Lake Huron's main basin. J. Great Lakes Res. 34, 395–403.

Sitar, S.P., Bence, J.R., Johnson, J.E., Ebener, M.P., Taylor, W.W., 1999. Lake trout mortality and abundance in southern Lake Huron, N. Am. J. Fish. Manag. 19(4), 881-900, DOI: 10.1577/1548-8675(1999)019<0881:LTMAAI>2.0.CO;2.

Smith, H.M., 1890. Report on an investigation of the fisheries of Lake Ontario. USDOC Fish. Bull. 10. Fisheries of Lake Ontario.

Smith, S.H., 1970. Species interactions of the alewife in the Great Lakes. Trans. Am. Fish. Soc. 99, 754-765. DOI:10.1577/1548-8659(1970)99<754:SIOTAI>2.0.CO;2

Solomon, C.T., Carpenter, S.R., Rusak, J.A., Vander Zanden, M.J., 2008. Long-term variation in isotopic baselines and implications for estimating consumer trophic niches. Can. J. Fish. Aquat. Sci. 65, 2191-2200.

Sudman, S., Bradburn, N.M., 1973. Effects of time and memory factors on response in surveys. J. Am. Stat. Assoc. 68, 805-815.

Syslo, J.M., Brenden, T.O., Guy, C.S., Koel, T.M., Bigelow, P.E., Doepke, P.D., Arnold, J.L., Ertel, B.D., 2020. Could ecological release buffer suppression efforts for non-native lake trout (*Salvelinus namaycush*) in Yellowstone Lake, Yellowstone National Park?. Can. J. Fish. Aquat. Sci. 77, 1010-1025.

Tanner, H.A., Tody, W.H., 2002. History of the Great Lakes salmon fishery: a Michigan perspective. Pages 139-154 *in* K.D. Lynch, M.L. Jones, W.W. Taylor, editors. Sustaining

North American Salmon: Perspectives Across Regions and Disciplines. Am. Fish. Soc., Bethesda, Maryland.

Tarrant, M.A., Manfredo, M.J., Bayley, P.B., Hess, R., 1993. Effects of recall bias and nonresponse bias on self-report estimates of angling participation. N. Am. J. Fish. Manag. 13, 217-222.

Taylor, B.W., 2007. The demographic bias of email as a survey method in a pediatric emergency population. Int. J. Med. Inform. 76, S392-S396.

Thayer, S.A., Loftus, A.J., 2012. Great Lakes recreational fisheries and their role in fisheries management and policy. Pages 399-440 i*n* W.W. Taylor, A.J. Lynch, N.J. Leonard, editors. Great Lakes fisheries policy and management: a binational perspective, 2nd edn. Michigan State University Press, East Lansing, Michigan, USA.

Tsehaye, I., Jones, M.L., Brenden, T.O., Bence, J.R., Claramunt, R.M., 2014. Changes in the salmonine community of Lake Michigan and their implications for predator–prey balance, Trans. Am. Fish. Soc. 143, 420-437, DOI: 10.1080/00028487.2013.862176.

Tucker, S., Moerke, A., Steinhart, G., Greil, R., 2014. First record of natural reproduction by Atlantic salmon (*Salmo salar*) in the St. Marys River, Michigan. J. Great Lakes Res. 40, 1022-1330. https://doi.org/10.1016/j.jglr.2014.08.009.

Volk, E.C., Bottom, D.L., Jones, K.K., Simenstad, C.A., 2010. Reconstructing juvenile Chinook salmon life history in the Salmon River Estuary, Oregon, using otolith microchemistry and microstructure. Trans. Am. Fish. Soc. 139, 535-549. DOI: 10.1577/T08-163.1.

Weber, S., Péclat, M., 2016. GEOROUTE: Stata module to calculate travel distance and travel time between two addresses or two geographical points. Statistical Software Components S458264, Boston College Department of Economics.

Wing, B.L., Masuda, M.M., Guthrie III, C.M., Helle, J.H., 1998. Some size relationships and genetic variability of Atlantic salmon (*Salmo salar*) escapees captured in Alaska fisheries, 1990-95. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-96, 32.

Worthington, T.A., Worthington, I., Vaughan, I.P., Ormerod, S.J., Durance, I., 2020. Testing the ecosystem service cascade framework for Atlantic salmon. Ecosys. Serv. 46, 101196.

Zahl-Thanem, A., Burton, R.J., & Vik, J. 2021. Should we use email for farm surveys? A comparative study of email and postal survey response rate and non-response bias. J. Rural Stud. 87, 352-360.