

An Assessment of the Impact of Algal Blooms on the Economic Contributions of Recreational Angling in the Michigan Waters of Lake Erie

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Executive Summary

Background: Since the 1990s, the frequency and intensity of harmful algal blooms (HABs) in Lake Erie have increased. A recent *National Geographic* article entitled, “Saving the Great Lakes” highlights HABs, and the changing climate and agricultural practices that contribute to the problem, as key challenges facing the Great Lakes (National Geographic 2020). In response to the 2013 Harmful Algal Bloom and Hypoxia Research and Control Act, the Federal Government has published a series of reports documenting research, technological, and management needs to combat HABs, most recently including NOAA’s report to Congress, *Harmful Algal Blooms and Hypoxia in the Great Lakes: An Interagency Progress and Implementation Report*. The report notes the increasing “size, duration, and prevalence of these scientifically-complex events in the Great Lakes region due to increased nutrient runoffs, mainly from nonpoint agricultural sources,” and states that “HABs and hypoxia cost the Great Lakes communities millions of dollars annually,” (NOAA 2020, 7). Despite the growing consensus on the main drivers of increasing HABs, analyses of the socio-economic impacts of HABs via their effects on recreational fishing in the Michigan waters of the Lake Erie are scarce. This is thus a key information gap of relevance to members of Lake Erie coastal communities as well as the stakeholders throughout Michigan and beyond that visit those communities.

Purpose: The purpose of this study was to assess the effects of mid-to-late summer algal blooms on the economic contribution of recreational anglers who fish the Michigan waters of Lake Erie. Specifically, the aim was to estimate the lost recreational fishing expenditures due to HABs, understand anglers’ preferences underlying their decisions about recreational fishing in response to HABs, and characterize the potential effect of these impacts on the economy of South East Michigan communities, especially those adjacent to Lake Erie. Recreational angling represents an important sector economically impacted by HABs, given its social, cultural, and economic value in general and for specific communities along the Lake Erie coastline. The economic impacts of HABs on recreational boating (other than fishing), sailing, beach-based recreation, marinas, municipal water intakes, commercial fishing, and other uses were not measured in this study. Also, the impacts reported here only pertain to the Michigan waters of Lake Erie, a relatively small area of that which is affected by HABs in all of Lake Erie.

Methods: This study applied a mixed methods approach to collect and analyze both qualitative and quantitative data and interlace that data with existing datasets characterizing recreational fishing in the Michigan waters of Lake Erie in 2019. To estimate forgone expenditures from HABs, a web survey of more than 500 respondents generated quantitative data on the number of fishing trips anglers cancelled due to HABs and anglers’ fishing expenditures. Creel survey data from the Michigan Department of Natural Resources Fisheries Division (MDNR) allowed the analysis to leverage survey results to estimate a range of total lost angler expenditures due to HABs in the Michigan waters of Lake Erie. The web survey also produced qualitative data on anglers’ attitudes and preferences underlying their decision-making in response to HABs. Finally, semi-structured interviews with charter boat captains constructed a qualitative account of the ways in which HABs impact the charter boat industry in Lake Erie.

Key Findings

- Survey respondents spent an average of \$225 per fishing trip on Lake Erie, including costs such as travel to and from the fishing site, fishing guide fees (charter boats), food and dining, hotels and other overnight accommodations, parking, having fish cleaned, bait, and ice, among other costs.
- Two thirds of survey respondents said that they had decided not to go fishing on Lake Erie due to the presence of algal blooms at least once in 2019. However, MDNR Creel survey data indicated only 26% of respondents cancelled trips due to HABs.
- Reasons for cancelling fishing trips during algal blooms included fear of negative health effects, not wanting to consume fish caught in an algal bloom, possible boat and equipment damage from blooms, perceived reductions in catchability (or the need to change locations to catch fish), and detriment to the aesthetic dimensions of the fishing experience.
- On average, survey respondents reported cancelling nearly 5 trips in 2019 due to algal blooms.
- The number of trips that anglers reportedly cancelled due to HABs represented between 12% and 29% of the number of trips they reported taking. Scaling this trip cancellation rate to total angler days reported by the MDNR Creel survey in the Michigan waters of Lake Erie for 2019 produced an estimated 8,755 to 21,398 cancelled fishing trips.
- Given reported per-trip expenditures, total lost expenditures for the 2019 fishing season in the Michigan waters of Lake Erie were estimated between \$1,969,875 and \$4,814,550.
- Applying an economic multiplier for dollars spent in fishing, hunting, and trapping for the South East region of Michigan (Calantone et al. 2019) implicates a potential economic impact between \$2,444,615 and \$5,974,857 in 2019.

Background

Algal blooms are overgrowths of microscopic algae that appear as scum, foam, or mats on the surface of the water in a variety of colors from green or yellow to brown, pink, or red. Some species of algae produce toxins that threaten human health, other organisms, and the broader aquatic ecosystems where they occur (Buteyko 2010), and blooms of these species are classified as harmful algal blooms. About one third of the 300 species of bloom-causing algae species are considered toxic (Hudnell et al. 2010). Density thresholds for the production of harmful effects differ from species to species, leading to variation in quantitative and operational definitions of HABs (Stauffer et al. 2019). But generally, HABs are defined as: “episodes during which large quantities of harmful forms of algae appear,” (Reutter et al. 2011 pp).

While algal blooms are a naturally occurring phenomena in most aquatic ecosystems, human-induced drivers are implicated in the accelerated frequency and severity of HABs (Paerl 2008). The formation of HABs is influenced by multiple factors including extreme weather events, non-native species and alterations to the natural food web, water pollution, climate change, water flow disruption, and nutrient loading from multiple sources, including urban and rural agricultural runoff (NSTC 2017). Phosphorous and nitrogen are essential nutrients for the growth of algae and are thus key limiting factors in the extent of HABs (Smith et al. 2015). Nutrient runoff and climate change, and the combination thereof, stand out as primary drivers of HABs, as algae biomass varies in response to the timing and magnitude of runoff events. Evidence suggests that HABs are increasing in frequency and severity in recent years due to climate change as more severe weather events are intensifying runoff and other environmental conditions that promote the growth of HABs (i.e., increasing frequency of storm events, warmer water temperatures, nutrient availability and light) (Gilbert et al. 2005; Graham et al. 2017; Buteyko 2010).

HABs occur in both inland and marine ecosystems. Of particular relevance to this report are the cyanobacterial HABs (cHABs) that occur in freshwater including Lake Erie. Reports of cHABs in freshwater environments throughout the US have been increasing in recent years, with the upper Midwest Plains and Great Lakes areas especially hard hit (Loftin et al. 2016; Carmichael and Boyer 2016). Cyanobacterial toxins cause a variety of health effects (Table 1). Cyanobacteria also cause water discoloration, unsightly and foul-smelling scums, hypoxia in the case of high biomass blooms, and they affect the taste and odor of drinking water (Lopez et al. 2008). HABs can negatively impact aquatic ecosystems through promoting reduction of dissolved oxygen, hypoxic conditions, and disruption of the food web (Graham et al. 2017; Gatz 2017). Toxins from HABs can also bioaccumulate in both aquatic and terrestrial wildlife as well as agricultural crops when affected water is used for irrigation (Brooks 2016).

A variety of economic costs and losses are associated with HABs, and the categorization of those costs varies from study to study. Categories include recreation and angling, shoreline property values, drinking water, irrigation and industrial water use, loss of biodiversity, commercial fisheries, public health, recreation and tourism, cultural benefits, and coastal monitoring and management (Smith et al. 2019; Anderson et al. 2000). This report focused specifically on estimating the economic costs from HABs associated with recreational angling in the Michigan waters of Lake Erie.

Table 1. Cyanobacterial toxins and associated human health effects. Source: Adapted from Lopez et al. (2008).

Toxin	Short Term Health Effects	Long Term Health Effects
Microcystins	Gastrointestinal, liver inflammation, hemorrhage and liver failure leading to death, pneumonia, dermatitis	Tumor promoter, liver failure leading to death
Nodularins	Similar to Microcystins	Similar to Microcystins
Saxitoxins	Tingling, burning, numbness, drowsiness, incoherent speech, respiratory paralysis leading to death	Unknown
Anatoxins	Tingling, burning, numbness, drowsiness, incoherent speech, respiratory paralysis leading to death	Cardiac arrhythmia leading to death
Cylindrospermopsin	Gastrointestinal, liver inflammation and hemorrhage, pneumonia, dermatitis	Unknown
Lipopolysaccharide	Gastrointestinal dermatitis	Skin tumors, unknown
Lyngbyatoxins		Potential link to neurodegenerative diseases
BMAA		Potential link to neurodegenerative diseases

A Brief History of HABs in Lake Erie

As the warmest and shallowest of the Great Lakes, as well as the most densely populated, Lake Erie is particularly vulnerable to HABs (Carmichael and Boyer 2016). In Lake Erie, the earliest reports of a major algal bloom occurred in 1931. Symptoms of stomach flu and gastroenteritis were associated with the bloom, indicating it may have produced toxins. From the 1950s to the 1960s, large-scale *Microcystis* bloom events (giving rise to the toxin microcystin) increased in frequency, with maximum biomass levels observed in late summer and early fall. Point-source phosphorus loading was believed to be the root cause. Peak levels of phosphorus entered the Lake in 1968, and the press highlighted HABs as evidence of Lake Erie's ecological decline (Morgan et al. 2014).

Throughout the late 60s and early 70s, phosphorus loading continued to negatively affect water quality and dissolved oxygen levels in Lake Erie until 1972, when the Great Lakes Water Quality Agreement was put forth by the US and Canadian governments. Specifically, this agreement aimed to cut phosphorus loading in half (Scavia et al. 2014). Subsequently, water quality improved, with reports of up to an 89% reduction in algae biomass in some parts of the Lake. In 1981, the target levels of phosphorus loading from both point and nonpoint sources were achieved, but interestingly dissolved oxygen levels did not recover as expected. Despite this, there were many more indications in the early 90s that the lake was improving, including thriving fish populations, decreased algal biomass, and improved sediment quality (Morgan et al., 2014).

Throughout the late 1980's and early 1990's, zebra and quagga mussels invaded the Lake Erie ecosystem (Scavia et al., 2014). During the same period, concentrations of soluble reactive phosphorus (SRP) increased each year, marking a second wave of serious effects of cyanobacteria on Lake Erie's water quality, with periodic HABs outbreaks (Smith et al. 2019; Morgan et al., 2014). It is difficult to isolate the

impact of zebra and quagga mussels, but many researchers believe they may have magnified cHABs blooms.

Since the late 1990s and early 2000s, HABs in Lake Erie have once again become regular annual occurrences (Smith et al. 2019). The greatest challenge faced by the region is the sharp increase of dissolved reactive phosphorus concentrations, which is the most available nutrient for algae, therefore promoting algal growth and the probability of harmful blooms (Hartig et al. 2008). In recent years (2008 to 2015) there have been six significant blooms in Lake Erie with toxic potential, and current blooms tend to occur between June 1 and October 31 almost every year. Dangerous levels of microcystin (above the World Health Organization's guidelines) have led to two shutdowns of municipal drinking water access. One of these occurred in 2013 in Carroll Township, Ohio. Another happened in 2014 in Toledo, Ohio, during which half a million people had drinking water access suspended (Brooks et al. 2016; Wynne & Stumpf, 2015). During the 2014 event, routine testing at the Collins Park Water Treatment Plant in Lucas County, Ohio found microcystin toxin levels in drinking water at three times the 1.0 microgram/L concentration threshold established by the Ohio Environmental Protection Agency and resulted in reported health problems (most commonly diarrhea, nausea, and vomiting, as well as anxiety and stress) among 16% of households participating in a needs assessment survey after the event (McCarty et al. 2016).

The major factors contributing to HAB events in Lake Erie are farming practices, weather events magnified by climate change, and the introduction of invasive species to the lake (Smith et al. 2015). Changes in regional agricultural practices such as increased demand for corn crops, which require more nutrient inputs, rising agricultural commodity prices, less diverse cropping systems and shorter crop rotation, and new types of fertilizer and application techniques, all potentially result in excess phosphorus availability (Smith et al. 2015). Changes in the climate affect seasonal precipitation and air and water temperatures, which can increase the "loading potential" and create more intense HABs (Collingsworth, 2017). Both phosphorus and nitrogen runoff contribute to the problem, although most regulatory efforts have been focused on phosphorus (Smith et al., 2015). As mentioned above, the presence of the invasive Zebra Mussel is believed to intensify bloom events when they occur. While many mussels filter algae, this species fails to consume algae with the potential to produce microcystin, while also contributing bioavailable phosphorus through excretion (Smith et al., 2015).

A previous Michigan United Conservation Clubs (MUCC) study found that hunting and fishing-related purchases in Michigan generate \$11.2 billion and support 117 million jobs, annually (Calantone et al. 2019). Visitors to Ohio's Lake Erie region spend more than \$10.7 billion per year, with \$2 billion spent on hunting and fishing opportunities. HABs negatively affect these economic contributions (Table 2). One study found that algal bloom advisories are associated with a 13.1% reduction in monthly fishing license sales, and based on these rates, a hypothetical three-month bloom (as occurred on Lake Erie in 2011) could potentially result in more than \$68,000 in losses in license sales in the state of Ohio (Wolf et al. 2017). Overall, analysis of the economic impacts and value reductions of HABs in Lake Erie are fairly sparse, with most studies pertaining to Ohio (e.g., Zhang & Sohngen 2018; Wolf et al. 2017; 2019) and a study on the Canadian Lake Erie Basin (Smith et al. 2019).

Table 2. Some recent studies on the economic impact of HABs in Lake Erie

Study	Economic dimension studied	Method/Approach	Findings
<p>Wolf et al. (2017)</p> <p>Scope: Ohio Lake Erie Anglers</p>	<p>Lost revenue from reduction in fishing license sales</p>	<p>Correlation between algae measures and monthly fishing permit sales</p>	<p>Fishing license sales drop 10% to 15% when algal conditions surpass WHO's moderate health risk advisory threshold of 20,000 cyanobacteria cells/mL</p> <p>For counties adjacent to Lake Erie, a summer-long algal bloom would result in 3,600 fewer fishing licenses issued and approximately \$2.25 million to \$5.58 million in lost fishing expenditures</p>
<p>Zhang & Sohngen (2018)</p> <p>Scope: Ohio Lake Erie Anglers</p>	<p>Willingness to pay for reduction in HABS</p>	<p>Mail survey and choice experiment</p>	<p>Anglers willing to pay \$8-10 more per trip for one less mile of boating through HABs to fishing site</p> <p>Anglers willing to pay \$65-\$96 per trip for improvement from murkier to clear water</p> <p>Anglers willing to pay an average of \$40-\$60 per trip of a policy that cuts upstream phosphorous loading by 40%</p> <p>The majority of welfare gains for anglers result from improving the non-catchable component of the fishing experience</p>
<p>Smith et al. (2019)</p> <p>Scope: Canadian Lake Erie Basin</p>	<p>Costs of HABs to recreational users, as well as other impacts</p>	<p>Modeling losses in household utility due to reduced recreational services</p>	<p>Algal blooms will impose equivalent annual costs equal to \$272 million in 2015 prices over a 30-year period if left unchecked, with the tourism industry suffering the largest market costs (\$110 million) and recreational users the largest non-market costs (\$115 million)</p>
<p>Wolf et al. (2019)</p> <p>Scope: Ohio Lake Erie Anglers</p>	<p>Consumer surplus of recreational anglers</p>	<p>Simulation based on latent class models of recreation choice</p>	<p>Recreational anglers would lose in aggregate \$69.1 million each year if water quality conditions became so poor as to close the Lake Erie Western Basin (as a result of both HABs and E. coli.)</p>

Research Questions

The purpose of this study was to assess the effects of algal blooms on the economic contribution of anglers who fish the Michigan waters of Lake Erie. While severe algal blooms can negatively impact Lake Erie basin communities in a number of ways, this research was focused on determining its effect on the contribution of recreational fishing. One of the purposes of this study is to inform policy-making; if the Michigan Legislature is to develop appropriate state policies related to algal blooms, it is critical for them to understand the effect that it has on the economic contribution of angling in Lake Erie watershed communities.

The study was designed to address the following research questions, all of which pertain specifically to the contributions of recreational anglers who fish in the Michigan waters of Lake Erie (Figure 1):

1. How do anglers describe the effect of algal blooms on their fishing experiences?
2. How do charter boat captains describe the effect of algal blooms on their businesses?
3. How do anglers change their fishing behavior (including cancelling fishing trips) in response to the presence of algal blooms?
4. What is the economic impact of changes in anglers' fishing behavior (i.e., reductions in expenditures due to trip cancellations) in response to the presence of algal blooms?

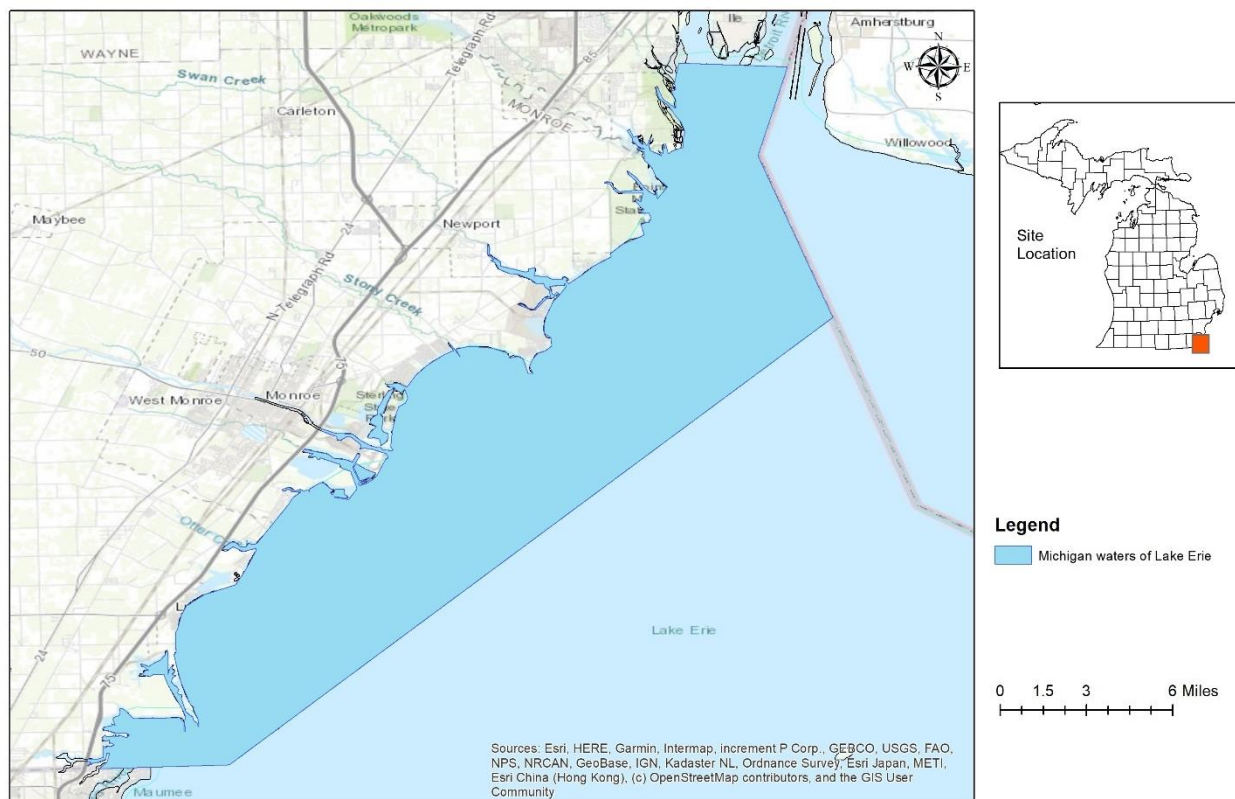


Figure 1. Map of the Michigan waters of Lake Erie. Source: Michigan Department of Natural Resources

Research Methods

Research Design

The data collected for this study pertained to the 2019 fishing season, the most recent fishing season at the time that data was collected for this study (March - June 2020). In 2019, the *Microcystis* cyanobacteria bloom in 2019 had a severity index¹ of 7.3, making it a relatively severe year for HABs (NOAA 2019). According to NOAA's 2019 *Lake Erie Harmful Algal Bloom Bulletin*:

The [2019] bloom developed rapidly and reached full intensity at the beginning of August [see Figure 4], a characteristic of recent blooms. The maximum areal coverage was about 700 square miles toward the end of August. Persistent strong winds in September kept the bloom down, causing a rapid decline with little bloom present in October. Like 2018, this is one of the earliest ends to the bloom we have seen. Scums were present in August but did not reach the scope of those observed in 2017 (NOAA 2019).

2019 is thus an appropriate year to examine relatively typical effects of HABs, given that it is among the 10 years out of the past 15 with significant bloom indexes, yet was not among the most severe during that period (NOAA 2019).



Figure 2. The *Microcystis* cyanobacteria bloom in western Lake Erie on August 5, 2019 taken with data derived from Copernicus Sentinel-3 data provided by EUMETSAT. This date captures the maximum biomass of the bloom. The greenish area along southwest Lake Erie and northeastward toward Canada is the bloom.

This study was undertaken using a mixed-methods approach, producing both qualitative and quantitative data. Quantitative data allowed the study to characterize:

- The number of fishing trips that respondents recalled taking during 2019;
- The number of fishing trips respondents recalled cancelling due to HABs in 2019; and
- Respondents' average expenditures per fishing trip

These data were then integrated with MDNR creel survey data on total fishing trips taken in the Michigan waters of Lake Erie during 2019 to estimate total fishing trips cancelled for the season and the

¹ The severity index measures bloom biomass over the peak 30 days of the bloom (NOAA, 2019).

related forgone expenditures. Additional descriptive quantitative data was used to describe relevant characteristics, attitudes, and preferences of the web survey sample.

Analysis of the study's qualitative data complemented the quantitative analysis by providing a rich account of the attitudes, preferences, and beliefs related to HABs reported by charter boat captains and recreational anglers. These data help to explain and interpret the quantitative data on angler fishing behavior and expenditures. Together, the quantitative and qualitative data provide an account of the impacts of HABs and the economic contributions of anglers of the Michigan waters of Lake Erie and anglers' decision-making processes underlying these impacts.

This study sought to understand the economic impact on Southeast Michigan (Genesee, Lapeer, Lenawee, Livingston, Macomb, Monroe, Oakland, Saint Clair, Washtenaw, and Wayne Counties). Indeed, the majority of expenditures studied in this report can be presumed to occur in the counties that abut the Michigan waters of Lake Erie, because that is where recreational fishing activity occurs. However, some expenditures (for example, gasoline for travel to launch sites), are likely to occur at points of origin or en route to launch sites. In this regard, it is worth noting that more than 70% of study participants (web survey respondents) live in Southeast Michigan (Figure 3). Just nine participants (1.7%) were from Ohio, one was from Ontario, and three were from elsewhere outside of Michigan. Among MDNR Creel survey respondents fishing the Michigan waters of Lake Erie in 2018², 85% of respondents were from Michigan and the rest were from Illinois (5), Indiana (9), Ohio (40), Wisconsin (3), and other states (6). Figure 4 shows that the Creel survey respondents who reported living in Michigan were concentrated in Southeast Michigan.

Data Collection and Analysis

Data was collected through a) semi-structured interviews with charter boat captains, and b) a web survey of recreational anglers who fished the Michigan waters of Lake Erie in 2019.

Semi-structured interviews

Semi-structured interviews were conducted with 14 charter boat captains who were selected using a snowball sampling method whereby captains were asked to provide the names of additional potential interview respondents. Original contacts were provided by key informants who knew charter boat captains through their experience working at the Michigan Department of Natural Resources. The interviews were conducted by phone and lasted about 30-45 minutes each. It is important to note that three of the charter boat captains interviewed fished out of Ohio exclusively and one charter boat captain fished out of Michigan and Ohio. However, their interview responses nonetheless provided insight into the general issue of how they and their clients reacted to HABs and potential effects on their businesses.

As is common practice in conducting semi-structured interviews, this study utilized an interview guide, which included a set of questions and prompts which were applied consistently across all interviews yet allowed the interviewer to pursue additional lines of questioning and relevant themes as they arose (Bernard 2018). The interview guide was developed to elicit the respondents' opinions on their personal history in the charter boat industry, how HABs have changed since fishers began their careers as charter boat captains, perceptions and reactions of their clients to HABs, and, relatedly, how HABs have affected

² The 2019 MDNR Creel survey mostly excluded the zip code question to adapt to the COVID-19 Pandemic.

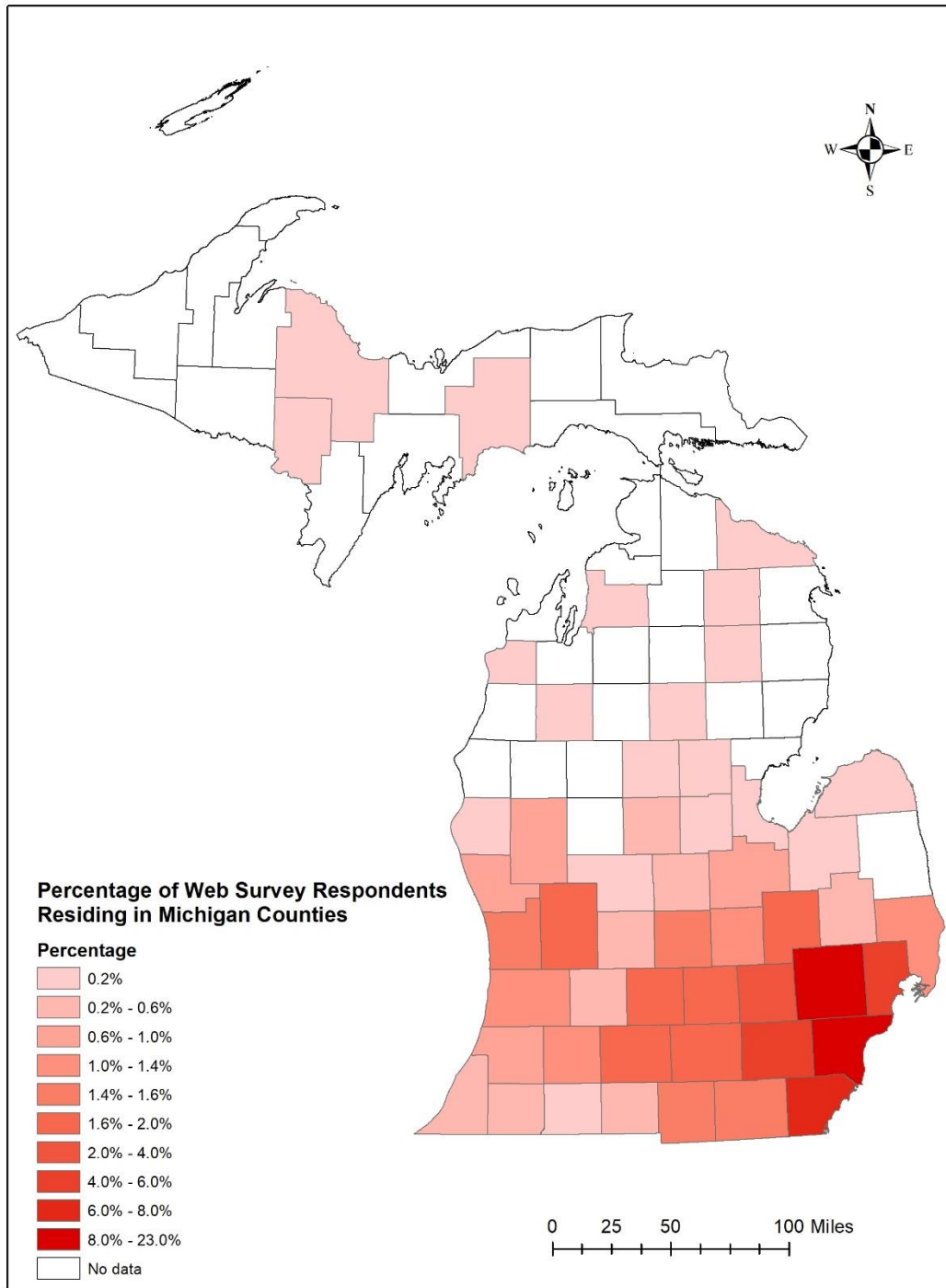


Figure 3. Map showing where web survey respondents live (Michigan counties).

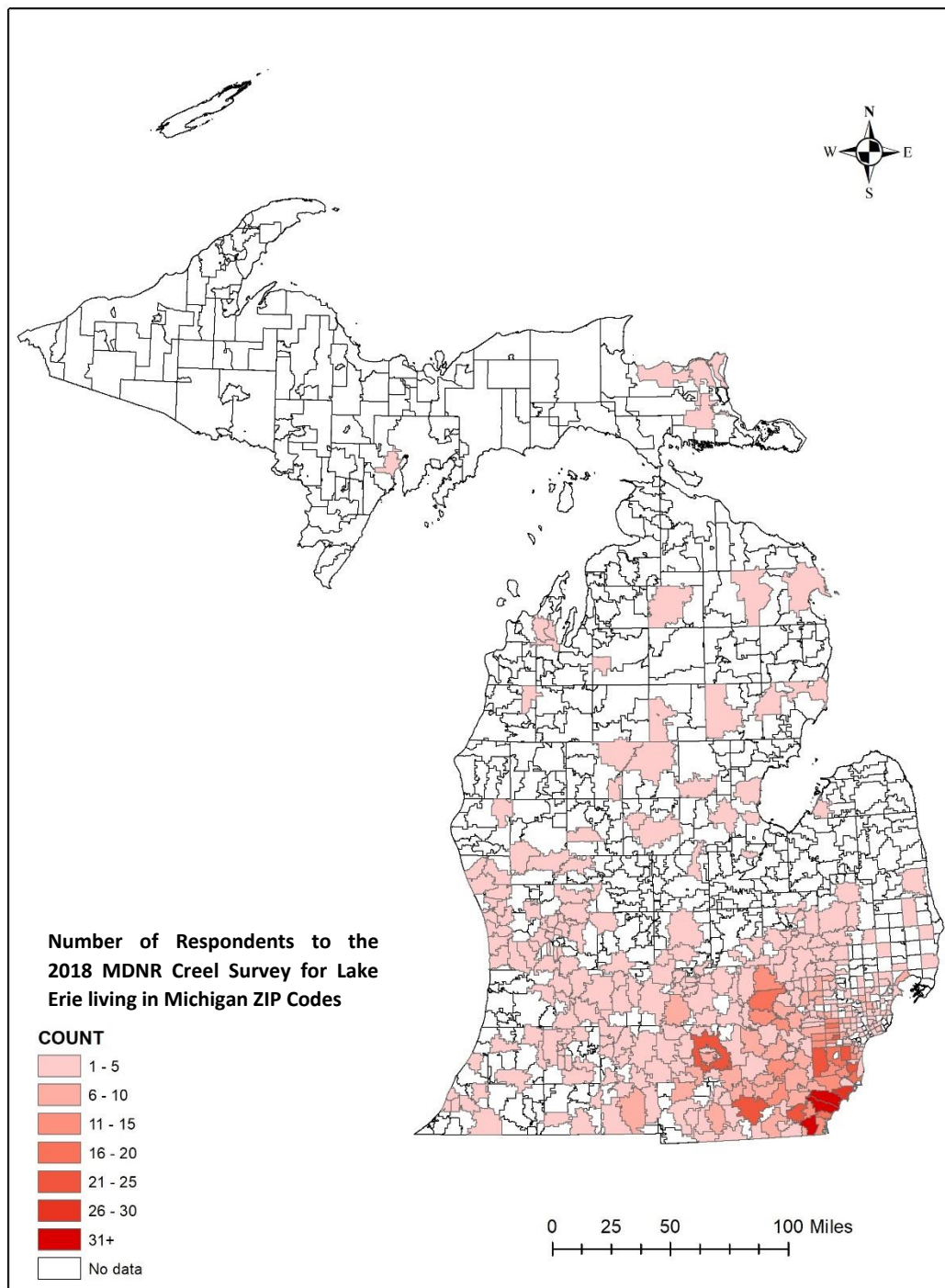


Figure 4. Map showing where MDNR Lake Erie Creel survey respondents live (Michigan ZIP codes).

their businesses. All 14 semi-structured interviews were audio-recorded and transcribed into word documents. Then, thematic analysis was conducted, sorting responses and identifying recurring themes related to impacts on charter boat business and clients' perceptions.

Web survey

A web survey was developed to generate four categories of data: 1) Demographic data about the respondents; 2) Basic information about respondents' fishing preferences and methods, in general and for 2019 specifically; 3) Fishing-related expenditures; 4) Attitudes, preferences, and beliefs related to algal blooms; and 5) Changes in fishing behavior in response to algal blooms. The questionnaire initiated by asking respondents whether they fished the Michigan waters of Lake Erie. A full list of survey items can be found in Appendix A.

The survey questionnaire was built in Qualtrics web survey software. A pilot version of the survey was sent to 8 known Lake Erie anglers who agreed to take it. Subsequently, 5 anglers participated in focus group discussions over Zoom to provide their feedback on the survey content, wording, structure, and timing. Accordingly, some adjustments were made to ensure ease of understanding, response input, and that responses appeared in a format amenable to the planned analysis.

The final version of the web survey was distributed via two listservs: the Michigan United Conservation Club³ email listserv and Metro-West Steelheaders⁴ email listserv. Recruitment also took place using a pinned post on two popular walleye discussion forums on Michigan Sportsman⁵ and Metro-Detroit Walleye Stalkers that anglers visit to post information and take part in discussions related fishing. Finally, recruitment at the 2020 Outdoorama⁶ show in Novi Michigan, on Friday, February 28, 2020 took place using a sign-up sheet at MUCC and Michigan Steelheaders booths. However, less than ten attendees signed up with their email addresses to receive a link to the survey. Survey respondents had an opportunity to provide their email address at the conclusion of the survey for the chance to win a gift card to Bass Pro Shops store via a raffle at the conclusion of the study.

The web survey was open for about four months, from early March to late June. During that time, the survey received 641 responses, of which 84 were incomplete, for a total of 557 completed questionnaires. Respondents took an average of 20.75 minutes to complete the survey. About 80% of responses were submitted in March, another 15% in April, and the remainder in May and June. About 70% of responses were from the Michigan United Conservation Clubs email listserv, another 23% from links in the Michigan Sportsman and Metro-Detroit Walleye Stalkers forums; and the remainder from the Metro-West Steelheaders listserv. As will be presented in the results section, responses from these three groups differed somewhat.

Quantitative survey data was cleaned and analyzed in using RStudio statistical computing software R Core Team (2020). Because some survey items had more responses than others, either due to incomplete surveys or because the item was not applicable to all respondents, the sample size (n) is

³ <https://mucc.org/>

⁴ <https://www.metroweststeelheaders.org/>

⁵ <https://www.michigan-sportsman.com/>

⁶ See: [outdoorama.com](https://www.outdoorama.com)

reported for the analysis of different survey questions in the results section. Qualitative data from the few open-ended questions included in the survey were analyzed thematically to identify themes related to anglers' attitudes toward HABs and reasons why they cancelled fishing trips due to HABs (for those respondents who indicated doing so).

Assessing the Effects of Algae Blooms on the Economic Contribution of Anglers

The effects of algal blooms on the economic contribution of anglers who fish in the Michigan waters of Lake Erie was estimated as follows (see Figure 5 below). First, the proportion of trips cancelled (due to HABs) to trips taken in 2019 was calculated from the survey responses. This proportion was then multiplied by the total number of angler trips in the Michigan waters of Lake Erie as reported by the 2019 MDNR Creel survey data, providing an estimate of the total number of trips that may have been cancelled in 2019, using the assumption that the responses of the survey sample are representative of the broader population of anglers fishing in the Michigan waters of Lake Erie Michigan. For various reasons detailed in the discussion section, this may be a problematic assumption. To interrogate the assumption, the authors of this study requested that identical survey items to be added to the 2020 Creel survey (asking respondents the number of trips cancelled due to HABs *in 2019*). This Creel data provides a percentage of respondents that cancelled at least one due to HABs and the number of trips that each of them cancelled. However, because the Creel data do not include information on the number of unique anglers, it is not possible to estimate the proportion of total trips cancelled based on the Creel data. Rather, it serves as a check to the trip cancellation rate found by the web survey. The estimate of 2019 total angler trips cancelled was then multiplied by the average trip cost reported in the web survey to estimate the total lost expenditures in 2019 due to HABs. Finally, economic multipliers calculated in a previous study on fishing, hunting, and trapping (Calantone et al. 2019) were applied to lost expenditures to provide a sense of the overall economic impact. Multipliers are estimates of the effect on a region's economy in terms of economic output per dollar spent (see Calantone et al. 2019).

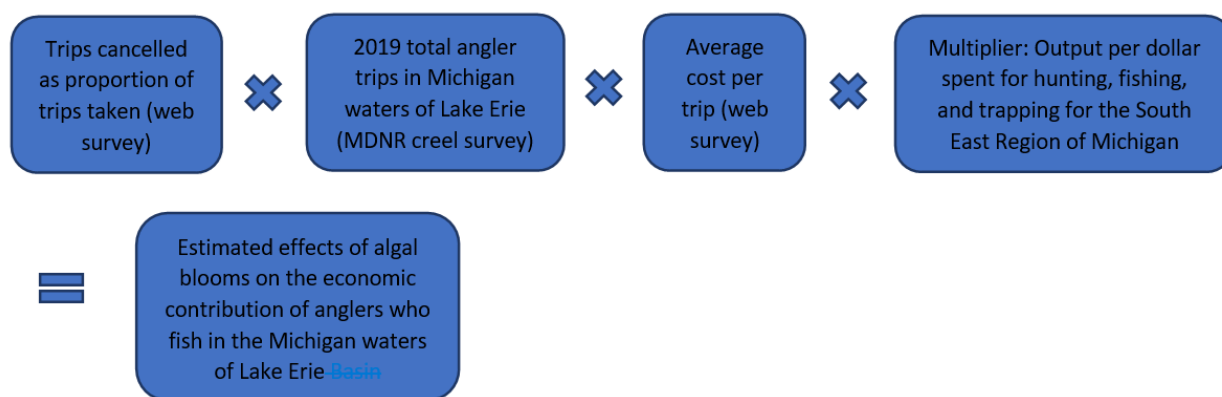


Figure 5. Approach to estimating the effects of algal blooms on the economic contribution of anglers who fish in the Michigan waters of Lake Erie

It is crucial to note that net value, rather than expenditures, is the accepted measure used in federal public policy decision-making to assess a project's potential contribution to economic development and, more broadly, economic approaches to cost-benefit analysis (Poe et al. 2013). The net value, also referred to as utility or consumer surplus, of a resource is "the difference between the amount an

individual would be willing to spend to access the resource and the amount that they actually have to pay for gasoline, lodging, entry fees, and food at the recreation site and other trip-related costs,” and therefore is distinct from expenditures and economic impact (Poe et al. 2013, 3). Thus, while the aim of this study was to evaluate changes in the economic contributions of anglers who fish in the Michigan waters of Lake Erie (hence the focus on evaluating lost expenditures and economic impact) this report also takes up a brief discussion of potential impacts on net value for recreational anglers.

Impacts of the COVID-19 Pandemic on study methods

Data collection activities for this study coincided with the beginning of the COVID-19 pandemic in the US and related policies restricting travel and in-person interactions in the state of Michigan. All semi-structured interviews were therefore collected by telephone. The interview guides were adapted to provide charter boat captains an opportunity to discuss the impacts of COVID-19 on their business, as this was a very prominent issue for them during the time of the interviews. Focus groups discussions providing feedback on the web survey were conducted over Zoom. The web survey was distributed and completed online. Ideally, the study would have included on-site interviews with anglers, but travel restrictions during the data collection period precluded this approach. Questions asked of anglers during the creel survey were conducted in person by MDNR personnel at boating access sites using social distancing and other safety protocols. Overall, however, the COVID-19 pandemic created only minimal disruptions to data collection. Because respondents were primarily recalling behavior from the 2019 fishing season, it is unlikely that responses were substantially affected by the COVID-19 situation.

Results

Charter Boat Captains’ Perceptions of HAB impacts

This section describes themes that emerged from charter boat captains’ interview responses. Throughout the section, charter boat captains are referred to by a number in lieu of their names to preserve their anonymity.

The charter boat captains interviewed described the ways that they perceive HABs affecting the fishing experience, fish behavior, their business, and the broader economy. Their responses varied with respect to how serious of an impact they perceived HABs as having, which may in part reflect differences in the species they tend to target, where they fish, and their general approach to the charter boat business. Regardless of these differences, all except one charter boat captain interviewed perceived negative impacts on their business from HABs.

The most direct negative impact from HABs that the charter boat captains reported was a reduction in clients and trips. For example, Captain 2 recalled his 2019 season:

"A good example is last year. You know...we are the walleye capital of the world. We have more walleye than anyplace else in the world. Our fishing is that good, and people aren't aware of it. Last June, I fished every day I could. In June, every single day I ran. There was, I think, four or five days I couldn't because of big winds, we can't go. We started getting a bloom there right around the fourth of July. I only ran six charters in July. I ran zero in August," (Captain 2).

Multiple respondents (e.g., Captains 2, 6, 8, and 11) pointed to the role of media coverage in influencing clients' decisions to book or cancel trips:

"It affects us drastically. If the news is going crazy and telling people as they do every now and again that their skin's going to melt when they touch the water, you know, that affects us pretty poorly...The year the news went crazy in Ohio, when they said you couldn't drink the water, you couldn't do this...the year that happened my business probably cut by 30%" (Captain 6).

Other charter boat captains said that customers actively seek out information on HABS when deciding whether to book fishing trips. According to one captain, "They hear it from us or they call bait shops...they'll say 'screw it, we won't even go out,'" (Captain 4). Only one charter boat captain (Captain 7) said he experienced no negative impacts while another (Captain 13) stated that he had not been in the business long enough to determine whether there had been a change.

Charter boat captains that work in Lake Erie throughout the season reported being more impacted by HABS than those who work elsewhere later in the summer. As Captain 15 explained, "You know, when the algae blooms are at their worst, the fish are usually up in Canada in the cooler waters...that's when I'm over in west Michigan chasing salmon...so they don't really affect me that much." But another captain explained, "but us guys who do not leave, like me and a few other guys, you know, we're sitting there for about two, three weeks every year not being able to do anything," (Captain 1). Almost all charter boat captains agreed that those who target perch were more negatively affected than those who primarily target walleye. Captain 1 noted "it's had a big detriment on the perch population. I mean, our perch fishing's almost non-existent last fall."

Another captain who works all year in Lake Erie stated that, while he used to run 150 trips per year, he now only runs from 85 up to 100 trips on a good year. He explained:

"See, what's going on with the algae – the fishing's really good every year until July and then it starts dropping off and it used to be our best month, August was our second-best month and September was our third-best month and that's all gone. You can catch a few fish, but the people don't want to work that hard for 'em. So, basically, the end of July and on, the business drops off severely," (Captain 9).

The same captain explained how devastating such a reduction in business can be:

"What you really need for a charter boat is a diesel 30 footer and it's \$150,000 to start. Then you've got equipment and everything else so you're going to have a floorplan of about 200 grand and that's okay if you can run 120 trips a year, you'll do fine. But if you're down to 60, 80, you ain't gonna make nothing," (Captain 9).

Multiple captains (4, 6, 8, 9, 11, 12, 13, 15) discussed the need to change fishing locations because of HABS and the costs associated with them, for example:

"Well, the algal blooms are devastating to our industry...it's devastating to our industry due to the fish migrate faster out of our area and thus we have, you know, less fish to work with, people don't like to see the green, there's a lot of negatives to it...I've actually had to compensate my business to move to the east during...August to September to accommodate my customers to be able to have the proper opportunity to catch fish. Well, you know it – I would say a standard year with an algal bloom first of all costs me an additional mound of money to travel to other areas leaving my area – I leave my area to fish, I take money away from where I live," (Captain 11).

Another charter boat captain explained:

"Sometimes we've got to go out like 15 miles just to try to find some clearer water. Cause you could try fishing in there, which we have just screwing around and you that body bait or that lure or whatever you're pulling, if it's not right in front of is nose, you're not going to catch no fish," (Captain 4).

The captains attributed changes in the location of good fishing to ecosystem interactions from HABs, for example hypothesizing that walleye follow prey away from blooms (Captain 9) or that oxygen depletion alters the timing of migration, for example Captain 13, who explained, "I think it depletes the oxygen and the fish migrate west earlier than what they used to." In addition to poor fishing, captains feel the need to avoid HABs areas for their clients' sake. As Captain 6 put it, "It's unsightly and it stinks, you know what I mean? ...so I end up going further from shore to get away from that more than anything else." Accessing locations free from HABs may be especially difficult for captains with smaller fishing boats who may be hesitant to go out as far.

In addition to negative perceptions by clients, Captains 12 and 13 described the potential effect of HABs on their boats, for example:

"Nor do I like the mess that it makes out of my boat. It's been known to actually, when we're trolling out there for fishing, when we get into the really bad stuff it's known to block up the screens on our transmissions and overheat transmissions on our engines so it's pretty devastating, I mean that can cost us a ton of money," (Captain 12).

As another captain explained, "I love to fish so much, but I hate to run that water through my engine," (Captain 13).

According to charter boat captains, clients, and even some captains themselves, are afraid or unwilling to consume fish caught in or around HABs (Captains 6, 9, 11, 12, 13, 14). For one charter boat captain who focuses on perch, the consumption issue was substantial enough that he feels a duty to inform clients of conditions ahead of time:

"Well, I'm always honest to them and I tell them that if it's green, we're not going to go. I think it's just a waste of time because if they're not going to be able to keep the fish...I'm not all about taking your money. I want you to come back here year after year," (Captain 14).

Another explained “well, I can’t take a customer out in that water and tell them that fish is safe to eat as it comes through green slime,” (Captain 12). Finally, the charter boat captains were aware of the potential for the negative aesthetic impact of HABs to drive away clients. They used descriptions such as “pea soup,” (Captains 1, 14) and “it resembles breaking up toilet paper,” (Captain 12).

Nonetheless, a couple of charter boat captains said that most of their clients are not as turned off by HABs, for example one who explained that “occasionally we get a few calls, people worried about it or actually cancelling, but the overall numbers of people asking about it...as long as we’re catching fish it doesn’t seem to really affect that part of it. As far as clients go, as long as we’re catching fish [they’re happy]” (Captain 5).

Web Survey Results

Basic Information about the Sample of Anglers Responding to the Survey

The average age of survey respondents was just under 59 years of age, with a range of 20 to 88 years of age. The vast majority (96%) of respondents were male, with only 12 female respondents of the 542 who reported gender. Respondents had an average of about 30 years fishing experience, with a range from 4 years to 72 years fishing.

Fishing Preferences and Behavior

Almost all respondents target walleye (549, n=578), 98 of whom targeted walleye exclusively. Perch was the next most common target species. While three quarters of the respondents (436) said that they target perch, only 8 said that they do so exclusively. Almost 15% of respondents (86) target bass, while 75 respondents said they target “whatever’s biting” and 33 mentioned other species, including carp, bluegill, crappie, catfish, darters, minnows, shiners, madtoms, and gar.⁷ Nearly all (97%) of respondents prefer to consume at least some of the fish that they catch from Lake Erie.

The most common type of fishing reported was fishing on a privately-owned boat (78%) or that of a friend or family member (46%), followed by charter boat fishing (18%) and dock fishing (11%). Most respondents (58%) only did one type of fishing, with 32% doing two types of fishing and only 9% and 1% doing three and all four types of fishing, respectively.

The average number of times that respondents fished recreationally on Lake Erie in 2019 was 41, with a median of 15 times, a minimum of 4 and a maximum of 187 times (n=562). Just over one quarter (148 respondents) reported fishing more than 100 times on Lake Erie in 2019.

Perceptions of Algal Blooms

Almost four fifths of respondents said that they sought information on the presence of algal blooms when planning to go fishing on Lake Erie, while 119 (21%) said that they do not (n=554). Websites (e.g., NOAA and MODIS satellite images, Facebook fishing groups, Michigan-Sportsman.com, Limnotech, Metro-Detroit Walleye Stalkers, MDNR) bait shops, friends, and charter boat captains served as sources

⁷ The authors of this study acknowledge that it is highly unlikely that madtoms and some other species would be targeted in Lake Erie and therefore question the veracity of this particular response, which was provided by one respondent, who indicated that he targeted “catfish, darters, minnows, shiners, madtoms”.

of information for the respondents. More than three quarters of respondents (435, n=554) reported having observed an algal bloom on Lake Erie, while 128, or 23%, had not (n=555).

The questionnaire asked respondents to rank a number of factors (weather conditions, wind conditions, water conditions, algae blooms, personal reasons, and fishing reports) as either “very important” “somewhat important” or “not important” in deciding whether to go fishing on Lake Erie on a given day. About 90% respondents said that algal blooms were either somewhat or very important, with more than half saying that algal blooms were a very important factor in their decision of whether to fish on a given day (Figure 6).

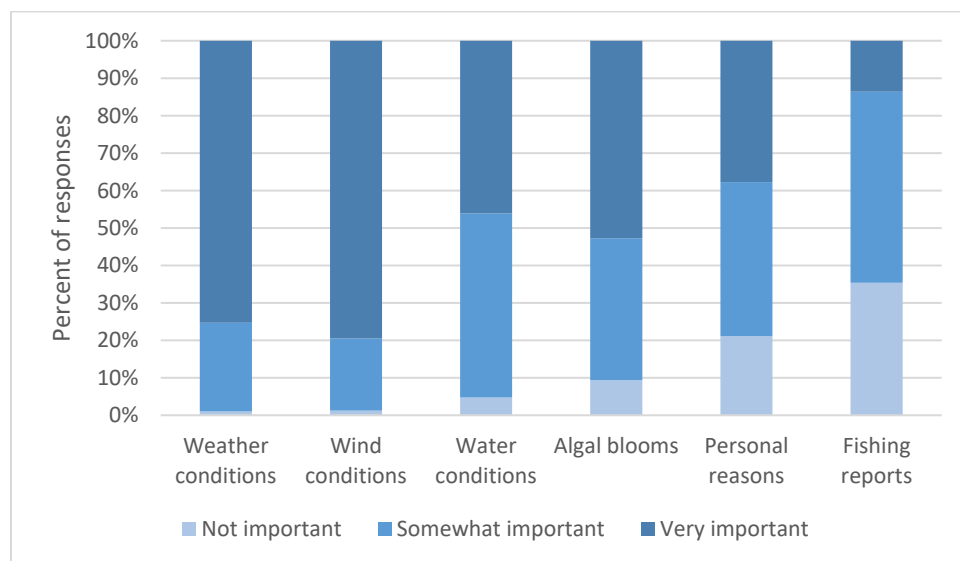


Figure 6. The importance of different factors in deciding whether to fish on a given day

Behavior in Response to Algal Blooms

The main behavioral responses to HABs of interest in this study were decisions about fishing methods, fishing locations, and, most importantly, whether or not to fish in the first place. Less than half of respondents (226, or 42%, n=542) said that the presence of an algal bloom has influenced them to alter how they fish on Lake Erie, for example: adapting fishing gear or methods based on presence and severity of HABs. One respondent explained, “We catch walleye and perch in algae bloom areas. You just have to vary our methods because the bloom affects the amount of light getting through to deeper depths. Change your lures/bait and you’ll be successful. Many others provided similar explanations, such as “Have to change tactics based on light penetration during bloom.”

Most respondents (429, or 75%, n=538) said that algal blooms influence where they fish. By way of explanation, respondents wrote in comments such as “seeking out cleaner / clearer water, more time on water traveling farther,” or “we do not fish there; we choose another area or go to a different lake.” Similar explanations were common.

Two thirds of respondents (363, or 66%, n=553) said that the presence of algal blooms has contributed to them deciding not to go fishing on Lake Erie. Among them, the most prominent reasons given were fear about the health effects of fishing in an algal bloom and not wanting to eat fish that came from an

algal bloom (109 respondents expressed such concerns). Many used the term toxic, writing responses like, “It’s TOXIC. Don’t touch the water,” and “It’s disgusting and toxic.” Respondents explained that their concerns of toxicity made them not want to eat the fish, writing statements such as “Toxic conditions affect safety of fish caught,” “I’m worried about the fish being contaminated,” “I’m not hungry enough to eat fish that come out of that algae,” and “not appetizing sight when you bring a perch up through that mess.” Effects on anglers’ desire to consume fish are important to consider, recalling the result reported above that 97% of survey respondents stated they prefer to consume at least some of the fish they catch. Besides stating they fear negative health effects, (e.g., “I don’t know what damage or health risks are associated with it,”), some respondents actually reported experiencing physical consequences, stating for example that it “causes me to cough and be worried,” “my eyes burn,” and, more generally, “I don’t like the way I feel after fishing in these conditions.”

The second most common reason that respondents provided for algal blooms having contributed to them deciding not to go fishing was equipment damage (91 respondents articulated this justification). As one respondent put it, algae “plays havoc on my boat and equipment.” Many were worried about effects on their motors. One respondent explained, “[I] have an inboard motor and am not running algae through my manifold and risers.” Others complained about having to clean the algae off their boats. “Don’t want to slime up a \$100,000 boat,” one respondent wrote. Some other respondents complained that the algae affects many different parts of the boat and fishing gear, for example one stated that it “ruins line, gear, stains boat, trailer, and seats, could not use live wells.”

Many respondents (73) indicated that algal blooms affect the fishing itself. A few respondents indicated that, “it negatively affects perch fishing,” while others suggest that it affects walleye as well, saying “the fish stop biting, especially perch and walleye. It shuts down completely.” Others made comments such as, “You wouldn’t be able to catch fish anywhere near the algae bloom,” “Fish don’t bite,” and “the fish have moved out.” Only a few respondents provided explanations for how they thought the algal blooms affected catchability, for example, “algae bloom means oxygenated water⁸, less forage base, and less game fish,” and “fish can’t see the baits when the algae is thick...so I move to cleaner water.”

Decisions not to go fishing were also shaped by the aesthetic or experiential impacts that algal blooms have on fishing (69 respondents). Aesthetic considerations usually went along with the other above-mentioned factors. Respondents wrote statements such as, “visually unpleasant. Usually goes hand in hand with poor fishing results,” “no fish, no swimming, just plain nasty,” and “smells bad, attracts bugs, its terrible.” Respondents compared the water during an algal bloom to “fishing in a swamp,” and, like some of charter boat captains, “pea soup.”

Usually, respondents pointed to a combination of reasons discussed above. As one angler listed, “stains boat, fishing is not good, smells terrible, reported health issues from algae.” These statements help to explain why algal blooms have influenced so many anglers not to go fishing when HABs are occurring. Respondents reported the effects on the fishing experience in multiple ways including increased equipment-related hassle and cost, impacts on the fishing itself, reduced benefits such as eating fish, creation of anxiety around health effects, and diminished overall enjoyment of the experience. These

⁸ The authors of this report suggested that the respondent meant to write “de-oxygenated water”.

multiple effects seem to come together to negatively affect the entire fishing experience. One respondent put it simply by stating that fishing in an algal bloom is “just not my idea of a good time.”

On average, survey respondents reported cancelling an average of nearly 5 trips (4.84, n=569), including those who cancelled no trips. Over one third (35%) of respondents reported cancelling no trips in 2019, a figure quite similar to the 34% who said that algal blooms have not ever contributed to them deciding not to go fishing on Lake Erie. Among just those respondents who cancelled at least one trip, the average number of trips cancelled was 7.5 during the 2019 season, with a range from 4 to 48 cancelled trips.

Web survey results on the proportion of anglers who cancelled trips due to HABs in 2019, and the number of trips cancelled due to HABs in 2019, were substantially higher than the results based on the same in-person questions asked during the 2020 Creel survey (which like the web survey asked respondents about their behavior during the 2019 fishing season). In contrast to the web survey results above, 26% of creel survey respondents who were asked reported cancelling fishing trips due to HABs in 2019 (n=226). The number of trips they cancelled ranged from 1 to 20. The average number of trips cancelled per respondent, including those who reported not cancelling any trips, was 1.73.

The total number of Lake Erie fishing trips cancelled in 2019 among web survey respondents (n=569) was 2,778 trips. The total number of Lake Erie fishing trips that the respondents reported taking in 2019 was 23,004 trips. Hence, the number of trips cancelled represents about 12% (12.07%) of reported trips taken. The sum of trips taken and trips cancelled (25,760 trips) provides an estimate of the hypothetical total number of trips among survey respondents had algal blooms not been a factor on Lake Erie in 2019. Interestingly, if this same procedure is applied to each individual respondent, then the number of trips cancelled per respondent represents, on average, 29.5 percent of the trips they did take, or 17 percent of the sum of trips taken plus trips cancelled. This suggests that those who take more trips in general may be cancelling a lower proportion of trips than those who take fewer trips, thus driving down the survey-wide proportion of trips cancelled compared to the average individual-level cancellation rate. In other words, avid anglers may be less deterred by algal blooms than the more occasional anglers. This phenomenon might also somehow relate to recall bias.

Fishing Trip Expenditures

Respondents reported the average expenditures per trip on different categories of costs associated with fishing trips, including travel to and from the fishing area, boat fuel, boat rental, bait, parking fees, hotels and other overnight accommodations, food and dining, having fish cleaned, ice, gear, and other costs. The mean, standard deviation, minimum, and maximum reported average per-trip costs for these items are reported in Table 3. Fishing Trip Costs in U.S. dollars by Category for All Data (N=569) are shown in Figure 7. Fishing Trip Costs by Category for All Data (N=569). Costs in U.S. dollars. Boxes represent interquartile range and median and points represent outliers. Separate responses were requested for each type of fishing if respondents indicated they participated in multiple types of fishing (e.g., charter boat fishing and fishing on a private vessel). Those cost categories that do not occur for all types of fishing (e.g., charter boat fees; boat fuel) are included in the “Other” category. Additional costs that respondents explicitly listed in the “Other” category include items such as tips for charter boat captains, power washing of boats, and prorated maintenance fees, as some examples.

Initial analysis of the trip costs revealed substantial outliers in the gear category. The survey question on average expenditure on gear per trip was intended to capture variable costs related to, for example, hooks, lures, and other gear that may be purchased as inputs to a single fishing trip. However, it was clear that some respondents did not interpret this question as such because there were figures of \$500, \$1,000, \$2,000 and even \$30,000 and \$50,000 reported. In order to address this problem and to avoid inflating estimates of per-trip costs, the decision was taken to remove the gear category entirely and replace gear costs with a flat rate of \$12 for all respondents. Note this is substantially lower than the \$354 average gear costs based on survey responses for private vessel fishing, for example. The amount of \$12 was based on expert solicitation with a long-time Lake Erie angler, and would include items such as hooks, lures, and other incidental gear that might be purchased for a single fishing trip.

Overall, the average cost per trip across all fishing types was \$225, with a standard deviation of 462 (n=569). Amounts spent on different categories differ somewhat across respondents who were recruited through the three different lists (Michigan United Conservation Clubs listserv, Metro-West Steelheaders listserv, and Michigan-Sportsman.com forum) (Figure 8), reiterating the need for future comparison between responses to this survey and the MDNR creel survey (see survey methods section). The total cost per trip reported by each respondent was multiplied by the number of trips that respondent cancelled to assess the cost of cancelled trips per respondent, which equaled \$1,204 (Table 3). Note that for respondents who reported per-trip costs for more than one category of fishing, the average of those different per-trip costs was taken for the purposes of this calculation.

Table 3. Fishing Trip Costs in U.S. dollars by Category for All Data (N=569)

	Mean	S.D.	Min	Max
Travel	42	54	0	500
Bait	31	62	0	540
Parking	6	18	0	300
Hotel	24	70	0	1000
Food	30	78	0	1600
Cleaning	11	211	0	5020
Ice	6	12	0	155
Other	63	257	0	4300
Gear	12	0	NA	NA
Average Cost per trip	225	462	NA	NA
Average Cost of all Cancelled Trips in 2019 per Respondent ⁹	1204	4952	NA	NA

Characterizing the Effect of HABS on Lake Erie Anglers' Economic Contributions

As described in the methods section, the approach to evaluating the effect of HABS on Lake Erie anglers' economic contributions to Southeast Michigan and beyond (see Figure 3 and Figure 4) is to combine key

⁹ The average cost of cancelled trips was calculated by multiplying the average cost per trip for a respondent by the number trips that he or she cancelled.

figures from the web survey with MDNR creel data to estimate the total lost revenues due to cancelled fishing trips to the Michigan waters of Lake Erie in 2019. Recall from above two key figures: The average cost (or expenditure) per trip per angler, \$225, and cancelled trips as a proportion of trips taken, 12.07% (the cancellation rate, herein).

To estimate the potential number of trips cancelled by the general population of anglers fishing the Michigan waters of Lake Erie, the total number of angler trips taken in the Michigan waters of Lake Erie in 2019 (72,537 angler trips) was multiplied by the above-mentioned cancellation rate (12.07%), yielding an estimated potential 8,755 cancelled trips for the 2019 season. Alternatively, when the respondent-level average cancellation rate is applied (29.5%) this yields an estimated potential 21,398 cancelled trips for the 2019 season. Thus, there were a potential 8,755 to 21,398 cancelled recreational fishing trips to the Michigan waters of Lake Erie in 2019.

Applying the average cost per trip reported by the web survey respondents (\$225) would imply lost expenditures for 2019 in the range of \$1,969,875 and \$4,814,550.

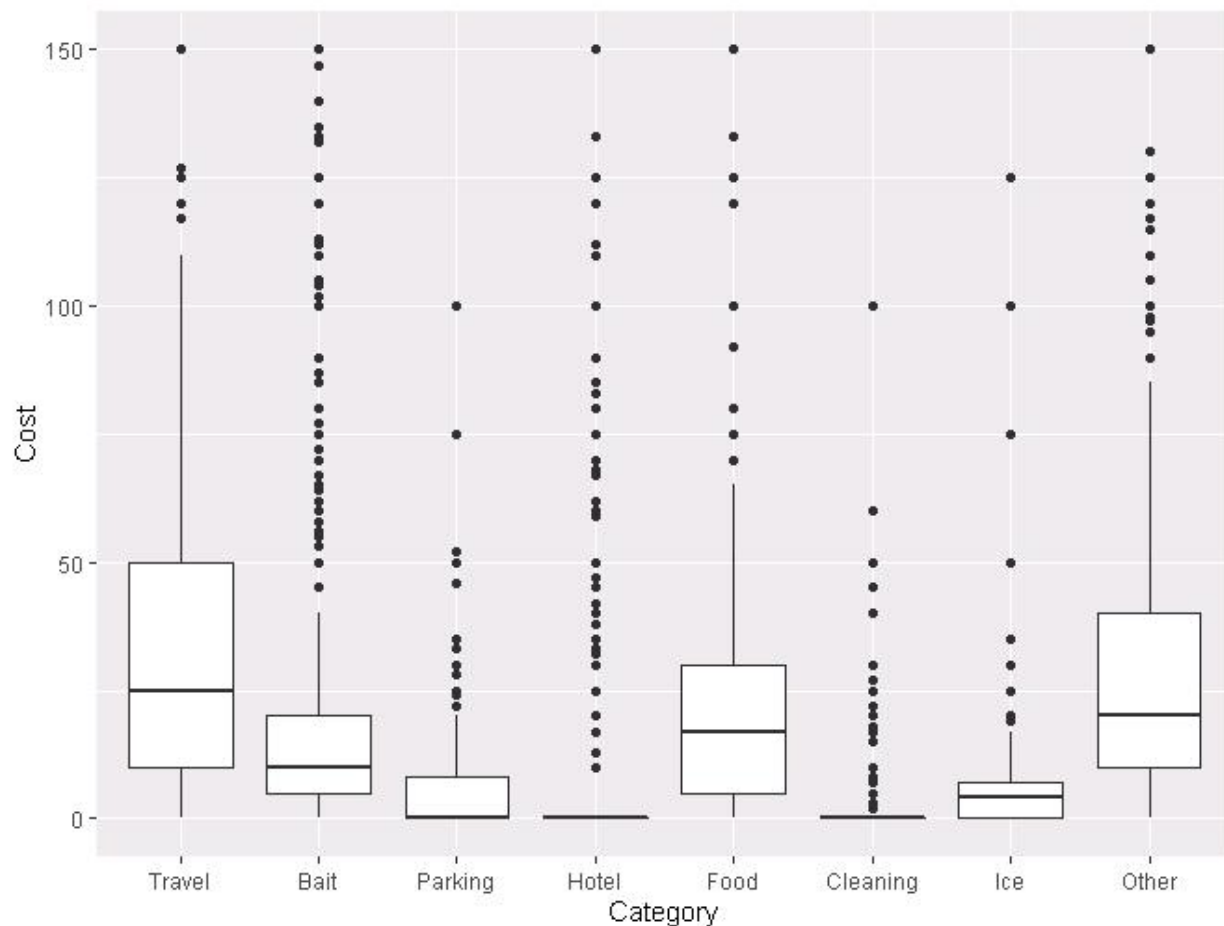


Figure 7. Fishing Trip Costs by Category for All Data (N=569). Costs in U.S. dollars. Boxes represent interquartile range and median and points represent outliers.

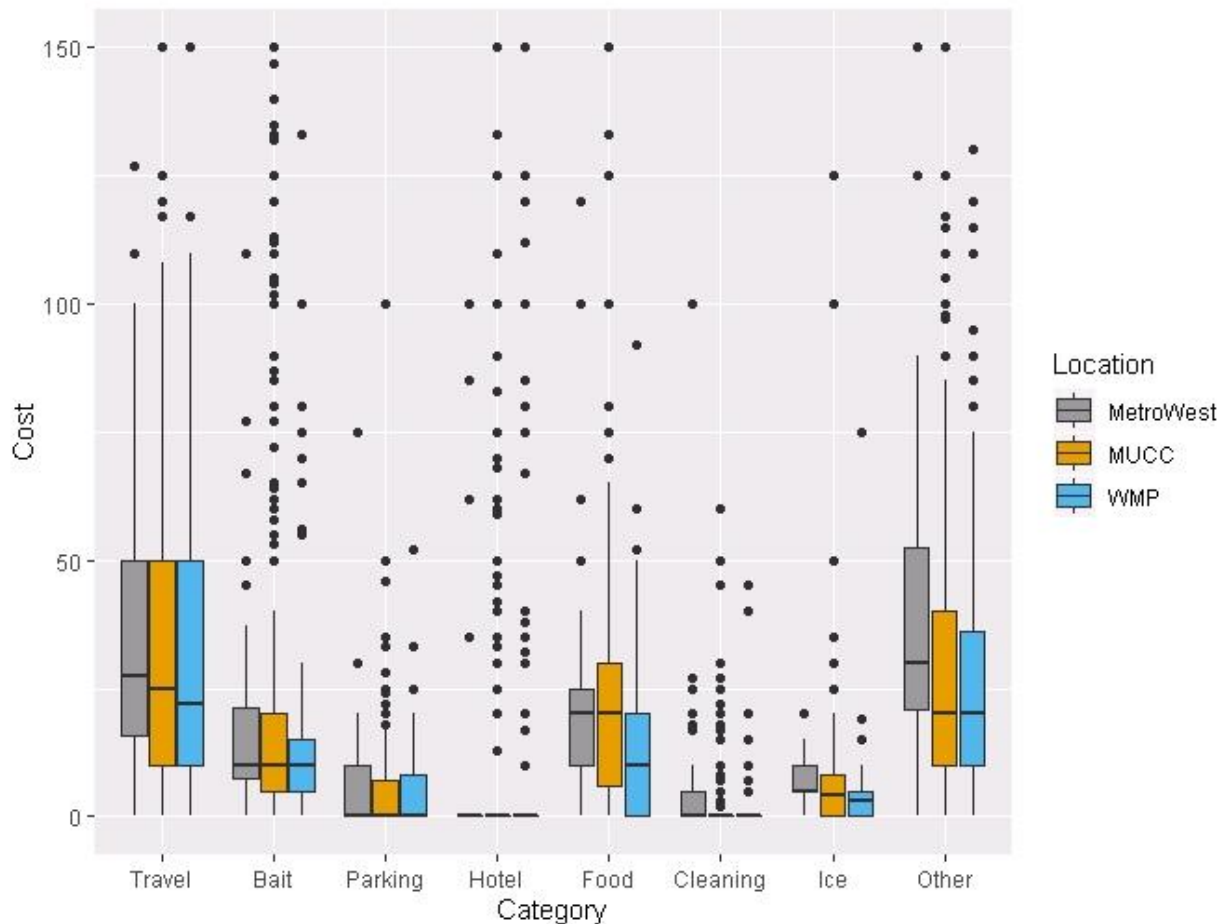


Figure 8. Fishing Trip Costs by Category for All Data (N=569) Subdivided by Recruitment Source. Boxes represent interquartile range and median and points represent outliers. Note: MetroWest = Metro-West Steelheaders email listserv, MUCC = Michigan United Conservation Clubs listserv, and WMP = Michigan-Sportsman.com fishing web forum.

Economic Impact

Finally, applying the economic multiplier for dollars spent in hunting, fishing, and trapping in the South East Region of Michigan (1.241) brings a potential economic impact to the region between \$2,444,615 and \$5,974,857 as a result of fishing trips cancelled due to HABs in 2019. These economic multipliers are intended to quantify the contribution to the regional economy (across all industries) for every dollar spent in hunting, fishing, and trapping. See Calantone et al. (2019) for a detailed explanation about the development of this and other multipliers for the region.

Discussion

The results of this study indicate that the impacts of HABs on the economic contributions of anglers who fished in the Michigan waters of Lake Erie in 2019 are somewhere in the order of about USD \$2 million to USD \$6 million. The economic impact can be interpreted in the context of the overall value of Great Lakes recreational fishing, which is estimated in the range of \$393 million to \$1.47 billion (2012 USD) (Poe et al. 2013), or \$438 million to \$1.64 billion in 2019 USD.

It is important to consider various sampling issues and their contribution to potential bias in the results of this study. Because the survey was distributed online to groups known to include Lake Erie anglers, the sample of respondents was non-random. It is possible that the sampling approach introduced bias into the responses. Specifically, it is possible that survey respondents are more avid anglers than the average Lake Erie angler, given their participation in online listservs and/or web forums related to angling. At this time, the study authors do not have a basis for predicting which way this would bias the results. On one hand, avid anglers may be more bothered by HABs than more casual anglers, and this could translate into cancelled trips. On the other hand, avid anglers may be more likely to continue fishing in spite of the presence of HABs, which could translate into fewer cancelled trips. Importantly, it is the proportion of cancelled trips relative to trips taken in 2019 that was used to assess expenditure reductions in this study, which could potentially mitigate any bias introduced regarding the number of trips taken and cancelled.

At the same time, comparison with MDNR Creel survey results suggest that web survey respondents may be more likely to cancel trips than the general population of anglers who fished the Michigan waters of Lake Erie in 2020. The difference in the proportion of web survey respondents who reported cancelling at least one fishing trip due to HABs in 2019 (66%) trips and the proportion of Creel respondents who were interviewed in person and reported cancelling at least one fishing trip due to HABs in 2019 (26%) is substantial. A couple of explanations seem plausible. First, as discussed above, the web survey sample may over-represent more avid anglers. Another potential explanation is that there was some self-selection bias of respondents into the web survey. In other words, respondents who were most concerned about the issue of HABs could have been those more likely to take the survey. The precise language used to recruit respondents to take the web survey appeared as follows:

Lake Erie anglers' fishing experiences: A short survey

Researchers from the Department of Fisheries and Wildlife at Michigan State University, together with Michigan United Conservation Clubs, are conducting a study to understand if Lake Erie anglers' fishing experiences are changing and what role – if any – algal blooms play in those changes.

Although HABs were not deliberately mentioned in the title, the description does indicate that algal blooms are a topic of the survey. Therefore, it is possible that the web survey responses suffered from selection bias.

Another explanation could relate to memory gaps in those responding during the creel survey. Respondents to the web survey reported their results primarily during the first few months of 2020 when the open water fishing season in that year had not yet started. They were asked to respond to questions regarding the most recently completed fishing season (2019), and the HABs effects had been only 5 or 6 months previous. Also, they could complete the questions at their leisure on-line, taking time to remember the events of the previous summer. A vast majority of the web responses were completed in March and April (95%) of 2020 - before or at the very beginning of the open-water fishing season. However, the creel survey questions were asked during the summer of 2020, by a clerk in-person at access sites, and respondents were asked to recall whether they cancelled trips and how many trips they

cancelled due to HABs from nearly an entire year prior (in 2019). It may be that fishing trips conducted are more likely remembered better than trips cancelled. In this regard, it is worth highlighting that recall bias regarding fishing effort (number of trips taken) has been shown to trend toward increasing over-reporting with greater time elapsed since the event being recalled (Connelly et al. 2000).

These results can also be contextualized in the context of a 2014 mail survey conducted with Lake Erie anglers from Ohio requesting information about the 2013 fishing season. Respondents to that survey took an average of 17.6 trips per year. Among respondents 16% reported not going fishing in response to HABs in 2013, while more than half of those respondents reported changing their behavior due to HABs, including changing their fishing location, not taking a trip, or altering the amount of time spent fishing (Sohnngen et al. 2015). Note that the severity of HABs in 2013 is roughly comparable to that in 2019 (NOAA 2019).

Trip costs data as calculated based on the web survey responses appear to be slightly higher than that reported in other studies. Data from a mail survey of Ohio anglers reported average expenditures per trip at around \$88 (around \$95 in 2019 USD), and using travel cost models, found the average trip value (consumer surplus, rather than expenditures) to be \$39 in the western basin (Sohnngen et al. 2015). Melstrom and Lupi determined the value of recreational fishing day trips at around \$30.¹⁰ Note that these studies did not include costs of charter boat fishing.

The qualitative data presented in this report provide insight into why respondents cancelled trips and changed their fishing behavior, and ultimately reduced their expenditures, due to HABs. According to the data, many anglers indicated that HABs impact the fishing/catchability itself, foul equipment, cause health concerns, inhibit desire to consume fish that are caught, and decrease the overall enjoyment of the fishing experience. The economic impact of water quality on fishing experiences in Lake Erie has been evaluated elsewhere. A study of Ohio anglers found they are willing to pay up to \$40 to \$60 per fishing trip for a policy that would reduce the dissolved reactive phosphorus loadings from Maumee by 40% (Wolf et al. 2017). Statements about the water quality and the negative impact of HABs on the aesthetic dimensions of the fishing experience are not idle complaints. Indeed, a different study found that typical Ohio Lake Erie recreational anglers are willing to pay between \$65 and \$96 per trip for water quality improvements from murkier to clearer water (Zhang and Sohnngen 2018).

This study provided an estimate of economic impact, which when interpreted with the appropriate cautions, can be useful to provide a sense of lost expenditures and their implications for the broader regional economy. This approach represents an important piece of the puzzle in understanding the impact of HABs on local economies. Although changes in utility or consumer surplus tend to be used in formal cost-benefit analyses for policy decision-making, there is a substantial scarcity of data for calculating these figures and various assumptions would need to be made regarding how HABs impact consumers' willingness to pay for recreational fishing experiences (see Smith et al. 2019). Indeed, the qualitative analysis of this study illuminating the multifaceted reasons why HABs impact the value of

¹⁰ Recall that the net value, also referred to as utility or consumer surplus, of a resource is "the difference between the amount an individual would be willing to access the resource and the amount that they actually have to pay for gasoline, lodging, entry fees, and food at the recreation site and other trip-related costs," and therefore is distinct from expenditures and economic impact (Poe et al. 2013, 3)

recreational fishing experiences should prove useful in informing future models of HABs impact on the value of recreational fishing. For example, the impact of catch has been studied (e.g., Melstrom and Lupi 2013) as well as water quality (e.g., Zhang and Sohngen 2018), but the combination of these and other factors such as equipment damage, ability to consume fish, etc. have not been considered together in a single function.

A very rough calculation of lost consumer surplus could be made by multiplying the estimated total number of trips cancelled from this study by estimated consumer surplus from other studies. For example, Poe et al. (2013) estimated the net value of one day of recreational fishing in the Great Lakes between \$20 and \$75 (2012 USD), or \$22 and \$84 in 2019 USD. Using the low end of estimated cancelled recreational trips in 2019 (8,755) generates an estimate of \$193,610 to \$734,420 in lost consumer surplus based solely on cancelled trips. Note, however, that these figures do not account for reductions in the value of the trips that were taken in spite of the presence of HABs.

Finally, although this evaluation of economic impact does not assess reductions in value, it provides some insight into how particular communities that rely in part on the recreational fishing industry may be impacted. The current study was concerned with the economic impact resulting from the perceptions and behavior of anglers who fish in the Michigan waters of Lake Erie. It is reasonable to assume that much of the economic impact occurs close to those Michigan waters, for example reductions in expenditures in hotels and restaurants proximate to boat launch sites. However, this will not have been the case for all expenditures. Consider, for example, the cost category of “travel to and from the fishing site”, which may involve spending both at anglers’ various points of origin as well as their destination near Lake Erie. The maps in Figures 2 and 3 illustrate where respondents to the web survey and MDNR creel survey reside, which in turn provides a sense of the geographic scope of economic impact. The MDNR creel survey included more respondents from outside of Michigan than the web survey, including from states as far as Texas and Arizona.

By the same token, it was beyond the scope of this study to determine where, if anywhere, anglers did spend money when they cancelled their trips to fish the Michigan waters of Lake Erie. It is possible, for example, that when anglers cancelled trips to Lake Erie, that they fished Lake Michigan instead, or took part in alternative recreational activities in Michigan. Without this information, it is impossible to specify the scale of economic impact – whether economic activity simply shifted to a different area of Michigan, out of the state, or into a different sector.

In summary, this report indicates, both qualitatively and quantitatively, that HABs negatively impact the fishing experience of most recreational anglers who use the Michigan waters of Lake Erie. Although the web survey may have generated unrepresentatively high estimates for the proportion of trips cancelled in 2019, the results nonetheless demonstrate that there is a significant economic impact from HABs, especially to the communities abutting the Michigan waters of Lake Erie including the charter boat industry, bait shops, convenience stores, and other service industries that derive livelihoods from recreational fishing.

The economic impact suffered from HABs as a result of changes in recreational anglers’ desire to fish the Michigan waters of Lake Erie represents just one facet of the overall impact of HABs for the area, which

spans a variety of sectors including tourism, food and beverage industries, other non-fishing recreation, as well as housing prices. As reviewed in this report, Smith et al. (2019) found that in Ohio, the effect of HABs in Lake Erie on the value (household utility) across multiple sectors could produce annual costs equal to \$272 million (in 2015 prices) over a 30-year period if nothing is done to address the HABs issue. There is no similarly comprehensive study for industries associated with Michigan's Lake Erie waters. However, this report provides one initial piece of the puzzle. Not only does the survey analysis of this report provide a dollar value estimate of the economic impact for Southeast Michigan, but anglers' responses to open-ended questions about how and why they are affected speak volumes. For most respondents, HABs fundamentally change the fishing experience. Anglers come to the Michigan waters of Lake Erie for more than to catch fish. They also come to enjoy the experience of being outside in a beautiful setting, enjoying the fresh air and the camaraderie with others. And if successful, they enjoy coming together for a meal of fresh caught fish with their families. When the water looks like pea soup and smells worse, and health concerns preclude eating the fish they catch, Michigan's families do not get the same value out of recreational fishing.

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Appendix A. Web Survey Items

A Background – participation in Lake Erie angling

A1 Do you fish recreationally on the Michigan waters of Lake Erie?

☐ Yes

☐ No

A2 For how many years have you been fishing on Lake Erie?

A2.1 In 2019, what kind of fishing license did you purchase?

☐ Resident Annual \$26

☐ Nonresident Annual \$76

☐ Senior Annual \$11

☐ 24-hour \$10

☐ 72-hour \$30

☐ Military License \$0

☐ Other (Please specify)

A3 What species do you target when fishing on Lake Erie? (Check all that apply)

☐

Walleye

☐

Perch

☐

Bass

☐

Whatever's biting

☐

Other (Please specify)

A4 Do you prefer to consume at least some of the fish you catch?

☐ Yes

☐ No

A5 How many times did you fish recreationally on Lake Erie in 2019?

A6 Compared to 5 years ago, the number of times you fished in 2019 was:

☐ About the same

☐ Much Higher

☐ Slightly higher

☐ Much lower

☐ Slightly lower

Display This Question:

If Compared to 5 years ago, the number of times you fished in 2019 was: = Much Higher

A6.1 Why do you think it was much higher?

Display This Question:

If Compared to 5 years ago, the number of times you fished in 2019 was: = Slightly higher

A6.2 Why do you think it was slightly higher?

Display This Question:

If Compared to 5 years ago, the number of times you fished in 2019 was: = Much lower

A6.3 Why do you think it was much lower?

Display This Question:

If Compared to 5 years ago, the number of times you fished in 2019 was: = Slightly lower

A6.4 Why do you think it was slightly lower?

A7 How important are the following factors to you when deciding whether or not to go fishing on Lake Erie:

	Not at all important	Moderately important	Very important
Weather conditions	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Wind	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Algae/Algae Blooms	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Personal Reasons; work, time available, etc.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Fishing Reports	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Water conditions	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

B1 What kind of fishing do you do on Lake Erie? (Check all that apply)

- ☐ Charter boat fishing
- ☐ Fishing from docks
- ☐ Fishing from my own personal vessel/private boat (including rented boat)
- ☐ Fishing from a boat owned by a friend, family member or personal acquaintance

B1.1 Economic contributions

The following questions will be asking for amounts in USD (US dollars). Please report your individual costs only (i.e., not the total costs for all participants in the fishing trip).

Display This Question:

If What kind of fishing do you do on Lake Erie? (Check all that apply) = Charter boat fishing

B2 For an average day of **charter boat fishing** on Lake Erie, how much do you spend on:

- ☐ Travel to and from fishing area?
- ☐ charter boat fees?
- ☐ bait?
- ☐ fishing gear?
- ☐ parking fees?
- ☐ hotels or other overnight accommodations?
- ☐ food and dining?
- ☐ having your fish cleaned?
- ☐ ice?

If What kind of fishing do you do on Lake Erie? (Check all that apply) = Charter boat fishing

B2.1 For an average day of **charter boat fishing** on Lake Erie, what other costs do you incur?
Write \$0 if no other costs.

- ☐ Amount (\$):
- ☐ Please specify those other costs:

Display This Question:

If What kind of fishing do you do on Lake Erie? (Check all that apply) = Fishing from docks

B3 For an average day of **fishing on the docs** on Lake Erie, how much do you spend on:

- ☐ Travel to and from fishing area?
- ☐ bait?
- ☐ fishing gear?
- ☐ parking fees?
- ☐ hotels or other overnight accommodations?
- ☐ food and dining?
- ☐ having your fish cleaned?
- ☐ ice?

Display This Question:

If What kind of fishing do you do on Lake Erie? (Check all that apply) = Fishing from docks

B3.1 For an average day of **fishing on the docs** on Lake Erie, what other costs do you incur?
Write \$0 if no other costs.

- ☐ Amount (\$):
- ☐ Please specify those other costs:

Display This Question:

If What kind of fishing do you do on Lake Erie? (Check all that apply) = Fishing from my own personal vessel/private boat (including rented boat)

B4 For an average day of fishing on your **private vessel/boat (including rented boat)** on Lake Erie, how much do you spend on:

- ☐ Travel to and from fishing area?
- ☐ boat rental?
- ☐ bait?
- ☐ fishing gear?
- ☐ boat fuel?
- ☐ parking fees?
- ☐ hotels or other overnight accommodations?
- ☐ food and dining?
- ☐ having your fish cleaned?
- ☐ ice?

Display This Question:

If What kind of fishing do you do on Lake Erie? (Check all that apply) = Fishing from my own personal vessel/private boat (including rented boat)

B4.1 For an average day of fishing on your **private vessel/boat** (including rented boat) on Lake Erie, what other costs do you incur? Write \$0 if no other costs.

- ☐ Amount (\$):
- ☐ Please specify those other costs:

Display This Question:

If What kind of fishing do you do on Lake Erie? (Check all that apply) = Fishing from my own personal vessel/private boat (including rented boat)

B4.2 For an average day of fishing on your **private vessel/boat** on Lake Erie, how many other individuals accompany you?

Display This Question:

If What kind of fishing do you do on Lake Erie? (Check all that apply) = Fishing from a boat owned by a friend, family member or personal acquaintance

B5 For an average day of fishing on a **boat owned by a friend, family member or personal acquaintance** on Lake Erie, how much do you spend on:

- ☐ Travel to and from fishing area?
- ☐ bait?
- ☐ fishing gear?
- ☐ boat fuel?
- ☐ parking fees?
- ☐ hotels or other overnight accommodations?
- ☐ food and dining?
- ☐ having your fish cleaned?
- ☐ ice?

Display This Question:

If What kind of fishing do you do on Lake Erie? (Check all that apply) = Fishing from a boat owned by a friend, family member or personal acquaintance

B6 For an average day of fishing on a **boat owned by a friend, family member or personal acquaintance** on Lake Erie, what other costs do you incur? Write \$0 if no other costs.

- ☐ Amount (\$):
- ☐ Please specify those other costs:

C Algal blooms experience

According to the National Oceanic and Atmosphere Administration (NOAA), Harmful Algal Blooms occur when algae grow out of control and produce toxic and harmful effects.

When they “bloom” it can cause serious harmful effects to fish, mammals, birds and even humans. The majority of HAB species are phytoplankton, which are microalgae (microscopic, single-celled algae) or cyanobacteria. Harmful Algal Blooms are distinct from larger weeds found in the water.

C1 Have you ever observed an algal bloom on Lake Erie?

- ☐ Yes
- ☐ No

C2 When you are planning to go fishing on Lake Erie, do you try to obtain information about whether there is currently an algal bloom?

- ☐ Yes
- ☐ No

Display This Question:

*If When you are planning to go fishing on Lake Erie, do you try to obtain information about whether ...
= Yes*

C2.1 What **sources** do you use to obtain information about whether there is currently an algal bloom on Lake Erie? (Check all that apply)

- ☐ Online website (specify)
- ☐ Friend
- ☐ Bait Shops
- ☐ Charter Boat captains

C3 Has the presence of an algal bloom ever contributed to you deciding **NOT** to go fishing on Lake Erie?

- ☐ Yes
- ☐ No

Display This Question:

If Has the presence of an algal bloom ever contributed to you deciding NOT to go fishing on Lake Erie... = Yes

C3.1 Is there any reason in particular that the presence of an algal bloom contributed to your decision **NOT** to go fishing?

C4 Has the presence of an algal bloom ever influenced you to alter **WHERE** you fish on Lake Erie?

- ☐ Yes
- ☐ No

C5 Has the presence of an algal bloom ever influenced you to alter **HOW** you fish on Lake Erie (for example, fishing gear or methods)?

☐ Yes

☐ No

C6 **How** does the presence of algal blooms affect your fishing experience?

C7 Please estimate the number of fishing trips you **cancelled** because of algal blooms in 2019:

C8 What **concerns** do you have related to algal blooms?

C9 Are there any other **comments** you wish to make? (Optional)

D Demographic Information (Optional)

D1 Gender:

☐ Male

☐ Female

D2 Age: (Fill in)

D3 Place of residence:

☐ Michigan

☐ Ohio

☐ Ontario

☐ Other

Display This Question:

If Place of residence: = Michigan

D3.1 County in Michigan:

D4 To enter the raffle for a Bass Pro Gift Card, please enter your email. Your email will **not** be stored alongside the responses.