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Fishing in greener waters: understanding the impact of harmful algal blooms on Lake Erie anglers and the potential for adoption of a forecast model

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Abstract

Harmful algal blooms (HABs) pose public health risks worldwide, because of the toxins that they can produce. Researchers have explored the impact of HABs on local economies, but know relatively about the decision-making that informs these behaviors that lead to financial losses. Understanding the factors that inform this decision-making is critical to developing mitigative solutions. This study seeks to understand how HABs in Western Lake Erie affect angler decision-making, before evaluating a possible decision-support tool—a harmful algal bloom forecast known as the Experimental Lake Erie HAB Tracker. The HAB Tracker provides a nowcast and five-day forecast of the spatial distribution and transport of *Microcystis*, the predominant species of harmful algae in Western Lake Erie. Data collected using focus groups and surveys were coded to identify key themes that influence angler decision-making. The theory of the diffusion of innovations provides an analytical framework to evaluate the potential for widespread adoption of the HAB forecast among Lake Erie anglers. Analysis of emerging themes revealed that Lake Erie anglers face three key decision-points when fishing in HABs: whether to fish, where to fish, and whether to eat the fish. Five primary variables factored into angler decisions on where and whether to fish including 1) perceptions of HAB aesthetics, 2) perceptions of the impact of HABs on angler health, 3) perceptions of the impact of HABs on fish, 4) communication methods, 5) perceptions of HABs by customers of charter captains. Most participants in this study sought to avoid fishing in HABs primarily for aesthetic reasons. Recreational anglers are more likely than charter captains to adopt the HAB Tracker as a decision-support tool, because it is compatible with their information needs and provides a relative advantage over existing sources of information. Charter captains are less likely to adopt the HAB Tracker, because they rely on their existing knowledge and social network for HAB information. If researchers can reduce the complexity of forecast information while increasing its accessibility and reliability, then all anglers will be more likely to adopt a HAB forecast as a decision-support tool while fishing in Lake Erie during bloom season.

Key Words
Harmful algal bloom; Lake Erie; Fishing; Stakeholder engagement; HAB Forecast

1. Introduction

Cyanobacteria are a natural part of global aquatic ecosystems. Yet given conditions with high nutrient concentrations and warm temperatures, toxin-producing cyanobacteria can reproduce rapidly to form large colonies known as harmful algal blooms (HABs). HABs are found in many nutrient-rich waterbodies worldwide, including every coastal state in the U.S. and all of the Great Lakes (NOS, 2017). Western Lake Erie provides a particularly favorable environment for HAB growth primarily in the shallow western basin, which receives its main nutrient load from the Maumee River (Kane et al., 2014). The blooms in Lake Erie are predominantly composed of *Microcystis*, a cyanobacterium that can produce a group of toxins called microcystins. *Microcystis* poses ecologically complex problems with substantial negative impacts to the public. Swimming in water contaminated with microcystin may result in irritation to the skin, eye, and throat (W.H.O., 1999), while ingestion may cause fever, headache, stomach cramps, vomiting and weakness (Carmichael, 2001; Carmichael and Boyer, 2016). In August 2014, the city of Toledo issued a “do not drink” order when microcystin contaminated the water supply, creating a water shortage among private citizens and industries. Over $200,000 was spent per month for extra powdered activated carbon treatment to recover Toledo’s drinking water system (Ohio EPA, 2012).

In addition to providing drinking water to 11 million people, Lake Erie also supports an economically important fishery (Lake Erie LaMP, 2011), which is threatened by the increasing size and frequency of HABs. A study by Wolf et al. (2017) concluded that between $2.25 million and $5.58 million in fishing license revenue could be lost during a large, summer-long algal bloom. The impact of microcystin on fish and those who eat contaminated fish is an active area of research. The Ohio Department of Health advises that fish caught during a bloom are safe to eat, as long as the organs are not eaten and citizens follow general advisories for fish consumption (Ohio Department of Health, 2017). The study that informs this recommendation found that although microcystin may accumulate in fish livers, it does not appear to accumulate in muscle tissue (Wilson et al., 2008). In a 2014 survey of Lake Erie recreational anglers, 65% of 553 respondents reported that their fishing behavior changed because of HABs in Lake Erie (Sohngen, 2015). Behavior changes included changing fishing locations, deciding not to fish, or spending less or more time fishing. Researchers have explored the socio-economic impact of HABs on Lake Erie fishing communities (Bingham, 2015; Wolf, 2017; Zhang and Songhen, 2018). However, existing studies have not explored the decision-making that motivates behaviors that lead to financial losses. Understanding the factors that inform this decision-making is critical to development of mitigative solutions. Developing mitigative tools for anglers to continue fishing despite the blooms has become essential as managers and policy makers work to develop long-term strategies for bloom reduction through domestic action plans (US EPA, 2018). We sought to meet this need through a systematic inquiry of the impacts of HABs on Lake Erie anglers, and the potential utility of a harmful algal bloom forecast to support angler decision-making.

Knowing where and when HABs occur in western Lake Erie may help anglers to avoid areas with dense blooms during trip planning, while enabling continued fishing in clearer areas of the lake. The Experimental Lake Erie Harmful Algal Bloom (HAB) Tracker can provide this information (Figure 1). The HAB Tracker is a next-generation research version of the forecast model in National Oceanic and Atmospheric Administration's (NOAA) operational Lake Erie Harmful Algal Bloom Bulletin (Wynne et al., 2013). The HAB Tracker shows the location of HABs in Lake Erie, how big they are, and where they are likely headed. Similar to a weather forecast, this tool provides a daily HAB nowcast showing present conditions, and a five-day forecast of the surface concentrations and vertical distribution of the blooms in Lake Erie. The location of the bloom is re-initialized in the model when cloud-free satellite images are available, usually 2-3 times per week. The model is initialized using the cyanobacterial index retrieval from a sensor on NASA's Aqua and Terra satellites, the Moderate Resolution Imaging Spectroradiometer (MODIS) (Wynne and Stumpf, 2015), and expressed as cyanobacterial chlorophyll concentrations (Rowe et al., 2016). Movement of the bloom is predicted using currents from the NOAA Lake Erie Operational Forecasting System and a Lagrangian particle dispersion model (Rowe et al., 2016). The NOAA Great Lakes Environmental Research Laboratory (GLERL) provided a version of the forecast to the public in 2014-2017 from July to October through their website (https://www.glerl.noaa.gov). The tracker was initially developed to provide public water systems with forecast information that allows them to prepare for changes to operations that are required to remove microcystins from drinking water. The HAB tracker was well received by water managers, which suggests that other stakeholders such as anglers may find a HAB forecast to be useful.

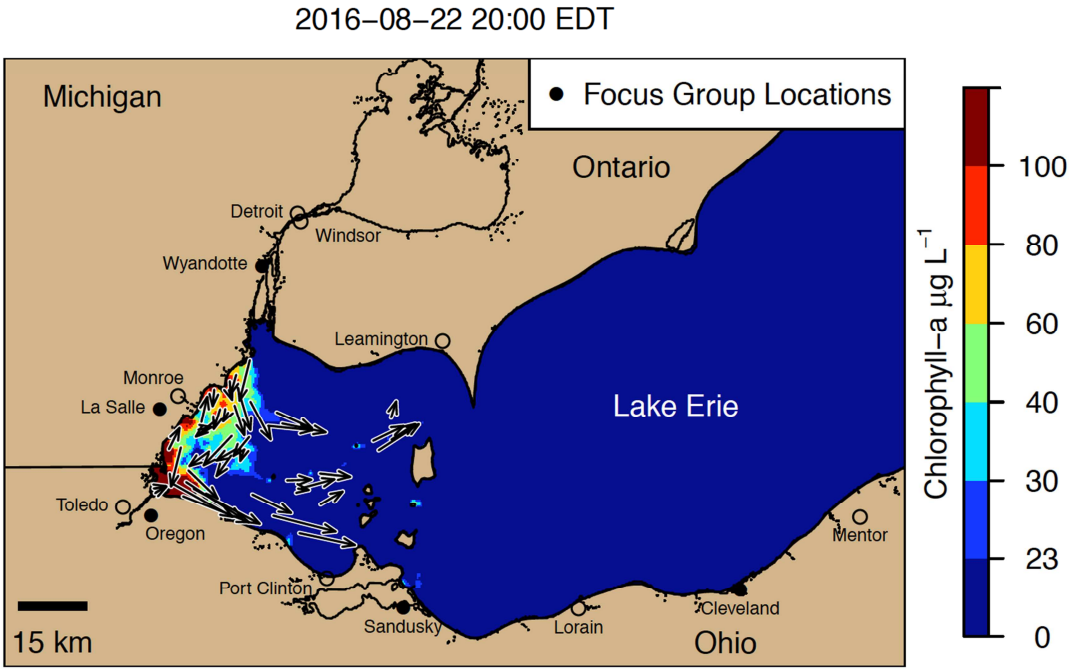

Figure 1. Example Lake Erie HAB Tracker forecast and focus group locations. The color scale indicates surface HAB concentration in terms of cyanobacterial chlorophyll-a when the forecast was issued on August 19th, 2016. The arrows indicate the forecast movement of the bloom for August 22nd, 2016.

To evaluate the potential for widespread adoption of the HAB Tracker by anglers; we worked with study participants to identify information needs and potential barriers to adopting the forecast tool. HAB Tracker developers will use this information to direct future improvements to the HAB Tracker. We used theory of diffusion of innovations as the theoretical framework for determining the likelihood of forecast adoption by analyzing angler preferences and information needs. Rogers (2003) identified five characteristics that determine whether a community will adopt an innovation, at what rate, and why. These characteristics include relative advantage, compatibility, complexity, trialability, and observability. Relative advantage measures preference for the innovation over other available technologies. Compatibility determines how well the innovation integrates with user experience. For example, developers must provide forecasts far enough in advance, so that anglers have time to adjust their plans if necessary. Complexity is a measure of the ease of use. If users are unable to understand the forecast language, complexity is an issue. Trialability is the ability of individuals to test the innovation prior to adoption. Observability is the ability of individuals to perceive the results of the innovation. If developers design the forecast tool to support the five characteristics of diffusion, then stakeholders are more likely to use the tool.

The main objectives of this study were: 1) to increase understanding of how HABs affect Lake Erie anglers when fishing in HABs by identifying the factors that contribute to their decision-making, 2) determine whether Lake Erie anglers are potential users of the HAB forecast model by evaluating qualitative data using the five characteristics of the theory of diffusion of innovations, and 3) develop recommendations for improvement of the HAB forecast model to increase likely adoption by Lake Erie anglers.

2. Methods

This study uses mixed methods including focus groups and surveys to support an inductive research approach, which is helpful when pursuing topics with a limited body of research such as the impact of freshwater harmful algal blooms on Lake Erie anglers. This approach reduces the introduction of researcher bias within experimental design, and ensures that the experiences of study participants grounds the study results.

2.1. Focus Groups

We conducted seven focus groups with forty-one participants, including twenty-one offshore recreational anglers and twenty charter boat captains who fish in areas of Lake Erie impacted by HABs (Table 1). Offshore recreational anglers and charter captains were targeted, because of the many fishing organizations within the region that could be contacted for participant recruitment. Members from three charter captain organizations and eight recreational fishing organizations participated in the study. Six participants (all recreational anglers) identified as being unaffiliated with a fishing organization, and were recruited through the recommendation of professional contacts or other participating anglers. Participants were divided into four focus groups for recreational anglers and three focus groups for charter captains, because homogeneity within focus groups is recommended to reduce response bias among individuals (Patton, 2002). Focus groups were held in communities surrounding the Western Basin of Lake Erie in Michigan and Ohio; including the communities of Wyandotte and La Salle in Michigan and Sandusky, Cleveland, and Oregon in Ohio (Figure 1). Each focus group lasted approximately two hours, and included a facilitated discussion directed by a semi-structured interview guide (see supplementary information).

Date	Location	Stakeholder Type	# of Participants
July 17, 2017	Wyandotte, MI	Recreational anglers	7
July 21, 2017	Sandusky, OH	Recreational anglers	6
August 3, 2017	Cleveland, OH	Recreational anglers	2
September 13, 2017	La Salle, MI	Charter captains	5
October 12, 2017	Oregon, OH	Charter captains	5
October 19, 2017	Oregon, OH	Charter captains	10
November 9, 2017	Oregon, OH	Recreational anglers	6

Table 1. Dates, locations, and number of participants for each focus group.

2.2. Survey Methods

Additional data collection methods included a survey conducted during focus groups to assess participant knowledge of HABs and the HAB Tracker, and an evaluation questionnaire conducted at the end of each focus group. We conducted surveys using Turning Point Interactive Polling Software to explore whether participant perceptions and knowledge of HABs were influenced by misidentification of the algae. The software and remote clickers allowed for anonymous survey responses that were captured, and reported back to participants during the focus groups. We presented participants with images of *Microcystis* and other species of non-harmful algae, before asking them to differentiate between them based on visual identification. Responses to these questions facilitated discussion regarding how *Microcystis* differentiates from non-harmful algae. Survey questions were also used to quickly determine the number of

participants familiar with the HAB Tracker, and who had used the HAB Tracker prior to attending the focus group (see supplementary information).

An evaluation questionnaire was used to obtain participant feedback on their experience with the focus groups (see supplementary information). Items within the questionnaire were used to measure constructs including participant satisfaction with the focus group experience, self-reported perceptions of knowledge gained about HABs during the focus group, the representativeness of focus group discussions to the diversity of opinions found within the target population, and the permissiveness of the focus group setting to open and honest dialogue.

2.3. Data Analysis

All interview transcripts were analyzed using Conventional Content Analysis (Hsieh, 2005), a process by which qualitative data is interpreted by identifying quotes that relate to emergent nodes and variables within the research questions. Nodes are labels assigned to categories of data during the coding process to organize similar data and assist with data retrieval. Nodes were not identified prior to data analysis, and instead emerged from readings of the text through inductive category development (Hsieh, 2005). In contrast, variables were identified prior to data collection to inform the creation of the research questions and interview guide. After interviews were transcribed, they were read as a whole by the researcher to develop initial impressions of variables, nodes, and the quotes that corresponded to them. After each focus group transcript was coded, the relationships between nodes and variables were analyzed to identify themes relevant to the research questions. NVivo qualitative data analysis software (QSR International Pty Ltd. Version 11, 2015) was used to code focus group transcripts, create concept maps, and organize memo writing. Concept mapping was used to visually demonstrate the relationship between variables and nodes. This tool aided in the identification of themes that were used to answer research questions and formulate recommendations for forecast model improvement. Memo-writing was used as a reflective tool throughout the research process, and consisted of writing down key impressions, variables, and themes that the researcher observed while reviewing the data (Charmaz, 2015). These memos and the identified themes were referred to when analyzing data in terms of the five characteristics of the diffusion of innovations.

2.4. Quality Assurance

To ensure that results accurately reflect the perceptions and behaviors of anglers, participants provided member checks by completing the evaluation questionnaires and reviewing study results to offer feedback on their accuracy (Denzin and Lincoln, 1994). In the questionnaire responses, several participants suggested additional perspectives should be included among focus group participants. However, these perspectives were not members of the target audience, and included commercial fishermen, on-shore anglers, recreational boaters, and tourists. Participants provided feedback on preliminary results during the Ohio Charter Captain's Conference (March 4, 2016) and during meetings with recreational angler organizations held at the conclusion of the study.

In the survey used to determine how well anglers could identify images of *Microcystis* in waterbodies, we found that in 78% of 127 responses, anglers correctly identified *Microcystis* when presented with alternatives including filamentous algae (*Cladophora*). We felt that this response rate, coupled with discussions at the beginning of the focus group regarding how to differentiate between *Microcystis* and non-harmful types of algae, provided sufficient

assurances that participants were not confusing *Microcystis* with non-harmful algae during focus group discussions.

3. Results

3.1 Key Themes that Impact Angler Decision-Making

To understand how HABs affects Lake Erie anglers, participants were asked how their practices change when fishing in HABs. In response to this question, three key decision-points emerged during discussion in every focus group: 1) whether to fish, 2) where to fish, and 3) whether to eat the fish that they catch during a bloom. The HAB Tracker is limited as decision-support tool for deciding whether to eat fish caught, because anglers base this decision on perceptions of health risk associated with microcystin contamination of fish. The HAB Tracker does not provide anglers with new information relating to these health risks. Therefore, the following results identify the five themes that influence angler decisions regarding whether and where to fish during a bloom: fishing aesthetics, perceptions of risk while fishing in HABs, the ability to catch fish, customer perceptions, and communications with peers (Figure 2). By identifying the themes and variables that influence angler decision-making, the likeliness of the diffusion of the product could be determined and recommendations for forecast model improvement could be made.

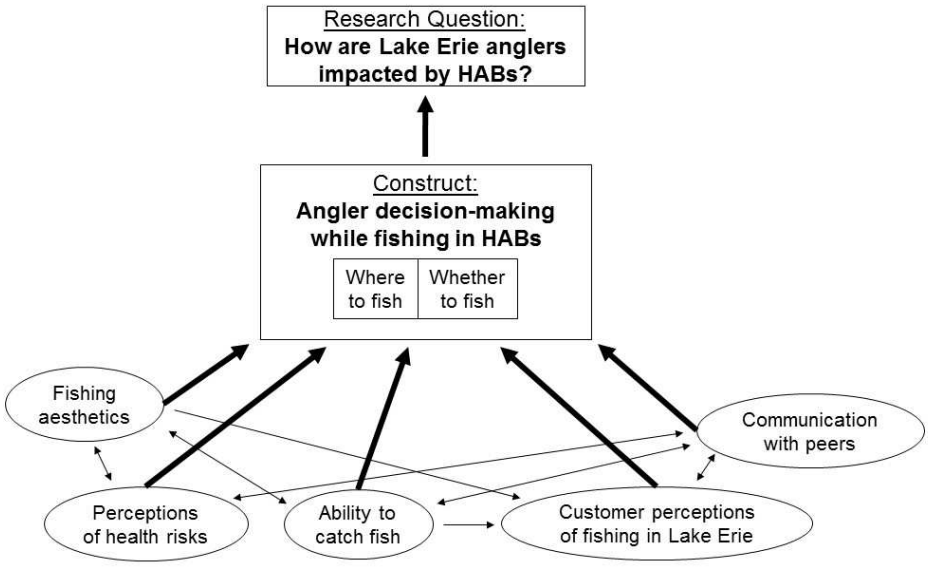

Figure 2. Concept map illustrating study results addressing how Lake Erie anglers are impacted by HABs. Rectangles represent key components of the study, including a research question and the construct used to answer that question. Bold arrows indicate a flow of information to answer the research question. Ovals represent the five themes that influence angler decision-making while fishing in HABs. Thin arrows signify relationships between themes as explained in the narrative of study results. For example, the two-directional arrow between fishing aesthetics and perceptions of health risks indicates that these two themes influence each other. The ability to catch fish influences aesthetic preferences. If anglers cannot catch fish in clear water, this influences their aesthetic preference for “green tinged water” that contains higher levels of phytoplankton. Alternatively, if HABs produce a green, odorous surface scum, these aesthetic conditions inform angler perceptions regarding the ability to catch fish.

Fishing Aesthetics

All anglers agreed that fishing in HABs detracts from the aesthetic experience of Lake Erie fishing. As one angler explained, "…the aesthetics of it are just kind of gross. All logic aside, there's beautiful clear water two miles away, so we'll go there." Many participants reported that the blooms have an unattractive appearance and an "acrid smell" that can be nauseating. The blooms can also stain the hull and planer boards green, requiring owners to wash their boats immediately following each trip. Although some anglers make a conscious choice to avoid HABs, others may avoid it without intent.

> *Well, you don't realize that you're doing it, but sitting here and thinking about it…I hear him saying all the time, "Well, that's all algae in here. Let's go out that way." So, it is affecting [where we fish] whether we consciously know it or not.*

All charter captains indicated that they fish during blooms, although some captains work harder to avoid bloom areas than other captains. Recreational anglers frequently indicated that in a highly concentrated bloom, they would choose not to go fishing or fish in a nearby lake without HABs. For anglers who prefer not to fish during HABs, bloom location and extent dictates their decision whether to fish. If the concentration of the algae is low or wave height and wind conditions encourage vertical mixing of the bloom, then anglers are more likely to continue fishing. Vertical mixing of the water column reduces surface scum and the negative appearance of the bloom. When mixing does not occur, one angler said, "You don't know if you have a walleye in tow until it gets out of the water." Anglers reported that during certain days of the 2015 bloom season, the algae coverage within the Western Basin was so extensive that they could not find clear patches of water during their fishing trips.

Perceptions of Health Risk while Fishing in HABs

Although all anglers agreed that HABs detract from fishing aesthetics, angler opinion on the health risks associated with HABs varied. All focus groups indicated that they were aware of the health concerns associated with HAB exposure [i.e. skin irritation, potential liver damage (Carmichael, 2001)]. Risk perception of microcystin exposure was a salient variable influencing recreational angler decision-making. As one recreational angler explained:

> *…Even though I don't know exactly why it's toxic, the fact that it's toxic algae….I mean, I'm not going to be swimming in it or anything, but the fish are coming up through that, and then I'm handling them and eventually eating them. We keep and we eat, so I would not fish in one.*

Some anglers, particularly charter captains, indicated that possible health risks do not deter their fishing. They accept the health risks to pursue their hobby or earn their livelihood. Charter captains in Ohio said that they fish in HABs, because they have no other choice, even though they associated a seasonal cough with exposure to decomposing *Microcystis* in the fall. Other anglers speculated whether microcystin exposure exacerbated the skin irritation that they experienced later in the fishing season. A few Ohio charter captains indicated their desire to cancel fishing trips in highly concentrated blooms, because of the negative impact they believed the blooms had on the fish and the embarrassment that they felt offering their customers a fishing trip through unappealing conditions.

…We were losing money last year [2015] right and left, because either our clients decided not to come because they saw the picture, or we decided on our own to say, "don't come." Because we reached a point where we couldn't catch the walleye anyway….

For the participants who chose to fish in HABs, one recreational angler explained that fellow participants might feel desensitized by the many environmental hazards associated with the lake over the years.

I think…at least to a point…that we've almost become immune to it. Because every day if you're in this genre, you're paying attention to what you're reading about the Metro beaches closing because of water quality….It's closed today, but next week we'll all go fishing on Friday, and the water's not a whole lot different than it was last week…. With everything else that's happening, I think maybe we're not as concerned as we should be.

The Ability to Catch Fish

Some anglers reported that they avoid fishing in blooms, because they observed that fish avoided these areas. Given the large, visible extent of the blooms, many anglers felt intuitively that the blooms must affect ecosystem functioning, and therefore game fish. Most participants believe that the extent of HABs coverage over the Western Basin, the depth of the mixing, and the level of toxicity determines the impact of HABs on fish.

If it's a light bloom, then it doesn't matter….Walleye don't like a lot of light. But if it becomes toxic, it's not alright and it's a flip of a coin. We don't know if it's releasing toxins yet, but the fish know….Those fish know if that algae bloom goes from more than a light bloom to a heavy bloom, and I guarantee then that there are no fish in it.

Some anglers observed that severe bloom extent or toxicity drives fish out of the Western Basin. They worried that blooms may be changing the historical migration patterns of the walleye. Several anglers speculated that bloom senescence increases release of microcystin, which causes fish to swim out of the area. However, a few charter captains and recreational anglers thought that the impact of HABs on the fish was minimal. These anglers believed that walleye and perch might seek the edges of the blooms for protection from the sun. They speculated that these gamefish would seek water that has a "green tinge" and that is not "gin clear with nothing in it", and that a light bloom may provide this quality of water. These anglers referred to instances when they or someone they knew had a successful fishing trip when casting through a bloom. This perception was more common in Michigan than in Ohio, where the blooms are often not as highly concentrated. When fishing in a bloom, Michigan charter captains explained a technique by which they clear the surface scum surrounding the boat by running their propeller. This afforded the captains and their customers with a clearer space within which to cast. Michigan charter captains embraced this technique as a way to adapt to the presence of the blooms. The Ohio charter captains were less enthusiastic about adapting to HABs. This may be because most Ohio charter captains felt that the blooms negatively affected the fish, whereas the Michigan charter captains did not. A few anglers expressed frustration specifically with trolling while trying to avoid the blooms.

When we troll, we have to have a pretty wide area to troll in. You could be trolling… and pretty soon you look out and all around your boat is just solid green. You go, "Okay…it's going to break loose here pretty soon." But no, it ain't working. So, you've got to pull up

all of your stuff, turn around, get back out of that algae, because the fish aren't biting in it.

Customer Perceptions

According to charter captains, the effect of the HABs on the charter fishing business is "massive." By most accounts, the spread of HABs in the past few years substantially affected the Ohio charter fishing industry.

Just looking at last year [2015], typically every one lost 25% of their business. Now, think about the fact that we only run from April until November. You've got to earn your living during that short time. We lost 6 weeks, because of the bloom last year….

Captains reported responding to these customer concerns in different ways. Charter captains in Michigan expressed frustration at customer fears that they felt were unfounded and provoked by sensationalized media coverage.

Right after that water scare in Toledo, I had a couple people cancel trips, because they were listening to the news….I had three or four more calls from people that fish with me every year, and they had been eating the fish for 15 damn years. What's the difference? They didn't get sick. They didn't die. Their kid's hair isn't falling out. Then they'll say, "Okay, we'll go."

These captains also reported that customers often deferred to their opinion regarding whether to continue with a trip or not. One Michigan Captain reported that he rarely receives questions from customers about algae while they book their trips. Instead, these questions came up almost as an afterthought while fishing. The captain then assured the customer that they believed that algae minimally affected fishing. Yet, all anglers expressed concern that if HABs persist, a negative public perception of Lake Erie will spread and local economies will suffer.

Angler 1: It's not only the fishing industry that's affected. It's bait stores, hotels, condos, restaurants, the whole gambit. People come up here to fish for a couple days. I have some people that come up for a week, and they're renting places and eating out every night. If they don't show up, you're losing money.

Angler 2: My neighbors come up every single weekend. It's just a summer cottage to them. When they see the algae, they wouldn't come up.

Communications with Peers

Peers are a trust-worthy source of information for all participants, and shape their perceptions of HABs. In two recreational angler focus groups, participants cited recommendations from friends as their justification for continuing to fish in HABs. Charter captains in particular emphasized the important role that peer-to-peer communication plays in the transfer of HAB knowledge. They feel motivated to educate themselves and each other, because they are an important source of HAB information for their customers.

> *We want to have answers for ourselves, but if our customers ask, we want to be able to answer some of those questions and at least speak intelligently about what we're talking about. We're not just here to throw our line in the water and catch a fish. The lake matters to us. It's our livelihood.*

This desire to share knowledge among peers was a primary driver for the organization of a charter boat association in Ohio. This organization's monthly meetings highlighted discussion of recent research, management efforts, and media coverage, so that the captains can share accurate information with their customers and other anglers who seek their advice.

3.2 Initial Angler Perceptions of the HAB Tracker

After discussing the impact of HABs on Lake Erie anglers, researchers introduced focus group participants to the HAB Tracker and asked for feedback on its potential utility. Of the forty-one anglers who participated in this study, only eleven anglers had heard of the HAB Tracker prior to participation in the focus group (Figure 3). Most anglers saw the HAB Tracker for the first time during the focus group, and did not have the opportunity to use the HAB forecast to plan a fishing trip. Most anglers said that they thought the HAB forecast would likely be useful, because it improves upon current methods of monitoring and predicting HABs. An angler explained, "A lot of times we didn't know…we'd take off for one spot, and then go look after another spot. Now, we just know where to go instead of wasting gas running around." Their current methods of monitoring and predicting HABs included viewing MODIS satellite imagery to track heavy concentrations of HABs in western Lake Erie. Anglers access MODIS true-color satellite imagery of Lake Erie by visiting the NOAA CoastWatch webpage for the Great Lakes region (www.coastwatch.glerl.noaa.gov/modis). Typically, anglers view the MODIS satellite imagery of Lake Erie the night before a fishing trip to identify where clear water might be located the following morning. However, anglers expressed frustration that the MODIS website is "hard to get to", and only useful "so long as it's not a cloudy day." The frequency of complete or partial cloud cover over Lake Erie decreases the reliability of the MODIS satellite imagery. MODIS also does not differentiate between HABs and sediment plumes, which means that anglers may misinterpret the information by mistaking a sediment plume for a bloom. The HAB Tracker uses the cyanobacterial index satellite retrieval, rather than true-color, and interprets the satellite imagery, visually defining where the blooms are and predicting where their movement.

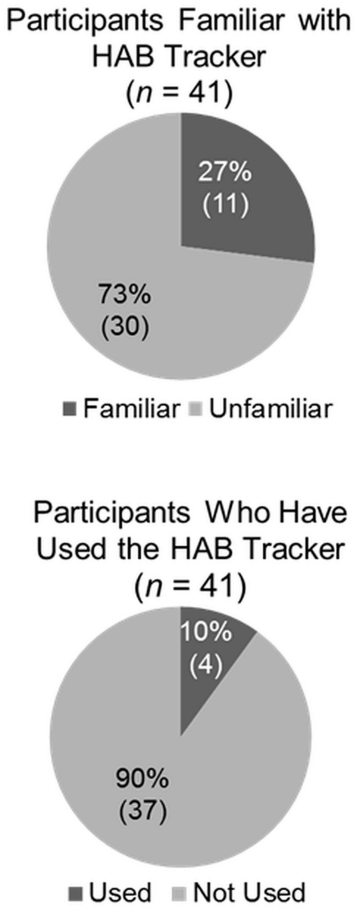

Figure 3. Number of participants who had heard of the HAB Tracker, and the number of participants who had used the HAB Tracker.

Concerns regarding the HAB Tracker

Although the majority of anglers viewed the HAB forecast model as a needed tool, other anglers remained skeptical. Several anglers said that they are satisfied with the information MODIS provides them, because it is not necessary to differentiate between HABs and sediment plumes. They seek boundary areas where "changes in water color" are likely to occur, because the fish seem to be attracted to transitional water. Other anglers indicated that they prefer to rely upon their personal knowledge of lake conditions to predict where HABs will occur. In the words of one Michigan captain, "It [the HAB forecast model] kind of tells us what we already know…I don't mean to be putting it down, because it's a good thing. It's just not anything that we're not seeing already." Anglers predicted that HABs would occur during days with calm water and warm temperatures in the months of July through early October: "If it's a flat, sunny day and there's been a lot of run-off, it's going to happen. It's going to happen fast." These anglers will refer to MODIS to confirm their predictions or add support to what they have experienced while fishing the Western Basin.

Other concerns included the reliability of HAB forecasts and a distrust of the motivations of HAB researchers and managers.

> *Instead of focusing on the algae bloom itself, you're* [researchers are] *going to focus on getting more sophisticated with tracking things. We need the problem fixed; we don't need to track it. I'm a fisherman. I can tell you where it's at.*

Some anglers observed that Lake Erie wind and weather forecasts are frequently inaccurate: "They can't predict the weather 5 days in advance. How are they going to predict this?" Anglers in three different focus groups emphasized that a reliable forecast supported by ground-truthing data is essential to the future utility of the HAB forecast for anglers. At least one individual in every focus group expressed concern that the HAB forecast model represents an effort by researchers to adapt to the HAB problem, rather than seek to mitigate it. The anglers explained that the HAB forecast would be of no use to them on days like the record-setting bloom in 2015, when thick algae covered the entire Western Basin. Several anglers worried that the efforts of researchers to address HABs were misdirected, and guided by interests in garnering funding for their work. Charter captains also worried about additional attention drawn to the HABs problem, which may prompt customers to cancel fishing trips, "I like what you have going on here, but I'm not going to go out and publicize it. I don't want people to know about it."

In addition to these concerns, anglers observed that the HAB Tracker website can be challenging to interpret and difficult to access. Anglers wondered how varying concentrations of cyanobacterial chlorophyll would affect them while fishing. They asked why researchers chose certain thresholds of *Microcystis* to define different colors within the scale. One angler suggested that the absence of lines of latitude and longitude on the forecast map made it difficult to determine your location. Finally, participants observed that the HAB Tracker did not provide other information on lake conditions, which may help anglers interpret the HAB Forecast. Requested information included water temperature, wave height, wind direction, wind velocity, water turbidity and dissolved oxygen coupled with concentrations of HABs. To gather this data, anglers visit a range of web sites the evening before a fishing trip. The participants recommended aggregating this information onto a single web page to reduce the time and effort required to access it, thereby adding value to the HAB Tracker webpage.

Many anglers emphasized the need for a mobile friendly web page or application to facilitate easy access. The HAB Tracker map presenting vertical mixing information requires users to click on different monitoring sites to populate data into the vertical mixing model. It is easy to select these sites with a mouse or cursor, but more difficult to select using a phone or tablet. Several anglers also worried that the name "HAB Tracker" may be difficult to find through a search engine, because the acronym "HAB" is unfamiliar. Focus group participants rarely referred to harmful algal blooms as "HABs", instead preferring the term "harmful algae" or "algae". Other barriers to accessing the website include navigation challenges. To access the HAB Tracker, anglers must click through several pages on NOAA-GLERL's website. Participants suggested featuring the HAB Tracker prominently on the NOAA-GLERL webpage and using simpler web link text that is easier to share. Anglers also suggested linking the HAB Tracker webpage to other popular websites, including the NOAA CoastWatch webpage for the Great Lakes region, which features MODIS satellite imagery.

4. Discussion

4.1 Understanding factors that contribute to angler decision-making

A literature review provides further support for the themes identified as key factors to angler decision-making while fishing in HABs (fishing aesthetics, health risks, communication with peers, the ability to catch fish, and customer perceptions). Our study found that aesthetics are important to the Lake Erie fishing experience, and that the negative affect of HABs on fishing aesthetics can influence an angler's decision regarding whether and where to fish. The literature on angler perceptions and behaviors supports this finding. Environmental quality (including aesthetics) is a key factor in assessing angler satisfaction with fishing experiences (Fedler and Ditton, 1994; Hampton and Lackey, 1975; Moeller and Engelken, 1972), especially in determining site choice (Hunt, 2005). Similarly, Washington State recreationalists reported via survey that lake aesthetics along with water quality were their two greatest concerns when recreating in inland lakes with HABs (Billingham, 2012).

Angler participants varied in their perceptions of risk associated with HABs, yet many anglers made decisions about risk acceptance based on personal and peer experiences. Personal observations of fish quality (Burger et al., 1998; Habron et al., 2008; Lauber et al., 2017; Pflugh et al., 1999) and experiential knowledge (Beehler et al., 2001) are described factors that anglers use to assess health risk in light of fish consumption advisories. Charter captains who participated in this study were more willing than recreational anglers to accept these risks, which corroborates findings by ethnographic researchers suggesting professional fishermen are unique in their acceptance of health risk (Knudsen, 2010). Overall, peer to peer communication among the fishing community has been documented as a preferred information source for anglers (Beehler, 2001; Habron, 2008; Mueller et al., 2008; Pflugh et al., 1999; Ramirez-Sanchez and Pinkerton, 2009), and these views were also expressed by focus group participants in this study.

Participants disagreed on the impact of HABs on their ability to catch fish. To date, there has been little to no research on the impact of cyanobacterial blooms on freshwater fish catch rates. A few studies on the spatial relationship between cyanobacterial blooms and fish populations have yielded mixed results (Godlewska et al., 2018; Kaczkowski et al., 2017; Sotton et al., 2011), and more research is needed to understand more broadly how fish respond to HABs in Lake Erie. Regardless of these uncertainties, studies have documented the negative impact that HABs has had and will likely continue to have on the recreational and charter fishing industries (Bingham, 2015; Wolf, 2017; Zhang and Songhen, 2018), which adds credence to charter captains concerns regarding negative perceptions of fishing in Lake Erie held by customers. These and other observations of angler knowledge and perceptions within this study serve to create a broader picture of angler decision-making and impact by HABs.

4.2 Using the theory of diffusion of innovations to evaluate the HAB Tracker

With this decision-making process in mind, the five characteristics of the theory of the diffusion of innovations (compatibility, relative advantage, complexity, trialability, and observability) were used to evaluate the usability of the Lake Erie HAB Tracker for anglers and

the likelihood of the diffusion of the Lake Erie HAB forecast. At a basic level, a HAB forecast model is compatible with the needs of anglers. This study provides evidence that anglers have an interest in avoiding harmful algal blooms in Lake Erie and use information to support their decision-making regarding where and whether to fish so that they may avoid the blooms. It is less clear whether the HAB Tracker provides a relative advantage for anglers in comparison to direct observation of lake conditions or satellite imagery. Rowe et al. (2016) showed that the HAB Tracker has on average greater accuracy than a persistence forecast, which assumes no change from the most recent satellite-derived bloom extent. Most recreational anglers perceived a relative advantage to using the HAB Tracker, because the location and extent of HABs are easier to interpret than the satellite imagery. Recreational anglers also may not be able to rely upon their own observations of lake conditions due to the infrequency of their fishing trips, lack of access to the social network of charter captains, and lack of familiarity with lake processes. In contrast, charter captains have more alternative sources of information and a less flexible decision-making process regarding whether and where to fish in Lake Erie during a bloom. They are better able to predict the location of HABs themselves based on the greater frequency of their fishing trips, near-daily observations of lake conditions, and radio communication with other charter captains on the lake. The compatibility of a HAB forecast model for charter captains depends on the forecast's accuracy at the geographic scale that interests them, which may require greater spatial detail than recreational anglers would require. Observability will play a crucial role in determining the compatibility and relative advantage of the HAB Tracker for charter captains. If charter captains observe that the HAB Tracker is able to provide accurate forecasts after multiple experimental trials at the spatial scale that they require, then they will be more likely to adopt the HAB Tracker. Given the inherent utility of a forecast to provide only the likelihood that an event will occur, a short period of trialability and observability may lead to early rejection of a forecast tool if poor performance occurs by chance in that period. The focus groups revealed that anglers might be predisposed to distrust researchers and forecasts, which increases the stakes during this period of trialability and observability.

4.3 Recommendations for forecast improvement to increase likely adoption

Issues regarding the complexity of the HAB Tracker included data interpretation and accessibility of the HAB Tracker website. Researchers may ameliorate these issues by adding language to the website explaining that cyanobacterial chlorophyll concentrations within the red color scale indicate a greater likelihood of surface scum formation. Anglers expressed a desire to avoid concentrated surface scum, which also tend to have higher concentrations of microcystin. Improving communication between researchers and the angling community might address issues of HAB Tracker compatibility, including the distrust of researchers and forecasts. This conclusion supports the findings of Dedual et al. (2013), who recommend communicating with anglers directly to understand their knowledge and break down social barriers that may shape negative perceptions of researchers. When asked how to improve communications with researchers, anglers suggest more direct communication to build rapport. This feedback supports the existing literature on recommendations for effective communication between researchers and the fishing community (Dedual et al., 2013; Holmes and Lock, 2010; McNie, 2007). Five out of the seven focus groups suggested that researchers increase the frequency of their contact with angler organizations by attending meetings, increasing contact through emails or phone calls to organization leaders, or by connecting with the social media presence of

angler organizations. A two-way flow of information also increases trust and improves the quality of interactions between fisheries managers/researchers and the fishing community (Holmes and Lock, 2010). By providing anglers with reliable opportunities for researchers to answer their questions regarding Lake Erie, researchers can contribute to a higher level of HAB knowledge among the Lake Erie fishing community, build confidence in the work of researchers, and increase the diffusion rate of HAB forecasts among anglers. By acknowledging the worth of angler knowledge and contributions to the work of researchers, this will further build trust and mutual respect (Hartley and Robertson, 2008).

Diffusion of the HAB Tracker may also occur if anglers reinvent the tool. Reinvention occurs as adopters change the intended purpose of a tool to suit their needs (Rice and Rogers, 1980). Charter captains indicated that they find the HAB forecast useful as a communications tool for discussing HABs with customers and their communities at large. Several anglers suggested that the HAB Tracker might provide a visual aide for educational purposes as they seek to educate the public about HABs and in some cases, advocate for management solutions to addressing the HAB issue. Further research is needed to document the diffusion and potential reinvention of the HAB Tracker in practice among anglers. This study functions as an initial data point in the process of diffusion. To assess the actual rate of adoption, occurrence of reinvention, or potential rejection of the tool, additional research is needed to document the dynamics of the diffusion process for the HAB Tracker.

5. Conclusion

This study sought to increase understanding of the impact of HABs on Lake Erie anglers and their decision-making when fishing in HABs, and to assess the likelihood of adoption of a HAB forecast among Lake Erie anglers as a decision-support tool. We found that five key themes factor into angler decision-making when fishing in HABs, including fishing aesthetics, perceptions of health risk while fishing in a HAB, the ability to catch fish, customer perceptions, and communications with peers. Analysis of these results using the five characteristics of the theory of diffusion of innovations determined that recreational anglers are more likely than charter captains to adopt the HAB Tracker as a decision-support tool. This is because the HAB Tracker is more compatible with the needs of recreational anglers and has a relative advantage over their existing sources of HAB information. Charter captains are likely to adopt the HAB Tracker as a decision-support tool only if the HAB Tracker is able to prove its accuracy and compatibility with charter captain informational needs during trials of HAB Tracker use. Both recreational anglers and charter captains highlighted issues of complexity, compatibility and relatively advantage that researchers can address by implementing recommendations for HAB Tracker improvement including increasing tool accessibility, improving interpretation of information, and improving the quality of interactions between researchers and anglers to foster trust and improve communication of user needs.

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Supplementary Material

Caption: Interview guide questions administered during angler focus groups.

Improving NOAA HAB Tracker:
A Forecasting & Decision Support Tool for Lake Erie Harmful Algal Blooms

University of Michigan, School of Natural Resources & Environment
Cooperative Institute for Limnology & Ecosystems Research
NOAA - Great Lakes Environmental Research Laboratory

INTERVIEW GUIDE

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1. Before we talk about HABs, I'd like to know a little bit about you as a fisher. How long have you been fishing in Lake Erie? *(Introduction)*

- Where do you like to fish generally?
- How frequently do you fish?
- What memberships or affiliations do you have with fishing associations/groups?

2. How would you describe a harmful algal bloom? *(Knowledge)*

- Why is it harmful? What have you heard about the toxins it produces?
- Do you have another name that you use for it? (*Communications*)
- How do you know it when you see it?

3. How have HABs changed your fishing practices? (*Decision-Making)*

- Do you fish during HABs events? Do you fish around them? Why?
- Do you modify your fishing techniques/equipment that you use during a bloom?

4. What concerns do you have about the future of HAB occurrences on Lake Erie? *(Perceptions)*

- Have you observed HABs having an impact on fish? Does it affect fish movement?
- Would you eat fish from Lake Erie during large blooms?/Have you eaten fish during a bloom?
- How might HABs influence the fishing industry?

5. When you want to know whether algal blooms are going to be an issue on a particular day, where have you gone for information? *(Decision-Making/Communications)*

- Who or what would you look to as a source of information?
- How would you access that information (telephone, online, face-to-face, etc?)
- How would you share this information with others? What others?
- Do you use social media or any other forums for sharing information about HABs?

(*Photo identification task break to identify Microcystis for the purpose of knowledge assessment)*

6. Why do you think HABs are in Lake Erie? (*Knowledge/Perceptions)*

- Where did they come from?

- How long have they been there?

7. Is there anything so far about HABs that we haven't talked about that you think we should?

(*Break for Dinner & Demonstration of NOAA HAB Tracker)*

8. How did you first hear about the National Oceanic & Atmospheric Administration Great Lakes Environmental Research Lab (NOAA GLERL)?

- What have you heard about the research that we do with harmful algal blooms (HABs)?

9. How might the HAB Tracker be useful to Lake Erie anglers? *(Perceptions)*

- How could the HAB Tracker be made *more useful* for anglers?
    - Should the information be displayed differently?
    - Should additional information be included? What information?
- What did you like/dislike about the HAB Tracker?

10. In what ways might the HAB forecast information change your fishing plans? *(Decision-Making)*

- If you have used the HAB Tracker before, how has it changed your fishing plans in the past?
- Under what conditions would you consider using the tool?

11. How could NOAA GLERL improve their communications with you about HABs information? (*Perceptions/Communications)*

- What changes in words and language GLERL uses to communicate about HABs be improved?
- How might the method of communicating be improved?

12. If you could ask the researchers to investigate any question that you have about HABs in Lake Erie, what would it be? *(Perceptions/Knowledge)*

13. Is there anything else that you'd like to tell me or that you think the researchers at GLERL should know about your experience with HABs?

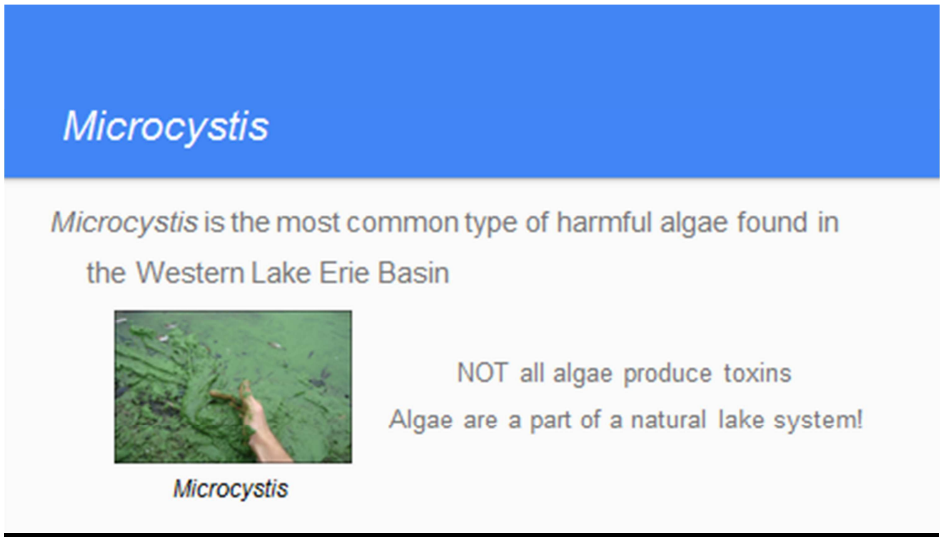
14. Would you be willing to use the HAB Tracker for the next 6 weeks, then participate in a follow-up interview over the phone to discuss your experience with the HAB Tracker?

15. Would you also be willing to review my summary of our focus group discussion and offer your feedback on the accuracy of my summary?

Supplementary Material

Caption: Powerpoint presentation provided to focus group participants to assess angler ability to differentiate between Microcystis and other non-harmful algae

Focus Group HAB Knowledge Assessment Presentation



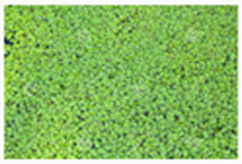
804

Which photo do you think is of *Microcystis*?

Using your clicker, please select the letter that corresponds to your answer.

(A) *Microcystis*

(B)



(C)

(D)

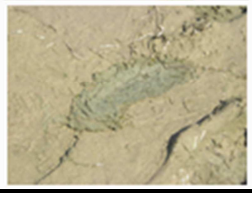
805

Which photo do you think is of *Microcystis*?

Using your clicker, please select the letter that corresponds to your answer.

(A)

(B)



(C)

(D) *Microcystis*

806

Which photo do you think is of *Microcystis*?

Using your clicker, please select the letter that corresponds to your answer.

(A)

(B) *Microcystis*

(C)

Discussion?

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Supplementary Material

Caption: Evaluation survey completed by participants at the close of each focus group.

2016 Lake Erie Anglers & HABs

Focus Group Evaluation

1. Do you identify primarily as a Lake Erie recreational fisher or Charter Boat Captain? (Circle one)

Recreational Fisher Charter Captain Other

2. Do you have any recommendations for how this focus group might have been improved?

For questions 3 - 6, please indicate how much you agree or disagree with the statement. Please also provide comments to explain your response.

3. I felt that my thoughts and opinions were heard by the group.

Strongly Agree Agree Neutral Disagree Strongly Disagree

Comments:

4. I feel that I am more knowledgeable about harmful algal blooms in Lake Erie.

Strongly Agree Agree Neutral Disagree Strongly Disagree

5. Are there members of the Lake Erie recreational fisheries community who are not represented here?

6. Are there any questions or concerns about HABs that the focus group did NOT cover, that you felt it should have? Please list them below.