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Research article

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 little 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.

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

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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 et al., 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 et al., 2015; Wolf et al., 2017; Zhang and Sohngen, 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 (Fig. 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.

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

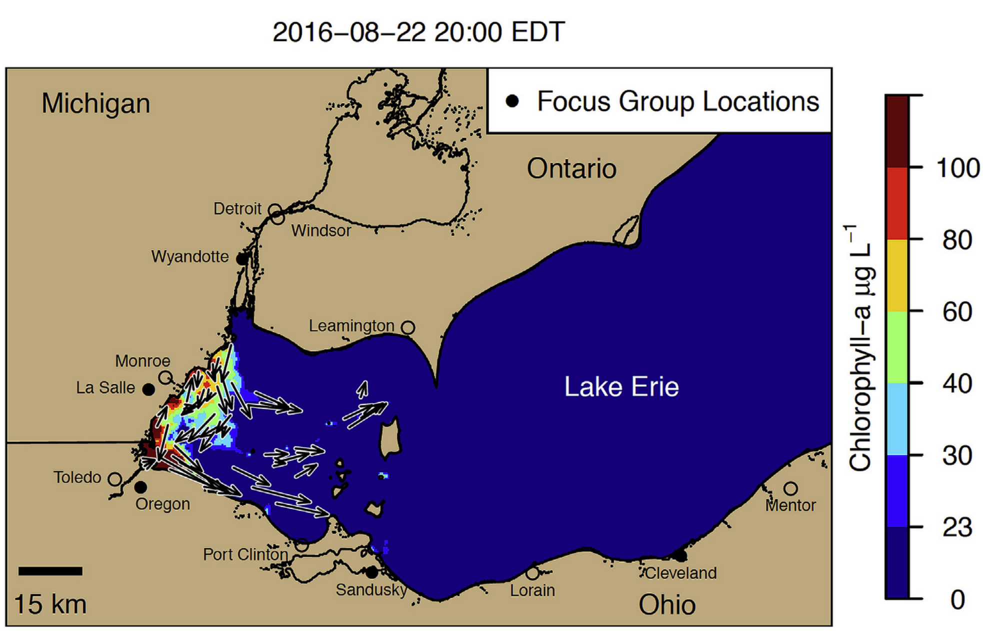

Fig. 1. Example Lake Erie HAB Tracker forecast and focus group locations. The color scale indicates surface HAB concentration in terms of cyanobacterial chlorophyll-a when the forecast was issued on August 19th, 2016. The arrows indicate the forecast movement of the bloom for August 22nd, 2016. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)