Nutrient management in Lake Erie: Evaluating stakeholder values, attitudes, and policy preferences

Green, Sierra Rae[a,b]*; Waldmann Rosenbaum, Carol[b,e]; Hughes, Sara[b]; Wu, Xinjie[b]; Dusicska, Emily[b]; Sun, Kathy[b]; Chaganti, Subba Rao[c]; Godwin, Casey[c]; Fraker, Michael[c]; Vanderploeg, Henry A.[d]

[a]Present address: 5209 Mesquite Drive, Pocatello, ID 83202 Email: Srgreen@umich.edu
[b]University of Michigan 440 Church St, Ann Arbor, MI 48109
[c]Cooperative Institute for Great Lakes Research (CIGLR), University of Michigan, 4840 South State Road, Ann Arbor, MI 48108
[d]NOAA Great Lakes Environmental Research Laboratory, 4840 S. State Road, Ann Arbor, MI 48108
[e]Michigan State University, Department of Integrative Biology, Kellogg Biological Station.

Given their role as Guest Editor, Casey Godwin had no involvement in the peer-review of this article and has no access to information regarding its peer-review. Full responsibility for the editorial process for this article was delegated to Marc Gaden.

Abstract

Harmful algal blooms (HABs) have impaired Lake Erie's western basin water quality since the 1960s. Though scientists agree that eutrophication is a key driver of HABs in Lake Erie, the role of nitrogen is still the subject of debate. The problem is twofold: (1) uncertainty in the specific causes of HABs can lead to inappropriate management solutions, and (2) managing a cross-boundary watershed requires collaboration and agreement on apt solutions from multiple stakeholders as well as many U.S. states and Canadian provinces. In our study, we interviewed 29 stakeholders actively involved in western Lake Erie's watershed. We analyzed the stakeholders' values, attitudes, and policy preferences to understand their differences, similarities, and their effects on management decisions. We found that stakeholders agree on the urgency of the problem and the necessity for increased nutrient management in Lake Erie's western basin. Furthermore, we found that stakeholders can be represented as distinct clusters based on their values, and these value-based clusters are associated with different policy preferences. The different opinions and preferences of these value clusters span across stakeholder sectors and may affect efforts toward policy change. Stakeholders often question the feasibility and effectiveness of existing policies and policy plans. The findings shed new light on the relationship between stakeholder type and environmental values, attitudes, and policy preferences. Collaboration on HABs in Lake Erie will require open lines of communication both to improve policy and to cultivate trust among the multiple parties in this diverse watershed.

Keywords: Harmful Algal Blooms, Lake Erie, Water Quality, Stakeholder Collaboration, Environmental Values, Nitrogen and Phosphorus Management

Introduction

Cooperation among stakeholders and policymakers is essential in maintaining large-lake ecosystem services. Managing the impacts and severity of harmful algal blooms (HABs) in Lake Erie is one of the most persistent challenges facing environmental officials in the Laurentian Great Lakes basin. Reducing HABs depends on managing nutrients, which requires understanding the interests and preferences of a broad range of stakeholders (Beegle et al., 2000). Despite Lake Erie's socio-economic importance to the region, it has experienced HABs since the 1960s, with costly effects on ecosystems and infrastructure (Allinger and Reavie, 2013). Here, we examine the values, attitudes, and policy preferences of Lake Erie stakeholders to inform policy and decision-making around nutrient management in the basin.

Harmful Algal Blooms in Lake Erie

Water quality issues caused by HABs affect the natural environment, recreation, household water use, and fisheries (Dai et al., 2012; Kim et al., 2020). Algal toxins, such as microcystin, can accumulate in the human body, cause liver and kidney damage (Harke et al., 2016) and make water unsuitable for drinking and swimming. Lake Erie provides drinking water to over 11 million people and generates $7 billion in associated annual revenue (US Environmental Protection Agency, 2004). However, despite the lake's socioeconomic importance, since the early 2000s HABs have resurged, threatening water quality in the lake. As recently as 2014, Toledo had to declare a state of emergency and issued a "do not drink" water quality advisory in response to elevated microcystin concentrations in drinking water (Jetoo et al., 2015). Toledo is not alone in facing HAB-related economic losses. HABs cause an estimated annual loss of $305 million in tourist revenue in Ohio and an estimated $25 million in Michigan's Monroe County (Bingham and Kinnel, 2020). Between 2011 and 2014, the Lake Erie fishing industry suffered $5.58 million (Wolf et al., 2017) in HAB-related losses. The impact of HABs, driven by runoff, remains a concern today.

HABs result from excess nutrient inputs from urban and agricultural activities (Robertson and Saad, 2011). To date, phosphorus (P) from fertilizer is known to be a primary HAB driver and has consequently received the most attention from regulators. However, recent work shows that nitrogen (N) may also play a significant role in HAB growth and toxicity (Newell et al.,

2019; Chaffin et al., 2018). In part as a response to the growing threat of HABs in Lake Erie during the mid-20th century, in 1972 the U.S. and Canada signed the Great Lakes Water Quality Agreement (GLWQA) (International Joint Commission (IJC), 1972). In the same year, the U.S. Congress strengthened the Clean Water Act (CWA). Following these changes, upgrading and expanding sewage treatment plants and regulating P in household detergents led to dramatic decreases in P loading and algal production in Lake Erie (De Pinto et al., 1986). By the mid-1980s, total P loading had decreased by 50% (Allinger and Reavie, 2013).

However, since the late '90s, HABs have returned to Lake Erie prompting Congress to pass the Harmful Algal Bloom and Hypoxia Research and Control Act to assess the issue. The research spurred by this legislation has determined the HAB resurgence stems primarily from two factors. First, previous legislation was not able to adequately address agricultural runoff sources of reactive phosphorus loading, which has increasingly plagued the lake (Kane et al., 2014; Guo et al., 2021; Stumpf et al., 2012). Second, successful colonization by the invasive quagga mussel has led to widespread disruption of the lake's internal nutrient cycles, favoring cyanobacterial species (Conroy et al., 2005). These findings served to highlight how often HABs affect water quality in Lake Erie's western basin, as well as the need for consistently updated phosphorus reduction targets (Sayers et al., 2019; Watson et al., 2016).

The GLWQA set a precedent between the United States and Canada for reducing annual nutrient loading to below agreed-upon targets (IJC, 1987). In response to the return of HABs in the 2000s, the GLWQA was amended to include a mandated target to reduce phosphorus loading in Lake Erie by at least 40% by 2025 with an interim goal of 20% reduction by 2020 and the implementation of adaptive management (IJC, 2012; Stow et al., 2020). Although phosphorus regulations since the 1970s have been partially successful in reducing total phosphorus loads, the current target of a 40% reduction in phosphorus loading will take time to achieve (Wilson et al., 2019). Lake Erie's coastal states are individually responsible for implementing nutrient management plans (Berardo et al., 2019), so there is no unified approach to reach target reductions in the lake. However, per IJC recommendation, Michigan and Ohio have collaborated on designing a framework for voluntary agricultural fertilizer use, called the "4R" approach, which stands for "right source, right rate, right time, and right place" (IJC, 2014; Ohio EPA, 2013; Bruulsema et al., 2009). The 4R approach relies primarily on voluntary farmer

engagement, yet programs managed by the USDA, such as the Environmental Quality Incentives Program (EQIP), Regional Conservation Partnership Program (RCPP), Conservation Stewardship Program (CSP), offer financial incentives and technical assistance to participants.

Thus far, the predominantly voluntary approaches to managing HABs in Lake Erie have reduced nutrient levels in Lake Erie, but not to sufficient levels necessary to successfully manage HABs (Wilson et al., 2019). In 2008, Lake Erie received an estimated load of 10,535 tons of phosphorus in contrast to 2020's estimated 9,335 tons—only an 11 percent decrease (Environment and Climate Change Canada, 2021). The small nutrient input level reduction suggests that the current policy may not be particularly effective in reducing nutrient loading.

Improving the effectiveness of voluntary approaches would require greater collaboration and support from stakeholders. Studies on nutrient management reform in the U.S. suggest that USDA voluntary programs suffer from extensive limitations including lack of technical assistance to help farmers with the design and implementation of nutrient reduction practices, and poorly targeted resources. For example, current programs are designed to reach as many farmers as possible and treat them equally, regardless of where best management practices (BMPs) would be most effective in reducing nutrients (Shortle et al., 2012). Given the diversity of stakeholders (including farmers, local residents, policy makers, etc.) it is also important that choices about policy design and policy tools are compatible with the social and political context, such as social norms and behavioral cues (Garnache et al., 2016), perceived difficulty of particular practices, social pressure, and trust in technical sources of information (Daxini et al.,2019). Thus, a better understanding of Lake Erie stakeholders may support the development of policies that produce higher collaboration and greater stakeholder engagement in reducing nutrient loads.

The Role of Stakeholder Values, Attitudes, and Policy Preferences

Stakeholders play a critical role in environmental decision-making processes. Stakeholders are individuals or groups involved in the process to develop policies and regulations that will affect them (Reed, 2008; World Bank, 1996). Stakeholders influence decision-making through various means, most commonly through political pressure, news and social media, and administrative and judicial processes (Weible, 2007). Stakeholder engagement also provides details, risk assessments, and information that both widens the scope and deepens

understanding of the issues at hand (Vliet et al., 2020), allowing for legislators to develop more advised management methods (Gill et al., 2018). Stakeholder cooperation and commitment are fundamental aspects of decision-making and facilitate policy implementation.

Stakeholder support can be critical for identifying and developing feasible and effective policy solutions to environmental problems like HABs. However, predicting or fostering stakeholder support can be challenging when there are large differences between stakeholder values, attitudes, and policy preferences. Stakeholders' values often shape their willingness to support policy change (Fritzsche and Oz, 2007; Pitas et al., 2019). Values are at the core of many theoretical frameworks that aim at explaining behavior, preferences, and social organization (Homer and Kahle 1988; Sabatier, 1988; Stern, 2000; Vaske and Donnelly, 1999). Even though the definition of values may vary between these frameworks and change over time (Ripberger et al., 2014), values are consistently the foundational reference for hierarchical cognitive processes that guide an individual's perception of the world, including one's policy preferences and alliances (Dunlap et al., 2000; Fulton et al., 1996). Values are highly resistant to change and can lead to conflicts over natural resource and environmental quality decisions (; O'Neill and Spash, 2000; Rokeach, 1973). Environmental policy conflicts often arise due to differences in individual values or the values of the organization or profession with which an individual is associated (Dietz et al., 2005; Vaske and Donnelly, 1998). A common example is environmental conflicts that center on preservation versus use values for natural resources (Stern and Dietz, 1994). For example, values affect support for wildland preservation (Vaske and Donnelly, 1999), park privatization (Pitas et al., 2019), national climate policies (Leiserowitz, 2006), and energy policies (Steg et al., 2005).

Values influence how environmental decisions are made (Dietz et al 2005). Chess et al. (1998) showed that a group's differences in values will influence the amount of deliberation and discussion that will be necessary for a decision to be reached. For example, in an environmental decision-making situation in which the level of value agreement is low and the level of knowledge is low, integrated deliberation between scientists and stakeholders would be required. Values also act as an input into the decision-making process, influencing individuals' preferences for participatory or top-down approaches. For example, in a survey of stakeholders involved in a marine protected area decision making process in California, Weible et al (2004)

found that an individual's values helped determine whether or not he or she preferred collaborative as opposed to top-down decision making.

An attitude has been defined as a mental state that must refer to some object, such as surface or groundwater, and can range from strongly to weakly developed (Bright and Manfredo. 1995; Eagly and Chaiken, 1993). Unlike values, attitudes are issue-specific and less likely to remain consistent across issue areas; attitudes can change with learning and experience. For policy making, issue-specific attitudes indicates that an individual's attitude toward an issue such as HABs management, may be different from his or her attitude toward other issues, such as land use or minimum wage increases, depending on the amount of information available on the topic or previous experience. These findings suggest the importance of understanding how attitudes are distributed among stakeholders, in an issue-specific context such as HABs management, in order for policies to be acceptable and relevant at a given time with a given group of stakeholders and policy makers as well as to predict how individuals will act in policy situations.

In environmental decision making, an individual's preference for policy outcomes is what is ultimately expressed to others. The range of policy preferences among a group of collaborators may serve to set the boundaries of the debate by establishing potential scenarios and acceptable outcomes. Preference for a given policy alternative may reflect the value an individual places on the perceived outcomes and his or her understanding of the effects of different actions on valued resources (Stern et al., 1995). Preferences can be seen as part of a social process, influenced by increasing scientific understanding and changing levels of individual and public awareness (Stern et al., 1995). Examples can be found in studies of the policy preferences of individuals playing an active role in environmental decision making and research, such as risk professionals in Washington, D.C. (Dietz and Rycroft, 1987), climate change experts (Morgan et al., 2001), and scientists and stakeholders involved in the creation of Marine Protected Areas in California (Weible et al., 2004).

Together, stakeholder values, attitudes, and policy preferences can shape collaborative governance strategies, helping to determine the feasibility, form, and success of policy solutions. Collaborative governance, or adaptive co-management, is often used or promoted as a strategy for nutrient management because it involves action by a range of stakeholder types and abilities (Folke et al., 2005). Collaborative management and compromise can be difficult when values differ among individuals or groups (Henry et al., 2010). However, there are examples of

successful collaborations among heterogeneous stakeholder groups, including for HAB management, such as in the Gulf of Mexico, the Gulf of Maine, and the U.S. Caribbean Islands (Anderson et al., 2019). Understanding stakeholder values, attitudes, and policy preferences can help identify feasible policy changes and support the design of effective collaborative processes.

Stakeholders in the Lake Erie Watershed

The western Lake Erie watershed includes Ohio, Michigan, Indiana, and Ontario. Within the Lake Erie region, government, non-government organizations (NGOs), and private stakeholders have an essential role to play in nutrient management. Government stakeholders include local, state, and federal agencies that often invest in projects to mitigate the effects of HABs in Lake Erie. NGO stakeholders include research institutions and advocacy groups that connect and communicate with landowners and farmers to understand and advance nutrient management strategies. NGOs also engage with other stakeholders and educate the general public about the Lake Erie HAB issue. Private stakeholders consist of privately owned businesses that are affected by regulations and nutrient reduction targets, including private landowners and farmers. Effective decision-making about managing HABs in Lake Erie may depend on collaborative efforts between all three stakeholder types.

Given the range of stakeholders in the Lake Erie basin, there is potential for mismatches between stakeholder values, attitudes, and policy preferences and nutrient management goals, making it difficult to implement plans and achieve desired results (Kalcic et al., 2016). For example, an examination of public support for water quality regulations in the Ohio region of the Lake Erie watershed showed that residents who worked in agriculture are less supportive of fines to regulate agricultural runoff (Guo et al., 2019-a). Another study in the region showed that differences in individual risk perception and beliefs helps determine public support for regulatory policies for nutrients (Guo et al., 2019b). Understanding patterns in stakeholder values, attitudes, and policy preferences specifically for HABs control measures in Lake Erie can help inform the design and implementation of more effective policies and programs (Gill et al., 2018; Henry et al., 2010; Rissman and Carpenter, 2015)

In our study, we seek to identify the values, attitudes, and policy preferences of different types of Lake Erie stakeholders. We also seek to gain insight into the potential barriers to and

opportunities for HAB management in Lake Erie going forward. The specific research questions we address are: Do the three different types of Lake Erie stakeholders:

- hold different environmental values? (Research question (RQ1)
- hold different policy attitudes? (RQ2)
- hold different policy preferences? (RQ3)

Methods

General study design

We conducted twenty-nine interviews with stakeholders involved in western Lake Erie watershed management. These stakeholders represent government, NGO, and private stakeholder types (Table 1). The average interviewee age was fifty-one, 69% identified as male, and 90% identified as Caucasian. The interviews were semi-structured and coded using NVivo to capture key themes and insights into stakeholder values, attitudes, and perceptions; information sources on Lake Erie HABs; and support for different nutrient management approaches. We also used the interview responses to characterize the relationships among stakeholders using social network analysis (see Electronic Supplementary Material (ESM) Appendix S1).

Identifying stakeholder participants

We created a list of individual stakeholders in the Lake Erie watershed through searches in previous publications, regional meetings, and websites for the organizations. Though not exhaustive, we believe our list represents a large share of the stakeholders actively involved in the decision-making process in western Lake Erie. After establishing our list, we categorized each stakeholder into their respective stakeholder types based on the organization they represent - either government, private sector, or NGO. We contacted 102 stakeholders by email and 24 agreed to participate in the study. Common reasons given by stakeholders who did not participate in the study were lack of time and privacy concerns. Once we set the interview times and dates, we sent the official consent form and interview questions to the interviewees per university human subjects protection protocols (ESM Appendix S2). We used a snowball sampling method to augment the list identified in our initial search by asking interviewees to suggest additional contacts for our research (Goodman, 1961). The snowball sampling method

resulted in an additional 5 participants, for a total of 29 interviewees that included eight government stakeholders, nine private sector stakeholders, and 12 NGO stakeholders.

Interview Questions

We developed a semi-structured interview guide with a combination of Likert-scale and open-ended questions. The interview questions can be found in ESM Appendix S2, and a summary of interview question types can be found in Table 2. The semi-structured interview style allowed interviewers to ask additional or follow-up questions when an interesting or new line of information developed during the interview (Segal, 2006). Our interview guide consisted of five sections—four based on the research questions and a fifth section characterizing the interviewees' demographics (ESM Appendix S2).

The first ten questions (ESM Appendix S2) we used to identify stakeholders' values. These questions were similarly used in Hughes (2006), originally adapted from Sabatier and Zafonte (1995), and aimed at identifying environmental values that were specifically tailored to Lake Erie's policy subsystem as opposed to trying to identify respondent's values as beliefs that transcend objects, situations, and issues (e.g., Schwart, 1992; Vaske and Donnelly, 1999). Question phrasing allowed interviewees to strongly agree with the statement if they believed the environment has intrinsic value and should be managed to enable public use without degradation. To reduce bias, these questions were phrased with different directionality, meaning that the same response would not always indicate agreement or disagreement (ESM Appendix S2). For example, the same response would not always indicate agreement towards one side of the spectrum between the public right to the environment and the individual's/economic right to the environment. We designed questions 1 to 10 as a multi-item scale for individuals' values regarding the environment. We used interviewee's responses to all the questions simultaneously to place them into values clusters, which we used to answer RQ2 and RQ3.

Questions 11 to 23 (ESM Appendix S2) aimed to identify stakeholder attitudes toward Lake Erie and HAB management. These thirteen questions contained both Likert scale and open-ended questions. Eight of the thirteen questions were specific to HABs, regarding HABs causes, the role of nutrients in fueling HABs, and HABs management. The remaining five questions addressed the importance and water quality in Lake Erie. These thirteen questions were designed

to capture attitudes such as what stakeholders see as main problems, the importance of Lake Erie to the region, and the drivers and barriers to nutrient management.

Questions 24 to 29 (ESM Appendix S2) were designed to identify stakeholders' policy preferences and consisted of six questions that were a mix of Likert scale and open-ended questions. The first two questions allowed stakeholders to rank their preferred policy approaches regarding HABs management, while the remaining four questions gave the stakeholders room to expand on their rankings. These questions were designed to capture stakeholder perceptions of policy feasibility, effectiveness, and challenges stakeholders face when designing and implementing new HABs management policies.

Questions 30 and 31 captured stakeholder relationships and formed the foundation of our network analysis. Interviewees were asked to identify those from the list they have worked with in the previous five years. The last two questions were standard demographic questions to ascertain the interviewee's age, race, sex, and political identity.

The interviews were conducted virtually on Google Meet, which allowed the Google extension Tactiq to create an interview transcript. Twenty-eight out of twenty-nine interviewees agreed to be recorded and have complete transcripts. We then quality-checked the transcripts and edited them for accuracy.

Quantitative Data Analysis

To assess whether stakeholders' values were different between stakeholder types (RQ1) we first calculated a value score for each person using an average of their answers to questions Q1-Q10 (ESM Appendix S2). We compared the scores of different stakeholder types by performing a One-way Analysis of Variance (ANOVA) on Ranks, which determines if the medians of two or more groups are different. This ANOVA approach does not make any assumptions about the distribution of the data and therefore is appropriate when the sample size is smaller than 30. The p-value was less than 0.05, therefore we concluded that individuals within stakeholder types hold significantly different values.

To assess whether attitudes and policy preferences differ between stakeholder types (RQ2 and RQ3), we compared the interviewees' responses to the ranking questions. We first determined the interviewee's highest ranked answer for each question, creating a first option distribution. We then compared the first option distribution within each stakeholder type by

testing whether the distributions were significantly different using multinomial tests. Multinomial tests determine if the distribution of multiple categories is the same as an expected distribution (Menzel, 2021). If the p-value of the comparison is smaller than 0.05, we conclude that the option preference of these two groups is significantly different.

Qualitative Data Analysis

We coded and analyzed the open-ended interview questions using NVivo (Release 1.0, QSR International, Doncaster, Australia). We used questions 1 to 23 of the interview guide as individual 'codebooks' in the NVivo software. We then coded each interviewee's responses to the questions in the individual codebooks by creating highly specific subcategories that were then sorted into a broad umbrella category. We developed categories after reading through each interviewee's answer to a question, and then assigned the answer to a specific category or subcategory. Using each of the developed subcategories, we were able to create a more general umbrella category to better analyze the interviewees' views. An example would be if interviewees had responded boating, fishing, and/or swimming, those answers would be placed in a specific subcategory and the umbrella category could be "recreation." Just as making umbrella categories allowed us to determine the number of interviewees that answered similarly, the specific subcategories allowed us to see what each interviewee stated specifically. We used the questions 11 to 23 to analyze how interviewees viewed Lake Erie, its environmental issues, and management strategies. We used questions 24 to 29 to analyze how interviewees viewed current policies and recommendations for future policies. We then summarized the results from the codebook into percentages based on the umbrella categories and compared the different stakeholder types and clusters (see Cluster Creation below). When applicable, we used Multinomial tests to see whether the observed frequencies in each umbrella category were significantly different among stakeholder types/clusters.

Cluster Creation

We identified clusters among interviewees based on values and stakeholder types to determine whether these clusters also shared similar attitudes and policy preferences. We used interview responses to Questions 1–10 to identify three 'values' clusters. We first reversed the scales for Questions 2, 4, and 8 to make the directionality consistent with the rest of the

questions. When interviewees opted out of answering a question, we assigned the average response of other interviewees to that same question to minimize the influence of that particular question to the individual's value score relative to the other interviewees. Next, we performed a cluster analysis, which divides individuals into groups (clusters), such that individuals are more similar to those within their group than to the ones in the other groups. We used the 'Kmeans' method to generate the clusters (groups). The 'Kmeans' method iteratively rearranges individuals in a predetermined number of clusters until it minimizes the distance between individuals and their cluster's center, grouping individuals with the most similar answers together.

To specify the number of clusters, we used the average silhouette approach, which assesses cluster quality by scoring individuals based on how well they fit their respective clusters in terms of similarity within and between groups. The grouping that received the highest score has the ideal number of clusters for the specific data. According to the average silhouette approach, the ideal number of clusters for our data is 2, followed by 3 and 4. However, we chose to use three clusters as that allowed us to visualize and explain differences and similarities between clusters more effectively and with more nuance (ESM Appendix S3). After generating the three values clusters, we performed a permutation test to see whether stakeholder types were randomly assorted between clusters or if there were patterns in how stakeholder types were divided into value clusters (Zeileis et al., 2008). The permutation test first creates a distribution of random clusters by dividing the stakeholders randomly into three groups multiple times (permutations). Then it compares how likely our specific cluster arrangement (composition) is within the distribution of random clusters. If the probability of our specific assortment is smaller than 0.05, we can say that the stakeholders are not randomly spread across the clusters. We used the resulting value clusters to help analyze RQ 2 and 3.

Considering that people's environmental values are multidimensional (Ripberger et. al., 2014), before visualizing the clusters, we performed a principal component analysis to focus on the first two principal components which explain 54.6% of the variance in stakeholder values (Figure 1). We also analyzed how each dimension was affected by individual questions to explain the meaning of the dimensions (ESM Appendix S3). By linking the dimensions to specific questions, we found that dimension one (horizontal axis) represents the spectrum between the public right to the environment and the individual's/economic right to the environment. Dimension two (vertical axis) represents the idea that the environment has intrinsic

value and should be managed for ecological benefit and that the environment should be managed for human benefit. It is important to note that the resulting scale is relative to the respondents' values. Questions to which their responses varied the most were more important in creating the clusters.

Network Analysis

To understand how stakeholders interact with each other through their organizations, we created a social network based on collaboration relationships reported by our interviewees. Networks help describe the relationships that individuals or entities have with each other and have several applications in understanding water resources management (Reed et al., 2009). The network analysis was completed supplementally to our research to help determine whether stakeholders work together. We established connections by asking the interviewee which individuals they have recently collaborated with concerning Lake Erie issues. We transcribed the results into a binary matrix, which we then used for further analysis. The Social Network Analysis is further explained in Appendix S1.

Results

Comparing stakeholder values (RQ1)

We found that the values between stakeholder types were not significantly different (one-way ANOVA on ranks, p-value=0.4271). Among the 10 value questions, only 2 (Questions 4 and 10) had significantly different responses between stakeholder types (one-way ANOVA on ranks, p-value=0.03). Because only 2 questions were significantly different, we used cluster analysis to identify stakeholders with shared values (see below).

Stakeholder views on Lake Erie water quality

All interviewees agreed that Lake Erie is vital to the region (Question 11: "On a scale from 1 to 5, with 1 being not important at all and 5 being extremely important, how important do you think that Lake Erie is to this region?"), with 79.3% of interviewees answering five while 20.7% answered four (Table 3). Interviewees' perceptions of Lake Erie's water quality over the past ten years ranged from good to poor (Table 3). However, 58% of interviewees perceived the water quality to be poor. Interviewees who stated they had a positive perception of Lake Erie's

water quality compared the current quality to previous years. “I would say that Lake Erie has made a tremendous comeback, but it is continuing to struggle to maintain a respectable level of water quality” (personal interview, P1-1, 09/03/2020). Most interviewees believed that HAB management should be prioritized. Indeed, HABs scored an average importance rating of 4.6 on a five-point scale (Question 21: “Giving a score from 1 to 5, with 1 being not important at all and 5 extremely important, how much should we prioritize HABs management in Lake Erie?”) (Table 3). The result from question 21 is consistent with the interviewees’ perception of the lake’s importance to the region, with interviewees rating Lake Erie’s importance on average 4.8 out of 5 (Table 3). Most stakeholders believed that Lake Erie’s importance to the region is tied to its economic and ecological values (Question 12, 58.2% of interviewees ranked economic values in the top two while 72.4% ranked ecological values in the top two). Household lake water use was rated highest by NGO and government stakeholders (Figure 2a).

Different stakeholder types held shared views on Lake Erie’s importance and water quality, but the views regarding the general state of Lake Erie were significantly different between all groups (Question 14: “If you were to describe the current state of Lake Erie to somebody unfamiliar with the region, how would you describe it?”. We coded interviewees’ answers as positive, negative, or neutral to perform a Multinomial test, p-value <0.05). Out of 12 negative views, NGO stakeholders made up seven of the negative views, while government stakeholders made up one and the private sector made up four. One private-sector interviewee stated, “When it is not choked with cyanobacteria, it may appear OK, but in truth, it is quite sick” (personal interview, P6-2, 07/21/2020). In contrast, private sector stakeholders held the most consistently positive views on the current state of Lake Erie, with three out of the four positive views being from private sectors and the remaining one from a government stakeholder. These four positive views cited the lake’s usability in the summer of 2020: “Currently, as of July 2020, it is great for fishing, great for recreation. We have a minimal problem this year with an algal bloom [sic]” (personal interview, P7-3, 07/29/2020). Government stakeholders represented the most neutral views (7 of 11 stakeholders with neutral views), generally describing the lake’s function or describing both its good and bad aspects: “I would describe it as Lake Erie is part of the system of the five Great Lakes that are a huge source of freshwater for the region as well as being very important to our economic and human development of the area. Lake Erie, because it is the shallowest, the smallest, the most biologically productive of those five Great Lakes, also

has the highest human development in its watershed [sic]" (personal interview, G5-2, 07/30/2020). There were three NGOs and one private-sector interviewee with neutral views.

Stakeholder views on the role of nitrogen in HABs

Most interviewees stated that nitrogen influences HABs. Of the NGO stakeholders, 55% said that nitrogen generally affects HABs, while the remaining 45% said nitrogen affects the blooms' toxicity. Among private stakeholders, 50% said nitrogen generally affects HABs, 25% said it affects toxicity, and 25% said it affects bloom size. Among government stakeholders, 37% said nitrogen generally affects HABs, 45% said it influences toxicity, and 18% said it influences bloom size.

Stakeholders' views reflected the uncertainty and scientific debate regarding the specific role of nitrogen on HABs. For example, two people said they did not feel they understood the science enough to answer the question, while others answered but prefaced that they are still reading articles about nitrogen's influence.

Stakeholders' attitudes

Across stakeholder types, interviewees rated policy effectiveness as the most important consideration for policy intervention, with 89% of all interviewees rating it as the top consideration. As one interviewee put it, "I would not accept a policy that I did not believe would work" (personal interview, G10-1, 07/17/2020). Stakeholder acceptance of a policy was the next most important criterion, with 54% of NGOs, 50% of government, and 37% of private stakeholder types rating it second (Figure 2c). Interviewees rated farmer engagement as the largest barrier to HAB management. More than 50% of the NGO and private stakeholders interviewed rated farmer engagement first. Government stakeholders tended to rate barriers more evenly, with their highest-rated option (33%) being 'other,' which included barriers such as weather, political will, and the economic status quo (Figure 2b).

Stakeholder policy preferences

The policy preferences were not significantly different across stakeholder types (Multinomial test, p-value>0.05). All stakeholders thought regulation holds great promise for addressing HABs in Lake Erie. NGO stakeholders typically stated a preference for regulatory

approaches, but many did not think regulation would be feasible. One NGO stakeholder stated, "I think standards are important. Most farmers are trying to do the right thing, but farm operations vary widely…" (personal interview, N3-3, 07/16/2020) in response to why regulations may not be feasible. The private and government stakeholders also preferred regulatory approaches but were divided on which approach would be the most feasible. One private stakeholder preferred market-based approaches stating, "any effective approach will be a long-term plan of market-based best practices in the Ag community [sic]" (personal interview, P6-2, 07/21/2020). Another private stakeholder preferred stronger regulations stating, "We have gone from basically 2005 with completely voluntary efforts to try to stop the problem coming in from the land. It still has not worked fifteen years later. We need to get to the regulation portion and get something done" (personal interview, P3-3, 07/17/2020).

All stakeholders believed that both federal and state agencies should oversee HAB management. Perhaps surprisingly, when asked "Who do you think should be in charge of managing HABs issues in Lake Erie," the NGO stakeholders did not mention the importance of stakeholder involvement or collaboration. On the contrary, private stakeholders mentioned that stakeholders should be involved in the process and government stakeholders also mentioned "collaboration" many times. One private-sector interviewee stated that "we really need all of these [organizations] together in a collaborative effort. There is no one person or agency that could do it alone" (personal interview, P8-1, 07/27/2020).

Creating clusters based on values (RQ1)

To understand the relationship between participants' values and their attitudes and policy preferences, we grouped participants into clusters based on their responses to the interview questions on values. Figure 1 displays the grouping of the interviewees into values clusters. The first dimension (horizontal) represents the spectrum between the public right to the environment and individual's/economic right to the environment; the first dimension explains 31.8% of the variation. The second dimension (vertical) describes whether the environment has intrinsic value and should be managed for ecological benefit (bottom) and whether the environment should be managed for human benefit (top); the second dimension explains 22.8% of the variation. Though there is a mixture of stakeholder types in each of the three value clusters, the stakeholder types

were not evenly spread among the clusters. A permutation test showed that the distributions of stakeholder types are different among the three clusters (p-value=0.02).

Cluster 1 did not contain any interviewees from the government stakeholder type, while value Clusters 2 and 3 had all three stakeholder types represented. Cluster 1 centered around the beliefs in stronger public rights to the environment and that the environment should be managed primarily for human benefit. Cluster 2 centered around stronger individual/economic rights to the environment and the belief that the environment should be managed primarily for human benefit. In contrast, Cluster 3 centered around the beliefs in stronger public rights to the environment and that the environment has intrinsic value and should not be managed primarily for human benefit. Many NGO stakeholders talked about how humans should not be considered separate from the environment. These value clusters have a wide range across the x-axis (Figure 1).

Differences in attitudes toward Lake Erie management between clusters

We found slight differences in attitudes and policy preferences between value clusters (Table 4). All value clusters generally rated ecological and economic aspects of Lake Erie as the most important, however, Cluster 3 has a stronger emphasis on Lake Erie's ecological value, especially when compared to Cluster 2 (Multinomial test, p-value=0, Figure 2a). Cluster 1 has the largest proportion of people holding a negative view towards the state of Lake Erie compared to other clusters (Multinomial test, p-value<0.05, Question 1). Cluster 3 held the most neutral views, with five interviewees, while Cluster 2 had four interviewees with neutral views and Cluster 1 had 2 interviewees with neutral views. The positive views were split two and two between Cluster 1 and Cluster 3. Cluster 1 also mentioned a lack of political will, capacity, and power as a challenge in agricultural runoff management. For example, "I would say it is largely due to a lack of political will to put the necessary procedures in place" (personal interview, P1-1, 09/03/2020).

Perspectives on how to evaluate HAB policies also help explain differences between clusters. We found that the second most important consideration for value Cluster 2 is significantly different from other clusters. Stakeholder acceptance was the second most important consideration for value Clusters 1 and 3 when considering a water quality policy in Lake Erie, with 64% and 50% of interviewees rating it second, respectively. In value Cluster 2,

public acceptance and their organizations' interests were tied for second at 33%. Across all value clusters, the highest perceived barrier to HAB management was farmer engagement. (Figure 2b).

Differences in policy preferences between clusters

Cluster 1 and 2 showed significantly different preferences for regulatory, voluntary, and market-based approaches to HAB management (multinomial tests, p-value=0.0221). In Cluster 1, 81% of interviewees rated regulatory approaches as their top preference (Figure 2d). Interviewees in cluster 1 often disparaged voluntary approaches as not beneficial: "My position would be to state that current voluntary policies are clearly failing. They are not effective at reducing the nutrient fluxes into the system because everyone expects no one to make an impact" (personal interview, G8-1, 07/29/2020).

Cluster 2 preferred both market-based and regulatory approaches, with each being rated first by 40% of the interviewees in this value cluster. Cluster 2 also believed that farmers should not be 'punished' more since they are already struggling: "To perform financially, we have to incentivize them in the positive, not be punitive in the negative " (personal interview, P2-2, 08/21/2020). Three interviewees suggested there should be a way for farmers to pass the cost of implementing better practices through the supply chain.

Cluster 3 preference is in between Cluster 1 and 2. In Cluster 3, 60% of interviewees rated regulatory approaches first. Four people in Cluster 3 believe that all aspects of the different policy approaches are needed when discussing feasibility. "Feasibility just depends on having the political will and the money to implement; that is what is keeping a lot of these practices from being implemented" (personal interview, 08/10/2020).

Discussion and Conclusion

Managing nutrient inputs that drive HABs is a challenging task, requiring the cooperation and support of a diverse range of stakeholders (Berardo et al., 2019). Previous research has shown that environmental values, attitudes, and preferences can shape support for policy change and the potential for stakeholder collaboration on a shared problem (Leiserowitz, 2006; Pitas et al., 2019; Steg et al., 2005; Vaske and Donnelly, 1999). In our study, we interviewed a diverse range of stakeholder types in the western Lake Erie basin to better understand the range of

values, attitudes, and policy preferences held, their relationship to one another, and how they are distributed between stakeholder types.

The assumption that within stakeholder types or interest groups, individuals share similar values and attitudes has been long contested (Sabatier and Zafonte, 1995). Our findings show that in the western Lake Erie basin, values are shared by stakeholders with different professional relationships to nutrient management. We also found that policy preferences were not significantly different between stakeholder types, but there were significant differences between Clusters 1 and 2, indicating that values affect policy preference. Rissman et al. (2017) similarly found that in southern Wisconsin, cultural worldviews (i.e., values) were the primary indicator of water quality policy support, while water pollution concern, perceived water quality, and self-interest all played a secondary role. Rissman's finding could help support collaboration in the basin as different stakeholder types can find common ground with one another.

Our findings also show how stakeholders view policy solutions to HABs in Lake Erie. Though stakeholders largely thought regulation would be most effective, views differed on the feasibility of passing and implementing regulation. Stakeholders anticipated a negative effect of increased taxation on farmers, which led to increased support for market-based approaches, like the Environmental Quality Incentives Program (EQIP) or other incentive-based programs. The anticipated negative effect on farmers mirrors a previous study of residents in Lake Erie's western basin which found mixed views on regulation;most people agree that farmers alone should not bear the burden, but that regulations are necessary to keep farmers accountable for their land management practices (Guo et al., 2019a). The same study found that support of regulatory measures decreased as the perceived effectiveness of a voluntary approach increased (Guo et al., 2019a). De Groot and Schuitema (2012) found that social norms—perceived public level of support for a specific policy—were an important consideration for people's personal support of regulatory approaches. Moreover, Rissman et al. (2017) argue that due to the role of social norms on acceptance of regulatory approaches, perceived equity between different interest communities such as farmers and coastal residents might increase acceptance of nutrient management policies. These studies suggest that one possible direction to decrease the gap between policy support, perceived effectiveness, and implementation feasibility at a lower (perceived) political cost, could be to increase discussion over improving voluntary approaches in collaborative decision making. From a stakeholder perspective, it might be easier to improve

existing nutrient management policies than agreeing on new ones (Garnache et al., 2016; Shortle et al., 2012). In regards to Lake Erie HABs management, improving the effectiveness of the current 4R program and incentive-based programs, like EQIP, could be the easiest way to manage HABs in the region.

Participation and engagement of a broad range of stakeholders is considered central to devising effective nutrient management strategies (Beegle et al., 2000). Uncertainty around policy effectiveness and feasibility may complicate efforts toward policy change unless there are opportunities for stakeholders to connect and communicate. When individuals with diverse backgrounds agree, there is a higher probability that the group will productively decide on a solution that may lead to effective policy changes (Goethals and Nelson, 1973). On the other hand, their differences could ultimately lead to policy solutions that benefit more people by "creating a dialogue between stakeholders with different knowledge and values" (De Nooy, 2013).

Our study is another step to understanding stakeholder interactions and nutrient management policy support in western Lake Erie's watershed. Future research can build on these findings. While we interviewed a large group of diverse stakeholders and had a good response rate, our approach is susceptible to self-selection bias and may result in an inflated level of concern when stakeholders that are more worried about the lake are more likely to participate. Future research could target a broader cross-section using a survey or methods relying on secondary data to further reduce self-selection bias. Also, our network analysis (ESM Appendix S1) shows that these specific Lake Erie stakeholders are well-connected and work collaboratively to some degree. Understanding the nature of these connections, the extent to which they enhance action, and how to foster a shared sense of trust and responsibility requires further research. Moreover, expanding the range of stakeholders included in the investigation should improve understanding of information flows and collaboration. One example of how to expand the range of stakeholders is by sending out a wide-spread survey that is able to reach more stakeholders in the region. Finally, future research could include an examination of trust among stakeholders within the basin. Harring and Jagers (2013) found that in addition to people's values, beliefs, and norms, both political trust and interpersonal trust affect people's attitudes towards increasing taxes on carbon dioxide emissions. While individuals' values are unlikely to change (Fulton et al., 1996; Homer and Kahle, 1988; Schwart, 1992), in Lake Erie's watershed,

reestablishing the trust between stakeholders could help narrow the gap between policy preference and perceived feasibility by not only increasing support for the improvement of voluntary approaches, but also by increasing the effectiveness of these approaches.

This study contributes to the understanding of western Lake Erie stakeholders, their motivation to support nutrient management policies and engage with one another. Although stakeholders of different types hold similar environmental values, these values can partially explain their preferences. Additionally, the gap between what stakeholders see as effective and feasible might lead them to prioritize less effective policies. To solve this gap, HAB management in Lake Erie will require open communication to allow for the realization that many stakeholders already share similar views and to decide on an accommodating yet effective direction for reducing nutrient inputs to the Lake.

Acknowledgments

Funding was awarded to the Cooperative Institute for Great Lakes Research (CIGLR) through the NOAA Cooperative Agreement with the University of Michigan (NA17OAR4320152). This is GLERL contribution number 2017. This CIGLR contribution number is 1209.

Literature Cited

Allinger, L. E., and Reavie, E. D., 2013. The ecological history of Lake Erie as recorded by the phytoplankton community. Journal of Great Lakes Research, 39(3), 365-382.

Anderson, C.R., Berdalet, E., Kudela, R.M., Cusack, C.K., Silke, J., O'Rourke, E., Dugan, D., McCammon, M., Newton, J.A., Moore, S.K., 2019. Scaling up from regional case studies to a global harmful algal bloom observing system. Frontiers in Marine Science 6, 250.

Beegle, D. B., O. T. Carton, and J. S. Bailey., 2000. Nutrient Management Planning: Justification, Theory, Practice. Journal of Environmental Quality 29 (1): 72–79.

Berardo, R., Turner, V.K., Rice, S., 2019. Systemic coordination and the problem of seasonal harmful algal blooms in Lake Erie. Ecology and Society 24.

Bingham, M., Kinnell, J., 2020. The Tourism Impacts of Lake Erie Hazardous Algal Blooms, Inland Waters-Dynamics and Ecology. IntechOpen.

Bright, Alan D. and Michael J. Manfredo. 1995. The quality of attitudinal information regarding natural resource issues: The role of attitude-strength, importance, and information. Society and Natural Resources.Vol. 8, pp. 399-414.

Bruulsema, T., Lemunyon, J., and Herz, B., 2009. Know your fertilizer rights. Crops and Soils, 42(2), 13-18.

Chaffin, J.D., Davis, T.W., Smith, D.J., Baer, M.M., Dick, G.J., 2018. Interactions between nitrogen form, loading rate, and light intensity on *Microcystis* and *Planktothrix* growth and microcystin production. Harmful Algae 73, 84-97.

Conroy, J.D., Edwards, W.J., Pontius, R.A., Kane, D.D., Zhang, H., Shea, J.F., Richey, J.N., and Culver, D.A., 2005. Soluble nitrogen and phosphorus excretion of exotic freshwater mussels (*Dreissena* spp.): potential impacts for nutrient remineralization in western Lake Erie. Freshwater Biology 50, 1146–1162.

Dai, G.Z., Shang, J.L., Qiu, B.S., 2012. Ammonia may play an important role in the succession of cyanobacterial blooms and the distribution of common algal species in shallow freshwater lakes. Global Change Biology 18, 1571-1581.

Daxini, A., Ryan, M., O, D. C., and Barnes, A. P., 2019. Understanding farmers' intentions to follow a nutrient management plan using the theory of planned behaviour. Land Use Policy, 85, 428–437. https://doi.org/10.1016/j.landusepol.2019.04.002

De Groot, J. I. M., and Schuitema, G., 2012. How to make the unpopular popular? Policy characteristics, social norms and the acceptability of environmental policies. Environmental Science and Policy, 19–20, 100–107. https://doi-org.proxy2.cl.msu.edu/10.1016/j.envsci.2012.03.004

De Nooy, W., 2013. Communication in natural resource management: agreement between and disagreement within stakeholder groups. Ecology and Society, 18(2).

De Pinto, J.V., Young, T.C., McIlroy, L.M., 1986. Great Lakes water quality improvement. Environmental Science and Technology 20, 752-759.

Dietz, Thomas, Amy Fitzgerald and Rachel Swom, 2005. Environmental Values. Annual Review of Environment and Natural Resources, 30:335-372.

Dietz, Thomas and Robert W. Rycroft, 1987. The Risk Professionals. New York: Russell Sage Foundation.

Dunlap, R. E., Van Liere, K. D., Mertig, A. G., and Jones, R. E., 2000. Measuring Endorsement of the New Ecological Paradigm: A Revised NEP Scale. Journal of Social Issues, 56(3), 425–442.

Eagly, A. H., and Chaiken, S., 1993. The psychology of attitudes. New York: Harcourt Brace Jovanovich, Inc.

Environment and Climate Change Canada, 2021. Canadian Environmental Sustainability Indicators: Phosphorus loading to Lake Erie. https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/phosphorus-loading-lake-erie.html#shr-pg0

Folke, C., Hahn, T., Olsson, P., and Norberg, J., 2005. Adaptive governance of social-ecological systems. Annu. Rev. Environ. Resour., 30, 441-473.

Fritzsche, D., Oz, E. 2007. Personal values' influence on the ethical dimension of decision making. Journal of Business Ethics 75, 335-343.

Fulton, D., Manfredo, M.J. and Lipscomb, J., 1996. Wildlife value orientations: A conceptual and measurement approach, Human Dimensions of Wildlife, 1:2, 24-47, DOI: 10.1080/10871209609359060

Garnache, C., Swinton, S. M., Herriges, J. A., Lupi, F., and Stevenson, R. J., 2016. Solving the Phosphorus Pollution Puzzle: Synthesis and Directions for Future Research. American Journal of Agricultural Economics, 98(5), 1334–1359.

Gill, D., Rowe, M., Joshi, S.J., 2018. Fishing in greener waters: understanding the impact of harmful algal blooms on Lake Erie anglers and the potential for adoption of a forecast model. Journal of Environmental Management 227, 248-255.

Goethals, G.R., Nelson, R.E., 1973. Similarity in the influence process: The belief-value distinction. Journal of Personality and Social Psychology 25, 117.

Goodman, L., 1961. Snowball Sampling. The Annals of Mathematical Statistics, 32(1), 148-170.

Guo, T., Gill, D., Johengen, T.H., Cardinale, B.L., 2019a. What determines the public's support for water quality regulations to mitigate agricultural runoff? Environmental Science and Policy 101, 323-330.

Guo, T., Nisbet, E. C., and Martin, J. F., 2019b. Identifying mechanisms of environmental decision-making: how ideology and geographic proximity influence public support for

managing agricultural runoff to curb harmful algal blooms. Journal of Environmental Management, 241, 264-272.

Guo, T., Johnson, L. T., LaBarge, G. A., Penn, C. J., Stumpf, R. P., Baker, D. B., and Shao, G. 2021. Less Agricultural Phosphorus Applied in 2019 Led to Less Dissolved Phosphorus Transported to Lake Erie. Environmental Science & Technology, 55(1), 283–291.

Harring, N. and Jagers, S., 2013. Should We Trust in Values? Explaining Public Support for Pro-Environmental Taxes. Sustainability 2013, 5, 210-227; doi:10.3390/su5010210

H2Ohio, 2019. Phosphorus Reduction Impact. http://h2.ohio.gov/about-h2ohio/

Harke, M.J., Steffen, M.M., Gobler, C.J., Otten, T.G., Wilhelm, S.W., Wood, S.A., Paerl, H.W., 2016. A review of the global ecology, genomics, and biogeography of the toxic cyanobacterium, *Microcystis* spp. Harmful Algae 54, 4-20.

Henry, A.D., Lubell, M., McCoy, M., 2011. Belief systems and social capital as drivers of policy network structure: The case of California regional planning. Journal of Public Administration Research and Theory 21, 419-444.

Homer, P.M., Kahle, L.R., 1988. A structural equation test of the value-attitude-behavior hierarchy. Journal of Personality and Social Psychology 54, 638.

Hughes, S. M., 2006. The changing value of water: The conundrum for future water manager. Michigan State University, Michigan, USA.

IJC, 1972. Great Lakes Water Quality Agreement.

IJC, 1987. Revised Great Lakes Water Quality Agreement of 1978 as amended by protocol.

IJC, 2012. Great Lakes Water Quality Agreement.

IJC, 2014. A Balanced Diet for Lake Erie: Reducing Phosphorus Loadings and Harmful Algal Blooms.

Jetoo, S., Grover, V.I., Krantzberg, G., 2015. The Toledo drinking water advisory: suggested application of the water safety planning approach. Sustainability 7, 9787-9808.

Kalcic, M.M., Kirchhoff, C., Bosch, N., Muenich, R.L., Murray, M., Griffith Gardner, J., Scavia, D., 2016. Engaging stakeholders to define feasible and desirable agricultural conservation in western Lake Erie watersheds. Environmental Science & Technology 50, 8135-8145.

Kane, D. D., Conroy, J. D., Peter Richards, R., Baker, D. B., and Culver, D. A. 2014. Re-eutrophication of Lake Erie: Correlations between tributary nutrient loads and phytoplankton biomass. Journal of Great Lakes Research, 40(3), 496–501.

Kim, K., Mun, H., Shin, H., Park, S., Yu, C., Lee, J., Yoon, Y., Chung, H., Yun, H., Lee, K., 2020. Nitrogen stimulates *Microcystis*-dominated blooms more than phosphorus in river conditions that favor non-nitrogen-fixing genera. Environmental Science & Technology 54, 7185-7193.

Leiserowitz, A., 2006. Climate change risk perception and policy preferences: the role of affect, imagery, and values. Climatic Change, 77(1–2), 45.

Menzel, U., 2021. EMT: Exact Multinomial Test: Goodness-of-Fit Test for Discrete Multivariate Data.

Morgan, Granger M., Louis F. Pitelka, and Elena Shevliakova. 2001. Elicitation of expert judgments of climate change on forest ecosystems. Climatic Change. 49: 279-307.

Newell, S.E., Davis, T.W., Johengen, T.H., Gossiaux, D., Burtner, A., Palladino, D., McCarthy, M.J., 2019. Reduced forms of nitrogen are a driver of non-nitrogen-fixing harmful cyanobacterial blooms and toxicity in Lake Erie. Harmful Algae 81, 86-93.

Ohio EPA, 2013. Ohio Lake Erie Phosphorus Task Force II Final Report.

O'Neill J. and Spash, C., 2000. Conceptions of Value in Environmental Decision-Making. Environmental Values. Vol. 9, pp.521-535

Pitas, N.A., Mowen, A.J., Mueller, J.T., Taff, B.D., Graefe, A., 2020. The role of values, ideologies, and attitudes in shaping public support for privatization in local park and recreation services. Journal of Leisure Research 51, 16-35.

R Core Team., 2020. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Reed, M. S., 2008. Stakeholder participation for environmental management: a literature review. Biological conservation, 141(10), 2417-2431

Reed, M. S., Graves, A., Dandy, N., Posthumus, P., Hubacek, K., Morris, J., Prell, C., Quinn, C.H., and Stringer, L.C., 2009. Who's in and why? A typology of stakeholder analysis methods for natural resource management. Journal of Environmental Management. 90(5), 1933–49.

Ripberger, J. T., Gupta, K., Silva, C. L., and Jenkins, S. H. C., 2014. Cultural Theory and the Measurement of Deep Core Beliefs Within the Advocacy Coalition Framework. Policy Studies Journal, 42(4), 509–527. https://doi.org/10.1111/psj.12074

Rissman, A.R., Carpenter, S.R., 2015. Progress on nonpoint pollution: barriers & opportunities. Daedalus 144, 35-47.

Rissman, A.; Kohl, P. and Wardropper, C., 2017. Public Support for carrot, stick, and no-government water quality policies. Environmental Science and Policy 76, 82–89.

Robertson, D.M., and Saad, D. A., 2011. Nutrient Inputs to the Laurentian Great Lakes by Source and Watershed Estimated Using SPARROW Watershed Models. JAWRA Journal of the American Water Resources Association 47, 1011-1033.

Rokeach, M. 1973. The nature of human values. New York: The Free Press.

Rolston, H. III., 1986. Philosophy Gone Wild: Essays in Environmental Ethics. Amherst, NY: Prometheus.

Sabatier, P. A., 1998. An advocacy coalition framework of policy change and the role of policy-oriented learning therein. Policy Sciences, 21(2–3), 129–168. https://doi.org/10.1007/BF00136406

Sabatier, P. A., and Zafonte, M. A., 1995. The views of bay/delta water policy activists on endangered species issues. Hastings West-Northwest Journal of Environmental Law and Policy, 2(2), 131-146.

Sayers, M.J., Grimm, A.G., Shuchman, R.A., Bosse, K.R., Fahnenstiel, G.L., Ruberg, S.A., Leshkevich, G.A., 2019. Satellite monitoring of harmful algal blooms in the Western Basin of Lake Erie: A 20-year time-series. Journal of Great Lakes Research 45, 508-521.

Scavia, D., DePinto, J.V., Bertani, I., 2016. A multi-model approach to evaluating target phosphorus loads for Lake Erie. Journal of Great Lakes Research 42, 1139-1150.

Schwartz, S. H., 1992. Universals in the content and structure of values: Theory and empirical tests in 20 countries. In M. Zanna (Ed.), Advances in experimental social psychology (Vol. 25, pp. 1-65). New York: Academic Press.

Segal, D. L., Coolidge, F. L., O'Riley, A., and Heinz, B. A., 2006. Structured and Semistructured Interviews. Clinician's Handbook of Adult Behavioral Assessment, 121–144.

Shortle, J.S.; Blandford, D.; Ribaudo, M.; Horan, R.D., 2012. Reforming Agricultural Nonpoint Pollution Policy in an Increasingly Budget-Constrained Environment. Environmental Science and Technology 46(3),1316-1325.

Steg, L., Dreijerink, L., and Abrahamse, W., 2005. Factors influencing the acceptability of energy policies: A test of VBN theory. Journal of Environmental Psychology, 25(4), 415–425. https://doi-org.proxy2.cl.msu.edu/10.1016/j.jenvp.2005.08.003

Stern, Paul C., 2000. Toward a coherent theory of environmentally significant behavior. Journal of Social Issues, 56(3), 407–424.

Stern, Paul C. and Thomas Dietz, 1994. The value basis of environmental concern. Journal of Social Issues 50:65-84.

Stern, Paul C., Thomas Dietz, Linda Kalof and Gregory A. Guagnano, 1995. Values, beliefs, and proenvironmental action: Attitude formation toward emergent attitude objects. Journal of Applied Social Psychology. 25:pp.1611-1636.

Stow, C.A., Glassner-Shwayder, K., Lee, D., Wang, L., Arhonditsis, G., DePinto, J.V., Twiss, M.R., 2020. Lake Erie phosphorus targets: An imperative for active adaptive management. Journal of Great Lakes Research 46, 672-676.

Stumpf, R. P., Wynne, T. T., Baker, D. B., Fahnenstiel, G. L., and Álvarez, I. 2012. Interannual Variability of Cyanobacterial Blooms in Lake Erie. PLoS ONE, 7(8), 1–11.

U.S. EPA, 2004. Lake Erie Lakewide Management Plan.

Vaske, Jerry J. and Maureen P. Donnelly, 1998. A value-attitude-behavior model predicting wildland preservation voting intentions. Society and Natural Resources. Vol 12, pp. 523-537

Vliet, O.V., Hanger, S., Nikas, A., Spijker, E., Lieu, J., 2020. The importance of stakeholders in scoping risk assessments—Lessons from low-carbon transitions. Environmental Innovation and Societal Transitions 35.

Watson, S.B., Miller, C., Arhonditsis, G., Boyer, G.L., Carmichael, W., Charlton, M.N., Confesor, R., Depew, D.C., Höök, T.O., Ludsin, S.A., 2016. The re-eutrophication of Lake Erie: Harmful algal blooms and hypoxia. Harmful Algae 56, 44-66.

Weible, C. M., 2007. An Advocacy Coalition Framework Approach to Stakeholder Analysis: Understanding the Political Context of California Marine Protected Area Policy. Journal of Public Administration Research and Theory: J-PART, 17(1), 95–117.

Weible, C., Sabatier, P.A., Lubell, M., 2004. A comparison of a collaborative and top-down approach to the use of science in policy: establishing marine protected areas in California. The Policy Studies Journal, Vol. 32, No. 2.

Wilson, R.S., Beetstra, M.A., Reutter, J.M., Hesse, G., Fussell, D.V., Johnson, L.T., King, K.W., Labarge, G.A., Martin, J.F., Winslow, C., 2019. Commentary: Achieving phosphorus reduction targets for Lake Erie. Journal of Great Lakes Research 45, 4-11.

Wolf, D., Georgic, W., Klaiber, H.A., 2017. Reeling in the damages: Harmful algal blooms' impact on Lake Erie's recreational fishing industry. Journal of Environmental Management 199, 148-157.

Zeileis, A., Wiel, M. A., Hornik, K., and Hothorn, T., 2008. Implementing a class of permutation tests: the coin package. Journal of statistical software, 28(8), 1-23.

Table 1. Descriptive table including interviewees' clusters, types, and specific occupation.

Code	Cluster	Stakeholder Type	Description
N1-1	1	NGO	Conservation Advocacy
N2-1	1	NGO	Conservation Advocacy
N5-1	1	NGO	Public Organization
N6-1	1	NGO	Aquatic Advocacy
N9-1	1	NGO	Aquatic Advocacy
N10-1	1	NGO	Conservation Advocacy
N11-1	1	NGO	Nonprofit Aquatic Research
N12-1	1	NGO	NGO Research
P1-1	1	Private	Agriculture
P5-1	1	Private	Agriculture
P8-1	1	Private	Aquatic
P9-1	1	Private	Aquatic
N4-1	2	NGO	Conservation Advocacy
G1-2	2	Government	Local Government
G6-2	2	Government	State Government
G7-2	2	Government	State Government
P2-2	2	Private	Agriculture
P6-2	2	Private	Agriculture
G5-3	3	Government	State Government
N3-3	3	NGO	Wildlife Advocacy
G2-3	3	Government	State Government
G3-3	3	Government	State Government
G4-3	3	Government	Local Government
G9-3	3	Government	Government Research
G10-3	3	Government	Government Research
N7-3	3	NGO	Conservation Organization
N8-3	3	NGO	Aquatic Advocacy
P3-3	3	Private	Aquatic
P7-3	3	Private	Agriculture

Table 2. Summary of interview instrument, including the variable measured and the type of question and scale. In Likert Scale questions, interviewees were asked how much they agree or disagree with a statement. In rating questions interviewees were asked to rate options from most to least important. Question are in ESM Appendix S2.

Question No.	Variable	Question Type
1-10	Value	Likert Scale (From 1 to 5)
11	Attitude	Likert Scale (From 1 to 5)
12	Attitude	Rating Scale
13	Attitude	Likert Scale (From 1 to 5)
14-19	Attitude	Open-Ended
20	Attitude	Rating Scale
21	Attitude	Likert Scale (From 1 to 5)
22	Attitude	Open-ended
23-24	Policy Attitude/Preference	Rating Scale
25-29	Policy Attitude/Preference	Open-ended
30-31	Network	Open-ended

Table 3. Descriptive statistics of quantitative questions. Asterisks indicate answers that were reversed.

Question No.	Mean	SD	Median	Max	Min
1	3.78	1.06	4	5	1
2*	4.12	0.65	4	5	3
3	3.63	1.01	4	5	1
4*	3.11	1.29	3	5	1
5	3.89	1.20	4	5	1
6	3.78	1.00	4	5	2
7	4.45	0.74	5	5	3
8*	3.14	0.95	3	5	1
9	4.83	0.38	5	5	4
10	4.86	0.44	5	5	3
11	4.79	0.41	5	5	4
13	3.45	0.74	4	4	2
21	4.55	0.57	5	5	3

Table 4. Main similarities and differences between clusters.

Cluster	Values	Attitudes	Policy Preferences
1	• Public rights to the environment. • The environment should be managed primarily for human benefit.	• Stronger emphasis on Lake Erie's economic value. • Largest proportion of people holding a negative view towards the state of Lake Erie. • Mentioned a lack of political will, capacity, and power as a challenge in agricultural runoff management. • Policy effectiveness is a priority, followed by stakeholder acceptance.	• Significantly different from cluster 2. • Stronger preference for regulatory approaches.
2	• Individual/economic rights to the environment. • The environment should be managed primarily for human benefit.	• Stronger emphasis on Lake Erie's ecological value, followed by household use. • Saw scientific agreement as a big challenge in nutrient management. • Public acceptance and their organizations' interests were more important than stakeholder's acceptance when considering a policy.	• Significantly different from cluster 1. • Divided preference for market-based and regulatory approaches.
3	• Public rights to the environment. • The environment has intrinsic value.	• Stronger emphasis on Lake Erie's ecological value. • Policy effectiveness is a priority, followed by stakeholder acceptance.	• Not significantly different from clusters 1 and 2. • Preference for regulatory approaches.

Figure captions

Figure 1. Principal component and cluster analysis of stakeholder responses. Each circle/triangle/square represents a single interviewee. The horizontal axis represents the spectrum between the public and economic/individual right to the environment and explains almost 32% of the data variance. The vertical axis represents the spectrum of the environment's intrinsic value or whether it should be managed for human benefit. The vertical axis explains 23% of the data variance. In cluster 1 there are 12 interviewees (five private, seven NGO). In cluster 2 there are 6 interviewees (three government, one private, two NGO). In cluster 3 there are 11 interviewees (one private, six government, four NGO).

Figure 2. Stacked bar charts showing interviewees' highest-rated options for questions 12, 20, 23, and 24. The options most people rated the highest in each cluster/stakeholder type take up the largest area in each column. NGO, Gov, Private, C1, C2, and C3 represent the three stakeholder types and three value clusters. **a)** question 12: Why do you think that Lake Erie is important to the region? **b)** question 20: what challenges do you think most impact the management of HABs in Lake Erie? Agreement*: Scientific agreement/ knowledge availability; Resources*: Resources for policy creation and enforcement; **c)** question 23: when considering a policy regarding water quality in Lake Erie, what is the most important consideration to your opinion? The option 'policy effectiveness' is excluded on this graph; **d)** question 24: what would be your preferred policy approach to addressing HABs in Lake Erie?

Figure 1

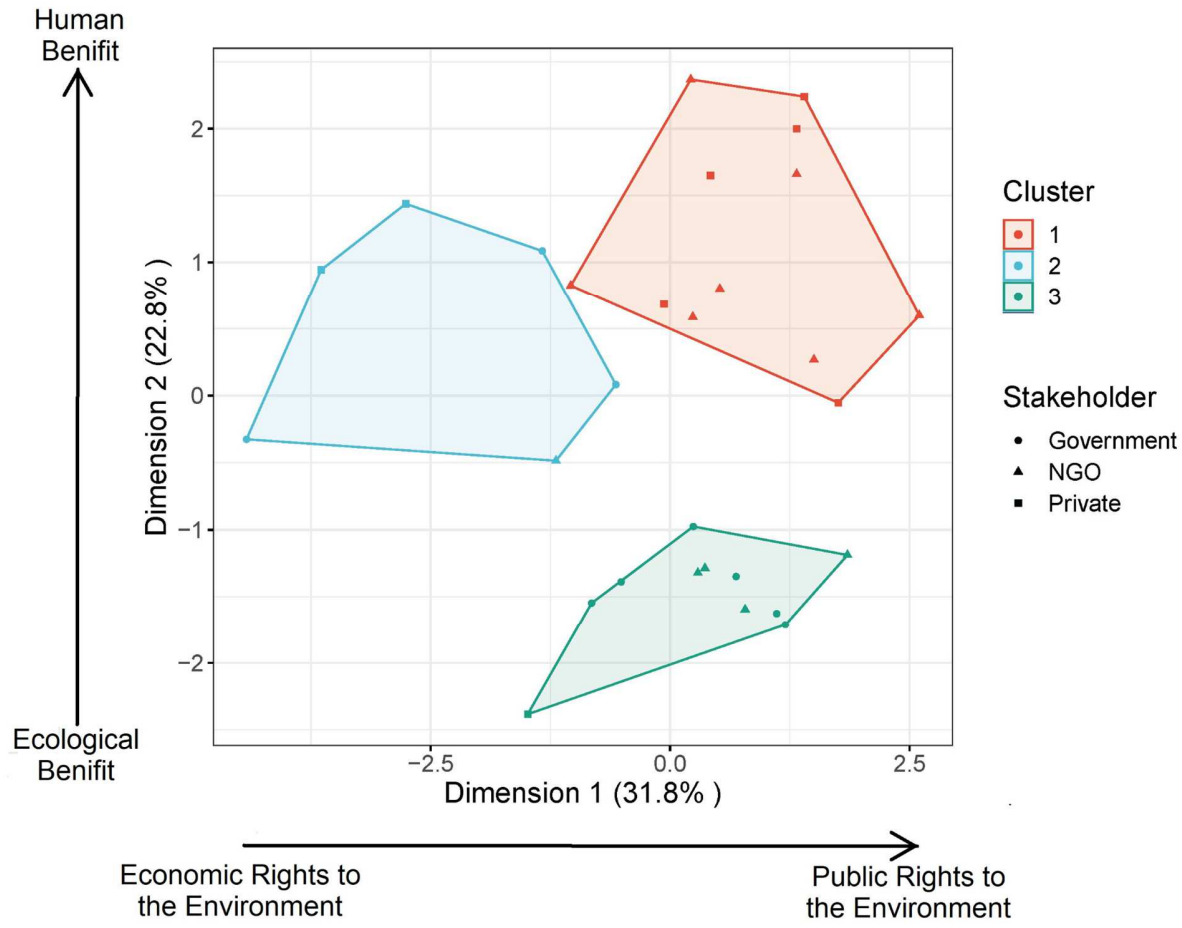
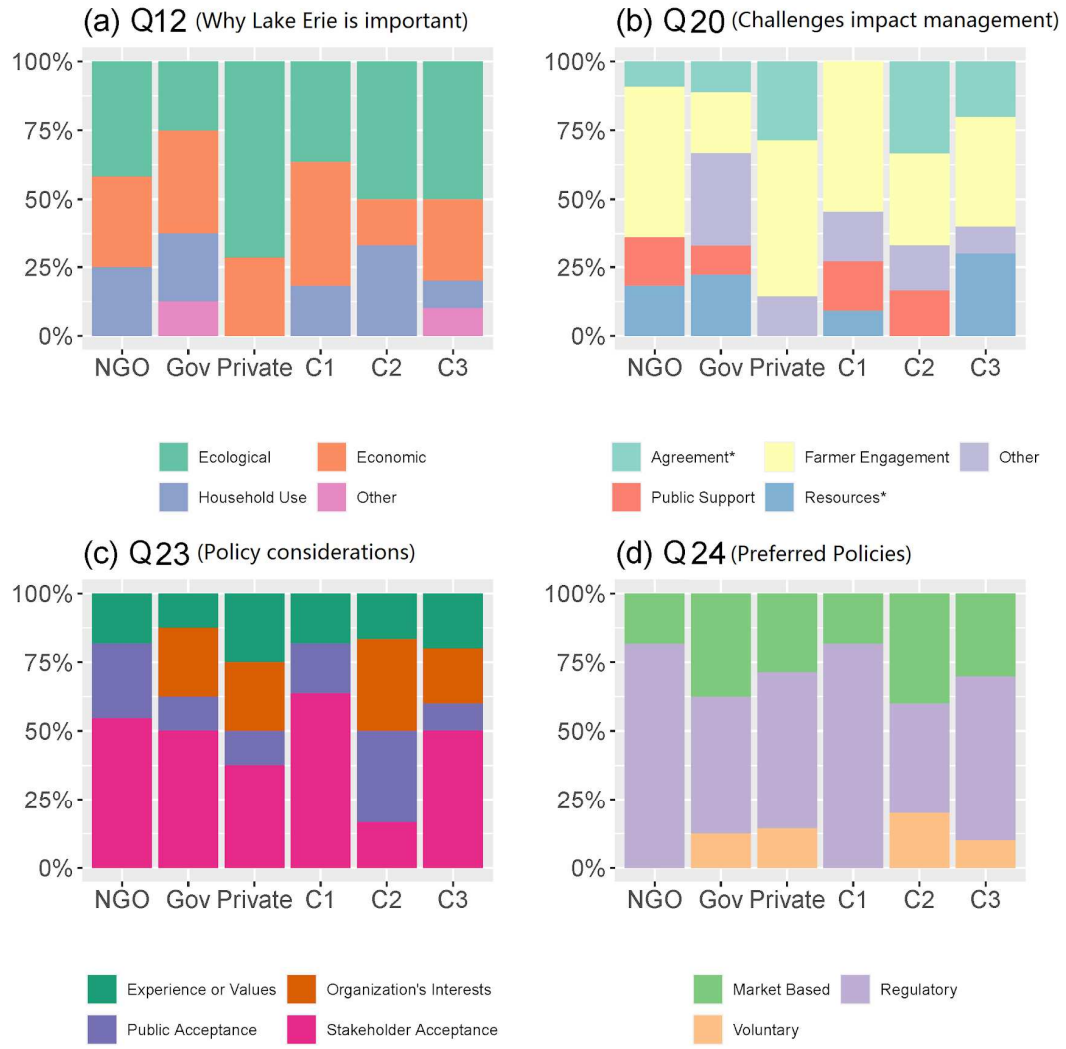

Human
Benifit
Ecological
Benifit
Economic Rights to
the Environment
Public Rights to
the Environment
Dimension 2 (22.8%)
Dimension 1 (31.8%)
2
1
0
−1
−2
−2.5
0.0
2.5
Cluster
1
2
3
Stakeholder
Government
NGO
Private

Figure 2


(a) Q12 (Why Lake Erie is important)
100%
75%
50%
25%
0%
NGO
Gov
Private
C1
C2
C3
Ecological
Economic
Household Use
Other
(b) Q20 (Challenges impact management)
Agreement*
Farmer Engagement
Other
Public Support
Resources*
(c) Q23 (Policy considerations)
Experience or Values
Organization's Interests
Public Acceptance
Stakeholder Acceptance
(d) Q24 (Preferred Policies)
Market Based
Regulatory
Voluntary