Are nutrient policy impacts on recreation in Lake Erie as murky as the water?

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Abstract

In this paper, we investigate the economic impacts of a 40% nutrient reduction policy on beach going and angler behavior by focusing on how individuals engaging in recreational activities respond to different ecological conditions in Lake Erie basins in terms of their frequency of day trips using negative binomial regression analysis. We designed and administered two contingent behavior surveys, one for beachgoers and one for anglers, which collected both stated and reveled preference data to estimate a trip demand function using the travel cost method. Their trip demand functions are then linked with outcomes from an industry leading ecological model – Ecopath with Ecosim (EwE) – that has been simulated the actual ecological changes from the 40% reduction policy to elucidate how the recreational trips are affected by the ecological changes triggered by the policy. Our results show that the Western basin exhibits the highest sensitivity to algae bloom characteristics, with clean conditions significantly boosting trips and poor environmental conditions leading to substantial welfare losses. We will explore these results in detail and complete the linking of the EwE ecological data once we've completed collection of angler survey data.

1. Introduction

Lake Erie is the most productive and populated lake among the five Great Lakes and provides an overall annual income to the regional economy of over $50 billion (Watson et al., 2016) through recreation, fishing, tourism, and shipping. However, Lake Erie has had a torturous history with equally impressive policy and management responses. For example, Lake Erie attracted nationwide attention during the late 1960's when media reported Lake Erie was 'dead' due to nutrient pollution that triggered the establishment of the EPA and the implementation of the Clean Water Act in 1972. In that same year, the Great Lakes Water Quality Agreement (GLWQA) was signed by Canada and the US, which initiated a phosphorus reduction program (De Pinto et al., 1986). The priority of reduction focused on point sources, such as wastewater treatment plants and detergents. A nutrient load target of 11,000 metric tons/year was reached by the late 1980s and water quality improved significantly (Burns et al., 2005). This success provided a clear and inspirational example that phosphorus control was effective and manageable even with a lake as the size of Lake Erie.

After years of steady improvement in water quality, Lake Erie has recently shown symptoms of nutrient pollution (Auer et al., 2010; Michalak et al., 2013; Scavia et al., 2014). Harmful algal blooms (HABs) have reappeared in the western basin and hypoxia area has increased in the central basin. Although the water quality problems differ among Lake Erie’s three basins (western basin, central basin and eastern basin), the major drivers are common and include nutrient loads, climate change, and invasive species.

Nutrient management has focused primarily on reducing total phosphorus loads and new loading targets.

Subsequently, the GLWQA was updated to reduce annual phosphorus loads to Lake Erie by 40% by 2025. This phosphorus reduction effort will focus on limiting those originating from agriculture.

Lower nutrient loads may eventually reduce HABs and hypoxia, and thereby improve water quality, yet may lead to lower fish production in Lake Erie, particularly in offshore regions (IJC, 2020), thereby, jeopardizing sustainability of fisheries. Ecosystem response to reduced loading is further complicated by the internal nutrient dynamics of Lake Erie and effects of additional interacting stressors (e.g., climate change and invasive species) on the food web. While provision and policy are needed to control HABs and hypoxia and to protect the ecosystem, focusing on policy (e.g., 40% nutrient reduction) driven by a single factor (e.g., nutrients) or a single management objective (e.g., a sustainable yellow perch fishery) may have unintended ecological consequences, and may or may not achieve desired economic improvements (IJC, 2020). The economic and ecological systems of Lake Erie are tightly coupled and present distinct tradeoffs between benefits and costs. For example, nutrient reduction may benefit general recreation and tourism through improved water quality but could negatively affect recreational and commercial fishing industries due to lower fish production and could impose significant costs on agricultural producers through regulation of phosphorus runoff – the main outlet for achieving the nutrient target. Moreover, changes in economic behavior as a response to nutrient reduction (e.g., overfishing of already stressed stocks) may further affect the ecological system as a feedback effect. To evaluate the impacts of a policy or management strategy, linkages between the economic and ecological systems need to be well-understood and accounted for to summarize all economic gains and losses from a policy or shock across all economic sectors (Warziniack et al., 2011, 2013; Carbone and Smith, 2013; McDermott et al., 2013). Using the framework, we will focus on the economic response to nutrient loading of the Lake Erie ecosystem to quantify the full economic impacts of nutrient reduction. We will investigate the direct effects of a 40% nutrient reduction policy on fisheries, recreation, and the broader economy. This investigation focuses on discerning how individuals engaging in recreational activities respond to alterations in Lake Erie's ecological conditions, specifically in terms of their frequency of day trips to the Lake Erie region. To achieve this, we designed and administered two contingent behavior surveys, one for beachgoers (e.g., sunbathing, walking pets, reading) and one for anglers to gather insights into both revealed behavior and contingent behavior, aiming to uncover the recreational demand function for each group using the travel cost method. Their trip demand functions are then linked with outcomes from an industry leading ecological model – Ecopath with Ecosim (EwE) – (in collaboration with a team of ecologists) that has been simulated the actual ecological changes from the 40% reduction policy (changes in ecology of Lake Erie as nutrient or food web change or other ecologically dependent characteristics like water-quality or HAB occurrences) to forecast the tangible alterations in the ecological landscape to elucidate how the recreational trips are affected by the ecological changes triggered by the policy. The results generated by this ecological model are then utilized as input for the established demand function, allowing us to define the recreation demand function as contingent upon ecological attributes.

While previous studies have employed combined stated preferences (SP) and revealed preferences (RP) (Cameron, 1992; Adamowicz et al., 1994) and survey method (Whitehead and Lew, 2020) to investigate the effects of ecological shifts on recreational behavior, none have integrated ecological data from simulations within an ecological model directly into their models. Our study utilizes this innovative approach to establish the recreation demand function as a direct function of ecological attributes. Having a better understanding of the value of fishery and changing patterns of behavior is relevant to the discussions that regulators and fishery managers are having regarding the policy. Our model will identify economic and ecological costs and benefits associated with current policy, and model's output and analysis can support decision maker's need to understand how the intervention influences all interconnected systems and dimensions.

Considering the issues involved in recreational demand modeling, due to the integer nature of the trip data, truncation of the data at zero visits (Englin and Shonkwiler, 1995) and some over-dispersion problems, the standard OLS estimator may not be the appropriate choice, however it has never been a rejected method for recreational demand analysis or travel cost method (Peterson, 2003). The models that have been used in numerous recent studies (Winkelmann, 2008) are Poisson and negative binomial count data models which capture most of these issues and result in an unbiased and consistent estimator. In this paper, we compare the results of negative binomial count data model. Due to overdispersion in the data, the Poisson regression model is unsuitable, as it relies on the assumption that the mean equals the variance.

Our results highlight the significant role environmental quality plays in shaping recreational behavior. Clean and odor-free beaches encourage visitation, while foul odors and harmful bacteria act as strong deterrents. Addressing these environmental challenges, particularly in high-use recreational areas, is essential to sustaining tourism and its associated economic benefits along the Lake Erie coastline. Additionally, demographic factors such as gender and age further influence trip behavior, suggesting a need for targeted strategies to maintain accessibility and appeal across diverse population groups.

The rest of the paper is organized as follows. Section 2, provides an overview of the methods used by previous literature, including revealed preferences, stated preferences and travel cost method. In section 3, we describe the details of the two surveys we designed and administered. Section 4 indicates the mathematical and empirical model including negative binomial regression method and data collected from the survey. In section 5, we then discuss the results from the application of the method and section 6 includes the welfare analysis. Section 7 provides an overview of the conclusions

2. Literature Review

Natural environmental resources play a significant role in supporting recreational activities. However, when these environments are damaged or degraded, the opportunities for recreation can be reduced or lost. This makes it essential to assess the condition of recreational areas, which is often done through nonmarket valuation methods. Estimating the value of these recreational opportunities is crucial for conducting a thorough cost-benefit analysis. One effective approach to this valuation is to analyze the demand for recreation. By assessing how changes in environmental quality affect consumer surplus— essentially, the benefits that individuals gain from recreation—policymakers can conduct welfare analysis. This helps them make informed decisions that balance the need for economic development with the importance of environmental protection.

Different literature has used different methods to provide that information for recreational demand and policy making. Many studies have explored the recreational behavior of people taking day trips to the Lake Erie area and its beaches mostly in the western basin due to the higher HAB severity. However, no comprehensive analysis has yet examined recreational activity across all beaches along Lake Erie while simultaneously considering all three basins (eastern, central, and western). For instance, Sohngen and Bielen (1999) analyzed the value of day trips to two Lake Erie beaches using the travel cost method, focusing on specific locations rather than the lake as a whole. This study addresses the need for a broader perspective by evaluating all of Lake Erie's beaches within a unified framework.

For the first part of our data, we focus on a survey targeted at beachgoers (e.g., sunbathing, walking pets, reading) to uncover the recreational demand function for this group using the travel cost method for three basins of Lake Erie. We build on the work of Wolf et al. (2019), who examined the impacts of harmful algal blooms (HABs) and E. coli contamination on recreational behavior in Lake Erie. In their study, they focused on 18 Ohio counties along the Lake Erie shoreline and collected data on trips to the lake during the summer of 2016. Their analysis concentrated on the western basin of Lake Erie, which has been repeatedly exposed to HABs for nearly 20 years. They utilized survey-based approaches and estimations based on the conditional logit, mixed logit, and latent class models of recreation choice. Their findings showed that travel costs had a negative and significant effect on recreational choices, with a value of -0.049. Moreover, they found that water quality measures, particularly algae and E. coli concentrations, significantly impacted recreational decisions. The coefficient on algae was negative and significant (-0.0121), confirming the hypothesis that HABs influence visitors' decisions to visit Lake Erie. Similarly, the concentration of E. coli had a significant negative impact (-0.0620) on site choice. As an extension of this study, we broaden the analysis to include all three basins of Lake Erie (western, central and eastern) to allow for a more comprehensive comparison of algae bloom impacts. This expansion includes data from

Michigan, Pennsylvania, and New York, in addition to Ohio counties facilitating a more regionally representative understanding of how HABs affect recreational behavior across the entire lake.

After the Exxon Valdez oil spill over in March 1989 and the contingent valuation of non-use values (Portney, 1994; Carson et al., 2003; Cameron, 1992; and Adamowicz et al., 1994; Cameron et al., 1996; Englin and Cameron, 1996) stated a new approach to the environmental valuation which was combining Stated Preference (SP) and Revealed Preference (RP) data to estimate the recreational demand function for environmental services. By combining data, the efficiency of benefit estimation can be improved and the consistency between the two types of data can be tested (Huang et al., 1997). In RP approach, we use behavioral data to estimate the ex-post willingness to pay for various commodities. The methods used for RP approach are included Travel Cost Method (TCM), hedonic price method, and etc. In the SP approach, we use hypothetical data to estimate the ex-ante willingness to pay for various commodities such as contingent valuation, contingent behavior, and conjoint analysis. Whitehead et.al (2000) show how stated preference methods can be used to value quality changes at a single site without imposing the assumption that individuals respond to objective measures of site quality. Later, Whitehead et al. (2008) revealed that combining RP and SP method has some advantages that can be addressed, such as SP data suffer from hypothetical bias and hypothetical choices that may not reflect constraints on behavior. Combining SP data with RP data grounds hypothetical choices with real choice behavior. Other literature confirmed that in environmental economics, the combination of RP and SP data maximizes the strengths of the two approaches while minimizing their weaknesses (Cameron, 1992; Adamowicz et al., 1994). Given their approach, we also use the combine RP and SP data in our survey design.

The Travel Cost Method (TCM) is commonly used in environmental valuation literature to estimate recreation demand as a function of trip costs. Travel cost recreation demand models are one approach that stems from Hotelling’s (1947) in which an outdoor recreation site's services require the consumer to incur the costs of a trip to that site. Travel costs serve as implicit prices meaning that all the trip expenses related to accommodation, transportation, etc.… are effectively present the prices and costs of a trip and they are not necessarily stated explicitly or purchased in the market. These costs reflect both people’s distances from recreation sites and their opportunity costs of time (Whitehead et al. 2000). Peterson (2003) focuses on using observed travel behavior to infer the value individuals place on recreational experiences. He applies the single-site travel cost model, which treats the number of trips taken to a recreational site as a function of travel costs, individual preferences, and site characteristics. Following the approach outlined by Peterson (2003) in the travel cost method, we aim to estimate the recreation demand function for the three basins of Lake Erie.

However, while previous studies have employed combined SP and RP approaches and survey method to investigate the effects of ecological shifts on behavior through the TCM, none have integrated ecological data from simulations within an ecological model directly into their models. Our study utilizes this approach to establish the recreation demand function as a direct function of ecological attributes. Notably, our study considers both beachgoers and anglers simultaneously providing a comprehensive understanding of recreational behavior across different user groups and along all three basins of Lake Erie to offer valuable insights for policymakers.

3. Data

In this paper we focus on the economic response to nutrient loading of the Lake Erie ecosystem to quantify the full economic impacts of nutrient reduction and alternative policy approaches. We will investigate the direct and indirect effects of a 40% nutrient reduction policy on fisheries, recreation, and the broader economy. This investigation focuses on discerning how individuals engaging in recreational activities respond to alterations in Lake Erie's ecological conditions, specifically in terms of their frequency of day trips to the Lake Erie region as count data. Therefore, incorporating detailed data to understand the impact of water clarity and fish populations on recreational trips, and ultimately revealing the broader economic implications is crucial. To achieve this, we devised a survey to gather insights into both revealed behavior and contingent behavior alongside ecological data for assessing the impacts and aiming to uncover the recreational demand function of participants.

Survey data will be used for two primary purposes: (1) to develop recreation sectors for the economic model (i.e., categories of expenditures and/or receipts) and (2) to empirically determine recreation demand as a function of ecosystem characteristics, which will be embedded in the economic model and will serve as a linkage between the ecological and economic systems. Recreational expenditure data collected from the funded survey are sufficient for developing the economic sector representation.

3.1 Survey Type

In order to conduct a comprehensive analysis, we designed and administered two contingent behavior surveys, that collected both stated and reveled preference data targeting distinct groups: anglers and individuals who chose Lake Erie for recreational purposes (e.g., sunbathing, walking their pets, reading…). Each survey will be built off existing methods of measuring trip demand that use a combination of RP and SP methods for each group using the travel cost method (e.g., Huang et al., 1997; Huang et al., 2012; Whitehead et al., 2000; Jeon et al., 2011; Melstrom and Lupi, 2013; Ready et al., 2018; Hunt et al., 2021) regarding recreational activities, commercial and recreational fishing. Both surveys asked similar RP questions regarding the number of trips taken (Jeon et al., 2011) to specific Lake Erie locations, home zip code, expenditures, preferences over activities, and demographic details such as households' income before taxes in dollars, gender (male, female, nonbinary/third gender), year of birth (age), marital status (never married, married, widowed, divorced, separated), employment status, and whether they had children under 18 or not. The SP questions (Wolf et al. ,2019), however, differed slightly depending on whether respondents received the angler or beachgoer survey. Beachgoing survey is aimed to ascertain how the presence and various characteristics of algal blooms (e.g., harmful bacteria, foul odor, and bloom size) and associated changes in water quality might influence the frequency of day trips. Additionally, respondents were queried on their awareness of advisories pertaining to water quality and safety indicators for activities like swimming and fish consumption, as well as how the presence of such advisories influenced their recreational plans. Respondents were presented with three hypothetical scenarios designed to assess how variations in bloom size (1-mile, 4-mile, 8-mile), with or without associated smell or harmful bacteria, might influence their trip-taking behavior. The bloom size and characteristics, such as presence of smell and harmful bacteria, were randomly varied across survey respondents. In angler survey participants were informed about various factors influencing fluctuations in fish catch rates and presented with hypothetical scenarios based on changes in the catch rate to study the expected changes in behavior following a similar approach to Ready et al. (2018). Sending separate surveys, one for anglers and one for beach goers, will enable targeting to ensure that we effectively sample our desired consumer types. We recognize there may be some overlap between beachgoers and anglers; however, the surveys designed to account for potential duplications.

We used a Qualtrics panel to procure the beachgoing survey sample, with required criterion that participants be 18 years or older, be residents of specific U.S. counties that border Lake Erie, (namely Ohio, Michigan, New York, and Pennsylvania) and must have visited a Lake Erie beach at least once in 2023, so our surveyed sample provides a representative snapshot of Lake Erie visitors. We collected approximately 2020 number of responses from the beachgoing survey. Since the model will incorporate demands for recreational behavior based on data collected from the survey, we also will be able to identify current patterns of recreation and forecast how those patterns and behaviors will change under variable economic and ecological conditions. The sample from the angler survey is drawn from Lake Erie recreational fishing license holders across the four U.S. states that border Lake Erie. Each state's Department of Natural Resources (DNR) provided us with email address of the license holders, and we are still in process of collecting angler responses. We expect to be done collecting angler responses by the end of January 2025.

In our dataset collected from beachgoing survey, we recorded the total number of day trips made by individuals to Lake Erie in 2023, treating this as count data and recorded change in number of trips given hypothetical level of bloom size and characteristics. Additionally, we captured data for trips taken during the peak algae bloom season, from July to September. Algae blooms in Lake Erie typically occur during the summer, particularly between these months, when nutrient-rich conditions and warmer water temperatures foster the growth of harmful algae. Moreover, this period coincides with high recreational activity due to warmer weather, summer vacations, and holiday weekends. Analyzing data from this period is essential, as it provides the most relevant information on how blooms affect recreational activities such as swimming, fishing, and boating and influence people's behavior and preferences during peak usage times. To determine the average cost of each trip per person in dollars, we collected information on the zip code, hometown city, and state of residence as the starting point of their journey, as well as the destination access point, county, and state they traveled to. This data allowed us to estimate the weighted average distance traveled by each individual in miles. We then multiplied this distance by the average cost per mile for the year 2023, sourced from the American Automobile Association at 81 cents that includes the cost of gas, vehicle depreciation and maintenance.

The data used in this analysis is truncated because we only sampled the individuals who visited Lake Erie at least once in 2023 and did not sample the entire population. Individuals truncated from this sample may include those who either did not visit the beach during2023, or those who never visit the beach. We corrected for the bias caused by sampling methods.

The geographic distribution of our respondents for beachgoing survey is illustrated in figure 1. According to the map's legend, the colors represent the range of participants from each county. The darkest shade of green indicates regions with the highest number of respondents from CB, followed by WB and EB.

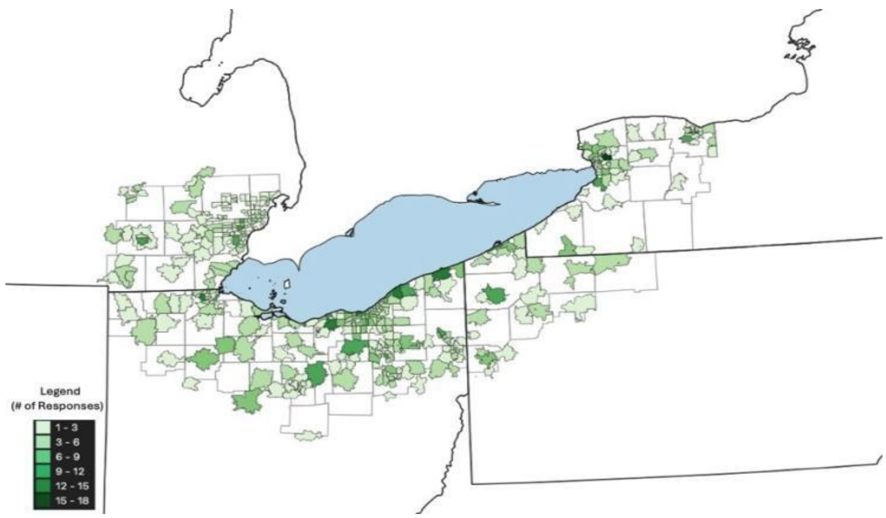

Figure 1: Distribution of participants (recreators)

I excluded 91 respondents from the analysis because their responses were either extreme outliers that skewed the results or lacked sufficient information to calculate their distance and average travel cost. Consequently, the final analysis was conducted on a sample of 1,929 individuals.

Key summary statistics indicate that beachgoing sample is comprised of mostly females (62%) with an average participant age of 46 years old. On average, respondents reported taking 11.6 day trips to Lake Erie beaches between July and September 2023. Following the introduction of algal blooms with hypothetical characteristics of algae bloom, the average number of trips decreased to 9.02, representing a reduction in visitation.

To understand and model motivations for recreational trips, we asked respondents in our beachgoing survey to rate the importance of six beach characteristics: proximity to home, beach size, cleanliness, safety, congestion, and environmental condition. These characteristics were rated using a five-point Likert scale. 79.5% respondents indicate that cleanliness and environmental condition are very important in their decision-making process when selecting a beach for their day trips.

Respondents were asked whether they recalled observing algae growth along the shore or in the water during their visits. This was described as green muck that might have been unsightly or foul-smelling. Approximately 41% of respondents reported that they did recall such algae growth and 33% reported being aware of water quality advisories at the locations they visited. For example, signage posted at the location (or online) indicating the level of safety related to swimming, general recreation, fish consumption, or water consumption. Of those that experienced a day trip in 2023 where algae growth was present, 20.5% reported no impact on their trip, while 14.5% indicated a shorter duration of stay in affected counties and 13% changed the activities they did in affected areas.

Each respondent was randomly presented with three out of twelve different algae bloom characteristics: bloom size (1-mile, 4-mile, 8-mile), foul odor existence (Yes/No), Harmful Bacteria existence (Yes/No). On average, the presence of an algae bloom with characteristics such as odor and harmful bacteria led to two fewer trips per respondent, with 10.5% reporting no change in their trip behavior. Respondents indicated that they care most about harmful bacteria, foul smell, bloom size and water quality, respectively.

4. Methodology

4.1 Empirical Model

The empirical analysis evaluates the factors influencing the actual number of trips respondents revealed they took to Lake Erie beaches and parks, as well as their hypothetical responses to changes in algal bloom characteristics. We first analyze the determinants of revealed trip behavior and subsequently assess how respondents would adjust their trips under hypothetical scenarios involving algal bloom characteristics, such as foul odors and harmful bacteria. Then, we calculate the consumer surplus for each basin as a measure of welfare. This provides valuable insights into the potential impacts and effectiveness of policy applications tailored to these regions.

Our analysis involves four steps. First, we estimate a recreation demand model using data on the total number of the day trips taken to western, central and eastern basin during July to September in the year 2023 as our dependent variable. Our focus in this step is on estimating the coefficient of travel cost for each basin which will be used in last step when we do consumer surplus analysis. Second, using the changes in day trips from our contingent behavior questions as dependent variable, we estimate three trip equations to see how observing the characteristics of algae bloom (i.e., foul odor and harmful bacteria) would shift the demand for trips. Third, the trip demand functions estimated are then linked with outcomes from an industry leading ecological model EwE that has been simulated the actual ecological changes from the 40% reduction policy to elucidate how the recreational trips are affected by the ecological changes triggered by the policy. Fourth, the results generated by this ecological model are then utilized as input for the established demand function, allowing us to define the recreation demand function as contingent upon ecological attributes. Step three and four will be done once we have angler survey data and ecological data generated through simulations within an ecological model.

We employ negative binomial count data model in the first and second steps of this analysis to estimate recreational trip demands. Using this method, the demand for trips will depend on the characteristics of recreation within Lake Erie and the estimated coefficients of the characteristics will define their marginal effects on numbers of trips taken. For example, we will quantify how many fewer trips are taken to each basin of Lake Erie if average cost of the trip increase (from economic model) or the water quality falls (from ecological model).

4.1.1 Negative Binomial

For first step, a model to account for the over-dispersed counts is based on the negative binomial probability distribution:

$$Prob(Y_i = y_i) = \frac{\Gamma(y_i + \alpha^{-1})}{\Gamma(y_i + 1)\Gamma(\alpha^{-1})} \left(\frac{\alpha^{-1}}{\alpha^{-1} + \mu_i}\right)^{\alpha^{-1}} \left(\frac{\mu_i}{\alpha^{-1} + \mu_i}\right)^{y_i}$$

$y_i: 0,1,2,\ldots$

Where Y_i is quantity demanded for each trip by individual i and μ_i is the expected value or mean of Y_i which depends on price of Y (travel cost), individual characteristics and additional variables such as algal bloom size, foul odor, and harmful bacteria. α is the dispersion parameter, which allows for the variance to be greater than the mean (accounting for overdispersion). $\Gamma(.)$ is the gamma function.

The moments of negative binomial distributing are as follows:

$$\mathrm{E}(y_i) = \mu_i \quad , \quad var(y_i) = \mu_i + \alpha\mu_i^2$$

Our analysis focuses on the three basins of Lake Erie, accounting for variations in ecological characteristics across basins. As a result, μ_i is also dependent on basin-specific characteristics.

Equation (1) shows the number of trips taken to (or recreation demand for) the Lake Erie by individual i in between July to September in 2023 to each basin and will be estimated from the survey data.

$$\mu_i = \exp\left(\beta_p Cost_i + \beta_i X_i\right) \qquad (1)$$

Where μ_i denotes the total number of day trips made by an individual i. Cost_i is average travel cost per day trip for each individual in dollars and the travel cost model is used to estimate the demand for trips to the beaches/parks, based on the price of obtaining a trip; X_i is a vector of individual i's characteristics, basin's characteristics faced by individual i and algal bloom characteristics. Basin's characteristics faced by individuals include observing algae growth along the shore/in the water, encountering a green muck or foul smelling, seeing beaches or parks have water-quality advisories in place, and algal bloom characteristics including algae bloom size, foul smell and harmful bacteria. β_p and β_i are parameters o be estimated. Table 1 shows the definition of the variables used and their mean value.

Table 1: Variable definition and summary statistic

Variable	Definition	N	Mean
Dtrip_JS	Number of the day trips taken to visit a beach/park along the Lake Erie coastline between July to September in 2023	1929	11.6
Dtrip_JS_algae	Number of the day trips taken to visit a beach/park along the Lake Erie coastline between July to September in 2023 after encountering algal bloom with defined hypothetical characteristics (10.5% of respondents reported no change in trips)	1929	9.02
Travel Cost	=$0.81*weighted average of distance*2	1929	71.99
Gender	=0 if male (serving as the reference category)	1929	0.37
Income	Approximate annual household income before taxes (in dollars)	1929	63252.53
Age	Respondent's age	1929	46
Children_under18	=1 if they have children under the age of 18 (35% of respondents reported having children under 18)	1929	0.35
Algae_presence	=1 if they remember being algae growth along the shore/in the water (41% of respondents reported that they did recall such algae growth)	1929	0.412
Advisory_presence	=1 if they remember any beaches/parks visited have water quality advisories in the place. (33% of respondents reported that they did recall such advisory)	1929	0.332
Water_acts	Day trips at beaches/parks involved Swimming, Kayaking, Boating, Boogie/SUP boarding, Fishing, jet ski, paddleboat (31% of respondents reported doing water activities)	1929	1.046

Shore_acts	Day trips at beaches/parks involved Sunbathing, Sightseeing/Enjoying nature, Exercise, Reading, Playing Games, Barbecue, dining, camping, building sandcastle, collecting rock, beach glass, seashells, photo shooting, kite flying, relaxing, partying, walking pets, walking (69% of respondents reported doing shore activities)	1929	2.342
Distance	Travel distance from home state to Lake Erie coastline beaches or parks (miles)	1929	45.11

5. Estimation Results

In the summer of 2023, the harmful algal bloom (HAB) in the western basin (WB) of the Lake Erie was characterized as moderately severe, with a severity index of approximately 3 to 4.5 out of 10. This was smaller than the prior year's bloom. The reduced extent in 2023 was attributed to unusually low precipitation levels in May, which resulted in lower phosphorus runoff into the lake—a key driver of these blooms. Despite its moderate size, the bloom still posed risks to recreation, tourism, and water quality, particularly impacting beach access and drinking water safety for surrounding communities. The central basin of the Lake Erie did not experience significant HABs comparable to the WB. The central basin (CB) typically deals more with hypoxia (low oxygen levels in bottom waters) rather than extensive surface algal blooms, as the water is deeper and less nutrient-rich near the surface compared to the WB. In the CB, hypoxia remained a significant issue, typically beginning in late spring or early summer due to water stratification which are particularly detrimental to aquatic life and can complicate water treatment processes. The hypoxic zone primarily develops in deeper parts of the basin and progresses from nearshore to offshore. Weather patterns, including strong winds, can cause upwelling, which brings hypoxic water to the surface, potentially affecting water quality at intake sites for drinking water plants. These events require rapid adjustments in water treatment to mitigate effects such as unpleasant taste, odor, and corrosion risks in distribution systems. The eastern basin (EB), being the deepest part of the lake (mean depth of 24 meters and a maximum depth of 63 meters), generally experiences less frequent and less severe hypoxia compared to the central and western basins. However, nutrient inputs and environmental changes still significantly impact its ecosystem. Excessive nutrient loads often lead to nuisance macroalgae (such as *Cladophora*), which can clog water intakes and foul beaches, impacting water quality and ecosystems.

The analysis evaluates how trip costs, demographic factors, and environmental quality (revealed preference) and algae bloom characteristics and their spatial extent (stated preference) all play a role in influencing trip behavior and associated welfare losses across the western basin, central basin, and eastern basin of Lake Erie. The results reveal substantial spatial heterogeneity, with distinct patterns in trip responses and welfare losses among the basins.

5.1 Revealed Trips to Lake Erie (Baseline Model)

Table 2 presents the results of the negative binomial regression analysis for revealed trips, highlighting the effects of individual respondent characteristics and average travel costs for trips to Lake Erie across three basins. The table report marginal effects, with standard errors in parentheses and significance levels indicated by stars. The key findings are as follows:

The marginal effect of trip cost is negative for all three basins but statistically insignificant for WB, suggesting that small changes in travel expenses may not strongly influence the number of trips taken to WB. The CB and EB exhibit larger and highly significant coefficients compared to the WB, indicating stronger sensitivity to trip cost in these regions. Gender has a large and statistically significant negative coefficient across all three basins, indicating that women are less likely to take trips than men. Similarly, age shows a significant negative effect in all three basins, with older individuals taking fewer trips to Lake Erie. The presence of children under 18 in the household has a negative, albeit statistically insignificant, effect in the WB, indicating minimal variation in trip behavior related to family composition in this region. This finding may be linked to the more severe health impacts of algal blooms in WB, potentially deterring families with children from visiting. In contrast, the CB and EB show a positive marginal effect, suggesting that households with children might be more likely to take trips to these areas, possibly due to comparatively lower health risks or other recreational amenities that cater to family-oriented activities.

Table 2: demographic characteristics

Variables	**Negative Binomial Model**		
	WB	**CB**	**EB**
Average Trip Cost	-0.000517273	-0.02629579***	-0.03176678***
	(5.864e-04)	(3.403e-04)	(7.034e-04)
Gender	-3.287062***	-1.933768***	-1.257387*
	(7.791e-02)	(4.673e-02)	(6.871e-02)
Age	-0.09691731***	-0.1644076***	-0.1102725***
	(2.367e-03)	(1.451e-03)	(2.073e-03)
Children Under 18	-0.4060952	0.4743145	1.928304***
	(8.272e-02)	(4.928e-02)	(7.199e-02)

5.2 Hypothetical Scenarios with Algal Bloom Characteristics

As previously mentioned, respondents were asked three contingent behavior questions regarding the size of the algal bloom (1 mile, 4 miles, and 8 mile), along with the presence or absence of foul odor and harmful bacteria associated with each bloom size. in all cases, they were asked how they would change their number of the trips in response to the hypothetical changes defined. In the second step, we estimate three demand equations, one for each bloom size. However, we hold constant the coefficients for individual characteristics and other common variables from the actual trip demand equation to isolate the impact of algae characteristics on recreational behavior.

To explore how environmental factors like algal blooms impact trip behavior, the coefficients of the common variables (trip cost, income, gender, age, and children under 18) from the baseline model are fixed using an offset term. This allows the hypothetical model to focus entirely on the effects of smell, bacteria, and their interaction.

The negative binomial regression model for stated trips across different algae bloom extensions shows that environmental quality is a critical determinant of recreational demand. The coefficients for algae bloom characteristics reveal significant differences in how foul odors and harmful bacteria, as well as their combinations, influence trip behavior across different spatial extensions.

Table 3 presents the results of the negative binomial regression model estimating the factors influencing the change in trips to Lake Erie across the WB, CB and EB for 1-mile extension of algal bloom size. In the absence of foul odor and harmful bacteria, the baseline effect on the number of trips is consistently positive across basins. This effect is strongest in the WB, with a coefficient of 1.93 ($p < 0.001$), indicating that visitors are highly drawn to the basin under favorable conditions. The CB follows with a smaller yet significant coefficient of 0.60 ($p < 0.001$), while the EB shows a marginally positive but statistically insignificant coefficient of 0.12. These findings highlight a gradient of preferences, where WB emerges as the most attractive destination in the absence of water quality concerns. The presence of foul odor has a significantly negative impact across all basins, with the magnitude of the effect varying considerably. In WB, the coefficient of -2.11 ($p < 0.001$) underscores a substantial deterrent effect, while CB shows a slightly smaller but still significant impact at -1.85 ($p < 0.01$). Interestingly, the negative effect intensifies dramatically in EB, where the coefficient reaches -4.90 ($p < 0.001$). This pronounced response in EB could reflect the unique visitor profile or smaller sample size, amplifying sensitivity to odor-related issues. Similarly, the presence of harmful bacteria negatively influences trip behavior, with its effect being basin dependent. The WB exhibits the smallest negative impact (-1.46, $p < 0.05$), suggesting that visitors to this basin may exhibit greater tolerance to such conditions. In contrast, the CB sees a significantly larger effect (-2.36, $p < 0.001$), indicating heightened sensitivity among its visitors. The EB once again shows the strongest reaction, with a coefficient of -5.96 ($p < 0.001$), underscoring the critical role of water quality in shaping visitor behavior in this basin. The interaction of foul odor and harmful bacteria yields mixed results. In WB and CB, the coefficients (-0.69 and -0.95, respectively) are negative but statistically insignificant, suggesting that the combined presence of these factors does not exacerbate their individual effects in these basins. However, the EB displays a strikingly negative and significant combined effect (-6.17, p < 0.001), pointing to a potential synergistic relationship where visitors react much more strongly to simultaneous exposure to these issues.

These results reveal notable heterogeneity in visitor behavior across Lake Erie basins. The WB's resilience to water quality issues may stem from its historical familiarity with algal blooms or other baseline attractions. Conversely, the CB's moderate sensitivity could reflect its mix of urban and natural recreational areas. The EB's heightened responsiveness likely reflects its distinct visitor profile or its smaller sample size, which may amplify variability in the estimates. The strong negative effects of foul odor and harmful bacteria emphasize the importance of maintaining water quality to sustain recreational activity across all basins.

Table 3: 1-mile extension of algal bloom size in Lake Erie Basins

Variables	**Negative Binomial Model**		
	WB	**CB**	**EB**
No Foul odor and No Harmful bacterial	1.9286***	0.6000***	0.1173
	(0.1153)	(0.1169)	(0.1734)
Foul odor	-2.108829***	-1.849808**	-4.897135***
	(0.1691)	(0.1612)	(0.2781)
Harmful bacterial	-1.459725*	-2.357829***	-5.963181***
	(0.1626)	(0.1661)	(0.2495)
Foul odor and Harmful bacterial	-0.6948718	-0.9503052	-6.1673***
	(0.2364)	(0.2332)	(0.3699)

Table 4 presents the results of the negative binomial regression model across three basins for 4-mile extension of algal bloom size. In the absence of foul odor and harmful bacteria, the number of trips shows a statistically significant and positive association across all basins. The coefficient for WB (1.8546***) indicates the highest baseline level of recreational trips compared to CB (0.6923***) and EB (0.8191***). This finding aligns with the understanding that WB, known for its shallow waters and close proximity to major urban centers, typically attracts more visitors, even under neutral environmental conditions. The presence of foul odor significantly reduces trips in WB and CB but not in EB. Specifically, trips decrease sharply in WB with a coefficient of -2.2998***, while the reduction in CB is less severe at -1.6808**. Interestingly, EB does not show a statistically significant response (-0.4259), suggesting that visitors to this basin may place less emphasis on olfactory cues or prioritize other factors, such as scenic value or less crowded shorelines. The presence of harmful bacteria leads to substantial reductions in trips across all basins. The magnitude of the effect is highest in WB (-2.9248***) and CB (-2.9961***), indicating that visitors are highly sensitive to health risks in these areas. Conversely, while EB shows a similar trend, the coefficient (-1.5572*) is smaller and marginally significant, likely reflecting the smaller sample size of respondents traveling to EB or differences in visitor demographics and preferences. The combination of foul odor and harmful bacteria further amplifies the negative impact on recreational trips, with WB experiencing the largest decline (-4.1780***). CB shows a slightly less severe effect (-2.9496***), while the combined effect in EB (-1.2689) is not statistically significant. This result underscores a higher tolerance or different visitor motivations for EB trips, which could include non-recreational activities or lesser reliance on water quality metrics compared to WB and CB.

These findings emphasize the heterogeneity in visitor responses across the three basins of Lake Erie. The WB is most sensitive to changes in environmental quality, reflecting its status as a highly utilized recreational area where visitors expect higher water quality. The CB, while also showing sensitivity, appears to have a somewhat more resilient visitor base. The EB stands out for its muted responses, possibly due to the smaller number of visitors, the basin's geographic and ecological characteristics, or the prioritization of non-environmental factors in travel decisions.

Table 4: 4-mile extension of algal bloom size in Lake Erie Basins

Variables	Negative Binomial Model		
	WB	**CB**	**EB**
No Foul odor and No Harmful bacterial	1.8546*** (0.1218)	0.6923 *** (0.1318)	0.8191 *** (0.1705)
Foul odor	-2.299772*** (0.1783)	-1.680849** (0.1802)	-0.4258892 (0.2472)
Harmful bacterial	-2.92477*** (0.1716)	-2.996053*** (0.1824)	-1.55719* (0.2453)
Foul odor and Harmful bacterial	-4.178028*** (0.2484)	-2.949579*** (0.2511)	-1.268869 (0.3498)

Table 5 presents the results of the negative binomial regression model across three basins for 8-mile extension of algal bloom size. In the absence of foul odor and harmful bacteria, the coefficients reveal a significant and positive association with recreational trips across all basins. The WB displays the strongest baseline association (1.7658***), underscoring its role as a popular destination for visitors even under favorable environmental conditions. The CB also exhibits a significant but more moderate positive response (0.7540***), reflecting its importance as a recreational area. In contrast, EB shows the weakest baseline association (0.4405*), which may be attributed to its lower visitation rates and distinct geographical and demographic factors. The presence of foul odor has a varied impact across basins. While the coefficient for WB (-0.8102) is negative, it does not reach statistical significance, suggesting that WB visitors might tolerate foul odor to some extent, likely due to its higher recreational value or accessibility. In CB, however, the impact is more pronounced and significant (-1.4411*), indicating a heightened sensitivity to odor-related water quality issues. Similarly, in EB, the coefficient (-1.1668) points to a negative association, although it is not statistically significant, potentially reflecting smaller sample sizes or differing visitor motivations. Harmful bacteria presence leads to significant reductions in trips in WB (-1.2583*) and CB (-1.3745*), highlighting the strong aversion of visitors to health risks in these areas. Notably, in EB, the coefficient is extremely small and statistically insignificant (-2.243e-15), suggesting that the limited visitation to this basin might be influenced by factors unrelated to algal bloom characteristics, such as geographic or recreational preferences. When foul odor and harmful bacteria are present simultaneously, the negative impact on trips diminishes across all basins compared to their individual effects. In WB and CB, the coefficients (-0.2003 and -0.5238, respectively) are negative but statistically insignificant, suggesting a possible tolerance threshold or unobserved factors mitigating the combined impact. In EB, the combined effect (-2.5390.) is marginally significant, indicating that such conditions may discourage the already limited number of visitors.

These results underscore the heterogeneous response of visitors across Lake Erie basins to deteriorating water quality caused by algal blooms. The WB appears to be the most resilient, potentially due to its accessibility and recreational amenities. The CB demonstrates greater sensitivity to both foul odor and harmful bacteria, reflecting the importance of water quality in shaping visitation patterns. The EB, with its distinct visitor dynamics and lower overall usage, exhibits muted and inconsistent responses.

Table 5: 8-mile extension of algal bloom size in Lake Erie Basins

Variables	**Negative Binomial Model**		
	WB	**CB**	**EB**
No Foul odor and No Harmful bacterial	1.7658 ***	0.7540***	4.405e-01*
	(0.1270)	(0.1183)	(1.900e-01)
Foul odor	-0.8101767	-1.441108*	-1.166751
	(0.1772)	(0.1749)	(2.619e-01)
Harmful bacterial	-1.258294*	-1.374485*	-2.243363e-15
	(0.1801)	(0.1752)	(2.687e-01)
Foul odor and Harmful bacterial	-0.2002724	-0.523792	-2.539014·
	(0.2515)	(0.2555)	(3.777e-01)

Overall, the results indicate that respondents are highly sensitive to environmental quality, particularly under smaller-scale algae bloom scenarios. As the spatial extent of the algae bloom increases, clean conditions remain a significant driver of increased trips, but their positive influence diminishes and the deterrent effects of foul odors and harmful bacteria evolve, with harmful bacteria remaining a stronger deterrent across all scales. These findings emphasize the need for basin-specific water quality management strategies to address recreational and environmental concerns effectively.

The comparison of results across the 1-mile, 4-mile, and 8-mile extensions of algal bloom size reveals meaningful differences in how visitors to Lake Erie basins respond to changes in water quality conditions. At the 1-mile extension, the baseline condition (no foul odor, no harmful bacteria) consistently shows positive effects on trips across all basins, with the Western Basin (WB) demonstrating the strongest response, followed by the Central Basin (CB) and a minimal effect in the Eastern Basin (EB). As the algal bloom extends to 4 miles, the magnitude of negative impacts from foul odor and harmful bacteria intensifies across WB and CB, suggesting heightened sensitivity to degraded water quality over a larger affected area. In EB, however, these negative effects remain severe and persistent, further emphasizing its vulnerability.

By the time the bloom extends to 8 miles, the results reveal a moderation in the WB and CB for certain variables, such as foul odor, where negative effects are present but smaller in magnitude compared to the 1-mile and 4-mile cases. However, in the EB, the already severe impacts grow even more pronounced, with foul odor and harmful bacteria substantially reducing trips, indicating that even slight declines in water quality can have devastating consequences for recreational activity in this region. This comparative analysis underscores the importance of proactive water quality management, particularly in EB, where the impacts of algal bloom extensions are disproportionately severe and require urgent attention.

6. Welfare Analysis Across Basins

In this section the consumer surplus is estimated to determine the value of annual visits to the beaches. Table 6 presents the welfare loss estimates which underscore the economic consequences of algae bloom extensions.

The results show that in the western basin, welfare losses are highest across all extensions, with losses of \$64,347.70 (1 mile), \$122,778.80 (4 miles), and \$60,575.19 (8 miles). This aligns with the WB being the most heavily utilized recreational region. While in the central basin the welfare losses are substantially smaller than in the WB, at \$2,932.07 (1 mile), \$3,017.96 (4 miles), and \$2,936.85 (8 miles), indicating lower recreational demand sensitivity to algae in the CB. The welfare losses are smallest in the eastern basin, with values of \$928.18 (1 mile), \$1,309.26 (4 miles), and \$949.42 (8 miles). The relatively limited recreational activity and smaller population in this region likely contribute to these lower impacts.

Table 6: Welfare Analysis Across Basins

Algal bloom Extension	**Consumer Surplus**		
	WB	**CB**	**EB**
1-mile	-64347.7	-2932.071	-928.1794
4-mile	-122778.8	-3017.964	-1309.261
8-mile	-60575.19	-2936.853	-949.4151

7. Conclusions

In this study, we evaluated the factors influencing both the actual number of trips respondents revealed they took to Lake Erie basins and their hypothetical responses to changes in algal bloom characteristics, such as foul odors and harmful bacteria. Additionally, we calculated the consumer surplus for each basin as a measure of welfare, offering valuable insights into the potential impacts of policy interventions tailored to these regions.

Efforts to address algal blooms and eutrophication are underway, with initiatives under the Great Lakes Water Quality Agreement (GLWQA) targeting phosphorus and nutrient reductions across all basins, including the EB. These efforts, which focus on mitigating hypoxia and oxygen depletion caused by excessive agricultural and urban nutrient inputs, remain critical for maintaining ecosystem health and recreational opportunities. Monitoring and modeling programs continue to inform nutrient management strategies, providing actionable data for future policy refinements.

Our findings reveal significant spatial heterogeneity in how algal bloom characteristics influence recreational demand. The western basin (WB) demonstrated the highest sensitivity, with clean conditions driving substantial increases in trips and poor environmental conditions resulting in pronounced welfare losses. In contrast, the central basin (CB) exhibited stronger negative responses to foul odors and harmful bacteria, while the eastern basin (EB) showed unique interactions between these factors, reflecting complex dynamics. Correspondingly, welfare losses were greatest in the WB, followed by the CB and EB, underscoring the disproportionate economic burden faced by the western region. Demographic and economic factors further shaped trip behavior. Men and younger individuals were more likely to take trips to Lake Erie, while travel costs were inversely associated with trip frequency. Overall, this study highlights the significant influence of algal bloom size and characteristics on recreational demand. While clean environmental conditions attract visitors, poor water quality—particularly the presence of harmful bacteria—acts as a powerful deterrent, with impacts varying across spatial scales. As the extent of algal blooms continues to grow, addressing these challenges becomes increasingly vital to sustain recreational activities and the economic benefits they bring to communities along the Lake Erie coastline.
This paper emphasizes the importance of targeted management strategies to mitigate algae bloom impacts, particularly in the WB, where recreational demand and welfare effects are most pronounced. Basin-specific policies are essential to optimize effectiveness, considering the distinct dynamics observed in the CB and EB. The focus on the WB is especially critical, given its shallower waters and higher nutrient loads, which contribute to more severe blooms compared to the other basins.

Future work:

In future, upon receipt of the angler survey data, we will replicate this process to ensure consistency and robustness in our analysis. Then we will delve deeper into these results and complete the integration of Ecopath with Ecosim (EwE) ecological data which will enable a comprehensive quantification of the economic impacts of the 40% nutrient reduction policy. This integration will allow us to estimate both the recreation demand function and the angler demand function as direct functions of ecological attributes.
Building on these analyses, we will assess the economic and ecological costs and benefits associated with the 40% nutrient reduction policy.

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