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Valuing Ecosystem Services and Downstream Water Quality Improvement in the U.S. Corn Belt

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Abstract

We develop a choice experiment (CE) to estimate the benefits of nutrient reductions in the US Corn Belt. The study area covers Illinois, Indiana, and Iowa, the three states that contribute the largest amount of nutrients to the Gulf of Mexico and whose nutrient reductions are vital to achieving targets to reduce the hypoxic dead zone in the Gulf. We find that the public places large values on various local ecosystem services, including aquatic biodiversity, aesthetics of increased farm landscape diversity associated with conservation practices, and water-based recreational activities. Moreover, the results indicate that upstream residents have a strong preference for water quality far downstream in the Gulf of Mexico as characterized by reducing the size of the dead zone. Our analysis of observed taste heterogeneity indicates that public preferences vary depending on familiarity with nutrient pollution issues, users versus non-users of local ecosystem services, and different age groups. Our findings inform policies to improve water quality in the Gulf of Mexico and local water bodies in the US Corn Belt.

Keywords Choice experiment · Corn belt · Generalized multinomial logit model · Gulf of Mexico · Nutrient pollution · Water quality · Willingness to pay

Abbreviations

ASC	Alternative specific constant
BS	Buffer strips
CC	Cover crops
CE	Choice experiment
GMNL	Generalized multinomial logit
MARB	Mississippi/Atchafalaya river basin
MWTP	Marginal willingness to pay

Disclaimer The findings and conclusions in this publication are those of the authors and should not be construed to represent any official USDA or U.S. Government determination or policy.

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USDA NASS	United States department of agriculture, national agricultural statistics service
US EPA	United States environmental protection agency
WTP	Willingness to pay

1 Introduction

There are extensive policy efforts to reduce nutrients across the Mississippi/Atchafalaya River Basin (MARB) to mitigate the hypoxic dead zone in the Gulf of Mexico while improving local water quality. Since the 2008 Hypoxia Action Plan that targets a 45% nutrient reduction by 2035 (US EPA, 2008), twelve states in the MARB have developed Nutrient Reduction Strategies that encompass various pollution sources (US EPA, 2017). Following the Strategies, for instance, these states have increased the total number of major sewage treatment plants required to have National Pollutant Discharge Elimination System (NPDES) permits for nitrogen or phosphorus by about 23% from 2014 to 2017 (US EPA, 2019). There are also continuing efforts to control agricultural nutrient loss, such as promoting conservation activities, leveraging various funding sources like federal and state programs, non-governmental organizations, or private sector entities (US EPA, 2018). In addition to these costly measures taken to date, further spending and actions are expected to be inevitable to meet the Gulf hypoxia goal. For example, Whittaker et al. (2015) estimate that incurring $338 billion to enroll all row crop acreage in the Upper Mississippi River Basin in the Conservation Reserve Program achieves the target size of the Gulf hypoxic zone (< 1900 square miles) for only two years out of their 42-year simulation. Given the considerable costs involved in nutrient reductions, it is essential to examine whether the policies would create sufficient social benefits.

This paper aims to estimate the benefit of nutrient reductions prompted by Gulf hypoxia in the three largest contributing states—Illinois, Indiana, and Iowa. These three states play a pivotal role in mitigating hypoxia, accounting for about 42 percent of nitrogen and 29 percent of phosphorus delivered to the Gulf among 31 states in the MARB (Robertson and Saad 2021). Using a choice experiment (CE), we estimate the value that the public places on reducing the Gulf of Mexico hypoxic zone to the target size and improving the provision of key non-market ecosystem services in their local waters. The specific ecosystem service attributes studied include freshwater biodiversity, water-based recreational activities, and agricultural landscape appearance during the winter. Unlike these local attributes, the reduced dead zone in the Gulf of Mexico represents water quality improvements occurring far downstream from upstream respondents' homes. Thus, our CE also informs how much value upstream residents place on downstream improvements relative to locally arising benefits of various water quality aspects. In analyzing choice data, we employ the generalized multinomial logit (GMNL) model that accommodates potential heterogeneity in preferences and scale (Fiebig et al. 2010) while re-parameterizing the GMNL model to obtain WTP directly from estimation. This method that estimates models in WTP space is increasingly used in CE applications because it avoids the skewed distributions of WTP with inconceivably large values, which may result from the conventional method that provides WTP by taking the ratio of estimated coefficients between a non-monetary and a monetary attribute (Scarpa et al. 2008; Train and Weeks 2005).

Despite a large body of research analyzing the benefit of water quality improvement in the MARB area, almost all the valuation papers lie outside of the Gulf of Mexico context, limiting their applicability to inform the extensive suite of nutrient reduction initiatives underway across the region. Much of the previous work is site-specific, concerning individual water bodies of interest and associated population segments. For example, papers report the WTP of Ohio recreational anglers in Lake Erie (Zhang and Sohngen 2018), property owners in two lake watersheds of Minnesota (Welle and Hodgson 2011), visitors and residents near Clear Lake in Iowa (Azevedo et al. 2001), or residents near Wisconsin's Lake Mendota (Stumborg et al. 2001). Although not directly motivated by Gulf hypoxia, some papers involve a broader range of water quality improvements and populations. Vossler et al. (2023) examine the total economic value of water quality improvements throughout the Upper Mississippi-Ohio-Tennessee River Basin, allowing for varying water quality by sub-watershed in the current and improved scenarios, different spatial scales at which water quality is improved, and whether an improved area includes the watershed where a respondent lives. The paper achieves this by using the Biological Condition Gradient (US EPA), which links the extent of anthropogenic stress to aquatic systems consistently across a large geographic area. Lant and Roberts (1990) explore the WTP for improved river quality caused by riparian wetlands in fourteen cities in Iowa and Illinois, which remained relatively intact compared to prairie potholes through the 1900s. Also, Londoño Cadavid and Ando (2013) estimate the WTP of residents in Urbana-Champaign, Illinois, for nearby stream quality improvement resulting from stormwater management. Outside the MARB area, Van Houtven et al. (2014) and Nelson et al. (2015) implement contingent valuation surveys to assess the value of nutrient reductions in the southeastern US and Utah, respectively.

Only a couple of studies assess welfare effects in the Gulf hypoxia setting. Hudson et al. (2005) focus on the adoption of precision agriculture in the MARB to reduce Gulf hypoxia and report a nonparametric WTP estimate of $30.5 per household as a one-time payment in a telephone survey of the US public. More recently, Parthum and Ando (2020) develop a CE to examine residents' WTP for nutrient reductions in a watershed in Illinois, with attributes including game fish species, fish population, algal bloom frequency, distance to the point of water quality improvement, and the likelihood that the study watershed supports the Gulf hypoxia target. As a state-wide CE on nutrient reduction, Shr and Zhang (2021) explore the effects of excluding a non-local attribute (Gulf hypoxic zone) or related information on WTP for local water quality attributes, such as algal toxins and nitrate in drinking water sources, and total welfare estimates in Iowa. Our paper provides a more comprehensive picture of the benefits of Gulf hypoxia reduction policies across the entire critical contributing region of the Corn Belt, assessing the drivers of preference heterogeneity while also allowing upstream households to trade off local water quality attributes against the Gulf of Mexico far downstream. Also, unlike Hudson et al. (2005) who focus on WTP to support precision agriculture to reduce Gulf nutrient loading, we examine the values attached to local ecosystem services that the public directly consumes that are associated with Gulf hypoxia reduction targets.

Among the ecosystem attributes in our CE, changing agricultural landscape appearance is rarely quantified in the Corn Belt region despite its significant implications (Prokopy et al. 2020). The status quo agricultural fields dominated by nearly homogeneous row crops have contributed to the Gulf dead zone, accounting for 78% of nitrogen and 66% of phosphorus loads (US EPA, 2008). Accordingly, changing farm management practices is an integral part of Nutrient Reduction Strategies in the MARB states, which often entails immediately visible visual modifications of the farm landscape. Among various conservation practices, we consider cover crops, buffer strips, and perennial field crops. These are the practices that all three states in our study list as most promising for addressing nonpoint source nutrient pollution (Illinois EPA et al., 2015; Indiana DOA et al., 2020; Iowa DOA et al., 2016). To our knowledge, only one paper estimates the aesthetic benefits of changing farm landscapes in the US Corn Belt; using a contingent valuation survey in Iowa, Grala et al. (2012) report that a household is willing to make a one-time payment of \$4.8–\$8.5 to install windbreaks on agricultural lands for visual amenities. Our CE explores preferences for landscape diversity during the winter months when winter cover crops, such as rye, are planted (i.e., after harvest in October until before planting in April or May). This attribute has four levels that represent gradually increasing landscape diversity, such as (1) bare soil after conventional tillage (baseline); (2) cover crops; (3) cover crops and buffer strips; and (4) cover crops, buffer strips, and perennial crops together.

The results show strong public demand for various ecosystem services and a reduced dead zone in the Gulf of Mexico, with significant heterogeneity in preferences across respondents. We further investigate the potential sources of preference heterogeneity and find that familiarity with or knowledge about the nutrient pollution issue, whether a respondent is an ecosystem service user, and respondent age explain variation in preferences. Finally, we showcase that aggregate welfare gains may be smaller than the costs of nutrient reductions when considering upstream areas alone. This result highlights the need to assess how much benefits would occur downstream and in the Gulf due to upstream nutrient reductions to evaluate the policies' net social gains while suggesting the importance of developing coordinated measures across the entire basin to achieve Gulf hypoxia targets.

Our paper makes several contributions to the non-market valuation literature and nutrient pollution policy discussions. First, we estimate economic benefits from nutrient reductions that can inform Gulf hypoxia policy evaluation. Despite the need for benefit estimates associated with mitigating Gulf hypoxia (CENR 2000), few studies examine relevant welfare effects. Second, our paper reveals how upstream residents value water quality far downstream relative to that in close proximity to their homes, which can inform the policy coordination process from the perspective of the entire MARB. Since hypoxia mitigating actions require concentrated clean-up costs upstream and dispersed benefits across the basin, harmonizing individual state-level policies to maximize net gains in the basin as a whole is essential. Lastly, we provide early evidence on the relatively considerable aesthetic benefits of agricultural landscape diversity in the US Corn Belt. Unlike much-studied consequences of adopting conservation practices on the environment and markets, research on their visual impacts is relatively scant.

2 Methods

2.1 The Choice Experiment

We design a choice experiment (CE) to assess public preferences and WTP for a range of attributes related to nutrient reductions. Table 1 presents five attributes and their levels used in our choice questions. The attributes were selected to encompass key ecosystem services arising from nutrient abatement, including ecological, recreational, and aesthetic features, based on the ecosystem services and non-market valuation literature. We finalized the attributes and levels by pretesting the survey in May 2021. Given the COVID-19 pandemic and the challenge of recruiting the general public in person for focus group meetings, we tested the survey with a total of 91 students from an undergraduate environmental economics course for non-economics majors from many different degree programs on the

Table 1 Attributes and levels in choice experiment

Attributes	Levels
Aquatic life	**No change** Aquatic insect species 25% increase and fish species 10% increase Aquatic insect species 40% increase and fish species 20% increase
Recreational activities	**Visual amenity and boating** Visual amenity, boating, and improved fishing and swimming
The size of the dead zone	**No change (5,400 *mile*^{2}, about the size of Connecticut)** Large decrease (1,900 *mile*^{2}, about 1/3 the size of Connecticut)
Winter landscape appearance	**Conventional tillage** Cover crops Cover crops and Buffers Cover crops, Buffers, and Perennials
Annual cost to household	**$0**, $5, $10, $25, $50

The levels in bold represent the status quo condition

University of Illinois at Urbana-Champaign campus. In the pretest, we utilized debriefing questions where we received feedback on the overall survey instrument, including the clarity of each attribute and level, landscape photograph-based images, and background information provided. After refining the questionnaire based on the pretest, we further tested it before the full launch.

The first attribute is the health of aquatic life in rivers, streams, and lakes near respondents' residences. We use increases in aquatic insects (macroinvertebrates) and fish species as a measure of overall freshwater biodiversity. In the information treatment that preceded the choice questions, we told respondents that increases in insects and fish species provide a good indicator of how healthy an aquatic ecosystem is because they play a critical role in the food web (Carter et al. 2017). We explained that aquatic insects feed on aquatic plants and other organic matter and are also the main food source for fish that are prey for birds and other wildlife. To ensure that respondents understand the attribute as representing overall aquatic biodiversity, we further emphasized that a larger increase in aquatic insects and fish species indicates higher levels of biodiversity and better aquatic ecosystem health. The potential magnitudes of insect and fish species increase at the medium and high improvement levels relative to the baseline are guided by water quality modeling and the estimated empirical relationship between nutrients and the total number of insect and fish species in the study region.[1]

[1] We use the SWAT (Soil and Water Assessment Tool) to obtain the range of total phosphorus (TP) concentrations in waters caused by various farm management practices. Then, we explore linear relationships between TP and the number of macroinvertebrate species as well as the number of macroinvertebrate species and fish species, using the US Environmental Protection Agency's National Lakes Assessment and the National Rivers and Streams Assessment data in our study region. Since no available water quality modeling covers our entire study region, we utilize modeling data from a typical watershed in the region (the Upper Sangamon River Watershed in Illinois) and assume that water quality changes simulated in this watershed can represent the changes in the study region. Although there are potentially more influential factors than TP alone in determining the abundance of aquatic species, we obtain a linear correspondence without incorporating those factors for the purpose of informing feasible attribute levels. Using TP in exploring the relationship is consistent with ecology studies that show nutrients as critical drivers for macroinvertebrates and fish species diversity (Egertson and Downing 2004; Koperski 2021). The linear relationships and the potential TP range from the SWAT inform how much macroinvertebrates and fish species can increase due to nutrient reductions relative to the baseline.

The second attribute is which water-based recreational activities a respondent can enjoy near one's home, representing the use-value of water bodies. The survey described that nutrient pollution could cause algae to grow that may make people or their pets sick when they come into contact with water. The survey then stated that when nutrient levels in water are too high it may lead to a closure that prevents swimming and that layers of algae on the surface water may decrease the quality of fishing experiences. Accordingly, the improved level of this attribute above the status quo includes improved fishing and swimming, in addition to the baseline activities of visual amenities and boating that do not involve direct water contact. These two levels are consistent with the predictions from water quality modeling and water quality data in the region for safe recreation in the current and improved quality waters.[2] Previous studies also use different degrees of water contact and associated activities to value recreational benefits from water quality improvements (Doherty et al. 2014; Stithou et al. 2012).

While the previous two attributes are presented as local benefits occurring near a respondent's residence, we include the size of the dead zone in the Gulf of Mexico to assess how the public located upstream values downstream water quality improvement. The survey explicitly stated that this attribute represents an improvement *not* occurring near where respondents live. The dead zone size in the baseline (5400 square miles) reflects the current five-year average (2015–2020, no data in 2016), while the improved level (1900 square miles) corresponds to the Gulf hypoxia target (US EPA, 2008).

The fourth attribute is winter farm landscape appearance. We focus on the visual diversity of agricultural fields when more conservation practices are implemented, which affects the aesthetic value of farm landscapes (van Zanten et al. 2014, 2016). The questionnaire defined this attribute as "how corn and soybean fields will appear after harvest in October until before planting in April or May." To provide the context relevant to nutrient pollution, we stated that nutrient reduction strategies include changing farm practices which could greatly transform how rural landscapes appear. Following the description, we presented respondents with visualizations for each landscape level. The first picture contained a stream crossing a bare crop field typical in the region after harvest and conventional tillage. We used this picture as a base image to visualize increasing landscape diversity by adding more conservation practices, holding constant other factors that may affect preferences for landscape views, such as viewing angle, time of day, weather, and the total size of the visible crop fields. The second picture included cover crops planted on the entire crop field instead of bare tilled soil, and the third picture included the addition of buffer strips along the stream that crosses the field. Building on the third image, the final picture added perennial crops in the fields alongside cover crops and stream buffers. For each visualization, we described added landscape elements and presented the landscape appearances in terms of their growing diversity. Adobe Photoshop was used to create these images in a consistent manner that is not entirely realistic but that ensures common landscape elements are

[2] Similar to the aquatic life attribute, we derive a linear correspondence between total phosphorus (TP) and Chlorophyll-a, a widely used indicator of algal toxins for recreational safety. According to the World Health Organization (WHO) guideline, Chlorophyll-a concentrations greater than 50 μg/L could entail a high risk of recreational exposure to toxins (WHO, 2003). Our SWAT modeling and the estimated linear effects of TP on Chlorophyll-a indicate that the baseline TP (300 μg/L) corresponds to the high risk for recreational water use (Chlorophyll-a = 90.9 μg/L) but decreases in TP can reduce Chlorophyll-a to the level sufficiently below the high-risk threshold where water bodies can support all types of recreation.

identical for different levels of the attribute. Artificially modified pictures of agricultural landscapes have been used in multiple studies to elicit public preferences for landscape aesthetics (Dupras et al. 2018; Schaak and Musshoff 2020; van Zanten et al. 2016).

The payment vehicle is an increase in annual property taxes, which has been adopted as a credible mechanism in relevant studies (Mullen et al. 2017; Parthum and Ando 2020). For respondents who are renters and may not directly pay property taxes, we clarified that the cost may be reflected in higher monthly rent charged by their landlord. We used five cost levels ($0, $5, $10, $25, and $50), informed by prior research in the region (Grala et al. 2012; Londoño Cadavid and Ando 2013; Parthum and Ando 2020).

We generate a D-optimal design in Ngene (ChoiceMetrics 2018), one of the most widely used software tools to build CEs. The essence of this design is maximizing the differences in the attribute levels across alternatives by creating orthogonal profiles for the first alternative and then making systematic changes to the attribute levels in the first alternative to construct subsequent alternatives (Street et al. 2005). Following this strategy, our design generates a total of 24 choice questions with D-efficiency = 94.3%. To address potential respondent fatigue, we divide the 24 questions into three blocks and randomly assign respondents to one, so that each respondent answers eight choice questions. Each choice question asks respondents to choose among three alternative water quality scenarios with different ecosystem attributes—two improvement options and a "No change" option. Figure 1 shows an example choice card.

The beginning of the questionnaire introduced our nutrient pollution issue by asking respondents to think of water bodies near where they live and express opinions about their quality, importance, and the predicted largest pollution source. Then, we provided all respondents with background information to ensure a common knowledge baseline that included: a description of nutrient pollution and different pollution sources, the dead zone in the Gulf of Mexico, and policy responses such as state Nutrient Loss Reduction Strategies and the 45% nutrient reduction target. The next section of the survey described the choice questions respondents would be asked, each consisting of two options for different environmental changes they would face under different policies and a "No change" option. The attributes and levels were explained. Given the hypothetical nature of our experiment, our survey included a cheap talk script immediately before the choice questions. The script alerted respondents that "people often state a larger amount of money than they are actually willing to pay" when making a hypothetical decision and asked them to imagine that their household is "actually facing the exact choices" presented. In addition, our script used a budget and substitute reminder, given a recent meta-analysis finding that combining cheap talk with the reminder can enhance its effectiveness (Penn and Hu 2019). Consistent with survey best practice recommendations (Johnston et al. 2017), we emphasize that survey responses are potentially consequential. In particular, the script stated that "the results of this survey will be made available to policymakers" and that "your responses could affect the decision of policymakers to develop and implement nutrient reduction strategies." After the choice questions, we collected additional respondent-specific data on relevant perceptions, attitudes, demographics, and respondent consumption levels of the ecosystem attributes studied. Appendix 1 provides the full survey instrument.

2.2 Survey Administration

We collected survey responses online via Qualtrics in the three states in June 2021. The survey firm stratified participants by gender, age, race, and income consistent with the

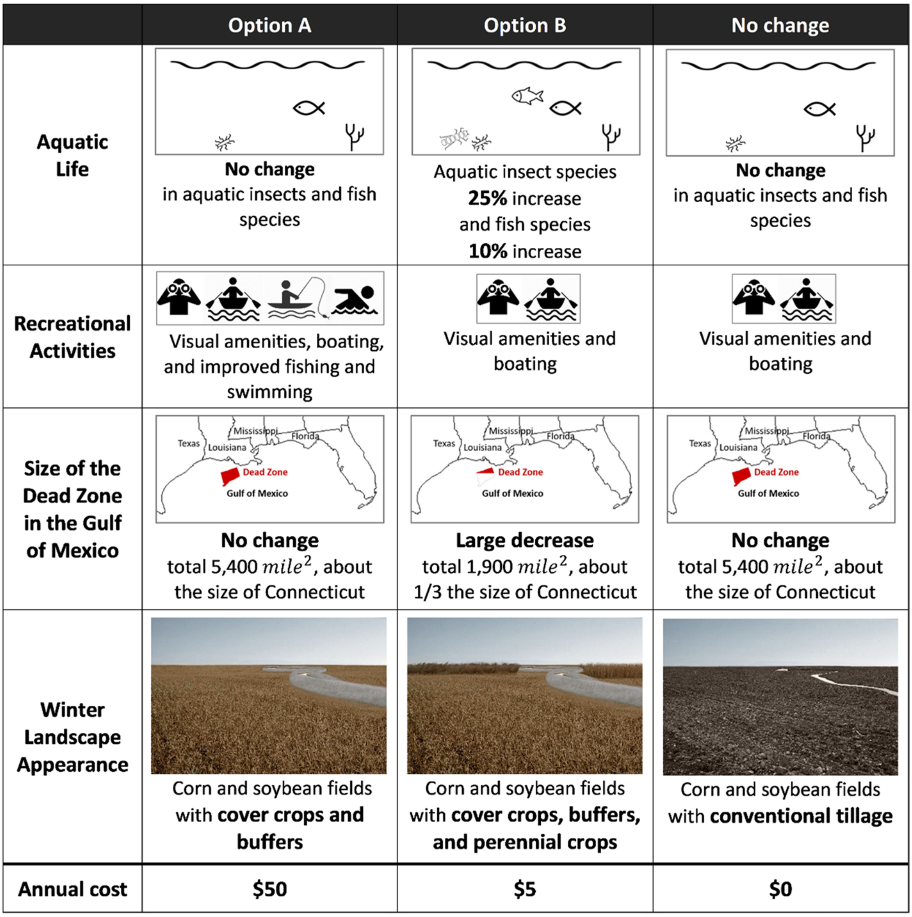


Fig. 1 Example choice card

population estimates in the 2019 American Community Survey (US Census Bureau 2019). Although our sample is representative for the population with respect to these characteristics, we note that the sample has a larger share of respondents with a college degree than the population. After eliminating incomplete responses, we use data from a total of 1,850 respondents. Table 2 summarizes the socio-economic and other respondent-specific characteristics of our sample.

We made an effort to identify invalid or fraudulent responses that are a common problem with online panels (e.g., Sandorf 2019; Sandorf et al. 2020). We included a simple validation question to filter out bots or inattentive respondents and eliminated 34 observations that provided incorrect responses. Duplicate IP addresses were present in the Qualtrics panel response data that may indicate more than one response from the same respondent or household; we estimated the models and WTP when excluding observations with duplicate IP addresses and verified that our findings are not affected by these suspect data.

Table 2 Summary Statistics of Socio-Economic Variables

	Pooled	Illinois		Indiana		Iowa	
	Sample (%)	Sample (%)	Census (%)	Sample (%)	Census (%)	Sample (%)	Census (%)
Gender							
Male	44.1	41.5	48.5	44.3	48.7	46.4	49.2
Female	55.1	57.7	51.5	55.1	51.3	52.8	50.8
Age							
18–34	26.2	26.2	30.0	25.6	30.0	26.8	29.6
35–54	34.1	35.2	33.5	34.3	32.8	32.9	31.4
55 +	39.7	38.6	36.5	40.1	37.1	40.3	39.1
Annual HH income							
< 50 k	44.9	43.7	38.7	47.7	44.4	43.3	41.3
50–150 k	47.3	47.9	45.6	44.9	46.4	49.1	48.9
150 k +	7.8	8.5	15.7	7.4	9.2	7.7	9.9
Education							
Bachelor's or more	43.3	48.9	32.1	38.0	24.3	43.3	26.3
Recreational user	77.4	72.3		76.7		82.8	
Often view landscape	54.9	43.0		58.0		62.9	
Farms as largest polluters	27.4	14.2		19.0		47.8	
Dead zone awareness	28.4	24.4		22.5		37.9	
Respondents (N)	1,850	591		621		638	

Census refers to 2019 American Community Survey 5-year. "Recreational user" is % respondents who participate in either sightseeing, boating, swimming, or fishing at water bodies; "Often view landscape" is % respondents who very often or somewhat often view rural landscapes during the winter months; "Farms as largest polluters" is % respondents who perceive farms as the most significant contributors to total nutrient pollution in the region; and "Dead zone awareness" is % respondents who were aware of the dead zone in the Gulf of Mexico before the survey

3 Econometric Framework

We employ a generalized multinomial logit (GMNL) model developed by Fiebig et al. (2010). The utility that an individual n obtains from alternative j in choice question t is represented by

$$U_{njt} = \boldsymbol{\beta}_{\boldsymbol{n}}^{\prime}\boldsymbol{X}_{\boldsymbol{njt}} + \varepsilon_{njt} \tag{1}$$

where $\boldsymbol{X}_{\boldsymbol{njt}}$ is a vector of observed attributes including the alternative specific constant (ASC) and household costs, $\boldsymbol{\beta}_{\boldsymbol{n}}$ is a vector of coefficients for the attributes that is individual n-specific, and ε_{njt} is the random error that is independently and identically distributed type I extreme value. The ASC takes the value of one for the status quo ("no change" option) in each choice question and zero otherwise, capturing unobserved respondent preferences towards maintaining the status quo. In the most general GMNL model, $\boldsymbol{\beta}_{\boldsymbol{n}} = \sigma_n\overline{\boldsymbol{\alpha}} + \gamma\boldsymbol{\eta}_{\boldsymbol{n}} + (1-\gamma)\sigma_n\boldsymbol{\eta}_{\boldsymbol{n}}$, where $\overline{\boldsymbol{\alpha}}$ is the mean attribute coefficients in the population, $\boldsymbol{\eta}_{\boldsymbol{n}}$ is individual deviations from the mean, σ_n is an individual n-specific scale of the error term, and γ is a parameter that determines how the variance of taste heterogeneity ($\boldsymbol{\eta}_{\boldsymbol{n}}$) is scaled ($\gamma \in [0, 1]$). The scale of the unincluded factors (σ_n) represents the variance of utility over different decision-making situations, and by allowing it to vary by respondents, the model accounts for different degrees of randomness in making choices across respondents (Train and Weeks 2005).

We use a GMNL with$\gamma = 0$, which has been adopted in multiple CE applications in the GMNL framework (e.g., Balogh et al. 2016; Parthum and Ando 2020; Shi et al. 2018; Zhang and Sohngen 2018). We also choose this particular GMNL model, considering that the estimated γ in the most general GMNL version is very close to zero (0.005) in the full sample and insignificant in Indiana and Iowa sub-samples,[3] while the other estimation results are broadly similar. In our model with$\gamma = 0$, both mean attribute coefficients ($\overline{\boldsymbol{\alpha}}$) and random taste coefficients ($\boldsymbol{\eta}_{\boldsymbol{n}}$) are scaled by σ_n :

$$U_{njt} = [\sigma_n(\overline{\boldsymbol{\alpha}} + \boldsymbol{\eta}_{\boldsymbol{n}})]^{\prime}\boldsymbol{X}_{\boldsymbol{njt}} + \varepsilon_{njt} \tag{2}$$

To ensure the positive domain, σ_n is assumed to be log-normally distributed. Specifically, $\sigma_n = \exp\left[\bar{\sigma} + \tau\epsilon_n\right]$ where $\bar{\sigma}$ is the mean parameter, τ is the parameter on the unobserved scale heterogeneity, and ϵ_n is the random term that is standard normally distributed. Following Fiebig et al. (2010), the constant $\bar{\sigma}$ is set as $-\tau^2/2$ so that $\mathrm{E}\left[\sigma_n\right] = 1$.

While WTP can be derived as a coefficient ratio of a non-monetary and a monetary attribute in Eq. (2), studies have shown that WTP obtained this way often results in counter-intuitive distributions of WTP with extreme values, such as the ratio of normal to log-normal distribution (Scarpa et al. 2008; Train and Weeks 2005). Alternatively, Greene and Hensher (2010) show that re-parameterizing the GMNL model can be an appealing approach because it can directly estimate WTP parameters with appropriate distributional assumptions. We adopt this approach and rewrite Eq. (2), first separating the monetary variable (P) and its coefficient (α_n^P):

[3] Keane and Wasi (2013) note that there is no reason to restrict γ to the [0, 1] interval and allow $\gamma < 0$ or $\gamma > 1$. In estimating the full GMNL model, we also estimated γ without the domain restriction.

$$U_{njt} = -\left(\sigma_n \alpha_n^P\right) P_{njt} + \left(\sigma_n \boldsymbol{\alpha_n}\right)' \boldsymbol{X_{njt}} + \varepsilon_{njt} \tag{3}$$

where $\boldsymbol{\alpha_n} = \overline{\boldsymbol{\alpha}} + \boldsymbol{\eta_n}$. Given that WTP for any non-monetary attribute can be calculated as $\text{WTP}_n = -\alpha_n/\alpha_n^P$, we can rewrite Eq. (3) to derive the WTP space specification:

$$U_{njt} = -(\sigma_n \alpha_n^P) P_{njt} + (\sigma_n \alpha_n^P) \mathbf{WTP}_{\boldsymbol{n}}' \boldsymbol{X_{njt}} + \varepsilon_{njt} = \sigma_n \alpha_n^P \left(-P_{njt} + \mathbf{WTP}_{\boldsymbol{n}}' \boldsymbol{X_{njt}} \right) + \varepsilon_{njt} \tag{4}$$

We normalize the price coefficient α_n^P to 1 in estimation. We specify that our random WTP parameters, including the ASC, follow a multivariate normal distribution and allow for possible correlations between the parameters. To estimate Eq. (4), we employ simulated maximum likelihood methods using the *gmnl* package in R (Sarrias and Daziano 2017). This paper uses 2,500 Halton draws for all models.

4 Results

4.1 Willingness to Pay Estimates for Nutrient Reductions

Table 3 presents the regression results of the generalized multinomial logit (GMNL) in WTP space model. Column 1 shows the results from the entire sample pooling all observations from the three states while columns 2 through 4 show the results for each individual state in isolation. In all columns, mean marginal willingness to pay (MWTP) coefficients for the attributes are positive and statistically significant at the 1% level or better, suggesting that respondents on average have a strong preference for improved provision of ecosystem services and a reduced dead zone in the Gulf of Mexico. The negative and large coefficient on the ASC dummy (no change) indicates that respondents on average derive great utility from reducing nutrient pollution relative to no change, consistent with other studies in the region (Parthum and Ando 2020; Shr and Zhang, 2021). The standard deviations of all random MWTP parameters are also significant at the 1% level or better, indicating unobserved heterogeneity in mean of the parameters.

The full sample results (column 1) show that respondents attach the greatest value to the high level of aquatic life diversity. Specifically, respondents would be willing to pay about \$33 each year to improve freshwater biodiversity characterized by a 40% increase in aquatic insect species and a 20% increase in fish species. This amount is over two times higher than that for direct water use for recreation; respondents are willing to pay about \$14 each year for improved fishing and swimming beyond visual amenities and boating. The relatively higher public WTP for aquatic ecosystems than water-based recreation at the most improved water bodies and the highest attribute levels is consistent with previous findings (Doherty et al. 2014; Stithou et al. 2012). For instance, Doherty et al. (2014) find that the public in Ireland would be willing to pay about €42 for good water clarity and smell, €25 for good ecosystem health, and €13 for all recreational activities (fishing, boating, swimming, kayaking) compared to a visual amenity alone. The paper attributes the relatively low WTP for recreation to a modest share of respondents participating in improved levels of recreational activities. In our study, respondents value aquatic biodiversity more than recreational improvement despite the majority of respondents engaging in at least one of the baseline activities (sightseeing and boating) and the improved levels of activities (fishing and swimming), 61.7% and 58.0%, respectively. Respondents also place a higher value on the medium level of aquatic life diversity than the recreational use, with

Table 3 Marginal willingness to pay estimates (GMNL-WTP space)

	(1) Pooled		(2) Illinois		(3) Indiana		(4) Iowa	
Mean MWTP ($/household year)	estimate	St. Err	estimate	St. Err	estimate	St. Err	estimate	St. Err
Aquatic life: med (insect 25%, fish 10% species increase)	24.43***	(1.48)	21.68***	(2.21)	23.53***	(2.49)	29.13***	(2.74)
Aquatic life: high (insect 40%, fish 20% species increase)	32.76***	(1.73)	26.69***	(2.45)	32.60***	(3.00)	36.32***	(3.33)
Recreation: improved fishing and swimming	14.39***	(1.22)	8.39***	(1.72)	14.70***	(2.15)	21.17***	(2.53)
Reduced dead zone	28.50***	(1.36)	22.54***	(1.91)	26.76***	(2.37)	33.23***	(2.62)
Winter landscape: cover crops (CC)	11.20***	(1.63)	9.09***	(2.48)	13.10***	(2.78)	12.22***	(2.83)
Winter landscape: CC + buffer strips (BS)	18.36***	(1.90)	10.45***	(2.83)	17.43***	(3.08)	25.37***	(3.49)
Winter landscape: CC + BS + perennials	23.81***	(1.75)	19.29***	(2.63)	19.47***	(2.78)	28.88***	(3.22)
ASC	− 119.74***	(7.90)	− 100.12***	(10.94)	− 129.40***	(14.67)	− 106.05***	(13.06)
Standard deviations in mean MWTP								
Aquatic life: Med (insect 25%, fish 10% species increase)	19.30***	(1.95)	17.28***	(2.93)	18.25***	(2.96)	23.97***	(3.16)
Aquatic life: high (insect 40%, fish 20% species increase)	42.17***	(2.44)	42.72***	(3.80)	43.75***	(3.88)	41.20***	(4.11)
Recreation: Improved fishing and swimming	27.37***	(1.54)	21.03***	(2.53)	28.52***	(2.86)	32.42***	(2.75)
Reduced dead zone	37.19***	(1.81)	29.52***	(2.57)	39.58***	(3.26)	41.78***	(3.29)
Winter landscape: cover crops (CC)	27.03***	(2.64)	26.70***	(4.14)	30.04***	(4.27)	29.52***	(4.04)
Winter landscape: CC + buffer strips (BS)	22.20***	(3.22)	16.47***	(5.48)	22.99***	(4.85)	37.24***	(4.66)
Winter landscape: CC + BS + perennials	23.48***	(2.70)	13.62***	(5.04)	25.21***	(4.30)	41.40***	(4.49)
ASC	158.54***	(9.08)	124.39***	(12.27)	207.79***	(21.42)	165.18***	(16.18)
Variance parameter in scale: Tau (τ)	1.35***	(0.09)	1.36***	(0.15)	1.73***	(0.18)	1.63***	(0.18)
Observations (Respondents)	14,800 (1,850)		4,728 (591)		4,968 (621)		5,104 (638)	
Log likelihood	− 10,729.4		− 3,583.5		− 3,610.0		− 3,494.9	
AIC	21,550.7		7,259.0		7,312.0		7,081.8	
BIC	21,900.5		7,556.2		7,611.5		7,382.5	

Column 1 provides the results of the generalized multinomial logit (GMNL) in WTP space model for the sample pooled over three states, and other columns provide the results for respective state. Standard errors are in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$

an average annual MWTP of about $24 for increases in aquatic insect species and fish species by 25% and 10%, respectively.

The attribute with the second-highest MWTP is reducing the size of the dead zone in the Gulf of Mexico, suggesting that respondents have a strong preference for downstream water quality significantly distant from their residence. The coefficient in the pooled sample from all three states (column 1) shows that respondents would be willing to pay $29 to reduce the dead zone to one-third of the current size, which corresponds to the regional target of 1,900 square miles (US EPA, 2008). The results also show that respondents derive an increasing level of utility as the diversity of winter rural landscape intensifies. In the pooled sample (column 1), respondents would be willing to pay $11 for cover crops, $18 for buffer strips along with cover crops, and $24 for perennial crops in addition to cover crops and buffer strips,[4] relative to the bare soil with conventional tillage baseline. The relative importance of attributes in the pooled sample results are broadly similar to each individual state sub-sample (columns 2 through 4).

It is worth mentioning that our estimated landscape benefits may partially capture some of the functional values of the conservation practices, such as reducing soil erosion and nutrient loss, given that a brief description of such benefits accompanied our landscape visualizations. Despite constantly emphasizing visual appearances when defining the landscape attributes and only displaying pictorial visualizations for this attribute, in contrast to the other attributes, it is impossible to rule out some respondents' WTP for the landscape attribute reflecting some amount of functional benefits. Separate analysis indicated that respondents who place greater importance on landscape appearances have a higher WTP for each landscape level, consistent with respondents having considered aesthetic features when making choices over the landscape attribute in the choice experiment. Taken together, it is reasonable to conclude that our benefit estimates do reflect aesthetic preferences for increasing cropland diversity. If respondents attributed some value to the functional benefits of conservation practices, a conservative interpretation of the landscape benefit estimate is that it is an upper bound for the aesthetic benefits. Future research may be able to intentionally estimate a more precise or pure aesthetic value for such practices to provide a more definitive valuation of this specific attribute in the current study.

4.2 Preference Heterogeneity

To investigate the possible sources of preference heterogeneity displayed in Table 3, we develop and test three hypotheses. First, we examine whether respondents with greater familiarity or knowledge about the nutrient pollution problem have a higher WTP for water quality improvements. In the survey, we included two questions that can measure how familiar a respondent is with nutrient problems: (1) what a respondent thinks is the largest source of nutrient pollution in water bodies near one's residence and (2) whether a respondent was aware of the Gulf dead zone before the survey. Figure 2 presents the results. About 27 percent of respondents correctly indicated agricultural sources as the most significant contributor to nutrient pollution ("Farms" in the left panel, Fig. 2) and 28 percent had prior exposure to the dead zone issues (the right panel). To test how the

[4] T-tests reject the null hypotheses of equal WTP estimates for (1) cover crops ($11) and buffers + cover crops ($18) with p-value < 0.001, and for (2) buffers + cover crops ($18) and perennials + buffers + cover crops ($24) with p-value = 0.002.

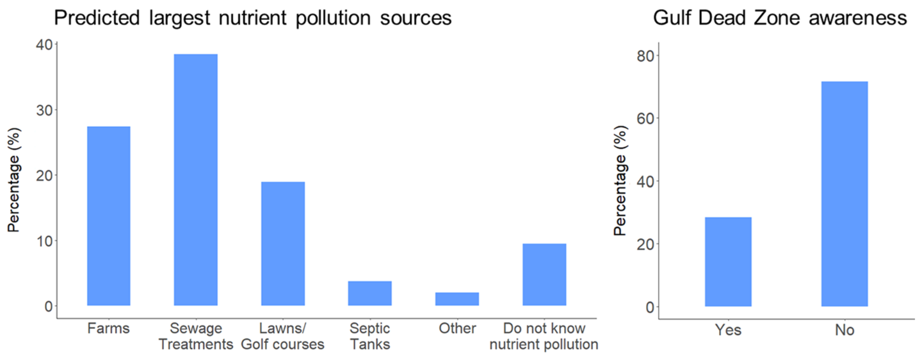


Fig. 2 Respondents' knowledge or familiarity with nutrient pollution issues. The figure shows respondents' answers from two questions that measure how much respondents are familiar with nutrient pollution issues. The two questions are (1) who they think is the most significant contributor to total nutrient pollution (left panel) and (2) whether they were aware of the Gulf dead zone before the survey (right panel)

different levels of knowledge correlate with WTP, we include interaction terms between attributes and each of two knowledge indicator variables. The first dummy takes the value of one if a respondent indicates farms as the largest nutrient pollution source in the region and zero otherwise, and the second dummy equals one if a respondent knew about the Gulf dead zone before the survey (zero otherwise). All attributes were tested except landscape aesthetics because prior knowledge does not necessarily correlate with this attribute.

Next, we expect that ecosystem service users place greater value on improved services than non-users, consistent with economic theory. In our CE, the relevant attributes are recreational activities and winter landscape appearances. For recreation, we interact the attribute with a recreational user indicator, which equals one if a respondent participates in at least one water-based recreational activity and zero otherwise. Additionally, we include the interaction terms between recreational users and aquatic life attributes to test if users also value aquatic biodiversity more than non-users. If true, this may suggest that greater freshwater biodiversity augments the utility users derive from recreational activities in water bodies, although we cannot test if the two attributes are indeed complements as the experimental design does not allow for interaction effects between attributes. We utilize a survey question that asked how often a respondent views rural landscapes during the winter months ('very often', 'somewhat often', 'occasionally', or 'rarely') to identify 'users' of agricultural landscapes. We create an indicator variable that equals one if a respondent 'very often' or 'somewhat often' views rural landscapes and zero otherwise.

The last hypothesis we test is how WTP for water quality improvement changes with different age groups. There is evidence that the elderly may be less willing to support environmental programs, such as climate change policies (Andor et al. 2018; Kellstedt et al. 2008). This makes intuitive sense, for example, given that environmental benefits often accrue over the long run and older people have relatively short time horizons compared to younger people. However, there exist contrasting findings, such as Popp (2001) showing that concern for later generations plays a role in provisioning better environmental outcomes. To explore whether different preference patterns exist for water quality issues by age, our model interacts membership in the two older groups (35–54 years and 55 + years) with the aquatic life and dead zone attributes, for comparison with the young adult group (18–34 years) base category.

Table 4 Observed preference heterogeneity model (GMNL-WTP space)

Mean MWTP ($/household year)	Estimate	St. Err
Aquatic life: medium (insect species 25%, fish species 10% increase)	22.42***	(3.15)
Aquatic life: high (insect species 40%, fish species 20% increase)	37.48***	(3.44)
Recreation: improved fishing and swimming	11.32***	(1.93)
Reduced dead zone	17.22***	(1.74)
Winter landscape: cover crops (CC)	5.54***	(2.14)
Winter landscape: CC + buffer strips (BS)	13.78***	(2.29)
Winter landscape: CC + BS + perennials	23.20***	(2.18)
ASC	− 129.08***	(8.28)
Observed heterogeneity		
Aquatic life: medium × farms as largest polluters	7.28***	(2.53)
Aquatic life: high × farms as largest polluters	14.43***	(2.65)
Recreation × farms as largest polluters	9.53***	(1.90)
Reduced dead zone × farms as largest polluters	18.71***	(1.96)
Aquatic life: medium × dead zone awareness	1.99	(2.36)
Aquatic life: high × dead zone awareness	− 1.65	(2.37)
Recreation × dead zone awareness	− 6.11***	(1.80)
Reduced dead zone × dead zone awareness	8.21***	(1.73)
Aquatic life: medium × recreational user	3.22	(2.63)
Aquatic life: high × recreational user	0.26	(2.54)
Recreation × Recreational user	3.93**	(1.89)
Winter landscape: (CC) × often view landscape	9.66***	(2.55)
Winter landscape: (cc + bs) × often view landscape	7.68***	(2.68)
Winter landscape: (CC + BS + perennials) × often view landscape	3.64	(2.51)
Aquatic life: medium × age 35–54	− 3.65	(2.66)
Aquatic life: high × age 35–54	− 9.19***	(2.74)
Reduced dead zone × age 35–54	1.90	(1.97)
Aquatic life: medium × age 55 +	− 2.91	(2.70)
Aquatic life: high × age 55 +	− 8.96***	(2.77)
Reduced dead zone × age 55 +	9.82***	(1.99)
Unobserved heterogeneity (Standard deviations in mean MWTP)		
Aquatic life: medium (insect species 25%, fish species 10% increase)	17.82***	(1.84)
Aquatic life: high (insect species 40%, fish species 20% increase)	40.87***	(2.32)
Recreation: improved fishing and swimming	26.26***	(1.53)
Reduced dead zone	35.27***	(1.75)
Winter landscape: cover crops (CC)	22.94***	(2.53)
Winter landscape: CC + buffer strips (BS)	19.99***	(3.31)
Winter landscape: CC + BS + perennials	21.33***	(2.77)
ASC	131.60***	(7.90)
Variance parameter in scale: Tau (τ)	1.32***	(0.08)
Observations (respondents)	14,800 (1,850)	
Log likelihood	− 10,661.2	
AIC	21,454.4	
BIC	21,956.1	

The table shows the results of the generalized multinomial logit (GMNL) in WTP space model including interaction effects between respondent-specific characteristics and attribute levels. Standard errors are in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$

Table 4 presents the estimates of the preference heterogeneity model in GMNL-WTP space. The results show that respondents who are more familiar or knowledgeable about nutrient pollution issues tend to place a greater value on water quality improvement. Specifically, respondents who correctly believe that farms are the largest pollution sources in the region attach greater values to all four attributes tested: improving aquatic life to medium or high levels, expanding recreational potential, and reducing the dead zone in the Gulf of Mexico. The positive relationship between issue familiarity and preferences for a good is consistent with previous work in other contexts, such as cold water corals protection (LaRiviere et al. 2014) or greywater reuse (Amaris et al. 2020). On the other hand, respondents who were aware of the dead zone problem in the Gulf of Mexico prior to the survey are more interested in mitigating the dead zone but less interested in expanding local water recreation potential than those without such knowledge. We are unable to explain these opposing effects but it would be interesting to investigate in future research whether altruistic attitudes or greater concern for one's impact on others than one's self amongst those with and without prior knowledge of the dead zone plays some role here. The model also confirms the hypothesis that whether a person is a user of ecosystem services is positively correlated with associated preferences. For example, recreational users are more willing to support improving recreational opportunities than non-users, and people who often view winter farm landscapes are more interested in growing landscape diversity using cover crops or a mix of cover crops and buffers compared to those who rarely or only occasionally see winter farm landscapes. The interaction effects of recreational users and aquatic life are statistically insignificant, suggesting no discernible difference in preferences for healthier aquatic ecosystems between recreational users and non-users. Finally, we find that age is a significant factor that explains preference heterogeneity. For example, the results indicate that compared to the youngest group (18–34 years), the middle age group (35–54 years) and the eldest group (55 + years) are less interested in high freshwater biodiversity. In contrast, the results reveal that, for the downstream improvement characterized by the reduced dead zone in the Gulf of Mexico, the eldest group (55 + years) has a higher WTP than the youngest group (18–34 years). Appendix 2 provides the results of testing the three hypotheses for each state sub-sample.

4.3 Scenario Analysis

Table 5 presents four potential nutrient reduction scenarios characterized by different attribute levels (top section) and corresponding welfare estimates at a household and state level (middle and bottom sections). Although it would be ideal to develop the scenarios linking different sets of nutrient reduction strategies to their eventual impacts on the aquatic ecosystem, we lack precise and complete knowledge of such links across our broad study region. Therefore, we construct potential combinations of ecosystem service levels that can arise from the three states' nutrient reduction strategies to provide information about the magnitudes and variation in expected welfare gains above the status quo. Scenarios A and B depict outcomes from moderate nutrient reductions while Scenarios C and D illustrate those from more ambitious nutrient reductions.

In Scenario A, nutrient reduction efforts improve aquatic life to the medium level and expand recreational potential. Since this scenario does not involve farm landscape changes, one may consider the outcomes as resulting from point source reductions, such as tighter nutrient discharge permits or urban nonpoint source reductions that only achieve local water quality benefits. The other three scenarios represent strategies that also engage

Table 5 Welfare estimates for the four policy scenarios

	Scenario A	Scenario B	Scenario C	Scenario D
Changes in ecosystem services and the Gulf dead zone				
Aquatic life	Aquatic insect 25%, fish 10% species increase	Aquatic insect 25%, fish 10% species increase	Aquatic insect 40%, fish 20% species increase	Aquatic insect 40%, fish 20% species increase
Recreational activities	Improved fishing, swimming	Improved fishing, swimming	Improved fishing, swimming	Improved fishing, swimming
Size of the dead zone in the Gulf	–	–	–	Reduced to 1,900 sq. miles
Winter landscape appearance	–	Cover Crops + Buffers	Cover Crops + Buffers + Perennials	Cover Crops + Buffers + Perennials
Individual annual benefits ($/household)				
Pooled	158.6 [141.6, 175.5]	176.9 [159.0, 194.8]	190.7 [172.5, 208.9]	219.2 [199.7, 238.7]
Illinois	130.2 [107.1, 153.3]	140.6 [116.6, 164.7]	154.5 [129.7, 179.3]	177.0 [150.7, 203.4]
Indiana	167.6 [136.2, 199.0]	185.1 [152.2, 217.9]	196.2 [162.7, 229.7]	222.9 [187.1, 258.8]
Iowa	156.4 [127.8, 184.9]	181.7 [150.9, 212.5]	192.4 [161.3, 223.6]	225.6 [191.7, 259.6]
Aggregate annual benefits (million $)				
Pooled	1,376.6 [1,229.7, 1,523.6]	1,536.1 [1,380.6, 1,691.5]	1,655.7 [1,497.7, 1,813.7]	1,903.1 [1,733.5, 2,072.8]
Illinois	630.9 [518.9, 742.9]	681.5 [564.9, 798.2]	748.7 [628.5, 868.8]	857.9 [730.3, 985.5]
Indiana	430.9 [350.2, 511.6]	475.7 [391.2, 560.2]	504.3 [418.2, 590.4]	573.0 [480.8, 665.3]
Iowa	197.9 [161.7, 234.0]	230.0 [191.0, 268.9]	243.5 [204.1, 282.9]	285.5 [242.6, 328.5]

MWTP estimates used to calculate individual and aggregate annual benefits are from the pooled and each state's sub-sample regression results in Table 3. The total number of households in the three states used to calculate aggregate annual benefits are 4,846,134 (Illinois), 2,570,419 (Indiana), and 1,265,473 (Iowa) based on 2019 American Community Survey 5-year. 95% confidence intervals calculated using the delta method are in brackets farmers to implement cover crops, buffers, or perennials. Thus, each scenario involves agricultural landscape changes depending on conservation practices installed. The policy measures in Scenario B incorporate farmers adopting cover crops and buffers, thus creating visual benefits from landscape diversity in addition to the local water quality outcome improvements in Scenario A. Scenario C further introduces perennials along with cover crops and buffers, resulting in the most diversified winter landscape, a higher level of aquatic life and greater recreational potential. In addition to the enhanced ecosystem services from local waters and agricultural fields in Scenario C, scenario D also considers the benefits of meeting the target size for the Gulf dead zone.

To calculate WTP per household for a set of attribute changes over the status quo in each scenario, we use MWTP estimates from the pooled model and each state sub-sample in Table 3. For example, Scenario A involves a moderate increase in aquatic life and improved recreational activities, for which a household's MWTP is $24.4 and $14.4, respectively, and the MWTP of $119.7 for moving away from the current situation (Table 3, model 1). Therefore, the total WTP per household is $158.6 as the sum of these MWTP amounts (Table 5, middle section). The aggregate annual benefits in the bottom section of Table 5 are calculated by multiplying individual annual benefits ($/household) by the number of households in the corresponding region.

Table 5 shows that the expected aggregate benefits across the entire study region vary between $1,377 million for moderately enhanced local aquatic diversity and recreation (A) and $1,903 million for the greatest improvements including the reduced dead zone downstream (D). The results also indicate the importance of increasing agricultural abatement via conservation practices. For example, when a certain level of nutrient reduction improves aquatic life and recreational opportunities, achieving that abatement via only point sources is valued at $1,377 million whereas reallocating part of that abatement to farms using cover crops and buffers yields $1,536 million due to additional benefits from a diversified winter landscape (A versus B). In general, implementing conservation practices is a strategy with lower marginal abatement costs than point source controls to reduce nutrients (Shortle and Horan 2013). Our results further suggest that given the considerable value placed on agricultural landscape aesthetics, advancing nonpoint reductions can be an even more appealing option than point source reductions to maximize net welfare in the region. More aggressive point and nonpoint reductions that involve all three conservation practices (i.e., cover crops, buffers, and perennials) yield $1,656 million when they lead to high aquatic diversity and improved recreational potential in addition to the most diversified landscapes (C), or $1,903 million when collective efforts upstream also reduce the Gulf dead zone to the target size of 1,900 square miles (D).

Next, we focus on cover crops that have occupied a prominent place in state nutrient loss reduction strategies, to illustrate whether installing cover crops might achieve net welfare gains in the region. We first calculate the aggregate benefits of planting cover crops, including the benefits from landscape diversity and water quality improvement. Given the lack of precise knowledge of how cover crops change ecosystem services over the entire study region, we assume several cases, as in the scenario analysis above. After obtaining the aggregate benefits, we derive the unit cost of cover crops ($/acre) required to make the aggregate net benefits equal to zero such that the aggregate cost of planting cover crops equals the aggregate benefits. Compared with the actual unit cost of cover crops in the region, this implied unit cost can provide information on the sign of the net benefits. For example, if the actual unit cost is higher (lower) than the calculated breakeven unit cost, the net benefits would be negative (positive). We assume cover crops are planted on half the total crop fields in the study area and generate the cover crop-induced visual landscape

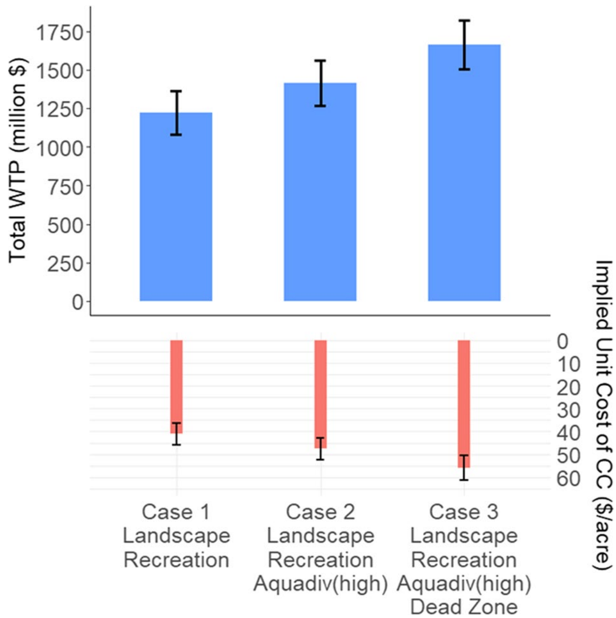


Fig. 3 Aggregate benefits and corresponding unit cost of planting cover crops where net benefits are equal to zero. Total WTP (Willingness to Pay) is aggregate annual benefits, which are obtained by multiplying WTP per household for an attribute improvement by the total number of households benefiting from that improvement and aggregating them over all attribute improvements, including the alternative specific constant. For the benefit estimates, we consider three potential cases: landscape change due to cover crops and improved recreational opportunities (Case 1); high aquatic biodiversity in addition to the previous case (Case 2); and, additionally, a reduction in the size of the dead zone (Case 3). The implied unit cost of CC (Cover Crops) is the level of the unit cost that makes the net aggregate benefits equal to zero, assuming 50% of cropland (29.7 million acres, 2017 Census of Agriculture) is planted to cover crops. That is, aggregate benefits = implied unit cost ($/acre) × 29.7 million acres. The error bars are 95% confidence intervals

benefits estimated in Table 3.[5] The cropland area used is 29.7 million acres based on the harvested cropland in Illinois, Indiana and Iowa from the 2017 Census of Agriculture from USDA NASS.

Figure 3 presents the total WTP estimates (top panel) and the corresponding implied unit costs of cover crops (bottom panel) that make the total costs equal to the total WTP estimates. We consider three hypothetical outcomes caused by cover crops: landscape change and improved recreational opportunities (Case 1 in Fig. 3); high aquatic biodiversity in addition to the previous case (Case 2); and, additionally, a reduction in the size of the dead zone (Case 3). In calculating the aggregate WTP, we exclude households in the Chicago area[6] from the households benefiting from the aquatic life and recreational

[5] We note that our survey elicited visual preferences by presenting a landscape photo where cover crops are planted on "all" crop fields shown (Appendix 1). However, given that people can generally view only a limited scope of the whole landscape surrounding them and that planting cover crops on the total cropland area is unrealistic, we maintain the 50% share as a reasonable policy scenario.

[6] We consider four counties for the Chicago area, including Cook County of the City of Chicago and three adjacent urbanized counties (Du Page, Will, and Lake counties). The total number of households in the four counties is 2,790,519 (2019 American Community Survey).

improvements and include the Chicago area with all other households in the entire study region receiving benefits for the landscape change and dead zone reduction attributes. The reason for excluding the Chicago area is that adopting cover crops would not be expected to improve local water quality near the Chicago region, given it is located far upstream of agricultural areas within the study region and includes minimal cropland planted to cover crops. Despite limited local cropland, we include Chicago area households as benefiting from cover crop-induced landscape change because Chicago area respondents (n = 353) indicated that they consume winter rural landscapes (very/somewhat often 32%, rarely/occasionally 68%). Our MWTP estimation for the Chicago area sub-sample shows similar magnitudes of MWTP for the landscape change to the full sample. The aggregate benefits from moving away from the status quo are included in all three cases, using the total households in the study area.

Figure 3 indicates that the average implied unit cost of cover crops required to offset total benefits for the three cases ranges from \$41.1/acre to \$56.0/acre; this implied cost range is almost entirely below the reported unit cost of around \$50/acre in the region (Bowman et al. 2022; Plastina et al. 2018; Roley et al. 2016). Since the implied unit cost is where the net benefit is zero, this indicates that, within the study region, the total cost of adopting cover crops on half of harvested acres may far outweigh associated benefits unless the highest biodiversity and dead zone reduction benefits are included. We note that there are additional potential benefits that cover crops can produce that are not included in our calculation, such as improved resilience to floods or reduced cost of nitrate removal from drinking water. In addition, cover crops can yield on-farm benefits, such as weed control and improved soil health, which can lower the net cost of adopting cover crops over multiple growing seasons. Nevertheless, the considerably low per-acre costs required at the breakeven point relative to the actual unit cost still suggest possibly negative net gains from these cover crop adoption scenarios in the study region. This observation underscores two important points. First, it is essential to consider improvements in downstream ecosystem services and associated welfare gains to assess whether nutrient reductions upstream are worth the costs in the Mississippi/Atchafalaya River Basin (MARB) as a whole. For instance, reductions in nutrient loads from the Corn Belt states could increase fish stocks and species in the Gulf of Mexico, enhancing commercial and recreational fisheries, ecological diversity, coastal residential property values, and other non-market marine ecosystem services. Given the economic and ecological significance of the Gulf and the negative impacts of hypoxia on fishing and habitat destruction (O'Connor and Whitall 2007), welfare gains in the Gulf from reduced nutrient inputs from upstream may be considerable. Although relevant research is incomplete, studies shed some light on this point. For example, Stefanski and Shimshack (2016) conduct a nationwide survey and report household WTP of \$35–\$107 for improved biodiversity in the Gulf via the expansion of Flower Garden Banks National Marine Sanctuary, finding that WTP values do not differ significantly across regions of the country. Second, the possibility of negative net gains within the study area implies the importance of policy coordination between individual states to achieve Gulf hypoxia targets. While the concentrated costs in our study are from upstream of the Gulf, benefits are dispersed, with a significant portion of the total benefits possibly arising outside the study area that incurs the expenses considered in this study. Unless net welfare gains over the entire MARB are guiding deployment of nutrient loss abatement in the upstream study region, effort levels are likely to fall short of what is necessary to meet national hypoxia goals and maximize net social benefits.

5 Conclusion

Addressing eutrophication and the Gulf of Mexico dead zone is highly challenging, requiring substantial pollution control costs and continued policy actions over the long run. To understand the benefits of such efforts, we examine public preferences for local ecosystem services from nutrient pollution reductions and a decreased dead zone in the Gulf. Our study encompasses the three US Corn Belt states—Illinois, Indiana, and Iowa—whose nutrient pollution is critical because they are known to be the states most responsible for Gulf hypoxia. Unlike most non-market valuation studies in the region that do not address Gulf hypoxia policy directly or focus only on a specific watershed or water body, this paper aims to provide more complete benefit estimates to inform Gulf hypoxia policy. We develop a choice experiment (CE) and analyze the CE survey data using generalized multinomial logit (GMNL) models that incorporate respondents' heterogeneity in tastes and scale, estimating these models directly in willingness to pay (WTP) space.

We find significant economic benefits associated with nutrient reductions in local water bodies and in the Gulf of Mexico. The results indicate that respondents on average place the greatest value on the highest level of freshwater biodiversity in local waters in the CE, represented as a 40% increase in aquatic insect species and a 20% increase in fish species, with a mean annual marginal WTP (MWTP) of about \$33 per household. This amount is more than two times the MWTP of \$14 that respondents place on unrestricted recreational use of local waters. The intermediate level of freshwater biodiversity also exhibits larger MWTP than unrestricted recreation, with a mean annual MWTP of \$24.

Overall, the positive WTP estimates for local water quality improvement found in this study are in line with other studies in the Corn Belt region that are not directly comparable. Parthum and Ando (2020) find the WTP of \$5 and \$0.17 for an extra game fish species increase and an added number of fish per 100 yards of a local river in Illinois, respectively. The local benefits in Shr and Zhang (2021) vary between \$1.9/month (\$23.1/year) for a 10% increase in lake clarity and \$4.7/month (\$56.0/year) for a 50% decrease in the frequency of detecting algal toxins in Iowa's source waters. We also find that the downstream water quality improvement attribute ranks second, above other locally arising benefits, in order of MWTP; respondents are willing to pay \$29 annually per household to reduce the Gulf dead zone to one-third of the current size. Though not directly comparable, this is consistent with Shr and Zhang (2021) that report Iowa resident WTP of \$1.4/month (\$16.6/year) for a more modest 10% decrease in the size of the Gulf hypoxic zone.

Lastly, we find that increased levels of land cover diversity based on landscape appearance with more conservation practices that provide winter soil cover are associated with increasingly higher WTP. Specifically, respondents are willing to pay about \$11 for cover crops relative to bare farm fields over winter, \$18 for buffers and cover crops, and \$24 for a mix of perennial crops, buffers and cover crops. The value of agricultural landscape changes generated by cover crops in our study (\$11 in the full sample and \$12 in the Iowa sub-sample, Table 3) is greater than Grala et al. (2012) who previously found WTP ranging from \$4.8 to \$8.5 per household in Iowa for landscape changes created by field windbreaks.

In addition, we introduce individual-specific covariates to examine whether some individual characteristics explain preference variations shown in our model. We hypothesize that preferences vary by different levels of issue familiarity, ecosystem service consumption, and age. We find that respondents who accurately recognize that agriculture is the largest contributor to total nutrient pollution are willing to pay more for nutrient reductions to improve aquatic biodiversity, recreational opportunities, and the dead zone in the Gulf of Mexico. Respondents with previous knowledge about the Gulf dead zone have higher WTP to mitigate the dead zone combined with lower WTP to improve local recreational opportunities. The results also indicate positive correlations between actual use of ecosystem services and associated WTP. For example, recreational users place a greater value on expanding recreational potential than non-users, and people with a relatively high frequency of viewing winter farm landscapes are more interested in increasing landscape diversity than those with lower frequency viewing. Regarding the impacts of age, we find that relative to the youngest age group (18–34 years), the older groups (35–54 years and 55 + years) place a lower value on aquatic biodiversity. In contrast, the oldest group (55 + years) places a greater value on reducing the dead zone in the Gulf of Mexico than the youngest group.

Although we consider how nutrient reductions in waterways could affect the level of ecosystem service attributes in developing our CE, our approach has several limitations. Ideally, we could use hydrological modeling results covering our whole study region to see how different nutrient reduction practices (e.g., conservation practices, point source reduction) achieve different nutrient concentration levels. However, due to the lack of such modeling for the entire multi-state area, we instead use a modeling result from a typical watershed in Illinois and assume that it represents the average relationship between nutrient concentrations and policy inputs across the three states studied. Moreover, we do not utilize explicit ecological production processes, instead relying on a rough empirically estimated relationship between the levels of total phosphorus and ecosystem services, such as aquatic species diversity. This approach may ignore potentially more influential factors affecting ecosystem service provision—e.g., physical habitat structures, water residence time, or temperature variability (Egertson and Downing 2004)—which are also spatially heterogeneous. Nevertheless, provided that nutrient reductions improve aquatic biodiversity and recreational opportunities, our WTP estimates can inform relevant welfare gains.

Lastly, while we focus on "upstream" benefits where nutrient reduction costs are mainly concentrated in the MARB, future work should examine corresponding benefits downstream, especially in the Gulf of Mexico. As our scenario analysis on cover crop adoption suggests, total abatement costs might be greater than associated benefits within the Corn Belt states unless the local benefits from the highest level of aquatic biodiversity and reduced size of the Gulf hypoxic zone are included. To evaluate the full social benefits of hypoxia reduction measures for comparison with the costs over the entire river basin, it is essential to include economic benefits from upstream pollution abatement that generate downstream benefits in the Gulf not included in this study. Moreover, this information is crucial to understanding the distribution of costs and benefits across the entire river basin and developing coordinated policy actions to achieve the basin-wide nutrient reduction targets while realizing the combined benefits and costs that accrue upstream and downstream.

Appendix 1

Survey Instrument

The survey instrument as it appeared to respondents in Qualtrics is provided below.

Consent

To begin the survey, please acknowledge the consent statement below. If you do not wish to participate, please close this window, and your session will end.

"I have read and understood the above consent form. I certify that I am 18 years old or older. By clicking the "Submit" button to enter the survey, I indicate my willingness to voluntarily take part in this study."

Submit

Screening and Demographic Questions

We care about the quality of our survey data and hope to receive the most accurate measures of your opinions. So, it is important to us that you thoughtfully provide your best answer to each question in the survey.

Do you commit to providing your thoughtful and honest answers to the questions in this survey?

- I will provide my best answers
- I will not provide my best answers
- I can't promise either way

Are you using a laptop computer, desktop computer or tablet with a 10-inch or larger screen to complete this survey?

- Yes
- No

What is your home zip code?

What is your sex?

- Male
- Female
- Non-binary

What is your age in years?

- 18-24 years
- 25-34 years
- 35-44 years
- 45-54 years
- 55-64 years
- 65 or more years

Which ethnicity or race most accurately describes how you identify yourself?

- White/Caucasian
- Black/African American
- Hispanic, Latino/a or Latinx
- American Indian or Alaska Native
- Asian/Pacific Islander
- Other (Please Specify)

What is your annual household income before taxes?

- Under $25,000 per year
- $25,000-$49,999 per year
- $50,000-$74,999 per year
- $75,000-$99,999 per year
- $100,000-$149,999 per year
- $150,000-$199,999 per year
- $200,000 or more per year

Questions Related to the Survey Topic

Before we get started, we would like to ask your opinions on water quality today.

Think of the rivers, streams, or lakes near where you live. Overall, what is your assessment of their water quality today?

- Very good
- Good
- Satisfactory
- Bad
- Very bad
- Not sure

What is your assessment of the health of aquatic life (e.g., plants, fish, birds, and other wildlife animals) in rivers, streams, or lakes near your house?

- Very healthy
- Healthy
- Neither healthy nor unhealthy
- Unhealthy
- Very unhealthy

How important is it for you to have good water quality in rivers, streams, and lakes near where you live?

- Extremely important
- Very important
- Moderately important
- Slightly important
- Not at all important

What do you think is the largest source of nutrient pollution in rivers, streams, and lakes near where you live?

- Fertilizer from lawns and golf courses
- Sewage and wastewater treatment plants in towns and cities
- Septic tanks
- Crops and livestock on farms
- Other (please specify)
- I do not know what nutrient pollution is

Background Information

This section provides background information to help you understand the survey.

Nutrient pollution

Nutrient pollution is caused by an excessive amount of nutrients (nitrogen, phosphorus) entering water bodies. There are multiple sources that contribute to nutrient pollution:

- Wastewater from sewage treatment plants or septic systems discharged into water bodies.
- Nutrients contained in fertilizers and manure can be lost from farm fields into nearby waterways without proper management practices in place.
- Urban stormwater can carry nutrients into waterways when it runs across streets, parking lots and rooftops.

When there are too many nutrients in water, they cause algae to grow in a layer on the surface of the water. This deprives aquatic life of sunlight and oxygen that are essential for survival and decreases recreational opportunities such as fishing, boating and swimming.

The Dead Zone in the Gulf of Mexico

Nutrients that enter local rivers, streams, and lakes in Illinois, Indiana and Iowa end up in the Mississippi River and the Gulf of Mexico. In the Gulf, the nutrients create a "Dead Zone" where low levels of oxygen kill marine life. According to a recent measure, the size of this Dead Zone is 5,400 square miles, an area nearly the size of Connecticut.

Policy Responses

To address local water quality degradation and the Dead Zone in the Gulf of Mexico, 12 states have established Nutrient Loss Reduction Strategies and have pledged to meet a 45% reduction in nutrient pollution by the year 2035. This includes Illinois, Indiana, and Iowa which are some of the biggest contributors to the Dead Zone.

Description of Attributes and Levels

In the next section, we will present you with eight choice questions.

Each question will ask you to choose your most preferred out of three options. The three options include two options representing different environmental changes you would face under different policies in your state and a "No change" option.

The two options that entail changes have different water quality improvement features:

1. the health of aquatic life;
2. the types of water-based recreational activities allowed;
3. the size of the dead zone in the Gulf of Mexico;
4. the winter landscape appearance of nutrient pollution-reducing farm practices; and
5. the annual cost to your household.

The third option is always "No change." It represents no improvement in water quality, the winter landscape as it appears today, and no new cost to your household.

Please read the following descriptions/explanations of each feature of water quality improvements contained in the choice questions. Please read carefully to make sure you understand the choice questions.

- Aquatic Life: How much aquatic insect species and fish species increase in rivers, streams, and lakes near where you live.

Aquatic insects and fish species provide a good indicator of how healthy an aquatic ecosystem is because they play a key role in the aquatic food web.

For example, aquatic insects (such as larvae of dragonflies and stoneflies, snails, and worms that live on the bottom of a waterbody) feed on aquatic plants or other organic matter and are also the main food source for fish that are prey for birds and other wildlife.

Thus, a larger increase in aquatic insect and fish species indicates higher levels of biodiversity and better aquatic ecosystem health.

- <u>Recreational Activities</u>: **Which water-based recreational activities you could enjoy in rivers, streams, and lakes near where you live.**

The level of nutrients in water can affect the types of recreational activities you can enjoy in rivers, streams, and lakes. This is because nutrient pollution can cause algae to grow that may make people or their pets sick when they come into contact water.

If nutrient levels in water are too high, a closure may prevent water-based activities like swimming.

Moreover, layers of algae on the surface water may decrease the quality of fishing experiences.

- **<u>Size of the Dead Zone in the Gulf of Mexico</u>: How will the size of the dead zone in the Gulf of Mexico change.**

Nutrient pollution reduction in the Mississippi River (coming from Illinois, Indiana, and Iowa) may improve water quality <u>downstream</u> in the Gulf of Mexico.

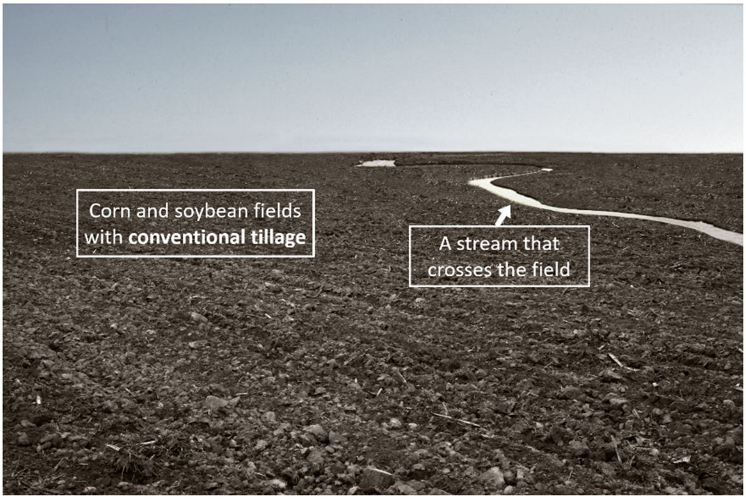
The above feature is distinct from other features of water quality improvements in the survey because it represents an improvement <u>not</u> occurring near where you live.

Note that it is possible to see no change in the size of the dead zone despite water quality improvements in your region and vice versa. This is because there are various other factors that affect the size of the dead zone.

- **<u>Winter Landscape Appearance</u>: How corn and soybean fields will appear after harvest in October until before planting in April or May.**

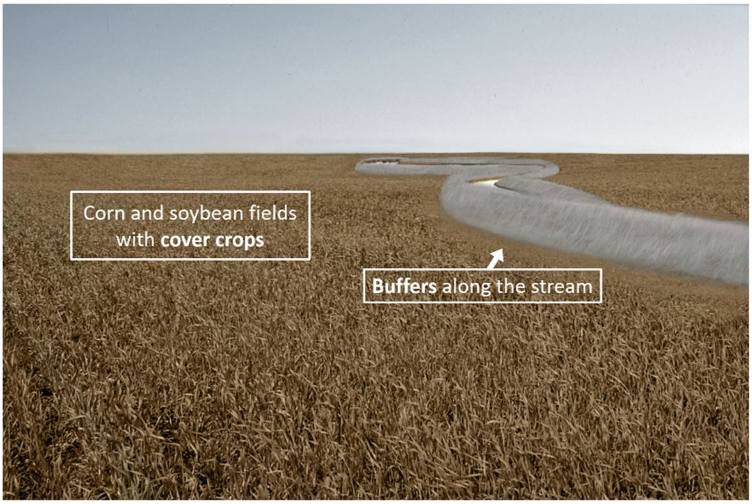
One of the nutrient reduction strategies in your state involves changing farm practices, and this can greatly transform how rural landscapes appear. Below we show four different landscape appearances that you may see in the survey.

1. The picture below represents the appearance of crop fields today during the winter months. This landscape is a result of "conventional tillage" where farmers plow crop fields after harvest and leave the soil bare. No soil cover makes land susceptible to erosion, and thus, nutrient loss into waterways like the stream in the picture.

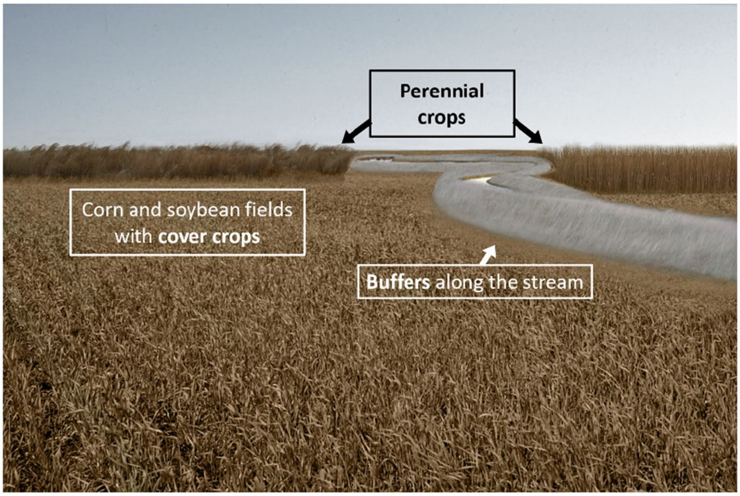


2. Instead, farmers can plant cover crops such as rye (cover crop pictured below) after harvest. The cover crops remain during the winter, and protect soil from erosion while scavenging nutrients that may otherwise be lost. The picture below presents winter landscape appearance of the conventional tillage field above when cover crops are planted over the winter.

3. Another way to reduce nutrient flows into waterways is to plant perennial grasses or trees as buffers along streams between crop fields and waterways. This works to intercept nutrient and soil runoff from the field, greatly reducing the transport of nutrients into waterways. The picture below presents a more diversified landscape apperance when implementing buffers in addition to cover crops.



4. Lastly, farmers can plant perennial crops in place of corn and soybeans. Perennials require many fewer nutrient inputs (i.e. fertilizer) and cover the soil over their entire lifespan (10+ years). Perennials can also provide revenue to farmers by selling them as livestock feed or bedding, or to produce bioenergy. The picture below presents the most diversified landscape appearance where all practices described are planted together instead of using conventional tillage.



- **Annual cost per household: Increase in annual property taxes paid by your household to pay for each option**

The increased cost (in dollars) per year paid in property taxes to contribute to the cost of water quality improvement. If you are a renter then this cost may be reflected in higher monthly rent charged by your landlord.

Cheap Talk and Policy Consequentiality

Final important note before you proceed:

Previous surveys found that people tend to make a different choice when making a hypothetical decision than they do when making choices in real life. A decision is hypothetical when you do not actually have to pay the money for the option you choose-- this is the kind of decision you asked to make in the following section. In this case, people often state a larger amount of money than they are actually willing to pay.

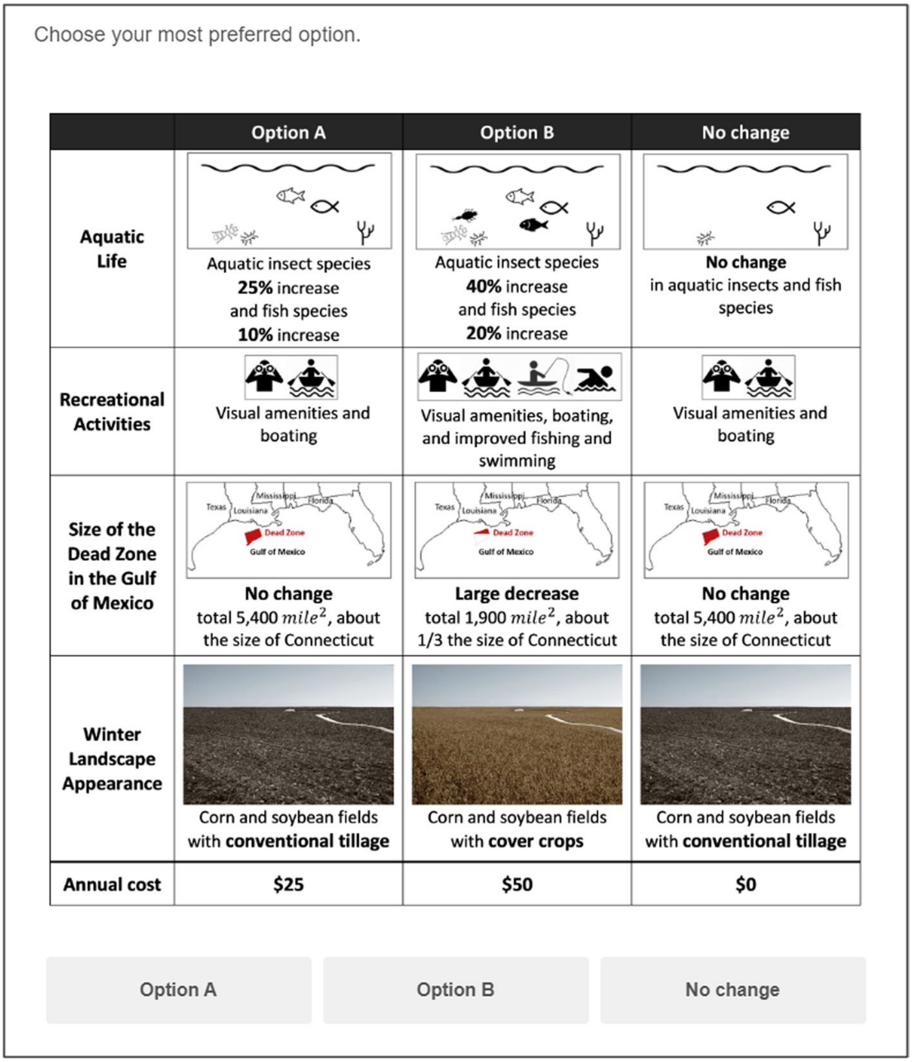
One reason why this difference might occur is as follows. In a hypothetical situation, people think that they are willing to pay the amount presented to them to make something good happen (such as water quality improvement). However, when people actually have to pay the money, they consider their household budgets and other purchases they could make with the money instead.

When answering each of the questions below, please imagine that your household is actually facing the exact choices. Please consider your household budget and other purchases you could no longer make if you choose to pay the selected amount in this survey.

Lastly, we want to inform you that the results of this survey will be made available to policymakers. This means that your responses could affect the decision of policymakers to develop and implement nutrient reduction strategies. Thus, it is important that you provide honest answers.

Choice Questions

At this section of the survey, we randomly assigned respondents to one of three blocks where each respondent answers eight choice questions. Below is an example of a choice question.



Choose your most preferred option.

	Option A	Option B	No change
Aquatic Life	Aquatic insect species **25%** increase and fish species **10%** increase	Aquatic insect species **40%** increase and fish species **20%** increase	**No change** in aquatic insects and fish species
Recreational Activities	Visual amenities and boating	Visual amenities, boating, and improved fishing and swimming	Visual amenities and boating
Size of the Dead Zone in the Gulf of Mexico	**No change** total 5,400 $mile^2$, about the size of Connecticut	**Large decrease** total 1,900 $mile^2$, about 1/3 the size of Connecticut	**No change** total 5,400 $mile^2$, about the size of Connecticut
Winter Landscape Appearance	Corn and soybean fields with **conventional tillage**	Corn and soybean fields with **cover crops**	Corn and soybean fields with **conventional tillage**
Annual cost	**$25**	**$50**	**$0**

Attribute Non-Attendance and Perceived Consequentiality

In the last section, you were asked to choose your preferred option among choices with different water quality features.

When you were making your choices, how frequently did you pay attention to each of the following features?

	Never	Rarely	Sometimes	Often	Always
Aquatic Life	○	○	○	○	○
Recreational Activities	○	○	○	○	○
Size of the Dead Zone in the Gulf of Mexico	○	○	○	○	○
Winter Landscape Appearance	○	○	○	○	○
Annual Cost	○	○	○	○	○

How likely do you think it is that this survey will affect future policy decisions on water quality improvement in your state?

- Unlikely
- Somewhat likely
- Highly likely
- Extremely likely

How likely do you think it is that you will have to pay for water quality improvement in your state?

- Unlikely
- Somewhat likely
- Highly likely
- Extremely likely

Additional Questions and a Survey Bot Check

Now, we are going to ask some questions about your opinions.

Do you support or oppose the established 45% nutrient pollution reduction target?

- Strongly support
- Support
- Neutral
- Oppose
- Strongly oppose

What types of water-based recreational activities do you participate in (before COVID-19)? [Select all that apply]

- Sightseeing or wildlife viewing at rivers, streams, or lakes
- Boating
- Swimming
- Fishing
- Other (Please specify)
- I do not participate in any water-based outdoor recreation activities

The following two questions refer to specific recreational activities a respondent chooses in the above question. We display the questions below when a respondent chooses 'Boating'.

How often do you participate in Boating (before COVID-19)?
If you selected multiple activities, choose the response based on the activity you participate in most frequently.

- Once per week or more frequently
- Once per month
- Several times per year (less than once per month)
- About once per year

Has your participation in Boating changed since before COVID-19?

- Yes, I have been doing the activity or activities more frequently since the pandemic began
- Yes, I have been doing the activity or activities less frequently since the pandemic began
- No

Before COVID-19, do you think that your recreational activities were ever restricted because of degraded water quality?

- Yes
- No

Were you aware of the Dead Zone issue in the Gulf of Mexico before this survey?

- Yes
- No

How important do you think it is to take actions to reduce the size of the Dead Zone in the Gulf of Mexico?

- Extremely important
- Very important
- Moderately important
- Slightly important
- Not at all important

How often do you view rural landscapes during the winter months (October to April)?

- Very often
- Somewhat often
- Occasionally
- Rarely

How important is the appearance of rural landscapes during the winter months (October to April) to you?

- Extremely important
- Very important
- Moderately important
- Slightly important
- Not at all important

Please click and drag each feature of water quality improvement listed below to <u>rank in order of importance</u> from 1 (most important) to 5 (least important).
The starting order is alphabetical.

- Annual Cost to your household
- Aquatic Life
- Recreational Activities
- Size of the Dead Zone in the Gulf of Mexico
- Winter Landscape Appearance

Which of the fees, service charges or taxes listed below do you currently pay? [Select all that apply]

- Water service bill
- Sewage treatment bill
- Property tax
- Water testing for private well
- Do not know
- Other (Please specify)

What best describes your primary drinking water source in your home?

- City or centralized public water system
- Private or shared well
- Others (Please specify)
- Do not know

Are you currently or were you previously a member of a conservation or environmental group or organization?

- Yes
- No

Select **CHOICE 2** below. The other choices are wrong.

- Choice 1
- **CHOICE 2**
- Choice 3

What is your marital status?

- Never married
- Married
- Widowed
- Divorced
- Separated

What is the highest level of education you have completed?

- Did not complete high school
- Completed high school
- Some college, no degree
- Associate's or Vocational degree after high school
- College Bachelor's degree
- Some college graduate work
- Completed graduate or professional degree (i.e. M.S., Ph.D., M.D., J.D.)

How many people (including yourself) live in your household?

1

2

3

4

Enter number greater than 4 below

How many people under the age of 18 live in your household?

0 (zero)

1

2

3

Enter number greater than 3 below

COVID-19 Impacts on Households

Please indicate the way(s) that your household has been impacted by the COVID-19 pandemic. [Select all that apply]

- We have been forced to have kids' school and/or adults' jobs conducted remotely from home at times or continuously
- One more household members has lost a job or a significant amount of income as result of the impacts on the economy
- One or more household members has tested positive for COVID-19
- One or more household members has died from COVID-19
- My household has taken on extra financial, childcare, eldercare or other obligations due to a friend, family member or service provider's health or economic vitality being impacted by COVID-19
- My household has been inconvenienced by the pandemic, but fortunately has not been significantly impacted in terms of health or work

As a result of uncertainty, health, or economic impacts due to the COVID-19 pandemic, my household has: [Select all that apply]

- Made fewer unnecessary purchases or delayed spending to save money
- Stopped contributing to or withdrawn savings from retirement, education, or other goals
- Not been able to pay rent or mortgage payments one or more times
- Not been able to afford medications and/or food
- Not been affected in any of these ways

Appendix 2

Observed Preference Heterogeneity Model by State

See Table 6

Table 6 Results of the generalized multinomial logit (GMNL) model in WTP space

	(1) Illinois		(2) Indiana		(3) Iowa	
Mean MWTP ($/household year)	estimate	St. Err	estimate	St. Err	estimate	St. Err
Aquatic life: medium (insect 25%, fish 10% species increase)	21.20***	(4.80)	24.50***	(5.70)	19.93***	(6.05)
Aquatic life: high (insect 40%, fish 20% species increase)	35.77***	(5.45)	31.87***	(6.27)	30.59***	(6.59)
Recreation: improved fishing and swimming	10.19***	(3.02)	6.42*	(3.62)	9.39**	(4.06)
Reduced dead zone	16.32***	(2.90)	16.81***	(3.50)	16.27***	(3.33)
Winter landscape: cover crops (CC)	8.43***	(3.21)	16.73***	(4.31)	7.89*	(4.33)
Winter landscape: CC + buffer strips (BS)	13.81***	(3.71)	16.71***	(4.54)	18.88***	(4.77)
Winter landscape: CC + BS + perennials	19.19***	(3.40)	18.07***	(3.81)	27.67***	(4.46)
ASC	− 77.54***	(9.13)	− 80.21***	(10.57)	− 108.36***	(13.73)
Observed heterogeneity						
Aquatic life: medium × farms as largest polluters	8.35*	(4.79)	1.80	(5.05)	7.39*	(4.07)
Aquatic life: high × farms as largest polluters	20.85***	(5.23)	− 4.99	(5.54)	19.70***	(4.61)
Recreation × farms as largest polluters	4.64	(3.74)	10.35**	(4.12)	13.53***	(3.21)
Reduced dead zone × farms as largest polluters	14.94***	(3.68)	28.58***	(4.50)	22.39***	(3.42)
Aquatic life: medium × dead zone awareness	2.58	(3.89)	4.86	(5.12)	− 7.75*	(4.11)
Aquatic life: high × dead zone awareness	− 4.23	(4.03)	− 4.74	(5.56)	− 2.38	(4.28)
Recreation × dead zone awareness	− 1.58	(2.90)	− 9.66**	(3.93)	− 11.25***	(3.26)
Reduced dead zone × dead zone awareness	− 1.78	(2.84)	2.43	(3.68)	21.74***	(3.33)
Aquatic life: medium × recreational user	6.58	(4.14)	− 4.13	(4.53)	12.47**	(5.30)
Aquatic life: high × recreational user	− 2.52	(4.13)	4.13	(4.73)	7.69	(5.40)
Recreation × recreational user	− 1.83	(3.05)	6.17*	(3.63)	11.83***	(4.06)
Winter landscape: (CC) × often view landscape	5.86	(4.08)	12.83**	(4.98)	10.43**	(5.06)[a]
Winter landscape: (CC + BS) × often view landscape	− 3.78	(4.64)	5.57	(5.05)	14.36***	(5.31)
Winter landscape: (CC + BS + Perennials) × often view landscape	− 2.55	(4.15)	3.05	(4.50)	5.10	(4.85)

Table 6 (continued)

	(1) Illinois		(2) Indiana		(3) Iowa	
Observed heterogeneity	Estimate	St. Err	Estimate	St. Err	Estimate	St. Err
Aquatic life: medium × age 35–54	− 5.44	(4.42)	0.48	(5.02)	− 0.60	(5.05)
Aquatic life: high × age 35–54	− 11.87***	(4.57)	− 6.97	(5.53)	− 5.86	(5.35)
Reduced dead zone × age 35–54	− 4.56	(3.27)	9.16**	(3.85)	− 1.27	(3.87)
Aquatic life: medium × age 55 +	− 8.11*	(4.44)	0.72	(5.03)	2.05	(5.08)
Aquatic life: high × age 55 +	− 14.98***	(4.81)	− 7.31	(5.23)	− 3.37	(5.39)
Reduced dead zone × age 55 +	13.55***	(3.37)	11.05***	(3.70)	− 0.58	(3.79)
Unobserved heterogeneity (Standard deviations in mean MWTP)						
Aquatic life: medium (insect 25%, fish 10% species increase)	3.33	(3.12)	22.84***	(3.33)	22.24***	(3.52)
Aquatic life: high (insect 40%, fish 20% species increase)	30.85***	(3.06)	48.88***	(4.50)	41.43***	(4.17)
Recreation: improved fishing and swimming	24.58***	(2.37)	32.57***	(3.31)	34.79***	(2.93)
Reduced dead zone	28.26***	(2.60)	40.93***	(3.55)	41.56***	(3.75)
Winter landscape: cover crops (CC)	30.17***	(4.03)	39.60***	(5.68)	34.53***	(4.39)
Winter landscape: CC + buffer strips (BS)	18.57***	(5.18)	20.62***	(4.80)	34.83***	(4.98)
Winter landscape: cc + bs + perennials	16.81***	(4.46)	21.49***	(4.50)	41.45***	(4.74)
ASC	171.03***	(16.79)	260.20***	(24.88)	170.81***	(17.50)
Variance Parameter in Scale: Tau (τ)	1.53***	(0.17)	1.72***	(0.13)	1.58***	(0.19)
Observations (respondents)	4,728 (591)		4,968 (621)		5,104 (638)	
Log likelihood	− 3,591.6		− 3,629.2		− 3,447.3	
AIC	7,315.2		7,390.5		7,026.5	
BIC	7,741.7		7,820.2		7,458.0	

The table shows the results of the GMNL-WTP space model in each of the three state sub-samples, including interaction effects between respondent-specific characteristics and attribute levels. "Farms as Largest Polluters" is an indicator that is equal to one if a respondent perceives farms as the most significant contributor to total nutrient pollution in the region and zero otherwise. "Dead Zone Awareness" is an indicator that is equal to one if a respondent was aware of the dead zone in the Gulf of Mexico before the survey and zero otherwise. "Recreational User" is an indicator that is equal to one if a respondent participates in either sightseeing, boating, swimming, or fishing at water bodies and zero otherwise. "Often View Landscape" is an indicator that is equal to one if a respondent views rural landscapes during the winter months very often or somewhat often and zero otherwise. Standard errors are in parentheses. *$p<0.1$, **$p<0.05$, ***$p<0.01$

[a]in column 3 indicates that the interaction effect (Winter Landscape: (CC) x Often View Landscape) is not robust. For example, the coefficient becomes statistically insignificant when the model includes interaction terms between the respondent-specific characteristic and "all" seven attribute levels in the design

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