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Research article

The potential impact of aquatic nuisance species on recreational fishing in the Great Lakes and Upper Mississippi and Ohio River Basins

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ABSTRACT

Concern over the potential transfer of aquatic nuisance species (ANS) between the Great Lakes basin and the Upper Mississippi River basin has motivated calls to re-establish hydrologic separation between the two basins. Accomplishing that goal would require significant expenditures to re-engineer waterways in the Chicago, IL area. These costs should be compared to the potential costs resulting from ANS transfer between the basin, a significant portion of which would be costs to recreational fisheries. In this study, a recreational behavior model is developed for sport anglers in an eight-state region. It models how angler behavior would change in response to potential changes in fishing quality resulting from ANS transfer. The model also calculates the potential loss in net economic value that anglers enjoy from the fishery. The model is estimated based on data on trips taken by anglers (travel cost data) and on angler statements about how they would respond to changes in fishing quality (contingent behavior data). The model shows that the benefit to recreational anglers from re-establishing hydrologic separation exceeds the costs only if the anticipated impacts of ANS transfer on sport fish catch rates are large and widespread.

1. Introduction

Prior to the construction of the Chicago Area Waterway System (CAWS), the Great Lakes and the Mississippi River Basins were hydrologically separated by a sub-continental divide. The CAWS breached this divide in the first decades of the 1900's to divert wastewater and industrial effluent from Chicago and the Lake Michigan shoreline to the “downstream” Des Plaines River and eventually the Mississippi River. Subsequently, this navigable system of canals, channels and locks developed into a transportation passageway and provided localized flood control. However, the continuous connectivity created by CAWS allows aquatic species to move between the Mississippi River and Great Lakes basins.[1]

Calls for re-separating the two basins have arisen in the last decade, fostered largely by concerns surrounding potential exposure of the Great Lakes basin to in-migration of Asian Carp (Bighead Carp and Silver Carp). These two non-native aquatic nuisance species (ANS) were introduced to aquaculture ponds in the southern United States in the 1970's to help control algae growth. They escaped during flood events, and now populate the Mississippi River and many of its tributaries, including the Illinois River, but are not yet established in the Great Lakes basin. Their potential impact on Great Lakes ecosystems and sport angling led a coalition of five states bordering the Great Lakes to initiate lawsuits, thus far unsuccessful, claiming that the US Army Corps of Engineers (USACE), the City of Chicago and the State of Illinois are creating a potential public nuisance by allowing Asian Carp to migrate through CAWS and threaten Great Lakes resources (see for example

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[1] A 2010 United State Army Corps of Engineers (USACE) report identifies three dozen potential surface water pathways in the Great Lakes and Mississippi River Interbasin Study area outside of CAWS that could also enable aquatic nuisance species transfer between the basins. For the most part these other pathways are located in the low lying areas on the interbasin divide and are intermittent. While some of these interbasin connections occur in natural marsh areas, others are created to backup behind dams and irrigation conveyances (USACE, 2010).

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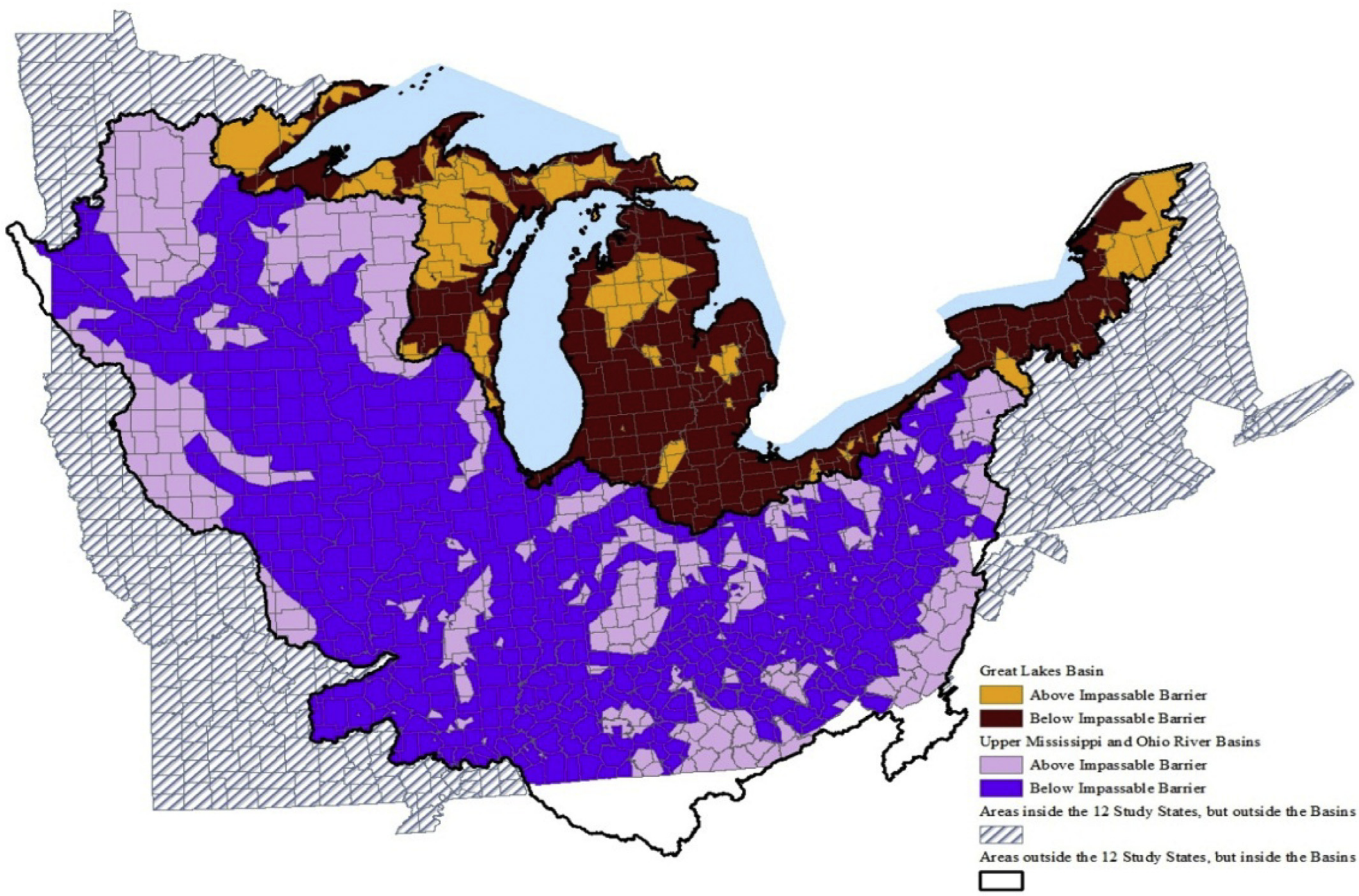

Fig. 1. GLMRIS study area.

Michigan v. U.S. Army Corps of Engineers, 758 F.3d 892 (7th Cir. 2014)). Partially in response, interagency/interstate committees (e.g. The Asian Carp Regional Coordinating Committee, 2012) have been created, and binational reports (e.g. Cudmore et al., 2011) commissioned on the risks and possible actions to prevent the introduction of Asian Carp to the Great Lakes. In 2007, the United States Congress directed the USACE to conduct the Great Lakes and Mississippi River Interbasin Study (GLMRIS).[2] The GLMRIS study included 12 states that contain most of the US portions of the Great Lakes, Upper Mississippi and Ohio River basins (Fig. 1). The primary objective of GLMRIS was to present a range of options and technologies to prevent the transfer of aquatic nuisance species between the Great Lakes and Mississippi River basins through aquatic pathways, with a focus on CAWS' five direct aquatic pathways between the two basins (USACE, 2014).

While public and legal attention has focused on movements of Asian Carp from the Mississippi Basin to the Great Lakes, the GLMRIS study addresses potential interbasin transfer of ANS in both directions. Based on a risk assessment that accounted for (1) the probability of ANS interbasin transfer through the CAWS and successful establishment in a new basin, and (2) the potential adverse impacts of that establishment, the USACE identified 13 species that posed a high or medium risk to invaded basins. These include three species potentially moving from the Mississippi River Basin to the Great Lakes (scud, silver carp and bighead carp) and 10 species posing a high or medium risk of transfer from the Great Lakes basin to the Mississippi River Basin (bloody red shrimp, fish hook water flea, grass kelp, red algae, a species of diatom, reed sweet grass, threespine stickleback, tubenose goby, ruffe and viral hemorrhagic septicemia virus) (USACE, 2014 pp. 59–60).

The GLMRIS Report sent to Congress (USACE, 2014) estimated investment and operating costs of eight possible alternatives for meeting the goal of preventing ANS transfer between the two basins. The most expensive, and most effective, control options involve hydrologic re-separation of the basins. These options will increase flood risks in the Chicago area, and will cost $15.5 billion to $18.3 billion in construction costs, with annual operation and maintenance costs of between $140 million and $160 million.

The GLMRIS report did not, however, endeavor to provide estimates of the benefits of preventing inter-basin transfer of ANS. An important component of those benefits is avoided potential damages to recreational angling. Estimating those potential damages requires predicting how anglers will respond to ANS-induced changes in fishing quality at a basin-wide scale. Existing models of angler behavior are limited to study areas much smaller than the Great Lakes basin or the Upper Mississippi basin. In this paper we report on a combined revealed preference – stated preference model of recreational angling that is capable of addressing basin-wide changes in sport fish catch rates that could occur as a result of inter-basin transfer of ANS. The model could also be used to evaluate other basin-wide phenomena, such as e.g. climate change or changes in nutrient loadings. Compared to previous efforts to model recreational angling, this research is novel in that it was

[2] (Section 3061(d) of the Water Resources Development Act of 2007, with further direction provided in Section 1538 of the Moving Ahead for Progress in the 21st Century Act, Public Law 112–141).

designed to address impacts over a multistate area, while at the same time allowing for place-specific changes in sport fish catch rates that might occur because of spatial differences in the distribution and abundance of a newly established ANS.

To accommodate the need for geographic coverage as well as locational specificity, we developed a modeling framework that makes use of both revealed and stated preference data. We implemented a combined travel cost/contingent behavior survey involving 3529 survey respondents across 12 states in the Great Lakes (GL) and Upper Mississippi and Ohio River Basins (UMORB).[3] Reflecting actual choices made by fishermen, the travel cost survey provides a snapshot of recreational angling patterns across a wide geographical area for calendar year 2011. With these measured recreational patterns as a base, the contingent behavior portion of the survey allows projection of how fishing activities and the associated net economic value of fishing might change if catch rates for different groups of game fish declined.

The remainder of this paper is organized as follows. We first review the basic conceptual framework of benefit measures appropriate for benefit-cost analyses of water resources. Given these foundations we present our economic modeling strategy, survey design and implementation and empirical results. In the final section we provide a discussion of our results and concluding thoughts.

2. Economic foundations: the appropriate benefit measure for benefit-cost analyses

Based on a report by the American Sportfishing Association (Southwick Associates, 2008), various media outlets claimed that the invasion of the Great Lakes by Asian Carp could “decimate” (Belkin, 2009) or “harm” (Economist, 2012) the “lakes' $7-billion-a-year fishing industry” (Wines, 2014). This $7 billion/year figure has popularly been interpreted as the value of the Great Lakes fishery at risk from ANS and has become an anchor in policy debates. It is essential to note, however, that the $7 billion figure is an estimate of the total impact of Great Lakes angling on regional economic activity. The calculation of this figure starts with an estimate of the “direct” angler expenditures in the region and then expands these expended dollar values using multipliers to account for indirect or ripple effects associated with re-spending that occurs within the region.

While the potential regional economic impact from ANS is of interest to local communities and policy makers, such expenditure-based measures have long been recognized as inappropriate for cost-benefit analyses of water-related recreational activities (USACE, 1983). There are two primary reasons why expenditures are not the same thing as benefits. First, calculation of direct and indirect expenditures on local goods and services does not account for the cost of providing these services. If an angler spends $20 on gasoline, the gas station owner is not $20 better off. Most of that money is used to pay for the wholesale cost of the gasoline, which usually has to be shipped in to the region. Second, if an angler spends money to go fishing, that angler cannot spend that same money on other goods and services. When a regional economic impact estimate is calculated, this decrease in expenditures on other activities is not netted out. For these reasons, the Congressional Budget Office report concluded, “Measures of economic activity such as the $7 billion … cannot be used to estimate changes in social welfare, to assess trade-offs among public policy alternatives, or to conduct benefit-cost analysis” (Buck et al., 2010, p. 7).

An approach that is consistent with the benefit-cost component of regulatory impact analyses under federal rulemaking is to estimate the net economic value that would be lost to anglers as a result of ANS transfer between basins. When an angler goes on a fishing trip, he or she gets enjoyment out of that experience and places some value on that enjoyment. The angler must pay some expenditures (on gasoline, bait, charter services, etc.) for the trip, but the anticipated value of the trip to the angler exceeds the cost to the angler. This must be true, or the angler would not go on the trip. The difference between the value to the angler of the trip and the cost to the angler is called the angler's consumer surplus from the trip.[4] The net economic value of the recreational fishery is the sum over all trips and over all anglers of these per-trip consumer surplus values.

The question of interest is, then, how would the net economic value associated with recreational angling change as a consequence of inter-basin transfer of ANS? The catch rate of a desired game fish might decline with the introduction and establishment of an ANS. Each angling trip would then be worth less to the angler and would therefore generate lower consumer surplus. At the same time, we would expect anglers to take fewer trips, so that net economic value would decline even more. Conversely, this loss in consumer surplus from ANS transfer can be viewed as the benefit accruing to recreationists from protecting the resource. Estimates of these benefits could then be compared to the projected costs of engineering options to control aquatic pathways between the Great Lakes and Upper Mississippi and Ohio River basins.

3. Methods of measuring the net value of recreational activities

The empirical challenge is twofold: first, we must measure both the value that anglers place on their angling experiences and their expenditures for those experiences, so that net economic value can be calculated, and second, we must predict how value and behavior will change as a result of changes in the angling resource. The Water Resources Council (USACE, 1983) has sanctioned two different non-market valuation methods – the travel cost method and the contingent valuation method –to estimate net economic value for recreational activities.

The *travel cost method* uses actual visitation data on the number of trips taken by anglers to available recreation sites to estimate the net economic value of the resource and how that net economic value changes as the quality of the resource changes. This method works by observing how often anglers visit different sites, and relating that behavior to differences in site proximity (cost to reach the site) and site quality. Anglers tend to visit more frequently sites that are closer to home and sites with higher fishing quality. By observing how these anglers trade off these two goals, the model imputes the value of fishing quality.

In this way, the travel cost method uses observed trip choices to indirectly estimate the consumer surplus associated with a trip. These trip choices reveal the angler's preferences. The travel cost method is therefore called a revealed preference approach to measuring net economic value. In contrast, *contingent valuation* relies on survey respondents' statements about their preferences to estimate the net economic value of a resource or the net economic

[3] Because of our focus on potential impacts of ANS transfer of Great Lakes fisheries, this study reports on an analysis of anglers who live in the eight Great Lakes states.

[4] For expositional simplicity, this discussion blurs an important distinction between consumer surplus, a benefit measure that holds income constant, and compensating variation, a benefit measure that holds utility constant. Value estimates presented here represent compensating variation. For a more rigorous discussion of different benefit measures, see Freeman (2003, pp 116–118).

value of a change in resource quality, and is therefore called a stated preference valuation approach. In traditional contingent valuation, survey respondents are asked questions about how much money they would pay to be able to experience different levels of fishing quality. A variation on contingent valuation, called *contingent behavior,* asks survey respondents how their behavior might change if the quality of the resource changes.

Various travel cost and contingent valuation studies of recreational angling in the Great Lakes basin since 1991 have provided estimates of consumer surplus per day of fishing that range from \$20 to \$75 in 2012 dollars (excluding outliers, see Poe et al., 2013 for a review). Multiplying this range by the US Fish and Wildlife Service estimate of 19.7 million Great Lakes angler days in 2011 (USFWS, 2014) provides a rough initial estimate of the aggregate net economic value of recreational angling in the Great Lakes ranging from \$393 million to \$1.475 billion. This range can serve as a point of comparison for the estimates found in this study's results.

4. Survey development and implementation

In this research, we combine travel cost and contingent behavior approaches to capture current pre-ANS-invasion recreational angling activities in the Great Lakes and Upper Mississippi and Ohio River basins and identify how these activities and the associated net economic value might change with decreases in catch rates associated with ANS. A series of focus groups with recreational anglers was conducted in November and December 2011. Based on these focus groups, and discussions with scientists knowledgeable about the recreational fishery and the potential impact of ANS transfer on the fishery, surveys of recreational anglers were conducted between January and August 2012.

Eight focus groups, with eight to 21 participants in each group, were conducted in various locations in the GLMRIS study region. The focus groups explored how anglers make decisions about fishing and how their behavior could change in reaction to changes in sportfish catch rates. Participants' responses helped us better understand the language used by anglers when discussing decisions of where to fish and what species to target, informing the wording used in the surveys.[5] Focus group participants expressed a range of potential responses to changes in sportfish catch rates: Some said that they would not change their behavior if catch rates were to fall; Others said that they would fish less often, or would change where they fish or what species they target. Still others said that they would see a decline in catch rates as a challenge to their abilities, and that they might fish even more. Most focus group participants easily understood the distinction between warm water (bass, perch, walleye, pike, etc.) and cold water (trout and salmon) target species, and were able' to say which category of fish species they primarily targeted on an individual fishing trip. Further, focus group participants understood the distinction between Great Lakes waters and tributaries to those waters. Of particular importance to developing the survey, focus group participants were *not* able to identify which waters were located upstream from barriers impassable to fish and which waters were located downstream from barriers impassable to fish. Therefore, the survey did not ask anglers to report whether their fishing trips were to waters upstream or downstream from impassable barriers, even though that distinction is important when considering potential basin-wide ANS impacts. In our subsequent simulation efforts, the fishing effort above and below impassable barriers had to be approximated from GIS data at the county level based on the spatial distribution of lake area and stream miles.

In all, the focus groups established: 1) that anglers across the region were able to distinguish between warm and cold water fish species and could organize their angling choice around fish categories and waterbody type (Great Lakes, inland lakes and ponds, rivers and streams, and anadromous runs); and 2) that anglers would understand and are able to describe how they would respond to changes in catch rates. A survey instrument was constructed based on feedback from the focus groups. In constructing the survey instrument, we adapted the angling-type categorization developed for Michigan State recreational anglers (Kikuchi, 1986; Jones and Sung, 1993), the econometric recreational angler framework developed in Hoehn et al. (1996; see also Lupi et al., 1998, 2003), and the site choice and expenditure elicitation framework used in the periodic New York State Statewide Angler Survey (Connelly et al., 1997). Attention was given to adapting these state-level applications to the geographic expanse and diverse fishing opportunities spanning the GLMRIS region. For example, because of lack of consistent creel data across states, it was not possible to replicate the detailed catch rate information that was collected by Hoehn et al. (1996) in their travel cost survey research in Michigan. Instead, we developed contingent behavior survey questions to estimate how recreational angling patterns and consumer surplus might change with changes in localized or regional catch rates. Further, the size of the GLMRIS area necessitated modeling methods that could combine specific data on angling choices within an angler's home state with less specific information about fishing undertaken outside of the angler's home state.

The survey was conducted in two stages: (1) a screening survey conducted over the telephone; and (2) a main survey conducted by mail or online depending on participant preference. The sample of anglers was recruited in each of the 12 GLMRIS states through a screening survey, which took place from January to March, 2012. In all states except Ohio and West Virginia, the sample was generated by randomly selecting fishing license records from the previous license year. License types included resident and non-resident licenses, both annual and short-term.[6] Among non-resident licenses, only those with addresses within the 12-state region were included in the sample. An initial sample of licenses was matched to telephone numbers using Lexis-Nexis searches. 78% of license holders were matched to a telephone number. These individuals were sent a pre-notice letter that described the study and requested their participation. Due to legal constraints, fishing license records could not be obtained for Ohio and West Virginia. Respondent samples were generated using random digit dialing in those two states.

In all 12 states, the initial telephone interview was used to identify anglers who met the survey inclusion criteria and to request participation in the subsequent mail/web survey. Less than 4% of contactees refused to participate in the screening interview. The screening process consisted of a short series of questions to determine if respondents fished in 2011 and intended to fish in 2012. Those individuals who agreed to participate in the subsequent survey were asked to provide their e-mail address or confirm their mailing address. Individuals recruited in this way were also asked several questions about how much and what type of fishing they did in 2011, leading to the following classification of anglers: anglers who fished the Great Lakes or Great Lakes tributaries; anglers who fish for trout and salmon, but who do not fish in the Great Lakes or Great Lakes tributaries; anglers who fished for warm water species and did not belong to one of the previous two groups. This

[5] See Evensen et al. (2013) for focus group scripts and results.

[6] Holders of one-day licenses were not surveyed, because such anglers are less likely to fish year after year, and their fishing effort makes up a very small proportion of the total number of fishing days.

information was used to target survey versions to individual respondents, and for assessing non-response bias after the subsequent survey.

In all, 7692 anglers were recruited to participate in the web/mail survey, which was conducted from late March through May 2012. Of these, 4562 chose to participate via the internet and 3112 chose to participate via mail.[7] Both internet and mail respondents were contacted multiple times to encourage response. Details on the protocols used in both the screening survey and the main survey are available in Ready et al. (2013).

The topics covered in the surveys can be divided into four primary areas: background information, household expenditure data for the most recent trip taken, recall data on fishing trips taken during the previous year (2011), and contingent behavior responses. Respondents were asked the zip code of their primary home and any secondary home. These were used to identify the origin for each fishing trip. For each trip taken during 2011, the following information was collected:

- The location (destination) of day trips taken within the study area. In the web survey, these locations were designated at the county level for the state in which respondents fished the most. Trips taken to the other 11 states in the study area were reported at the state level. In the mail survey, these locations were designated at the county level for the respondents' state of residence. Trips taken to the other 11 states were reported in aggregate.
- The location of overnight trips taken within the 12-state study area. In the web survey, these locations were designated by the nearest city, village, or town (which were subsequently coded to the county level). In the mail survey, these locations were designated at the county level for the respondents' state of residence. Trips taken to all other 11 states were reported in aggregate.
- The number of day trips and overnight trips taken to each location. Web survey respondents also provided the total number of days spent fishing on all overnight trips to each location.
- The primary type of fishing on the fishing trips to each location. Following Hoehn et al. (1996), seven fishing types were designated: Great Lakes for trout and salmon (GLCold); Great Lakes for warm water species (GLWarm); inland lakes and ponds for trout and salmon (ILCold); inland lakes and ponds for warm water species (ILWarm); salmon or steelhead on anadromous spawning runs (Anad); rivers and streams for trout and salmon, but not on spawning runs (RSCold), and rivers and streams for warm water species (RSWarm).

After collecting data on trips taken in 2011, the web survey automatically added together all day and overnight trips by fishing type. In the mail survey, respondents did this addition themselves. Respondents were then asked whether 2011 represented a “normal year” for them, in terms of fishing participation. If it did not, for example because the respondent was ill or injured during part of the 2011 fishing season, respondents were asked to report the total number of day trips and overnight trips they take, by fishing type, in a normal year.

The contingent behavior questions then explored how angler behavior would change if fishing quality was reduced, as compared to behavior in a normal year. Respondents were presented with a hypothetical scenario wherein catch rates would decrease by specified amounts for some of the seven fishing types. Catch rate decreases ranged from 0% to 50%, based on discussions with USACE ecologists, to cover the range of possible impacts of ANS on sportfish populations in the study area.[8] Respondents were asked to state how many day trips and overnight trips they thought they would take, by fishing type, under the scenario presented. Thirty different hypothetical scenarios were developed. Each respondent was randomly assigned one scenario from among a subset of the 30 scenarios that were most likely to influence types of fishing in which they engaged, based on how they had been classified in the screening survey. An example of the contingent behavior elicitation format from the web survey is provided in Fig. 2.

For each origin site in the dataset (zip code centroid of the angler's address) and each possible destination (county centroid), one-way travel distance and travel time were calculated, using the software PC-Miler. For anglers who owned a second home, the address closer to the destination county was used. Based on responses to a question included in the survey, it was assumed that 77% of fishing trips would be taken using light-duty trucks or SUVs and 23% would be taken using cars. Average vehicle operating costs were valued at $0.29 per mile and included maintenance, depreciation and tire wear (AAA, 2011) and fuel costs based on average fuel efficiency data for cars and light trucks (USBTS, 2012) and average fuel prices (USEIA, 2012). The cost of traveling to each destination also included an estimate of the opportunity cost of travel time, calculated as 1/3 of the angler's hourly wage rate, imputed from the angler's stated annual income. This approach is consistent with standard practice in recreational behavior studies (Parsons, 2003). Anglers who did not report their income were assigned the state-level average value calculated from respondents who did report their income.

While there are 1042 potential destination counties in the data set, many of these destinations far exceed the distances that would reasonably be travelled in a day trip from the angler's zip code of origin. To eliminate day trips that likely were undertaken for a primary purpose other than fishing, a cutoff travel time of 150 min (2.5 h) was applied for all fishing types except trips taken for anadromous fishing. Anadromous anglers were found to travel farther, on average, than anglers pursing other types of fishing. The time cutoff for anadromous fishing was set at 180 min (3 h). These cutoffs were chosen so that the data would capture at least 95% of the trips indicated by survey respondents, but still minimize the effect of outlier observations and possible multi-purpose trips.

5. Econometric model

The econometric model employs a nested logit framework that breaks down the angler's decision making into a series of sequential decisions. Nested logit models have recently been used in state-level recreational fishing analyses in the Great Lakes (e.g. Melstrom and Lupi, 2013; Melstrom et al., 2015) as well as in studies of other recreational choices (Zimmer et al., 2012).

The nesting framework used here is depicted in Fig. 3. Each angler faces N choice occasions per fishing season. In our application, each day is considered to be a unique choice occasion. On each choice occasion, the angler behavior is modeled as if they are making a series of decisions. First, they decide whether to go fishing that day, or do something else (the participation decision). If the angler decides to go fishing, they next decide which of the seven fishing types to engage in (the fishing type decision). Finally, having

[7] Some individuals who had agreed to participate were found to live outside the 12-state study area, and were later excluded.

[8] While it is possible that ANS may increase catch rates of certain species, and hence possibly increase the value of recreational fishing in “invaded areas,” such consideration was precluded by the USACE in the survey design.

Type of fishing (inside the shaded area on the map)	# of DAY trips I take in a NORMAL year to do this type of fishing	% Change in # fish caught per day fishing	# of DAY trips I would take to do this type of fishing
Great Lakes for trout and salmon	<<N1ad>>	No Change	______
Great Lakes for warmwater species	<<N2ad>>	30% less than normal	______
Inland lakes and ponds for trout and salmon	<<N3ad>>	No Change	______
Inland lakes and ponds for warmwater species	<<N4ad>>	No Change	______
Salmon or steelhead on spawning runs	<<N5ad>>	30% less than normal	______
Rivers and streams for trout and salmon, but not including spawning runs	<<N6ad>>	No Change	______
Rivers and streams for warmwater species	<<N7ad>>	50% less than normal	______
Total freshwater fishing DAY trips (sum of all seven categories)	<<NTotalAd>>		______

Fig. 2. Example of the contingent behavior question format. Values in the second column are calculated based on prior survey responses and inserted by the survey software.

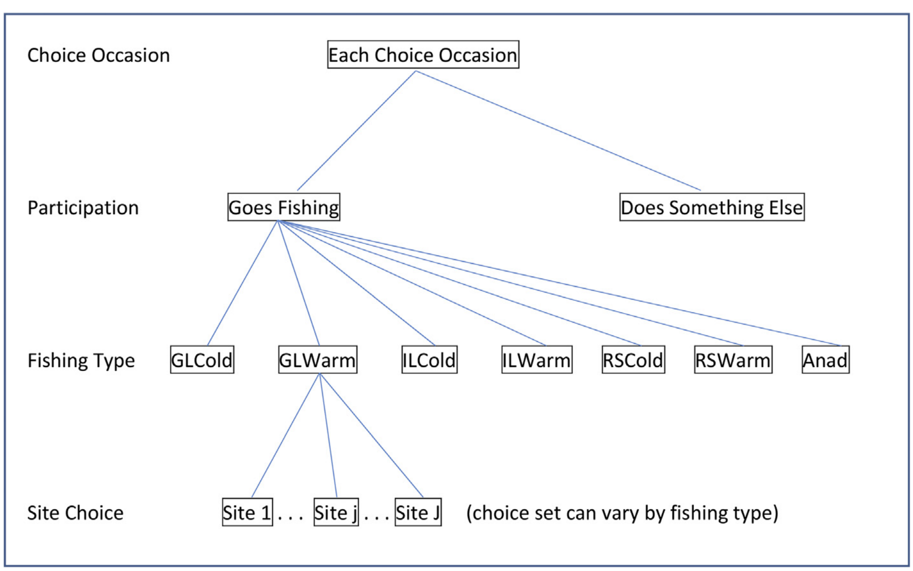

Fig. 3. Nested logit decision tree.

decided to go fishing and having decided the fishing type, the angler decides where to go fishing (the site choice decision).[9] Only counties that were within the specified travel time from the angler's home and that offer the fishing type chosen were considered as feasible destinations for a trip, so the set of available destination options varies from angler to angler and from fishing type to fishing type.

It is assumed that each fishing type/destination combination generates a different level of utility for the angler, and that the angler chooses the combination that provides the highest level of utility. The utility from staying home is normalized and set equal to

[9] In fact, the angler's decision is not necessarily made sequentially. Rather, the nesting structure reflects assumptions about how similar different fishing experiences are. The nesting structure used here assumes that two days spent fishing for the same fishing type at different sites are more similar to each other in the angler's mind than two days spent fishing for different fishing types at the same site. Alternative nesting structures were explored.

0, providing the baseline against which all other utilities are measured. The utility that individual i obtains from engaging in fishing type k in county j consists to two components, a deterministic component, U_{ij}^k, and a random component, ε_{ij}^k

$$V_{ij}^k = U_{ij}^k + \varepsilon_{ij}^k \tag{1}$$

The inclusion of the random component allows for the possibility that the angler might do different things on different days. The deterministic component is assumed to take the following form

$$U_{ij}^k = \beta TC_{ij} + \gamma^k Q_j^k + \mu X_i + \delta_k Z_i^k + \varphi^k ln\left(CR_j^k\right) + \omega^k S_i + \tau CB_i \tag{2}$$

where

i = index for individual
j = index for county; j = 1,2, …,1042
k = index for fishing type; k = 1,2, …,7
TC_{ij} = Round trip travel costs from centroid of i's home zip code to centroid of jth county.
β = Marginal utility of income.
Q_j^k = Vector of site characteristics relevant to fishing type k.
γ^k = Vector of marginal utilities of site characteristics for fishing type k.
X_i = Vector of characteristics of the individual that affect the participation decision.
μ = Vector of parameters for participation decision (marginal impact of each element of X_i on utility from going fishing).
Z_i^k = Vector of characteristics of the individual that affect utility from fishing type k.
δ^k = Vector of fishing type choice parameters for fishing type k (marginal impact of each element of Z_i^k on utility from engaging in fishing type k).
CR_j^k = Catch rate for fishing type k in county j, expressed as percent of 2011 catch rate.
φ^k = parameter to capture influence of catch rate reduction on utility from fishing type k.
S_i = Dummy variable for whether a trip is based on stated behavior or on actual behavior (=1 if "normal year" or contingent behavior; = 0 if actual trip taken in 2011).
ω^k = parameter to capture systematic differences for fishing type k between actual trip behavior and "normal year" and contingent behavior for fishing type k.
CB_i = Dummy variable for stated behavior trips in response to a contingent behavior scenario (=1 if contingent behavior; = 0 if actual trip taken in 2011 or normal year behavior)
τ = parameter to capture inferred quality changes in contingent behavior scenario
ε_{ij}^k = random error term in utility for individual i of engaging in fishing type k in county j

The first four components on the right hand side of equation (2) are standard in site-choice travel cost models. The fifth term is novel. It models the responsiveness of fishing-type choice to changes in catch rates. Previous state-level analyses have used creel survey data (e.g. Melstrom and Lupi, 2013), biomass estimates (e.g. Melstrom et al., 2015), or site-specific estimates of catch rate from the survey itself (e.g. MacNair and Desvousges, 2007) to serve as indicators of site-specific catch rates. Our multi-basin survey covered 12 states, and it was not possible to get consistent catch rate information across all the 1042 counties and seven fishing types. Further, catch rates will vary from angler to angler, making it difficult to construct hypothetical future scenarios for numerical catch rate changes that are meaningful for all anglers. Instead, we define a catch rate measure, CR_j^k, as a percentage of the baseline (2011) catch rate. For all actual trips taken in 2011 and all "normal year" trips, $CR_j^k = 1$, so that $\ln(CR_j^k) = 0$. For contingent behavior trips, $CR_j^k<1$ for fishing types whose catch rate declines in the hypothetical scenario, so that $\ln(CR_j^k)<0$. As CR_j^k declines toward 0, $\ln(CR_j^k)$ declines to -∞ in the limit. The functional form therefore imposes the restriction that no trips will be taken to a destination that has a catch rate of zero. For CR_j^k between zero and one, the functional form chosen is very flexible with regards to the impact of catch rate reductions on behavior. As CR_j^k declines at a site, the probability of the site being chosen declines, but at a rate that depends on the value of φ^k. If φ^k is small, then the probability of choosing a specific site/type combination declines slowly with small decreases in catch rate. If φ^k is large, then the probability of choosing that site/type combination declines rapidly with small decreases in catch rate. An intermediate value of φ^k gives a roughly linear relationship between catch rate and the probability of choosing the site.

The sixth term in (2) captures the any systematic difference between how often anglers claim to go fishing in a "normal year" and how often they actually go fishing. Such a bias could occur for several reasons. First, most studies of recall bias find that anglers tend to overestimate how often they have gone fishing in the past (for example Tarrant et al., 1993). Second, anglers may predict their future fishing behavior without taking into account events such as illness or injury that would affect their participation. If anglers tend to overstate (understate) how often they go fishing for a particular fishing type in a normal year, ω_k will be positive (negative) for that fishing type. An implicit assumption of the model is that the magnitude of overstatement or understatement in fishing frequency will be the same in "normal year" data as in the contingent behavior data.

Finally, the seventh term in (2) captures any quality changes for the contingent behavior scenario that are inferred by the survey respondent but that are not actually described in the scenario. Survey respondents may believe that a scenario that reduces catch rates for some fishing types might logically reduce catch rates for all fishing types, even if the question explicitly states otherwise. If survey respondents view the contingent behavior scenario as having a negative impact on quality over and above that described, then the parameter τ will be negative.[10] An implicit assumption is that the magnitude of this effect is the same for all fishing types.

For actual trips taken in 2011, $\ln(CR_j^k) = \ln(1) = 0$, $S_i = 0$ and $CB_i = 0$, so the fifth, sixth and seventh terms will disappear.

The three sequential decisions are assumed to be independent across the N choice occasions. The probability that an individual angler goes fishing at site j for fishing type k can be decomposed into the product of the conditional choice probabilities:

$$\Pr(j,k,p) = \Pr(j|k,p) \times Pr(k|p) \times Pr(p) \tag{3}$$

where p is an indicator for participation (=p if the angler goes fishing on that occasion, = np if the angler does not go fishing on that occasion). Following McFadden (1974), these choice probabilities can be expressed as logistic functions of angler utility.

[10] Model results presented in Appendix D of the USACE 2014 GLMRIS Report to Congress (http://glmris.anl.gov/documents/docs/glmrisreport/Appendix_D-Economic_Analyses.pdf) differ from those presented here because the earlier model did not include this term.

Assuming that the random components are independently distributed Type 1 extreme value, then the choice probabilities can be represented as logistic functions (Train, 2009). Letting C_i^k be the set of sites (counties in our case) accessible to individual i that offer fishing type k, the conditional site choice probability is given by

$$Pr_i(j|k,p) = \frac{exp\left(U_{ij}^k/\lambda^k\right)}{\sum_{j\in C_i^k}\left\{exp\left(U_{ij}^k\ /\lambda^k\right)\right\}} \tag{4}$$

where λ^k is a fishing-type-specific scale parameter. A small value of λ^k means that, within that fishing type, anglers view different sites as being similar to each other. In situations where the destination county for a specific trip was only known at the state level, the numerator of (4) was a summation over all feasible sites that might have been visited on that trip.

On a given choice occasion, V_{ij}^k is a random variable. It is possible to calculate the expected value of the utility generated by the best available fishing site for a fishing type, which is given by

$$EU_i^k = \lambda^k ln\left[\sum_{j\in C_i^k}\left\{exp\left(U_{ij}^k\ /\lambda^k\right)\right\}\right] \tag{5}$$

The probability of choosing fishing type k, conditional of going fishing, depends on the expected utility from fishing type k as compared to the expected utility of the other fishing types, as follows

$$\Pr(k|p) = \frac{exp\left[EU_i^k/\sigma\right]}{\sum_{h\in 1\ldots 7}\left\{exp\left[EU_i^h/\sigma\right]\right\}} \tag{6}$$

where σ is the scale parameter for fishing type decision. In this case, σ measures how similar the different fishing types are to each other, in the angler's mind.

The expected value of going fishing is equal to the expected value of the utility generated by the best available fishing option on that choice opportunity, given by

$$EU_i^p = \sigma ln\left[\sum_{h\in 1\ldots 7}\left\{exp\left[EU_i^h/\sigma\right]\right\}\right] \tag{7}$$

Finally, the probability that individual i goes fishing on a given choice occasion depends on the expected utility from going fishing, according to

$$Pr(p) = \frac{exp\left(EU_i^p/\rho\right)}{1 + exp\left(EU_i^p/\rho\right)} \tag{8}$$

where ρ is the scale parameter for the participation decision. If the nested logit model has been specified appropriately, then we would expect $\rho > \sigma > \lambda^k$. That condition is sufficient, but not necessary, for the model to be consistent with expected utility theory (Herriges and Kling, 1996). Because the three scale parameters are not uniquely identified, ρ is traditionally normalized to equal 1. The probability of doing something other than going fishing is then 1-Pr(p).

The likelihood function for all individuals is then given by

$$lnL = \sum_i\left\{\sum_k\sum_j\left(F_{ij}^k \ln[Pr_i(j,k,p)]\right) + \left(N - \sum_k\sum_j F_{ij}^k\right)\ln(1 - Pr_i(p))\right\} \tag{9}$$

where F_{ij}^k is the number of times during the season angler i took a trip to destination j to do fishing type k. Note that each angler can show up in the likelihood function three times: once for their 2011 trip data, once for their normal year trips, and once for their contingent behavior trips.

Having estimated the parameter values using maximum likelihood estimation, it is possible to calculate the expected value of the utility that an angler will receive, per choice occasion. This is given by

$$EU_i^{co} = \rho ln\left[1 + exp\left(\sigma IV_i^p\ /\rho\right)\right] \tag{10}$$

On some (or most) fishing occasions, the angler will choose to stay home, and receive utility of 0. On some occasions, the angler will go fishing, and receive positive utility. The expected value per choice occasion will therefore be positive for all anglers, and will depend on the fishing quality at sites available to the angler.

ANS transfer resulting in a change in catch rates would affect the expected utility for each fishing occasion. The change in net economic value over an entire season from such an event is called the compensating variation (CV) for the change in conditions, and is given by

$$CV_i = N*\frac{EU_i^{co}(0) - EU_i^{co}(1)}{-\beta} \tag{11}$$

where $EU_i^{co}(0)$ is the expected utility per choice occasion under the baseline (2011) catch rates and $EU_i^{co}(1)$ is the expected utility per choice occasion under the new conditions.

6. Angler and site characteristics data

Angler characteristics included in X_i and Z_i^k were obtained from the survey. Potentially endogenous angler characteristics, i.e. those that might be affected by the angler's choice set such as boat ownership, were excluded. The following characteristics were included in one or both terms: income, whether the angler was full-time employed, age, and gender.

For each fishing type, the site characteristic included in Q_j^k included measures of the quantity and quality of the fishing resource in each county. Quantity measures varied by fishing type. For the Great Lakes fishing types, quantity was measured as shoreline miles. For inland lake fishing types, quantity was measured as area of lakes and ponds in the county, in square miles. For the flowing water fishing types, quantity was measured as miles of streams (stream order 3–4) and miles of rivers (stream order 5–7) in the county. Lake and pond area and stream mile measures were obtained from the National Hydrography Dataset.

For inland fishing types, resource quality was measured by the Aquatic Habitat Quality Index. This index, developed by the National Fish Habitat Partnership, measures the intensity of human disturbance of the landscape that can affect aquatic habitats. Low index values indicate high risk of habitat degradation, while high index values indicate low risk of habitat degradation (downloaded

Table 1
Anglers and days fished in each state.

State	Sample	Mean Days on Day Trips	Mean Days on Overnight Trips	Total # of Anglers ($\times10^3$)	Total Days Fished ($\times10^6$ from survey)	# of Days Fished in 2011 ($\times10^6$ from NSFHWAR)
IA	188	31.5	7.4	269.0	10.5	6.9
IL	117	26.9	12.8	605.6	24.0	15.6
IN	248	34.0	7.5	332.1	13.8	21.5
KY	209	23.7	3.0	404.4	10.8	10.2
MI	386	29.3	5.5	805.8	28.0	26.7
MN	485	20.1	7.1	1024.0	27.9	24.9
MO	372	24.0	7.9	545.9	17.4	14.4
NY	322	28.8	3.4	589.6	19.0	29.1
OH	287	29.6	2.0	520.8	16.5	19.1
PA	350	34.9	4.9	635.6	25.3	9.9
WI	481	27.9	5.6	728.6	24.4	15.3
WV	96	37.3	5.5	162.6	7.0	4.8
Total	3539	28.0	5.9	6623.9	224.5	198.6

from ecosystems.usgs.gov/fishhabitat/).

A fishing-type specific constant was included for each fishing type, to account for differences in utility across fishing types. To account for spatial variation in fishing quality within each fishing type, state-level constants were included for all inland fishing types other than anadromous. The omitted state for identification during estimation was Michigan. For the anadromous and Great Lakes fishing types, the shorelines of the lakes were divided into 11 county groups as follows: north shore of Lake Superior, south shore of Lake Superior, northeastern Lake Michigan including Grand Traverse Bay, northwestern Lake Michigan including Green Bay, western shore of Lake Michigan, southern shore of Lake Michigan, eastern shore of Lake Michigan, Lake Huron, Lake St. Clair and western Lake Erie, central and eastern Lake Erie, and Lake Ontario. Shoreline county group specific constants were included in the model, with Lake Ontario as the omitted group.

7. Results

7.1. Response rate and total fishing effort

Of those who were determined to be eligible to participate in the survey based on their responses to the initial telephone survey, 47% agreed to complete the web or mail survey. Across the two survey modes, the completion rate was 46% (50% for web respondents and 41% for mail respondents), for an overall response rate of 22% generating a final sample of 3539 survey respondents. Comparing respondents to non-respondents based on the screening questions showed that respondents were slightly more likely to fish every year, slightly more likely to be lake fishermen (Great Lakes and inland lakes), and slightly more likely to target salmon and trout. Respondents and non-respondents fished a similar total number of days, on average.

For each state, Table 1 shows the number of survey respondents, the mean number of days spent fishing on day trips and overnight trips (from the survey), the total number of anglers (from license sales data), and the total days fished by anglers living in the state (equal to mean days fished multiplied by number of licensed anglers). For comparison, the total number of days fished in 2011 as estimated from the National Survey of Fishing, Hunting, and Wildlife Associated Recreation (USFWS, 2014) is presented as well. Estimates from the National Survey include fishing in all US states, while our estimates only include fishing within our 12-state study area. Overall, our estimate of fishing activity by anglers living in the study area exceeds the National Survey estimate by 13%.

Table 2 shows the average number of fishing days per angler and the total number of fishing days in the study area by fishing type. The totals do not match exactly between Tables 1 and 2 due to rounding error. Averages per angler are weighted by the number of anglers in each state. By far, the most popular fishing type is fishing on inland lakes and ponds for warm water species, followed by fishing on rivers and streams for warm water species. It should be remembered that the study area includes many non-Great Lakes states and many counties that do not offer trout or salmon fishing. Of the total fishing effort in the study area, about 42% occurred within the Great Lakes basin and 58% occurred in the Upper Mississippi and Ohio River basins.

7.2. Model estimation

The parameter estimates presented here were estimated using data for day trips only, which account for 82% of total fishing effort. Attempts to model overnight trips using a nested logit failed to converge. Modeling overnight trips is a much more challenging task. Anglers rarely take overnight trips to destinations close to home, which makes it difficult to identify the impact of travel cost on behavior. In order to focus on angling behavior in the Great Lakes basin, model results presented here are estimated based only on 3046 responses from anglers who live in the eight Great lakes states.[11]

The model parameters were estimated in two steps. First, the model was estimated using only 2011 trip data (actual trips taken), with ρ normalized to equal 1. Because $S_i = 0$, $CB_i = 0$ and $ln(CR_j^k) = 0$ for all 2011 trips, the parameters ω^k, τ and φ^k are not estimated during the first step regression. This was done so that all parameters other than ω^k, τ and φ^k would be estimated based only on actual trip behavior, not on stated behavior, and would therefore be directly comparable to previous state-level models. In the second step, the estimated parameters from the first step regression were held fixed, and φ_k, τ and ω_k were estimated using the "normal year" and contingent behavior data. This approach is admittedly inefficient, and there is the concern that estimated standard errors will be biased, particularly in the second-stage regression.[12]

[11] In model applications, trip predictions and values are expanded by 22% (i.e. divided by 0.82) to account for overnight trips. This approach assumes that overnight trips to a particular site for a particular fishing type generate the same consumer surplus per day as day trips to that same site for the same fishing type.

[12] The model was also estimated with all data pooled, stacking the actual trip data, normal year data, and contingent behavior data, so that all parameters were estimated simultaneously. Simultaneous estimation of all parameters gave results that are qualitatively similar to the sequentially estimated model presented here, but with lower levels of statistical significance for some estimated parameters. Simultaneous estimation results are available from the authors.

Table 2
Fishing effort per angler and total fishing effort, by fishing type.

Fishing Type	Average Days on Day Trips	Average Days on Overnight Trips	Total Days Fished in 2011 ($\times 10^6$)
Great Lakes for trout and salmon	1.4	0.3	10.9
Great Lakes for warm water species	1.9	0.5	16.0
Inland lakes and ponds for trout and salmon	1.3	0.2	10.0
Inland lakes and ponds for warm water species	14.0	3.6	116.9
Rivers and streams for trout and salmon	2.8	0.6	22.4
Rivers and streams for warm water species	5.7	0.7	42.3
Salmon or steelhead on spawning runs	0.7	0.2	5.9
Total	27.8	6.1	224.4

To account for potential differences in error variance between stated behavior and actual trip choices, we allow the scale parameters, σ and ρ, to differ between the first and second stage. This allows for the possibility that answers to the "normal year" and contingent behavior questions may be noisier (higher variance in the error term) than the actual fishing data from 2011 (Whitehead et al., 2008). Because we do not have information on site choice in the "normal year" and contingent behavior data, it is not possible to estimate new values of the site choice scale parameters, λ^k, in the second stage regression.

In initial regressions, some of the estimated site-choice scale parameters, λ^k, were larger than the fishing-type scale parameter, σ, which could be inconsistent with a random utility model. For this reason, the site-choice scale parameters were constrained to equal each other. Results are presented in Table 3 for first stage regression using the 2011 travel cost data.[13] The results are consistent with economic theory, which predicts that the coefficient on travel cost will be negative, and that the scale parameters will satisfy the inequalities $\lambda<\sigma<\rho$, with ρ normalized to equal 1 in the first stage.[14]

The estimates of μ show how fishing participation (frequency) varies with individual angler characteristics. Higher income anglers fish less frequently. This could suggesting that fishing is an inferior good, or it could be due to the higher opportunity cost of time. Anglers with full time employment also fish less frequently, perhaps because they have less time to allocate to recreation. The relationship between age and fishing frequency has an inverted U shape, with a peak at around 25 years of age. Female anglers fish less frequently than male anglers. Estimates of δ^k show how angler characteristics affect fishing type choice. The coefficients presented show the relative influence as compared to ILWarm, the most commonly chosen fishing type. Income and age were not found to affect fishing type choice. Full time employed anglers were more likely to engage in Anadromous, GLCold, RSCold and RSWarm fishing. Female anglers were less likely to engage in Anadromous, GLCold, GLWarm, ILCold and ILWarm fishing.

Coefficients for the site quality and quantity measures (γ^k) are of the expected signs and almost all are statistically significant. Great Lakes shoreline counties with more shoreline miles are more likely to be visited for GLCold and GLWarm trips. For all five inland fishing types, counties with higher values of the Aquatic Habitat Quality Index were more likely to be visited. Counties with more lake area are more likely to be visited for ILWarm and ILCold trips. Counties with more river miles are more likely to be visited for RSCold, RSWarm and Anadromous trips. Counties with more stream miles are more likely to be visited for RSCold and RSWarm trips. However, stream miles had a negative impact on Anadromous trips, suggesting that Anadromous anglers are targeting counties located lower in the watersheds.

Second stage regression results are presented in Table 4. The estimated stated trip constants, ω^k, are all positive and statistically significant, indicating that anglers, on average, report more trips in a normal year than they took in 2011. The estimated catch rate index coefficients, φ^k, are also positive and statistically significant, indicating that, for all fishing types, decreased catch rate would lead to lower fishing participation. The fishing type that was most sensitive to decreases in catch rate was GLCold, while the fishing type that was least sensitive was Anadromous.

The contingent behavior scenarios were constructed with catch rate decreases for some, but not all fishing types. Survey respondents may infer that the scenario will also result in quality changes for supposedly unaffected fishing types. Survey responses provided some evidence that this occurs. About 22% of survey respondents received a contingent behavior scenario where the catch rate reductions affected fishing types that the respondent does not engage in a normal year. In such a case, respondents should be expected to report no change in their behavior, since the fishing types they target would be unaffected. However, 25% of these respondents reported that they would take fewer trips in response to the scenario than they take in a normal year. This is consistent with the idea that survey respondents infer negative consequences over and above those explicitly described in the scenario. The second stage estimation results are consistent with this. The estimated value of the relevant parameter, τ, is less than zero, suggesting that anglers view the scenario negatively independent of the described changes in catch rate.

The scale parameter for fishing type choice, σ, estimated from the stated trips data was larger than that estimated from the data on actual 2011 trips. This suggests that anglers project a higher rate of substitution between fishing types than they actually exhibit. The participation scale parameter, ρ, is less than 1, the normalized value imposed for the 2011 data, suggesting that stated trip data is less noisy than actual trip data (i.e. more predictable). This may be because stated trip frequency reflects intentions, while actual trip frequency is influenced by random events such as weather and illness.

8. Model applications

The estimated coefficients reported in Tables 3 and 4 can be used to calculate an estimate of the net value of a single fishing day. Over an entire season, each angler is expected to take a certain number of trips of each fishing type. This will vary between anglers. If fishing quality for one or more fishing types declines, then an angler may choose to take fewer fishing trips in total. If the decrease

[13] State-specific and county-group specific constants for each fishing type are not presented here, but are available from the authors.

[14] Alternative nesting structures were considered, including structures that grouped together cold water fishing types versus warm water fishing types and structures that group together Great Lakes fishing types versus inland fishing types. However, in each case, some scale parameters from lower branches were found to be larger than scale parameters from upper branches, suggesting that these nesting structures do not accurately model how anglers view different fishing opportunities.

Table 3
First Stage Model Estimation Results using Actual Trip Data.

Variable		Estimated Coefficient	T-Stat
Travel Cost (β)		−0.00322	−17.61
Angler Characteristics that Affect Participation Decision (μ)	Ln(Income/1000)	−0.1277	−14.09
	Fulltime Employed (=1)	−0.1798	−13.51
	Age/100	1.3221	6.10
	Age/100 Squared	−2.7370	−12.40
	Female (=1)	−0.6665	−36.53
Angler Characteristics that Affect Fishing Type Decision (δ^k). ILWarm is the excluded fishing type.	GLCold × Fulltime Employed	0.0301	7.64
	GLCold × Female	−0.0243	−3.57
	GLWarm × Fulltime Employed	0.0043	1.33
	GLWarm × Female	−0.0144	−2.54
	Anad × Fulltime Employed	0.0530	9.47
	Anad × Female	−0.0678	−5.82
	ILCold × Fulltime Employed	0.0032	0.84
	ILCold × Female	−0.0197	−2.94
	RSCold × Fulltime Employed	0.0190	5.56
	RSCold × Female	−0.0322	−5.74
	RSWarm × Fulltime Employed	0.0110	4.76
	RSWarm × Female	0.0013	0.36
Site Quality Measures by Fishing Type (γ^k)	GLCold Fishing-Type Constant	−1.7450	−32.12
	GLCold × Shoremiles	0.4802	7.16
	GLWarm Fishing-Type Constant	−1.7899	−33.67
	GLWarm × Shoremiles	0.8313	10.96
	Anadromous Fishing-Type Constant	−1.9876	−40.81
	Anadromous × Habitat Score	0.0401	7.21
	Anadromous × Category 3–4 Stream Miles	−0.0701	−3.20
	Anadromous × Category 5–7 Stream Miles	0.5154	6.26
	ILCold Fishing-Type Constant	−1.9997	−40.38
	ILCold × Habitat Score	0.0472	10.03
	ILCold × Lake Acres	0.1573	9.35
	ILWarm Fishing-Type Constant	−1.7739	−33.23
	ILWarm × Habitat Score	0.0273	11.96
	ILWarm × Lake Acres	0.1839	17.11
	RSCold Fishing-Type Constant	−2.0241	−41.36
	RSCold × Habitat Score	0.0721	15.29
	RSCold × Category 3–4 Stream Miles	0.0402	3.50
	RSCold × Category 5–7 Stream Miles	0.2320	5.03
	RSWarm Fishing-Type Constant	−1.8546	−35.75
	RSWarm × Habitat Score	0.0148	5.96
	RSWarm × Category 3–4 Stream Miles	0.1242	12.34
	RSWarm × Category 5–7 Stream Miles	0.3725	11.45
Scale Parameter for Fishing-Type-Choice (σ)		0.0650	15.95
Scale Parameter for Site Choice (λ)		0.0543	14.00

in the number of trips taken is small, then the loss in net economic value, per displaced trip, is measured by the ratio of the scale parameter for the fishing type choice divided by the absolute value of the parameter for travel cost. Applying this method results in an estimated net economic value of $20.21 per fishing day. This net value is at the lower end of the range of published estimates for fishing in the Great Lakes basin (Poe et al., 2013), possibly because it is based not only on Great Lakes fishing but also on fishing in inland waters in the Great Lakes basin and the UMORB, which may be less highly valued.

The estimate of $20.21 represents the net value per displaced trip for a change in quality that results in a small change in fishing

Table 4
Second Stage Model Estimation Results using Stated Trip (Normal year and Contingent Behavior) Data.

Variable		Estimated Coefficient	T-Stat
Catch Rate Index Coefficient (φ_k)	GL Cold	0.1594	9.33
	GL Warm	0.0877	14.57
	Anad	0.0362	5.50
	IL Cold	0.0623	4.45
	IL Warm	0.0610	8.60
	RS Cold	0.1311	39.19
	RS Warm	0.1342	16.69
Stated Behavior Constants (ω_k)	GL Cold	0.5112	109.09
	GL Warm	0.6076	55.25
	Anad	0.3843	69.10
	IL Cold	0.4619	110.54
	IL Warm	1.1443	369.48
	RS Cold	0.7401	190.15
	RS Warm	0.8576	192.33
CB Constant (τ)		−3.3936	−176.46
Scale Parameter for Fishing Type Choice (σ)		0.3574	512.83
Scale Parameter for Participation Choice (ρ)		0.6750	274.72

behavior (Haab and McConnell, 2002). The GLMRIS study was motivated by concerns that ANS transfer between basins could result in large decreases in fishing quality that would result in large changes in fishing participation. The model estimated here can be used to calculate the total consumer surplus loss associated with specific ANS transfer scenarios that specify changes in fishing quality for each of the seven fishing types in each county. The resulting loss in consumer surplus can then be compared to the investment and maintenance costs of options to prevent inter-basin transfer, to determine whether the investment passes a cost-benefit test.

In the GLMRIS report, the USACE concluded that it was not able to generate numerical predictions of potential changes in sport fish abundance from ANS transfer. However, a recent study (Lauber et al., 2016) used the Delphi technique with an expert panel of aquatic ecologists to develop credible, internally-consistent ANS transfer scenarios. They develop several scenarios of the potential impacts on Great Lakes sport fish populations from specific ANS. Of particular interest here are the scenarios they developed for Asian Carp introduction into the Great Lakes.

Asian Carp are filter-feeders that eat plankton. They spawn in large, slow-moving rivers. The expert panel surveyed by Lauber et al. (2016) concluded that Asian Carp could become established in the Great Lakes basin, spawning in suitable tributary rivers and moving offshore as adults in areas with sufficient food resource. The panel developed six scenarios that describe the range of potential impacts that were considered plausible if Asian Carp do become established in large numbers. These scenarios differ in the assumptions about where Asian Carp would become established in the Great Lakes, and what trophic consequences they would have.

Here we focus on the scenario from Lauber et al. that has the most drastic consequences for sport fishing, their scenario 2c. Under that scenario, Asian Carp become established in the pelagic portions of all Great Lakes except Lake Superior, which does not have sufficient plankton concentrations to support adult Asian Carp. Asian Carp compete with Alewives for the plankton resource, causing a collapse in Alewife populations that in turn causes a large (80%) reduction in Coho and Chinook Salmon populations in Lakes Michigan and Ontario. Lake Huron experienced a similar decrease in Salmon populations as a result of alewife collapse in 2003, and the Salmon populations in Lake Huron are not expected to decline further than they already have. Asian Carp would also have small impacts on warm water sportfish species, through competition and as a prey resource (for details, see Lauber et al., 2016). This scenario is plausible and internally-consistent, but the expert panel deemed it “Unlikely” to occur, even if Asian Carp do become established in the Great Lakes basin. We take this scenario as a “worst case” scenario for the potential impact that Asian Carp might have on Great Lakes fishing, but recognize that it has a low probability of occurrence.

This scenario would affect three fishing types, GLCold, GLWarm and Anadromous. The impact on each fishing type was calculated as a weighted percentage, weighting by the relative importance of each species to total fishing in that fishing type, as measured by creel surveys. For example, the scenario anticipates 80% declines in Coho and Chinook Salmon in Lakes Michigan and Ontario, but does not predict changes in Lake Trout or Steelhead abundance, since Lake Trout and Steelhead do not depend on Alewives to the same extent as Salmon. The average decrease in fish abundance for GLCold fishing type is therefore less than 80%.

The impacts of this scenario on fishing behavior are provided in Table 5 [15]. In the scenario, Coho and Chinook Salmon experience the largest declines in abundance, and the two fishing types that are most affected are GLCold and Anadromous, with a 72% reduction in fishing effort for GLCold and an 11% reduction in effort for Anadromous fishing, which sees a smaller decline in fishing in effort in part because that fishing type is the least sensitive to catch rate. In contrast, fishing for GLWarm increases. Part of this is due to increased abundance of some warm water fish species. However, most is due to substitution whereby anglers switch from GLCold and Anadromous to other fishing types. Because of this substitution, overall fishing activity declines only slightly. This substitution can be seen most clearly in the increase in inland fishing, whose quality does not change in the scenario.

The impacts of the scenario on anglers is shown in Table 6. The largest negative impacts, both in terms of angling participation and in terms of consumer surplus enjoyed, are experienced by anglers who live in states that border Lakes Michigan and Ontario, the two lakes that would experience large declines in Salmon abundance. Ohio residents actually experience improved fishing quality, because of positive impacts on Yellow Perch and Bass. The total annual impact of the scenario on consumer surplus is a loss of $138.7 million, with a 95% confidence interval of ($121.2 million, $162.8 million).

By way of comparison, proposed options to hydrologically separate the two basins are estimated to have investment costs of at least $15.5 billion and annual costs of at least $140 million. Using a 3% real discount rate, the present value of these costs over 30 years is $18.2 billion. In order for the benefits to anglers to exceed these costs, the potential loss in annual consumer surplus would have to exceed $885 million. We note that the projected loss from the scenario is less than the annual operations and maintenance costs of the proposed option. We conclude that—based on the benefit-cost test– the threat that Asian Carp pose to Great Lakes fisheries is not sufficient on its own to justify the expense of hydrologic separation of the basins.

However, Asian Carp are not the only ANS species of worry. We consider, next, scenarios where inter-basin transfer of ANS (possibly many species) results in decreases in catch rates for all fishing types for all waters in the Great Lakes basin, and explore how severe those catch rates would have to be to justify the cost of hydrologic separation. Because the mechanism for these potential impacts is ANS transfer through waterways, we restrict impacts to those waters located below impassable barriers. This analysis gives us upper-bound estimates of the total potential impact of ANS transfer into the Great Lakes basin. Fig. 4 presents the annual loss in angler net economic value associated with Great Lakes basin-wide declines in catch rates ranging from 10% to 50%. The loss in net economic value increases roughly linearly with the reduction in catch rate. A 50% reduction in catch rates for all fishing types in the Great Lakes basin below impassable barriers results in a loss in net economic value of $1.34 billion, with a 95% confidence interval of ($1.13 billion, $1.63 billion). In order for hydrologic separation to pass a cost-benefit test based only on potential impacts to catch rates in the Great Lakes basin, it would have to prevent catch rates declines of 33% across all fishing types.

Finally, we consider the potential impact of ANS transfers in both directions. Indeed, the USACE identified more species of concern that could potentially transfer from the Great Lakes basin to the Mississippi River basin than those that might transfer into the Great Lakes basin. The model was run using catch rate losses of 10%—50% for all fishing types in both the Great Lakes and the UMORB basins. The results are shown in Fig. 4. With ANS transfer in both directions resulting in catch rate decreases in both basins, a blanket decrease in catch rates of 24% in all waters below impassable barriers would be sufficient to generate losses large enough to justify the cost of hydrologic separation. We note that the model

[15] 95% confidence intervals for all estimates were generated using Monte Carlo simulation with 10,000 parameter draws. Confidence intervals for values presented in Tables 5 and 6 are available in the supplementary materials.

Table 5
Projected effects of worst-case Asian Carp scenario on number of fishing trips (1,000s) by fishing destination and fishing type.

Destination State	Baseline GLCold	Scenario GLCold	Baseline GLWarm	Scenario GL Warm	Baseline Anad	Scenario Anad	Baseline Inland	Scenario Inland	Baseline All FT	Scenario All FT
IL	1726	113	810	965	–	–	13,869	15,282	16,404	16,361
IN	714	37	308	367	614	574	11,514	12,061	13,150	13,039
MI	1967	846	4113	4297	1383	1158	21,986	23,070	29,450	29,371
MN	162	144	40	41	19	19	24,557	24,600	24,778	24,803
NY	773	346	1553	1645	922	857	15,515	15,868	18,764	18,717
OH	340	296	2179	2343	501	484	11,703	11,634	14,723	14,757
PA	152	135	374	376	272	271	24,637	24,653	25,435	25,435
WI	2359	406	1691	1979	358	270	27,003	28,562	31,411	31,217
Total	8193	2323	11,070	12,014	4070	3632	150,783	155,731	174,115	173,701
Change		−5869		944		−438		4947		−415
Change (%)		−71.6%		8.5%		−10.7%		3.3%		−0.2%

Table 6
Projected effects of worst-case Asian Carp scenario on number of fishing trips and consumer surplus (CS) of fishing by state of angler residence.

State of Residence	Anglers in State	Total Trips Taken – Baseline ($\times 10^3$)	Total Trips Taken – Scenario ($\times 10^3$)	Change in Total Fishing Days ($\times 10^3$)	Percent Change Fishing Days	Average CS Change per Angler	Total CS Change ($\times 10^6$)
Illinois	605,649	22,953	22,786	−167.4	−0.73%	-$91.66	-$55.5
Indiana	332,061	12,964	12,922	−42.1	−0.32%	-$43.13	-$14.3
Michigan	805,792	28,042	27,963	−78.3	−0.28%	-$33.14	-$26.7
Minnesota	1,024,003	27,215	27,213	−2.5	−0.01%	-$0.72	-$0.7
New York	589,557	18,983	18,950	−33.8	−0.18%	-$19.57	-$11.5
Ohio	520,789	14,878	14,886	8.5	0.06%	$5.27	$2.7
Pennsylvania	635,557	24,855	24,854	−1.4	−0.01%	-$0.71	-$0.5
Wisconsin	728,604	24,225	24,128	−97.6	−0.40%	-$44.12	-$32.1
Totals	5,242,032	174,115	173,700	−414.6	−0.24%	-$26.45	-$138.7

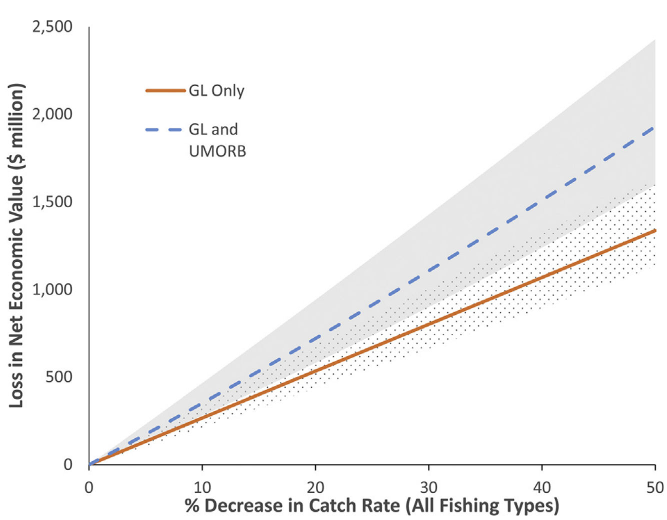

Fig. 4. Estimated Annual Loss in Net Economic Value from Basin-Wide Reductions in Catch Rates (95% CIs shown as shaded regions).

developed here is not as well suited to predicting impacts from basin-wide changes in catch rate in the UMORB basins, because it excludes anglers who live in states like Iowa and Kentucky that are located (at least partially) within the UMORB basins but do not border a Great Lake. The estimated impacts shown in Fig. 4 for catch rate decreases in both basins therefore understate the total impact of these scenarios. We also note that our model does not include Canadian anglers, and only measures costs to US anglers.

9. Summary and discussion

This research estimated the net value to anglers of recreational fishing in the Great Lakes and Upper Mississippi and Ohio River basins. Using focus groups and mail and web-based surveys of recreational anglers, we used travel cost techniques to establish baseline recreational fishing values and develop an economic model of angler behavior. These travel cost methods were paired with contingent behavior responses to estimate how recreational angling and net economic values would be affected by reductions in catch rates that might be associated with inter-basin transfer of aquatic nuisance species.

The model estimated here was used to evaluate a potential “worst case” scenario for an invasion of Asian Carp into the Great Lakes. The estimated impact on the net economic value enjoyed by Great Lakes anglers was large, but not large enough to justify the high projected cost of hydrologic re-separation of the Great Lakes and Upper Mississippi River basins. Hydrologic re-separation would pass a cost-benefit test if ANS transfer from the Mississippi River basin to the Great Lakes basin was anticipated to cause a decrease in sport fish catch rates in the Great Lakes basin of 33% for all fishing types in all waters located below impassable barriers. Alternatively, a cost-benefit test would be passed if ANS transfer in both directions was anticipated to cause a decrease in sport fish catch rates in both basins of 24% for all fishing types in all waters located below impassable barriers. While there have been well-documented cases where individual fish species have experienced significant declines in abundance due to introduction of ANS (for example Smith and Tibbles, 1980), we are not aware of a large river basin system that has experienced significant catch rate declines of *all* sport fish species due to ANS.

It is important to note that the projected net economic benefits estimate presented here do not take into account the time lag between ANS transfer and sport angling impacts, which would depend on ANS spread rates. If it takes several years for ecological impacts to manifest, the present value of the impacts would be smaller. With information on spread rates and spatially explicit projections of catch rate impacts, the model could be used to evaluate ANS impacts in each year. On the other hand, the analysis does not account for impacts on Canadian fisheries, and does not include impacts on anglers who live outside of the eight states included in our study area. Finally, recreational behavior models such as the one estimated here assume that anglers will respond to changes in catch rates quickly. It may take time for anglers to adjust to decreases in catch rates. Still, our results do suggest that maintaining catch rates by preventing inter-basin transfer through the CAWS could pass a cost-benefit test only if impacts on sport fish are large and widespread.

We also note that our analysis only considers one category of impacts from ANS transfer: impacts on recreational angling that occur through changes in catch rate. ANS transfer can affect recreational angling in other ways as well, such as gear fouling, restrictions on gear type (for example felt-soled vs rubber-soled waders), requirements that restrict gear movement (including gear drying and boat check requirements), and, in the case of silver carp, the potential for injury or annoyance to boaters when the invasive fish jump in the air. For these reasons, our estimates of the costs to anglers of ANS transfer (and thus the benefit from hydrological re-separation) are likely under-estimates. Further, our analysis does not include costs or benefits that fall on other sectors, such as impacts on other recreationists (non-angling boaters, beach visitors, birders) and non-recreational impacts such as fouling of water intakes or health impacts from harmful algal blooms, the costs of which could be substantial. For these reasons, our analysis is not a complete cost-benefit analysis of proposals to re-establish hydrological separation. But the results clearly show that it is difficult to justify the costs of hydrological re-separation solely based on the potential impact on recreational angling catch rates.

Lastly, we point out that the analysis done here assumes that inter-basin transfer would only occur through the CAWS, and that hydrologic re-separation would prevent such transfer. However, ANS transfer can occur through other means, including transport on boats and fishing gear, with bait, and through accidental or intentional release. To the extent that transfer can occur through other means, the potential benefit from hydrologic re-separation is diminished.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jenvman.2017.10.025.

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