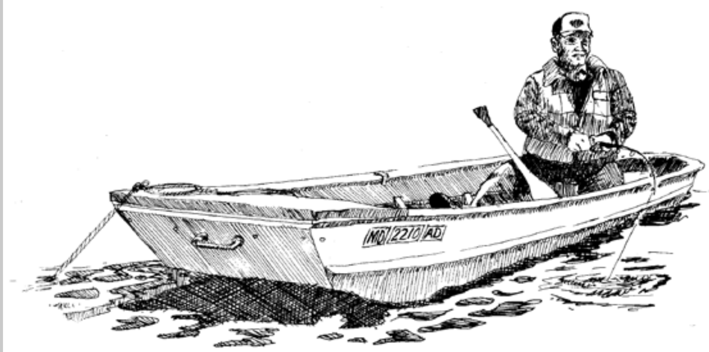
Impacts of Aquatic Invasive Species on Sport Fish and Recreational Fishing in the Great Lakes: Possible Future Scenarios



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EXECUTIVE SUMMARY

The rate of invasions of non-native aquatic invasive species (AIS) has accelerated in the Great Lakes in recent years. To date, several hundred non-native species have entered the lakes. Some AIS have been shown or are predicted to cause considerable harm, and the effects of AIS on recreational fisheries has been a point of particular concern. Recreational angling in the Great Lakes is popular and highly valued. Poe et al. (2012) estimated that Great Lakes anglers enjoy 18 million fishing days per year with a net economic value of $0.4 to 1.3 billion annually. Management decisions aimed at limiting AIS introduction or spread should be informed by estimates of the potential consequences of those AIS on this highly valued recreational fishery.

Ready et al. (2012) developed a model to address this need. Based on a survey of over 3,500 recreational anglers in 12 states in the Great Lakes, Upper Mississippi and Ohio River basins, they developed a model of recreational angler behavior that explains: (a) how often anglers go fishing, (b) where they go fishing, and (c) what types of fish (coldwater or warmwater) they target. Using these data, the model estimates the net economic value that anglers receive from the sportfishing resource. The model can therefore be used to project the impact of AIS-induced changes in sportfish catch rates on recreational fishing effort and on the net economic value that anglers place on the fishery.

The model estimated by Ready et al. is the most comprehensive model available for evaluating and predicting recreational angling in the Great Lakes region. However, the model has some limitations. First, the model was estimated using data on trips from a very large study region that extends far beyond the boundaries of the Great Lakes basin. A model estimated using data on angler behavior from only the Great Lakes region would better reflect angler behavior in that region. Second, the model is relatively simplistic in how it models angler behavior, particularly with regards to how anglers choose what type of fishing to do, and how that choice would change in response to changes in fishing quality. A refined model is needed that better captures how anglers make these choices.

Projecting of the impacts of AIS on recreational angling and anglers requires first estimating the ecological effects of AIS on recreational fish populations.Anticipating the impacts of AIS on recreational fish populations in a large, complex system, such as the Great Lakes, is challenging. Even under the best of circumstances, there is often considerable uncertainty about the likely impacts of AIS. Trying to reach single-estimate ecological forecasts of how AIS will affect fish may not be wise.

Scenario-building may be a more appropriate approach to assess the possible future effects of AIS in the Great Lakes. This approach recognizes that uncertainty is fundamental in planning for the future. Scenario development involves preparing multiple internally consistent descriptions that represent a range of plausible futures and outcomes. While any individual scenario may have a very low probability, as a set, scenarios can set boundaries around a range of possible futures.

Our project, therefore, had three objectives:

- Refine the model estimated by Ready et al. (2012) to better reflect and better model the behavior of recreational anglers in the Great Lakes states.

- Develop a set of plausible, science-based, internally consistent ecological scenarios about the possible effects of AIS on recreationally important fish populations in the Great Lakes.
- Use the refined recreational angling model to project the impact that these AIS scenarios would have on angler behavior and on the net economic value of recreational fishing in the Great Lakes.

Methods

Using angler survey data collected by Ready et al. (2012), a new model of recreational angling behavior was estimated. Compared to the model estimated by Ready et al., the new model 1) is based on a smaller geographic area, to better reflect angler behavior in the Great Lakes region, 2) better models the decision of what type of fishing to engage in and how that decision is affected by angler characteristics, and 3) accounts for response patterns in the survey data that may have biased the previous model to overstate the degree to which anglers will change their behavior in response to changes in fishing quality.

To generate AIS scenarios, we recruited 10 aquatic ecologists and fisheries managers from the Great Lakes region to participate in a scenario-building process. This process took place in three stages: (a) an initial Delphi survey to identify AIS of concern for the Great Lakes; (b) a two-day workshop in which scenarios describing the possible effects of 5 different AIS on recreational fish stocks and catch rates were developed; and (c) an iterative process—following the workshop--of reviewing and refining these scenarios and assessing their likelihood. Each scenario included quantitative estimates of the possible effects of AIS on different types of recreational fish populations and recreational fishing. Although we did not expect any single one of these individual estimates to represent a likely outcome, collectively the estimates for the set of scenarios for each AIS portrayed a range of plausible outcomes from the perspective of the expert panel.

Using the refined angler behavior model, we projected the impacts that each scenario would have on angler behavior and the economic value of the Great Lakes recreational fishery.

Results

Workshop participants developed scenarios for five species considered among the most likely to affect recreational fish stocks: bighead and silver carp, northern snakehead, grass carp, hydrilla, and quagga mussel. Fifteen ecological scenarios were developed representing a range of possible ecological outcomes if one of these five AIS became established or spread in the Great Lakes. The different scenarios for each AIS were based on different assumptions about the ecological processes that would be most important.

- **Bighead and silver carp.** The best case ecological scenario considered included: (a) a 5% decrease in salmonids throughout the Great Lakes; and (b) 10-25% increases in largemouth and smallmouth bass, yellow perch, and walleye in high productivity areas (Green Bay, Saginaw Bay, Bay of Quinte, Lake St. Clair, and the Western and Central Basins of Lake Erie). The worst case scenarios included: (a) a 10% decrease in largemouth and smallmouth bass and a 40% decrease in yellow perch and walleye in high productivity areas; or (b) an 80% decrease in coho and chinook salmon in Lakes Michigan and Ontario.

- **Northern snakehead.** The best case ecological scenario considered was no net effect on the populations of fish species that are important to recreational anglers. The worst case scenario included: (a) a 15% decrease in walleye throughout the Great Lakes and a 15% decrease in largemouth and smallmouth bass and yellow perch in high productivity areas; and (b) a 5% decrease in salmonids throughout the Great Lakes.
- **Grass carp.** The best case ecological scenario considered included projections of a 5% decrease in yellow perch and a 15% decrease in centrarchids (members of the freshwater black bass family, including bluegills and other sunfish) besides largemouth and smallmouth bass throughout the Great Lakes. The worst case considered was a 10% decrease in yellow perch and a 50% decrease in largemouth bass, northern pike, and other centrarchids besides smallmouth bass.
- **Hydrilla.** The best case scenario was a 15% increase in yellow perch, largemouth bass, northern pike, and muskellunge throughout the Great Lakes. The worst case scenario included decreases of yellow perch, largemouth bass, northern pike, and muskellunge of 15% throughout the Great Lakes, 25% in Green Bay, Saginaw Bay, and the Bay of Quinte, and 30% in Lake St. Clair.
- **Quagga Mussel.** The best case scenario was no further effect on the recreational fishery. The worst case scenario included an 80% decrease in coho and chinook salmon in Lake Michigan.

Based on these scenarios, we projected that the five AIS considered could have a range of possible effects on recreational fishing participation and value. The worst case scenarios for Asian carp and quagga mussel could involve losses of $129,000,000 to $139,000,000 in angler consumer surplus and 375,000 to 400,000 fewer fishing trips annually in the Great Lakes states. But aquatic invasive species could also lead to improvements in recreational fishing. Certain scenarios for hydrilla and Asian carp led to projected gains of up to $30,000,000 in value and 85,000 fishing trips annually. Scenarios projecting improvements were much less common than those involving losses, however.

The pattern of states affected would vary depending on the particular scenario, but generally those in the central Great Lakes region were expected to bear the greatest impacts. Illinois and Michigan had the potential to be most negatively affected. Wisconsin, Indiana, Ohio, and New York also bore substantial negative effects under some scenarios while Pennsylvania and Minnesota tending to be less affected. In those scenarios involving improvements to recreational fishing, Michigan and Ohio would be most likely to experience the greatest benefits.

It is important to recognize that the impacts on recreational fishing participation are often less severe than the ecological effects of AIS with which they are associated. There are several reasons for this. To begin with, anglers target some species much more heavily than others. If an AIS affects species that receive less attention from anglers in the Great Lakes (e.g., centrarchids), the effects on recreational fishing participation and value will not be as substantial. In addition, some types of fishing are much less affected by the opportunity to catch fish than others. Those anglers who fish anadromous runs in particular are less likely to reduce their fishing as fish populations decrease. Finally, many anglers switch from one type of fishing to another as the quality of their preferred type of fishing declines. In these scenarios, if one type of Great Lakes fishing declined, many anglers would take more trips for other types of Great Lakes fishing and, even more importantly, would take more trips to inland waters.

Our research is not able to generate precise estimates of the future effects of AIS on recreational fishing participation and value. Indeed, our approach was premised on the assumption that precise estimates are impossible given the uncertainty associated with large ecological systems. Nevertheless, our work considerably narrows the range of possible AIS impacts that must be considered. Accepting the best and worst case scenarios from the set would involve projections from a $30 million improvement in the Great Lakes recreational fishery to a $139 million loss. Although that range is quite wide, it provides reasonable endpoints that policy makers can consider when evaluating options to control the AIS considered in this report and perhaps AIS more generally.

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INTRODUCTION

The rate of invasions of non-native aquatic invasive species (AIS) has accelerated in the Great Lakes in recent years (Mills et al. 1993, 2003). To date, several hundred non-native species have entered the lakes, many through ballast waters (Holeck et al. 2004). In the near future, we may expect to see several new species in the Great Lakes from the area around the Black and Caspian Seas (Kolar and Lodge 2001) as well as several species of Asian carp (Kolar et al 2007).

Some AIS have been shown or are predicted to cause considerable economic costs (Pimentel 2001). For example, zebra mussels (*Dreissena polymorpha*) and quagga mussels (*Dreissena rostriformis bugensis*) are reducing water flows in pipes and increasing costs to private and municipal plants that use water from the lakes (Naleepa and Schloesser 2014). They also increase water clarity thereby promoting Cladophora growth in the nearshore (Hecky et al. 2004, Higgins and Vander Zanden 2010) and other aquatic macrophytes in embayments and lakes (Zhu et al. 2006, Mayer et al. 2014), which may or may not be seen as a positive outcome. However, mussels can also increase property values as a result of the increased water clarity associated with mussel filtering (Limburg et al. 2010). Other species may be replacing a native species without causing large scale ecosystem perturbations (such as the amphipod *Echinogammarus echinus*, a replacement that is not likely to be noticed by anglers or affect most people's enjoyment of the lakes (Limen et al. 2005). Other species may improve the quality of angling and recreational activities – the round goby (*Neogobius melanostromus*) consumes zebra mussels and provide a forage species for warmwater fish species such as black bass and some coldwater species such as brown trout (*Salmo trutta).*

While much research has been conducted on the ecological implications of AIS in the Great Lakes, less research has addressed the implications for recreational angling. Although exotic species certainly alter the original food web structure of the Great Lakes, their impact on recreational fishing and on anglers can be varied. For example, many cold-water anglers in the Great Lakes are seeking chinook salmon (*Oncorhynchus tshawytscha*) that rely on alewife (*Alosa pseudoharengus*) and rainbow smelt (*Osmerus mordax*) as the main prey species. None of these three species are native to the system.

It is important to understand the impact of AIS on recreational anglers and to be able to quantitatively predict how angler behavior will change in response to those impacts. This is important for two reasons. First, recreational angling in the Great Lakes is popular and highly valued. Poe et al. (2012) estimated that Great Lakes anglers enjoy 18 million fishing days per year with a net economic value of $0.4 to 1.3 billion annually (measured in 2012 dollars).[1] Second, management decisions aimed at limiting AIS introduction or spread should be informed by estimates of the potential consequences of those AIS on the highly-valued recreational fishery.

[1] Net economic value is defined as the benefit that recreational anglers receive from being able to use the fishery in its current condition. This is the appropriate measure of benefit for use in cost-benefit analysis of management actions. This benefit measure is conceptually different from measures of regional economic impact due to expenditures by anglers. The contribution of the Great Lakes fishery (commercial and recreational) to the regional economy has been estimated as high as $8 billion (American Sportfishing Association 2013).

Our research had three objectives.

Objective 1: Develop a compact, reduced-form model of Great Lakes recreational angling that projects how sport fishing participation and value would change as a result of AIS-induced changes in sport fish abundance.

In a recently-completed project funded by the U.S. Army Corps of Engineers (Ready et al. 2012), we conducted a large survey of over 3,500 recreational anglers in 12 states in the Great Lakes, Upper Mississippi and Ohio River basins. Based on this survey, the team developed a model of recreational angler behavior that explains 1) how often anglers go fishing, 2) where they go fishing, and 3) which types of fish (coldwater or warmwater[2]) they target, and that estimates the net economic value that anglers receive from the sportfishing resource. The model can be used to project the impact of AIS-induced changes in sportfish catch rates on recreational fishing effort and on the net economic value that anglers place on the fishery. For the U.S. portions of the Great Lakes, the model is spatially explicit to counties, and distinguishes between fishing for salmonids and fishing for warmwater species.

The potential utility of the previously-estimated recreational angling model to policy discussion of the Great Lakes fishery is limited, however. The existing model was estimated using data on trips from a very large study region that extends far beyond the boundaries of the Great Lakes basin. Anglers who live very far from the Great Lakes, for example in Kentucky and Missouri, may make fishing decisions differently from anglers who have access to the Great Lakes. Consequently, we re-estimated the model using the subset of anglers who live in the Great Lakes states, so that the model parameters better reflect angler behavior within the Great Lakes basin.

Furthermore, the existing model was complex and cumbersome. It requires specialized software and an analyst familiar with its structure. Evaluating one scenario for one year can take several hours of computing and analyst time. To be useful for management and research purposes, a simplified model was needed that is user friendly, can be run on a widely-available software platform, and that is streamlined so that it can be run quickly with minimum analyst processing. In addition to its potential use for management decision making regarding AIS, a simplified recreational angling model is of great potential use to aquatic ecologists who are modeling fish community dynamics. A compact, stand-alone recreational angling model could be incorporated directly into Ecopath/Ecosim as a subroutine to account for angler reactions to changes in fish stocks and the resulting feedbacks through fishing mortality.

Objective 2: Develop a set of plausible, science-based ecological scenarios about the possible effects of AIS on recreationally important fish populations in the Great Lakes.

The second project objective was to develop a set of plausible, science-based, internally-consistent scenarios of how AIS might invade or expand in the Great Lakes, and what implications those scenarios would have for recreationally-targeted fish species.

[2] In this report, the term "coldwater" fish species are limited to salmonids, and "warmwater" fish species includes species that are sometimes referred as coolwater species, such as walleye and yellow perch.

The potential magnitude of future ecological impacts of AIS on Great Lakes fish communities is unknown and the subject of intense public debate. With little scientific basis, stakeholders are making projections of the impacts of AIS on sport fish populations that range from negligible to catastrophic. There is a need for sound, science-based assessments of the potential impact of AIS on Great Lakes sport fisheries and on the anglers who utilize those fisheries.

Objective 3: Project the impact that AIS scenarios would have on angler behavior and on the net economic value of recreational fishing in the Great Lakes.

The third objective was, for each AIS scenario developed as part of objective 2, to use the reduced form model developed as part of objective 1 to evaluate the impact of the AIS scenario on Great Lakes fishing participation (days spent fishing for salmonids and for warmwater species, by specific areas within each lake) and on the net economic value that anglers enjoy from the Great Lakes fishery.

The AIS scenarios developed as part of this project therefore provide information both on the potential ecological impacts of selected AIS, but also on their impact on recreational anglers. These scenarios can provide managers and stakeholders with a range of possible futures that will inform and rationalize debate over the potential impact of AIS on sport fish populations and on sport fishing participation and value.

Methods

AIS Scenario Development

We recruited a group of 10 aquatic ecologists and fisheries managers from the Great Lakes region to serve as experts. These 10 individuals and one member of the project team were the participants in the scenario-building process. Six were from universities (Cornell University, The Ohio State University, Purdue University, University of Minnesota-Duluth, and University of Notre Dame). Five were from U.S. or Canadian government agencies (Department of Fisheries and Oceans Canada, National Oceanic and Atmospheric Administration's Great Lakes Environmental Research Laboratory, Ontario Ministry of Natural Resources, and U.S. Geological Survey's Great Lakes Science Center). They were selected so that collectively they would provide expertise on all five Great Lakes and a wide range of invasive species taxa.

The scenario-building process took place in three stages: (a) an initial Delphi survey to identify AIS of concern for the Great Lakes; (b) a two-day workshop in which scenarios describing the possible effects of five different AIS on recreational fish stocks and catch rates were developed; and (c) an iterative process of review and refinement of these scenarios and assessment of their likelihood.

<u>Initial Delphi Survey</u>. The Delphi survey consisted of a series of three anonymous questionnaires completed by participants. Each round of the survey was implemented by email using a web-based survey instrument. Participants answered the questions independently, rather than in collaboration with each other. In the first iteration, participants were asked to respond to four open-ended questions designed to identify AIS that are most likely to have new or additional negative impacts on populations of recreationally important fish species in the Great Lakes:

a) What AIS that are not now in the Great Lakes and could conceivably affect populations of recreational fish species do you consider most likely to invade the Great Lakes from other areas?
b) What AIS that are currently in the Great Lakes and that could conceivably have additional effects on populations of recreational fish species do you consider most likely to increase in prevalence or to invade new areas of the Great Lakes?
c) Of the species you identified in questions (a) and (b), which species would you consider most likely to have new negative impacts on the populations of recreational fish species in the Great Lakes?
d) Of the species you identified in questions (a) and (b), which species do you consider most likely to have widespread negative impacts on the populations of recreational fish species in the Great Lakes?

For each question, participants identified one or more AIS and explained, in several brief statements, their reasons for listing each. We synthesized these responses by compiling an aggregate list of all AIS listed for each question and a verbatim compilation of the reasons offered by each respondent for listing each species.

In the second questionnaire (distributed approximately one month after the distribution of the first questionnaire), participants reviewed the aggregate list of AIS generated in the first iteration of the survey and assessed (a) how likely they thought it was that each AIS would invade the Great Lakes from other areas, (b) invade new areas of the Great Lakes from within the Great Lakes, (c) have new negative impacts on populations of recreational fish species in the Great Lakes, and (d) have widespread negative impacts on the populations of recreational fish species in the Great Lakes. They made these assessments using a standardized 4-point scale (not at all likely, possibly, likely, or almost certain). Following the Delphi approach, participants were provided the compilation of the reasons other participants had offered for suggesting each species in the first round of the survey. They were asked to offer any additional reasons for their own answers (those that they did not provide in the initial survey) in a series of brief bullet points. We calculated the means, medians, and frequencies of responses to each of the standardized questions and compiled a verbatim record of the reasons offered by each respondent for their answers.

In the final questionnaire (distributed approximately one month after the distribution of the second questionnaire), participants responded to the same standardized questions they responded to in the second questionnaire. They were provided with a quantitative summary of how participants responded to these questions in the previous questionnaire and a verbatim compilation of all the reasons offered by respondents for their answers in the previous two rounds of the survey.

We compiled the results of this final round of the survey and developed flow diagrams that synthesized participants' thinking about the mechanisms that would lead to each AIS having an effect on recreational fish stocks. These materials were distributed to the expert panel prior to the workshop. In addition, experts were provided with a list of references (compiled from literature suggested by panel members) that they could review prior to the workshop.

Scenario-building Workshop. The scenario-building participants and project team gathered for a two-day workshop October 16-17, 2014, at the Cornell Biological Field Station at Shackelton Point in Bridgeport, New York (http://www.cbfs.dnr.cornell.edu/). At the outset of the workshop, the project team reviewed the results of the Delphi survey, and participants selected the AIS for which they wanted to develop scenarios. In making these selections, participants considered which species were most likely to affect recreational fish stocks in the Great Lakes and how knowledgeable they and the other participants were about each AIS. They made an effort to represent a range of taxa across the set of AIS selected and a range of ecological functions (piscivore, planktivore, macrophyte, etc.).

For each AIS selected, the project team facilitated discussions in which participants developed scenarios projecting the possible effects of the AIS on recreationally important fish if those AIS were to become established in the Great Lakes. Each scenario was allowed to vary geographically (from lake to lake and even between regions within a lake), although participants did not focus heavily on parsing out effects across systems. Based on, but not limited by the flow diagrams described earlier, participants specified the mechanisms by which they expected each AIS to affect recreational fish and identified and discussed key uncertainties that could influence the type and magnitude of these effects. For some potential invaders, multiple scenarios were developed that differed in the assumed extent to which the species became established. Each AIS was considered individually; possible interaction effects among multiple AIS were not assessed.

Each scenario included quantitative estimates of the possible effects of AIS on different types of recreational fish populations and recreational fishing. Although we did not expect any single one of these individual estimates to represent a likely outcome, collectively the estimates for the set of scenarios for each AIS portrayed a range of plausible outcomes from the perspective of the expert panel. The operating assumption here was that the net value of fishing as an economic activity would be driven primarily by changes in catch rates. For the sake of simplicity, participants mostly assumed that catch rates would be directly correlated with the size of recreational fish populations and, therefore, developed estimates of the impacts of AIS on fish populations. However, in a few cases, participants also considered whether catch rates might be driven by other AIS-induced changes that would make fish harder or easier to catch.

Scenario Review and Refinement. Following the workshop, participants engaged in an iterative process of reviewing and refining the scenarios. No substantive changes were made to the quantitative estimates generated during the workshop, but the descriptions of the mechanisms underlying the AIS effects on recreational fish were clarified and minor changes to estimates were made to remove inconsistencies. Participants also rated the likelihood of each scenario.

The specific steps involved in this review and refinement process were:

- In November 2014, participants commented on bulleted summaries of each scenario to ensure that these summaries accurately reflected discussions at the workshop.
- In March and April 2015, participants reviewed final written descriptions of each scenario and rated the likelihood of each, under the maintained assumption that the AIS were to become established in the Great Lakes. Each scenario could describe effects of

AIS on multiple fish species, and the likelihood of the entire scenario was rated (as opposed to rating the likelihood of effects on individual species included in the scenario). Likelihood was rated on the following scale: Remote (<1%); Highly Unlikely (1-10%), Unlikely (11-25%), Possible, but not Likely (26-50%), Likely (51-75%), Highly Likely (75-90%), Near Certain (91-100%). Many participants offered rationales for their ratings.

- In July 2015, participants were provided with a summary of how all participants rated the likelihood of each scenario and the comments offered to support those ratings, and then they rated the scenarios again. These final ratings are those which are reported in this report.

Economic Model

The economic model of angler behavior and value was estimated using data generated by a survey of anglers conducted in 2012. That survey was conducted as part of a research project funded by the U.S. Army Corps of Engineers. The details of how that survey was developed and implemented are described in Ready et al. 2012.

Here, the data from that angler survey is used to re-estimate the angler behavior model. Specifically, the following innovations were made to the model reported in Ready et al. 2012:

- The sample of anglers used for estimating the model was restricted to those anglers who live in one of the Great Lakes states, to better reflect behavior of anglers in the Great Lakes basin
- The model was expanded to incorporate the effect of angler characteristics on fishing type choice
- The model was expanded to account for inferred quality changes in contingent behavior responses
- A standalone simulation program that can be used to incorporate scenario projections into ecological models is developed

Specifics of these model refinements are described in greater detail in a later section on modeling.

Scenario Evaluation

The spatially explicit scenarios describing how AIS might affect recreational fish species populations had to be translated into a particular form for use in our economic model.

- The geographic boundaries we used in defining our scenarios corresponded to each of the Great Lakes or specific parts of those lakes. Our economic model requires scenarios to be defined at the county level.

- The scenarios were defined for particular recreational fish species. Our model requires scenarios to be defined for coldwater (salmonids) and warmwater (non-salmonid) species groups.

Translating Scenarios to the County Level. Our scenarios focused on nine bodies of water (or parts of bodies of water):

- Lake Ontario
- Lake Erie – eastern basin
- Lake Erie – central and western basins
- Lake St. Clair
- Lake Huron – Saginaw Bay
- Lake Huron – rest of lake
- Lake Michigan – Saginaw Bay
- Lake Michigan – rest of lake
- Lake Superior

(Although some scenarios also included projections for the Bay of Quinte, the Bay of Quinte borders Canada and our model only applies to the U.S. Consequently, the Bay of Quinte is not included as part of this discussion.)

Because the scenarios we developed included only Great Lakes fishing types (Great Lakes coldwater, Great Lakes warmwater, and anadromous), counties were assigned to one of the nine bodies of water based on the amount of shoreline of those counties that bordered those bodies of water. Most counties bordered only a single body of water. For those counties that bordered more than one body of water, the percentage of shoreline bordering each body of water was calculated using county maps.

Translating Scenarios to Coldwater and Warmwater Groupings. To translate the scenarios from projections of the effects on individual species to projections of the effects on coldwater and warmwater groupings, we relied on creel survey data to estimate the proportion of catch (or harvest or effort, if catch data were unavailable) for each individual species within each grouping. For example, if a scenario projected a 20% decrease in yellow perch (but no other species) and yellow perch made up 75% of the catch in a particular body of water, we estimated a 15% decrease in the catch of warmwater fish overall in that body of water.

FUTURE EFFECTS OF AQUATIC INVASIVE SPECIES ON SPORT FISH

Workshop participants developed scenarios for bighead carp *Hypophthalmichthys nobilis* and silver carp *Hypophthalmichthys molitrix* (pelagic planktivores), hydrilla *Hydrilla verticillata* (macrophyte), northern snakehead *Channa argus* (piscivore), grass carp *Ctenopharyngodon idella* (herbivore), and quagga mussel (benthic planktivore). These species were considered among the most likely to affect recreational fish stocks for a variety of reasons including their proximity to or presence in the Great Lakes, the availability of pathways through which they could invade, their ability to survive and breed in the lakes, and the identification of mechanisms through which they could affect recreational fish. Descriptions of each of the scenarios developed are presented below along with ratings of the likelihood of each scenario by the participants.

Because we were evaluating the utility of a particular approach to assessing possible future invasive species impacts, the scenarios presented below are the product of workshop discussions without any modifications after the fact (other than those minor modifications described above). Although members of the expert panel drew on their knowledge of the literature in developing the scenarios (sometimes citing specific facts or figures during discussions), they did not tend to formally reference literature sources during workshop discussions. Consequently, we do not augment these scenarios with literature citations, thus emphasizing that they are a product of the group process as it took place during the workshop rather than a product of a review of the ecological literature.

Bighead and Silver Carp

Bighead and silver carp (Asian carp) are pelagic filter feeders that consume both phytoplankton and zooplankton and therefore are potential competitors with existing prey species of most important sportfish species (Kolar 2007). They can grow sufficiently large to have a size refuge from predatory fish. Because of similarity in food selection and body size, we expect the two species to have similar ecological effects. To date, three individual Bighead Carp have been caught in Lake Erie (Kocovsky et al. 2012). Workshop participants agreed on a number of foundational assumptions that would influence the types of effects that these species would have if they became established in the Great Lakes:

- Asian carp would spawn in Great Lake tributaries. Their distribution could, therefore, be limited by the availability of spawning rivers. However, suitable rivers are available in at least some Great Lakes.
- They would move offshore as adults only in areas with high enough food concentration offshore.
- Asian carp would be unlikely to be temperature constrained in any of the Great Lakes.
- The primary limitation on their distribution would be food availability.
- It is uncertain how well young carp would survive in clearer waters, given that they reside in turbid, productive waters; predation on young carp could potentially be high. Because of their rapid growth and large size potential, carp would be much less susceptible to predation as they age.

Two broad scenarios (each with sub-scenarios) describing the possible effects of Asian carp on recreational fish populations were developed that differed in how widely carp become established in the Great Lakes.

- In the first scenario (AC-1), the experts assumed that Asian carp would become established only in high productivity bays in the Great Lakes, near large tributaries, and in the western and central basins of Lake Erie, because they currently are abundant in highly productive, turbid river systems in North America and Europe.
- In the second scenario (AC-2), the experts assumed that Asian carp also would become established in the pelagic portions of all lakes, except for Lake Superior where pelagic plankton concentrations are too low.

Scenario AC-1

Under this scenario, Asian carp would become established in the following high productivity areas: Green Bay, Saginaw Bay, Bay of Quinte, Lake St. Clair, and the western and central basins of Lake Erie.

Asian carp would compete with salmonids' prey species (e.g., alewife) during the periods in which these prey species were in shallow waters and bays, potentially reducing the abundance of prey for adult salmonids. It is also possible that young salmonids would feed on Asian carp eggs while the salmonids are in rivers, but this beneficial effect for salmonids was expected to be small. Workshop participants agreed that a 5% decrease in salmonids throughout the Great Lakes under this scenario would be a reasonable outcome.

The effects of carp on warmwater and coolwater species (species other than trout and salmon) would be more complicated. Non-salmonids could possibly be affected by four different processes: (1) Asian carp could compete directly with larval yellow perch (*Perca flavescens*) and walleye (*Sander vitreus*) for zooplankton thereby decreasing growth rates and increasing mortality rates of these two species, (2) Asian carp could compete with the prey species of adult yellow perch and walleye (including gizzard shad (*Dorosoma cepedianum*), emerald shiner (*Notropis atherinoides*), alewife, and rainbow smelt) thereby decreasing prey available to adult walleye and yellow perch; (3) Asian carp could release young yellow perch and walleye from predation by serving as an alternate prey for adult walleye, yellow perch, white perch (*Morone Americana*) and other piscivores; and (4) young Asian carp could serve as a prey resource for large-bodied adult walleye, northern pike (*Esox Lucius*), muskellunge (*Esox masquinongy*), largemouth bass (*Micropterus salmoides*), and smallmouth bass (*Micropterus dolomieu*).

The magnitude of the effects of Asian carp on non-salmonid species would depend on which of these processes dominated. Consequently, we developed three sub-scenarios for how warmwater and coolwater species would be affected in high productivity bays and the western and central basins of Lake Erie. Results of past modeling work with which workshop participants were familiar helped to inform alternate scenarios describing how these four processes would interact to affect particular recreational fish species.

- Scenario AC-1a. All four processes would occur: direct competition, indirect competition, predation release, and carp as a prey source. Largemouth and smallmouth bass would increase by 10% as they benefitted from Asian carp as a prey resource. Yellow perch would increase by 10% because the benefits of release from predation by White perch would be expected to be larger than the effects of direct and indirect competition with Asian carp. For walleye, however, the negative effects of competition would be expected to be larger than the positive effects of predation release and a new prey resource. Walleye would be expected to decrease by 10%.
- Scenario AC-1b. Positive effects of the carp on non-salmonid species (release from predation for yellow perch and walleye and young carp serving as a prey resource for largemouth and smallmouth bass) would dominate over the negative effects (direct and indirect competition). Largemouth and smallmouth bass would increase by 10% (as they did under Scenario 1A). Yellow perch would increase by 15%. Walleye would increase by 25%.
- Scenario AC-1c. The competition of Asian carp with all non-salmonid species would be the dominant effect. Under this assumption, we would expect a 10% decrease in largemouth and smallmouth bass and a 40% decrease in yellow perch and walleye.

Scenario AC-2

Under this scenario, Asian carp would also become established in the pelagic portions of all Great Lakes except for Lake Superior, which has too low plankton density. This scenario is considered less likely than Scenario AC-1. The food density in pelagic areas may be too low for large filter feeders, which need to swim through and filter a large amount of water to maintain themselves and grow. Past modeling has suggested this limitation could prevent the establishment of a large filter feeder off shore. If Asian carp did become established in pelagic areas, their abundance would be limited by the available prey biomass in these areas; in particular, they might not thrive in cold areas where zooplankton production is low.

We considered the effects of Asian carp only on coldwater species (trout and salmon) under this scenario; possible effects on warmwater species as specified in scenario AC-1 were not considered for the sake of simplicity and our desire to focus on the most unique impacts of pelagic establishment. The impacts on coldwater species detailed in Scenario AC-2 could therefore be additive to the impacts on non-salmonid species detailed in Scenario AC-1.

Carp would affect salmonids primarily through indirect competition. In particular, Asian carp would compete with alewife for food, leading to a reduction in alewife availability to salmonids. Workshop participants anticipated a threshold effect under this scenario; either Asian carp would have little effect on alewife and salmonids, or alewife populations would collapse, and salmonids would follow. Consequently, we developed three subscenarios for how salmonids could be affected.

- Scenario AC-2a. Sufficient zooplankton and phytoplankton production would exist offshore to support both alewife and Asian carp. Asian carp would have no effect on salmonids (beyond the 5% decrease described under Scenario AC-1).

- Scenario AC-2b. The establishment of Asian carp offshore would begin to lead to a decline in alewife, but fisheries managers would recognize this decline and reduce salmonid stocking to avoid an alewife collapse. Coho salmon (*Oncorhynchus kisutch*) and chinook salmon would decrease by 20% in Lakes Michigan and Ontario. Other salmonids would not be expected to be affected. Lake trout (*Salvelinus namaycish*), rainbow trout (*Oncorhynchus mykiss*), and brown trout (*Salmo trutta*) would switch from alewife to round goby as a food source, and would be unaffected. In addition, newly hatched lake trout would be released from predation by alewife and released from competition with other salmon and would experience no net negative effects.
- Scenario AC-2c. The establishment of Asian carp offshore would lead to a collapse in the alewife population. Without this food source, an 80% decrease in coho and chinook salmon was identified as possible in Lakes Michigan and Ontario. A similar decrease has already happened in Lake Huron, and the expert panel did not predict further declines in that lake.

The mean and median ratings of the likelihood of each scenario (under the maintained assumption that Asian carp were to become established in the Great Lakes) ranged from "highly unlikely" to "possible, but not likely" (Table 1). Although none of the scenarios were perceived to be likely, those perceived as most likely were those in which Asian carp would cause:

- A 10% increase in largemouth bass, smallmouth bass, and yellow perch in high productivity areas and a 10% decrease in walleye in these same areas (AC-1a) and no effect on salmonids beyond the 5% decrease specified in all scenarios (AC-2a); and
- A 20% decrease in coho and chinook salmon in Lakes Michigan and Ontario and a 5% decrease in other salmonids in all the Great Lakes (AC-2b).

Northern Snakehead

Northern snakehead is an obligate air-breather and can therefore survive in poorly oxygenated water such as shallow ponds and swamps (Courtenay and Williams 2004). It feeds almost entirely on fish (Saylor et al. 2012). In the United States, it has spread primarily through intentional or accidental release. It is established in the Potomac River and several other locations on the east coast, and suitable habitats for this species occur across the Great Lakes basin (Herborg et al. 2007). Both parents guard their eggs and newly hatched larvae in a floating nest. Workshop participants agreed on a number of foundational assumptions that would influence the types of effects that this species would have if it were to become established in the Great Lakes:

- Based on areas of North America where it has become established, northern snakehead would be expected to be limited to river systems and nearshore areas. It is generally restricted to shallow, warmer waters. It would not be expected to establish in pelagic portions of the Great Lakes.
- Northern snakehead is tolerant of low oxygen conditions and a wide range of temperatures, although a narrower range of temperature is needed for spawning.
- The presence of vegetation helps spawning, but is not a necessary condition for spawning.

Table 1. Scenario-building participants' ratings of the perceived likelihood of scenarios describing how AIS could affect the Great Lakes recreational fisheries

Scenario	Number of participants Remote (1)	Highly unlikely (2)	Unlikely (3)	Possible but not likely (4)	Likely (5)	Highly likely (6)	Almost certain (7)	Mean	Median
Bighead and Silver Carp									
AC-1a	0	1	2	2	4	0	0	4.0	4.0
AC-1b	0	5	3	1	0	0	0	2.6	2.0
AC-1c	0	4	2	1	2	0	0	3.1	3.0
AC-2a	0	1	4	0	2	2	0	4.0	3.0
AC-2b	0	2	3	2	1	1	0	3.6	3.0
AC-2c	1	2	4	2	0	0	0	2.8	3.0
Northern Snakehead									
NS-1	0	0	2	2	5	0	0	4.3	5.0
NS-2	0	2	2	2	2	1	0	3.8	4.0
Grass Carp									
GC-1	1	2	3	2	0	1	0	3.1	3.0
GC-2	0	2	2	1	4	0	0	3.8	4.0
GC-3	0	0	2	3	3	1	0	4.3	4.0
Hydrilla									
H-1	0	2	2	1	3	1	0	3.9	4.0
H-2	0	3	2	1	3	0	0	3.4	3.0
H-3	0	4	3	0	2	0	0	3.0	3.0
Quagga Mussel									
QM-1	0	1	3	2	3	0	0	3.8	4.0

- Northern snakehead would be expected to functionally act like other piscivores, such as bass, northern pike, and bowfin (*Amia calva*).

A key uncertainty about northern snakehead is whether it would simply replace other predators already present in the system (with the overall abundance of predator and prey species unchanged) or whether they would increase overall levels of predation and drive down populations of both predator and prey species. Members of the expert panel reported that in the Chesapeake Bay region, bass numbers have gone down 35% while northern snakehead has increased in abundance, but the impacts on other species are not clear. If northern snakehead simply replaces other predators, they may not affect catch rates at all because snakehead could itself become a popular sportfish. If it does impact other species, it would be expected to impact warmwater and coolwater fishes primarily, although they might also feed on young salmonids in river mouths as the salmonids are running down the rivers. Two scenarios were developed reflecting this uncertainty.

- Scenario NS-1. Northern snakehead would partially replace largemouth bass and northern pike but not otherwise affect recreational fish abundance. The net effect on the system would be small. Anglers would eventually switch from bass and northern pike to northern snakehead, and overall catch rates would not change. (This switch in angler behavior could take time because many anglers place special value on bass.)
- Scenario NS-2. The presence of northern snakehead would increase the levels of overall predation in the Great Lakes and drive down prey populations. They also would outcompete native species for prey, resulting in a decrease in predator populations. They would affect the populations of smallmouth bass, walleye, yellow perch, largemouth bass, and young salmonids running down streams. Effects on most warmwater and coolwater species would be limited to high productivity areas such as Green Bay, Saginaw Bay, Bay of Quinte, Lake St. Clair, and the western and central basins of Lake Erie, in which they would decrease by 15%. Walleye numbers would decrease by 15% in all portions of all lakes, however, because they migrate through lakes on an annual basis so that processes in nearshore areas affect the population throughout the lakes. Anadromous coldwater species would decrease by 5% in all Great Lakes.

The mean and median ratings of the likelihoods of each scenario ranged from “possible, but not likely” to “likely” (Table 1). The scenario in which northern snakehead had a minimal effect on the system (NS-1) was considered more likely than the scenario with negative aggregate impacts on sport fish populations (NS-2).

Grass Carp

Grass Carp is an herbivore. It has tolerance for a wide range of temperatures, but is likely to be limited by the availability of spawning habitat. It has been introduced to many small water bodies for control of aquatic vegetation. Although introduced fish were supposed to be triploid and sterile, reproducing populations are now established in the Mississippi River basin. Some natural reproduction has occurred in Lake Erie (Chapman et al. 2013), but it has not yet become abundant in the Great Lakes basin. Workshop participants agreed on a number of foundational assumptions that would influence the types of effects that this species would have if it were to become more widespread in the Great Lakes:

- Because there are no other native fish in the Great Lakes that consume primarily macrophytes, grass carp could have novel impacts if it became abundant. Grass Carp would reduce and alter aquatic vegetation, which could lead to altered wetlands and nearshore habitat, increased bank erosion in protected embayments, and increased predation on age-0 fish by predators because of the reduced cover.
- Grass Carp would live in littoral zones and affect nearshore areas that support warmwater and coolwater fishes. The fish species most likely to be affected by grass carp are largemouth bass, northern pike, yellow perch, and most other centrarchids. Smallmouth bass would be less affected, and walleye and salmonids would be minimally affected.
- Although certain species might be exposed to increased predation, largemouth bass and northern pike might also gain certain benefits if they prey on young carp.
- The magnitude of the effects of grass carp on sportfish populations would depend on how numerous and widespread carp become, which would determine the degree to which they reduce macrophyte habitat. Predation by northern pike and largemouth bass might influence the degree to which carp become established.

Three primary scenarios were developed:

- Scenario GC-1. Grass Carp would reduce macrophyte habitat in all Great Lakes. Under this scenario, largemouth bass (which are most dependent on macrophytes), northern pike, and most other centrarchids would all decrease by 50% in all Great Lakes. Yellow perch would decrease by 10%. Walleye would be unaffected.
- Scenario GC-2. Grass Carp would become established, but not as numerous and widespread as under Scenario 1, so macrophyte habitat would be reduced to a lesser degree. Consequently, warmwater and coolwater species would be less affected. Largemouth bass, northern pike, and most other centrarchids (besides smallmouth bass) would decrease by 25%, and yellow perch would decrease by 5%.
- Scenario GC-3. As under Scenario 2, grass carp would become established, but not as numerous and widespread – specifically because of predation by northern pike and largemouth bass. Centrarchids other than bass would decrease by 15%, and yellow perch would decrease by 5%. Largemouth bass and northern pike would be unaffected because the benefits from preying on carp would roughly balance the negative effects of habitat losses.

The mean and median ratings of the likelihoods of each scenario ranged from “unlikely” to somewhat more than “possible, but not likely” (Table 1). Of the three scenarios, the scenario in which grass carp would lead to a 15% decrease in centrarchids other than bass and a 5% decrease in yellow perch was considered most likely (GC-3).

Hydrilla

Hydrilla is an aquatic macrophyte that can form dense monocultures in areas it invades. It is spreading northwards from Florida were it was likely introduced through the aquarium trade (Langeland 1996). It is easily spread by recreational boaters when they move their boats from one waterbody to another and it is already present in Cayuga Lake, New York, which is within the Great Lakes watershed. Surface mats usually first occur in July or August and remain through the rest of the growing season. Workshop participants agreed on a number of foundational assumptions that would influence the types of effects that this species would have if it became widespread in the Great Lakes:

- Some plant cover (around 50%) is beneficial to fish by offering a refuge from predation. The problem with hydrilla is that, given the appropriate ecological conditions, it can form dense monocultures which is a less suitable habitat for young fish. Hydrilla also makes it difficult for fish to navigate in and out of wetland areas.
- Hydrilla has the potential to lead to dissolved oxygen depletion in nursery areas. Oxygen depletion would only be a problem in warm, shallow areas with little water flow. These areas might comprise only a small proportion of shoreline areas, but they are important areas for fish.
- Hydrilla could both colonize areas that do not now have macrophytes and replace macrophytes that are currently in the lake. Hydrilla can colonize deeper areas than some (but not all) other macrophytes. The establishment of hydrilla will be limited by turbidity.
- Most effects on fisheries would be confined to wetland areas. These areas are important for northern pike and bass, particularly largemouth bass. Workshop participants were uncertain how important wetland areas were to yellow perch. Salmonids are not as dependent on wetlands.
- In addition to affecting fish populations, dense beds of hydrilla could make it more difficult for anglers to catch the fish that are there. Therefore, catch rates might decline even more than fish populations.

Given general agreement on the above pathways, three scenarios for the effects of hydrilla on sportfish populations were developed. These scenarios differ with regard to the areas that hydrilla colonize.

- <u>Scenario H-1</u>. Under this scenario, hydrilla would replace native plants in the Great Lakes, but would not change the habitat structure of enough areas to affect fish populations. The changes in plant species could shift non-salmonid species composition towards largemouth bass and esocids, but not affect overall recreational species populations.
- <u>Scenario H-2</u>. Hydrilla would form dense monocultures in shallow, calm embayments, which would reduce habitat quality. These habitat changes would negatively impact warmwater and coolwater fish, leading to a 15% reduction in catch rates for yellow perch, largemouth bass, northern pike, and muskellunge in all Great Lakes. The reduction would be greater in areas of the lake that are productive; catch rates would be expected to decrease by 25% in Green Bay, Saginaw Bay, and the Bay of Quinte and 30% in Lake St. Clair. Catch rates might decrease even more than fish abundance because of the difficulty in catching fish in dense stands.)
- <u>Scenario H-3</u>. Hydrilla would colonize only deeper areas of the lakes that were not currently colonized by other macrophytes. These newly vegetated areas would provide habitat and attract warmwater and coolwater fish and provide additional habitat and

fishing opportunities. Catch rates would increase by 15% for yellow perch, largemouth bass, northern pike, and muskellunge in all lakes.

The mean and median ratings of the likelihoods of each scenario ranged from “unlikely” to “possible, but not likely” (Table 1). The scenario in which hydrilla did not affect recreational fish catch rates was considered most likely of those considered (H-1).

Quagga Mussel

Quagga mussel is a benthic filter-feeder that invaded the Great Lakes in the late 1980s (Mills et al. 1996). The species is well established in most of the Great Lakes and has replaced zebra mussels (Dreissena polymorpha) in most locations (Karatayev et al. 2014). Quagga mussels consume phytoplankton and may reduce zooplankton through competition. If quagga mussels were to increase further, the reduction in zooplankton productivity coupled with increases in salmon (through stocking, increases in wild reproduction, or immigration) could result in an alewife collapse and drastically reduce coho and chinook salmon.

Scientists have debated whether quagga mussels contributed to the collapse of alewife in Lake Huron, as the densities of quagga mussels were low when alewife collapsed. The current densities of quagga mussels in Lakes Michigan and Ontario are an order of magnitude higher than in Lake Huron. It is particularly unlikely that quagga mussels would lead to the collapse of alewife in Lake Ontario, where the densities of quagga mussels are decreasing. Lake Michigan, which has lower productivity, may be more susceptible.

One scenario was developed, reflecting the possibility that quagga mussels could contribute to an alewife collapse in Lake Michigan. Under this scenario (QM-1), quagga mussels would increase further in Lake Michigan and lead to an 80% decrease in coho and chinook salmon, but would not impact other salmonids.

The mean and median rating of the likelihood of this scenario was “possible, but not likely” (Table 1).

MODELING ADVANCES TO GREAT LAKES/MISSISSIPPI RIVER ANGLING MODEL (GLMRAM)

In a previous project funded by the U.S. Army Corps of Engineers, the project team surveyed 3,539 recreational anglers in 12 states in 2012. The states surveyed are shown in Figure 1. Survey respondents were asked how often they went fishing during the calendar year 2011, where they went fishing, and what type of fishing they engaged in. Respondents were also asked how their angling behavior would change if fishing quality (specifically, catch rates) were to change.

Based on data from the survey, the team developed a quantitative model of recreational angler behavior, called the Great Lakes/Upper Mississippi Recreational Angling Model (GLMRAM). GLMRAM is a repeated nested logit random utility model (RUM) that models recreational angler behavior in the study area. The model explains and predicts the following recreational behaviors:

- how often a recreational angler goes fishing
- what type of fishing they do
- where they fish
- how much net economic value the angler enjoys from fishing
- how those behaviors and value would change if catch rates were to change

Details on how the survey was conducted and how the model was developed and estimated are presented in Ready et al. (2012).

In the current project, the team made several improvements to the model to make it more useful for scenario analysis in the Great Lakes basin. These improvements are described in detail in this section of the report. The improvements include:

- Restricting the sample of anglers used for estimating the model to those anglers who live in one of the Great Lakes states
- Using angler characteristics to help explain and predict fishing type choice
- Accounting for inferred quality changes in contingent behavior responses
- Development of a standalone simulation program that can be used to incorporate scenario projections into ecological models

Two additional modeling improvements were explored,

- Modeling correlation in fishing type choice
- Modeling overnight trips

However, in these two cases, the efforts did not result in improvements to the GLMRAM model, and were abandoned.

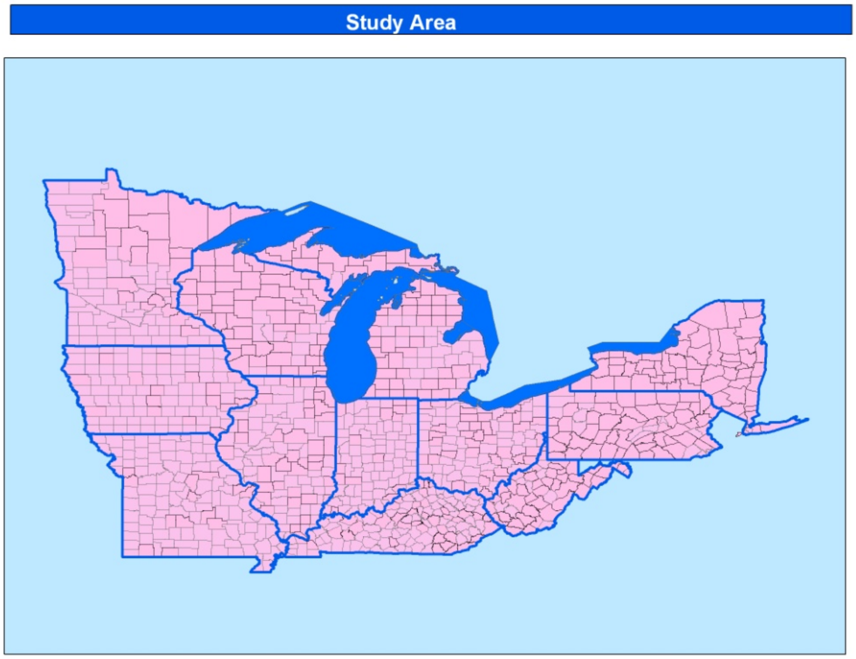

Figure 1. Study Area

In order to explain the improvements made to GLMRAM, it is necessary to provide some detail on its structure and method of estimation.

Definition of a Fishing Trip

A fishing trip is defined as a trip taken away from home for the primary purpose of recreational angling. The trip begins when the angler leaves home and ends when he/she returns home again. For a given angler, a fishing trip is completely described by three factors:

- whether the trip is a day trip or an overnight trip
- the trip origin and destination
- the type of fishing done on the trip

Day Trips vs Overnight Trips

Trips where the angler leaves home and returns on the same day are defined as day trips. Trips where the angler is away from home overnight are defined as overnight trips. Day trips accounted for 90% of total fishing trips taken by surveyed anglers and 83% of total fishing days. The previous version of GLMRAM modeled day trip behavior only, and then multiplied predicted trip frequencies by an expansion factor to predict total fishing effort. In this project, an attempt was made to model overnight trips as well.

Definition of Origin and Destination for a Trip

The study area (Figure 1) includes 1024 counties. Each county is treated as a unique fishing destination. Each time an angler goes fishing, he or she must choose one destination (county) for that trip. For trips where the angler fished from a boat, the destination county is defined as the county where the boat was launched. For trips where an angler fished in more than one county, the angler was asked to report the county he or she primarily fished in during that trip. Fishing trips taken to destinations outside of the study area are not included in the dataset or the model. An important determinant of where anglers go fishing is the cost of reaching the destination. Travel cost from the angler's home to the destination is calculated for each trip and includes both the vehicle operating costs and the opportunity cost of the angler's travel time. Details on the calculation of travel costs are provided in Ready et al. (2012).

For each trip, the trip origin is the zip code of either the angler's primary residence or their secondary residence if they have one. If a respondent has two homes, travel cost is measured from both the primary home zip code and the secondary home zip code, and the lesser of the two calculated travel costs is used.

For each angler in the survey, a Site Choice Set was constructed for each fishing type. The Site Choice Set includes all counties that support the indicated fishing type that the angler can reach within a specified cutoff driving time. Based on the distribution of trips observed in the survey, a one-way cutoff time of 2.5 hours was used for all fishing types except for anadromous fishing, where a 3 hour cutoff time was used.

The original GLMRAM model modeled angler behavior throughout the study area, and was estimated based on survey responses from anglers in all 12 states in the study area. The new model estimated here is focused on scenarios that affect conditions in the Great Lakes basin. To better measure angler behavior in the relevant area, we now exclude anglers who live in states located far from the Great Lakes basin, namely Iowa, Missouri, Kentucky and West Virginia. The new model presented here is estimated using only anglers living the eight Great Lakes states. However, in order to fully characterize all of the fishing opportunities faced by those anglers, the complete set of 1024 destination counties is retained. For destination counties in Iowa, Kentucky, Missouri and West Virginia, this means that only trips originating in the other eight states are modeled. For this reason, trip counts to counties in those four states are underestimates of the actual number of trips taken to those counties. Consequently, the GLMRAM model is not intended to predict total fishing effort in those four states.

Fishing Type

We identify seven different types of freshwater fishing that occur within the study area. These are:

1. GLCold – fishing in the Great Lakes for coldwater species (trout and salmon)
2. GLWarm – fishing in the Great Lakes for warmwater species
3. ILCold – fishing in inland lakes and ponds for coldwater species (trout)
4. ILWarm – fishing in inland lakes and ponds for warmwater species

5. RSCold – fishing in rivers and streams for coldwater species (trout - excluding anadromous runs)
6. RSWarm – fishing in rivers and streams for warmwater species
7. Anad – fishing in rivers that drain into the Great Lakes for salmon and trout that are swimming upstream to spawn (anadromous runs)

Not every type of fishing can be done in every county in the study area. GLCold and GLWarm can only be done from counties that border the Great Lakes. ILCold and RSCold can only be done in counties that have coldwater fish (trout) present, either naturally or stocked. Anad can only be done in counties that have rivers with anadromous runs. Counties were designated as supporting coldwater fishing if either a survey respondent reported taking a trip to that county to fish for RSCold or ILCold or the county was identified by its state fish management agency as supporting wild or stocked coldwater fishing. Similarly, counties were designated as supporting anadromous fishing if they included river stretches hydrologically connected to the Great Lakes and either a survey respondent reported engaging in anadromous fishing in the county or a state fish management agency identified the county as supporting anadromous fish runs.
Each fishing trip is assigned to one fishing type. For fishing trips where more than one type of fishing occurs, the respondent was asked to report the fishing type they primarily engaged in during that trip.

Data Collected

Three different types of data were collected. First, anglers were asked to report trip data for every fishing trip they took within the study region during 2011. Second, if the angler felt that 2011 was not a normal year with regards to their fishing activity, the angler was asked how many trips of each fishing type they take in a normal year. Third, anglers were asked how many fishing trips they would take if recreational quality, as measured by catch rate, were to decrease.

Data on 2011 Trips

The angler survey was conducted using both internet and mail survey instruments. These two survey modes collected slightly different information about trips taken in 2011. In both surveys, complete information was collected for all trips taken within the respondent's home state. This information included

- the destination county
- the fishing type
- whether the trip was a day trip or an overnight trip
- if an overnight trip, the number of days spent fishing on the trip

The same information was collected for trip taken outside the respondent's home state, but the level of spatial detail on the destination varied depending on the survey mode. In the web survey, for trips taken outside the home state, survey respondents reported the state where the trip was taken, but not the county. In the mail survey, anglers reported only that the trip was taken outside the home state. The specific state or county of the destination was not reported. Trips taken to destinations outside the 12-state study area were not reported or modeled.

Normal Year Trip Frequency Data

Anglers may have felt that 2011 was not a normal year for them, perhaps due to illness or injury or some other unusual situation. After reporting their 2011 fishing trip data, each respondent was asked how many times they go fishing in a "normal year." Specifically, respondents reported the total number of day trips and the total number of overnight trips taken for each fishing type in a normal year. No destination information was collected for this data.

Contingent Behavior Trip Frequency Data

Respondents were then asked to imagine that fishing quality, as measured by catch rates, were to decline. Each respondent was presented with a catch rate decline scenario. Different respondents were presented with different scenarios. In each scenario, catch rate declines varied by fishing type, but did not vary by county. Declines were described as a percentage of the catch rate for that fishing type in 2011.

Respondents were asked how many times in a year they would go fishing for each fishing type if catch rates were to decline according to the presented scenario. Respondents were not asked where they would go fishing, only how many total day and overnight trips they would take for each fishing type.

In each scenario, up to three different fishing types experienced declines in catch rate. The remaining fishing types were unaffected. Care was taken to explain that not all fishing types would be affected. However, survey respondents may have inferred that fishing quality would decline even for fishing types that were listed as having no change. For example, if coldwater fishing in streams and rivers decline in quality, it may be logical to assume that warmwater fishing in streams and rivers will also decline in quality, even if the scenario states no decline for that fishing type. To account for the possibility that anglers infer changes in fishing quality that are not described in the scenario, a shifter term is included in the angling model. This shifter term was not included in the original GLMRAM, and represents an improvement to the model.

Actual Behavior vs Stated Behavior

Both the normal year trip data and the contingent behavior trip data are based on angler statements about what they typically do or about what they would do. This type of data is called stated behavior data. This is in contrast to the 2011 trip data which is based on actual behavior. Previous research has shown that anglers tend to report future trip participation at higher rates than is observed in actual trip behavior. This could be due to optimism on the anglers' part, where they report the amount of angling they plan to do, but fail to take into account events that could prevent them from fulfilling those plans, such as sickness or other unanticipated events (Englin and Cameron 1996; Hensher et al 1998). In the model developed below, terms are included to adjust for any upward bias of stated behavior relative to actual behavior.

Trip Decision Model

Anglers are assumed to make their trip decisions (whether to go fishing, what type of fishing to do, where to go fishing) based on the utility they receive from engaging in each fishing type in each county. A repeated nested logit random utility model is assumed (Morey et al. 1993). In the model, each angler has N opportunities to go fishing (choice occasions). In the estimation, N is set equal to 365, but the model results are not very sensitive to this assumption. On each choice occasion, the angler makes a series of decisions. First, they decide whether or not to take a trip (participation decision). If they decide to take a trip, they then decide what type of fishing to do (fishing type decision). Once they have decided what type of fishing to do, they decide where to go fishing (destination decision). The destination decision is constrained by the fishing type decision – the angler can only go to destinations that offer that type of fishing. The decision tree for each fishing opportunity is shown in Figure 2.

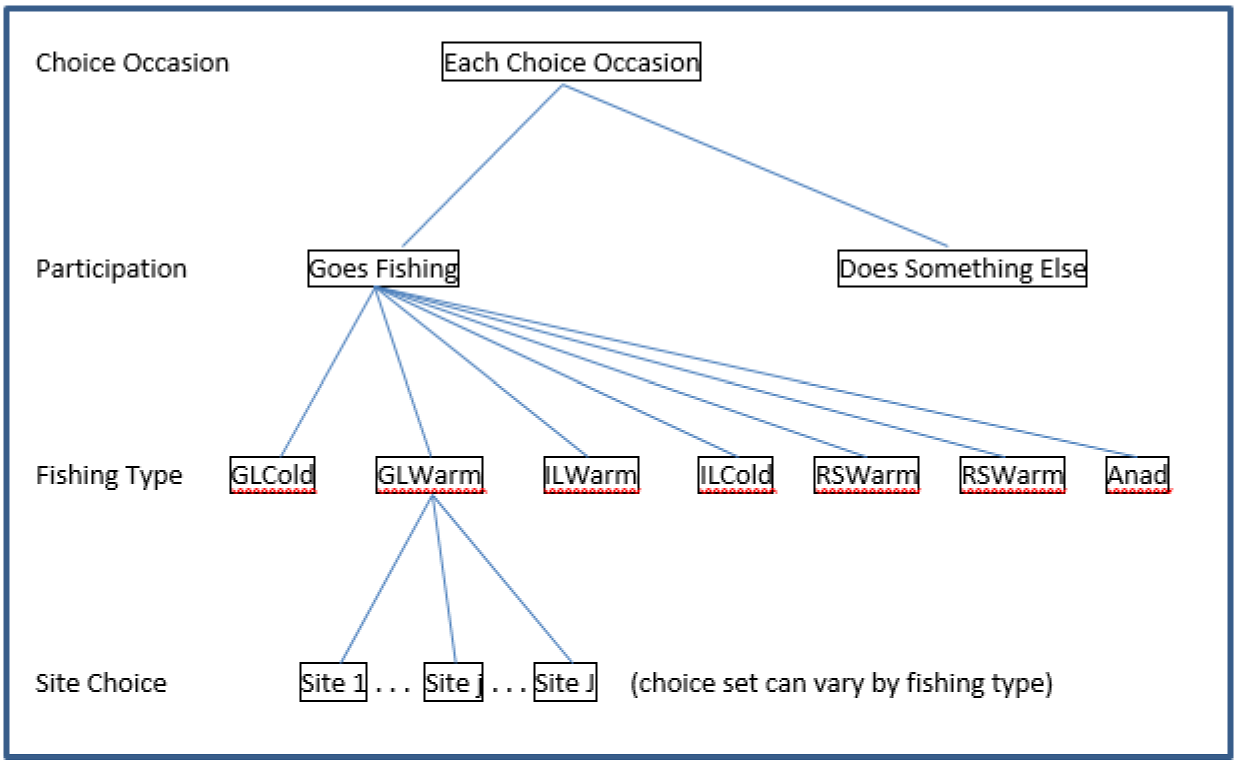

Figure 2. Nested Logit Decision Tree

The decision tree shown in Figure 2 is the tree that was used in the original GLMRAM model. In this project, alternative decision trees are explored. Specifically, the fishing type decision is modeled in a stepwise fashion, rather than all at once, to account for the possibility that some fishing types are more similar to each other than others. More detail is provided in the Results section below.

The Utility Function

An angler is assumed to obtain utility of 0 if they choose to stay home and do something other than going fishing. This provides 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

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

The deterministic component is assumed to take the following form

$$U_{ij}^k = \gamma_k Q_{jk} + \beta TC_{ij} + \varphi^k ln\left(CR_j^k\right) + \mu X_i + \delta_k Z_i + \omega_k S_i + \ \tau CB_i$$

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. If a respondent has two homes, travel cost to the jth county is measured from both the primary home zip code and the secondary home zip code, and the lesser of the two calculated travel costs is used.
β =	Marginal utility of income.
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.
Q_{jk} =	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).
S_i =	Dummy variable for whether a trip is based on stated behavior or on observed behavior (=1 if normal year or contingent behavior; =0 if actual trip taken in 2011).
ω_k =	parameter to capture influence of hypothetical bias 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

This model includes two advances relative to the original GLMRAM model. First, the original GLMRAM model included a vector of angler characteristics that affected the participation decision, X_i, but did not include a vector of angler characteristics that affected the fishing type decision, Z_i^k. In the original model, angler characteristics could influence how often an angler went fishing, but not what type of fishing the angler does. In the new GLMRAM estimated here, angler characteristics affect both the frequency of participation and the type of fishing chosen. For example, female anglers may fish less frequently than male anglers, and may tend to choose different fishing types than male anglers.

Second, the model includes a shifter to account for quality changes for the contingent behavior scenario that are inferred by the survey respondent but that are not actually described in the scenario, as described above. 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.

Site Quality Measures

For each fishing type, the site quality measures included in Q_{jk} included a fishing-type specific constant, plus the following specific quality measures

For GLCold and GLWarm:
- Constants for each of 11 contiguous groups of Great Lakes shoreline counties
- Great Lakes Shoreline Miles in each county

For Anadromous:
- Constants for each of 11 shoreline county groups
- Aquatic Habitat Quality Index
- Miles of streams in the county (stream order 3-4)
- Miles of rivers in the county (stream order 5-7)

For ILCold, ILWarm:
- Constants for each state (Omitted state is Michigan)
- Aquatic Habitat Quality Index
- Lake area in the county (square miles)

For RSCold, RSWarm
- Constants for each state (Omitted state is Michigan)
- Aquatic Habitat Quality Index
- Miles of streams in the county (stream order 3-4)
- Miles of rivers in the county (stream order 5-7)

The 11 county groups used for Great Lakes and anadromous fishing are shown in Figure 3. The aquatic habitat quality index was developed by the National Fish Habitat Partnership, and 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 from ecosystems.usgs.gov/fishhabitat/).

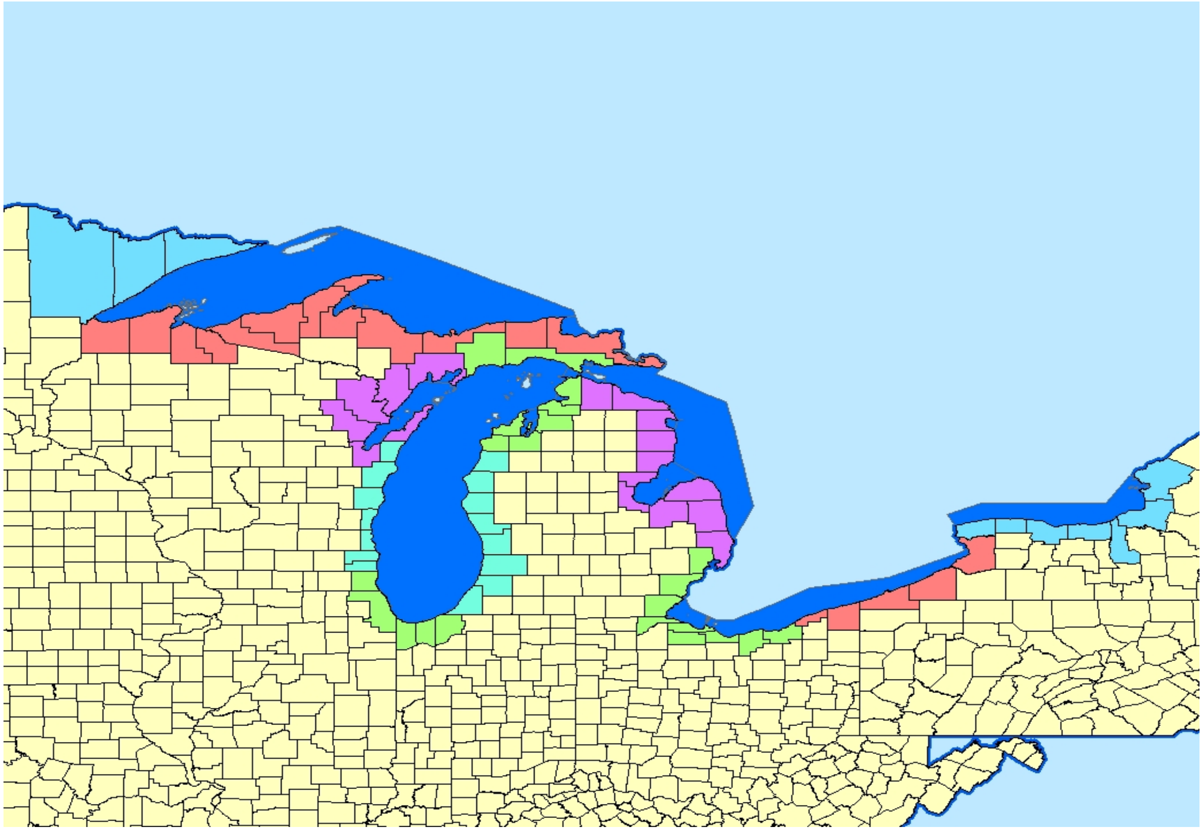

Figure 3. Great Lakes county groups.

County groups are from east to west: 1 – Northern Lake Superior/Minnesota; 2 – Southern Lake Superior; 3 – Green Bay; 4 – Southern Lake Michigan/Wisconsin; 5 – Southern Lake Michigan/Indiana; 6 – Eastern Lake Michigan; 7 – Northern Lake Michigan; 8 – Lake Huron; 9 – Lake St. Clair, Western Lake Erie; 10 – Eastern Lake Erie; 11 – Lake Ontario. In estimations, county group 11 is the omitted group.

Influence of Catch Rate on Utility and Behavior

The catch rate measure, CR_j^k is defined as a percentage of the baseline (2011) catch rate. For all observed 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. A positive value of the parameter φ_k therefore implies that the utility from a fishing trip for fishing type k decreases as catch rate for that fishing type decreases. 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 catch rate of 0. For CR_j^k values between 0 and 1, the shape of the utility function depends on the magnitude of φ_k . If φ_k is small, then the utility decline from a small catch rate decrease will tend to be small. If φ_k is large, then the utility decline from a small catch rate decrease will be larger.

Because of the natural log transformation, a large decline in catch rate will always result in a large decrease in utility for all values of φ_k.

The flexibility of the model means that it should be used with caution when projecting impacts of catch rate reductions outside the range of the data. In the catch rate reduction scenarios presented to survey respondents, catch rates for each fishing type were reduced by between 0% and 50%. Complete loss of a fishing type will logically lead to no fishing for that fishing type. However, we have little information about the how quickly utility declines as catch rates declines exceed 50%.

It should be noted that the catch rate changes in the contingent behavior scenarios were all decreases or no change. Survey respondents were not presented with scenarios that involve increases in catch rates. However, the AIS scenarios developed here include some increases in sport fish catch rates for some fish types. It is reasonable to expect that angler behavior is roughly symmetric for increases in catch rate and decreases in catch rate, however projecting angler behavior in response to increases in catch rate does represent extrapolation outside the range of our data, and projections of angler behavior in response AIS scenarios with catch rate increases should be interpreted with caution.

Angler Behavior

The model assumes that, each day, the angler evaluates the utility from every possible trip (every fishing type/site combination). The deterministic component for each available trip will be the same from day to day. However, the random error term for each trip will change from day. This is the variation that motivates the idea that anglers will do different things on different days.
On each day, the angler first determines whether there is any fishing opportunity that would generate a utility greater than 0. If best available fishing trip on that day has negative utility, then the angler stays home and does something else (the participation decision). For most anglers, this is the choice made on most days. If there is a fishing trip that generates positive utility on that day, the angler then determines which fishing type that trip belongs to (the fishing type decision). Finally, the angler decides which destination gives the highest utility on that day (the site choice decision), and engages in that observed fishing trip. So, for every observed trip, we know that that observed trip generated positive utility that was higher than for all other possible trips.
On any given choice occasion, the researcher does not know in advance which fishing opportunity will generate the highest utility, or whether that utility will be positive. However, it is possible to calculate the probability that a given trip will give higher utility than all other available trips.

In the nested logit model, the probability of taking a trip to destination g to engage in fishing type k is decomposed as follows

$$\Pr(p,k,g) = \Pr(p) * \Pr(k|p) * \Pr(g|k,p)$$

where

p,np = indicator for participation (=p if angler goes fishing on that occasion; np if angler does not go fishing on that occasion)

k = fishing type chosen
g = destination chosen (described in more detail below)

Conditional Site Choice Probability - $\Pr(g|k,p)$

Complete information on destination choice is not available for all trips. In some cases, we only know which state or states were visited. Let $g=1,2,\ldots,G_i^k$ be an index, where each value of g represents an observed trip destination for angler i. If the observed trip destination is within the angler's home state, then g will represent a unique county. If the observed trip destination is outside the angler's home state, then g will represent a set of counties. For example, if the angler indicates that the trip was to a particular state other than the home state, then g represents all counties within that state that lie in the site choice set, i.e. those counties that offer that type of fishing and that are within the travel time cutoff for the angler.

The conditional probability of individual i taking a trip to destination set g, conditional on going fishing for fishing type k, is given by

$$\Pr(g|k,p) = \frac{\sum_{j \in C_{ig}^k} \left\{ exp\left(U_{ij}^k / \lambda_k \right) \right\}}{\sum_{j \in C_i^k} \left\{ exp\left(U_{ij}^k / \lambda_k \right) \right\}}$$

where

C_i^k = individual i's full choice set for fishing type k. Includes all counties within the cutoff travel time from i's zip code that offer fishing type k.
C_{ig}^k = set of counties included in destination set g for fishing type k for individual i. C_{ig}^k is always a subset of C_i^k. If the visited county is known (i.e. in home state), C_{ig}^k will include that county only; if the visited county is not known, but visited state or states is known, C_{ig}^k will include all relevant counties in that state or states. For "normal year" trips and contingent behavior trips, no information about destination is known, and C_{ig}^k includes all of the same counties as C_i^k.
λ_k = Scale parameter for the site choice decision for fishing type k

The scale parameter measures how "similar" different sites are within a fishing type. A small value of λ_k means that, within a fishing type, anglers view different sites as being similar to each other.

On a given choice occasion, U_{ij}^k is a random variable. It is possible to calculate the expected value of the highest utility that angler i will obtain from fishing type k. That is equal to the expected value of the utility generated by the best available fishing site for that fishing type, which is given by

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

Fishing Type Choice Probability - $\mathbf{Pr}(\boldsymbol{k}|\boldsymbol{p})$

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

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

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. If the nested logit model is specified correctly, then two different fishing sites for the same fishing type will tend to be more similar than two different sites for different fishing types, and σ is expected to be larger than each of the λ_k values.

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

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

Probability of Going Fishing (participation) - $\mathbf{Pr}(\boldsymbol{p})$

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

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

where ρ is the scale parameter for the participation decision. If the nested logit model has been specified appropriately, then we would expect $\rho > \sigma > \lambda_k$. In this model, the three scale parameters are not uniquely identified. Traditionally, ρ is normalized to equal 1.
The expected utility per choice occasion is given by

$$EU_i^{co} = \rho \ln\left(1 + exp\left({EU_i^p}/{\rho}\right)\right)$$

Welfare Measures

With knowledge of the model parameters, it is possible to calculate welfare impacts of changes in access, site quality, or catch rate. This is given by the ratio of the change in expected utility over the season divided by the marginal utility of income. The change in net economic value over an entire season from a change in conditions is called the compensating variation (CV) for the change in condition, given by:

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

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

For some changes in conditions that prevent anglers from taking trips that they otherwise would have taken, it is possible to calculate a user day value. Examples would include closure of a site that prevents all trips to that site, or a decrease in catch rate for a specific fishing type that induces anglers to take fewer trips of that fishing type. For changes in conditions that displace angler trips, a user day value is defined as the compensating variation for the change in conditions divided by the expected number of fishing days that would be displaced by the change in conditions.

The user day value will differ depending on why angler trips are being displaced. Consider first a change in access or catch rate that discourages or prevents anglers from visiting a specific site or set of sites for a specific type of fishing. Anglers will take fewer trips to the affected site or sites, but will substitute and fish some of the displaced trips at other, unaffected sites. If the number of displaced fishing days (the decrease in fishing days at the affected site or sites) is small, then the compensating variation per displaced fishing day for fishing type k is given by $-\lambda_k/\beta$. This user day value is appropriate for use when valuing changes that affect one site or a small group of sites. It accounts for substitution away from the affected site or sites to other, unaffected sites. Alternatively, a change in conditions could discourage or prevent anglers from fishing for a specific fishing type at all sites. Anglers will fish less often for that fishing type, but will substitute and fish some of the displaced days for other, unaffected fishing types. If the number of displaced fishing days is small, then the compensating variation per displaced fishing trip is given by $-\sigma/\beta$. This user day value is appropriate for use when valuing changes that affect one fishing type across the entire study region. It accounts for substitution away from the affected fishing type to other fishing types.

Finally, a change in conditions could prevent an angler from doing any type of fishing at any site (complete closure of all recreational fishing). For an angler with a very low probability of going fishing, the user day value associated with complete loss of all fishing is given by $-\rho/\beta$. This is an extreme situation that is well outside the range of our observed data. Any estimate of this type of user day value will be very unreliable.

In all three cases, the formula for user day value is strictly valid only for changes that displace a small number of trips.

Construction of the Likelihood Function

Model parameters are estimated using maximum likelihood. The likelihood function for an entire season's trip behavior is given by

$$lnL = \sum_i \left\{ \sum_k \sum_g \left(F_{ig}^k \ln[\Pr(g,k,p)] \right) + \left(N - \sum_k \sum_g F_{ig}^k \right) \ln(1 - \Pr(p)) \right\}$$

Where

N =	number of choice occasions per year (set at 365)
F_{ig}^k =	Number of times during the season angler i took a trip to destination g to do fishing type k

Note that each angler can show up in the likelihood function up to three times: once for their 2011 trip data, once for their normal year trips, and once for their contingent behavior trips.

Estimation

Model parameters are estimated in two steps. First, the model is estimated using only 2011 trip data (actual trips taken). For the first stage regression, the participation scale parameter, ρ, is normalized to 1. Because S_i=0, CB_i=0 and $\ln(CR_j^k)$=0 for all 2011 trips, the parameters φ_k, ω_k and τ cannot be identified during the first step regression. This was done so that all parameters other than φ_k, ω_k and τ would be estimated based on observed 2011 trip behavior only, and would not be based on stated behavior data that may overstate fishing participation. In the second step, the estimated parameters from the first step regression were held fixed, and φ_k, ω_k and τ were estimated using all of the data, including 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.

We account for the possible tendency of anglers to overstate trip frequency in the normal year and contingent behavior data by estimating a parameter for each fishing type, ω_k, that captures differences in trip frequency between stated behavior and actual trips taken. A second issue with stated behavior relative to actual behavior is that survey respondents may report stated behavior choices that imply random error terms that have higher variance than that implied by actual choice behavior. It has been speculated that recreationists facing actual trip choices have more of an incentive to evaluate their own utility, reducing the variance in the error terms. To account for potential differences in error variance between hypothetical and actual trip choices, we estimate in the second stage regression new values for σ and ρ, so that the scale parameters for the hypothetical trip behavior are allowed to differ from the scale parameters for the actual 2011 trip behavior. Because we do not have information on site choice in the stated behavior data, it is not possible to estimate new values of the site choice scale parameters for stated behavior data.

Results

Overnight Trip Model

The previous version of GLMRAM modeled day trips only. In this project, we attempted to estimate an overnight trip model.

There are four main challenges that make modeling overnight trips more difficult than modeling day trips. First, the length of the trip (number of days fished) is under the control of the angler, and will tend to be correlated with the distance travelled to reach the fishing site (i.e. longer distance trips will tend to include more fishing days). Longer trips will likely generate more value for the angler, but will also cost more, particularly in lodging costs. It is difficult to model why one angler will choose a shorter trip and another will chose a longer trip. Second, the cost of lodging during an overnight trip varies widely from angler to angler, and is somewhat under the control of the angler. For example, some anglers choose to camp while on a fishing trip while others stay at a hotel. These differences in cost are difficult to measure, but have important implications for behavior. For example, an angler may report in the survey that they drove 300 miles to fish at a particular site for three days. That angler may have chosen that destination because they could stay at a friend's cabin for little or no cost. It is very difficult to model such a choice. We would need to know not only the lodging cost at the site that was chosen, but also the lodging cost at all other possible destinations. Third, anglers take far fewer overnight trips than day trips, so there is much less data on where anglers go for overnight trips. This makes it difficult to reliably estimate model parameters. Fourth, the spatial pattern of overnight trip destinations resembles a donut, with very few overnight trips taken close to home. This pattern suggests that anglers prefer destinations that are farther from home, which would imply that higher travel costs to reach a destination are viewed positively, a result that is not consistent with economic theory or intuition.

We estimated an overnight model that treats all overnight trips the same, regardless of trip length, and treats lodging costs as constant at all destinations. This approach abstracts away from two choices that are made by the angler. While the resulting model is simpler and more tractable, it loses some realism.

Unfortunately, the specified model could not be reliably estimated. The estimation method used to identify model parameters involves a search for parameter values using numerical optimization methods. Two issues arose. First, the estimated model parameters were not consistent with utility theory. Specifically, the scale parameters for the fishing type decision and the site choice decision were both larger than the scale parameter for the participation decision, a result that is not consistent with utility theory. This result may be due to the "donut hole" in trip behavior. Second, the numerical search for model parameters failed to converge within specified tolerances. While the resulting parameter estimates are likely close the estimates that would have been obtained if convergence had been achieved, the estimated standard errors for those parameter estimates are not reliable, making statistical inference about the model parameters impossible.

For these reasons, the attempt to model overnight trips was abandoned. The new GLMRAM takes the same approach as was taken in the first version of GLMRAM, where the day trip model results are multiplied by expansion factors to account for fishing days on overnight trips.

Alternative Nesting Structures

The original GLMRAM was estimated using the nesting structure shown in Figure 2. In this project, alternative nesting structures were explored. Specifically, the fishing type decision was modeled using a more complex, multi-step decision tree.

Nesting captures the idea that an angler may view some types of trips as more similar to each other than others. For example, if we consider three trips

- a trip to a stream in county A to fish for trout
- a trip to a stream in county B to fish for trout
- a trip to a lake in county A to fish for bass

It is quite possible that an angler would view the first and second trips as being more similar to each other than to the third trip. The nesting structure captures this idea by putting all trips to streams to fish for trout in one branch of the decision tree.

It may be that anglers view some fishing types as more similar to each other as well. This was explored by looking at anglers who took more than one type of fishing trip, to see whether certain combinations of fishing types tended to occur more frequently. Looking over all anglers, some pairs of fishing types were more common than would be expected if anglers were following the decision tree shown in the Figure 2. After adjusting for the relative popularity of each individual fishing type, the following fishing type combinations were more frequent than would be expected

GL Warm and GL Cold
IL Cold and RS Cold
GL Cold and Anad
RS Cold and Anad
RS Warm and IL Warm

This suggests a nesting structure where inland warm water fishing forms one branch, and all other fishing types (Great Lakes, Anadromous, and inland cold water) form a second branch. Such a nesting structure is shown in Figure 3.

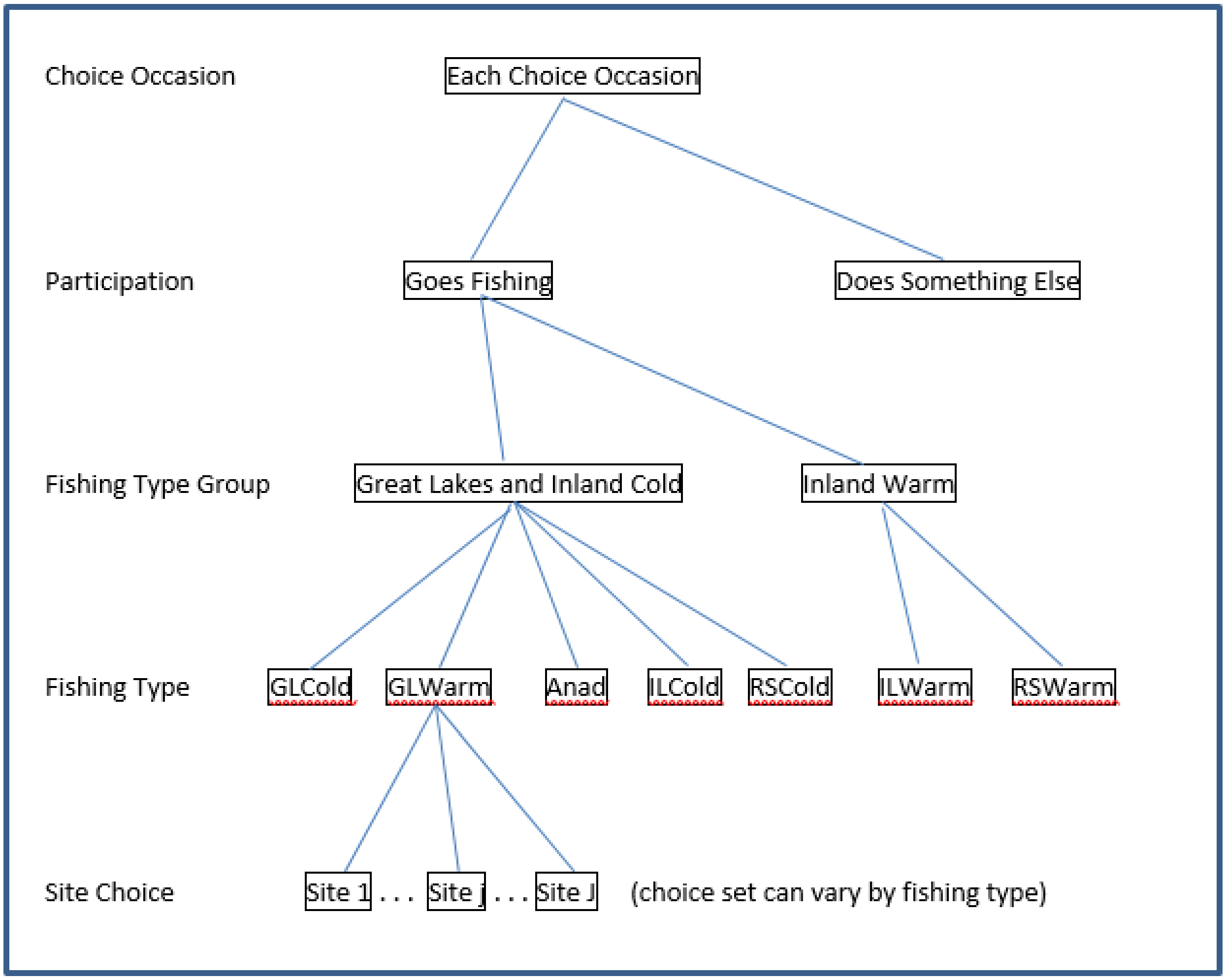

Figure 3. Alternative Nesting Structure

The nesting structure shown in Figure 3 was modeled and estimated. However, some scale parameters from lower branches were found to be larger than scale parameters from upper branches, which is inconsistent the expected utility theory, and suggests that the alternative nesting structure is not a good representation of how anglers view different fishing opportunities. Other alternative nesting structures, for example treating Great Lakes fishing as a separate nest, and treating ILCold and RSCold as a separate nest, gave similar disappointing results. For this reason, the effort to model a more complex nesting structure was abandoned, and the nesting structure in Figure 2 was adopted for the new GLMRAM estimation.

It is likely that different anglers view fishing types in different ways. Some anglers may view trout fishing on a stream as similar to bass fishing on a stream. Others may view trout fishing on a stream as similar to trout fishing on a lake. A single nesting structure may not accurately reflect all anglers' decision processes.

Day Trip Model – General Results

The likelihood function was maximized using the fmincon routine in Matlab, with numerically derived standard errors. Parameter estimates are presented in Table 1, along with numerically derived t-statistics.

An estimation where the seven site-choice scale parameters were unrestricted resulted in some site-choice scale parameters, λ_k, larger than the estimated fishing-type scale parameter, σ, which would be inconsistent with a random utility model. Hence, a common value of $\lambda_k = \lambda$ for all k fishing types is estimated. With this restriction, the scale parameters were found to follow the pattern $\lambda<\sigma<1$, as predicted by utility theory.

Coefficients for continuous site quality measures are of the expected signs and almost all are statistically significant. Counties with more shoreline miles are more likely to be visited for GLCold and GLWarm trips. Counties with more lake area are more likely to be visited for ILWarm and ILCold trips. Counties with more stream miles are more likely to be visited for RSCold and RSWarm trips. Counties with more river miles are more likely to be visited for RSWarm and Anad trips. More river miles did not have a significant impact on visitation for RSCold trips, suggesting that RSCold anglers are targeting smaller streams. Stream miles had a negative impact on Anad trips, suggesting that anadromous anglers are targeting counties located lower in the watersheds. Finally, higher values of the Aquatic Habitat Quality Score were associated with more trips for all five inland fishing types.

The second stage estimation included 2011 data, normal year data and contingent behavior data. The second stage regression results show that anglers tend to predict more trips when reporting stated behavior than they actually take (i.e. $\omega_k>0$), consistent with earlier studies. This was true for all fishing types.

For all fishing types, decreased catch rate would lead to decreased fishing participation (i.e. $\varphi^k>0$). The fishing type that was most sensitive to decreases in catch rate was GLCold, while the fishing type that was least sensitive was Anadromous.

Based on the estimation results, the user day values for changes that affect trips to a given site is \$16.88, while the user day value for changes that affect all trips of a single fishing type is \$20.21. The scale parameter for fishing type choice, σ, estimated from the hypothetical trips data was larger than that estimated from the data on 2011 trips. This would suggest that anglers predict a higher rate of substitution between fishing types than they actually exhibit. For scenario predictions, the scale parameters estimated from the 2011 data were used.

Inferred Scenario Quality Changes

Another innovation in this version of GLMRAM is the inclusion of a term to capture the possibility that survey respondents infer negative consequences from the contingent behavior scenario other than those explicitly described. Examination of the normal year and contingent behavior responses suggests that survey respondents exhibit this pattern of responses. 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 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. Or, increases in fishing effort in the unaffected categories might be expected to the extent that respondents substitute into this fishing type category. Instead, 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. 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.

Inclusion of a shifter term to capture inferred quality changes affects the estimated catch rate responsiveness coefficients. One consequence of this model refinement is that the estimated catch rate responsiveness coefficients reported here are smaller than those reported in Ready et al. 2012. The estimates reported here should be viewed as more reliable than those reported in Ready et al. 2012.

Influence of Angler Characteristics on Fishing Type Choice

The previous version of GLMRAM estimated the influence of angler characteristics on fishing frequency. The new version of GLMRAM also estimates the influence of angler characteristics on fishing type choice. Five angler characteristics were found to be influential:

- The angler's income
- Whether the angler is full time employed
- The angler's age and the square of the angler's age
- Whether the angler is female

Any of these factors can influence both the frequency of fishing (though the parameter μ) and the fishing type chosen (through the parameter δ_k). The form of the utility function requires that if a variable appears in X_i, then it must not appear in at least one Z_i^k. In the estimation here, all six variables were included in X_i, but none of the variables were included in Z_i^k for the most popular fishing type, ILWarm. In this way, μ captures the influence of each variable on participation, and δ_k captures the relative effect of the parameter on fishing type choice, as compared to choosing ILWarm. A positive value of μ for a variable means that higher values of that variable tend to make an angler fish more frequently. A positive value of δ_k for a given fishing type means that higher values of that variable make the angler more likely to choose that fishing type, compared to ILWarm.

In the estimation, it was found the while age and income affect participation, they were not strong predictors of fishing type. These were therefore included in X_i, but not in Z_i^k. The estimation results for μ show that higher income anglers fish less frequently, full time employed anglers fish less frequently, older anglers fish more frequently (but the relationship is curved, with the effect diminishing with age), and female anglers fish less frequently.

The estimation results for δ_k show that anglers who are full time employed are more likely to engage in GLCold, RSCold, RSWarm and Anad, relative to ILWarm. Female anglers are less likely to engage in all fishing types except RSWarm and ILWarm.

Boat ownership was found to be strongly correlated with fishing type choice. However, an analysis of boat ownership found that anglers who live closer to the Great Lakes are significantly more likely to own boats. This shows that boat ownership is a choice made by anglers in response to fishing opportunities. If fishing quality changes, the decision whether to own a boat may change. For this reason, boat ownership should not be used to predict fishing behavior in the face of changing fishing quality.

Creation of a Standalone Simulation Program

The model described here was used to run simulations for the scenarios developed by the panel of workshop participants. We are in the process of developing a standalone executable program that will run scenario simulations without requiring access to Matlab. This is being done using Matlab’s Compiler program. The standalone simulation program will be made available to ecological modelers, so that they can incorporate angler behavioral response into ecological models such as Ecopath/Ecosim. Initial testing will be conducted collaboratively with workshop participants. After the program is refined, it will be made broadly available through web download.

Table 2. GLMRAM model estimation results

Variable	Estimate	T-Stat	Description
<u>Site Quality Measures - GLCold</u>			
GLCold	-1.7450	-32.12	Fishing-type-specific constant
GLCold Grp 1	0.0565	4.61	County group constant - County group 1
GLCold Grp 2	-0.0049	-0.71	County group constant - County group 2
GLCold Grp 3	-0.0049	-0.59	County group constant - County group 3
GLCold Grp 4	-0.0958	-8.80	County group constant - County group 4
GLCold Grp 5	-0.0464	-8.02	County group constant - County group 5
GLCold Grp 6	-0.0358	-5.49	County group constant - County group 6
GLCold Grp 7	-0.1041	-7.70	County group constant - County group 7
GLCold Grp 8	-0.1724	-10.73	County group constant - County group 8
GLCold Grp 9	0.0206	2.81	County group constant - County group 9
GLCold Grp 10	0.0041	0.53	County group constant - County group 10
GLCold x shoremi	0.4802	7.16	Shoreline Miles
<u>Site Quality Measures – GLWarm</u>			
GLWarm	-1.7899	-33.67	Fishing-type-specific constant
GLWarm Grp 1	0.0086	0.41	County group constant - County group 1
GLWarm Grp 2	-0.0138	-1.56	County group constant - County group 2
GLWarm Grp 3	-0.0160	-1.26	County group constant - County group 3
GLWarm Grp 4	0.0261	3.46	County group constant - County group 4
GLWarm Grp 5	-0.0473	-6.40	County group constant - County group 5
GLWarm Grp 6	-0.0530	-5.66	County group constant - County group 6
GLWarm Grp 7	0.0737	8.39	County group constant - County group 7
GLWarm Grp 8	0.0809	10.22	County group constant - County group 8
GLWarm Grp 9	0.1236	12.18	County group constant - County group 9
GLWarm Grp 10	0.0929	8.96	County group constant - County group 10
GLWarm x Shoremi	0.8313	10.96	Shoreline Miles
<u>Site Quality Measures – Anadromous</u>			
Anad	-1.9876	-40.81	Fishing-type-specific constant
Anad Grp 1	0.0488	1.41	County group constant - County group 1
Anad Grp 2	0.0177	1.28	County group constant - County group 2
Anad Grp 3	0.0908	7.30	County group constant - County group 3
Anad Grp 4	-0.0374	-1.95	County group constant - County group 4
Anad Grp 5	0.0652	6.64	County group constant - County group 5
Anad Grp 6	0.0556	6.05	County group constant - County group 6
Anad Grp 7	0.0346	2.52	County group constant - County group 7
Anad Grp 8	0.0129	1.10	County group constant - County group 8
Anad Grp 9	0.1457	11.82	County group constant - County group 9

Anad Grp 10	0.1309	10.55	County group constant - County group 10
Anad x habscore	-0.0701	-3.20	Aquatic habitat quality score
Anad x strms34	0.5154	6.26	Miles of streams (stream order 3-4)
Anad x strms57	-0.0032	-17.61	Miles of rivers (stream order 5-7)
Site Quality Measures – ILCold			
ILCold	-1.9997	-40.38	Fishing-type-specific constant
IL x ILCold	-0.0008	-0.09	State-specific constant – Illinois
IN x ILCold	-0.0039	-0.48	State-specific constant – Indiana
MN x ILCold	-0.0759	-4.95	State-specific constant - Minnesota
NY x ILCold	0.0901	10.58	State-specific constant - New York
OH x ILCold	0.0228	3.07	State-specific constant - Ohio
PA x ILCold	0.1055	12.18	State-specific constant - Pennsyvlania
WI x ILCold	-0.0616	-7.55	State-specific constant - Wisconsin
ILCold x habscore	0.0472	10.03	Aquatic habitat quality score
ILCold x lake area	0.1573	9.35	Lake Area
Site Quality Measures – ILWarm			
ILWarm	-1.7739	-33.23	Fishing-type-specific constant
IL x ILWarm	-0.0202	-5.04	State-specific constant – Illinois
IN x ILWarm	-0.0284	-8.84	State-specific constant – Indiana
MN x ILWarm	-0.0278	-5.43	State-specific constant - Minnesota
NY x ILWarm	0.0213	3.84	State-specific constant - New York
OH x ILWarm	-0.0163	-4.68	State-specific constant - Ohio
PA x ILWarm	0.0121	2.56	State-specific constant - Pennsyvlania
WI x ILWarm	0.0097	2.86	State-specific constant - Wisconsin
ILWarm x habscore	0.0273	11.96	Aquatic habitat quality score
ILWarm x lake area	0.1839	17.11	Lake Area
Site Quality Measures – RSCold			
RSCold	-2.0241	-41.36	Fishing-type-specific constant
IL x RSCold	-0.1939	-7.93	State-specific constant – Illinois
IN x RSCold	-0.0441	-5.52	State-specific constant – Indiana
MN x RSCold	-0.1093	-7.62	State-specific constant - Minnesota
NY x RSCold	0.0668	9.25	State-specific constant - New York
OH x RSCold	-0.0381	-5.31	State-specific constant - Ohio
PA x RSCold	0.0860	11.31	State-specific constant - Pennsyvlania
WI x RSCold	-0.0713	-10.43	State-specific constant - Wisconsin
RSCold x habscore	0.0721	15.29	Aquatic habitat quality score
RSCold x strms34	0.0402	3.50	Miles of streams (stream order 3-4)
RSCold x strms57	0.2320	5.03	Miles of rivers (stream order 5-7)
Site Quality Measures - RSWarm			

RSWarm	-1.8546	-35.75	Fishing-type-specific constant
IL x RSWarm	-0.0052	-0.95	State-specific constant – Illinois
IN x RSWarm	0.0024	0.56	State-specific constant – Indiana
MN x RSWarm	-0.0403	-4.98	State-specific constant - Minnesota
NY x RSWarm	0.0569	8.95	State-specific constant - New York
OH x RSWarm	0.0084	2.04	State-specific constant - Ohio
PA x RSWarm	0.0506	9.05	State-specific constant - Pennsyvlania
WI x RSWarm	0.0230	5.47	State-specific constant - Wisconsin
RSWarm x habscore	-1.8546	-35.75	Aquatic habitat quality score
RSWarm x strms34	-1.8546	-35.75	Miles of streams (stream order 3-4)
RSWarm x strms57	-1.8546	-35.75	Miles of rivers (stream order 5-7)
Travel Cost			
β	-0.00322	-17.61	Round Trip Travel Cost
Angler Characteristics that affect participation decision			
μ – ln(income)	-0.1277	-14.09	natural log of income/10000
μ – FT employment	-0.1798	-13.51	=1 if full time employed
μ - Age	1.3221	6.10	Age/100
μ – Age squared	-2.7370	-12.40	(Age/100)^2
μ - female	-0.6665	-36.53	=1 if angler is female
Angler Characteristics that affect fishing type choice - GLCold			
δ – FT employment	0.0301	7.64	=1 if full time employed
δ – female	-0.0243	-3.57	=1 if angler is female
Angler Characteristics that affect fishing type choice - GLWarm			
δ – FT employment	0.0043	1.33	=1 if full time employed
δ – female	-0.0144	-2.54	=1 if angler is female
Angler Characteristics that affect fishing type choice - ILCold			
δ – FT employment	0.0032	0.84	=1 if full time employed
δ – female	-0.0197	-2.94	=1 if angler is female
Angler Characteristics that affect fishing type choice - RSCold			
δ – FT employment	0.0190	5.56	=1 if full time employed
δ – female	-0.0322	-5.74	=1 if angler is female
Angler Characteristics that affect fishing type choice - RSWarm			
δ – FT employment	0.0110	4.76	=1 if full time employed
δ – female	0.0013	0.36	=1 if angler is female
Angler Characteristics that affect fishing type choice - Anad			

δ – FT employment	0.0530	9.47	=1 if full time employed
δ – female	-0.0678	-5.82	=1 if angler is female
<u>Scale Parameters – 2011 Trip Data</u>			
σ – 2011 data	0.0650	15.95	Scale parameter for fishing type decision
λ – 2011 data	0.0543	14.00	Scale parameter for site choice decision
<u>Catch Rate Index Coefficient</u>			
φ – GLCold	0.1594	9.33	Catch Rate Index Coefficient for GLCold
φ - GLWarm	0.0877	14.57	Catch Rate Index Coefficient for GLWarm
φ – ILCold	0.0623	4.45	Catch Rate Index Coefficient for ILCold
φ – ILWarm	0.0610	8.60	Catch Rate Index Coefficient for ILWarm
φ – RSCold	0.1311	39.19	Catch Rate Index Coefficient for RSCold
φ – RSWarm	0.1342	16.69	Catch Rate Index Coefficient for RSWarm
φ – Anad	0.0362	5.50	Catch Rate Index Coefficient for Anad
<u>Stated Behavior Data Shifters</u>			
ω - GLCold	0.5112	109.09	Stated trip data constant for GLCold
ω - GLWarm	0.6076	55.25	Stated trip data constant for GLWarm
ω - ILCold	0.4619	110.54	Stated trip data constant for ILCold
ω - ILWarm	1.1443	369.48	Stated trip data constant for ILWarm
ω - RSCold	0.7401	190.15	Stated trip data constant for RSCold
ω - RSWarm	0.8576	192.33	Stated trip data constant for RSWarm
ω - Anad	0.3843	69.10	Stated trip data constant for Anad
Inferred Quality Change Shifter			
τ	-3.3936	-176.46	Shifter for Contingent Behavior Data
<u>Scale Parameters – Stated Trips Data</u>			
σ – Stated Behavior	0.3574	512.83	Scale parameter for fishing type choice
ρ – Stated Behavior	0.6750	274.72	Scale parameter for participation choice

FUTURE EFFECTS OF AQUATIC INVASIVE SPECIES ON SPORT FISHING

The possible ecological effects of AIS described earlier in this report are related to but distinct from, the social and economic effects of AIS on recreational fishing. A particular species of sport fish could be severely affected by AIS, but if the overall effort for and harvest of that species was minimal to begin with, that AIS would have minimal impact on recreational fishing participation and value. In addition, fishing participation is not always directly correlated with the size of preferred recreational fish populations. Some anglers, particularly those who fish anadromous runs, are much less motivated by catch rate than others, and even if fish populations decline, they will keep fishing. Also, many anglers will switch from a preferred type of fishing to a less preferred type as fish populations decrease, and so their participation decreases to a lesser degree than fish populations do. In this section, we project the effects of each of the AIS scenarios we developed on recreational fishing participation and economic value.

Asian Carp

Scenarios AC-1a and AC-2a

While scenarios AC-1a and AC-2a differ in the assumed spatial distribution of Asian carp within the lakes, the resulting impacts on sport fish catch rates are identical. In these scenarios (Table 2), Asian carp would have a small negative effect (5%) on salmonids throughout the Great Lakes and affect certain warmwater species in high productivity areas. Walleye would decrease in high productivity areas, but yellow perch and smallmouth bass would increase.

The economic model projects a relatively small effect of this scenario on fishing participation in the study region. The total number of fishing trips was projected to decrease by only 0.02%, with the biggest decreases in fishing participation by anglers from Michigan, Indiana, New York, Wisconsin, and particularly Illinois (Table 4).

The change in consumer surplus follows a similar pattern. The overall mean loss in consumer surplus across all Great Lakes states would be \$2.79/angler, but the loss would be higher in the states with the biggest decrease in fishing participation. In Illinois, consumer surplus would decrease by \$10.49/angler (Table 4). The total consumer surplus loss under this scenario would be \$14,635,449.

Because salmonids in the Great Lakes would be the most negatively affected under this scenario, the biggest drop in fishing trips would be trips for Great Lakes coldwater species (10.50% decrease) (Table 5). A small drop in the number of anadromous fishing trips, which are less sensitive to changes in fishing quality, was observed. Substantial increases in other types of fishing would nearly make up for the decrease in the Great Lakes coldwater fishery. The Great Lakes warmwater fishery showed the biggest percentage increase as anglers switched over from the less productive salmonid fishery and took advantage of the increase in some species in the warmwater fishery.

Anglers from Ohio would increase their overall number of fishing trips and would experience an increase in average consumer surplus of \$5.27 (Table 4). The Great Lakes fishery in Ohio is largely a warmwater fishery (Table 5), and the harvest is dominated by yellow perch, which increased under this scenario.

Table 3. Tabular summary of scenarios describing possible effects of Asian carp on recreational fish populations.

	Warmwater Species Affected		Salmonid Species Affected	
Scenario	Area Affected	Species Effects	Area Affected	Species Effects
1a	Green Bay, Saginaw Bay, Bay of Quinte, Lake St. Clair, and the Western and Central basins of Lake Erie	Largemouth and smallmouth bass (10% increase). Yellow perch (10% increase) Walleye (10% decrease)	All Great Lakes	5% decrease in all salmonids
1b	Green Bay, Saginaw Bay, Bay of Quinte, Lake St. Clair, and the Western and Central basins of Lake Erie	Largemouth and smallmouth bass (10% increase). Yellow perch (15% increase) Walleye (25% increase)	All Great Lakes	5% decrease in all salmonids
1c	Green Bay, Saginaw Bay, Bay of Quinte, Lake St. Clair, and the Western and Central basins of Lake Erie	Largemouth and smallmouth bass (10% decrease) Yellow perch and walleye (40% decrease)	All Great Lakes	5% decrease in all salmonids
2a	Green Bay, Saginaw Bay, Bay of Quinte, Lake St. Clair, and the Western and Central basins of Lake Erie	Largemouth and smallmouth bass (10% increase). Yellow perch (10% increase) Walleye (10% decrease)	All Great Lakes	5% decrease in all salmonids
2b	Green Bay, Saginaw Bay, Bay of Quinte, Lake St. Clair, and the Western and Central basins of Lake Erie	Largemouth and smallmouth bass (10% increase). Yellow perch (10% increase) Walleye (10% decrease)	All Great Lakes (warmwater) Lakes Michigan and Ontario (salmonids)	Coho and chinook salmon (20% decrease)
2c	Green Bay, Saginaw Bay, Bay of Quinte, Lake St. Clair, and the Western and Central basins of Lake Erie	Largemouth and smallmouth bass (10% increase). Yellow perch (10% increase) Walleye (10% decrease)	All Great Lakes (warmwater) Lakes Michigan and Ontario (salmonmids)	Coho and chinook salmon (80% decrease)

Table 4. Projected effects of Asian carp scenario 1a on number of fishing trips and consumer surplus (CS) of fishing by state of residence.

State of Residence	Anglers in State	Total Trips Taken - Baseline	Total Trips Taken - Scenario	Average Fishing Days per Angler - Baseline	Average Fishing Days per Angler- Scenario	Percent Change Fishing Days	Change in Total Fishing Days	Average CS Change per Angler	Total CS Change
Illinois	605,649	24,044,265	24,025,601	39.70	39.67	-0.08%	-18,664	-$10.49	-$6,351,216
Indiana	332,061	13,780,532	13,775,836	41.50	41.49	-0.03%	-4,696	-$4.84	-$1,605,948
Michigan	805,792	28,041,562	28,033,960	34.80	34.79	-0.03%	-7,601	-$3.24	-$2,613,144
Minnesota	1,024,003	27,852,882	27,850,806	27.20	27.20	-0.01%	-2,075	-$0.69	-$708,532
New York	589,557	18,983,735	18,977,465	32.20	32.19	-0.03%	-6,271	-$3.64	-$2,147,248
Ohio	520,789	16,456,932	16,464,970	31.60	31.62	0.05%	8,038	$5.27	$2,745,500
Pennsylvania	635,577	25,295,965	25,294,751	39.80	39.80	0.00%	-1,213	-$0.65	-$416,161
Wisconsin	728,604	24,408,234	24,397,858	33.50	33.49	-0.04%	-10,376	-$4.86	-$3,538,701
Totals	5,242,032	178,864,106	178,821,248	34.12	34.11	-0.02%	-42,858	-$2.79	-$14,635,449

Table 5. Projected effects of Asian carp scenario 1a on number of fishing trips by fishing destination and fishing type.

Dest 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	1,725,547	1,552,131	809,585	825,584	-	-	13,869,165	14,017,995	16,404,297	16,395,710
IN	713,613	641,661	308,497	314,527	614,066	610,663	11,513,909	11,570,772	13,150,084	13,137,622
MI	1,967,235	1,759,516	4,113,200	4,204,888	1,383,431	1,368,746	21,985,573	22,091,918	29,449,440	29,425,067
MN	161,547	144,093	40,312	40,812	19,031	18,754	24,556,699	24,581,996	24,777,588	24,785,655
NY	773,423	689,886	1,553,377	1,571,229	921,868	913,903	15,515,243	15,576,936	18,763,911	18,751,954
OH	340,028	295,296	2,179,052	2,344,267	501,257	483,470	11,702,794	11,632,425	14,723,132	14,755,458
PA	151,952	135,084	373,963	375,423	272,186	270,932	24,636,998	24,646,195	25,435,100	25,427,634
WI	2,359,265	2,114,406	1,691,497	1,754,122	357,750	353,440	27,003,034	27,170,666	31,411,546	31,392,634
Total	8,192,611	7,332,073	11,069,483	11,430,851	4,069,589	4,019,907	150,783,415	151,288,903	174,115,099	174,071,734
Change		-860,538		361,368		-49,682		505,487		-43,365
Change (%)		-10.50%		3.26%		-1.22%		0.34%		-0.02%

Scenario AC-1b

In this scenario (Table 2), Asian carp would have a small negative effect (5%) on salmonids throughout the Great Lakes, but there would be increases in largemouth and smallmouth bass, yellow perch, and particularly walleye in high productivity areas (Green Bay, Saginaw Bay, Bay of Quinte, Lake St. Clair, and the Western and Central basins of Lake Erie).

The economic model projects a very small positive overall effect of this scenario on fishing participation and value in the study region (Table 6). The number of fishing trips was projected to increase by only 0.01%. Increases of 0.03% would be seen in Michigan and Minnesota, and an increase of 0.48% would be seen in Ohio, while the largest percent decreases would be seen in Illinois, Indiana and Pennsylvania (Table 7).

The overall mean increase in consumer surplus would be $0.74/angler, but Michigan and Ohio would have gains in consumer surplus of $11.03/angler and $14.75/angler respectively, while Illinois would see a loss in consumer surplus of $9.55/angler (Table 6). Total consumer surplus over all states under this scenario would increase by $3,885,262, although there would be losses in particular states.

Because salmonids in the Great Lakes were negatively affected under this scenario to a similar degree as they were under Scenario 1a, this scenario generated a similar loss in fishing trips for Great Lakes coldwater species (10.89%) (Table 7). A small drop in the number of anadromous fishing trips was would also occur. However, the increase in the number of trips taken in the Great Lakes warmwater fishery (9.24%) would more than compensate for losses in other types of fishing trips.

The increases in fishing trips and consumer surplus for anglers from Ohio and Michigan (Table 6) can be attributed to the fact that these states have Great Lakes warmwater fisheries that would improve under this scenario (Table 7).

Table 6. Projected effects of Asian carp scenario 1b on number of fishing trips and consumer surplus (CS) of fishing by state of residence.

State of Residence	Anglers in State	Total Trips Taken - Baseline	Total Trips Taken - Scenario	Average Fishing Days per Angler - Baseline	Average Fishing Days per Angler- Scenario	Percent Change Fishing Days	Change in Total Fishing Days	Average CS Change per Angler	Total CS Change
Illinois	605,649	24,044,265	24,027,264	39.70	39.67	-0.07%	-17,001	-$9.55	-$5,781,316
Indiana	332,061	13,780,532	13,776,021	41.50	41.49	-0.03%	-4,511	-$4.65	-$1,543,373
Michigan	805,792	28,041,562	28,067,614	34.80	34.83	0.09%	26,052	$11.03	$8,885,256
Minnesota	1,024,003	27,852,882	27,850,845	27.20	27.20	-0.01%	-2,036	-$0.68	-$695,266
New York	589,557	18,983,735	18,977,473	32.20	32.19	-0.03%	-6,262	-$3.64	-$2,144,323
Ohio	520,789	16,456,932	16,479,383	31.60	31.64	0.14%	22,451	$14.75	$7,680,130
Pennsylvania	635,577	25,295,965	25,295,327	39.80	39.80	0.00%	-638	-$0.34	-$218,540
Wisconsin	728,604	24,408,234	24,401,498	33.50	33.49	-0.03%	-6,736	-$3.15	-$2,297,307
Totals	5,242,032	178,864,106	178,875,424	34.12	34.12	0.01%	11,318	$0.74	$3,885,262

Table 7. Projected effects of Asian carp scenario 1b on number of fishing trips by fishing destination and fishing type.

Dest 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	1,725,547	1,550,905	809,585	824,837	-	-	13,869,165	14,011,088	16,404,297	16,386,830
IN	713,613	641,595	308,497	314,469	614,066	610,569	11,513,909	11,568,909	13,150,084	13,135,541
MI	1,967,235	1,746,051	4,113,200	4,612,354	1,383,431	1,352,234	21,985,573	21,748,679	29,449,440	29,459,317
MN	161,547	144,093	40,312	40,812	19,031	18,754	24,556,699	24,581,784	24,777,588	24,785,443
NY	773,423	689,800	1,553,377	1,570,730	921,868	913,796	15,515,243	15,576,457	18,763,911	18,750,783
OH	340,028	286,495	2,179,052	2,528,141	501,257	468,686	11,702,794	11,509,960	14,723,132	14,793,282
PA	151,952	134,425	373,963	371,654	272,186	269,478	24,636,998	24,630,895	25,435,100	25,406,452
WI	2,359,265	2,107,334	1,691,497	1,828,765	357,750	352,256	27,003,034	27,120,974	31,411,546	31,409,328
Total	8,192,611	7,300,698	11,069,483	12,091,762	4,069,589	3,985,772	150,783,415	150,748,744	174,115,099	174,126,976
Change		-891,913		1,022,278		-83,817		-34,671		11,877
Change (%)		-10.89%		9.24%		-2.06%		-0.02%		0.01%

Scenario AC-1c

In this scenario, Asian carp would have a small negative effect (5%) on salmonids throughout the Great Lakes and negative effects on warmwater species in high productivity areas. Largemouth and smallmouth bass would decrease in high productive areas by 10%, and yellow perch and walleye would decrease by 40%.

The economic model projects a negative effect of this scenario on fishing participation and consumer surplus (Table 8). This effect is larger than the effects seen under either of the previous two scenarios because warmwater species are now being negatively affected. The number of fishing trips would decrease by 0.13%. The largest decreases in fishing participation (Table 9) would be seen Michigan in Michigan (0.23%), Wisconsin (0.27%) and Ohio (1.43%). Illinois and Pennsylvania would actually see increases in total fishing activity, as anglers switch from Great Lakes fishing to inland fishing.

The projected mean decrease in consumer surplus was $14.88/angler (Table 8), much higher than under the previous two scenarios. Ohio and Michigan would see decrease in consumer surplus of $41.93/angler and $41.73/angler, respectively. Total consumer surplus across the GL basin under this scenario would decrease by $77,991,055.

Fishing trips would decline for both Great Lakes coldwater species (9.04%) and Great Lakes warmwater species (18.52%) (Table 9). Small increases would be seen for the other fishing types.

Table 8. Projected effects of Asian carp scenario 1c on number of fishing trips and consumer surplus (CS) of fishing by state of residence.

State of Residence	Anglers in State	Total Trips Taken - Baseline	Total Trips Taken - Scenario	Average Fishing Days per Angler - Baseline	Average Fishing Days per Angler- Scenario	Percent Change Fishing Days	Change in Total Fishing Days	Average CS Change per Angler	Total CS Change
Illinois	605,649	24,044,265	24,019,322	39.70	39.66	-0.10%	-24,943	-$14.04	-$8,502,693
Indiana	332,061	13,780,532	13,774,973	41.50	41.48	-0.04%	-5,558	-$5.71	-$1,897,148
Michigan	805,792	28,041,562	27,942,981	34.80	34.68	-0.35%	-98,581	-$41.73	-$33,628,248
Minnesota	1,024,003	27,852,882	27,850,671	27.20	27.20	-0.01%	-2,211	-$0.74	-$754,674
New York	589,557	18,983,735	18,977,429	32.20	32.19	-0.03%	-6,307	-$3.66	-$2,159,710
Ohio	520,789	16,456,932	16,393,123	31.60	31.48	-0.39%	-63,809	-$41.93	-$21,835,100
Pennsylvania	635,577	25,295,965	25,292,193	39.80	39.79	-0.01%	-3,772	-$2.04	-$1,294,832
Wisconsin	728,604	24,408,234	24,385,012	33.50	33.47	-0.10%	-23,222	-$10.87	-$7,918,650
Totals	5,242,032	178,864,106	178,635,704	34.12	34.08	-0.13%	-228,403	-$14.88	-$77,991,055

Table 9. Projected effects of Asian carp scenario 1c on number of fishing trips by fishing destination and fishing type.

Dest 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	1,725,547	1,557,017	809,585	828,762	-	-	13,869,165	14,045,640	16,404,297	16,431,419
IN	713,613	641,920	308,497	314,759	614,066	611,026	11,513,909	11,579,055	13,150,084	13,146,760
MI	1,967,235	1,793,279	4,113,200	3,083,507	1,383,431	1,415,188	21,985,573	23,089,959	29,449,440	29,381,933
MN	161,547	144,093	40,312	40,812	19,031	18,754	24,556,699	24,582,746	24,777,588	24,786,405
NY	773,423	690,314	1,553,377	1,573,993	921,868	914,432	15,515,243	15,579,336	18,763,911	18,758,076
OH	340,028	345,577	2,179,052	1,304,462	501,257	568,335	11,702,794	12,293,982	14,723,132	14,512,355
PA	151,952	138,380	373,963	396,821	272,186	278,225	24,636,998	24,722,583	25,435,100	25,536,009
WI	2,359,265	2,141,360	1,691,497	1,476,286	357,750	357,944	27,003,034	27,352,706	31,411,546	31,328,296
Total	8,192,611	7,451,939	11,069,483	9,019,403	4,069,589	4,163,904	150,783,415	153,246,006	174,115,099	173,881,253
Change		-740,672		-2,050,080		94,314		2,462,591		-233,846
Change (%)		-9.04%		-18.52%		2.32%		1.63%		-0.13%

Scenario AC-2b

In this scenario (Table 2), coho and chinook salmon would decrease by 20% in Lakes Michigan and Ontario. We assumed that warmwater species would be affected as under scenario 1a, the scenario that had mixed positive and negative effects on warmwater species.

The economic model projects a negative overall effect of this scenario on both participation and value (Table 10). The number of fishing trips was projected to decrease by 0.08%. By destination state (Table 1), the largest percent decrease in fishing trips would occur in Indiana (0.31%) with decreases also in Wisconsin (0.19%), Illinois (0.20%), Michigan (0.11%), and New York (0.11%). Ohio would see an increase in the number of fishing trips (0.22%).

The overall mean decrease in consumer surplus would be $9.41/angler (Table 10). Illinois would suffer a decrease in mean consumer surplus ($34.44) more than twice that of any other state. Consumer surplus in Ohio would increase by $5.27/angler. Total consumer surplus under this scenario would decrease by $49,330,998.

Because the Great Lakes coldwater fishery would be most negatively affected, the number of trips for this type of fishing would decrease substantially, by 27.69% (Table 11). Anadromous fishing would also decrease, but by only 2.02%. Great Lakes warmwater fishing would show an increase (4.65%),as would inland fishing (1.12%).

The biggest loss in fishing trips for salmonids would be in Illinois, Wisconsin, and Michigan (Table 11).

Table 10. Projected effects of Asian carp scenario 2b on number of fishing trips and consumer surplus (CS) of fishing by state of residence.

State of Residence	Anglers in State	Total Trips Taken - Baseline	Total Trips Taken - Scenario	Average Fishing Days per Angler - Baseline	Average Fishing Days per Angler- Scenario	Percent Change Fishing Days	Change in Total Fishing Days	Average CS Change per Angler	Total CS Change
Illinois	605,649	24,044,265	23,982,976	39.70	39.60	-0.25%	-61,289	-$34.44	-$20,856,533
Indiana	332,061	13,780,532	13,765,121	41.50	41.45	-0.11%	-15,411	-$15.87	-$5,268,213
Michigan	805,792	28,041,562	28,016,042	34.80	34.77	-0.09%	-25,520	-$10.85	-$8,739,933
Minnesota	1,024,003	27,852,882	27,850,779	27.20	27.20	-0.01%	-2,103	-$0.70	-$718,018
New York	589,557	18,983,735	18,970,929	32.20	32.18	-0.07%	-12,806	-$7.43	-$4,382,878
Ohio	520,789	16,456,932	16,464,970	31.60	31.62	0.05%	8,038	$5.27	$2,745,483
Pennsylvania	635,577	25,295,965	25,294,725	39.80	39.80	0.00%	-1,239	-$0.67	-$425,261
Wisconsin	728,604	24,408,234	24,373,965	33.50	33.45	-0.14%	-34,269	-$16.04	-$11,685,645
Totals	5,242,032	178,864,106	178,719,507	34.12	34.09	-0.08%	-144,600	-$9.41	-$49,330,998

Table 11. Projected effects of Asian carp scenario 2b on number of fishing trips by fishing destination and fishing type.

Dest 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	1,725,547	1,136,365	809,585	863,913	-	-	13,869,165	14,370,843	16,404,297	16,371,121
IN	713,613	461,283	308,497	328,733	614,066	615,167	11,513,909	11,704,366	13,150,084	13,109,550
MI	1,967,235	1,508,172	4,113,200	4,227,654	1,383,431	1,347,433	21,985,573	22,334,079	29,449,440	29,417,339
MN	161,547	144,100	40,312	40,813	19,031	18,754	24,556,699	24,587,036	24,777,588	24,790,702
NY	773,423	604,492	1,553,377	1,588,429	921,868	905,900	15,515,243	15,644,801	18,763,911	18,743,622
OH	340,028	295,323	2,179,052	2,344,332	501,257	483,479	11,702,794	11,632,888	14,723,132	14,756,020
PA	151,952	135,120	373,963	375,458	272,186	270,947	24,636,998	24,647,870	25,435,100	25,429,394
WI	2,359,265	1,639,213	1,691,497	1,814,828	357,750	345,633	27,003,034	27,550,774	31,411,546	31,350,448
Total	8,192,611	5,924,067	11,069,483	11,584,159	4,069,589	3,987,313	150,783,415	152,472,656	174,115,099	173,968,196
Change		-2,268,543		514,676		-82,276		1,689,241		-146,903
Change (%)		-27.69%		4.65%		-2.02%		1.12%		-0.08%

Scenario AC-2c

In this scenario (Table 2), coho and chinook salmon would decrease by 80% in Lakes Michigan and Ontario. We assumed that warmwater species would be affected as under scenario 1a. This is an extreme scenario that involves decreases in catch rates outside the range of reductions included in the scenarios presented to survey respondents. As such, model projections should be interpreted with caution.

The economic model projects a negative effect of this scenario on fishing participation and value in the study region (Table 12). The number of fishing trips would decrease by 0.24%. By destination state (Table 13), the largest percentage decrease in fishing participation would occur in Wisconsin (0.62%), followed by Michigan (0.27%), Illinois (0.26%) and New York (0.25%). Ohio would see an increase (0.23%) in the number of fishing trips.

The overall mean decrease in consumer surplus would be $26.45/angler (Table 12), the largest under any of the Asian carp scenarios. Illinois would suffer a decrease in mean consumer surplus/angler ($91.66) over twice that of any other state. Consumer surplus in Ohio would increase by $5.27/angler. Total consumer surplus under this scenario would decrease by $138,672,867.

Because the Great Lakes coldwater fishery would be severely negatively affected in Lakes Michigan and Ontario, the number of trips for this type of fishing would decrease by 71.72% (Table 13). Anadromous fishing would also decrease, but by only 10.80%. Great Lakes warmwater fishing would show the greatest percentage increase (8.55%). Inland fishing would also increase (3.29%).

The loss in Great Lakes fishing trips for salmonids would be particularly severe in Wisconsin, Illinois, and Indiana with losses of 83% to 95% (Table 13). Michigan and New York would both have losses of 55-57% in this fishing type, too. The percentage increases in Great Lakes warmwater fishing would be highest in Indiana, Illinois, and Wisconsin, as anglers substitute away from Great Lakes coldwater species to Great Lakes warmwater species.

Table 12. Projected effects of Asian carp scenario 2c on number of fishing trips and consumer surplus (CS) of fishing by state of residence.

State of Residence	Anglers in State	Total Trips Taken - Baseline	Total Trips Taken - Scenario	Average Fishing Days per Angler - Baseline	Average Fishing Days per Angler- Scenario	Percent Change Fishing Days	Change in Total Fishing Days	Averag e CS Change per Angler	Total CS Change
Illinois	605,649	24,044,265	23,881,089	39.70	39.43	-0.68%	-163,176	-$91.66	-$55,514,783
Indiana	332,061	13,780,532	13,738,621	41.50	41.37	-0.30%	-41,910	-$43.13	-$14,320,837
Michigan	805,792	28,041,562	27,963,486	34.80	34.70	-0.28%	-78,075	-$33.14	-$26,704,354
Minnesota	1,024,003	27,852,882	27,850,710	27.20	27.20	-0.01%	-2,172	-$0.72	-$741,520
New York	589,557	18,983,735	18,950,004	32.20	32.14	-0.18%	-33,731	-$19.57	-$11,539,361
Ohio	520,789	16,456,932	16,464,970	31.60	31.62	0.05%	8,038	$5.27	$2,745,406
Pennsylvania	635,577	25,295,965	25,294,644	39.80	39.80	-0.01%	-1,321	-$0.71	-$453,791
Wisconsin	728,604	24,408,234	24,313,940	33.50	33.37	-0.39%	-94,294	-$44.12	-$32,143,628
Totals	5,242,032	178,864,106	178,457,465	34.12	34.04	-0.23%	-406,641	-$26.45	-$138,672,867

Table 13. Projected effects of Asian carp scenario 2c on number of fishing trips by fishing destination and fishing type.

Dest 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	1,725,547	112,091	809,585	965,180	-	-	13,869,165	15,284,680	16,404,297	16,361,952
IN	713,613	36,484	308,497	366,972	614,066	574,013	11,513,909	12,061,475	13,150,084	13,038,944
MI	1,967,235	843,260	4,113,200	4,297,997	1,383,431	1,157,231	21,985,573	23,072,097	29,449,440	29,370,584
MN	161,547	144,143	40,312	40,813	19,031	18,755	24,556,699	24,599,628	24,777,588	24,803,339
NY	773,423	346,402	1,553,377	1,645,554	921,868	856,356	15,515,243	15,868,786	18,763,911	18,717,097
OH	340,028	295,427	2,179,052	2,344,510	501,257	483,511	11,702,794	11,634,082	14,723,132	14,757,530
PA	151,952	135,236	373,963	375,560	272,186	270,999	24,636,998	24,653,087	25,435,100	25,434,882
WI	2,359,265	403,967	1,691,497	1,979,641	357,750	269,199	27,003,034	28,564,583	31,411,546	31,217,390
Total	8,192,611	2,317,010	11,069,483	12,016,228	4,069,589	3,630,063	150,783,415	155,738,416	174,115,099	173,701,718
Change		-5,875,600		946,745		-439,526		4,955,001		-413,381
Change (%)		-71.72%		8.55%		-10.80%		3.29%		-0.24%

Asian Carp Summary

None of the Asian carp scenarios were projected to lead to a large percentage change in the total number of fishing trips in the study region (Table 14). Part of the reason for this, however, was that the region was large (8 states), and only certain states would be affected under each scenario. A second reason is that anglers are projected to substitute away from fishing types that are adversely affected to unaffected fishing types, particularly inland. However, fishing trips for specific fishing types show larger impacts, especially trips for salmonid fishing on the Great Lakes.

Several scenarios lead losses of well over 100,000 fishing trips taken each year with the most severe scenario leading to a loss of 406,641 fishing trips. The losses in total consumer surplus ranged up to $140,000,000 per year for the most severe scenario. One scenario led to a small increase in the number of fishing trips and an increase of consumer surplus of nearly $4,000,000.

Table 14. Summary of effects of Asian carp scenarios on fishing participation and consumer surplus.

Scenario	Change in Total Fishing Days	Percent Change in Fishing Days	Average CS Change per Angler	Total CS Change
AC-1a	-42,858	-0.02%	-$2.79	-$14,635,449
AC-1b	11,318	0.01%	$0.74	$3,885,262
AC-1c	-228,403	-0.13%	-$14.88	-$77,991,055
AC-2a	-42,858	-0.02%	-$3.81	-$19,973,947
AC-2b	-144,600	-0.08%	-$9.41	-$49,330,998
AC-2c	-406,641	-0.23%	-$26.45	-$138,672,867

Northern Snakehead

The first northern snakehead scenario (NS-1) was projected to have no negative effect on recreational fishing quality and so is not discussed.

Scenario NS-2

Under this scenario (Table 15), Asian carp would have a small negative effect on salmonids throughout the Great Lakes and negative effects on a number of warmwater species. In high productivity areas, northern snakehead would lead to a 15% decrease in smallmouth and largemouth bass and yellow perch. In addition, it would lead to a 15% decrease in walleye throughout the Great Lakes.

The economic model projects a negative effect of this scenario on recreational fishing (Table 16). The number of fishing trips would decrease by 0.08% in the 8-state region. By state of destination (Table 17), the highest percentage decreases are in Ohio (0.57%), Wisconsin (0.19%) and Michigan (0.18%). Small increases in fishing trips are projected in Pennsylvania and Illinois, mostly for inland fishing.

The overall mean decrease in consumer surplus would be $9.09/angler (Table 16). Michigan would have the highest decrease in $23.23 followed by Ohio ($16.98/angler) and Illinois ($12.86). Total consumer surplus decrease under this scenario would be $47,672,924. Great Lakes fishing trips would decline for both coldwater species (9.62%) and warmwater species (7.86%) (Table 17). Small percentage increases would occur for the other fishing types. Collectively, these increases would make up for all but 142,572 of the Great Lakes fishing days lost.

The percentage of Great Lakes coldwater fishing days lost would be fairly consistent across the Great Lakes states with 9-11% of the days lost in all states but Ohio (7%).

The loss in Great Lakes warmwater fishing trips would be particularly large in Ohio and Michigan (Table 17). The percentage of Great Lakes warmwater fishing days lost would be highest in Minnesota (19%) but the total number of days lost would be highest in Michigan, which has a much more significant Great Lakes warmwater fishery than Minnesota.

Table 16. Tabular summary of scenarios describing possible effects of northern snakehead on recreational fish populations.

	Warmwater Species Affected		Salmonid Species Affected	
Scenario	Area Affected	Species Effects	Area Affected	Species Effects
1	None	None	None	None
2	All Great Lakes	Smallmouth bass, yellow perch, and largemouth bass (15% decrease in Green Bay, Saginaw Bay, Bay of Quinte, Lake St. Clair, and Western and Central basins of Lake Erie). Walleye (15% decrease lakewide)	All Great Lakes	5% decrease

Table 16. Projected effects of Northern Snakehead scenario 2 on number of fishing trips and consumer surplus (CS) of fishing by state of residence.

State of Residence	Anglers in State	Total Trips Taken - Baseline	Total Trips Taken - Scenario	Average Fishing Days per Angler - Baseline	Average Fishing Days per Angler- Scenario	Percent Change Fishing Days	Change in Total Fishing Days	Averag e CS Change per Angler	Total CS Change
Illinois	605,649	24,044,265	24,021,396	39.70	39.66	-0.10%	-22,869	-$12.86	-$7,791,517
Indiana	332,061	13,780,532	13,775,348	41.50	41.48	-0.04%	-5,184	-$5.33	-$1,771,119
Michigan	805,792	28,041,562	27,986,763	34.80	34.73	-0.20%	-54,799	-$23.23	-$18,721,679
Minnesota	1,024,003	27,852,882	27,850,188	27.20	27.20	-0.01%	-2,693	-$0.90	-$919,791
New York	589,557	18,983,735	18,976,630	32.20	32.19	-0.04%	-7,105	-$4.13	-$2,433,677
Ohio	520,789	16,456,932	16,431,116	31.60	31.55	-0.16%	-25,817	-$16.98	-$8,841,466
Pennsylvania	635,577	25,295,965	25,293,338	39.80	39.80	-0.01%	-2,626	-$1.42	-$901,853
Wisconsin	728,604	24,408,234	24,389,784	33.50	33.47	-0.08%	-18,450	-$8.64	-$6,291,821
Totals	5,242,032	178,864,106	178,724,563	34.12	34.09	-0.08%	-139,543	-$9.09	-$47,672,924

Table 17. Projected effects of Northern Snakehead scenario 2 on number of fishing trips by fishing destination and fishing type.

Dest 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	1,725,547	1,555,697	809,585	829,173	-	-	13,869,165	14,037,579	16,404,297	16,422,448
IN	713,613	641,909	308,497	314,895	614,066	610,989	11,513,909	11,575,796	13,150,084	13,143,589
MI	1,967,235	1,783,576	4,113,200	3,629,463	1,383,431	1,393,234	21,985,573	22,591,276	29,449,440	29,397,549
MN	161,547	144,755	40,312	32,678	19,031	18,851	24,556,699	24,589,028	24,777,588	24,785,312
NY	773,423	691,276	1,553,377	1,558,839	921,868	915,462	15,515,243	15,584,991	18,763,911	18,750,568
OH	340,028	317,664	2,179,052	1,870,597	501,257	521,115	11,702,794	11,930,061	14,723,132	14,639,437
PA	151,952	136,734	373,963	385,476	272,186	274,504	24,636,998	24,684,857	25,435,100	25,481,571
WI	2,359,265	2,132,542	1,691,497	1,577,997	357,750	356,426	27,003,034	27,285,086	31,411,546	31,352,051
Total	8,192,611	7,404,151	11,069,483	10,199,119	4,069,589	4,090,581	150,783,415	152,278,675	174,115,099	173,972,527
Change		-788,459		-870,365		20,992		1,495,260		-142,572
Change (%)		-9.62%		-7.86%		0.52%		0.99%		-0.08%

Grass Carp

Scenarios GC-1

Under this scenario (Table 18), grass carp would lead to a 50% decrease in largemouth bass, pike, and other centrarchids besides smallmouth bass in the Great Lakes warmwater fishery throughout the Great Lakes. It would lead to a 10% decrease in yellow perch in the same area.

The economic model projects a slight negative effect of this scenario on recreational fishing in the study region (Table 19). The number of fishing trips would decrease by 0.04% with the highest percentage decrease in Ohio (0.30%).

The overall mean decrease in consumer surplus would be $3.94/angler (Table 24). Michigan and Ohio would have the highest decreases (both over $8.00/angler). Total consumer surplus decrease under this scenario would be $20,639,556. Great Lakes fishing trips would decline by 7.47% for warmwater species (Table 20). The loss in Great Lakes warmwater fishing trips would be greatest for Illinois (12.58%) and Indiana (11.84%). Increases of 1.01% in Great Lakes coldwater fishing and 1.17% in anadromous fishing would occur, with smaller percentage increases for other fishing types, as anglers substitute away from affected fishing types.

Table 18. Tabular summary of scenarios describing possible effects of grass carp on recreational fish populations.

	Warmwater and Coolwater Species Affected		Salmonid Species Affected	
Scenario	Area Affected	Species Effects	Area Affected	Species Effects
1	All Great Lakes	Largemouth bass, pike, and other centrarchids besides smallmouth bass (50% decrease). Yellow perch (10% decrease).	None	None
2	All Great Lakes	Largemouth bass, pike, and other centrarchids besides smallmouth bass (25% decrease). Yellow perch (5% decrease).	None	None
3	All Great Lakes	Centrarchids besides bass (15% decrease). Yellow perch (5% decrease).	None	None

Table 19. Projected effects of Grass Carp scenario 1 on number of fishing trips and consumer surplus (CS) of fishing by state of residence.

State of Residence	Anglers in State	Total Trips Taken - Baseline	Total Trips Taken - Scenario	Average Fishing Days per Angler - Baseline	Average Fishing Days per Angler- Scenario	Percent Change Fishing Days	Change in Total Fishing Days	Averag e CS Change per Angler	Total CS Change
Illinois	605,649	24,044,265	24,033,678	39.70	39.68	-0.04%	-10,588	-$5.96	-$3,607,006
Indiana	332,061	13,780,532	13,778,481	41.50	41.49	-0.01%	-2,050	-$2.11	-$700,619
Michigan	805,792	28,041,562	28,022,285	34.80	34.78	-0.07%	-19,277	-$8.16	-$6,575,410
Minnesota	1,024,003	27,852,882	27,852,503	27.20	27.20	0.00%	-379	-$0.13	-$128,692
New York	589,557	18,983,735	18,976,234	32.20	32.19	-0.04%	-7,501	-$4.36	-$2,567,751
Ohio	520,789	16,456,932	16,443,910	31.60	31.57	-0.08%	-13,022	-$8.56	-$4,457,230
Pennsylvania	635,577	25,295,965	25,295,156	39.80	39.80	0.00%	-809	-$0.44	-$278,852
Wisconsin	728,604	24,408,234	24,401,421	33.50	33.49	-0.03%	-6,813	-$3.19	-$2,323,994
Totals	5,242,032	178,864,106	178,803,668	34.12	34.11	-0.04%	-60,438	-$3.94	-$20,639,556

Table 20. Projected effects of Grass Carp scenario 1 on number of fishing trips by fishing destination and fishing type.

Dest 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	1,725,547	1,743,462	809,585	707,761	-	-	13,869,165	13,947,951	16,404,297	16,399,174
IN	713,613	719,418	308,497	271,985	614,066	618,743	11,513,909	11,538,605	13,150,084	13,148,752
MI	1,967,235	1,981,911	4,113,200	3,869,754	1,383,431	1,395,372	21,985,573	22,196,159	29,449,440	29,443,196
MN	161,547	161,664	40,312	40,513	19,031	19,047	24,556,699	24,561,311	24,777,588	24,782,534
NY	773,423	784,174	1,553,377	1,440,997	921,868	933,233	15,515,243	15,589,702	18,763,911	18,748,106
OH	340,028	349,722	2,179,052	1,996,631	501,257	515,918	11,702,794	11,816,853	14,723,132	14,679,125
PA	151,952	152,846	373,963	378,795	272,186	273,770	24,636,998	24,657,565	25,435,100	25,462,975
WI	2,359,265	2,381,852	1,691,497	1,536,482	357,750	361,016	27,003,034	27,110,096	31,411,546	31,389,447
Total	8,192,611	8,275,049	11,069,483	10,242,918	4,069,589	4,117,099	150,783,415	151,418,243	174,115,099	174,053,310
Change		82,439		-826,566		47,510		634,828		-61,789
Change (%)		1.01%		-7.47%		1.17%		0.42%		-0.04%

Scenarios GC-2

Under this scenario (Table 18), grass carp would lead to a 25% decrease in largemouth bass, pike, and other centrarchids besides smallmouth bass in the Great Lakes warmwater fishery throughout the Great Lakes. It would lead to a 5% decrease in yellow perch in the same area.

This scenario involves smaller impacts of sport fish catch rates than Scenario GC-1, and results in smaller negative impacts on the recreational fishery. The number of fishing trips would decrease by 0.02% with the highest percentage decreases in Ohio (0.15%), followed by Wisconsin and New York (0.04%) (Table 22).

The overall mean decrease in consumer surplus would be $1.93/angler (Table 21), about half of that under scenario GC-1. Anglers in Michigan and Ohio would have the highest consumer surplus decreases, with decreases of $3.92/angler and $4.14/angler respectively. Total consumer surplus loss under this scenario would be $10,112,427. Great Lakes fishing trips would decline by 3.64% for warmwater species (Table 22). The loss in Great Lakes warmwater fishing trips would be highest for Illinois (6.31%) and Indiana (6.35%). Increases of 0.50% in Great Lakes coldwater fishing and 0.56% in anadromous fishing would occur, with smaller percentage increases for other fishing types.

Table 21. Projected effects of Grass Carp scenario 2 on number of fishing trips and consumer surplus (CS) of fishing by state of residence.

State of Residence	Anglers in State	Total Trips Taken - Baseline	Total Trips Taken - Scenario	Average Fishing Days per Angler - Baseline	Average Fishing Days per Angler- Scenario	Percent Change Fishing Days	Change in Total Fishing Days	Averag e CS Change per Angler	Total CS Change
Illinois	605,649	24,044,265	24,038,906	39.70	39.69	-0.02%	-5,360	-$3.01	-$1,826,012
Indiana	332,061	13,780,532	13,779,464	41.50	41.50	-0.01%	-1,067	-$1.10	-$364,675
Michigan	805,792	28,041,562	28,032,295	34.80	34.79	-0.03%	-9,267	-$3.92	-$3,161,535
Minnesota	1,024,003	27,852,882	27,852,700	27.20	27.20	0.00%	-182	-$0.06	-$61,791
New York	589,557	18,983,735	18,980,200	32.20	32.19	-0.02%	-3,535	-$2.05	-$1,210,317
Ohio	520,789	16,456,932	16,450,630	31.60	31.59	-0.04%	-6,302	-$4.14	-$2,157,168
Pennsylvania	635,577	25,295,965	25,295,554	39.80	39.80	0.00%	-410	-$0.22	-$141,444
Wisconsin	728,604	24,408,234	24,404,747	33.50	33.50	-0.01%	-3,487	-$1.63	-$1,189,484
Totals	5,242,032	178,864,106	178,834,497	34.12	34.12	-0.02%	-29,609	-$1.93	-$10,112,427

Table 22. Projected effects of Grass Carp scenario 2 on number of fishing trips by fishing destination and fishing type.

Dest 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	1,725,547	1,734,585	809,585	758,519	-	-	13,869,165	13,909,019	16,404,297	16,402,123
IN	713,613	716,644	308,497	288,905	614,066	616,495	11,513,909	11,526,648	13,150,084	13,148,692
MI	1,967,235	1,974,196	4,113,200	3,998,051	1,383,431	1,389,092	21,985,573	22,086,096	29,449,440	29,447,436
MN	161,547	161,603	40,312	40,406	19,031	19,039	24,556,699	24,558,934	24,777,588	24,779,981
NY	773,423	778,504	1,553,377	1,500,277	921,868	927,222	15,515,243	15,549,952	18,763,911	18,755,955
OH	340,028	344,675	2,179,052	2,091,185	501,257	508,281	11,702,794	11,757,527	14,723,132	14,701,668
PA	151,952	152,396	373,963	376,372	272,186	272,966	24,636,998	24,647,206	25,435,100	25,448,940
WI	2,359,265	2,370,762	1,691,497	1,612,351	357,750	359,409	27,003,034	27,057,504	31,411,546	31,400,026
Total	8,192,611	8,233,364	11,069,483	10,666,066	4,069,589	4,092,505	150,783,415	151,092,885	174,115,099	174,084,820
Change		40,753		-403,417		22,915		309,470		-30,279
Change (%)		0.50%		-3.64%		0.56%		0.21%		-0.02%

Scenarios GC-3

Under this scenario (Table 18), grass carp would not affect bass but would lead to a 15% decrease in centrarchids besides bass and a 5% decrease in yellow perch throughout the Great Lakes. This is the least severe of the Grass Carp scenarios.

The economic model projects a negative effect of this scenario on fishing participation and value in the study region (Table 23). The number of fishing trips would decrease by 0.02% or 29,562 trips, which is almost identical to the projected decrease under scenario GS-2. Despite the fact that scenario 3 has less of a population decline in several recreational fish species, the decrease in fishing does not substantively change because the decline in yellow perch is the same, and the effort for yellow perch is much larger than the effort for the other species in the Great Lakes.

The pattern of decrease in consumer surplus was also similar to that under scenario GC-2. The overall mean loss in consumer surplus was $1.88/angler (Table 23). Michigan and Ohio would have the highest losses, with decreases of $3.92/angler and $4.28/angler respectively. Total consumer surplus loss under this scenario would be $9,876,241. Great Lakes fishing trips would decline by 3.55% for warmwater species (Table 24). The number of days of Great Lakes warmwater fishing lost would be greatest in Michigan, Ohio, and Wisconsin. Increases of 0.48% in Great Lakes coldwater fishing and 0.55% in anadromous fishing would occur, with smaller percentage increases for other fishing types.

Table 23. Projected effects of Grass Carp scenario 3 on number of fishing trips and consumer surplus (CS) of fishing by state of residence.

State of Residence	Anglers in State	Total Trips Taken - Baseline	Total Trips Taken - Scenario	Average Fishing Days per Angler - Baseline	Average Fishing Days per Angler- Scenario	Percent Change Fishing Days	Change in Total Fishing Days	Averag e CS Change per Angler	Total CS Change
Illinois	605,649	24,044,265	24,039,061	39.70	39.69	-0.02%	-5,204	-$2.93	-$1,772,852
Indiana	332,061	13,780,532	13,779,535	41.50	41.50	-0.01%	-996	-$1.03	-$340,526
Michigan	805,792	28,041,562	28,032,293	34.80	34.79	-0.03%	-9,268	-$3.92	-$3,161,710
Minnesota	1,024,003	27,852,882	27,852,744	27.20	27.20	0.00%	-138	-$0.05	-$46,907
New York	589,557	18,983,735	18,980,561	32.20	32.19	-0.02%	-3,175	-$1.84	-$1,086,930
Ohio	520,789	16,456,932	16,450,424	31.60	31.59	-0.04%	-6,508	-$4.28	-$2,227,707
Pennsylvania	635,577	25,295,965	25,295,566	39.80	39.80	0.00%	-398	-$0.22	-$137,277
Wisconsin	728,604	24,408,234	24,405,029	33.50	33.50	-0.01%	-3,205	-$1.50	-$1,093,332
Totals	5,242,032	178,864,106	178,835,213	34.12	34.12	-0.02%	-28,893	-$1.88	-$9,867,241

Table 24. Projected effects of Grass Carp scenario 3 on number of fishing trips by fishing destination and fishing type.

Dest 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	1,725,547	1,734,386	809,585	758,263	-	-	13,869,165	13,907,967	16,404,297	16,400,616
IN	713,613	716,435	308,497	290,998	614,066	616,344	11,513,909	11,525,948	13,150,084	13,149,725
MI	1,967,235	1,974,395	4,113,200	3,996,604	1,383,431	1,389,194	21,985,573	22,086,449	29,449,440	29,446,643
MN	161,547	161,589	40,312	40,382	19,031	19,037	24,556,699	24,558,477	24,777,588	24,779,484
NY	773,423	777,983	1,553,377	1,505,790	921,868	926,677	15,515,243	15,546,468	18,763,911	18,756,919
OH	340,028	344,823	2,179,052	2,088,303	501,257	508,507	11,702,794	11,759,316	14,723,132	14,700,949
PA	151,952	152,393	373,963	376,334	272,186	272,971	24,636,998	24,647,020	25,435,100	25,448,718
WI	2,359,265	2,369,927	1,691,497	1,619,833	357,750	359,282	27,003,034	27,053,443	31,411,546	31,402,485
Total	8,192,611	8,231,931	11,069,483	10,676,507	4,069,589	4,092,012	150,783,415	151,085,088	174,115,099	174,085,537
Change		39,320		-392,977		22,423		301,673		-29,562
Change (%)		0.48%		-3.55%		0.55%		0.20%		-0.02%

Grass Carp Summary

In keeping with the scenarios for the other AIS, none of the grass carp scenarios were projected to lead to a large percentage change in the total number of fishing trips in the study region (Table 25). The scenarios all lead to losses of 29,000 to 60,000 fishing trips taken each year. The losses in total consumer surplus ranged from $10,000,000 to $21,000,000 per year. These losses are less than those for the most severe scenarios for Asian carp and northern snakehead. Even though some of the scenarios involved sizable negative impacts on recreational fish species, most of these species were less sought after than the species affected by the other AIS, leading to lesser effects on fishing participation and value.

Table 25. Summary of effects of grass carp scenarios on fishing participation and consumer surplus.

Scenario	Change in Total Fishing Days	Percent Change in Fishing Days	Average CS Change per Angler	Total CS Change
GC-1	-60,438	-0.04%	-$3.94	-$20,639,556
GC-2	-29,609	-0.02%	-$1.93	-$10,112,427
GC-3	-28,893	-0.02%	-$1.88	-$9,867,241

Hydrilla

Hydrilla were not projected to affect recreational fish populations under the first scenario (H-1), and so that scenario is not evaluated.

Scenarios H-2

Under this scenario (Table 26), hydrilla would lead to a 15% decrease in yellow perch, largemouth bass, pike, and muskellunge throughout the Great Lakes with higher declines in high productivity areas.

The number of fishing trips would decline by 0.06% under this scenario with the highest percentage decrease in Ohio followed by Wisconsin, New York and Michigan (Table 27).

The overall mean decrease in consumer surplus would be $6.64/angler (Table 26). Michigan would have the highest decrease at $16.88/angler. Total consumer surplus decrease under this scenario would be $34,814,477. Great Lakes fishing trips would drop by 12.55% for warmwater species (Table 27), with the largest percent decreases in Illinois, Indiana and Wisconsin. Increases of 1.59% in Great Lakes coldwater fishing and 1.84% in anadromous fishing would occur. Inland fishing would increase by 0.72%.

Table 26. Tabular summary of scenarios describing possible effects of hydrilla on recreational fish populations.

	Warmwater and Coolwater Species Affected		Salmonid Species Affected	
Scenario	Area Affected	Species Effects	Area Affected	Species Effects
1	None	None	None	None
2	All Great Lakes	Yellow perch, largemouth bass, pike, and muskies (15% decrease, 25% decrease in Green Bay, Saginaw Bay, and Bay of Quinte, 30% decrease in Lake St. Clair).	None	None
3	All Great Lakes	Yellow perch, largemouth bass, pike, and muskies (15% increase)	None	None

Table 27. Projected effects of Hydrilla scenario 2 on number of fishing trips and consumer surplus (CS) of fishing by state of residence.

State of Residence	Anglers in State	Total Trips Taken - Baseline	Total Trips Taken - Scenario	Average Fishing Days per Angler - Baseline	Average Fishing Days per Angler- Scenario	Percent Change Fishing Days	Change in Total Fishing Days	Averag e CS Change per Angler	Total CS Change
Illinois	605,649	24,044,265	24,027,717	39.70	39.67	-0.07%	-16,548	-$9.31	-$5,639,325
Indiana	332,061	13,780,532	13,777,599	41.50	41.49	-0.02%	-2,933	-$3.02	-$1,002,296
Michigan	805,792	28,041,562	28,001,679	34.80	34.75	-0.14%	-39,882	-$16.88	-$13,599,721
Minnesota	1,024,003	27,852,882	27,852,422	27.20	27.20	0.00%	-460	-$0.15	-$156,416
New York	589,557	18,983,735	18,974,158	32.20	32.18	-0.05%	-9,577	-$5.56	-$3,278,738
Ohio	520,789	16,456,932	16,437,375	31.60	31.56	-0.12%	-19,557	-$12.85	-$6,693,482
Pennsylvania	635,577	25,295,965	25,294,791	39.80	39.80	0.00%	-1,174	-$0.64	-$404,588
Wisconsin	728,604	24,408,234	24,396,390	33.50	33.48	-0.05%	-11,844	-$5.54	-$4,039,912
Totals	5,242,032	178,864,106	178,762,131	34.12	34.10	-0.06%	-101,975	-$6.64	-$34,814,477

Table 28. Projected effects of Hydrilla scenario 2 on number of fishing trips by fishing destination and fishing type.

Dest 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	1,725,547	1,752,908	809,585	657,585	-	-	13,869,165	13,989,740	16,404,297	16,400,234
IN	713,613	722,003	308,497	257,076	614,066	620,863	11,513,909	11,549,706	13,150,084	13,149,648
MI	1,967,235	1,994,012	4,113,200	3,602,689	1,383,431	1,406,983	21,985,573	22,420,958	29,449,440	29,424,643
MN	161,547	161,680	40,312	40,542	19,031	19,049	24,556,699	24,562,386	24,777,588	24,783,656
NY	773,423	787,282	1,553,377	1,409,103	921,868	936,475	15,515,243	15,610,023	18,763,911	18,742,881
OH	340,028	354,777	2,179,052	1,906,282	501,257	523,577	11,702,794	11,877,343	14,723,132	14,661,980
PA	151,952	153,268	373,963	381,231	272,186	274,532	24,636,998	24,666,998	25,435,100	25,476,030
WI	2,359,265	2,396,736	1,691,497	1,425,834	357,750	363,178	27,003,034	27,186,250	31,411,546	31,371,998
Total	8,192,611	8,322,667	11,069,483	9,680,342	4,069,589	4,144,658	150,783,415	151,863,404	174,115,099	174,011,070
Change		130,056		-1,389,142		75,068		1,079,989		-104,029
Change (%)		1.59%		-12.55%		1.84%		0.72%		-0.06%

Scenarios H-3

Under this scenario (Table 26), hydrilla would lead to a 15% increase in yellow perch, largemouth bass, pike, and muskellunge throughout the Great Lakes.

The economic model projects a positive effect of this scenario on fishing participation and value in the study region (Table 30). The number of fishing trips would increase by 0.05% with the highest percentage increases in Ohio (0.45%) followed by New York (0.11%) and Wisconsin (0.09%).

The overall mean increase in consumer surplus would be $5.64/angler with the biggest increases in Ohio ($12.80/angler) and Michigan ($11.38/angler) (Table 29). Total consumer surplus increase under this scenario would be $29,574,008. Great Lakes fishing trips would increase by 10.50% for warmwater species (Table 30). Small decreases of 2.43% in Great Lakes coldwater fishing and 1.62% in anadromous fishing would occur as anglers shifted to take advantage of the improved warmwater opportunities. The percentage decreases in other fishing types would be smaller.

Table 29. Projected effects of Hydrilla scenario 3 on number of fishing trips and consumer surplus (CS) of fishing by state of residence.

State of Residence	Anglers in State	Total Trips Taken - Baseline	Total Trips Taken - Scenario	Average Fishing Days per Angler - Baseline	Average Fishing Days per Angler- Scenario	Percent Change Fishing Days	Change in Total Fishing Days	Averag e CS Change per Angler	Total CS Change
Illinois	605,649	24,044,265	24,060,214	39.70	39.73	0.07%	15,948	$8.97	$5,433,287
Indiana	332,061	13,780,532	13,783,561	41.50	41.51	0.02%	3,030	$3.12	$1,035,619
Michigan	805,792	28,041,562	28,068,445	34.80	34.83	0.10%	26,884	$11.38	$9,172,911
Minnesota	1,024,003	27,852,882	27,853,334	27.20	27.20	0.00%	452	$0.15	$153,702
New York	589,557	18,983,735	18,993,412	32.20	32.22	0.05%	9,677	$5.62	$3,313,218
Ohio	520,789	16,456,932	16,476,405	31.60	31.64	0.12%	19,472	$12.80	$6,666,761
Pennsylvania	635,577	25,295,965	25,297,193	39.80	39.80	0.00%	1,228	$0.67	$423,490
Wisconsin	728,604	24,408,234	24,418,127	33.50	33.51	0.04%	9,893	$4.63	$3,375,020
Totals	5,242,032	178,864,106	178,950,691	34.12	34.14	0.05%	86,584	$5.64	$29,574,008

Table 30. Projected effects of Hydrilla scenario 3 on number of fishing trips by fishing destination and fishing type.

Dest 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	1,725,547	1,698,817	809,585	965,888	-	-	13,869,165	13,751,587	16,404,297	16,416,291
IN	713,613	705,090	308,497	361,183	614,066	607,184	11,513,909	11,477,541	13,150,084	13,150,997
MI	1,967,235	1,946,238	4,113,200	4,445,659	1,383,431	1,366,836	21,985,573	21,697,627	29,449,440	29,456,360
MN	161,547	161,409	40,312	40,094	19,031	19,012	24,556,699	24,550,964	24,777,588	24,771,479
NY	773,423	759,753	1,553,377	1,696,847	921,868	907,419	15,515,243	15,421,100	18,763,911	18,785,118
OH	340,028	326,224	2,179,052	2,444,668	501,257	480,410	11,702,794	11,538,495	14,723,132	14,789,796
PA	151,952	150,630	373,963	367,022	272,186	269,834	24,636,998	24,606,853	25,435,100	25,394,339
WI	2,359,265	2,326,950	1,691,497	1,910,081	357,750	353,100	27,003,034	26,849,214	31,411,546	31,439,345
Total	8,192,611	8,075,111	11,069,483	12,231,441	4,069,589	4,003,794	150,783,415	149,893,380	174,115,099	174,203,726
Change		-117,499		1,161,957		-65,795		-890,035		88,627
Change (%)		-1.43%		10.50%		-1.62%		-0.59%		0.05%

Hydrilla Summary

The hydrilla scenarios produced the widest range of possible effects of an AIS on fishing participation and consumer surplus – from negative to neutral to positive effects. As was typical for the scenarios for the other AIS, none of the hydrilla scenarios was projected to lead to a large percentage change in the number of fishing trips in the study region (Table 31). One scenario led to a projected loss of 102,000 annual fishing trips and a consumer surplus loss of nearly $35,000,000. Another projected a gain of over 85,000 fishing trips yearly and a consumer surplus increase of nearly $30,000,000.

Table 31. Summary of effects of hydrilla scenarios on fishing participation and consumer surplus.

Scenario	Change in Total Fishing Days	Percent Change in Fishing Days	Average CS Change per Angler	Total CS Change
H-1	0	0.00%	$0.00	$0
H-2	-101,975	-0.06%	-$6.64	-$34,814,477
H-3	+86,584	+0.05%	+$5.64	$29,574,008

Quagga Mussel

The single scenario developed for quagga mussel (Table 32) would lead to an 80% drop in coho and chinook salmon in Lake Michigan.

The effects of this scenario on Great Lakes coldwater fishing participation and economic value would be substantial for surrounding states. The number of fishing trips would drop by 0.22%, which is a small percentage of trips in the 8-state region (Table 34). But the 383,538 trips lost would be almost entirely in only 4 states: Illinois, Wisconsin, Michigan, and Indiana.

The overall mean decrease in consumer surplus would be $24.49/angler (Table 33), but again the impact is concentrated in states surrounding Lake Michigan, with the highest impact in Illinois ($91.23/angler) followed by Wisconsin ($44.16), Indiana ($42.62) and Michigan ($33.18). Total consumer surplus decrease under this scenario would be $128,359,771. Great Lakes fishing trips would decline by 63.78% for coldwater species and 8.01% on anadromous runs (Table 34). The declines would be greatest in percentage terms in Illinois and Indiana, where Great Lakes trips for coldwater fish would decline by 93-95%. The loss of more than 5,000,000 coldwater fishing trips would be made up in part by a 5.08% increase in Great Lakes warmwater fishing and a 3.05% increase in inland fishing.

Table 32. Tabular summary of scenario describing possible effects of quagga mussel on recreational fish populations.

	Warmwater and Coolwater Species Affected		Salmonid Species Affected	
Scenario	Area Affected	Species Effects	Area Affected	Species Effects
1	None	None	Lake Michigan	Coho and chinook salmon (80% decrease).

Table 33. Projected effects of Quagga Mussel scenario 1 on number of fishing trips and consumer surplus (CS) of fishing by state of residence.

State of Residence	Anglers in State	Total Trips Taken - Baseline	Total Trips Taken - Scenario	Average Fishing Days per Angler - Baseline	Average Fishing Days per Angler- Scenario	Percent Change Fishing Days	Change in Total Fishing Days	Averag e CS Change per Angler	Total CS Change
Illinois	605,649	24,044,265	23,881,869	39.70	39.43	-0.68%	-162,397	-$91.23	-$55,252,022
Indiana	332,061	13,780,532	13,739,109	41.50	41.38	-0.30%	-41,423	-$42.62	-$14,154,044
Michigan	805,792	28,041,562	27,963,346	34.80	34.70	-0.28%	-78,215	-$33.18	-$26,738,633
Minnesota	1,024,003	27,852,882	27,852,772	27.20	27.20	0.00%	-109	-$0.04	-$37,251
New York	589,557	18,983,735	18,983,735	32.20	32.20	0.00%	0	$0.00	$0
Ohio	520,789	16,456,932	16,456,932	31.60	31.60	0.00%	0	$0.00	-$47
Pennsylvania	635,577	25,295,965	25,295,965	39.80	39.80	0.00%	0	$0.00	$0
Wisconsin	728,604	24,408,234	24,313,839	33.50	33.37	-0.39%	-94,395	-$44.16	-$32,177,774
Totals	5,242,032	178,864,106	178,487,568	34.12	34.05	-0.21%	-376,539	-$24.49	-$128,359,771

Table 34. Projected effects of Quagga Mussel scenario 1 on number of fishing trips by fishing destination and fishing type.

Dest 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	1,725,547	118,472	809,585	964,371	-	-	13,869,165	15,276,942	16,404,297	16,359,786
IN	713,613	38,097	308,497	366,175	614,066	584,700	11,513,909	12,054,886	13,150,084	13,043,857
MI	1,967,235	939,814	4,113,200	4,215,098	1,383,431	1,170,525	21,985,573	23,065,343	29,449,440	29,390,780
MN	161,547	161,606	40,312	40,313	19,031	19,032	24,556,699	24,576,385	24,777,588	24,797,335
NY	773,423	773,423	1,553,377	1,553,377	921,868	921,868	15,515,243	15,515,243	18,763,911	18,763,911
OH	340,028	340,167	2,179,052	2,179,290	501,257	501,293	11,702,794	11,704,644	14,723,132	14,725,394
PA	151,952	151,952	373,963	373,963	272,186	272,186	24,636,998	24,636,998	25,435,100	25,435,100
WI	2,359,265	443,908	1,691,497	1,939,171	357,750	274,195	27,003,034	28,558,123	31,411,546	31,215,398
Total	8,192,611	2,967,439	11,069,483	11,631,758	4,069,589	3,743,798	150,783,415	155,388,564	174,115,099	173,731,560
Change		-5,225,171		562,275		-325,791		4,605,149		-383,538
Change (%)		-63.78%		5.08%		-8.01%		3.05%		-0.22%

Conclusions

The five AIS considered have a range of possible effects on recreational fishing participation and value, according to study projections (Table 35). The worst case scenarios for Asian carp and quagga mussel could involve losses of $130,000,000-$140,000,000 in consumer surplus per eyar and 375,000-400,000 fishing trips annually. Improvements to recreational fishing were also considered possible outcomes for Hydrilla and Asian carp, with projected gains of almost $30,000,000 in value and 86,000 fishing trips annually. Scenarios projecting improvements were less common than those involving losses, however.

The pattern of states affected would vary depending on the particular scenario, but generally those in the central Great Lakes region were expected to bear the greatest impacts (Table 36). Illinois and Michigan had the potential to be most negatively. Wisconsin, Indiana, Ohio, and New York also bore substantial negative effects under some scenarios while Pennsylvania and Minnesota tended to be less affected. In those scenarios involving improvements to recreational fishing, Michigan and Ohio would be most likely to experience the greatest benefits. Scenarios that generated increases in fishing and value generally involved increases in warmwater species, which are more heavily targeted in these two states.

It is important to recognize that the impacts on recreational fishing participation are often less severe than the ecological effects of AIS with which they are associated. There are several reasons for this. To begin with, anglers target some species much more heavily than others. If an AIS affects species that receive less attention from anglers in the Great Lakes (e.g., centrarchids), the effects on recreational fishing participation and value will not be as substantial. In addition, some types of fishing are much less affected by the opportunity to catch fish than others. Those anglers who fish anadromous runs in particular are less likely to reduce their fishing as fish populations decrease. Finally, many anglers switch from one type of fishing to another as the quality of their preferred type of fishing declines. In these scenarios, if one type of Great Lakes fishing declined, many anglers would take more trips for other types of Great Lakes fishing and, even more importantly, take more trips to inland waters.

Our research is not able to generate precise estimates of the future effects of AIS on recreational fishing participation value. Indeed, our approach was premised on the assumption that precise estimates are impossible given the uncertainty associated with large ecological systems. Nevertheless, our work considerably narrows the range of possible AIS impacts that must be considered. Accepting the best and worst case scenarios from the set would involve projections from a $30 million improvement in the Great Lakes fishery to a $139 million loss. Although that range is quite wide, it provides reasonable endpoints that policy makers can consider when evaluating options to control the AIS considered in this report, and perhaps AIS in general.

Table 35. Summary of projected effects on recreational fishing participation and consumer surplus, by AIS.

AIS	Change in Consumer Surplus		Change in Total Fishing Trips over all States	
	Best Case	Worst Case	Best Case	Worst Case
Asian carp	$3,885,262	-$138,672,867	11,318	-406,641
Northern snakehead	$0	-$47,672,924	0	-139,543
Grass carp	-$9,867,241	-$20,639,556	-28,893	-60,438
Hydrilla	$29,574,008	-$34,814,477	86,584	-101,975
Quagga mussel	-$128,359,771	-$128,359,771	-376,539	-376,539

Table 36. Summary of projected effects on recreational fishing participation and value, by state.

State of Residence	Change in Consumer Surplus: Best Case	Change in Consumer Surplus: Worst Case	Change in Fishing Trips from that State: Best Case	Change in Fishing Trips from that State: Worst Case
Illinois	$5,433,287	-$55,514,783	15,948	-163,176
Indiana	$1,035,619	-$14,320,837	3,030	-41,910
Michigan	$9,172,911	-$33,628,248	26,884	-98,581
Minnesota	$153,702	-$919,791	452	-2,693
New York	$3,313,218	-$11,539,361	9,677	-33,731
Ohio	$7,680,130	-$21,835,100	22,451	-63,809
Pennsylvania	$423,490	-$1,294,832	1,228	-3,772
Wisconsin	$3,375,020	-$32,177,774	9,893	-94,395

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