MINNESOTA AQUATIC INVASIVE SPECIES RESEARCH CENTER
UNIVERSITY OF MINNESOTA

Minnesota Bigheaded Carps Risk Assessment

A report for the Minnesota Department of Natural Resources

-Final-

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Executive Summary

Introduction

Aquatic natural resources are ecologically, culturally, economically, and politically important to the state of Minnesota. Two aquatic invasive species that pose a threat to these resources are bighead carp (*Hypophthalmichthys nobilis*) and silver carp (*H. molitrix*), which are collectively referred to as bigheaded carps. Bigheaded carps are native to East Asia and were introduced into the southern United States during the early 1970's, where they were promoted by state and federal agencies as a nonchemical way to improve water quality in retention ponds, sewage lagoons, and aquaculture operations. Subsequent unintentional release and large flood events allowed these species to escape into the Mississippi River, where they began reproducing and spreading. They are considered invasive species in the United States because of their potential to disrupt ecosystems by consuming large amounts of plankton and, in the case of silver carp, the ability to jump up to 10 feet in the air and create a recreation hazard. In Minnesota, 33 individual bigheaded carp have been captured through 2016, varying from 0 to 6 individuals per year. However, all of the captures have been adults and there is not thought to be a reproducing population of bigheaded carps in the state. The nearest reproducing population of bigheaded carps is thought to be in southern Iowa.

Project Need and Purpose

Bigheaded carps pose a threat to the state of Minnesota, but there has yet to be a systematic study of how their arrival would impact different waterbodies across the state. This project helps fill this gap by assessing the risks from bigheaded carps to the waterbodies of Minnesota. Specifically, this risk assessment estimates both the likelihood that bigheaded carps would establish in 4 select watersheds and the resulting severity of 4 salient potential adverse effects. The findings from this risk assessment can help the management context in Minnesota in many ways. First, these findings can help prioritize areas of the state for management actions by determining which watersheds are at higher risk. Second, these findings can help justify reasoned management actions by estimating the likely impacts of bigheaded carps if no additional management actions are taken. Third, this risk assessment can help refine societal expectations for what the arrival of bigheaded carps would look like.

Methodology

The risk assessment was completed using a multi-step process. First, focus groups and a survey were conducted to determine which potential adverse effects – i.e., potential undesirable changes caused by bigheaded carps – were most important to examine in the risk assessment. Second, a two-day expert, deliberative workshop was held to complete the major analytical portion of the risk assessment. After the workshop, project researchers and a self-selected group of workshop participants authored this report based on the results from the workshop.

Finally, in March 2017 a draft version of this report was presented and discussed during a meeting exploring the findings and implications of the risk assessment. This final report was revised based on the feedback from that meeting.

Step #1: Identifying potential adverse effects & Narrowing scope

During the first step of the risk assessment process, five focus groups were conducted to create a comprehensive list of potential adverse effects. Three focus groups were held with personnel from the Minnesota Department of Natural Resources (MNDNR) and two with individuals active in the non-governmental organization stakeholder community in Minnesota. Due to the large list of potential adverse effects that was generated during these focus groups, a survey was conducted to prioritize those considered most important for Minnesota. The survey was completed by those who took part in the focus groups and the participants of the subsequent deliberative risk assessment workshop.

The four potential adverse effects that emerged from the survey and were studied in the risk assessment are: 1) decrease in non-game fish populations; 2) decrease in game fish populations; 3) reduction in species diversity and ecosystem resilience; and 4) decrease in recreation quality from the jumping silver cap hazard. For the scope of the risk assessment, the following watersheds were selected in consultation with the MNDNR: Sand Hill River Watershed, Nemadji River Watershed, Lower St. Croix River Watershed, and the Minnesota River – Mankato Watershed. These watersheds were chosen to represent a diversity of basins and river types, to be relevant to the state's current decision making context, and, when possible, to be worst-case scenarios – watersheds in each basin that are likely to be most favorable to bigheaded carps.

Step #2: Risk assessment workshop

The second step of the risk assessment process was the two-day expert, deliberative risk assessment workshop held in March 2016. Twenty-three individuals with expertise on bigheaded carps and/or Minnesota's waterways participated in the risk assessment workshop, including individuals from 5 federal agencies, 5 academic institutions, MNDNR, natural resource agencies from 2 other states, and a stakeholder group. A combination of facilitated small and large group discussions was used to characterize the risk of the four potential adverse effects in each of the four watersheds. This was done by sequentially characterizing: 1) the likelihood that bigheaded carps would establish in each watershed if they arrived there, 2) the resulting abundance of bigheaded carps in each watershed, and 3) the severity of the potential adverse effects caused by the resulting abundance of bigheaded carps. The time scale considered for each step was within 10 years of arrival. The overall risk was a product of the likelihood of establishment and the severity of the potential adverse effect.

Important methodological considerations

This assessment estimated the risks from bigheaded carps assuming they arrive in each watershed considered. It was outside the scope of this assessment to examine how likely it is that bigheaded carp will arrive in each watershed. There continues to be important management and research taking place to slow the spread of bigheaded carps, so that arrival is prevented. This risk assessment estimates what would happen if bigheaded carps do arrive in these different watersheds, helping to make clear where to prioritize, and what is at stake in, management actions.

For the game fish and non-game fish potential adverse effects, risk assessment workshop participants selected one important fish species to focus on for each watershed. Although the study of additional fish species is warranted, it fell outside the scope of this assessment. The fish species that were selected, however, provide useful insights on the risks posed to game and non-game fish in Minnesota.

Throughout this project, there was an explicit effort to involve a breadth of resource managers and stakeholders from Minnesota. These participants provided needed local expertise on the state's waterways and ensured that the value judgments within the risk assessment were informed by stakeholders and managers.

Risk Assessment Findings

The findings from this assessment reveal that the risks posed by bigheaded carps vary across watersheds and potential adverse effects. Figure E1 summarizes the estimated establishment probabilities (size of square) and consequence levels (color of square) generated by the participants. The Minnesota River-Mankato watershed was estimated to have the highest probability of establishment (70%), followed by the Lower St. Croix River (45%) and Nemadji River watersheds (38%), with the lowest probability for the Sand Hill River watershed (22%). The consequence levels varied across watersheds and potential adverse effects, with lower consequence levels generally for the Nemadji River and Sand Hill River watersheds and for the non-game fish and game fish potential adverse effects.

Given that overall risk is a product of the probability of establishment and consequence level, the larger the square and the more red the color, the higher is the risk. The highest estimated risk, therefore, was for Species diversity/Ecosystem resilience and Recreation jumping hazard for the Minnesota River – Mankato watershed, and the Recreation jumping hazard for the Lower St. Croix River watershed. The certainty for the risk characterizations were generally low, due largely to the lack of data concerning invasions of bigheaded carps in waterbodies similar to those found in Minnesota.

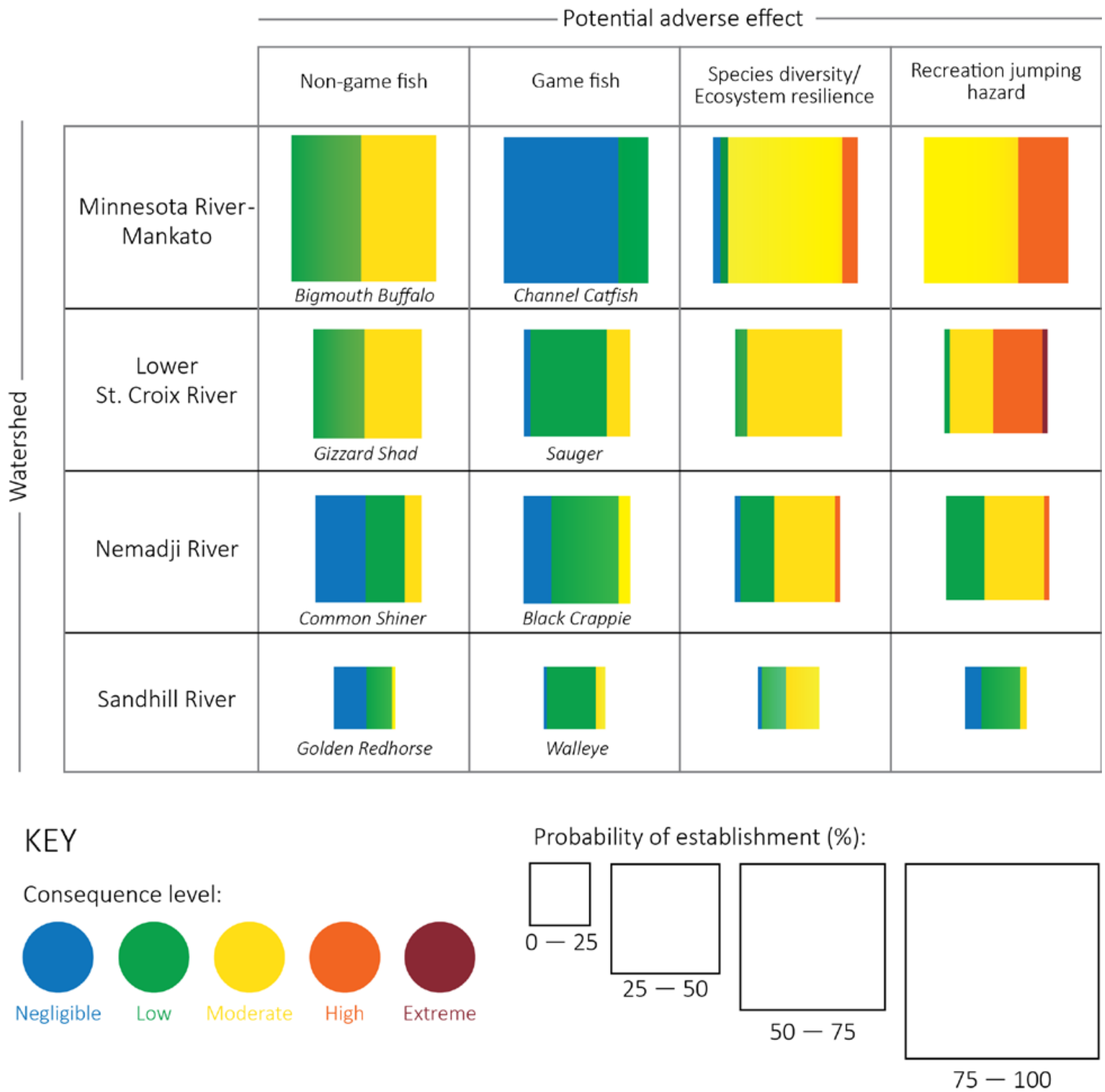

Figure E1: Summary of Minnesota Bigheaded Carps Risk Assessment findings. The size of the squares corresponds to the estimated probability of establishment for bigheaded carps in that watershed. The color of the squares corresponds to the consequence levels that participants deemed to be most likely for each potential adverse effect, with the width of the color proportional to the number of participants who chose that consequence level as most likely. Also provided for each watershed are the common names for the fish species considered.

A variety of factors influenced the characterizations of risk. Overall, the major determinants of establishment likelihood involved factors affecting the probability of successful spawning by bigheaded carps and the survival of their young-of-the-year. These included several biotic and abiotic factors, such as spawning habitat, water temperature, flow regime, nursery habitat, food resources, and potential predators. With regards to the non-game and game fish potential adverse effects, the non-game fish species considered for the Minnesota River - Mankato and the Lower St. Croix were planktivores (Bigmouth Buffalo and Gizzard Shad), and the expected dietary and habitat overlap with bigheaded carps led about half of participant to select a moderate consequence level. Non-planktivore fish species were generally considered to have a low or negligible consequence level. The severity of potential adverse effects are also likely to vary within a watershed with, for example, areas of greater severity in the shallows and backwaters of rivers where bigheaded carps are more likely to reach higher densities and take part in jumping behavior.

Discussion & Implications

These risk assessment findings support the need for a reasoned and timely response to the threats posed by bigheaded carps. First, the findings show that the Minnesota River – Mankato and similar watersheds are at a higher risk, followed by the Lower St. Croix River and similar watersheds. Unfortunately, these two watersheds are found in the southern and eastern parts of the state, which are closest to the current invasion front. These findings support the need to prioritize management that can slow or prevent the spread into these areas, or that can lessen the consequence levels of any resulting adverse effects.

Second, the risks posed by bigheaded carps are not uniformly high or uniformly low across potential adverse effects and watersheds. Because there is not uniformly low risk, it is important to take reasoned action in response to the threat. Because there is not uniformly high risk, it is important to consider the collateral damage of possible management actions, to ensure actions do less harm to native species than bigheaded carps would. For example, non-selective barriers on rivers have been shown to cause extirpations of native fish species. Species-selective deterrents, however, such as those using sound, provide the potential to slow the spread of bigheaded carps while not hurting native fish populations. While research is still advancing on such deterrents, the potential is promising. Other possible management actions that don't harm natives include improving ecosystem resilience, restoring top native predators such as flathead catfish, and eliminating cross-watershed connections.

To pursue a balanced and reasoned approach to management, it is important that decisions weigh: 1) the potential effects if no management actions are taken (i.e., risks from bigheaded carps); 2) the efficacy of management actions on bigheaded carps; 3) the effects of management actions on native species (i.e., collateral damage). The goal is to pursue research and management that can prevent the spread of bigheaded carps and reduce the severity of any adverse effects, while avoiding disproportionate harm to native species.

This risk assessment provides one part of the equation to determine the desired response to bigheaded carps in Minnesota, a response that should not be based on either reactionary apathy or fear. While this assessment is a necessary first step, additional work is required. First, looking explicitly at the economic aspects of bigheaded carp risks and of management actions would also help inform decision making, and the risks characterized here provide a good starting point for that effort. Second, the approach to, and findings from, this risk assessment can be built upon to examine the risks to other watersheds in Minnesota or the region. Finally, there is a need to regularly update these findings to keep up with the relevant scientific literatures.

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1 Introduction

1.1 Minnesota context

Aquatic natural resources are ecologically, culturally, economically, and politically important to the state of Minnesota. Minnesota has an abundance of surface water, more than 11,000 lakes and 69,000 miles of rivers and streams. Those waters are vitally important to both recreation and commerce within the state (MNDNR 2013). About 800,000 watercraft are registered in Minnesota, which is the most per-capita of any state in the nation (Kelly 2014). There are 1.3 million licensed resident anglers and the state attracts another 259,000 non-resident anglers each year. Fishing related expenditures total an estimated $2.4 billion annually (USFWS 2011), and when recreational boating is added to those expenditures, the economic impact is approximately $5.5 billion annually (2015 National Marine Manufacturers Association).

Lake Superior and the Mississippi River also serve as important waterways for shipping in Minnesota. Minnesota's portion of the Mississippi River system is used to move more than half of Minnesota's agricultural exports, which in 2013 was 9.2 million tons of freight valued at nearly $2 billion. In 2015, 11.6 million tons of freight traveled on the Mississippi River system (MNDOT 2016). Minnesota's portion of Lake Superior was used to move 58 million tons of freight in 2013, which was valued at $7.2 billion (MNDOT 2016b). Commercial fishing is another economic use of Minnesota's waterways, with an estimated 3.5 million pounds of fish harvested annually (MNDNR 2016).

Protecting the waterways of Minnesota from the threats posed by aquatic invasive species falls under the authority of the Minnesota Department of Natural Resources (MNDNR) and a host of federal agencies, such as the United States Fish and Wildlife Service (USFWS), the United States Geological Survey (USGS), the National Park Service (NPS), and the United States Army Corps of Engineers (USACE).

1.1.1. Bigheaded carps

Bighead carp (Hypophthalmichthys nobilis) and silver carp (Hypophthalmichthys molitrix), (collectively referred to as bigheaded carps[1]) are native to East Asia and considered invasive species in the United States, where they are listed as injurious species under the United States Lacey Act. These species were introduced into the southern United States during the early

[1] Concerning terminology, in this document "bigheaded carps" will be used to refer to bighead and silver carp. "Asian carp" is used to refer to bighead, silver, grass (*Ctenopharyngodon idella*), and black (*Mylopharyngodon piceus*) carp. "Invasive carp" is also used to refer to the four Asian carp species, as that is the terminology used by the Minnesota Department of Natural Resources.

1970's when they were promoted by state and federal agencies as a nonchemical and environmentally friendly way to improve water quality in retention ponds and sewage lagoons, and to aid in fish aquaculture operations (Kelly et al. 2011). Subsequently, unintentional release and large flood events allowed these species to escape into the Mississippi River drainage, where they began reproducing and expanding their distribution (Kelly et al. 2011). Bigheaded carps have migrated up into portions of the Mississippi and Missouri rivers, and adjoining tributaries, dispersing into new habitats and ecosystems (Asian Carp Regional Coordinating Committee 2014). Bigheaded carps are considered one of the most concerning aquatic invasive species in North American because of their potential to disrupt ecosystems from the bottom up and, in the case of silver carp, to cause a recreational hazard by jumping up to 10 feet in the air when startled (USFWS 2014).

Silver carp can exceed 3.5 feet in length and weigh up to 60 pounds, while bighead carp can exceed 5 feet in length and weigh over 100 pounds (USFWS 2014, Kolar et al. 2007). In US waters, silver carp generally have a lifespan of 5 to 7 years and reach sexual maturity between 2 and 4 years of age, whereas bighead carp generally have a lifespan of 8 to 10 years and reach sexual maturity between 2 and 4 years of age (Kolar et al. 2007); however, some individuals have been known to live more than 25 years (Duane Chapman, personal communication). Bigheaded carps consume phytoplankton and zooplankton; silver carp consume mainly phytoplankton, while bighead carp consume zooplankton and other microorganisms. Both species can also consume detritus (Kolar et al. 2007). Individuals grow rapidly and can quickly become too large for most piscivorous North American fish to consume. Bigheaded carps spawn in turbulent flowing water once water temperatures exceed 18 ºC and spawning is typically triggered by rising water levels (Abdusamadov 1987, Kolar et al. 2007). Eggs are semi-buoyant but, if not kept in suspension by currents, they will settle to the bottom, which is detrimental to their survival (George et al. 2016). This means a minimum length of river is required for embryos to develop successfully (Garcia et al. 2013, Kolar et al. 2007, Krykhtin and Gorbach 1981). After hatching, larval bigheaded carps move into backwater areas. Many native large river fish are dependent on backwater resources (especially as nursery habitat) and so bigheaded carps' use of backwaters may be particularly impactful.

Both bighead and silver carp have high fecundity (Kolar et al. 2007) and the potential to populate new areas and reach high abundances, given favorable environmental conditions (Asian Carp Regional Coordinating Committee 2014). The ability to reach high abundances contributes to the impacts bigheaded carps can have on North American river ecosystems as well as on recreational river use. Silver carp jump from the water and can strike and injure recreational users (Spacapan et al. 2016). Additionally, bigheaded carps can disperse over great distances, contributing to their spread throughout North America (Degrandchamp et al. 2008;

Coulter et al. 2016a). The overlap in food resources and feeding efficiency of bigheaded carps lead them to be successful competitors with native planktivores such as gizzard shad (Dorosoma cepedianum) and bigmouth buffalo (Ictiobus cyprinellus) (Irons et al. 2007, Sampson et al. 2009) and the young of native species that also consume planktonic resources (USFWS 2014, Kolar et al. 2007). Bigheaded carps can also alter plankton communities and increase production of undesirable cyanobacteria, further altering invaded ecosystems (Radke and Kahl 2002). Increases in bigheaded carp abundance have been correlated with changes in the relative abundance of native fishes (Solomon et al. 2016). The rapid growth of bigheaded carps means that they are only consumed by native predators at small sizes (i.e., young-of-year). The high fecundity, rapid growth, feeding habits, mass spawning events, and dispersal capacity all contribute to the invasion success of bigheaded carps (DeGrandchamp et al. 2008, Carlson and Vondracek 2014).

As of November 2016, 33 individual bigheaded carp have been captured in Minnesota, varying from 0 to 6 individuals per year (Figure 1-1). Captured silver carp have weighed between 15.8 and 19.1 pounds, averaging 17.9 pounds. Captured bighead carp have weighed between 21.3 and 47.5 pounds, averaging 31.7 pounds. Most of these bigheaded carp have been captured on the Mississippi River, with some captured on the St. Croix and Minnesota Rivers (Figure 1-2). All captures have been adults, and therefore the population of bigheaded carps is considered a non-reproducing population at this time in Minnesota. The nearest reproducing population in the Mississippi River system is thought to be in southern Iowa (Figure 1-2). For the Missouri River watershed, which includes far southwestern Minnesota, the nearest reproducing population is below Gavins Point Dam on the mainstem, and in the James River, which is a tributary.

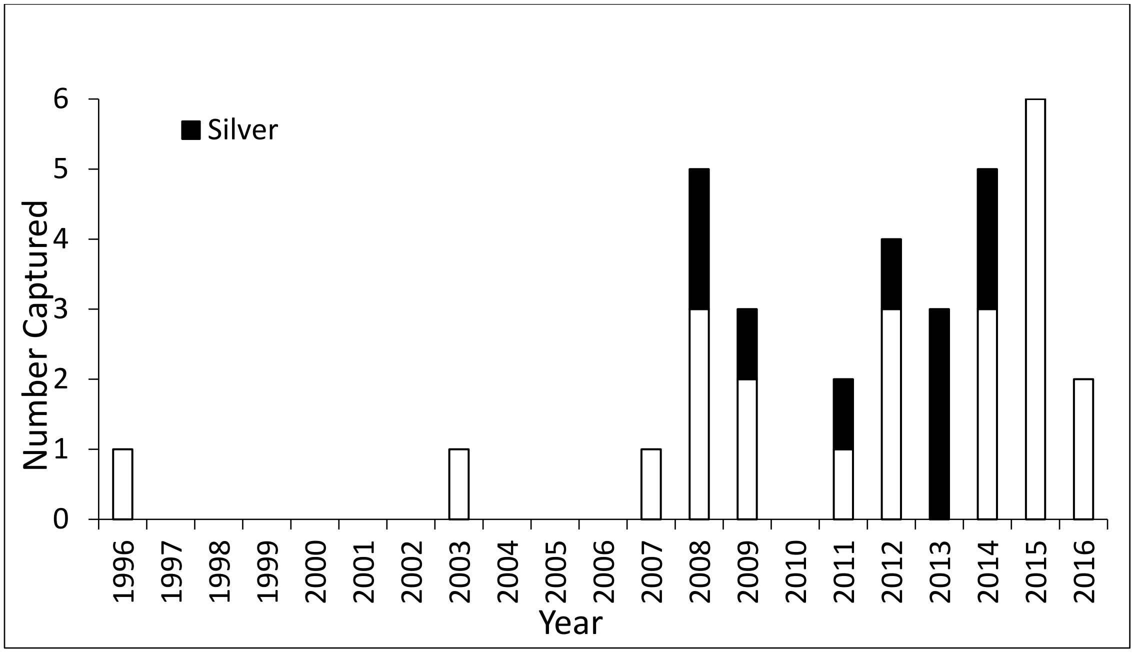


Figure 1-1. Number of individual silver (shown in black) and bighead (shown in white) carp captured per year in Minnesota as of November 2016.

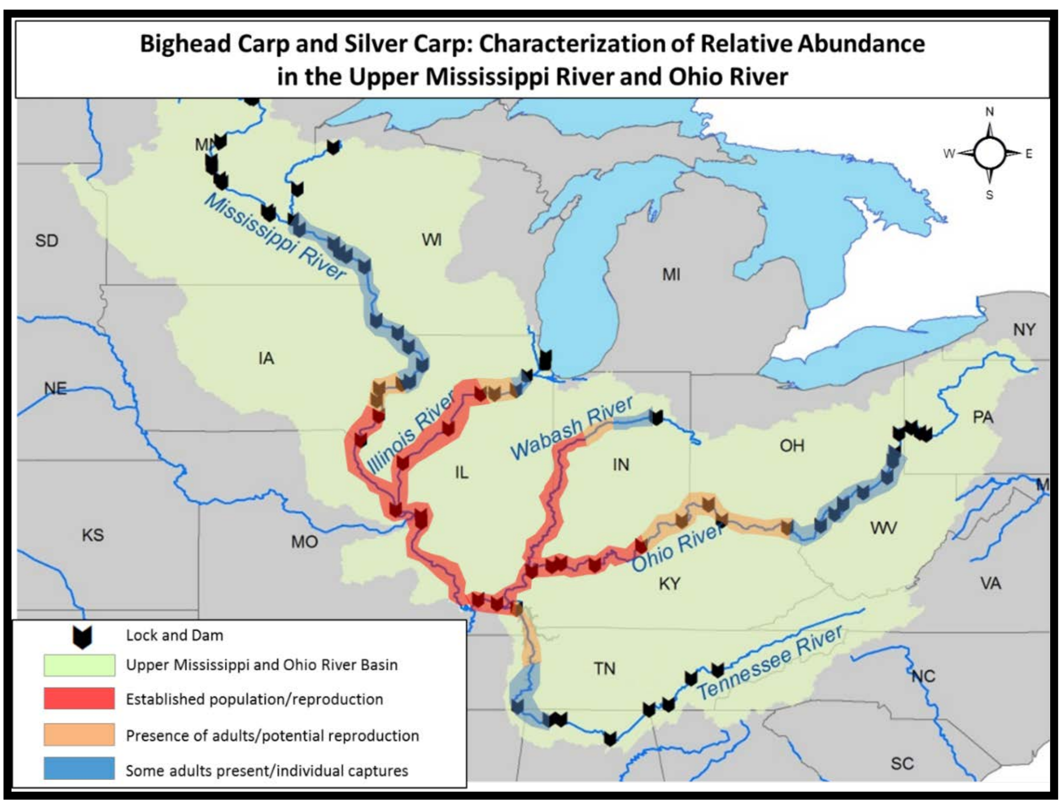


Figure 1-2. Characterization of Relative Abundance of bigheaded carps in the Upper Mississippi River and Ohio River. (Figure from USFWS 2015).

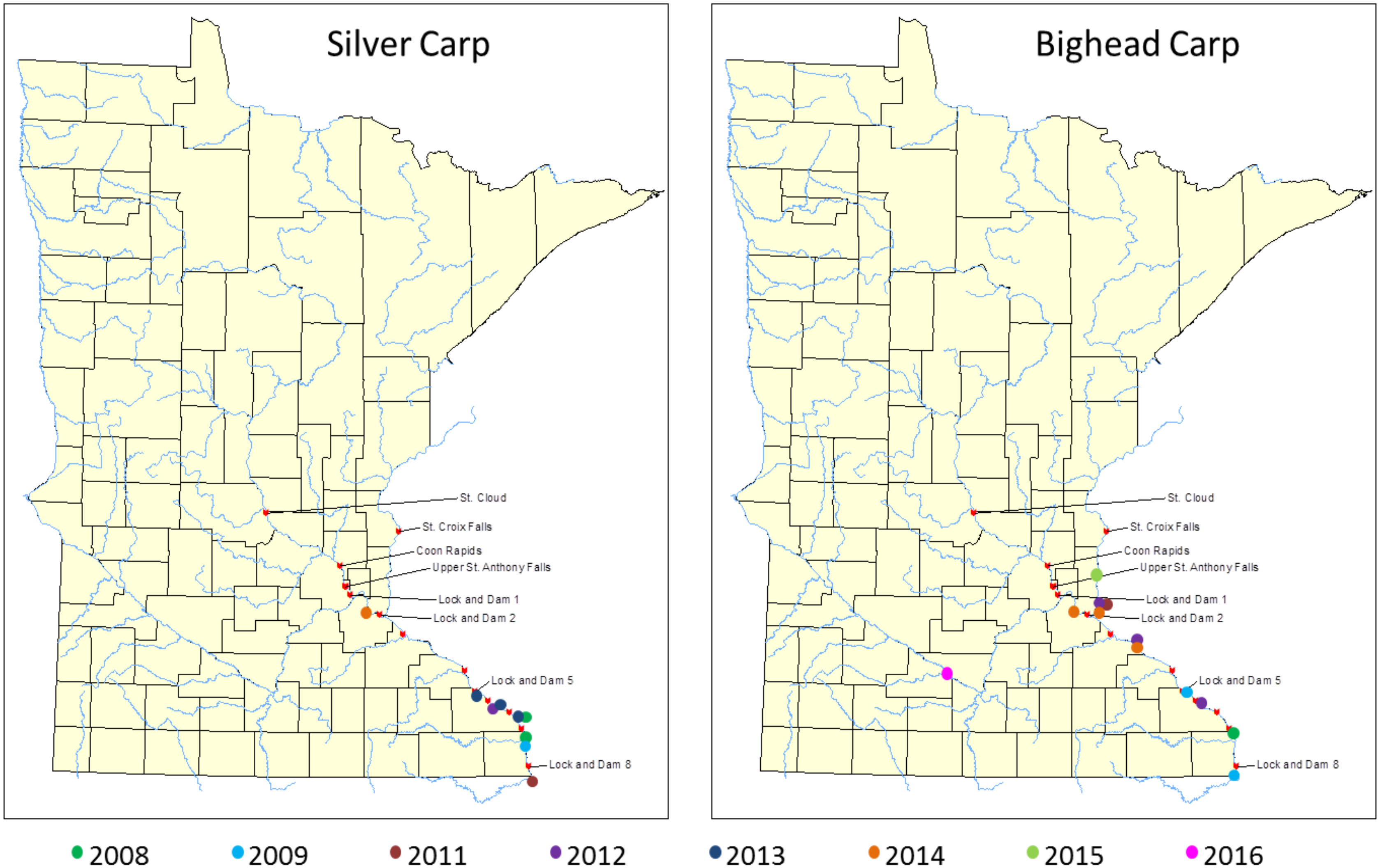


Figure 1-3. Locations that individual bigheaded carps have been found in Minnesota since 2008.

1.1.2. Existing management of bigheaded carps in Minnesota

Given that individual bigheaded carp are being captured in Minnesota but there is not yet an established (i.e., self-sustaining reproducing) population, there is a need to pursue and explore management to address this potential threat. The MNDNR is highly engaged with the management of bigheaded carps in Minnesota. The agency uses the Minnesota Invasive Carp Action Plan (MNDNR 2014) to guide activities. Plan elements include: 1) early detection and monitoring of susceptible waters; 2) prevention and deterrence; 3) response preparation; 4) management and control; and 5) outreach and communication. More specifically, the MNDNR is actively engaged in monitoring Minnesota waters for changes in bigheaded carp population size, range expansion, and reproduction; preventing or limiting range expansion at strategic locations; and accelerating research on control strategies. The MNDNR publishes an annual invasive species report that highlights invasive carp management activities (2011, 2012, 2013, 2014, 2015 Invasive Species Annual Report).

1.1.2.1. Assessment, detection, and monitoring of Invasive Carp

MNDNR Fisheries released a GIS spatial map depicting where invasive carp may spread by their own swimming capabilities in November 2013 (MNDNR 2013b). This included assigning relative risk of invasive carp passage at stream barriers and identification of potential watershed breaches. Since publication, work has been done to verify watershed breaches. The MNDNR invasive carp monitoring program was established in 2012. The MNDNR relies on six methods to detect and monitor the expansion and population changes of invasive carp in Minnesota: traditional fisheries monitoring programs; targeted sampling; contracted commercial fishing; monitoring the commercial catch; reported sightings; and environmental DNA (eDNA) sampling by the USFWS. The monitoring program targets all life stages of carp: egg, larval, juvenile, and adult. MNDNR fisheries began a fish telemetry study in spring of 2013 to understand fish movement around lock and dams and in the Mississippi River system. The USFWS also connected the receiver system with one located in Missouri to help monitor carp movements throughout potions of those two rivers.

1.1.2.2. Preventing upstream movement into northern Minnesota

The MNDNR believed that the best way to keep bigheaded carps out of the Upper Mississippi River watershed was to close the Upper St. Anthony Falls Lock. It required an act of Congress to close the lock, which is administered by the United States Army Corps of Engineers (USACE). Lock closure provisions were included in the Water Resources Reform and Development Act (WRRDA) bill which was signed into law by President Obama on June 10, 2014. The lock was closed on June 10, 2015. Additionally, the Minnesota Legislature approved $16 million in 2011 to fund improvements to the Coon Rapids Dam, including features to make it a more effective barrier against passage by bigheaded carps. Based on a 79-year flow record, fish passage through the dam would be possible an average of 4-5 days every ten years. Although the Coon Rapids Dam may be passable by invasive carp in rare high-water conditions, it provides important redundancy to the barrier at Upper St. Anthony Falls.

1.1.2.3. SW MN barriers

In 2011, the Iowa DNR captured two bighead carp with a bag seine in East Okoboji Lake, Iowa. The following year, a commercial fishing seine haul captured both bighead and silver carp from Iowa's Big Spirit and East Okoboji lakes. If bigheaded carps are able to swim upstream from Big Spirit Lake, they have the potential to reach lakes in southwest Minnesota. In fiscal year 2013, the MNDNR received funding from the Outdoor Heritage Fund (OHF) to place barriers in this region to limit invasive carp expansion. To help prevent the migration of invasive carp into southwest Minnesota, the MNDNR partnered with Iowa DNR to install an electric deterrent at the outlet of the Iowa Great Lakes, located on Lower Gar Lake. This deterrent became operational in May 2013. The area fisheries office in Windom, MN also identified seven sites where barriers could be installed to prevent the spread of invasive carp into high value lakes or between watersheds. Work was completed at these sites in November 2015.

1.1.2.4. Minnesota and Mississippi Rivers

The MNDNR is partnering with Minnesota State University - Mankato to evaluate invasive carp deterrents in the Minnesota River. University partners will collect and analyze data on hydrologic and geomorphic characteristics to determine potential locations and feasibility for deterrent measures. The project also will examine biological data to identify habitats that are highly suitable for invasive carp. Lastly, in spring 2015 researchers began investigating the Minnesota River - Red River watershed boundary to determine if the two watersheds can become connected during high water events. The MNDNR is beginning to look at potential actions at Lock and Dam 5 on the Mississippi River to slow the upstream expansion of carp. The installation of an acoustic/bubble deterrent has been proposed as a possible action.

1.1.2.5. Partnerships

In 2012, the Minnesota legislature appropriated funds to create an Aquatic Invasive Species Research Center at the University of Minnesota, in collaboration with the Commissioner of Natural Resources. The research center is pursuing a number of research initiatives, including:

1. Understanding and developing strategies for implementing eDNA as a molecular technique to assess potential presence of invasive carp in large Minnesota rivers;
2. Evaluating the potential to detect and locate invasive carp through the use of "Judas fish," a new behavioral tool to locate aggregations of invasive fish so they might be tracked and/or removed;

3. Developing food, pheromone, and hormone attractants for invasive carp to induce high-density aggregation for the purposes of fish detection, measurement, control and removal;
4. Conducting an assessment of effectiveness of enhanced bubble curtains as deterrents of invasive carp movement into small tributaries;
5. Installation of sound deterrents to deter invasive carp in the Mississippi River;
6. Assessing the potential use of native pathogens as invasive carp control agents;
7. Conducting risk analyses to identify invasive carp control priorities and methods.

In addition, the Sorensen laboratory at the University of Minnesota is continuing with LCCMR and MNDNR funding to study fish and carp passage around and through locks and dams in the Mississippi River, and ways the locks and dam operations might be safely altered to prevent the invasion and establishment of silver and bigheaded carp. The possibility of altering gate operations at specific structures to hold back carp at these locations without effecting scour is the focus of various types of numeric modeling. Results are promising and suggest carp passage is already very low at some key structures and might be reduced to a few percent of present values at no cost and in ways that do not appear to enhance scour or affect lock usage and thus might be acceptable for management (Peter Sorensen, personal communication). In addition, laboratory research with specific sounds that also appear unlikely to strongly affect many native fishes suggests that they could be placed into locks to prevent most carp passage. This scheme has been described but field tests have not yet been funded.

1.1.3. Tensions and conflicts facing management and the need for risk assessment

Even with many management actions already taking place in Minnesota, there is a need for work to help prioritize future management actions. Informational interviews with state and federal agency personnel during the scoping of this project indicated support for a bigheaded carps risk assessment that could identify areas of the state most at risk from bigheaded carps, characterize factors influencing the level of risk, and help prioritize management. Research on the tensions and conflicts facing the management of invasive carp in Minnesota also supports the need for a bigheaded carps risk assessment in Minnesota (Kokotovich and Andow 2017). Kokotovich and Andow (2017) conducted 16 in-depth interviews with state and federal agency officials, researchers, and stakeholders involved with invasive carp management in Minnesota to learn about the tensions and conflicts impacting management. Findings from these interviews reveal a complex set of issues revolving around three areas of tension and conflict: 1) scientific uncertainty concerning the effects of Asian carp in Minnesota and the efficacy and non-target effects of possible management actions; 2) social uncertainty concerning both the lack of societal agreement on how to respond to Asian carp and the need to avoid acting from apathy and/or fear; and 3) the desired approach to research and management. Scientific uncertainty and social uncertainty were seen to reinforce each other and complicate efforts to determine the desired approach to invasive carp research and management.

The scientific uncertainty surrounding the likely effects of invasive carps in Minnesota emerged as an important area of tension and conflict hampering management, both because it was seen as complicating decisions on individual management actions and because it was seen as potentially reinforcing apathy- and fear- based societal responses. A risk assessment was seen as a way to help address this area of tension and conflict. Knowing more about the likely effects of invasive carp in Minnesota could help identify reasoned management actions and prevent societal reactions based on apathy or fear. For example, interviewees stated that the decision making about management actions such as species-selective deterrents or non-selective barriers should be based on both the likely consequences from invasive carps and the likely effects of the deterrent or barrier, including its efficacy on invasive carps and its non-target impacts on native ecosystems. Without both sides of the equation, it is difficult to pursue well-informed decision making. Interviewees also described how individuals and institutions will be less likely to act from apathy (e.g., believing invasive carp will cause no impacts and therefore management is unimportant) or fear (e.g., believing invasive carp will cause catastrophic impacts and management actions should be taken regardless of their collateral damage) if the likely effects of bigheaded carps in MN are better understood (Kokotovich and Andow 2017). As a result, the risk assessment presented here – characterizing the risks from bigheaded carps for Minnesota – will be useful to the current decision making and societal context.

It is important to explicitly note that the risk assessment findings reported here provide information that is at once necessary and insufficient to inform the management of bigheaded carps in MN. Any decision about a particular management action, such as a deterrent or barrier, must be based on the likely effects of bigheaded carps as well as on careful scrutiny of the proposed action itself. Decision making regarding management actions should take into account the ecological, social, and economic impacts of bigheaded carps and of the proposed action, including consideration of the probabilities and conditions of those impacts. This work, due to necessary limitations of scope, only partially addresses the host of factors needed to inform a potential management decision, and should be used in a way that acknowledges this.

1.2. National context

1.2.1. Existing effects and management efforts

Many other areas of the United States have experienced invasions from bigheaded carps. Insights emerging from studies of these areas are important to efforts to predict and avoid consequences from bigheaded carps in Minnesota.

1.2.1.1. Illinois River

The Illinois River is a highly modified waterway that is the direct connection between the Mississippi River basin and the Great Lakes Basin, via the Chicago Area Waterway System. Since the early 1990's bigheaded carps in the Illinois River have gradually expanded their range and continued to increase in numbers such that they currently dominate the fish biomass (nearly 70%) in some navigation pools. Prior evidence has demonstrated significant declines in body condition of gizzard shad (−7%) and bigmouth buffalo (−5%) following the bigheaded carps invasion (Irons et al. 2007).

Beginning in 2009 the Illinois Department of Natural Resources and several agencies took an aggressive approach to inhibit the expansion of bigheaded carps into the Great Lakes. The overall goal of the Asian Carp Regional Coordinating Committee (ACRCC) is to prevent Asian carp from establishing self-sustaining populations in the Chicago Area Waterway System (CAWS) and Lake Michigan. Efforts to prevent the spread of bigheaded carps to the Great Lakes have been underway for over 6 years (see Asian Carp Monitoring and Response Plan, Interim Summary Reports 2010, 2011,2012,2013,2014, and 2015 (asiancarp.us)). In response to threats posed to the Great Lakes by bigheaded carps, the ACRCC and the Asian Carp Monitoring and Response Workgroup have identified the following projects to gain further understanding of Asian carp, improve methods for capturing Asian carp, and directly combat the expansion of Asian carp range. During this time, goals, objectives, and strategic approaches have been refined to focus on five key objectives in the Monitoring and Response Plan (see 2016 Monitoring and Response Plan for Asian Carp in the Illinois River and Chicago Area Waterway System (asiancarp.us)):

1. Determination of the distribution and abundance of any Asian carp in the CAWS, and use of this information to inform response removal actions;
2. Removal of any Asian carp found in the CAWS to the maximum extent practicable;
3. Identification, assessment, and reaction to any vulnerability in the current system of barriers to prevent Asian carp from moving into the CAWS;
4. Determination of the leading edge of major Asian carp populations in the Illinois River and the reproductive successes of those populations; and

5. Improvement of the understanding of factors behind the likelihood that Asian carp could become established in the Great Lakes.

1.2.1.2. Wabash River

The Wabash River, a large tributary to the Ohio River, originates in western Ohio before flowing west and south through Indiana to form the border between Indiana and Illinois. The watershed is 85,326 km^2 (Gammon 1998) and is > 60% agriculture. The river has one mainstem dam in the upper reaches, creating > 600 km of free-flowing river. Bighead carp were first detected in the Wabash River watershed in 1995 and silver carp in 2003 (USGS NIS 2016). Bigheaded carps are considered established although they occur at lower abundances than in other North American invaded rivers (i.e., Illinois River; Stuck et al. 2015). The Wabash River watershed contains a potential pathway for bigheaded carps to the Great Lakes basin via the Little River and Eagle Marsh (USACE 2010). However, this hydrological connection has since been blocked with the construction of an earthen berm (NRCS 2016]). In addition to hydrologic separation, management of bigheaded carps in the Wabash River watershed has focused on monitoring and angler education to prevent spread into areas not already invaded (D. Keller, Personal communication). Monitoring activities include acoustic telemetry (including in the Little River to monitor the Eagle Marsh pathway; Coulter et al. 2016b), pathogen surveys (Thurner et al. 2014), spawning surveys (e.g, Coulter et al. 2013; Coulter et al. 2016a), and eDNA surveys (e.g., Erickson et al. 2016). Some commercial fishermen harvest bigheaded carps but there is not currently an effort to deplete the population (D. Keller, personal communication). Since the invasion of bigheaded carps, the Wabash River fish assemblage showed increased efficiency in energy transfer, and a change in the dominant functional feeding group (planktivore-omnivores to benthic invertivore; Broadway et al. 2015). Abundance of low trophic level fishes has increased, a change likely driven by increasing numbers of bigheaded carps (Broadway et al. 2015).

1.2.1.3. Mississippi River – South of Minnesota

The Mississippi River Basin is the largest drainage basin in North America and covers approximately 3,225M square kilometers and includes all or parts of 31 states and two Canadian provinces. Throughout much of the Mississippi River and many of its associated tributaries, bigheaded carp populations are considered established. However, relative abundance or biomass is lower in the northern reaches of the Mississippi River (i.e., Minnesota, Wisconsin, and Iowa). Bigheaded carps were first observed in lower portions of the Mississippi River in the 1970s and 1980s but recently have been documented at locations in the upper reaches of the Mississippi River. Despite the well-established naturally recruiting populations particularly in the southern reaches (below Keokuk, Iowa) of the Mississippi River, extremely limited empirical evidence on the effects of Asian carp exists in the Mississippi River basin.

Mississippi River Basin (further south than Minnesota) fish community data collected from 2003-2015 by the Long Term Resource Monitoring program and the Missouri Department of Conservation suggest that the relative abundance of bigheaded carps has increased exponentially, while relative abundance and condition of some native fishes has declined (Phelps et al. In Review). Standardized sampling evaluations of floodplain lakes of the Mississippi River yielded similar results; floodplain lake fish communities were drastically altered by abundant bigheaded carps after their invasion (Phelps et al. In Review). Furthermore, laboratory experiments corroborated field evidence, showing that bigheaded carps reduced native fishes abundance through competition for prey. To this end, multiple lines of evidence suggest bigheaded carps are reducing the abundance of native fishes in the Mississippi River south of Minnesota (Phelps et al. In Review). Reductions in bigheaded carps in the Mississippi River (south of Minnesota) could reduce the decline in native fish abundances and prevent further expansion throughout North America (Seibert et al. 2015). Currently, minimal harvest occurs but efforts are in place to inform constituents about Asian carp through outreach and education.

1.2.2. Previous risk assessments and the need for a MN risk assessment

There have been two primary bigheaded carps risk assessments conducted in North America (Kolar et al. 2007; Cudmore et al. 2012). Kolar et al. (2007) provided a summary of the biology, distribution, and organismal risk of the bighead, silver, and largescale silver carp for the United States. The judgment of risk was for the overall risk potential of these species, based on the probability of establishment and the consequences of establishment. The authors assessed seven elements of risk, using a risk scale of low, medium, or high, with a 5-point certainty scale (Very certain, Reasonably certain, Moderately Certain, Reasonably Uncertain, Very uncertain). The seven elements assessed were: 1) Estimated probability of the exotic organism being on, with, or in the pathway; 2) Estimated probability of the organism surviving in transit; 3) Estimated probability of the organism successfully colonizing and maintaining a population where introduced; 4) Estimated probability of the organism spreading beyond the colonized area; 5) Estimated economic impact if established; 6) Estimated environmental impact if established; and 7) Estimated impact from social and/or political influences. These seven elements of risk were assessed at the scale of the entire United States.

The risk for silver and bighead carp for the first 4 elements having to do with establishment were all characterized as high – very certain, the highest risk and certainty ratings possible. The 5th and 6th element, for economic and environmental effect, were both characterized as medium to high risk – reasonably certain, for both bighead and silver carp. The 7th element, for social and/or political influences, was characterized as medium risk – reasonably certain. The overall risk potential for both bighead and silver carp was considered high. This level of risk was deemed unacceptable for the United States and one that "justifies mitigation to control negative effects" and means that silver and bighead Carp are "organisms of major concern for the United States" (Kolar et al. 2007, p. 155).

Cudmore et al. (2012) conducted a binational risk assessment of bigheaded carps for the Great Lakes basin to provide advice for management actions. The scope of the risk assessment was determined during a workshop of Great Lakes researchers, managers, and decision makers. The focus was on assessing, for each one of the Great Lakes, the likelihood of arrival, survival, establishment, and spread, and the magnitude of ecological consequences, given the current management context. Five-point scales were used for characterizations of likelihood, consequence, and certainty. The overall characterization of risk was a function of the probability of introduction and the magnitude of ecological consequence. Probability of introduction was characterized as:

Probability of Introduction = Min [Max (Arrival, Spread), Survival, Establishment]

Based on the agreed upon scope, a draft risk assessment was created by the authors and presented to a larger expert peer review group that came to consensus on the all of the risk assessment rankings (Cudmore et al. 2012).

For the Minnesota context, it is especially useful to review the findings of Cudmore et al. (2012) for Lake Superior, because that Great Lake borders the state. Lake Superior received overall risk scores that were lower than the other Great Lakes because of a lower likelihood of introduction and a lower likely ecological effect (Table 1-1) (Cudmore et al. 2012).

Table 1-1. Risk characterization for Lake Superior from binational risk assessment. (From Cudmore et al. 2012).

Element	Rank	Certainty
Arrival	Very Unlikely	Moderate
Spread	Very Likely	High
Max (Arrival, Spread)	Very Likely	High
Survival	Very likely	High
Establishment	Moderate	Moderate
P(Introduction)	Moderate	Moderate
Ecological Impact ~20 years	Low	Moderate
Ecological Impact ~50 years	Moderate	Moderate
Overall risk ~20 years	**Low-Moderate**	**Moderate**
Overall risk ~50 years	**Moderate**	**Moderate**

Kolar et al. (2007) and Cudmore et al. (2012) characterized the potential risks from bigheaded carps for the US and the Great Lakes, yet these risk assessments are not sufficient to inform decision making in Minnesota. There is a need for a risk assessment that has an appropriate geographic scale, that is informed by the MN decision making context, and that involves people knowledgeable of the ecology and decision making context of Minnesota. First, a risk assessment with the correct geographic scale would provide the specificity necessary to help identify which parts of Minnesota are most at risk and what adverse effects are most likely in different parts of the state. Second, people involved with the MN decision making context, such as state and federal agency personnel and local stakeholders, should be involved in the risk assessment scoping process to determine, for example, which watersheds and potential adverse effects are most important to study. Third, there is a need to involve people in the risk assessment with the right expertise to assess the risks for particular watersheds within Minnesota. This local expertise is key to being able to apply the findings from other areas impacted by bigheaded carps to the Minnesota context. A risk assessment focused on Minnesota can provide the level of detail and nuance to be most useful for the local decision making context.

2 Methodology

The methodology for this risk assessment followed a deliberative approach (NRC 1996) and contained three major steps. First, the specific scope of the risk assessment was determined by state agency personnel and local stakeholders. Second, a two-day expert workshop was held to characterize the risk to Minnesota from bigheaded carps. Finally, project researchers and a select group of workshop participants created this report that summarizes the outcomes from the workshop.

2.1 Defining scope

Initial informational interviews and project research (Kokotovich and Andow 2015; Kokotovich and Andow 2016) revealed one overarching goal and two objectives to guide the risk assessment. The overarching goal was to characterize the risks from bigheaded carps to Minnesota to inform management and research. The two objectives for the risk assessment were: 1) determine what areas of the state are most at risk; and 2) determine which potential adverse effects are most likely to result from an invasion and their level of consequence. Given the constraints of this project, it was not possible to assess all watersheds of the state and all potential adverse effects. Because of this, state agency personnel and stakeholders were engaged to help determine two foundational parts of the scope: the watersheds and potential adverse effects to be studied. MNDNR personnel and stakeholders were asked to help define the scope given their knowledge of the state's water resources and the current bigheaded carps decision making context.

An important assumption of this risk assessment involves its focus on the establishment and effects of bigheaded carp, and not on their spread. Classically, the assessment of invasive species risk involves two steps, exposure analysis and effects analysis. Exposure analysis includes estimating the likelihood of introduction, establishment and spread, while effects analysis includes estimating the likelihood and severity of the ecological, economic, or social consequences from that exposure (Anderson et al. 2004). This risk assessment focuses on characterizing the likelihood of establishment and the consequence of resulting effects, assuming bigheaded carps arrive in each watershed. Work has been conducted to understand the spread potential (MNDNR 2013b), and research and management continue to help slow the spread (Zielinski & Sorensen 2016; Kennedy 2016). Ideally, management actions will be successful in slowing or stopping the spread of bigheaded carps into the state. However, an understanding of whether and how bigheaded carps will negatively impact watersheds if they do arrive can help prioritize management, determine what collateral damage from management actions are justified, and help inform societal expectations on bigheaded carps.

The process to select the potential adverse effects – i.e., potential consequences from bigheaded carps in need of evaluation – for the risk assessment had two parts. First, 5 focus groups were held to create a list of all potential adverse effects, 3 with personnel from the MNDNR and 2 with stakeholders involved with bigheaded carps in Minnesota. Focus group participants created a list of all potential adverse effects that could result from the establishment of Asian carp in Minnesota (Kokotovich and Andow 2015). Second, in advance of the risk assessment workshop, an online survey was conducted to decide which potential adverse effects were most important to study. The survey was conducted with 30 people who were either taking part in the risk assessment workshop or had participated in one of the focus groups. From these survey findings, four potential adverse effects were identified: decrease in non-game fish populations, decrease in game fish populations, reduction in species diversity and ecosystem resilience, and decrease in recreation quality due to the silver carp jumping hazard. In addition to being highly ranked individually, these potential adverse effects are consequential to other highly valued aspects of Minnesota's waterways: 1) overall ecological health, 2) public attitudes towards waterways, and 3) opportunities for, safety of, and quality of recreational boating and fishing.

The watersheds were chosen to represent a diversity of basins and river types, to be relevant to the state's current decision making context, and, when possible, to be worst-case scenarios – watersheds in each basin that are likely to be most favorable to bigheaded carps. Minnesota has eight major watersheds that drain the state's waters and the Minnesota River, St. Croix River, Red River, and Great Lakes basins were prioritized for this project. To help select the specific watershed within these basins, a ranking process based on measurable variables was used to select the watersheds that were most likely to be favorable to bigheaded carps. Factors generally seen as correlating to establishment and effect that were used in this estimation included: perennial cover; fish species richness; phosphorus risk; and aquatic disruptions/dams. The four watersheds selected to be the focus for this risk assessment were: Sand Hill River Watershed (HUC 09020301), Nemadji River Watershed (HUC 04010301), Lower St. Croix River Watershed (HUC 07030005), and Minnesota River - Mankato Watershed (HUC 07020007) (Figure 2-1). For the purposes of this report we will sometimes shorten the names of these watersheds to, for example, St. Croix River and Minnesota River.

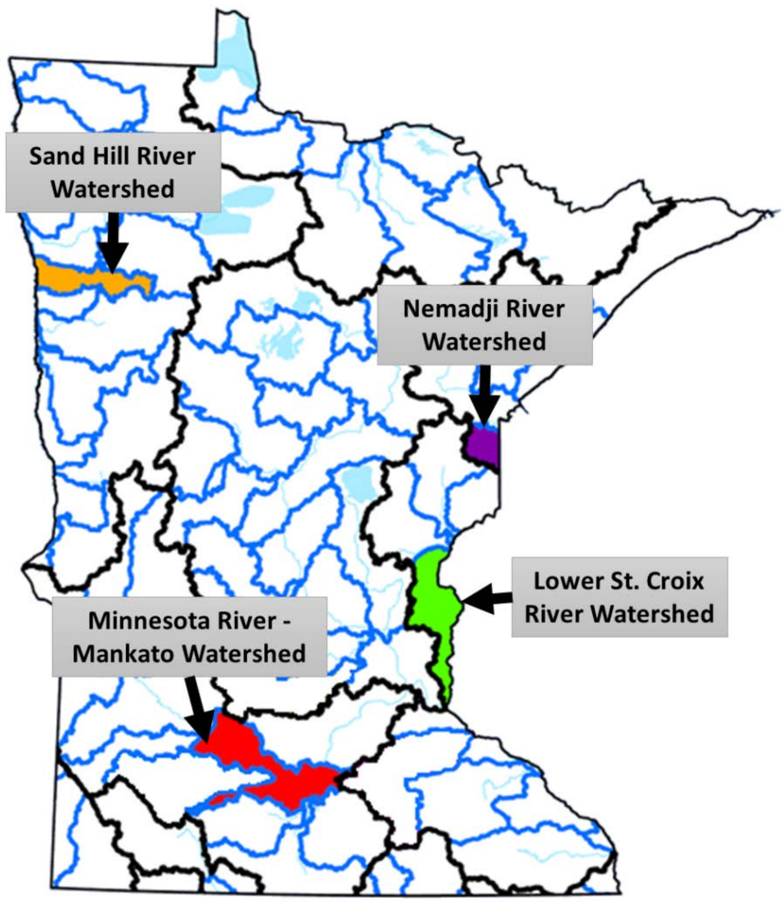


Figure 2-1. Map of watersheds selected for risk assessment.

2.2 Risk Assessment Workshop

On March 8th and 9th 2016 a workshop was held at the University of Minnesota to conduct the main parts of the risk assessment. Twenty-three experts on bigheaded carps and Minnesota's waterways participated in the risk assessment workshop, including individuals from 5 federal agencies, 5 academic institutions, the MNDNR, natural resource agencies from 2 other states, and a stakeholder group. The attendees were selected to ensure the needed expertise on both bigheaded carps and Minnesota's waterways was present to deliberate on and characterize the risk. A mixture of small and large group discussions was used to characterize the overall risk, which was characterized in three steps: the likelihood that bigheaded carps would establish in each watershed, the resulting abundance of bigheaded carps in each watershed, and the severity of adverse effects caused by the resulting abundance.

2.2.1 Workshop day 1: Likelihood of establishment and resulting abundance

Day one started with a large group discussion to create a list of biotic and abiotic factors that influence whether bigheaded carps establish in a particular watershed and their resulting abundance (see Section 3). This large group discussion helped identify important principles to inform the establishment and abundance characterizations that would be taking place during the remainder of the first day. Each participant was then assigned to one of four small groups, and each group was associated with one of the selected watersheds. Each small group had a graduate student facilitator who was familiar with the workshop process and had expertise in fisheries or risk assessment. Selected participants from the MNDNR began the small group session by describing the watershed and its relevant characteristics. The facilitators then guided each group through their two objectives for the first day.

First, each group characterized the likelihood that bigheaded carps would establish in their particular watershed, given arrival. Specifically, they estimated the likelihood that bigheaded carps would establish in their watershed within 10 years of their arrival, assuming they arrive with enough individuals to where establishment would be possible under ideal conditions. Also, it was assumed that the current management context would not change. Groups were not taking into account how likely it is that bigheaded carps arrive in the watershed, but were only focusing on what the risk would be if they arrive. The goal was to identify the watersheds that are most at risk if bigheaded carps arrive. Each participant used 5-point scales to characterize the likelihood of establishment (Table 2-1) and the certainty of their characterization (Table 2-2). These scales were adapted from previous Asian carp risk assessments (Cudmore et al. 2012).

Table 2-1. Establishment likelihood scale and percentages range.

Establishment likelihood scale	Establishment likelihood range (%)
Very unlikely	0 – 5%
Low	5 – 40%
Moderate	40 – 60%
High	60 – 95%
Very likely	95 – 100%

Table 2-2. Certainty scale and definition.

Certainty Scale	Definition of scale
Very low	±90%; E.g., little to no information to guide assessment
Low	±70%; E.g., based on ecological principles, life histories of similar species, or experiments
Moderate	±50%; E.g., inference from knowledge of species
High	±30%; E.g., primarily peer reviewed information
Very high	±10%; E.g., extensive, peer-reviewed information

After characterizing the likelihood of bigheaded carp establishment, each small group characterized the resulting abundance of bigheaded carps in their watershed, assuming they were to establish. Five-point scales were used to characterize the resulting abundance (Table

2-3) and the certainty of their characterization (Table 2-2). This abundance level was used in Day 2 to characterize how severe the adverse effects would be. For example, a very high resulting abundance of bigheaded carps would be expected to lead to more severe adverse effects than a very low resulting abundance.

Table 2-3. Resulting abundance scale and definition.

Resulting abundance scale	**Definition of scale**
Very low	Few individuals, <1% of total fish biomass
Low	1 – 5% of total fish biomass
Moderate	5 – 25% of total fish biomass
High	25 – 60% of total fish biomass
Very high	>60% of total fish biomass

With each of these characterizations, participants also characterized their justifications, areas of disagreement, and research needs. The small group did not need to come to consensus on the characterizations; in fact, they made each characterization individually. Participants were encouraged to explore and record any differences in reasoning that led to divergent characterizations. The small group format allowed groups to become familiar with their watershed and to discuss issues in much more detail than would be possible if the large group addressed each watershed.

After the small groups made their characterizations, all participants reassembled for the final large group discussion of Day 1. This discussion consisted of three parts that were repeated for each small group: 1) the small group presented their characterizations of establishment likelihood and resulting abundance for their watershed and summarized their justifications; 2) other workshop participants asked questions and raised any concerns about the characterizations to the small group; 3) all workshop participants then characterized the establishment likelihood and abundance for the watershed in question based on the small group's report and subsequent discussion. These characterizations provided by all workshop participants based on the recommendations of the small group were the ones that informed the subsequent overall characterization of risk. Both the small group and large group characterizations were recorded and are presented in each of the watershed sections within this report.

2.2.2 Workshop day 2: Adverse effects

Day 2 started with a large group discussion where participants created a list of potential risk pathways that could lead from bigheaded carps to the adverse effects being analyzed (see Section 3). Participants also discussed the key biotic and abiotic factors that influence whether an adverse effect is likely to take place as a result of a particular risk pathway. The small groups from Day 1 met again, this time to discuss and characterize each potential adverse effect for each watershed. Small groups began by characterizing the potential impact on plankton within the watershed, as that was deemed an important intermediary step for some of the other potential adverse effects. For the potential adverse effects, participants used a 5-point scale to describe the consequence level (Negligible; Low; Moderate; High; Extreme) and certainty (Table 2-2) of their characterization. Precise definitions were provided for the consequence scale specific to each adverse effect (see Appendix B). Small groups characterized the severity of an adverse effect based on the likely resulting abundance of bigheaded carps in that watershed. These resulting abundances were the ones determined by the large group characterization on Day 1. Small groups characterized the adverse effects twice, once for the most likely abundance and a second time for the second most likely abundance. Due to time limitations, however, the large group characterizations were only conducted for the most likely resulting abundance. The difference between a small group's adverse effects characterization for the most likely and second most likely resulting abundances was used to understand how the overall characterization of risk would change if the second most likely resulting abundance was achieved (Section 8.3). The process for the large group characterizations of adverse effects was the same as Day 1: small group report back, discussion, and characterization of each adverse effect for the particular watershed. The characterizations of the adverse effects are presented in each subsequent watershed section within this report.

2.3 Overall Risk Characterization

At the end of the workshop, participants had characterized the likelihood that bigheaded carps would establish in each of the four watersheds and the likely severity of the resulting adverse effects. In order to determine the overall risk for each watershed, the characterizations of establishment and adverse effects needed to be combined. These overall risk characterizations for each watershed are presented in Section 8. They were arrived at by turning the establishment characterizations from the workshop into a single percentage for each watershed and combining it with the adverse effect characterizations. The likelihood of establishment for each watershed was turned into a single percentage using the following calculation: First, the individual likelihood characterizations were weighted based on the certainty scores provided by the participants. The weighting factors were assigned as $\frac{\mathbf{1}}{\boldsymbol{Certainty}\,\%}$ as shown in Table 2-4.

Table 2-4. Weighting factor provided to establishment likelihood

Certainty Score	Weighting factor provided to establishment likelihood
Very High (±10%)	1/.1 = 10
High (±30%)	1/.3 = 3.33
Moderate (±50%)	1/.5 = 2
Low (±70%)	1/.7 = 1.43
Very Low (±90)	1/.9 = 1.11

Second, the overall likelihood of establishment was then calculated using the following equations, where ERHi = high value of the establishment likelihood range for category i, and ERLi = the low value of the establishment likelihood range for category i:

$$Overall\ Likelihood\ of\ Establishment$$
$$= \sum_{i=Very\ unlikely}^{Very\ likely} \frac{Sum\ of\ weighted\ scores\ in\ category\ i}{Sum\ of\ weighted\ scores\ across\ all\ categories} * \frac{ERHi + ERLi}{2}$$

An example calculation for the Sand Hill River is provided in Table 2-5.

The weighting factor allowed us to incorporate the certainty expressed by the participants into the establishment scores, thereby incorporating the certainty into the overall characterization of risk. Participants were not told that their certainty scores would be used as a weighting factor, so there was no motivation to change their certainty scores to influence the weighting of their characterization. Given that most certainty scores ranged between Very Low and Moderate, this weighting factor did not have a significant effect on the overall likelihood of establishment for each watershed. The overall likelihood of establishment calculated with and without the weighting factor differed by less than 2% for each watershed.

The overall risk characterization score was calculated as the Probability of Consequence Level Given Arrival and combined the overall establishment likelihood with the adverse effect characterizations. An example of this calculation for the Minnesota River is shown in Table 2-6.

This means that if bigheaded carps were to arrive in the Minnesota River (with enough individuals to make establishment possible), participants thought there was a 70% chance that they would establish. If they were to establish, 47.6% of participants thought bigheaded carps would have a low impact on Bigmouth Buffalo and 52.4% of participants thought bigheaded carps would have a moderate impact on Bigmouth Buffalo. So the probability of a low consequence given arrival is (.476)(.70) = .33 or 33% and the probability of a moderate consequence given arrival is (.524)(.70) = .37 or 37%. The remaining probability equals the estimated likelihood that bigheaded carps would not establish in the Minnesota River watershed (30%).

Table 2-5. Calculation for overall establishment percentage for the Sand Hill watershed. Initial = Number of participants who characterized the likelihood and certainty. W.S. = Weighted scores, based on the weighting factor in Table 2-4.

		Likelihood of establishment							
		Very unlikely (.00-.05)		Low (.05-.40)		Moderate (.40-.60)		High (.60-.95)	Very likely (.95-1.00)
		Initial	W.S.	Initial	W.S.	Initial	W.S.		
Certainty of assessment	5 – Very high certainty								
	4 – High certainty			4	13.33				
	3 – Moderate certainty	2	4	9	18				
	2 – Low certainty	1	1.43	3	4.29	1	1.43		
	1 – Very low certainty					1	1.11		
Overall Likelihood of Establishment Calculation:									
A	Calculate proportion of weighted scores in each likelihood category	.12 = (4+1.43)/43.59		.82 = (13.33+18+4.29)/ 43.59		.06 = (1.43+1.11)/ 43.59			
B	Calculate midpoint of each likelihood range	.025 = (.05+.00)/2		.225 = (.40+.05)/2		.5 = (.60+.40)/2		.775	.975
C	$\sum A * B$	(.12*.025)+(.82*.225)+(.06*.5) = .22 = Overall Likelihood of Establishment							

Table 2-6. Calculation used for overall risk characterization score.

MN River Game fish: Bigmouth Buffalo – Adverse effect characterizations	Negligible	Low	Moderate	High	Extreme
		.476	.524		
MN River – Establishment Likelihood for MN River	.70				
Overall risk characterization = Probability of consequence level given arrival	Negligible	Low	Moderate	High	Extreme
		.33 = (.476)(.70)	.37 = (.524)(.70)		

2.4 Risk Assessment Report

The writing of this risk assessment report had multiple steps and involved project researchers and workshop participants. At the workshop itself individual workshop participants volunteered to help with the writing of this report (Appendix A). This group of authors included representatives from each watershed/small group. Notes from the small group workshop sessions were provided to the authors from each group. The authors from each watershed used those notes to draft the section describing the characterizations of their watershed. This included the following sub-sections: an introduction to the watershed; the final characterizations (i.e., establishment likelihood, resulting abundance, adverse effects); justifications for the characterizations; and research needs. In addition to these sections on the watersheds, certain workshop participants contributed to other sections of the report, mainly the introduction. After the report was compiled, it was provided to all workshop participants for review. Comments from the workshop participant reviews were incorporated into the March 15th, 2017 draft version of the report. This March 15th draft of the report was then presented to state and federal agency officials, representatives from local units of government, stakeholders, and members of the public at the March 2017 “Risk-based management for bigheaded carps workshop” held at the University of Minnesota (for outcomes from the meeting, see Appendix C). This 2017 workshop provided an opportunity to discuss the findings and management implications of the risk assessment. Feedback from this workshop helped inform this final version of the risk assessment report.

Project researchers (Adam Kokotovich & David Andow) assembled and revised the different sections of the report and wrote the Executive Summary, Methodology, Overall Risk Characterization, Discussion, and Appendices. The overall conclusions in this report are based on the findings that emerged from the risk assessment, but represent the views of the project researchers.

3 Possible biotic and abiotic factors and pathways to adverse effects

During the workshop, participants spent parts of each morning in a large group discussion addressing pertinent issues for each day's objectives. On Day 1 participants produced a list of possible biotic and abiotic factors impacting establishment and abundance (Table 3-1). On Day 2 they produced a list of possible risk pathways to potential adverse effects and the factors affecting them (Table 3-2).

Table 3-1. Biotic and abiotic factors that may possibly influence the likelihood of establishment and resulting abundance of bigheaded carps (BC).

Factors	*Description*
Suitable flow and thermal conditions	• Hydrology: Flow and depth of system – habitat suitability o Fragmentation & Impoundment – Needed length of suitable flow for successful reproduction o River discharge during and immediately after peak spawning (during suitable thermal window) – temporal flow suitability o Existence of sustained flood pulse • Thermal regimes (climate suitability)—habitat suitability o Timing of necessary thermal conditions o Thermal window contracts moving northward o Climate change may influence this • Frequency of suitable conditions
Morphological alterations	• Channelization and channel sinuosity o Channel sinuosity and lack of channelization could improve availability of backwater habitat
Water quality	• Water clarity o Turbidity (organic & inorganic) & Color (e.g. tannins) – Improves larval survival o Clarity for feeding/adult habitat • Dissolved oxygen • Extent to which waterbody is impaired o Ability of BC to exploit impaired waterbodies
Conditions for larval development	• Conditions that prevent settling of eggs • Turbid conditions to prevent predation of larvae
Habitat diversity for use by various BC life stages	• Backwater habitat for adults and young of year • Timing of connectivity between backwater habitat and main channel • Alternate flow sources/mixing
Adequate food source	• Plankton • Prevalence of cyanobacteria • Nutrient concentration
BC adult population	• Density (positive effects on establishment, could have density dependent effects on abundance) • Age composition • Condition

Possible changes to BC	• Hybridization • Adaptation
Existing fish community and impacts on various life stages of BC	• Impacted community vs. intact community • Predation/predator community and spatial distribution • Alternate prey community structure • Competition • Effects from fragmentation on native community
Other possible predation	• Bird community
Current management of fisheries	• Commercial fishing harvest rates (downstream) for BC and other fish that could serve as competitors • Flow management

Table 3-2. Potential risk pathways from bigheaded carps to adverse effects and the factors affecting them. ↑ = Increase in; → = Leads to.

<table>
<tr><td>↑BC→Plankton (reduction in abundance or quality)→Shift in native fish feeding pathways to less preferred foods→Game & non-game fish (reduction in abundance or quality)
Emerald shiner changed to benthic feeding</td></tr>
<tr><td>↑BC→Plankton (reduction in abundance or quality)→Planktivores (reduction in abundance or quality)→Piscivores (reduction in abundance or quality)→ Game & non-game fish (reduction in abundance or quality of both planktivores and piscivores)

Factors

Planktivores could be adults or juveniles
Competition with and predation on larval fish
Bigger effect in lakes/pools/backwaters where plankton are more likely to be affected
Decrease in omega-3 levels in pelagic fish

Comments on specific species

Walleye

EcoSim modelling on Lake Erie
Cladocerans important for larval walleye
Emerald shiner loss

Paddlefish (nongame)

Eating BC larvae?
Loss of plankton forage

Crappies in Mississippi River could eat juvenile BC

</td></tr>
<tr><td>↑BC (taking up physical space)→Displacement of native fish →Game & non-game fish (reduction in abundance or quality)
Limited spawning and nursery habitat</td></tr>
<tr><td>↑BC (silver carp)→Jumping hazard→ Impacts on recreation

At 40% CPUE (~60% biomass) boat electrofishing in James River saw jumping

Might differ for larger river (less effect on silver carp, less likely to jump)
Patchiness—more concentrated areas (high biomass category) have jumping; backwaters specifically

Peoria (75% biomass) saw extreme impacts
</td></tr>
</table>

• At low abundances of silver carp there are occasional jumpers
• Boat traffic levels influence detection and effects
• In the Iowa Lakes area, there are silver carp and lots of boat traffic, but no reported jumping
• Harder to get them to jump in deep water, more likely to jump in shallow water
  o In 1-1.5 m, silver carp jump even with non-motorized boats (Wabash, low abundance)
• In IL River, silver carp can jump even without boat noise (could be from other threat)
• Impacts on fishing opportunities (Positive? Negative?)
  o Loss of fishing tournaments
  o Bass in IL River doing well in absence of fishing
  o Risk/ hassle for anglers

↑BC→Plankton (reduction in abundance or quality)→Planktivores (reduction in abundance or quality)→Piscivores (reduction in abundance or quality)→ Species that depend on plankton and fish (reduction in abundance or quality)→Species diversity/resilience reduction
• Forcing native species into smaller feeding niches
• Less able to cope with additional stressors, e.g.: fragmentation; other AIS; habitat loss
• Bald eagles, river otters, pelicans, other terrestrial piscivores
  o Cormorant biomass increased in EcoSim model with BC
  o Increased IL River use by pelicans
  o Loss of bald eagle prey
• Impacts on mollusk

↑BC→Plankton (reduction in abundance or quality of crustacean zooplankton)→Increased light penetration→Chlorophyll a increase → Game & non-game fish (reduction in abundance or quality) • Fish impacts unknown • Changes in rotifers/phytoplankton
↑BC→Bioturbation from bottom feeding→Algae bloom → Decreased oxygen → Game & non-game fish (reduction in abundance or quality) • Only when very low abundance of food in water column

4 Minnesota River

4.1 Introduction to watershed

The Minnesota River has a total length of 668 kilometers from the headwaters of the 115 km-long Little Minnesota River along the Coteau des Prairies, to the 42 km-long Big Stone Lake, before 511 km of the Minnesota River proper to its confluence with the Mississippi River in the Twin Cities. The Minnesota River Valley was carved by the much larger Glacial River Warren at the end of the last ice age when it was the primary outlet of Glacial Lake Agassiz.

The river's 44,800 km^2 watershed was primarily tallgrass prairie prior to European settlement but is now dominated by row-crop agriculture. Extensive wetland drainage and stream channelization has resulted in increased runoff and channel erosion (Schottler et al. 2013). The Minnesota River now carries the largest sediment load to the Mississippi River of any tributary north of Illinois (Lenhart et al. 2013) and is a major contributor of phosphorous and nitrates to downstream waters including Lake Pepin and the anoxic Mississippi Gulf Dead Zone.

Despite water quality impairments and habitat degradation, free-flowing reaches of the Minnesota River and its tributaries have diverse fish assemblages. The lower 386 kilometers of the Minnesota, from the Mississippi confluence to Granite Falls Dam, represents the longest dam-free river reach in Minnesota. At Granite Falls a 6 meter high hydropower dam creates a barrier to fish passage. Forty of the 97 native species documented in the Minnesota River watershed are absent upstream of the Granite Falls Dam. The lake sturgeon (Acipenser fulvescens), Minnesota's largest fish species, was historically found to the river's headwaters in Big Stone Lake but now ends its range at the Granite Falls dam. Following the 2013 removal of the Minnesota Falls dam (5.6 km downstream of Granite Falls), 15 native fish species have returned that had not been found upstream of that dam. These included rare (SGCN - Species in greatest conservation need) species like paddlefish (Polyodon spathula), lake sturgeon, blue sucker (Cycleptus elongates), and black buffalo (Ictiobus niger), as well as important game species like flathead catfish (Pylodictis olivaris) and sauger (Sander canadensis). Similar recolonization of native fishes has followed removal of dams on Minnesota River tributaries like the Pomme de Terre, Cottonwood, and Lac qui Parle rivers.

The species richness of native mussels has declined significantly in the Minnesota River watershed. Of the 43 native mussels historically found in the Minnesota River watershed, 20 species have been extirpated from the basin (Sietman 2007). Water quality impairments, sedimentation, zebra mussels, fragmentation and other factors can adversely affect native mussel populations. Nationally, 22 of 26 extinctions of native mussels have been attributed to dam construction (Haag 2009). Skipjack herring, (Alosa chyrsochloris) the sole host of ebonyshell (Fusconaia ebeba) and elephant ear mussel (Elliptio crassidens), were also found to Big Stone Lake but were extirpated from the upstream Mississippi watershed shortly after construction of Lock and Dam 19 near Keokuk, Iowa (Tucker and Theiling 1999; Fuller 1980; Fuller 1974). This subsequently led to functional extirpation of the two mussel species. Ebonyshell mussels were historically the most abundant mussel in the Upper Mississippi and Lower Minnesota Rivers. Conversely, dam removals have resulted in returns of native mussels following the return of host fish species. Removal of the Appleton Milldam on the Pomme de Terre river resulted in the recolonization of three native mussels that had been extirpated upstream of the dam.

Several characteristics of the Minnesota River are specifically relevant to bigheaded carp life history, habitat requirements, and interrelationships with other fish species. Relevant attributes of bigheaded carps include:

1) Juvenile bigheaded carp likely require backwater habitat, particularly those that have periodic anoxic conditions and low predator abundance.
2) Bigheaded carps spawn in flowing water at warmer water temperatures, usually when temperatures reach 20^{o} C and when current velocities exceed 15-25 cm/s.
3) Bigheaded carps have plantivorous feeding habits including the ability to consume and digest cyanobacteria.
4) Young bigheaded carps are highly susceptible to predation.

The 175 km reach of the Minnesota River between Redwood Falls and St. Peter drops 26 meters in elevation for an average slope of 0.0015 percent. The reach has a sinuosity of 1.5 with numerous oxbow backwaters. The Minnesota River has increased in width by 52% and shortened by 7% since 1938 and by 12% since 1854 due to hydrologic changes (Lenhart et al. 2013). The decline in sinuosity of the Minnesota has resulted in the addition of new backwaters due to meander cutoffs, but bed incision resulting from increased slope or increases in fine sediment supply can isolate or fill these backwaters. A few bedrock outcrops and riffles with coarse substrates exist near Redwood Falls but most of the reach has a sand or silt bed.

River flows and their seasonal variations are critical in defining available habitat as well as species interactions (Aadland 1993). Water levels of the Minnesota River at Mankato have nearly 4 meters of average annual fluctuation and low flows dewater a significant proportion of the river channel (Table 4-1; Figure 4-1; Figure 4-2). As flows fall, backwaters drain and many are disconnected from the main channel. This contrasts with impounded rivers like the Illinois and Upper Mississippi which are held at a normal pool elevation during low flows maintaining static water levels and lateral connectivity to many of the backwaters.

Table 4-1. Flow statistics for the Minnesota River at Mankato for the period 1902 to 2016 (USGS gage 05325000). Flood recurrence intervals are Log Pearson Type II regressions for annual peak flow data 1903 through 2015).

Annual mean flow	110 m^3/s
Record peak flow	2625 m^3/s in 1965, est. 3115 m^3/s in 1881
Lowest daily mean flow	0.9 m^3/s in 1934
Record peak stage	9.2 m
Minimum stage (gage control)	Near zero gage depth tied to riverbed
Annual minimum median daily flow	10.6 m^3/s
Annual maximum median daily flow	196 m^3/s
1.5 year flood (instantaneous peak)	325 m^3/s
2-year flood (instantaneous peak)	504 m^3/s
10-year flood (instantaneous peak)	1368 m^3/s
100-year flood (instantaneous peak)	2717 m^3/s

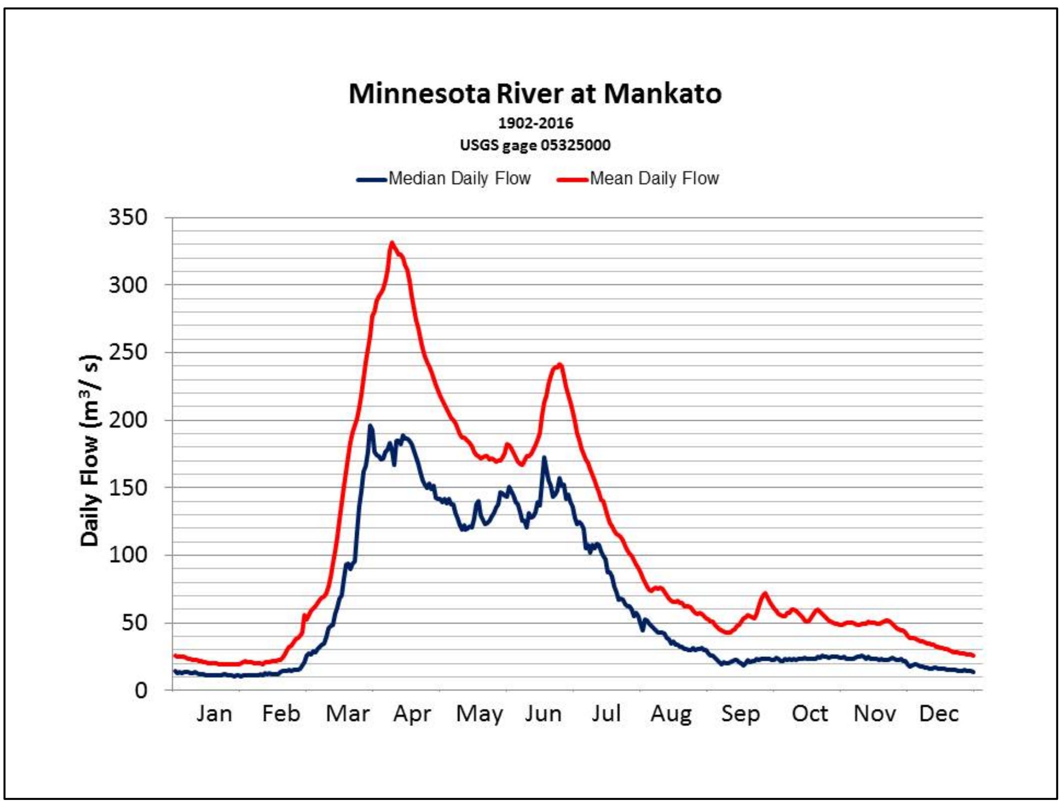


Figure 4-1. Median and mean daily flows over the period of record (1902-2016) for the Minnesota River at Mankato (USGS gage 05325000).

Figure 4-2. The Minnesota River downstream of Mankato near the median peak flow and the median annual minimum daily flow. The median peak flow shown in top photo (487 m^3/s - June 23, 2010) and the median annual minimum daily flow shown in bottom photo (11 m^3/s – November 5, 2003). Note differences in wetted area, backwater area and connectivity at the two flows.

4.2 Likelihood of establishment

4.2.1 Justifications

The entire small group characterized the likelihood of establishment in the Minnesota as high (Table 4-2), and the large group characterizations largely aligned (Table 4-3). The justification for this characterization included that the Minnesota has characteristics that would support establishment including extensive oxbow backwaters, suitable temperature regimes, eutrophic water quality, and adequate size. The small group concluded that the climate of the Minnesota River would support establishment since silver carp colonized and reproduced in the James River upstream to North Dakota at latitudes north of the Minnesota River. In addition, since bigheaded carps are long-lived fish, they do not need to successfully reproduce every year to maintain a population.

Key areas of uncertainty stemmed from the fact that to date, only one grass carp, one bighead carp and no silver carp have been documented in the Minnesota despite direct connections to the Mississippi River. Access is limited during low flows by the upper locks and dams but the Tainter gates of these dams are open during floods which allows fish passage. The lack of recruitment of grass carp (Ctenopharyngodon idella) that have been present in low numbers in northern parts of the Mississippi River for a longer period of time may suggest unfavorable conditions for bigheaded carps due to similar spawning habits. Although it is unclear whether the scarcity of bigheaded carps suggests that the watershed has limiting factors or if establishment will simply take more time, the group felt that is was more likely the latter.

4.2.2 Final characterizations

Table 4-2. MN River Likelihood of Establishment – Small Group Final Characterization.

		Likelihood of establishment				
		Very unlikely (.00-.05)	Low (.05-.40)	Moderate (.40-.60)	High (.60-.95)	Very likely (.95-1.00)
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)					
	Moderate certainty (+/- 50%)				J, D, F	
	Low certainty (+/- 70%)				A, C, E	
	Very low certainty (+/- 90%)					

Table 4-3. MN River Likelihood of Establishment – Large Group Characterization.

		Likelihood of establishment				
		Very unlikely (.00-.05)	Low (.05-.40)	Moderate (.40-.60)	High (.60-.95)	Very likely (.95-1.00)
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)			2		
	Moderate certainty (+/- 50%)			1	11	
	Low certainty (+/- 70%)			1	5	
	Very low certainty (+/- 90%)					

4.2.3 Research needs

Research needs discussed included: 1) Total biomass of bigheaded carps and native species in impounded and free-flowing rivers; 2) Information on the limnology, water quality (including dissolved oxygen), seasonal connectivity, coverage and relationships to flow, fish assemblages and resident predators of backwaters; 3) Changes in growth rates where high biomass exists and long-term effects on populations; 4) Native predators and fish communities, limnology, and influence of hypoxia in backwaters; and 5) Hypoxia tolerance of bigheaded carps at each life stage and during winter ice cover.

4.3 Resulting abundance

4.3.1 Justifications

The small group discussion reflected that it is difficult to predict the resulting abundance of bigheaded carps if they become established in the Minnesota River. This is because the resulting abundance would be dependent on a number of abiotic and biotic factors including seasonal variations in flow, temperature regimes and associated growth rates, water chemistry and dissolved oxygen, winter mortality, suitability of habitat for the suite of life history stages, predation mortality from other fish species and piscivorous birds, competition by native planktivores, and disease-related mortality. After discussing these factors, the small group's characterization of resulting abundance was moderate (5/6) with low or very low certainty, while one member chose high resulting abundance (Table 4-4). The large group was split between moderate (12/20) and high (8/20) resulting abundance (Table 4-5).

Factors influencing this characterization included that during low flow conditions, fish can become concentrated at high densities in remaining pools. While this may lead to higher local abundance, it may also affect predation mortality, interspecific and intraspecific competition, disease transmission, and stress.

Since juvenile bigheaded carps depend heavily on backwater habitat, the dynamics of these backwaters are important. Juvenile silver and bighead carp are able to survive low dissolved oxygen due to a vascularized lower jaw extension that enables respiration at the water surface (Adamek and Groch 1993). This adaptation facilitates predator avoidance in anoxic backwaters where less tolerant predators may not exist. Hypoxia is common in backwaters of agricultural rivers (Shields et al. 2011). During drought conditions, hypoxia in pools in the Minnesota River has also been observed.

Although water quality data in backwater habitats of the Minnesota River is limited, early observations have indicated the use of backwaters by a variety of predatory fish species. Most shallow eutrophic water bodies in Minnesota are also vulnerable to winter hypoxia. Under these conditions, respiratory adaptations of juvenile bigheaded carps to hypoxia may not apply due to ice cover. During low flows, fish would be forced out of dewatered backwaters and concentrated in the remaining wet parts of the main channel. This may influence predation mortality of all life stages of bigheaded carps.

For predators to control fish populations, they must be abundant enough to cause significant mortality. Predation of adult silver carp estimated at up to 2 kg by increasing numbers of white pelicans (Pelecanus erythrorhynchos) has been observed on the Illinois River by one of the small group members. Marsh Lake in the upper Minnesota River has the largest white pelican rookery in North America and could help to control bigheaded carps in the Minnesota River (Wires et al. 2005).

The Minnesota River is noted for its flathead catfish, a species that can reach weights of over 23 kg and is capable of consuming individual fish up to 30% of their own body weight (Davis 1985). Flathead catfish may be a significant predator on bigheaded carps, as they have been shown to be an effective predator on common carp (Cyprinus carpio) (Davis 1985). While Flathead catfish are found in the Illinois River where bigheaded carps are very abundant, they are heavily exploited and the Illinois River has no harvest limit on flathead catfish for either commercial or recreational fisheries. The Minnesota River has no commercial harvest on flatheads and a limit of two fish for recreational harvest with only one fish over 24 inches.

Small-bodied fish species may also be important predators on bigheaded carps by feeding on eggs, larvae, and juveniles (Johnson and Dropkin 1992). In the Susquehanna River, spotfin shiners are an important predator on American shad (Alosa sapidissma) eggs and larvae. Like the bigheaded carps, American shad are pelagic spawners. Spotfin shiners are one of the most abundant cyprinids in the Minnesota River and its tributaries.

There were disagreements about the role of impoundments, suspended sediment, available plankton resources and predators in determining the abundance of bigheaded carps.

4.3.2 Final characterizations

Table 4-4. Resulting abundance – Small Group Final Characterization.

		Resulting abundance (% of total fish biomass)				
		Very low (Few individuals, <1%)	Low (1-5% of total fish biomass)	Moderate (5-25% of total fish biomass)	High (25-60% of total fish biomass	Very high (>60% of total fish biomass)
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)					
	Moderate certainty (+/- 50%)				J	
	Low certainty (+/- 70%)			D, F, E		
	Very low certainty (+/- 90%)			C, A		

Table 4-5. Resulting abundance – Large Group Characterization.

		Resulting abundance (% of total fish biomass)				
		Very low (Few individuals, <1%)	Low (1-5% of total fish biomass)	Moderate (5-25% of total fish biomass)	High (25-60% of total fish biomass	Very high (>60% of total fish biomass)
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)					
	Moderate certainty (+/- 50%)			4	4	
	Low certainty (+/- 70%)			6	4	
	Very low certainty (+/- 90%)			2		

4.3.3 Research Needs

Research needs discussed included: 1) the role of refugia from predators on existing bigheaded carp populations and their abundance; 2) relationships of river stage to backwater connectivity and coverage area; 3) effects of latitude, climate and interactions of climate and habitat on the abundance of bigheaded carps; and 4) the timing and duration of backwater connectivity as well as coverage area relationships to river stage and the hydrology of the Minnesota River.

4.4 Adverse Effects

During the characterization of potential adverse effects, the small group characterized the consequence of each adverse effect for the likely abundance of bigheaded carps that was determined in the previous step. The small group also characterized the consequence resulting from the second most likely abundance of bigheaded carps. For the Minnesota River small group, the first abundance was “Moderate” and the second abundance was “High”. In the tables below, the characterization for the “Moderate” abundance is noted with “A”, “B”, “C”, etc. whereas the characterization for the “High” abundance is noted with “A_H”, “B_H”, “C_H”. The letters represent different individuals within the small group.

4.4.1 Change in plankton

4.4.1.1 Justifications

The small group acknowledged that observed shifts in plankton species composition and size structure are typical where bigheaded carps have become established and abundant. Effects on phytoplankton have been variable but often associated with smaller algal fragments. Xie and Lui (2001) found increases in water clarity and cessation of blooms due to grazing by bigheaded carps on cyanobacteria while Carruthers (1986) found no significant effect on cyanobacteria blooms or water clarity and Lieberman (1996) found increased turbidity in a pond stocked with silver and bighead carp. A number of studies have shown a decline in cladocerans and a shift to a smaller size structure of zooplankton (Radke 2002; Cooke et al. 2009; Garvey et al. 2012) with one study showing an opposite shift to a larger size structure in cyanobacteria dominated subtropical Asian lakes (Zhang et al. 2013). To capture the nuance within the changes to plankton community, the small group characterized both the change in total biomass of plankton and the consequence from the change in plankton community composition.

4.4.1.2 Final characterizations

Table 4-6. MN River Change in total biomass of plankton – Small group characterizations.

		Change in total biomass of plankton						
		Large increase	Moderate increase	Small increase	No change	Small decrease	Moderate decrease	Large decrease
Certainty of assessment	Very high certainty (+/- 10%)							
	High certainty (+/- 30%)							
	Moderate certainty (+/- 50%)			C C_H	A, J A_H, J_H			
	Low certainty (+/- 70%)				F F_H			
	Very low certainty (+/- 90%)				E E_H			

Table 4-7. MN River Change in plankton community composition – Small group characterizations.

		Consequence				
		Negligible	Low	Moderate	High	Extreme
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)				C	
	Moderate certainty (+/- 50%)				E, F, J E_H, J_H	C_H
	Low certainty (+/- 70%)				A	A_H, F_H
	Very low certainty (+/- 90%)					

4.4.2 Consequence for non-game fish

4.4.2.1 Justifications

The small group chose spotfin shiner and bigmouth buffalo as example nongame species to assess potential effects of bigheaded carps due to their relative abundance and potential for competition and resource limitations. Bigmouth buffalo are planktivores, while spotfin shiners are invertivores.

Spotfin shiners are generalized invertivores primarily consuming insects (Dobie et al. 1956) but Becker (1983) also notes consumption of small fishes, carp eggs, plankton, and other items. Johnson and Dropkin (1992) and Johnson and Ringler (1998) found spotfin shiners to be a major predator on American shad fry in the Susquehanna River. Like the bigheaded carps, American shad are pelagic spawners. As a result, spotfin shiners may actually benefit by preying on the eggs and fry of bigheaded carps. Spotfin shiners spawn in crevices, are often associated with riffles, and prefer slow riffle habitat as both juveniles and adults (Aadland 1993; Aadland and Kuitunen 2006). The small group considered the likely adverse effect consequence level for spotfin shiners to be negligible (4/5) or low (1/5) since dietary and habitat overlap with bigheaded carps is limited (Table 4-8), and the large group also characterized the consequence level as between negligible and low (Table 4-9).

The small group considered the consequence of invasion by bigheaded carps to bigmouth buffalo to be more significant since they are planktivorous and have dietary and habitat overlap with that of bigheaded carps (Table 4-10). The large group also considered the consequence to bigmouth buffalo to be more significant than for spotfin shiner, characterizing the adverse effect consequence level between low and moderate (Table 4-11). Irons et al. (2007) found a 5% decline in condition factor for bigmouth buffalo in the Illinois River associated with increased abundance of bigheaded carps. Bigmouth buffalo consume zooplankton as well as benthic invertebrates. Bigmouth buffalo also have habitat overlap with bigheaded carps since they spawn in flooded backwaters and floodplains. As discussed above, the evaluated reach of the Minnesota River is not impounded so feeding ecology of bigmouth buffalo may be different due to differences in the density and composition of zooplankton, and feeding strategies of native fishes. Commercial harvest of bigmouth buffalo in the Minnesota River is limited to one commercial fisherman with an annual catch of 450 to 1360 kg. Bigmouth buffalo is also targeted by an unknown number of bow-fisherman.

The small group determined that the greatest potential for interaction between bigheaded carps and native fishes is for species with the greatest dietary and habitat overlap. Sampson et al. (2009) evaluated dietary overlap of bigheaded carps with 3 plantivorous fishes and determined it to be greatest for gizzard shad, less for bigmouth buffalo, and least for paddlefish. These species are the most prominent planktivores in the Minnesota River. In addition to species that are planktivorous as adults, early life stages (particularly larvae) of most fish species feed on meiofauna (invertebrates generally between 45 μm and 1 mm in size) that can include species consumed by bigheaded carps.

While dietary overlap by bigheaded carps could adversely affect growth and survival of native planktivorous species and early life stages of other fishes, available bigheaded carp eggs and fry could provide a new food source. Predation on bigheaded carp fry or juveniles by sauger and black crappie (Pomoxis nigromaculatus) was indicated by group members familiar with examples from the Illinois River. Unlike most native fish species, bigheaded carps are capable of feeding on and digesting cyanobacteria, thus tapping into a relatively unexploited resource. Juvenile channel catfish (Ictalurus punctatus) and blue catfish (Ictalurus furcatus) consumed and increased body mass when fed silver carp fecal pellets (Yallaly et al. 2015).

Several studies have shown downward trends in commercial harvest, relative abundance, or catch per unit effort for certain native fish species concurrent with increases in the abundance of bigheaded carps. However, determining mechanisms, cause, and effect is complicated by the dynamic nature of fish populations (particularly lotic species) that cycle with annual variations in hydrology, climate, harvest, and other factors. In the Illinois River, Garvey et al. (2012) found declines in standardized catches of bigmouth buffalo, white bass, freshwater drum, sauger, black crappie, and common carp concurrent with increases in bigheaded carps but these trends could not be directly attributed to bigheaded carps since the downward trends began prior to bigheaded carps establishment. For example, a sauger stocking program began in in the Illinois River in 1990 following declining abundance from the 1970s to 1990s which was prior to establishment of bigheaded carps (Heidinger and Brooks 1998). Both sauger and black crappie fisheries were reportedly doing well by group members familiar with the Illinois River.

Relative abundance trends must be evaluated with the recognition that the addition of bigheaded carps can result in large increases in total biomass that are not necessarily associated with declines in native species biomass. A controlled study by Arthur (2010) using 46 sites in Southeast Asia with paired wetlands, controls and replicates found no changes to native species richness or biomass despite a 180% increase in total biomass resulting from stocked bigheaded carps. This may be due to the unique ability of bigheaded carps to digest cyanobacteria including toxic Microcystis (Chiang 1971) which enables them to take advantage of a food resource that most native fishes cannot.

Attributing declines in native species richness associated with invasive species is complicated by concurrent declines associated with water pollution, land-use changes, overfishing and other factors (Gurevitch and Padilla 2004). This is especially true for effects of non-predatory species like bigheaded carps on native species in river systems. A number of papers associating native fish species declines with bigheaded carps have been based on heavily stocked fish culture basins where alterations by fertilization, habitat alteration, nutrients, fragmentation and predator removal were implemented; and, in some cases, reported impacts were to other artificially maintained fish stocks. For instance, a paper by Barthelmes (1984), widely cited as evidence of effects on percids, reported a decline in zooplankton abundance (except in the littoral zone) and an unsuccessful year class of stocked zander (Sander lucioperca) in a 20 hectare German Lake following extreme stocking rates of 10,000 silver carp per hectare. While this research has some applications for pond culture of food fish as intended, it has limited implications for wild native fish populations in a connected watershed. Donghu Lake, China has also been cited as an example of native species extirpation related to bigheaded carps (Kumar 2000). However, native fishes were actively removed after the lake was designated as a fish farm lake, separated into a series of ponds and heavily stocked with bigheaded carps, severely polluted by raw sewage and industrial waste, and separated from the Yangtze River by dike construction. Natural lakes connected to the Yangtze typically have 100 fish species but only 30-40 species in lakes where connections have been blocked (Ping and Chen 1997). Fu et al. (2003) identified separation of Donghu from the river as a primary factor in the loss of native fish species, and identified reconnection of the Yangtze River to its lakes as the most immediate restoration need to mitigate loss of fish biodiversity.

Reproduction of many Minnesota fish species has been associated with seasonal spawning migrations up higher gradient tributaries (Aadland et al. 2005) where the habitat of bigheaded carps is marginal. Large migrations and associated reproduction have been documented in the Yellow Medicine River and other Minnesota River tributaries. The reproductive contributions of these tributaries to the Minnesota River fish community may limit the competition effects of bigheaded carps on associated native species.

4.4.2.2 Final characterizations

Table 4-8. MN River Consequence for non-game fish (Spotfin shiner) – Small group characterizations.

		Consequence				
		Negligible	Low	Moderate	High	Extreme
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)					
	Moderate certainty (+/- 50%)	A, F A_H, F_H	J_H			
	Low certainty (+/- 70%)	E, C E_H, C_H	J			
	Very low certainty (+/- 90%)					

Table 4-9. MN River Consequence for non-game fish (Spotfin shiner) – Large group characterization for moderate abundance of bigheaded carps.

		Consequence				
		Negligible	Low	Moderate	High	Extreme
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)					
	Moderate certainty (+/- 50%)	9	2			
	Low certainty (+/- 70%)	2	8			
	Very low certainty (+/- 90%)					

Table 4-10. MN River Consequence for non-game fish (Bigmouth buffalo) – Small group characterizations.

		Consequence				
		Negligible	Low	Moderate	High	Extreme
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)					
	Moderate certainty (+/- 50%)					
	Low certainty (+/- 70%)		F	C_H, E_H, F_H	J_H	
	Very low certainty (+/- 90%)		A	C, J, E A_H		

Table 4-11. MN River Consequence for non-game fish (Bigmouth buffalo) – Large group characterization for moderate abundance of bigheaded carps.

		Consequence				
		Negligible	Low	Moderate	High	Extreme
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)					
	Moderate certainty (+/- 50%)		2	4		
	Low certainty (+/- 70%)		7	3		
	Very low certainty (+/- 90%)		1	4		

4.4.3 Consequence for game fish

4.4.3.1 Justifications

The small group evaluated important game species in terms of abundance and potential interactions with bigheaded carps. Important game species of the Minnesota River included flathead catfish, channel catfish, walleye, smallmouth bass, and sauger. Most game species in the Minnesota River have low dietary overlap with bigheaded carps as juveniles and adults but may have some overlap as larvae. However, many of the game species have reproductive strategies that limit this potential. Walleye (Sander vitreus) and sauger spawn primarily in riffles which are most available in steeper tributaries to the Minnesota River where habitat for bigheaded carps is marginal. Flathead catfish spawn in nest cavities and guard their eggs and fry. Centrarchids like smallmouth bass (Micropterus dolomieu) spawn in backwaters in cleared out nests and also guard their eggs and early fry stages, but would have some potential for interactions in these backwaters. Northern pike also spawn in backwaters and floodplains but spawn very early and young may benefit from predation on bigheaded carp fry.

The group chose channel catfish (Ictalurus punctatus) as an example game species to assess potential effects of bigheaded carps due to their relative abundance and importance as a game fish.

Channel catfish are generalized invertivores as juveniles with increasing fish, crayfish, frogs and other items in their diets as adults (Becker 1983). Channel catfish spawn in cavities like muskrat tunnels and guard their fry for about a week after they hatch. Age-0 channel catfish prefer riffle mesohabitat with shallow to moderate depths and moderate velocities but are widely distributed across habitat types. Both juvenile and adult catfish prefer pool habitat (Aadland 1993; Aadland and Kuitunen 2006). Since there is relatively little dietary overlap with bigheaded carps, there is low potential for competition. Adult channel catfish may prey on juvenile bigheaded carps. Juvenile channel catfish ate and increased body mass when fed silver carp fecal pellets (Yallaly et al. 2015). The small group determined that bigheaded carps would have negligible adverse consequences for channel catfish due to the low dietary and habitat overlap (Table 4-12), while the large group characterized the consequence level between negligible and low (Table 4-13).

4.4.3.2 Final characterizations

Table 4-12. MN River Consequence for game fish (Channel catfish) – Small group characterizations.

		Consequence				
		Negligible	Low	Moderate	High	Extreme
Certainty of assessment	Very high certainty (+/- 10%)	A A_H				
	High certainty (+/- 30%)	C, E, F, J C_H, E_H, F_H, J_H				
	Moderate certainty (+/- 50%)					
	Low certainty (+/- 70%)					
	Very low certainty (+/- 90%)					

Table 4-13. MN River Consequence for game fish (Channel catfish) – Large group characterization for moderate abundance of bigheaded carps.

		Consequence				
		Negligible	Low	Moderate	High	Extreme
Certainty of assessment	Very high certainty (+/- 10%)	1				
	High certainty (+/- 30%)	7				
	Moderate certainty (+/- 50%)	7	1			
	Low certainty (+/- 70%)		2			
	Very low certainty (+/- 90%)		1			

4.4.4 Consequence for species diversity/ecosystem resilience

4.4.4.1 Justifications

Predicting effects of bigheaded carps on species richness and ecosystem resilience was particularly challenging for the small group since species diversity and ecosystem resilience, while related, constitute complex and somewhat different questions. Effects on species richness could be habitat-specific and localized or at the watershed scale. Ecosystem resilience, or the ability of the system to recover from disturbance, was assessed as it pertains to colonization by bigheaded carps. In terms of species invasions, the entire species assemblage of the Minnesota River is comprised of species that invaded since the last ice age. As each of these species colonized the watershed they likely had variable effects on the biotic community by altering competition, predation, and food web structure. While river systems are dynamic, connections in the stream network allow migrations across a broad range of available habitats for reproduction, changing habitat needs with season, optimal foraging, recolonization following drought, hypoxia, and catastrophic events, and habitat partitioning in response to competition and predation pressures. The question is whether the addition of bigheaded carps would significantly alter this resilience.

Group predictions on the effects of bigheaded carps on species richness and ecosystem resilience ranged more widely among group members than other variables. The range of these predictions were likely related to differences in the way members viewed this topic and spatial scales of effect. Some individuals indicated the potential for localized, habitat specific changes in species richness especially in backwaters, while others responded in terms of projected watershed scale effects. Combining species richness effects with ecosystem resilience may also have affected variability in predictions. The majority of participants of both the small and large groups rated consequences for species richness/ecosystem resilience as moderate (Table 4-14; Table 4-15).

One of the problems in evaluating effects of bigheaded carps on native species is that most of the literature is from impounded and regulated systems like the Illinois River, so group discussions evaluated important differences in free-flowing rivers like the Minnesota River. Pelagic plankton production in free-flowing rivers is limited since plankton are continually swept downstream by flowing water and due to suspended sediment that limits light penetration. Reservoirs increase phytoplankton production by increasing residence time and by increasing light penetration as suspended sediment fall out of suspension (Søballe and Kimmel 1987). Algal concentrations at several sites on the Upper Mississippi River increased

40-fold following dam construction (Baker and Baker 1981). Like phytoplankton, zooplankton abundance in the pelagic zone also increases with increasing residence time (Reckendorfer et al. 1999), decreasing velocity (Walks 2007) and increasing water clarity (Hart 1986). Zooplankton biomass increased approximately 19-fold following impoundment of Cat Arm Lake in Newfoundland (Campbell et al. 2011). Havel et al. (2009) concluded that reservoirs were the primary source of cladocerans and copepods in the Missouri River due to exponential declines in abundance with distance from mainstem dams. Conversely, Santucci et al. (2004) found that low-head dams adversely affected macroinvertebrates and stream fishes by degrading habitat, water quality, and fragmentation.

Interactions of bigheaded carps with early life stages of native fishes were a particular concern raised in small group discussions due to potential dietary overlap. Since bigheaded carps have been shown to affect abundance and composition of pelagic meiofauna, it is important to evaluate this in the context of its potential impact on native fish species. While it is often assumed that meiofauna, the food of most larval fish species, exists primarily in the water column, this is not typically true of unimpounded rivers. King (2004) found meiofauna densities to be 100 times greater in the epibenthic zone (upper 1 cm of sediment and lower 11 cm of water column) than in the pelagic zone of all habitat types in a floodplain river. Shiozawa (1991) also found high microcrustacean densities in the benthos of slow-water habitats in Minnesota streams. Therefore, while native larval fish depend on meiofauna, much of it exists at the river bed rather than in the water column. In contrast to the bigheaded carps that are adapted to feeding in the water column but poorly adapted to feeding on benthos due to their upward directed supra-terminal lower jaws, most native fishes of the Minnesota River have downward directed sub-terminal lower jaws adapted to benthic feeding. The effects of bigheaded carps on epibenthic meiofauna are a research need.

Due to the inability to swim in strong current, most species of larval and age-0 fish tend to congregate in low velocity areas (Aadland and Kuitunen 2006) including backwater habitats. Shifting to shallow habitats can also be a means of predator avoidance for small-bodied fishes (Schlosser 1987). Quantitative prepositioned electrofishing sampling provides some perspective on the distribution of age-0 fish. In the Yellow Medicine River (1988-2008) age-0 fish densities were highest in sampled shoreline habitat in 11 years, riffles in 5 years, backwaters in 2 years and run habitat in 1 year (Figure 4-3). Year to year density was extremely variable due to differences in flow, geomorphic change to the site, flood magnitude, and other factors. Connected backwaters were not present in the study reach in all years. Drought in 1988 concentrated fish in remaining habitat and provided suitable conditions for age-0 fish across habitat types, particularly backwaters.

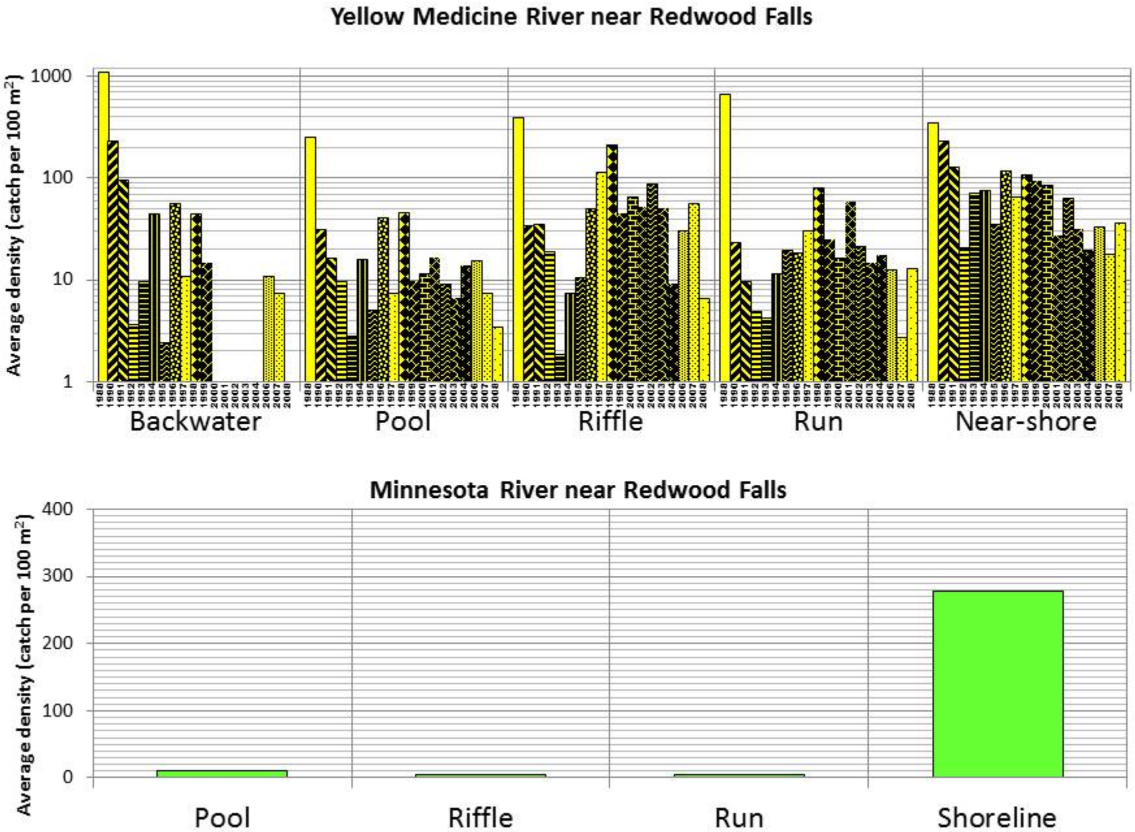


Figure 4-3. Density of age-0 fishes in sites on the Minnesota (1990) and Yellow Medicine (1988-2008) Rivers. Based on quantitative electrofishing gear across habitat types. Connected backwaters were not present during sampling in the Minnesota River reach or in some years on the Yellow Medicine River reach. Near-shore was within 2 meters of the edge of water.

Densities of larval fishes (cyprinids, catastomids and centrarchids, <25 mm) in 17 rivers across Minnesota were highest in close proximity to the stream bed in very shallow water less than 10 cm deep (Figure 4-4). Age-0 fish (all species) in the Minnesota and Yellow Medicine rivers were highest in water less than 20 cm deep. The use of very shallow water by age-0 fishes and close proximity to the stream bed support the importance of epibenthic meiofauna as a food resource. Since native species of free-flowing rivers are adapted to feeding on epibenthic meiofauna, the free-flowing Minnesota River is likely to respond differently than impounded and fragmented systems like the Illinois and Upper Mississippi rivers to colonization by pelagic feeding bigheaded carps.

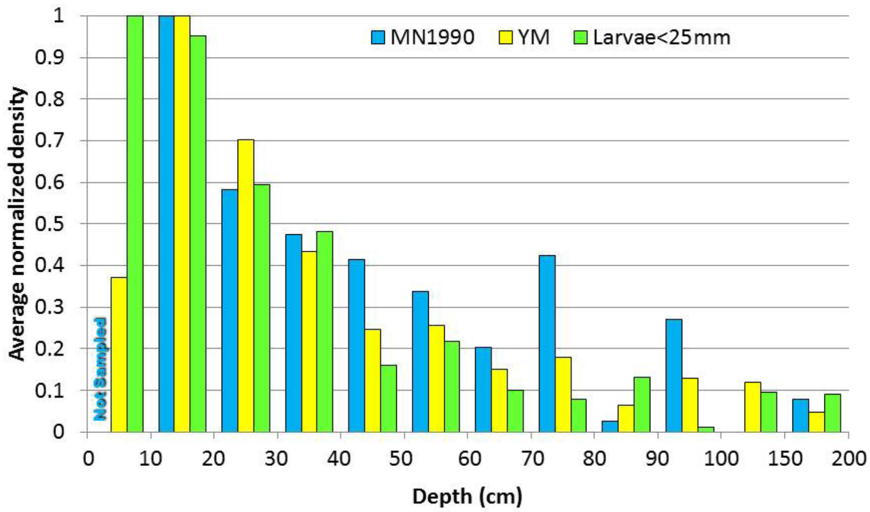


Figure 4-4. Distribution of age-0 fish of all species in the Minnesota River (1990) and Yellow Medicine River (1988-2008) and for larval fish across 17 rivers in Minnesota. Based on quantitative prepositioned electrofishing samplers.

The potential abundance of the bigheaded carps and resulting effects on native species in the assessed reach of the Minnesota River may also be limited by that fact that it is free-flowing. Stuck et al. (2015) found silver carp abundance of the impounded Illinois River to be over three times higher than that in the free-flowing Wabash River. The potential of bigheaded carps to alter plankton composition and affect native species in the Minnesota River was considered to be most likely in backwater habitats, which bigheaded carps prefer. Competition with native species in hypoxic backwaters is likely to be limited to tolerant species.

4.4.4.2 Final characterizations

Table 4-14. MN River Consequence for species diversity/ecosystem resilience – Small group characterizations.

		Consequence				
		Negligible	Low	Moderate	High	Extreme
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)					
	Moderate certainty (+/- 50%)					
	Low certainty (+/- 70%)			D D_H, E_H	C_H, J_H	
	Very low certainty (+/- 90%)	A A_H		E, F, J	C F_H	

Table 4-15. MN River Consequence for species diversity/ecosystem resilience – Large group characterization for moderate abundance of bigheaded carps.

		Consequence				
		Negligible	Low	Moderate	High	Extreme
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)					
	Moderate certainty (+/- 50%)			4		
	Low certainty (+/- 70%)			6	1	
	Very low certainty (+/- 90%)	1	1	5	1	

4.4.5 Consequence for recreational boating and fishing from jumping silver carp hazard

4.4.5.1 Justifications

This question assumes colonization of the Minnesota River by silver carp (bighead carp do not tend to jump) at moderate and high densities, those characterized as the most likely resulting abundances for the Minnesota River-Mankato watershed in Day 1 of the workshop. The small group considered use of the river and silver carp densities to be primary variables in determining hazards to boaters. Much of the use of the Minnesota River is from river banks due to navigational hazards and limited access points. Bank anglers would be less vulnerable to hazards from jumping silver carp than boat anglers. Silver carp tend to jump where they exist at high densities or when they are confined in a narrow channel or shallow water and are startled by approaching boats. While motor boats tend to startle and elicit jumping by greater numbers of fish, canoes can also elicit jumping.

The small group characterized the consequence to recreational boating and fishing from jumping silver carp at a moderate (5/6) to high (1/6) consequence level (Table 4-16), and the large group characterization was also split between moderate (13/20) and high (7/20) consequence (Table 4-17). When the small group considered a high, instead of moderate, resulting abundance of bigheaded carps in the Minnesota River-Mankato watershed, the consequence level was split between high (4/6) and extreme (2/6).

Hazards associated with jumping carp have not necessarily resulted in a reduction in recreational fishing in rivers with high silver carp densities like the Illinois River since determined anglers are not deterred. However, a change in demographics or strategies of users may exist. Some boaters have made modifications such as protective netting or changes in operation to reduce risks while others are likely to go elsewhere. The group considered that some people may come to the river specifically to see silver carp.

4.4.5.2 Final characterizations

Table 4-16. MN River Consequence for recreational boating and fishing from jumping silver carp hazard – Small group characterizations.

		Consequence				
		Negligible	Low	Moderate	High	Extreme
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)				J F_H	J_H
	Moderate certainty (+/- 50%)			C, D	D_H	C_H
	Low certainty (+/- 70%)			A, E, F	A_H, E_H	
	Very low certainty (+/- 90%)					

Table 4-17. MN River Consequence for recreational boating and fishing from jumping silver carp hazard – Large group characterization for moderate abundance of bigheaded carps.

		Consequence				
		Negligible	Low	Moderate	High	Extreme
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)			2	3	
	Moderate certainty (+/- 50%)			5	4	
	Low certainty (+/- 70%)			5		
	Very low certainty (+/- 90%)			1		

4.4.6 Adverse Effects: Research needs

Research needs include baseline data for diversity and biomass of native species in the Minnesota River, including for phytoplankton and zooplankton abundance and composition in the main channel and backwater habitats of the Minnesota River. In addition, there is a need for a better understanding of meiofauna densities in the pelagic and epibenthic zones in the Minnesota River across habitat types including backwaters and main channel riffles, runs, pools, and near-shore areas.

To further understand potential interactions between bigheaded carps and native fishes, research needs include: 1) comparative lateral and vertical distributions of native fishes, particularly the larval life stage, across backwaters and other habitats; 2) the relative contributions of tributaries to the recruitment of native fishes in the Minnesota River; 3) the comparative abundance of bigheaded carps in tributaries of rivers (with established populations) of different sizes and habitat characteristics (slope, backwater habitat, etc.); and 4) the effects of bigheaded carps on meiofauna in free-flowing rivers.

Research needs concerning the jumping hazard include incidence rates of silver carp related injuries for boaters, paddlers, and shore anglers on a similar river system with moderate or high silver carp abundance.

4.5 Overarching uncertainties, research needs & areas of disagreements

Predicted effects associated with bigheaded carps in the Minnesota River are heavily dependent on how abundant they become. There was general agreement within both the small and large group that bigheaded carps have a substantial probability of becoming established at some level in the Minnesota River. There was progressively less agreement and certainty on predicted abundance and effects on native species. Since establishment, abundance, effects on plankton community and, ultimately, interactions with native species have compounding uncertainty, this is to be expected.

5 St. Croix River

5.1 Introduction to watershed

The lower St. Croix River is a 6th order river that borders Minnesota and Wisconsin and flows into Pool 3 of the Mississippi River. The 2370 km^2 watershed is a mix of agricultural, forested, and urban land use. The upper portion of the watershed is primarily forested, with agriculture and urban use becoming more prevalent in the lower portion of the watershed. The watershed contains numerous lakes and wetlands that reduce flooding and sediment transfer in the St. Croix River. As such, water clarity is generally high. The lower St. Croix River starts at the confluence of the Snake River and is characterized by a meandering and braided channel before widening into Lake St. Croix. Lake St. Croix is a 3115 ha widening of the river that is 42km in length and a maximum depth of 24m. Given that it has long retention times, it has many lake characteristics such as wave action, internal production, and thermal stratification. Water clarity is relatively high for a large river system (2.5m). There is an impassable dam near Taylors Falls, 84km from the convergence with the Mississippi River. The St. Croix River has a diverse fish community with nearly 100 fish species recorded. Imperiled large river fishes such as lake sturgeon, paddlefish, and blue sucker (Cycleptus elongates) are routinely collected during MNDNR fish sampling. Primary game fish include white bass (Morone chrysops), walleye, smallmouth bass, and sauger (MNDNR 2014b). Forage base for these sportfish include gizzard shad, emerald shiners (Notropis atherinoides), and spottail shiners (Notropis hudsonius). Three aquatic invasive species, Eurasian watermilfoil (Myriophyllum spicatum), rusty crayfish (Orconectes rusticus), and zebra mussel (Dreissena polymorpha), are already established in the St. Croix River.

5.2 Likelihood of establishment

5.2.1 Justifications

The likelihood of bigheaded carps establishment in the Lower St. Croix Watershed was characterized by the small group as mostly moderate (3/5), with one person characterizing it as high and one characterizing it as low (Table 5-1). The large group characterization of establishment likelihood was mainly moderate (15/21), but ranged from low (5/21) to high (1/21). For the establishment likelihood characterization a closed system was assumed (i.e., no open connection with the Mississippi River). The resulting abundance was characterized for both a closed and open system, and the effects characterizations were all for an open system – i.e., one that took into account the connection with the Mississippi River. Participants thought the study area provided suitable food resources, water temperature, and flows (for reproduction) for bigheaded carps, but thought it lacked in nursery areas, spawning habitat, and turbidity. Because of the widening of the river and decreased flows, zooplankton is presumed to be abundant as a food source in Lake St. Croix. In addition, increasing phosphorous loads to the St. Croix River are likely to increase overall productivity.

Historical peak flows and water temperatures in the St. Croix River are conducive as spawning cues for bigheaded carps. Specifically, occasional increased flows in July were noted in the historical hydrograph that match current spawning conditions observed in Midwest US rivers. However, there was uncertainty as to whether eggs would be able to hatch before settling out into the slow flowing portion of the river because the distance from St. Croix Falls dam to Lake St. Croix is only 39km. This distance is considerably shorter than the 100km reported in the literature that is thought to be needed for successful spawning (Kocovsky et al. 2012). Participants were uncertain as to whether carp actually needed 100km of free flowing river as stated in the literature, or whether this distance could be considerably less based on anecdotal evidence. The group also questioned whether the area below Taylors Falls would provide a suitable spawning area given the water depth and area (i.e., is it large enough to support mass spawning of bigheaded carps). Another factor limiting the recruitment of bigheaded carps is the lack of suitable nursery areas. There are few turbid backwater habitats available in the St. Croix River. The primary nursery habitat would be Lake St. Croix, but eggs may not develop fully before they settle out into the lake portion. Water clarity is high throughout the river and in Lake St. Croix, which participants also thought would reduce recruitment through increased predation of carp eggs and larvae.

The St. Croix River is unlike systems where bigheaded carps are currently found in terms of water clarity and species diversity. In the Midwest US, bigheaded carps are typically found in abundance in turbid river systems. There was uncertainty as to what affect clear water would have on egg and larval survival in terms of predation. Also, the number of potential fish predators on bigheaded carps was considered higher than in systems where they are currently found. Whether the high abundance of predators could control bigheaded carp populations was unknown.

5.2.2 Final characterizations

Table 5-1. St. Croix River Likelihood of Establishment - Small Group Final Characterization (Closed System Assumptions).

		Likelihood of establishment				
		Very unlikely (.00-.05)	Low (.05-.40)	Moderate (.40-.60)	High (.60-.95)	Very likely (.95-1.00)
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)				R	
	Moderate certainty (+/- 50%)			P, O, M		
	Low certainty (+/- 70%)		Q			
	Very low certainty (+/- 90%)					

Table 5-2. St. Croix River Likelihood of Establishment – Large Group Characterization (Closed System Assumptions).

		Likelihood of establishment				
		Very unlikely (.00-.05)	Low (.05-.40)	Moderate (.40-.60)	High (.60-.95)	Very likely (.95-1.00)
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)					
	Moderate certainty (+/- 50%)		2	7	1	
	Low certainty (+/- 70%)		3	7		
	Very low certainty (+/- 90%)			1		

5.2.3 Research needs

Participants disagreed on the length of free flowing river needed for egg development of bigheaded carps; however, models exist to help determine the length of river needed based on water temperature and velocity (FluEgg model; Garcia et al. 2013). Better information on temperature and flows are needed in this area to input into the FluEgg model to determine whether the area is suitable for spawning.

Research is needed on whether adult bigheaded carp avoid clear water habitats and what affect clear water has on the recruitment of bigheaded carps. Recruitment of bigheaded carps could be reduced in clear water due to increased predation on their eggs and larvae.

5.3 Resulting abundance

5.3.1 Justifications

The small group determined that carp would likely sustain themselves at a low abundance in the St. Croix River when considered a closed system (Table 5-3). The group was between low and moderate certainty in this prediction. Participants justified this low abundance in that there would be low recruitment, but growth of individuals would be high because of high zooplankton densities. A diverse fish community should keep numbers low due to predation and no available niches for carp to fill. The group thought that the systems in which bigheaded carps have become abundant were heavily disturbed before invasion and had numerous open niches for bigheaded carps to fill. Under an open system scenario, immigration from the Mississippi River could be large and there are no deterrents to adult carp survival in terms of prey and water temperature in the St. Croix River. As a result the large group, considering the open system scenario, largely characterized the resulting abundance of bigheaded carps as moderate (13/21), the second most characterized abundance being low (5/21) followed by high (3/21) (Table 5-4). The open system scenario is assumed for the remainder of the characterizations to take into account the connection between the St. Croix and Mississippi rivers.

5.3.2 Final characterizations

Table 5-3. St. Croix River Resulting Abundance – Small Group Final Characterization (Closed System Assumptions).

		Resulting abundance (% of total fish biomass)				
		Very low (Few individuals, <1%)	Low (1-5% of total fish biomass)	Moderate (5-25% of total fish biomass)	High (25-60% of total fish biomass	Very high (>60% of total fish biomass)
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)					
	Moderate certainty (+/- 50%)		P, O			
	Low certainty (+/- 70%)	Q	M, R			
	Very low certainty (+/- 90%)					

Table 5-4. St. Croix River Resulting Abundance – Large Group Characterization (Open System Assumptions)

		Resulting abundance (% of total fish biomass)				
		Very low (Few individuals, <1%)	Low (1-5% of total fish biomass)	Moderate (5-25% of total fish biomass)	High (25-60% of total fish biomass	Very high (>60% of total fish biomass)
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)					
	Moderate certainty (+/- 50%)		3	9	1	
	Low certainty (+/- 70%)		2	3	2	
	Very low certainty (+/- 90%)			1		

5.3.3 Research needs

Group members identified several research needs. There was a large need in determining adult preference for clear or turbid waters. The question of whether bigheaded carps would actively avoid the St. Croix River due to clear water and select the Minnesota River because of its turbid conditions was unknown. There was also uncertainty in how well we understood the fish community in the St. Croix River in terms of food webs and available niches. A better monitoring program of the fish community in the St. Croix River was considered necessary to identify any impacts from an established population of bigheaded carps. The group thought more research was needed on predation of bigheaded carps by native fish in terms of what sizes could be preyed upon and by which species.

5.4 Adverse Effects

During the characterization of potential adverse effects, the small group characterized the consequence of each adverse effect for the likely abundance of bigheaded carps that was determined in the previous step. The small group also characterized the consequence resulting from the second most likely abundance of bigheaded carps. For the St. Croix River small group, the first abundance was “Moderate” and the second abundance was “Low”. In the tables below, the characterization for the “Moderate” abundance is noted with “P”, “Q”, “R”, etc. whereas the characterization for the “Low” abundance is noted with “P_L”, “Q_L”, “R_L”. The letters represent different individuals within the small group.

5.4.1 Change in plankton

5.4.1.1 Justifications

At a moderate abundance scenario, the majority of panelists thought there would be a small decrease in plankton abundance after the establishment of bigheaded carps (Table 5-5). In the low abundance scenario, the panel unanimously thought there would be no change in plankton abundance. The decrease was predicted to be small given that there is ample prey in the system that could potentially accommodate another planktivore species such as bigheaded carps. Participants thought that a more likely scenario was a community shift from larger to smaller bodied zooplankters. As a result, overall zooplankton biomass may only decrease slightly, but quality zooplankton (e.g., larger cladocerans) may experience a more significant decrease. Also, rotifer abundance may increase from a decrease in predation from larger zooplankters.

5.4.1.2 Final characterizations

Table 5-5. St. Croix River Change in total biomass of plankton – Small group characterizations.

		Change in total biomass of plankton						
		Large increase	Moderate increase	Small increase	No change	Small decrease	Moderate decrease	Large decrease
Certainty of assessment	Very high certainty (+/- 10%)							
	High certainty (+/- 30%)				P_L			
	Moderate certainty (+/- 50%)				O_L, R_L	P		
	Low certainty (+/- 70%)				R Q_L	O, Q		
	Very low certainty (+/- 90%)							

5.4.2 Consequence for non-game fish

5.4.2.1 Justifications

Gizzard shad, a planktivorous fish species, was chosen as the non-game fish for this watershed because they are a common forage fish in the St. Croix River and play an important role in structuring predator populations. There is also evidence from the literature that diet overlap is high between bigheaded carps and gizzard shad (Irons et al. 2007). Three of four small group members believed that the consequence of a moderately abundant population of bigheaded carps would be low for gizzard shad, and one thought it would be moderate (Table 5-6). The large group characterizations were divided between low (9/19) and moderate (10/19) consequence (Table 5-7). This is primarily due to the fact that the panel concluded that there would only be small effects on the overall zooplankton biomass after the establishment of bigheaded carps. Also, the group thought that gizzard shad could switch food resources (e.g. detritus) and continue to maintain their current abundance. The group did concede that habitat overlap would be high and there was some discussion on the potential for reduced fitness of gizzard shad and potential for this to lower overall abundance. Body condition of gizzard shad has decreased in the Illinois River after establishment of bigheaded carps, which led some participants to predict a moderate negative consequence on gizzard shad in the St. Croix River. Effects on gizzard shad in a low abundance scenario were predicted to be negligible.

5.4.2.2 Final characterizations

Table 5-6. St. Croix River Consequence for non-game fish (Gizzard Shad) – Small group characterizations.

		Consequence				
		Negligible	Low	Moderate	High	Extreme
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)	O_L, P_L, R_L				
	Moderate certainty (+/- 50%)	Q_L	O	Q		
	Low certainty (+/- 70%)		P, R			
	Very low certainty (+/- 90%)					

Table 5-7. St. Croix River Consequence for non-game fish (Gizzard Shad) – Large group characterization for moderate abundance of bigheaded carps.

		Consequence				
		Negligible	Low	Moderate	High	Extreme
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)					
	Moderate certainty (+/- 50%)		3	6		
	Low certainty (+/- 70%)		6	4		
	Very low certainty (+/- 90%)					

5.4.3 Consequence for game fish

5.4.3.1 Justifications

The small group chose sauger as its game species as this species is commonly targeted by anglers in the St. Croix River and is sampled in relatively high abundance in MNDNR sampling. The small group predicted a low level of consequence from bigheaded carps on sauger populations with moderate certainty (Table 5-8). The large group also characterized the level of consequence for sauger as low (13/18), followed by moderate (4/18) and negligible (1/18) (Table 5-9). The effect on sauger populations would largely result from a decrease in abundance and condition of prey (primarily gizzard shad). However, small group members thought that sauger could switch to alternate prey such as young-of-year freshwater drum. Sauger may also prey on young-of-year bigheaded carp as an alternative to gizzard shad. The group thought that negative effects of bigheaded carps could be partially offset by a potential decrease in angler pressure on sauger if bigheaded carps were to establish – a result of fewer anglers wanting to be on the river if a moderate population of bigheaded carps were present. However, it was unknown if angler pressure would decrease with a moderate population of bigheaded carps. Effects on sauger were negligible for the low abundance of bigheaded carps scenario.

5.4.3.2 Final characterizations

Table 5-8. St. Croix River Consequence for game fish (Sauger) – Small group characterizations.

		Consequence				
		Negligible	Low	Moderate	High	Extreme
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)	Q_L, R_L				
	Moderate certainty (+/- 50%)	O_L, P_L	O, P, R			
	Low certainty (+/- 70%)		Q			
	Very low certainty (+/- 90%)					

Table 5-9. St. Croix River Consequence for game fish (Sauger) – Large group characterization for moderate abundance of bigheaded carps.

		Consequence				
		Negligible	Low	Moderate	High	Extreme
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)					
	Moderate certainty (+/- 50%)		9	3		
	Low certainty (+/- 70%)		4			
	Very low certainty (+/- 90%)	1		1		

5.4.4 Consequence for species diversity/ecosystem resilience

5.4.4.1 Justifications

The small group thought that a moderate change in species diversity would take place under a scenario with moderate carp abundance, ranging from high to low certainty (Table 5-10). The group agreed that species diversity would be most affected at lower trophic levels, with changes in zooplankton communities. Group members thought there would be a potential shift from large-bodied cladocerans to higher abundances of rotifers. There was high certainty regarding this shift in lower trophic levels, but changes in higher trophic levels were uncertain. Although the group was less certain about effects on fish diversity, the high number of intolerant fish species in the St. Croix River may make it easier to detect a change in species diversity. The large group also characterized the consequence largely as moderate (17/19) (Table 5-11).

5.4.4.2 Final characterizations

Table 5-10. St. Croix River Consequence for species diversity/ecosystem resilience – Small group characterizations.

		Consequence				
		Negligible	Low	Moderate	High	Extreme
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)			Q		
	Moderate certainty (+/- 50%)	R_L	O_L, P_L	P, R		
	Low certainty (+/- 70%)			O Q_L		
	Very low certainty (+/- 90%)					

Table 5-11. St. Croix River Consequence for species diversity/ecosystem resilience – Large group characterization for moderate abundance of bigheaded carps.

		Consequence				
		Negligible	Low	Moderate	High	Extreme
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)			1		
	Moderate certainty (+/- 50%)		1	8		
	Low certainty (+/- 70%)		1	7		
	Very low certainty (+/- 90%)			1		

5.4.5 Consequence for recreational boating and fishing from jumping silver carp hazard

5.4.5.1 Justifications

The small group characterized the jumping hazard impact of a moderate population of bigheaded carps on recreational boating and fishing at both a high consequence level (3/4) and low consequence level (1/4), with varying degrees of certainty (Table 5-12). Although the overall chance of getting struck by a silver carp was considered low, the reactions by the public to such events was predicted to be high. Given that there are abundant alternative water resources around the area, small group members thought people would rather go elsewhere to recreate than risk being struck by a silver carp. However, because most of the boating traffic occurs in the lake portion of the river, encounters between bigheaded carp and boats maybe rare given the depth and area of the lake portion and that silver carp are more likely to jump in shallow or confined waters. Group members thought it was more likely to encounter jumping silver carp in a confined area as opposed to the open expanse of Lake St. Croix. The large group characterized the consequence level of the jumping hazard to recreational boating and fishing as predominantly high (9/19) and moderate (8/19), and also extreme (1/19) and low (1/19) (Table 5-13).

5.4.5.2 Final characterizations

Table 5-12. St. Croix River Consequence for recreational boating and fishing from jumping silver carp hazard – Small group characterizations.

		Consequence				
		Negligible	Low	Moderate	High	Extreme
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)		P_L, R_L	O_L	O	
	Moderate certainty (+/- 50%)				R	
	Low certainty (+/- 70%)		P	Q_L	Q	
	Very low certainty (+/- 90%)					

Table 5-13. St. Croix River Consequence for recreational boating and fishing from jumping silver carp hazard – Large group characterization for moderate abundance of bigheaded carps.

		Consequence				
		Negligible	Low	Moderate	High	Extreme
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)				4	1
	Moderate certainty (+/- 50%)			2	4	
	Low certainty (+/- 70%)		1	5	1	
	Very low certainty (+/- 90%)			1		

5.4.6 Adverse Effects: Research needs

Group members thought that a food web study would be beneficial to understanding the potential role bigheaded carps would play in the system. A potential energy pathway study using stable isotope analysis would be beneficial to understanding food webs in the St. Croix River before and after establishment by bigheaded carps. There was disagreement as to whether comprehensive studies currently exist examining zooplankton community response to invasions by bigheaded carps in other rivers. Data on zooplankton communities in rivers is sparse compared to lakes and reservoirs. The group also wanted more information on current zooplankton communities to know whether prey resources were sufficient to maintain gizzard shad abundance when resources are also in demand by bigheaded carps.

The group wanted better estimates of species richness and diversity in the St. Croix River. A more intense monitoring program is needed to detect any changes in diversity as a result of establishment by bigheaded carps. In addition panelists thought it would be difficult to detect changes in gizzard shad and sauger abundance given current fish sampling protocols.

Panelists wanted more information on what influences sauger recruitment in the St. Croix River and thought that recruitment might be driven more by hydrology than prey availability. If hydrology drove recruitment success, than a decrease in prey resulting from bigheaded carps may not have a negative effect on sauger. However, hydrology and other environmental conditions could also be driving available prey resources for sauger, and panelists thought additional research was needed in this area. The group was unsure how anglers would respond to different levels of bigheaded carps abundance. Would angler pressure on sauger decrease because there would be fewer anglers on the river, or would it increase if there were fewer recreational boaters for the anglers to compete with?

Panelists were uncertain as to whether bigheaded carps would be at the water's surface near boats given the clear water of the St. Croix River. It is possible that bigheaded carps would stay in deep water to avoid sunlight and not have many encounters with boats. The group also was uncertain as to the density of bigheaded carps needed for jumping behavior. There were also questions surrounding how the public would react to jumping bigheaded carps and what factors would influence differences across reactions. Whether anglers would become acclimated to this new phenomenon and eventually return to boating on the St. Croix River was unknown.

5.5 Overarching uncertainties, research needs & areas of disagreements

Because the St. Croix River system is different than systems where bigheaded carps are currently found, participants had difficulty determining whether or not they would succeed in such an environment. The effects of water clarity and aquatic species diversity on the establishment of bigheaded carps and their effects on the system was a common uncertainly throughout the scenarios. Bigheaded carps are currently found in high abundance in impaired river systems, such as the Illinois River. Whether the St. Croix River would be more resilient to invasion given that it is less impaired is unknown. Research into how bigheaded carps react to clear water is needed to accurately determine the potential risk of invasion into these low turbidity systems.

Another common theme across scenarios was the need for baseline information (fish diets, zooplankton, etc.) to detect future changes. Fish sampling is currently conducted every 3 to 6 years on the St. Croix River by the MNDNR. Sampling gear has varied across years from electrofishing, trap nets and gill nets. A more rigorous and standardized sampling protocol for both fish and zooplankton is needed to address potential changes in these aquatic communities.

6 Nemadji River

6.1 Introduction to watershed

The Nemadji River flows 111 km from its headwaters at Maheu Lake in Pine County to Allouez Bay in the St. Louis Estuary, which covers 4,856 ha at the west end of Lake Superior. The Nemadji River watershed covers 112,260 ha on the southwest corner of Lake Superior. The Nemadji watershed includes numerous streams, 17,141 ha of wetlands (National Wetlands Inventory Data), and 35 lakes greater than 4 ha located mostly in the watershed's headwaters area. Land use in the watershed's Minnesota portion is mostly related to rural forestry, pasture production for hay cutting, and some beef cattle. Lakeshores are developed, although not as intensively as is typical in northern counties. The watershed is in the Northern Lakes and Forest Ecoregion, which is dominated by glacial till in ground moraines and drumlins and highly erodible clay soils. Glacial till occurs throughout the upper watershed, whereas the lower one-third of the watershed is covered in red clay from Quaternary geology, sometimes up to 61 m thick; this layer was deposited during a geologic period when glacial lakes covered the region (MPCA 2014).

The Nemadji River is famous for its turbid, clay-filled water which is visible as a large plume in the western end of Lake Superior after any significant rain event. Though red clay erosion is natural, human activities on the land in the last century have accelerated the natural process, and as a result the river has cut deep valleys into the surrounding bluffs. During the pre-settlement era the landscape was covered with mature coniferous trees that stabilized the riparian areas near the rivers and streams. During the mid 1800s loggers removed the forest in the watershed and coarse woody structure in streams. Logging converted forest to permanent agriculture, streams were cleared to efficiently transport logs to sawmills, and many roads and railroads were cut through the basin. This all led to efficient hydrologic pathways for water to get to the river quickly (Natural Resources Conservation Service and U.S. Forest Service 1998). While 69% percent of the watershed is now reforested, the deciduous trees adjacent to streams may not be an effective sediment filter, or may not form a sturdy or deep enough root system to hold soils in place in currently downcut channels. Many red clay slumps in the watershed move downhill despite tree cover, likely due to shallow groundwater movement beneath the root zone. The riparian areas along the stream vary greatly in width and quality (Natural Resources Conservation Service and U.S. Forest Service 1998). Nearly 90% of the fine sediment in the river is due to bluff erosion and slumping, and 74% of this sediment ultimately ends up in Lake Superior (CSWCD 2017).

Despite substantial impairment from turbidity and siltation, the Minnesota portion of the Nemadji watershed contains 40% of Lake Superior's migratory trout and salmon spawning habitat in Minnesota (Minnesota Department of Natural Resources, unpublished information). Streamflow is somewhat stable compared to the much more dynamic streams of the North Shore of Lake Superior in Minnesota. Mean discharge during the warmer summer months varies from 0.14-0.42 cubic meters per second (cms) in upstream reaches to an annual average of 6.48-21.12 cms during June-September in 2011-2015 at the lower Nemadji River gauge (U.S. Geological Survey 2016). Average precipitation in the area is about 76.2 cm per year. The upper reaches remain cool enough during the summer months to support growth for brown trout (Salmo trutta), which requires temperatures of 5-23 C. The long-term mean air temperature in summer is 16.7 C. The watershed contains numerous beaver dams and man-made impoundments, which block movements of anadromous steelhead rainbow trout; 4-8 beaver dams are removed annually in a major tributary, the Blackhoof River, to maintain anadromous passage. The upstream reaches contain limited numbers of brook, brown, and rainbow trout and also small populations of suckers, chubs, and minnows. In the upstream reaches the stream gradient averages 2.5 m/km and the stream is 4.9 m wide on average. At the downstream end of the Nemadji River, stream gradient drops to less than 1.3 m/km and widens to 18.2 m on average. Near the river mouth gravel bars can prevent some canoe and kayak traffic during summer months, and the fish species composition is similar to that in the St. Louis Estuary. The mouth of the Nemadji River is an area of side-channel wetlands that extend for about 1.6 km upstream. Wetlands at the mouth of the Nemadji cover about 26.4 ha and support the spawning beds of over 60 warm water fish species, including muskellunge, perch, bass, walleye, and northern pike. Lamprey also occur in the river, and are actively controlled by the US Fish and Wildlife Service. This area is identified by the Lake Superior Binational Program as important habitat to the Lake Superior ecosystem for coastal wetlands as well as fish and wildlife spawning and nursery grounds. The St. Louis Estuary supports diverse recreational activity including boating, fishing, canoeing and kayaking, and also a considerable amount of barge and large vessel traffic, as the Duluth/Superior Port is one of the busiest ports in the world.

The fish community of the St. Louis Estuary system is composed of a diverse mix of warm and cool-water species that are common to many Minnesota lakes. Several of these fishes support an active fishery, including walleye, northern pike, muskellunge, lake sturgeon, channel catfish, black crappie, and smallmouth bass. The fishery has developed over the past 20 years as the waters have become less contaminated; however, fish consumption advisories are still in place for larger predatory fishes. Summer angling effort has ranged from 93,315 hours in 2015 to 295,621 hours in 2003 (Minnesota DNR unpublished documents; Lindgren 2004a). For comparison, the highest recent angling effort on the Minnesota waters of Lake Superior proper was 204,881 hours in 2015. In the Estuary, anglers prefer walleyes, accounting for 86% of the targeted summer effort in 2003 (Lindgren 2004a). In recent years, the adult walleye population has varied between 60,070 (± 24,484) in 1981 to 97,887 (± 24,484) in 1993. Lake sturgeon abundance has increased to the point that a catch-and-release season was implemented in 2015 to protect the populations (Minnesota DNR unpublished data). Minnesota and Wisconsin stocked muskellunge annually from 1983 through 2005 and both states actively managed muskellunge by regular fish surveys. Regarding other fishes, yellow perch and black crappie are sought almost exclusively during the winter Lindgren 2004b). Winter anglers sought yellow perch 18.7% of the time and black crappie 42.1% of the time in the winter of 2002/2003, whereas anglers did not target yellow perch and only targeted black crappie 1.6% of the time in the summer of 2003. Anglers also targeted northern pike 13.1% of the time during winter and 7.2% of the time during summer. The other fishes are targeted by less than 5% of all other anglers yet add to the unique diversity of the fishery in the St. Louis Estuary.

The primary prey fishes in the Estuary are trout-perch (Percopsis omiscomaycus), yellow perch, white sucker, and redhorse (Moxostoma sp), and also juveniles of many predators and numerous cyprinids including common carp. Yellow perch growth rates are relatively fast and survival to larger sizes is low, which indicate that predation on yellow perch is intense. Boygo (2015) surveyed open water areas of the Estuary in 2015 with a bottom trawl and caught a wide variety of small fishes, including black crappie (27%), trout-perch (23%), and yellow perch (17%). Spottail shiners were also common, occurring at lower densities in 77.5% of the trawl samples. The abundance of a new invasive fish, white perch (Morone americana), may be increasing (Boygo 2015).

The Estuary contains several aquatic invasive fishes, including sea lamprey, eurasian ruffe (Gymnocephalus cernuus), common carp, white perch, rainbow smelt (Osmerus mordax), round goby (Neogobius melanostomus), and tubenose goby (Proterorhinus semilunaris). Eurasian ruffe were first observed in Wisconsin DNR seines in 1986, and expanded quickly in Minnesota DNR gill nets, increasing from 0 fish/net in 1987 to 16.3 fish/net in 1992. Catches subsequently declined to less than 4 fish/net in 1994-2005. Boygo (2015) observed a 10-fold decrease in bottom trawl catches compared to 1989-2004. Catches may have declined due to small mean length, a possible consequence of intensive predation following intensive predator stocking by both Wisconsin and Minnesota in 1989 to 1993 and from other fishes whose populations expanded as Estuary conditions improved. Other invasive fishes appear to be at low levels in the Estuary, possibly due to the Estuary's high fish diversity. No native species appear to be recently extirpated or in danger of being imperiled due to the high diversity; rather, continued improvements to the Estuary have improved the habitats for many fishes.

The lower Nemadji system has suffered many abuses and yet retains many natural features and is now being protected and rehabilitated because the system contains ecologically rich mesic hardwood forests, floodplain forests, and marshes. The marshes are diverse, contain mostly native species, function well ecologically, and provide summer residency for some uncommon resident birds. Invasive plants are still quite localized in disturbed areas such as levees and formerly dredged areas. The Nemadji River Bottoms at the lower end of the river are also identified as a Lake Superior Basin Priority Site due to the high quality floodplain wetlands and the erodibility of the soils in this area. Continued improvements to the Nemadji River and the St. Louis Estuary will benefit native fishes, however the reduction in sedimentation may also provide additional nursery habitat for newly invading species. Species that are produced in the Nemadji River and are not transported by high currents into Lake Superior can spread out into the St. Louis Estuary. That estuary contains an abundance of shallow, productive, backwater habitat for juvenile fishes and a variety of habitats and substrates for adult fishes to grow and reproduce.

6.2 Likelihood of establishment

6.2.1 Justifications

Members of the Nemadji River small group thought that bigheaded carps would have a relatively high (60-95 %) likelihood of establishment, and most (3 of 5) members were highly certain of this assessment (Table 6-1). Differences of opinion were wider with the larger group, where most (11 of 20) characterized bigheaded carps as having a low likelihood of establishment, while 6 of 20 thought there was a moderate likelihood of establishment (Table 6-2). Most members of the larger group were moderately certain of this assessment. These and all subsequent characterizations considered the Nemadji estuary along with the larger St. Louis Bay estuary, because of their physical connection.

Discussion around likelihood of bigheaded carps establishment in the Nemadji River included the variability in habitat suitability for bigheaded carps spawning, feeding and growth. Although much of the upper Nemadji River is trout habitat that is cold, clear and unlikely to support growth of bigheaded carps, it also provides over 48 km of free flowing potential spawning habitat for bigheaded carps, and the productive St. Louis Bay Estuary at the downstream end of the Nemadji River provides suitable habitat for juveniles and adults. Earlier studies of bigheaded carps spawning in China (Yi et al. 1988, reviewed by Kolar et al. 2007) suggested that bigheaded carps required specific hydrologic and thermal requirements to spawn successfully, and a minimum of 161 km for eggs to drift downstream, hatch and settle into favorable backwater nursery habitats. However, recent research by Kocovsky et al. (2012), Garcia et al. (2013), Deters et al. (2013), and Coulter et al. (2013) suggests that reproductive ecology of introduced bigheaded carps is more plastic. Bigheaded carps can spawn successfully at lower temperatures, and in less turbid water and shorter river habitats (<26km) than previously thought. Some group members thought bigheaded carps may not be able to spawn in spring when river flows are cold and fast, but could spawn during August as temperatures increase and flows decline. Nursery habitat for young bigheaded carps was thought to be poor in the upper river where plankton biomass is low and predation from trout and gobies would be high, but would be suitable in the lower river and estuary which are productive, turbid environments. As an example, the group noted that cisco (Coregonus artedi), a native planktivore inhabits the St. Louis estuary in summer. Other members noted that bigheaded carps inhabit multiple habitat types in China's Yangtze River, including colder streams. Members considered uncertainty associated with climate warming that could improve thermal habitat quality for bigheaded carps, and presence of other invasive species such as round goby that have thrived in the Nemadji River.

6.2.2 Final characterizations

Table 6-1. Nemadji River Likelihood of Establishment - Small Group Final Characterization.

		Likelihood of establishment				
		Very unlikely (.00-.05)	Low (.05-.40)	Moderate (.40-.60)	High (.60-.95)	Very likely (.95-1.00)
Certainty of assessment	Very high certainty (+/- 10%)					
Certainty of assessment	High certainty (+/- 30%)				S, U, X	
Certainty of assessment	Moderate certainty (+/- 50%)				W	
Certainty of assessment	Low certainty (+/- 70%)				T	
Certainty of assessment	Very low certainty (+/- 90%)					

Table 6-2 Nemadji River Likelihood of Establishment – Large Group Characterization.

		Likelihood of establishment				
		Very unlikely (.00-.05)	Low (.05-.40)	Moderate (.40-.60)	High (.60-.95)	Very likely (.95-1.00)
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)					
	Moderate certainty (+/- 50%)		9	4	2	
	Low certainty (+/- 70%)		1	1		
	Very low certainty (+/- 90%)		1	1	1	

6.2.3 Research needs

Key research needs were to understand why bigheaded carps are not abundant in coldwater streams, or why they are present but not established. Some small group members thought the water would be too cold for reproduction or growth, or that river flows may be too high, and predation by coldwater fish communities may be too intense. The small group felt it would be useful to investigate other watersheds where there are enough adults to establish but no evidence that bigheaded carp have successfully established. Members felt that some uncertainties regarding the establishment of bigheaded carps could be answered by development and application of temperature and flow models for the Nemadjii River, application of bioenergetics and stock-recruit models to predict growth potential and reproductive success, respectively, and further studies of juvenile bigheaded carp movement patterns.

6.3 Resulting abundance

6.3.1 Justifications

Most (4 of 5) small group members were moderately certain that bigheaded carps would comprise a moderate (5-25% of total fish biomass) level of abundance, with one member being highly certain (Table 6-3). Members felt that bigheaded carps abundance would fall on the low side (5-10% of total fish biomass, including anadromous fishes) of this abundance category. Half (10/20) of the larger group felt that bigheaded carps would reach a moderate level of abundance, with 8 of 20 assessing bigheaded carps abundance as low and 2 of 20 individuals assessing potential abundance as very low (Table 6-4). Most (14 of 20) large group members were moderately certain of their assessment, while certainty of other members ranged from very low or low (5 of 20 individuals) to high (1 of 20 individuals).

Factors affecting the assessment of potential abundance of bigheaded carps were similar to those mentioned for their establishment. The small group felt that bigheaded carps would not have enough plankton to support growth in the upper watershed, so would be confined to the St. Louis Bay Estuary which is more productive. The group thought that the ability of bigheaded carps to persist would rely on their ability to feed on alternative food sources in the lower river and estuary, including detritus and fish larvae. Therefore the whole estuary, including the Nemadji River and St. Louis Bay, would need to be managed as one system. Western Lake Superior zooplankton abundance has varied, between 1996 and 1997, from 20 to 55/L (Johnson et al. 2004), whereas zooplankton abundance in the lower Missouri River varied, between habitats, from 5 (chute habitat) to 45/L (backwater habitat) (Dzialowski et al. 2013). Zooplankton densities were significantly higher in the backwaters habitat than the chute habitat of the lower Missouri River. Rotifers dominated (30/L) the zooplankton community in the lower Missouri River, while adult copepods density was measured at about 0.9/L, and no cladocerans were documented there. In contrast, cladoceran density in Western Lake Superior ranged from 0.3 to 1.2/L, while adult and juvenile copepod density ranged from 10 to 14/L, and rotifer density ranged from 9 to 39/L. Thus, density of large zooplankton has been somewhat higher in western Lake Superior than in the lower Missouri River. Zooplankton density in western Lake Superior historically supported a population of cisco from which commercial landings exceeded 1 million pounds annually (Anderson and Smith 1971). Diets of the cisco and bigheaded carps are similar—both are often zooplanktivorous. Thus, if the cisco can sustain a fishable population in the Lake Superior's Duluth-Superior area, which includes the St. Louis River estuary and connected, nearshore lake habitat, then bigheaded carps may find adequate food resources also establish self-sustaining populations there. Also, thermal habitat in the nearshore waters of western Lake Superior is likely more suitable to growth and feeding than the colder waters of the upper Nemadji River. Thus, food and thermal habitat combined may be suitable, in portions of western Lake Superior, to enable populations of bigheaded carps to establish there, if introduced.

Several studies of the diet of bigheaded carps indicate they can readily consume a variety of prey types that may be available in St. Louis Bay estuary. Chen (1982) found diet of bigheaded carps in China included bacteria, detritus, phytoplankton and zooplankton. The ability of bigheaded carps to consume small plankton is related to their gill raker size. Bighead carp have average gill raker widths ranging from 20-60 µm, and can consume particles down to 17 µm, while pore size of silver carp gill rakers ranges from 20-25 µm and can allows them to consume particles down to 8 µm (Opuszynski 1981; cited in Sampson et al. 2009). Sampson et al. (2009)

found that the diet of bigheaded carps in backwater lakes of the Illinois and Missouri River was dominated by rotifers, and cautioned that the competition for prey may be greatest in less productive habitats of the Great Lakes. Cooke and Hill (2010) used bioenergetics modeling to investigate the potential for bigheaded carps to grow at ambient temperatures and prey densities in Great Lakes habitats. They found bigheaded carps would not show positive growth in open water habitats of the Great Lakes, but would grow well in productive embayments, estuaries and wetland habitats. They noted that bigheaded carps could achieve positive growth in habitats with lower prey densities and temperatures, owing to lower metabolic costs. Bigheaded carps diet flexibility, potential availability of suitable prey, and cooler water temperatures in the St. Louis Estuary may combine to support positive growth and low to moderate abundance of bigheaded carps.

6.3.2 Final characterizations

Table 6-3. Nemadji River Resulting Abundance – Small Group Final Characterization.

		Resulting abundance (% of total fish biomass)				
		Very low (Few individuals, <1%)	Low (1-5% of total fish biomass)	Moderate (5-25% of total fish biomass)	High (25-60% of total fish biomass	Very high (>60% of total fish biomass)
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)			T		
	Moderate certainty (+/- 50%)			X, U, S, W		
	Low certainty (+/- 70%)					
	Very low certainty (+/- 90%)					

Table 6-4. Nemadji River Resulting Abundance – Large Group Characterization.

		Resulting abundance (% of total fish biomass)				
		Very low (Few individuals, <1%)	Low (1-5% of total fish biomass)	Moderate (5-25% of total fish biomass)	High (25-60% of total fish biomass	Very high (>60% of total fish biomass)
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)		1			
	Moderate certainty (+/- 50%)	2	7	5		
	Low certainty (+/- 70%)			3		
	Very low certainty (+/- 90%)			2		

6.3.3 Research needs

The small group identified research needs to better evaluate potential abundance of bigheaded carps in the Nemadji River estuary, and connected, nearshore areas of western Lake Superior. Needs included a desire for case histories of establishment by bigheaded carps in ecosystems similar to the Nemadji River watershed; estimates of straying rates of bigheaded carps from connected systems such as the St. Louis estuary; studies of flexibility in bigheaded carps feeding behavior; homing tendencies of bigheaded carps; and minimum habitat requirements for bigheaded carps in free-flowing waters.

Areas of disagreement and uncertainty about bigheaded carps potential abundance included whether water flows and temperature were too cold to support successful reproduction and recruitment of carp, whether to consider only habitat in the St. Louis Bay Estuary or within the whole watershed, and what types of food were available to support bigheaded carps growth.

6.4 Adverse Effects

During the characterization of potential adverse effects, the small group characterized the consequence of each adverse effect for the likely abundance of bigheaded carps, arrived at earlier in the process. The small group also characterized the consequence resulting from the second most likely abundance of bigheaded carps. For the Nemadji River small group, the first abundance was “Moderate” and the second abundance was “Low.” In the tables below, the characterization for the “Moderate” abundance is noted with “S”, “T”, “U”, etc. whereas the characterization for the "Low" abundance is noted with "S_L", "T_L", "U_L". The letters represent different individuals within the small group.

6.4.1 Change in plankton

6.4.1.1 Justifications

In its first characterization of the effects of bigheaded carps on plankton, the small group largely believed (4 of 5 individuals) that consumption by a moderately abundant bigheaded carps population would cause a moderate decrease in plankton biomass (Table 6-5). One individual felt that bigheaded carps would cause a large decrease in plankton biomass. For the second characterization for a low resulting abundance of bigheaded carps, most (3 of 5 individuals) thought plankton biomass would show a small decrease, with a range from no change in biomass to a moderate decrease in biomass.

The groups identified several potential adverse effects resulting from a reduction in quality or abundance of plankton due to bigheaded carps consumption. Reduced quality or abundance of plankton may cause a shift in native fish diets to less preferred foods, resulting in reduced fish abundance, growth or condition. Reduced abundance of plankton could cause a reduction in abundance of native planktivores, which potentially would reduce abundance of piscivores and/or game fish. The groups recognized that planktivores could be either larval or juvenile stages of piscivorous fish (e.g., walleye) or adult stages of prey fish such as common shiners, gizzard shad or cisco. Native planktivores also may experience a reduction in habitat in competition with bigheaded carps, making them less able to cope with additional stressors (other aquatic invasive species, habitat fragmentation) or more available to predators. Bigheaded carps' consumption of plankton in the water column could increase light penetration, which may reduce densities of game and non-game fish. Bioturbation by bighead carps feeding on the bottom could stimulate algal blooms, reduce water column oxygen concentrations, and potentially reduce abundance or quality of game and non-game fishes.

Empirical studies of bigheaded carp effects on fishes in the Illinois and Missssissippi River indicate that bigheaded carp consumption has reduced biomass of large zooplankton, which coincided with reduced condition of native planktivores including gizzard shad and bigmouth buffalo (Irons et al. 2007). A modeling study to project impacts of bigheaded carp invasion in Lake Erie found a reduction in biomass of large zooplankton, with a decline in biomass of native planktivores (Zhang et al. 2016).

6.4.1.2 Final characterizations

Table 6-5. Nemadji River Change in total biomass of plankton – Small group characterizations.

		Change in total biomass of plankton						
		Large increase	Moderate increase	Small increase	No change	Small decrease	Moderate decrease	Large decrease
Certainty of assessment	Very high certainty (+/- 10%)							
	High certainty (+/- 30%)							
	Moderate certainty (+/- 50%)					S_L, U_L	S, U, W	X
	Low certainty (+/- 70%)				W_L	T_L	T X_L	
	Very low certainty (+/- 90%)							

6.4.2 Consequence for non-game fish

6.4.2.1 Justifications

Common shiner was chosen as the non-game species because of its high relative abundance in the watershed compared to other species.

The small group varied from low to moderate certainty in their judgment that if bigheaded carps reached a moderate level of abundance, they would have a negligible to moderate effect on common shiner abundance through a reduction in plankton biomass (Table 6-6). At a low abundance, the group felt that bigheaded carps would have a negligible to low adverse effect on common shiner. The larger group also largely felt that bigheaded carps would have a negligible (9 of 19 individuals) to low (7 of 19 individuals) effect on common shiner, with 3 of 19 individuals predicting a moderate effect (Table 6-7). As justification for their decision, the small group members stated that common shiner is an omnivore, and could switch to other prey sources if bigheaded carps depleted the available biomass of plankton. The small group also mentioned that in the Illinois River where bigheaded carps are abundant, few examples have been reported of detectable effects of bigheaded carps on native fishes. On the other hand, two individuals mentioned that even a modest decrease in plankton biomass could have moderate effects on common shiners in a low productivity system like the Nemadji River.

6.4.2.2 Final characterizations

Table 6-6. Nemadji River Consequence for non-game fish (Common Shiner) – Small group characterizations.

		Consequence				
		Negligible	Low	Moderate	High	Extreme
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)					
	Moderate certainty (+/- 50%)	W W_L	X_L	X		
	Low certainty (+/- 70%)	S S_L, T_L, U_L	T, U			
	Very low certainty (+/- 90%)					

Table 6-7 Nemadji River Consequence for non-game fish (Common Shiner) – Large group characterization for moderate abundance of bigheaded carps.

		Consequence				
		Negligible	Low	Moderate	High	Extreme
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)					
	Moderate certainty (+/- 50%)	3	1	3		
	Low certainty (+/- 70%)	6	6			
	Very low certainty (+/- 90%)					

6.4.3 Consequence for game fish

6.4.3.1 Justifications

Black crappie is one of the most targeted sportfish in the Nemadji River during both open water and ice covered periods. Thus, the Nemadji River small group chose to evaluate the potential effects of bigheaded carps on black crappie to forecast potential effects on this important fishery. The small group predicted that a moderate abundance of bigheaded carps in the Nemadji River watershed would have a negligible (undetectable changes; 2 of 5 participants) to low (small decrease in the population leading to minor reduction in angling quality; 3 of 5 participants) effect on black crappie but the group only had low (4 of 5 participants) to moderate (1 of 5 participants) certainty (Table 6-8).

Justifications for the small group's predictions focused largely on the group's previous predictions that bigheaded carps would reach a fairly low total biomass (5-25% of total fish biomass) and would only reduce plankton resources by 5-15% in this system, which would have a minimal effect on black crappie. The group also discussed how the Nemadji River's heterogeneous habitats may allow for habitat separation between the two species. Other justifications for the small group participants' predictions included the higher trophic position of black crappie compared to bigheaded carps, low diet overlap between species as adults, and lack of evidence that high densities of bigheaded carps have negatively affected sportfishes in other areas of invasion (e.g., Illinois River). However, there was concern that black crappie early life stages may compete with bigheaded carps for plankton, potentially resulting in reduced survival of larvae and recruitment. Under the scenario of low bigheaded carps abundance in the Nemadji River, the small group predicted a negligible (5 of 5 participants) effect on black crappie and the members had low (3 of 5 participants) to moderate (2 of 5 participants) certainty. Uncertainties recognized by the group when making this decision included how successful and abundant bigheaded carps would be in a coldwater environment, and the ability of black crappie to move around to microhabitats within the Nemadji River to reduce spatial overlap with bigheaded carps and adapt to changing environmental conditions. The group also identified that their prediction could be improved by reviewing pre- and post-bigheaded carp invasion data on black crappie populations in other locations (e.g., lower and middle Mississippi River, Illinois River).

The large group characterization for bigheaded carps adverse effect on black crappie in the Nemadji River varied from negligible (5 of 19 participants), to low (12 of 19 participants), and moderate (2 of 19 participants). The large group's certainty level concerning black crappie ranged from very low (3 of 19 participants), to low (15 of 19 participants), and moderate (1 of 19 participants) (Table 6-9).

6.4.3.2 Final Characterizations

Table 6-8. Nemadji River Consequence for game fish (Black Crappie) – Small group characterizations.

		Consequence				
		Negligible	Low	Moderate	High	Extreme
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)					
	Moderate certainty (+/- 50%)	W U_L, W_L				
	Low certainty (+/- 70%)	X S_L, T_L, X_L	S, T, U			
	Very low certainty (+/- 90%)					

Table 6-9. Nemadji River Consequence for game fish (Black Crappie) – Large group characterization for moderate abundance of bigheaded carps.

		Consequence				
		Negligible	Low	Moderate	High	Extreme
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)					
	Moderate certainty (+/- 50%)	1				
	Low certainty (+/- 70%)	3	11	1		
	Very low certainty (+/- 90%)	1	1	1		

6.4.4 Consequence for species diversity/ecosystem resilience

6.4.4.1 Justifications

Beyond their potential impacts on individual fish species in the Nemadji River, bigheaded carps also may affect species diversity and ecosystem resilience. The small group predicted that a moderate abundance of bigheaded carps in the Nemadji River watershed would have a low (minimal change in ecosystem structure or function; 2 of 5 participants) to moderate (detectable change in ecosystem structure, function, and ability to withstand stressors; 3 of 5 participants) effect on species diversity and ecosystem resilience and the small group had low confidence in their prediction (5/5 participants)(Table 6-10).

Although the small group recognized several mechanisms by which bigheaded carps could affect the ecosystem (e.g., competition with native planktivores), participants generally predicted a low to moderate effect of bigheaded carps on the Nemadji River ecosystem due to 1) predicted changes in native species distributions instead of biomass following bigheaded carps invasion and 2) bigheaded carps would likely only occupy the lower portion of the watershed, leaving the upper reaches intact. The small group also discussed the large number of invasive species already present within the Nemadji River watershed (e.g., round goby (Neogobius melanostomus), spiny water flea (Bythotrephes longimanus), alewife (Alosa pseudoharengus), sea lamprey) and was uncertain how another invasive species would interact with or change the current ecosystem structure and function. The small group then predicted a low abundance of bigheaded carps population would have a negligible (undetectable changes in ecosystem structure and function; 2 of 5 participants) or low (3 or 5 participants) effect on the Nemadji River ecosystem, but the small group still had low certainty in their decision (5 of 5 participants). The small group desired additional information on effects of bigheaded carps on ecosystem structure and function in other invaded ecosystems and how they may interact with other invaders at higher (e.g., sea lamprey, salmonids) and lower (e.g., zebra mussels, spiny water flea) trophic levels to alter ecosystems.

The large group predicted more substantial effects of bigheaded carps on the Nemadji River structure and function compared with the small group, with individuals anticipating negligible (1 of 19 participants), low (6 of 19 participants), moderate (11 of 19 participants), and high (significant changes to ecosystem structure, function, and ability to withstand stressors; 1 of 19 participants) effects. The large group had very low (4 of 19 participants), low (7 of 19 participants), and moderate (8 of 19 participants) certainty (Table 6-11).

6.4.4.2 Final characterizations

Table 6-10. Nemadji River Consequence for species diversity/ecosystem resilience – Small group characterizations.

		Consequence				
		Negligible	Low	Moderate	High	Extreme
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)					
	Moderate certainty (+/- 50%)					
	Low certainty (+/- 70%)	T_L, W_L	T, W S_L, U_L, X_L	S, U, X		
	Very low certainty (+/- 90%)					

Table 6-11. Nemadji River Consequence for species diversity/ecosystem resilience – Large group characterization for moderate abundance of bigheaded carps.

		Consequence				
		Negligible	Low	Moderate	High	Extreme
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)					
	Moderate certainty (+/- 50%)	1	3	4		
	Low certainty (+/- 70%)		3	4		
	Very low certainty (+/- 90%)			3	1	

6.4.5 Consequence for recreational boating and fishing from jumping silver carp hazard

6.4.5.1 Justifications

Bigheaded carps also pose a risk to humans due to the leaping behavior of silver carp that could disrupt boating activities and result in collisions and physical injury. The small group predicted that a moderate abundance of bigheaded carps would have a moderate (occasional sightings of jumping carp and minor changes in boating and fishing; 3 of 5 participants) to high (regular sightings of jumping carp, occasional collisions, and changes in boating and fishing; 2 of 5 participants) effect on recreational opportunities in the Nemadji River watershed but had very low (±90%; 2 of 5 participants) or low (±70%; 3 of 5 participants) certainty (Table 6-12).

The small group discussed the morphology of the Nemadji River and recreational boating in the area. Those familiar with the system indicated that most recreational boating occurs at the confluence of the Nemadji River with Lake Superior which is generally very shallow with the exception of a shipping channel that is maintained at a deeper depth. Recreational boating is perceived to be low in general, resulting in low probability of boater interactions with a moderate abundance of bigheaded carps. However, people who do recreate in this area often use the shallow confluence flats which might increase interactions and collisions with silver carp. This could alter recreational boater and angler behavior, resulting in increased use of the deeper shipping channel that may increase interactions between recreational and commercial boaters. The small group then predicted that a low abundance of bigheaded carps would have a low (rare sightings of jumping carp but does not cause change in boater behavior; 3 of 5 participants) to moderate (2 of 5 participants) effect on recreational boating and fishing but participants had very low (±90%; 2 of 5 participants) to low (±70%; 3 of 5 participants) certainty. The large group generally agreed with the small group (Table 6-13). The large group predicted that bigheaded carps would have a low (7 of 19 participants), moderate (11 of 19 participants) or high (1 of 19 participants) effect on recreational boating and fishing in the Nemadji River.

6.4.5.2 Final characterizations

Table 6-12. Nemadji River Consequence for recreational boating and fishing from jumping silver carp hazard – Small group characterizations.

		Consequence				
		Negligible	Low	Moderate	High	Extreme
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)					
	Moderate certainty (+/- 50%)					
	Low certainty (+/- 70%)		T_L, W_L	T, W X_L	X	
	Very low certainty (+/- 90%)		S_L	S U_L	U	

Table 6-13. Nemadji River Consequence for recreational boating and fishing from jumping silver carp hazard – Large group characterization for moderate abundance of bigheaded carps.

		Consequence				
		Negligible	Low	Moderate	High	Extreme
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)					
	Moderate certainty (+/- 50%)			3		
	Low certainty (+/- 70%)		6	6	1	
	Very low certainty (+/- 90%)		1	2		

6.4.6 Adverse Effects: Research needs

The Nemadji River small group identified several research needs to better predict potential adverse effects of a bigheaded carps invasion. The small group recognized that pre- and post-invasion data would valuable for monitoring and understanding the effects of a bigheaded carps invasion. The group identified a suit of unique native species (e.g., cisco, lean lake trout, kiyi (Coregonus kiyi)) in the Nemadji River watershed that could be affected by a bigheaded carps invasion and recommend long-term monitoring of these populations to potentially assess pre- and post-invasion population changes. The small group noted that most monitoring to date in other regions of bigheaded carps invasion has focused on plankton and planktivorous fishes: the small group saw a need to better understand how bigheaded carps may affect native piscivores (either positively or negatively). The small group also saw value in better understanding metabolic processes, growth, and consumption demands of bigheaded carps in coldwater, oligotrophic systems where growing degree days and food resources are limited in order to better understand their potential ecosystem effects. Finally, little is known regarding environmental conditions and stressors that trigger silver carp jumping behavior. The small group thought an experiment identifying factors resulting in jumping behaviors would improve communications between recreational boaters, fishers, and biologists regarding risks associated with recreating in areas invaded by bigheaded carps.

6.5 Overarching uncertainties, research needs & areas of disagreements

The Nemadji River small group generally agreed on the effects, or lack thereof, of bigheaded carps on native fishes, ecosystems, and recreational boaters and fishers, and had no major areas of conflict or disagreement. However, the certainty level was low and the small group identified several areas where additional research would improve their understanding of the ecosystems effects of bigheaded carps, with a focus on the Nemadji River. To date, most work on bigheaded carps is being conducted on large, warmwater rivers (e.g., Mississippi, Illinois, Ohio, Missouri). In contrast, little is known if bigheaded carps could successfully invade a small, cool/coldwater river, and if so, what effects they would have on these systems. Further, the small group discussed the suite of invasive species that currently occupy the Nemadji River watershed, including round goby, spiny water flea, zebra and dreissenid mussels, salmonids, and sea lamprey. The group desired information on how existing invaders may compete with or facilitate the invasion of bigheaded carps, how populations of existing invaders may change through the establishment of a new invader, and resulting impacts to ecosystem structure, function, and resilience. The small group also discussed the opportunity and ability of organisms to move within the Nemadji River watershed in response to a bigheaded carps invasion and desired information on movement rates of fishes between the Nemadji River, St. Louis Estuary, and Lake Superior.

7 Sand Hill River

7.1 Introduction to watershed

The Sand Hill River Watershed drains approximately 1259km^2 of northwestern Minnesota (Erickson et al. 2015), and spans parts of two Level III Ecoregions: the North Central Hardwoods and the Lake Agassiz Plain (Omernik et al. 1988). The upper and eastern 10% of the Sand Hill River Watershed lies within The North Central Hardwood Forests Ecoregion, in which Omernik et al. (1988) characterized land cover and land use as a mosaic of forests, wetlands, lakes, crops, pastures, and dairies. In contrast, the Lake Agassiz Plain that underlies the lower and western 90% of the Sand Hill River Watershed is a flat agricultural area, formerly covered by tallgrass prairie and dominated presently by rowcrops such as soybeans, sugar beets, and corn (Omernik et al. 1988).

The majority (71%) of the Sand Hill River waterway is altered (Anderson et al. 2014). Sand Hill Lake is the headwaters of the Sand Hill River. The Sand Hill River has one noteworthy tributary, Kittelson Creek, which begins as the outlet of Kittelson Lake, and flows nearly 20km to its confluence with the Sand Hill River. In the upper and eastern reaches that flow through glacial moraine and the beach ridge regions, the Sand Hill River generally follows its natural course, but in the lower and western reaches that flow across the Lake Agassiz Plain, the river was ditched by the US Army Corps of Engineers in the late 1950s, removing 18 miles of channel (USACE 2013). These alterations were in addition to four drop structures and two dams that were added to the mainstem to reduce flooding and improve drainage (Anderson et al. 2014). Most of the tributaries in the lower half of the watershed are ditches.

The Minnesota Pollution Control Agency sampled 19 biological monitoring sites for fish and macroinvertebrates in the Sand Hill River Watershed. Forty-five species of fish were detected throughout the watershed (Anderson et al. 2014) with most of these being smaller and/or benthic species. No imperiled species were present in the watershed but a variety of small-bodied species are abundant, and some minnow species characterized as sensitive in this ecoregion (e.g., longnose dace (Rhinichthys cataractae)) were present in the upper reaches of the watershed. Several game fish are present in this watershed including yellow perch (Perca flavescens), walleye, northern pike, and several Ictaluridae catfish. Common carp is the only aquatic invasive species known to occur in this watershed. Fish biotic integrity generally improved from headwaters to confluence, which was largely a result of connectivity of the lower half of the watershed maintaining connectivity with the Red River of the North and barriers (i.e., grade improvement structures and dams) preventing movement into the upper half of the watershed. This is supported by the macroinvertebrate data which indicated greater proportions of tolerant taxa in the lower and channelized reaches, relative to the upper, more natural reaches of the watershed (Anderson et al. 2014).

7.2 Likelihood of establishment

7.2.1 Justifications

The small group believed that there is a low likelihood of establishment of bigheaded carps in the Sand Hill River Watershed and a majority of the large group (16/21) felt similarly (Table 7-1; Table 7-2). Justification for this characterization included, first, native fishes in the lower part of this watershed are unable to recolonize above the grade improvement structures and dams, so it is reasonable to assume that it would be similarly difficult for bigheaded carps to expand upstream as well. Second, establishment implies self-sustaining populations, which are unlikely given the overall scarcity of rearing habitat for juvenile bigheaded carps.

7.2.2 Final characterizations

Table 7-1. Sand Hill River Likelihood of Establishment - Small Group Final Characterization.

		Likelihood of establishment				
		Very unlikely (.00-.05)	Low (.05-.40)	Moderate (.40-.60)	High (.60-.95)	Very likely (.95-1.00)
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)		K			
	Moderate certainty (+/- 50%)		L, H			
	Low certainty (+/- 70%)		G, I			
	Very low certainty (+/- 90%)					

Table 7-2. Sand Hill River Likelihood of Establishment - Large Group Characterization.

		Likelihood of establishment				
		Very unlikely (.00-.05)	Low (.05-.40)	Moderate (.40-.60)	High (.60-.95)	Very likely (.95-1.00)
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)		4			
	Moderate certainty (+/- 50%)	2	9			
	Low certainty (+/- 70%)	1	3	1		
	Very low certainty (+/- 90%)			1		

7.2.3 Research needs

Research needs identified include: identification of settling areas and the development of a Fluvial Egg Drift Simulator model. Second, there is little documentation of bigheaded carps using shallow, flashy, channelized or ditched habitats, so experimentation in artificial streams would benefit our ability to predict their establishment in watersheds like the Sand Hill River, where those habitat conditions are abundant.

7.3 Resulting abundance

7.3.1 Justifications

Given that bigheaded carps establish in the Sand Hill River, the small group estimated they would reach moderate to high abundances (Table 7-3). The large group estimated the likely abundance of bigheaded carps in the Sand Hill River would be very low to high, with varying levels of certainty but the majority of experts estimated that bigheaded carps abundance would be moderate (Table 7-4). The fish assemblage in the Sand Hill River is dominated by small- to medium-bodied fishes (e.g., central mudminnow (Umbra limi), creek chub (Semotilus atromaculatus)) with low abundances of medium and large fishes (e.g., white sucker (Catostomus commersonii), yellow perch) and no planktivores (MPCA 2014b) that may directly compete with bigheaded carps (e.g., bigmouth buffalo) (Irons et al. 2007; Sampson et al. 2009). Therefore, it is expected that bigheaded carps will be able to establish an ecological niche.

Sand Hill River waters are nutrient-rich (MPCA 2014b) which could provide abundant resources for bigheaded carps. Additionally, bigheaded carps are large-bodied relative to many Sand Hill

River species meaning that, at low densities, bigheaded carps could compose a high percentage of total fish biomass. The Sand Hill River is separated hydrologically by four dams that restrict lateral connectivity (MPCA 2014b) and may restrict movement and spawning of bigheaded carps to the lower Sand Hill River. However, plans to remove these dams in the near future (Sand Hill River Fish Passage Project 2016) could increase connectivity to backwater and low flow habitats; areas preferred by bigheaded carps (Kolar et al. 2007; Calkins et al. 2012) that could lead to higher abundances in the Sand Hill River. Overall, it is expected that the lower Sand Hill River would have the highest abundances of bigheaded carps due to emigration from the Red River and low velocity habitats at the Red – Sand Hill River confluence.

7.3.2 Final characterizations

Table 7-3. Sand Hill River Resulting Abundance – Small Group Final Characterization.

		Resulting abundance (% of total fish biomass)				
		Very low (Few individuals, <1%)	Low (1-5% of total fish biomass)	Moderate (5-25% of total fish biomass)	High (25-60% of total fish biomass	Very high (>60% of total fish biomass)
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)				G	
	Moderate certainty (+/- 50%)			H, K	I	
	Low certainty (+/- 70%)				L	
	Very low certainty (+/- 90%)					

Table 7-4. Sand Hill River Resulting Abundance – Large Group Characterization.

		Resulting abundance (% of total fish biomass)				
		Very low (Few individuals, <1%)	Low (1-5% of total fish biomass)	Moderate (5-25% of total fish biomass)	High (25-60% of total fish biomass	Very high (>60% of total fish biomass)
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)		1			
	Moderate certainty (+/- 50%)		3	7	2	
	Low certainty (+/- 70%)	1	1	4	1	
	Very low certainty (+/- 90%)			1		

7.3.3 Research needs

The Sand Hill River is dissimilar from most rivers in which bigheaded carp populations have been observed (e.g., Illinois River, Middle Mississippi River) contributing to uncertainty around the abundance they may achieve but hydrology, resource availability, and thermal regime have all been examined as factors that can influence the establishment and abundance of bigheaded carps (Kolar et al. 2007; Calkins et al. 2012; Kocovsky et al. 2012). Modeling efforts, coupled with hydrological surveys, could help resolve uncertainty (e.g., Kocovsky et al. 2012; Garcia et al. 2013; Garcia et al. 2015) surrounding availability of adequate habitats for all life history stages. Additionally, surveys could reveal the presence of backwater and nursery habitats. It is also unknown whether backwater habitats are a necessity for bigheaded carps or simply a preferred habitat, and whether bigheaded carp populations can reach high abundances in rivers lacking slackwater areas. Thus, information on habitat use of bigheaded carps and ecosystem characteristics that contribute to different abundances of bigheaded carps would be vital in adding certainty to predictions of post-invasion abundance in the Sand Hill River.

7.4 Adverse effects

During the characterization of potential adverse effects, the small group characterized the consequence of each adverse effect for the likely abundance of bigheaded carps that was determined in the previous step. The small group also characterized the consequence resulting from the second most likely abundance of bigheaded carps. For the Sand Hill River small group, the first abundance was “Moderate” and the second abundance was “Low”. In the tables below, the characterization for the “Moderate” abundance is noted with “G”, “H”, “I”, etc. whereas the characterization for the “Low” abundance is noted with “G_L”, “H_L”, “I_L”. The letters represent different individuals within the small group.

7.4.1 Change in plankton

7.4.1.1 Justifications

One of the most well documented consequences of invasion by bigheaded carps is a decline in abundance of larger crustacean zooplankton and an increase in the plankton proportions that are composed by rotifers (e.g., Sass et al. 2014). However, the Sand Hill River currently does not likely support a large plankton community due to light limitations from turbidity and a rapid flushing rate despite high nutrient run-off. Small-bodied plankton that are not consumed by bigheaded carps may benefit from nutrients imported by migrating bigheaded carps (e.g., Polis et al. 1997) or from predatory release as bigheaded carps consume larger, predatory zooplankton. Additionally, bigheaded carps migrate over long distances (DeGrandchamp et al. 2008; Coulter et al. 2016b), and so individuals may move into or out of the Sand Hill River from the Red River seasonally, moving nutrients and seasonally altering food web dynamics. Feces from bigheaded carps may result in more bioavalaible nutrients in the water column which may stimulate phytoplankton growth. Excretion from bigheaded carps may compensate for their feeding activities. Therefore, the small group estimated that there would be a small decrease in plankton biomass at a moderate abundance of bigheaded carps with low to high certainty (Table 7-5). At low densities of bigheaded carps, the small group estimated that there would be either no change in plankton biomass or a slight increase (Table 7-5). However, there was uncertainty regarding the current abundances and assemblage of plankton in the Sand Hill River. If there are few crustacean zooplankton currently present, bigheaded carps may have less of an impact on plankton biomass.

7.4.1.2 Final characterizations

Table 7-5. Sand Hill River Change in total biomass of plankton – Small group characterizations.

		Change in total biomass of plankton						
		Large increase	Moderate increase	Small increase	No change	Small decrease	Moderate decrease	Large decrease
Certainty of assessment	Very high certainty (+/- 10%)							
	High certainty (+/- 30%)				I_L, K_L	H, I	G	
	Moderate certainty (+/- 50%)				H_L	K		
	Low certainty (+/- 70%)			G_L	L_L	L		
	Very low certainty (+/- 90%)							

7.4.2 Consequences for non-game fish

7.4.2.1 Justifications

In addition to altering plankton composition, bigheaded carps may also affect native fish species in the Sand Hill River. Many of the species that compose the fish assemblage in the Sand Hill River Watershed rely on benthic resources; therefore golden redhorse (Moxostoma erythrurum) was selected as a representative species to evaluate the potential impacts of bigheaded carps. The small and large groups estimated negligible to low impacts of a moderate abundance of bigheaded carps on golden redhorse with large differences in certainty (Table 7-6; Table 7-7). The impacts of bigheaded carps on the planktonic community and native planktivores are well established (Radke and Kahl 2002; Sass et al. 2014), but there have only been limited studies on their potential effects on the benthic fish community (e.g., Yallaly et al. 2015). Impacts on the benthic community would be indirect and, therefore, difficult to distinguish from other sources of change. Overall, group members agreed that there would be little direct competition for food resources but that bigheaded carps could physically displace golden redhorse from some habitats. Bigheaded carps present in a low abundance would likely have a negligible to low impact on golden redhorse because it would be less likely golden redhorse would be displaced and other impacts from bigheaded carps would also be reduced. Bigheaded carps may consume eggs or larvae of benthic species during routine feeding activities, which could negatively impact golden redhorse populations. However, this has yet to be documented. Bigheaded carps may potentially stimulate the benthic food web because food items being digested by bigheaded carps have a short retention time in the digestive tract (Kolar et al. 2005). Therefore, excreted items may be only partially digested and could be a food resource for benthic fishes (Yallaly et al. 2015).

7.4.2.2 Final characterizations

Table 7-6. Sand Hill River Consequence for non-game fish (Golden Redhorse) – Small group characterizations.

		Consequence				
		Negligible	Low	Moderate	High	Extreme
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)	K_L, L_L, G_L	I_L			
	Moderate certainty (+/- 50%)	G H_L	K			
	Low certainty (+/- 70%)	L	H	I		
	Very low certainty (+/- 90%)					

Table 7-7. Sand Hill River Consequence for non-game fish (Golden Redhorse) – Large group characterization for moderate abundance of bigheaded carps.

		Consequence				
		Negligible	Low	Moderate	High	Extreme
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)	1				
	Moderate certainty (+/- 50%)	7	3			
	Low certainty (+/- 70%)	2	4	1		
	Very low certainty (+/- 90%)		1			

7.4.3 Consequences for game fish

7.4.3.1 Justifications

Bigheaded carps may affect game fish populations in the Sand Hill River through several mechanisms. Piscivorous game fish may consume young-of-year or juvenile bigheaded carps but bigheaded carps may also compete with larval and juvenile game fish for planktonic resources which could decrease condition and impact recruitment. Schools of young bigheaded carps may displace young game fish from refuge or nursery habitats resulting in increased predation on native species as they are forced into open habitats. Bigheaded carps may also indirectly produce changes in the food web that would decline forage fish abundance, negatively impacting piscivorous game fish. The Sand Hill River contains several game fish species (MPCA 2014b) and impacts of bigheaded carps on two species were evaluated: northern pike (Esox lucius) and walleye (Sander vitreus). Northern pike spawn earlier than bigheaded carps (northern pike: 8 - 12ºC, Casselman and Lewis 1996; bigheaded carp: 17 - 28ºC, Coulter et al. 2016a) and shift from planktivory to piscivory rapidly (beginning around 4 cm in total length, Frost 1954). As a result, young northern pike may be piscivorous when bigheaded carps spawn which would allow young individuals to exploit this seasonal resource. The small and large group discussions determined that the ability of northern pike to exploit small bigheaded carps as a food resource would overcome any potential declines cause by decreased availability of native forage fish or competition between larval northern pike and bigheaded carps for plankton. Therefore, bigheaded carps were estimated to have a negligible impact on northern pike at low or moderate densities, with moderate to very high certainty (Table 7-8; Table 7-9).

Alternatively, the groups estimated that bigheaded carps are likely to have a low to moderate impact on walleye, with moderate to low certainty. Walleye can reproduce later in the year than northern pike (5 - 16 ºC, Johnson 1961) and young walleye spawned later would likely still be planktivorous when bigheaded carps reproduce and so would be unable to feed on young bigheaded carps. Adult walleye could consume young bigheaded carps but only for a short window of time which the groups expect would lead to an overall negative impact on walleye (Table 7-10; Table 7-11). Uncertainty was high but could be improved with behavioral studies to determine if northern pike and walleye consume young bigheaded carps and if young bigheaded carps can displace native fishes from refuge habitats. Many of the positive or negative impacts that bigheaded carps could have on native game fish are dependent on bigheaded carps reproducing within the Sand Hill River. If bigheaded carp reproduction does not occur in the Sand Hill River, then both northern pike and walleye may show little effect as young bigheaded carps would not be available for consumption.

7.4.3.2 Final characterizations

Table 7-8. Sand Hill River Consequence for game fish (Northern Pike) – Small group characterizations.

		Consequence				
		Negligible	Low	Moderate	High	Extreme
Certainty of assessment	Very high certainty (+/- 10%)	G G_L, I_L				
	High certainty (+/- 30%)	K, L, I H_L, K_L, L_L				
	Moderate certainty (+/- 50%)	H				
	Low certainty (+/- 70%)					
	Very low certainty (+/- 90%)					

Table 7-9. Sand Hill River Consequence for game fish (Northern Pike) – Large group characterization for moderate abundance of bigheaded carps.

		Consequence				
		Negligible	Low	Moderate	High	Extreme
Certainty of assessment	Very high certainty (+/- 10%)	2				
	High certainty (+/- 30%)	8				
	Moderate certainty (+/- 50%)	5				
	Low certainty (+/- 70%)	1	2			
	Very low certainty (+/- 90%)			1		

Table 7-10. Sand Hill River Consequence for game fish (Walleye) – Small group characterization, for moderate abundance only.

		Consequence				
		Negligible	Low	Moderate	High	Extreme
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)					
	Moderate certainty (+/- 50%)		G, K, L,			
	Low certainty (+/- 70%)		I	H		
	Very low certainty (+/- 90%)					

Table 7-11. Sand Hill River Consequence for game fish (Walleye) – Large group characterization for moderate abundance of bigheaded carps.

		Consequence				
		Negligible	Low	Moderate	High	Extreme
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)	1				
	Moderate certainty (+/- 50%)		7			
	Low certainty (+/- 70%)		7			
	Very low certainty (+/- 90%)		1	3		

7.4.4 Consequences for species diversity/ecosystem resilience

7.4.4.1 Justifications

Species diversity and resilience are important components of healthy ecosystems by maintaining ecosystem function when exposed to environmental changes. Ecosystem resilience may come from a redundancy (fish that may serve similar functions or fill similar ecological niches) in the roles of species in the ecosystems and it appears that there are redundant species in the Sand Hill River fish assemblage (MPCA 2014b). Therefore, even if a species is lost or declines due to invasion by bigheaded carps there are other species present which can maintain ecosystem function. Planktivores (e.g., bigmouth buffalo) that may directly compete with bigheaded carps are species most likely to be affected from an invasion by bigheaded carps (Irons et al. 2007; Sampson et al. 2009) but these species are not present in the Sand Hill River fish assemblage. Therefore, the small and large group discussions predict that the consequences of invasion by bigheaded carps on species diversity and ecosystem resilience would be low to moderate when bigheaded carps are present at a moderate abundance (Table 7-12; Table 7-13). It was also estimated that the effects of bigheaded carps on diversity and resilience would be low to negligible at low bigheaded carps density. Certainty around these estimates ranged from very low to moderate due to the difficulty involved in relating declines in diversity or resilience directly to bigheaded carps. There is also variability among sites and years in the survey data of fish assemblages (MPCA 2014b) which may make declines in diversity or resilience difficult to detect. Additional uncertainty was from the unknown effects that bigheaded carps may have on the benthic community, which constitutes a large portion of the Sand Hill River fish assemblage.

7.4.4.2 Final characterizations

Table 7-12. Sand Hill River Consequence for species diversity/ecosystem resilience – Small group characterizations.

		Consequence				
		Negligible	Low	Moderate	High	Extreme
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)					
	Moderate certainty (+/- 50%)					
	Low certainty (+/- 70%)		K G_L, I_L	G, I		
	Very low certainty (+/- 90%)	K_L	H_L, L_L	H, L		

Table 7-13. Sand Hill River Consequence for species diversity/ecosystem resilience – Large group characterization for moderate abundance of bigheaded carps.

		Consequence				
		Negligible	Low	Moderate	High	Extreme
Certainty of assessment	Very high certainty (+/- 10%)					
	High certainty (+/- 30%)					
	Moderate certainty (+/- 50%)	1	4	2		
	Low certainty (+/- 70%)		2	5		
	Very low certainty (+/- 90%)		1	3		

7.4.5 Consequences for recreational boating and fishing from jumping silver carp hazard

7.4.5.1 Justifications

Most experts in the small and large group discussions felt that bigheaded carps in moderate abundance would have a low or moderate impact on recreational boating and fishing in the Sand Hill River, with most ranking their certainty as moderate or high. At low densities of bigheaded carps, recreators would be less likely to encounter them and so their effects on boating and angling would be negligible to low. Overall, many experts felt that recreational boating would show no change (Table 7-14; Table 7-15). There is very limited boating and fishing activity currently occurring on the Sand Hill River. Most of the angling pressure in the Sand Hill River comes from locals who would likely continue to fish due to the river's proximity, regardless of the abundance of bigheaded carps. However, boating and fishing activities may be negatively impacted if bigheaded carps were to invade lakes within the Sand Hill River watershed. Specifically, jumping silver carp may deter some recreators but it is unknown what abundances of bigheaded carps are needed to cause declines in recreational use. Additional information on abundances of bigheaded carps and declines in recreational activities from other river systems would help to refine estimated impacts.

7.4.5.2 Final characterizations

Table 7-14. Sand Hill River Consequence for recreational boating and fishing from jumping silver carp hazard – Small group characterizations.

		Consequence				
		Negligible	Low	Moderate	High	Extreme
Certainty of assessment	Very high certainty (+/- 10%)		H_L, L_L	G		
	High certainty (+/- 30%)	G_L, I_L	H, K, K_L	L		
	Moderate certainty (+/- 50%)			I		
	Low certainty (+/- 70%)					
	Very low certainty (+/- 90%)					

Table 7-15. Sand Hill River Consequence for recreational boating and fishing from jumping silver carp hazard – Large group characterization for moderate abundance of bigheaded carps.

		Consequence				
		Negligible	Low	Moderate	High	Extreme
Certainty of assessment	Very high certainty (+/- 10%)		1			
	High certainty (+/- 30%)	2	4			
	Moderate certainty (+/- 50%)	3	2	1		
	Low certainty (+/- 70%)		5	1		
	Very low certainty (+/- 90%)					

7.4.6 Adverse effects: Research needs

Most studies on the impacts of bigheaded carps have focused on changes in native planktivores that may directly compete with the carp, and changes in zooplankton composition and abundance that may result from feeding by bigheaded carps. Because of the focus on zooplankton and competition, experts were fairly confident in assessing what changes are likely to occur in Sand Hill River plankton abundance. However, surveys of existing plankton abundance and composition in the Sand Hill River would help to further improve estimated impacts of bigheaded carps. Additionally, surveys would help to document changes in plankton that may occur following invasion by bigheaded carps. Because there is relatively little information available on the impacts of bigheaded carps on species they are not in direct competition with, further research is needed to determine how bigheaded carps may impact other native species, including the benthic community. Uncertainty around the estimated impacts of bigheaded carps on benthic oriented species, like golden redhorse, could be improved through evidence from river systems that have already been invaded including information related to changes in abundance or condition, potential physical displacement of native species, and impacts on recruitment through competition for planktonic resources. Additionally, information on the caloric and nutrient content of bigheaded carp feces will aid our understanding of how bigheaded carps may affect benthic communities.

There is also relatively little information on which predatory species consume bigheaded carps, contributing to uncertainty in how invasion by bigheaded carps will impact piscivorous species. Many predatory game fish like Northern Pike and Walleye may benefit from exploiting the high abundances of bigheaded carps that can occur following a successful spawning event. Feeding studies can help resolve uncertainty and determine what piscivorous species consume bigheaded carps and when. Piscivores are gape limited and bigheaded carps may rapidly outgrow the gape of many native predators. Therefore, modeling efforts to determine if bigheaded carps can spawn in the Sand Hill River would help determine if there will be young-of-year present for piscivorous fishes to consume, which could positively impact native piscivores. Bigheaded carps may negatively impact native prey that native piscivores typically exploit through competition for planktonic resources. Further research is needed to determine if bigheaded carps compete with native forage fish enough to cause a decline in abundance that could impact native game fishes.

The impacts of bigheaded carps on ecosystem function and resilience have not been examined in depth. Because bigheaded carps compete for resources, they could cause the loss or decline of some species. While reduced condition has been documented in some native species directly competing with bigheaded carps (e.g., Irons et al. 2007), the impacts of bigheaded carps on many other species had not been assessed. Bigheaded carps may also impact ecosystem functions including nutrient processing and cycling but these mechanisms remain unevaluated. Additional research is needed on the whole ecosystem impacts of bigheaded carps rather than focused studies on impacts on specific native species.

Further research is also needed to better evaluate the possible impacts of bigheaded carps of fishing and boating activities in the Sand Hill River. The small group believed that some information on the impacts of bigheaded carps on recreation likely already exist and a study released following group discussions shows that bigheaded carps negatively impact river use (Spacapan et al. 2016). Additionally, it may be informative to determine the densities of bigheaded carps that can cause a decline in boating or fishing activities. There may be a threshold abundance of bigheaded carps where lower abundances have no impact on recreation but high abundances decrease recreational use.

7.5 Overarching uncertainties, research needs & areas of disagreements

Much of the uncertainty surrounding this assessment of the impacts of bigheaded carps in the Sand Hill River results from ecological differences between this river and rivers in which bigheaded carps have been studied. Some portions of the Sand Hill River watershed are connected by shallow, small, or channelized habitats that are unlike areas where the movements and habitat use of bigheaded carps have been studied. Therefore, it is unclear whether bigheaded carps may use these habitats and whether or not they will readily move through them to reach other areas in the watershed. Further, in the James River basin in eastern South Dakota, a prairie stream that drains a predominantly agricultural landscape similar to the Sand Hill River basin, juvenile bigheaded carps were most abundant in low velocity, protected embayment formed by natural confluences with tributaries (Hayer 2014). In the Sand Hill River basin, few of these natural tributaries and confluences exist, so reproduction and recruitment in the Sand Hill River basin would, to our knowledge, be the first documented successful reproduction and recruitment in this type of habitat. Additionally, many fishes in the Sand Hill River are benthic and research on how bigheaded carps affect the benthic community (fish, invertebrates, microbes) would be invaluable. Minnesota Pollution Control Agency and Minnesota Department of Natural Resources currently conduct environmental surveys at multiple Sand Hill River locations and continued monitoring will be vital for detecting changes in the ecosystem if bigheaded carps do invade. Additionally, stakeholder surveys may help determine the current extent of boating and angling activities in the Sand Hill River to better assess recreational changes in the future.

8 Overall Risk Characterization

8.1 Overall establishment probabilities, resulting abundances, and potential adverse effect consequence levels

The overall characterizations of risk for each adverse effect in each watershed were arrived at by combining the overall predicted probability of establishment (Table 8-1) and the potential adverse effect characterizations (Table 8-3). The process used to arrive at these characterizations is described in the methodology (Section 2.3). The overall predicted probabilities of establishment are listed in Table 8-1. The Minnesota River – Mankato watershed had the highest overall predicted probability of establishment, at 70%, followed by the Lower St. Croix River at 45%, Nemadji River at 38%, and the Sand Hill River at 22%.

Table 8-1 Overall probability of establishment for each watershed.

Watershed	Overall Probability of Establishment
Minnesota River - Mankato	.70
Lower St. Croix River	.45
Nemadji River	.38
Sand Hill River	.22

The potential adverse effects were characterized for the most likely resulting abundance of bigheaded carps in each watershed, given establishment of bigheaded carps (Table 8-2). The potential adverse effects were also characterized for the second most likely resulting abundance level, but only in the small group. The directional shift in the small group adverse effect characterizations from the first to second most likely abundance level provides an indication of how the overall risk characterizations would change if the second most likely abundance level is realized (see Section 8-3).

The potential adverse effect consequence levels were characterized for each watershed for the most likely resulting abundance level (moderate) of bigheaded carps. These characterizations show the proportion of workshop participants who believed that a moderate abundance of bigheaded carps would result in each consequence level for each potential adverse effect (Table 8-3).

Table 8-2. Most likely and second most likely resulting abundance levels of bigheaded carps for each watershed.Included in parentheses are the percentages of participants who characterized the resulting abundance at each level.

Watershed	Most likely resulting abundance level	Second most likely resulting abundance level
Minnesota River - Mankato	Moderate (60%)	High (40%)
Lower St. Croix River	Moderate (62%)	Low (24%)
Nemadji River	Moderate (50%)	Low (40%)
Sand Hill River	Moderate (57%)	Low (24%)

Table 8-3. Summary of the consequence levels for the potential adverse effects. Percentages represent the proportion of workshop participants who characterized each potential adverse effect at a particular consequence level. For example, 52% of workshop participants thought that there would be a negligible impact on the Spotfin Shiner in the Minnesota River – Mankato watershed, if bigheaded carps establish in the watershed with a moderate abundance.

Potential Adverse Effect & Watershed	**Consequence level**				
	Negligible	**Low**	**Moderate**	**High**	**Extreme**
Non-Game Fish					
Minnesota: Spotfin Shiner	.52	.48			
Minnesota: Bigmouth Buffalo		.48	.52		
St. Croix: Gizzard Shad		.47	.53		
Nemadji: Common Shiner	.47	.37	.16		
Sand Hill: Golden Redhorse	.53	.42	.05		
Game Fish					
Minnesota: Channel Catfish	.79	.21			
St. Croix: Sauger	.06	.72	.22		
Nemadji: Black Crappie	.26	.63	.11		
Sand Hill: Norther Pike	.84	.11	.05		
Sand Hill: Walleye	.05	.79	.16		
Species diversity/ Ecosystem resilience					
Minnesota	.05	.05	.79	.11	
St. Croix		.11	.89		
Nemadji	.05	.32	.58	.05	
Sand Hill	.06	.39	.55		
Recreation Jumping Hazard					
Minnesota			.65	.35	
St. Croix		.05	.42	.48	.05
Nemadji		.37	.58	.05	
Sand Hill	.26	.63	.11		

8.2 Overall risk characterizations

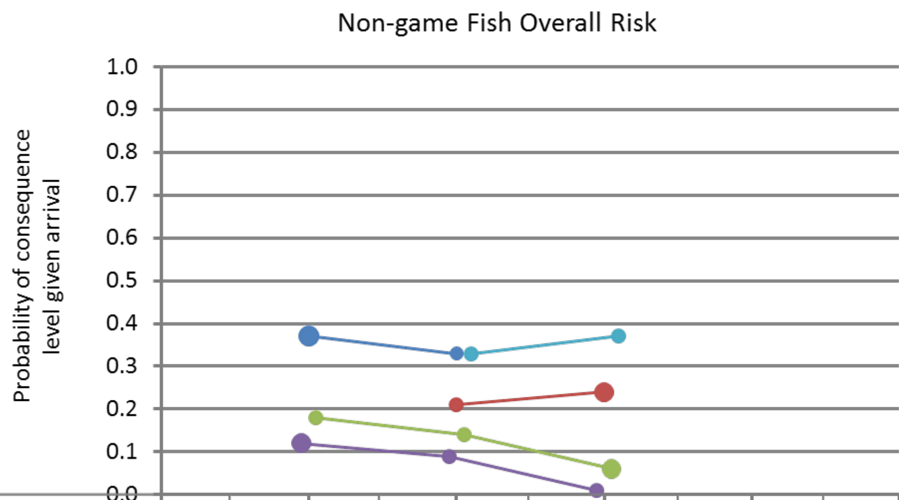
The overall risk characterizations, calculated as the probability of a specific consequence level given arrival of bigheaded carps to the watershed, are provided in Figures 8.1 – 8.4. As described in detail within the methodology (Section 2.3), the overall risk is a function of which consequence levels are expected given the likely resulting abundance of bigheaded carps and how likely those consequence levels are. How likely they are is dependent upon the overall establishment probability. As a result, watersheds with lower overall probabilities of establishment are more likely to have a lower overall risk. So the Sand Hill River watershed, for example, frequently has the lowest overall risk because of the fact that the overall likelihood of establishment was only 22%. The probabilities of all the consequence levels for a particular adverse effect and watershed sum to the overall probability of establishment for that watershed.

For the non-game fish (Figure 8-1), the overall risk varied between the consequence levels of negligible and moderate across all watersheds. The fish species and watershed combinations most likely to result in a moderate consequence level were the bigmouth buffalo in the Minnesota River (37%) and the gizzard shad in the St. Croix River (24%); both these fish species are planktivores. The other three fish species characterized for the non-game fish were not planktivores and were most likely to have a consequence level of negligible, followed by low. The certainty levels with these overall risk characterizations were either low or moderate.

The game fish overall risk (Figure 8-2) varied between the consequence levels of negligible and moderate for all watersheds. Unlike the non-game fish overall risk that had two watershed and fish species combinations most likely to result in a moderate consequence, all the watershed and fish species combinations for the game fish had the negligible or low consequence level as the most likely to occur. The most likely consequence level for the St. Croix River and sauger combination was low (33%) followed by moderate (10%) and negligible (2%). The most likely consequence level for the Nemadji River and black crappie combination was low (24%), followed by negligible (10%) and moderate (4%). The most likely consequence level for the Sand Hill River and walleye combination was also low (17%), followed by moderate (4%) and negligible (1%). For the Minnesota River and channel catfish, the most likely consequence level was negligible (55%), followed by low (15%), and for the Sand Hill River and northern pike, the most likely consequence level was negligible (19%), followed by low (2%) and moderate (1%). The certainty levels varied widely from high to very low. There were higher certainties for the lower consequence levels, with high certainty for three of the five negligible consequence levels and very low certainty for three of the four moderate consequence levels.

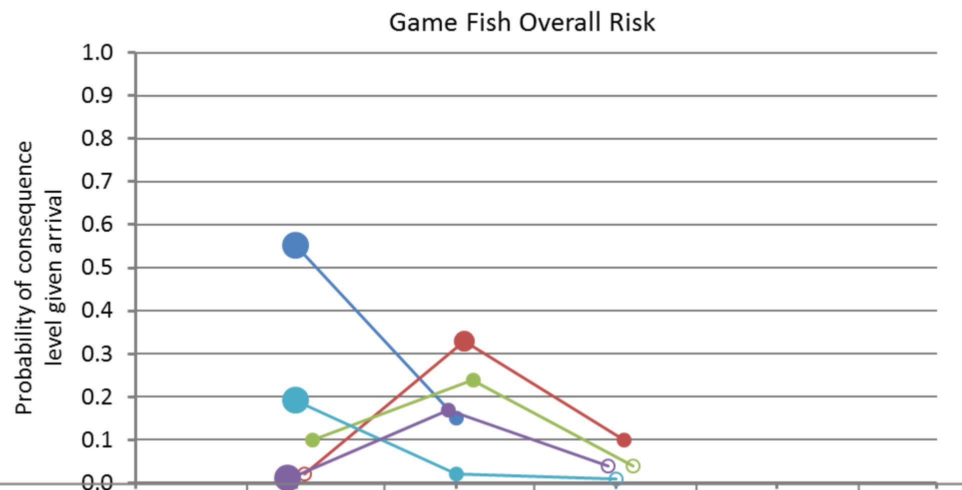
The species diversity/ecosystem resilience overall risk predictions (Figure 8-3) varied from negligible to high, and the moderate consequence level was the most likely for each of the watersheds. The Minnesota River watershed was the most likely watershed to result in the consequence levels of moderate (55%) and high (7%). The St. Croix River watershed was next most likely to result in a moderate consequence level (40%), followed by the Nemadji (22%) and the Sand Hill River (12%). For all watersheds except the Minnesota River, low was the second most likely consequence level after moderate. For the Minnesota River, high was the next most likely (7%). The only other watershed to have a high consequence level characterized was the Nemadji River at a 2% likelihood. The certainty levels for this overall risk varied from very low to moderate.

The jumping hazard overall risk (Figure 8-4) varied from negligible to extreme across all four watersheds. The Minnesota River watershed was the most likely of the 4 watersheds to result in a consequence level of high (24%), even though moderate was the Minnesota River's most likely consequence level (46%). The most likely consequence level for the St. Croix River was high (21%), followed closely by moderate (19%), with the smallest likelihoods being extreme (2%) and low (2%). The most likely consequence level for the Nemadji was moderate (22%), followed by low (14%) and high (2%), while the most likely consequence level for the Sand Hill River watershed was low (14%) followed by negligible (6%) and moderate (2%). The certainty levels for this jumping hazard overall risk ranged from low to high.



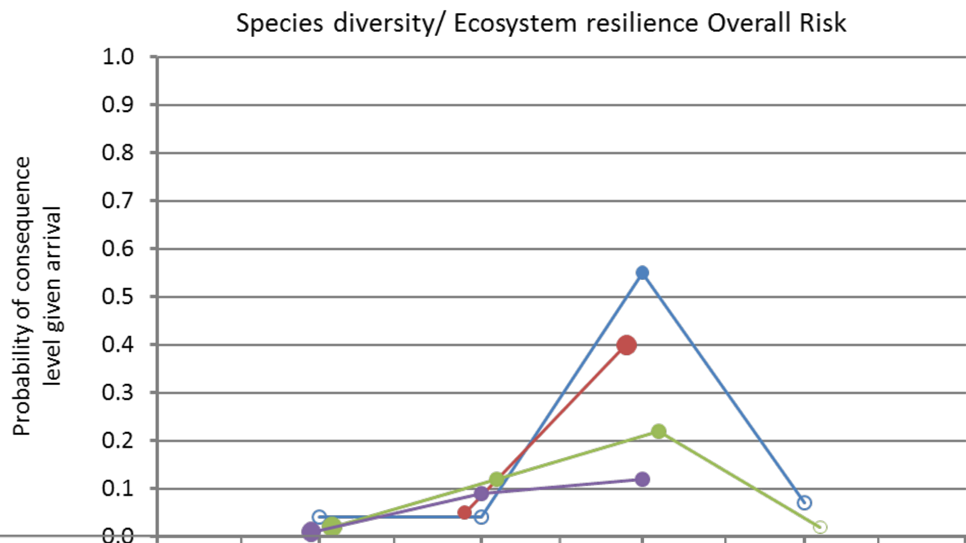
Consequence level :	Negligible	Low	Moderate	High	Extreme
MN: Bigmouth Buffalo		.33 (L)	.37 (L)		
MN: Spotfin Shiner	.37 (M)	.33 (L)			
St. Croix: Gizzard Shad		.21 (L)	.24 (M)		
Nemadji: Common Shiner	.18 (L)	.14 (L)	.06 (M)		
Sand Hill: Golden Redhorse	.12 (M)	.09 (L)	.01 (L)		

Figure 8-1. Non-game Fish Overall Risk. The x-axis lists the 5 possible consequence levels that workshop participants characterized, from least severe (Negligible) to most severe (Extreme). The y-axis displays the probability of each consequence level, given arrival of bigheaded carps. The probability that the bigheaded carps would not establish is not included here, but makes up the remainder of the probability of consequence. For example, for the St. Croix River watershed, the probability that bigheaded carps would NOT establish given arrival was estimated as .55 = 1 –.21 –.24. The certainty of the characterizations for each consequence level are represented in the table (VL=Very Low; L= Low; M=Moderate; H=High; VH = Very High) and by marker size (same 5 point scale with larger circles equaling greater certainty, and the hollow circle indicating Very Low).



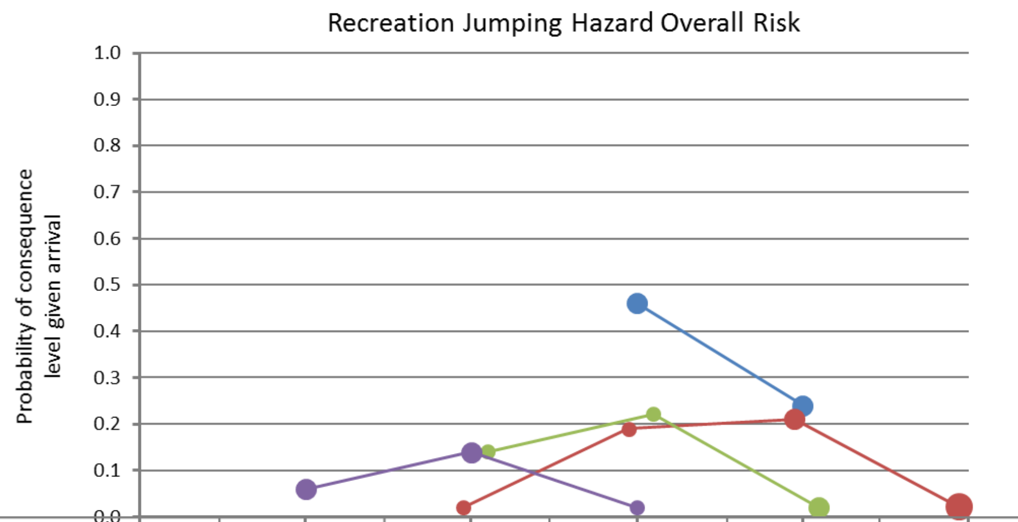
Consequence level :	Negligible	Low	Moderate	High	Extreme
Minnesota: Channel Catfish	.55 (H)	.15 (L)			
St. Croix: Sauger	.02 (VL)	.33 (M)	.10 (L)		
Nemadji: Black Crappie	.10 (L)	.24 (L)	.04 (VL)		
Sand Hill: Northern Pike	.19 (H)	.02 (L)	.01 (VL)		
Sand Hill: Walleye	.01 (H)	.17(L)	.04 (VL)		

Figure 8-2. Game Fish Overall Risk. The x-axis lists the 5 possible consequence levels that workshop participants characterized, from least severe (Negligible) to most severe (Extreme). The y-axis displays the probability of each consequence level, given arrival of bigheaded carps. The probability that the bigheaded carps would not establish is not included here, but makes up the remainder of the probability of consequence. For example, for the Minnesota River - Mankato watershed, the probability that bigheaded carps would NOT establish given arrival was estimated as .30 = 1 –.55 –.15. The certainty of the characterizations for each consequence level are represented in the table (VL=Very Low; L= Low; M=Moderate; H=High; VH = Very High) and by marker size (same 5 point scale with larger circles equaling greater certainty, and the hollow circle indicating Very Low).



Consequence level :	Negligible	Low	Moderate	High	Extreme
Minnesota	.04 (VL)	.04 (VL)	.55 (L)	.07 (VL)	
St. Croix		.05 (L)	.40 (M)		
Nemadji	.02 (M)	.12 (L)	.22 (L)	.02 (VL)	
Sand Hill	.01 (M)	.09 (L)	.12 (L)		

Figure 8-3. Species diversity/Ecosystem resilience Overall Risk. The x-axis lists the 5 possible consequence levels that workshop participants characterized, from least severe (Negligible) to most severe (Extreme). The y-axis displays the probability of each consequence level, given arrival of bigheaded carps. The probability that the bigheaded carps would not establish is not included here, but makes up the remainder of the probability of consequence. For example, for the St. Croix River watershed, the probability that bigheaded carps would NOT establish given arrival was estimated as .55 = 1 –.05 –.40. The certainty of the characterizations for each consequence level are represented in the table (VL=Very Low; L= Low; M=Moderate; H=High; VH = Very High) and by marker size (same 5 point scale with larger circles equaling greater certainty, and the hollow circle indicating Very Low).



Consequence level :	Negligible	Low	Moderate	High	Extreme
Minnesota			.46 (M)	.24 (M)	
St. Croix		.02 (L)	.19 (L)	.21 (M)	.02 (H)
Nemadji		.14 (L)	.22 (L)	.02 (M)	
Sand Hill	.06 (M)	.14 (M)	.02 (L)		

Figure 8-4. Recreation Jumping Hazard Overall Risk. The x-axis lists the 5 possible consequence levels that workshop participants characterized, from least severe (Negligible) to most severe (Extreme). The y-axis displays the probability of each consequence level, given arrival of bigheaded carps. The probability that the bigheaded carps would not establish is not included here, but makes up the remainder of the probability of consequence. For example, for the Minnesota River - Mankato watershed, the probability that bigheaded carps would NOT establish given arrival was estimated as .30 = 1 –.46 –.24. The certainty of the characterizations for each consequence level are represented in the table (VL=Very Low; L= Low; M=Moderate; H=High; VH = Very High) and by marker size (same 5 point scale with larger circles equaling greater certainty, and the hollow circle indicating Very Low).

8.3 Change in overall risk from second most likely resulting abundance

Small group adverse effect consequence characterizations for the second most likely resulting abundance of bigheaded carps provide an approximation of the direction and magnitude of change in the overall risk if such a resulting abundances were to be realized. The second most likely resulting abundance was high for the Minnesota River watershed and low for all other watersheds. Presented here are the direction and degree of change in consequence, and accompanying certainty, characterization for each small group member for each small group.

For the Minnesota River (Table 8-4), the high resulting abundance characterizations led to the following changes in relation to the moderate abundance: 1) an increase in certainty, 2) an increase in consequence level, 3) both an increase in certainty and consequence level, or 4) no change. The increase in consequence level was seen for the following potential adverse effects: non-game fish (bigmouth buffalo only), species diversity/ecosystem resilience, and recreation jumping hazard. The most significant shift came for the recreation jumping hazard, where most members (5/6) anticipated an increase in consequence level of one, and one member anticipated an increase of two. Such a shift would result in the overall risk for the recreation jumping hazard to range from high to extreme, instead of from moderate to high.

For the St. Croix River Watershed, the changes from the low resulting abundance varied, but were generally a decrease in consequence by one or sometimes two levels (Table 8-5). The change in certainty varied but was generally an increase in certainty. For the Nemadji River Watershed, the changes from the low resulting abundance ranged from no change to a decrease of one consequence level for non-game and game fish (Table 8-6). For the species diversity/ecosystem resilience and recreation jumping hazard potential adverse effects in the Nemadji River Watershed, small group members agreed that the low abundance would lead to a decrease in consequence by one level. There were generally no changes in certainty. The changes in consequence level for low resulting abundance in the Sand Hill River Watershed ranged from no change to a decrease in consequence by two levels (Table 8-7).

These changes in consequence level for the second most likely abundance provide a type of uncertainty analysis for the overall risk characterization. Specifically, they highlight how the uncertainty surrounding the resulting abundance of bigheaded carps may influence the overall risk characterizations. The most noteworthy finding from these changes is that for the Minnesota River there is either no change or an increase in the consequence level, and for the other watersheds there is either no change or a decrease in the consequence level. This means that for the second most likely abundance, the overall risk would increase or stay the same for the Minnesota River Watershed and would decrease or stay the same for the remaining watersheds.

Table 8-4. Changes in the MN River-Mankato Watershed consequence characterization for High resulting abundance. The table presents how small group members changed their consequence characterization for each potential adverse effect when considering the second most likely abundance level (High) compared to the most likely abundance level (Moderate). The number indicates the number of small group members. The middle square (shaded) indicates that the characterization of both consequence level and certainty was the same for both abundances.

MN River: Non-game fish; Spotfin Shiner

		Increase or decrease in severity of consequence				
		-2	-1	No change	+1	+2
Increase or decrease in certainty	+2					
	+1			(1)		
	No change			(4)		
	-1					
	-2					

MN River: Non-game fish; Bigmouth Buffalo

		Increase or decrease in severity of consequence				
		-2	-1	No change	+1	+2
Increase or decrease in certainty	+2					
	+1			(2)	(1)	
	No change				(2)	
	-1					
	-2					

MN River: Game fish; Channel Catfish

		Increase or decrease in severity of consequence				
		-2	-1	No change	+1	+2
Increase or decrease in certainty	+2					
	+1					
	No change			(5)		
	-1					
	-2					

MN River: Species diversity/Ecosystem resilience

		Increase or decrease in severity of consequence				
		-2	-1	No change	+1	+2
Increase or decrease in certainty	+2					
	+1			(2)	(1)	
	No change			(2)	(1)	
	-1					
	-2					

MN River: Recreation jumping hazard

		Increase or decrease in severity of consequence				
		-2	-1	No change	+1	+2
Increase or decrease in certainty	+2				(1)	
	+1					
	No change				(4)	(1)
	-1					
	-2					

Table 8-5. Changes in the St. Croix River Watershed consequence characterization for Low resulting abundance. The table presents how small group members changed their consequence characterization for each potential adverse effect when considering the second most likely abundance level (Low) compared to the most likely abundance level (Moderate). The number indicates the number of small group members. The middle square (shaded) indicates that the characterization of both consequence level and certainty was the same for both abundances.

St. Croix: Non-game fish; Gizzard Shad						
		Increase or decrease in severity of consequence				
		-2	-1	No change	+1	+2
Increase or decrease in certainty	+2		(2)			
	+1		(1)			
	No change	(1)				
	-1					
	-2					

St. Croix River: Game fish; Sauger						
		Increase or decrease in severity of consequence				
		-2	-1	No change	+1	+2
Increase or decrease in certainty	+2		(1)			
	+1		(1)			
	No change		(2)			
	-1					
	-2					

St. Croix River: Species diversity/Ecosystem resilience						
		Increase or decrease in severity of consequence				
		-2	-1	No change	+1	+2
Increase or decrease in certainty	+2					
	+1		(1)			
	No change	(1)	(1)			
	-1					
	-2			(1)		

St. Croix River: Recreation jumping hazard						
		Increase or decrease in severity of consequence				
		-2	-1	No change	+1	+2
Increase or decrease in certainty	+2			(1)		
	+1	(1)				
	No change		(2)			
	-1					
	-2					

Table 8-6. Changes in the Nemadji River Watershed consequence characterization for Low resulting abundance. The table presents how small group members changed their consequence characterization for each potential adverse effect when considering the second most likely abundance level (Low) compared to the most likely abundance level (Moderate). The number indicates the number of small group members. The middle square (shaded) indicates that the characterization of both consequence level and certainty was the same for both abundances.

Nemadji: Non-game fish; Common Shiner						
		Increase or decrease in severity of consequence				
		-2	-1	No change	+1	+2
Increase or decrease in certainty	+2					
	+1					
	No change		(3)	(2)		
	-1					
	-2					

Nemadji River: Game fish; Black Crappie						
		Increase or decrease in severity of consequence				
		-2	-1	No change	+1	+2
Increase or decrease in certainty	+2					
	+1		(1)			
	No change		(2)	(2)		
	-1					
	-2					

Nemadji River: Species diversity/Ecosystem resilience						
		Increase or decrease in severity of consequence				
		-2	-1	No change	+1	+2
Increase or decrease in certainty	+2					
	+1					
	No change		(5)			
	-1					
	-2					

Nemadji River: Recreation jumping hazard						
		Increase or decrease in severity of consequence				
		-2	-1	No change	+1	+2
Increase or decrease in certainty	+2					
	+1					
	No change		(5)			
	-1					
	-2					

Table 8-7. Changes in the Sand Hill River Watershed consequence characterization for Low resulting abundance. The table presents how small group members changed their consequence characterization for each potential adverse effect when considering the second most likely abundance level (Low) compared to the most likely abundance level (Moderate). The number indicates the number of small group members. The middle square (shaded) indicates that the characterization of both consequence level and certainty was the same for both abundances.

Sand Hill River: Non-game fish; Golden Redhorse						
		Increase or decrease in severity of consequence				
		-2	-1	No change	+1	+2
Increase or decrease in certainty	+2		(1)	(1)		
	+1		(2)	(1)		
	No change					
	-1					
	-2					

Sand Hill River: Game fish; Northern Pike						
		Increase or decrease in severity of consequence				
		-2	-1	No change	+1	+2
Increase or decrease in certainty	+2					
	+1			(2)		
	No change			(3)		
	-1					
	-2					

Sand Hill River: Species diversity/Ecosystem resilience						
		Increase or decrease in severity of consequence				
		-2	-1	No change	+1	+2
Increase or decrease in certainty	+2					
	+1					
	No change		(4)			
	-1		(1)			
	-2					

Sand Hill River: Recreation jumping hazard						
		Increase or decrease in severity of consequence				
		-2	-1	No change	+1	+2
Increase or decrease in certainty	+2					
	+1	(1)	(1)	(1)		
	No change			(1)		
	-1	(1)				
	-2					

9 Discussion

These risk assessment findings support the need for a reasoned and timely response to the threats posed by bigheaded carps. The findings show that the Minnesota River – Mankato and similar watersheds are at a higher risk, followed by the Lower St. Croix River and similar watersheds. Unfortunately, these two watersheds are found in the southern and eastern parts of the state, which are closest to the current invasion front. These findings support the need to prioritize management that can slow or prevent the spread into these areas, or that can lessen the consequence levels of any resulting adverse effects.

This section further discusses the key insights that emerged from this risk assessment, including: 1) the severity of risk varies across watersheds; 2) the severity of risk varies across potential adverse effects; 3) given the varying severity of risk, management decisions should consider the potential effects of bigheaded carps, of management action on bigheaded carps, and of management actions on native species; 4) research needs exist that could help improve the characterization of risk from bigheaded carps; and 5) this type of risk assessment process is well suited to inform decision making and societal discussions about invasive species.

9.1 Implications for management

9.1.1 The severity of risk varies across watersheds

This risk assessment reveals a gradient in the severity of overall risk across the watersheds we examined. The differences in overall risk across watersheds were a result of differing establishment probabilities and potential adverse effect consequence levels. First, the overall predicted probability of establishment for each watershed varied from a low of 22% (Sand Hill River) to a high of 70% (Minnesota River – Mankato), with 45% (Lower St. Croix River) and 38% (Nemadji River) in the middle. As described in Section 4 to Section 7, the biotic and abiotic factors influencing these differences included: spawning habitat, suitable temperature, suitable flow regimes, nursery habitat, food resources, potential predators, and adequate turbidity to avoid predation.

The other aspect of overall risk was the potential adverse effect characterizations (Table 8-3). These represent the estimated adverse effect consequence levels from bigheaded carps for each watershed, assuming bigheaded carps were to arrive, establish, and reach a moderate abundance (judged to be the most probable abundance level for all watersheds). The characterizations showed that when a moderate, high, or extreme consequence level was present for an adverse effect, it was always most probable in either the Minnesota River –

Mankato watershed or the Lower St. Croix River watershed. The consequence levels for the Nemadji River watershed largely ended up higher than the Sand Hill River and below the Minnesota River - Mankato and Lower St .Croix River.

For the non-game and game fish adverse effects, the higher consequence levels occurred for the planktivore fish species being considered (bigmouth buffalo for Minnesota River - Mankato and gizzard shad for the St. Croix River), because these species were seen as more likely to have dietary and habitat overlap with bigheaded carps. Other non-game and game fish species were deemed more likely to not have habitat and dietary overlap with bigheaded carps and to be able to find alternative prey if their primary prey were impacted by bigheaded carps.

One of the issues participants grappled with while characterizing the recreational jumping hazard potential adverse effect was the importance of risk perception. Participants expressed uncertainty concerning the degree to which a small number of jumping carp could have a large impact on recreation for a particular waterbody. Overall, for the severity of risk for the recreation jumping hazard, the differences across watersheds were attributed to differences in boating use and the density of bigheaded carps.

The overall risk, defined as the probability of consequence level given arrival, was determined by combining the establishment likelihood and the potential adverse effect consequence level (Figures 8-1 to 8-4). Higher consequence levels with larger probabilities represented higher levels of overall risk. The relative rankings of the overall risk, then, were: Minnesota > St. Croix > Nemadji > Sand Hill. There were a couple of places where this ranking did not hold true, including the game fish overall risk, where the Minnesota River was near the lowest risk, because the chosen game fish, channel catfish, was seen as having low dietary and habitat overlap with bigheaded carps.

For the resulting abundances of bigheaded carps, all watersheds had moderate for the most likely abundance and low for the second most likely abundance, except for the Minnesota River – Mankato watershed which had high as its second most likely abundance (Table 8-2). The result of this is that whereas the consequence levels of the potential adverse effects for the Sand Hill, St. Croix, and Nemadji watersheds would stay the same or decrease for the second most likely abundance level, the consequence levels for the Minnesota River potential adverse effects would increase or stay the same (see section 8.3). This provides further justification for the Minnesota River – Mankato watershed to have the highest overall risk.

The severity of the potential adverse effects are also likely to vary within a watershed with, for example, greater severity in the shallows and backwaters of rivers where bigheaded carps are more likely to reach higher densities and take part in jumping behavior.

9.1.2 The severity of risk varies across potential adverse effect

In addition to varying across watersheds, the severity of risk also varied across potential adverse effect. The overall risk posed to non-game fish, game fish, species diversity/ecosystem resilience, and recreation from the jumping hazard all varied notably. For example, the risks to non-planktivore non-game fish and all game fish were estimated as most likely to be negligible or low, with less than 10% of participants characterizing the consequence level as moderate (Figure 8-1; Figure 8-2). The risks to planktivorous non-game fish were slightly higher – most likely to be a moderate consequence level, followed by a low consequence level. Overall, then, workshop participants predicted that there would not be a high or very high consequence level for the non-game and game fish assessed in these watersheds, and believed the risk to these non-game and game fish species were lower than the risks posed to species diversity/ecosystem resilience and recreation from the jumping hazard.

The overall risk for the species diversity/ecosystem resilience potential adverse effect was notably higher than for the non-game and game fish species in consequence level, with moderate being considered the most likely consequence level for all watersheds. Two watersheds (Minnesota and Nemadji) had a small number of participants characterize the consequence level as high. Finally, the overall risk for the recreation jumping hazard saw the largest likelihoods of a high consequence level (24%, Minnesota and 21%, St. Croix), and the only example of an extreme consequence level (2%, St. Croix).

9.1.3 Management actions based on the variation of risk

The fact that there was not a uniform level of low risk across potential adverse effects and watersheds emphasizes the need to take reasoned action in the face of the threat posed by bigheaded carps. Given that the Minnesota River – Mankato and St. Croix River watersheds were at higher risk, it is important to take actions that can help reduce: 1) the likelihood that bigheaded carps will arrive in these watersheds, 2) the likelihood they will establish in these watersheds; and 3) the severity of the resulting adverse effects if they do establish. Possible management actions include, for example, species-selective deterrents, improving ecosystem resilience, restoring top native predators such as flathead catfish, and eliminating cross-watershed connections. Such management actions may take place in the watershed at risk, or, especially when trying to reduce spread, in an adjacent watershed or further downstream on the Mississippi River.

The fact that there was not a uniform level of high risk across potential adverse effects and watersheds is also important for management decision making. To ensure management actions do more good than harm, management decision making should consider: 1) the risks posed by bigheaded carps, 2) the effects of the management actions on bigheaded carps, and 3) the collateral damage effects of the management actions on native species (Kokotovich and Andow 2017; Buckley & Han 2014). Given the need to weigh these factors when considering management actions, the lack of a uniform high risk is consequential. It means that it is especially important to consider the possible collateral damage of management actions on native species, to ensure management actions do less harm than bigheaded carps are likely to.

This insight is especially significant in the context of potentially using species-selective deterrents or non-selective barriers as management actions, as they have the potential to have adverse consequences for native species. For example, the Granite Falls Dam in Minnesota provides an illustration of non-selective barrier effects on species richness and ecosystem resilience, with 40 of 97 native species in the watershed absent upstream of the dam (Aadland 2015). This is typical of 32 barrier dams evaluated across Minnesota with an average of more than 40 percent of native species found in the respective watersheds abruptly absent from the entire watershed upstream of these barriers. The conclusion that the barriers caused these species extirpations is validated by a rapid return of most of the absent species following dam removals (Aadland 2015). Sensitive species and species of greatest conservation need are most vulnerable to fragmentation while pollution-tolerant species are least effected. Extirpation and extinction of native fish and mussels resulting from dam construction and fragmentation has been well documented in the U.S. and globally (Rhinne et al. 2005; Haug 2009; Fu et al. 2003; Quinn and Kwak 2003). Therefore, if a primary intent of any proposed management action is to protect native species from bigheaded carps it should be considered that, based on data from existing non-selective barriers in Minnesota and elsewhere, the construction of non-selective barriers or non-selective deterrents may be counterproductive. Alternatively, species-selective deterrents, such as those using sound, provide the potential to slow the spread of bigheaded carps while not hurting native fish populations. While research is still advancing on such deterrents, this potential is promising. Other possible management actions that do not cause such harm natives include improving ecosystem resilience, restoring top native predators such as flathead catfish, and eliminating cross-watershed connections.

9.2 Implications for research

9.2.1 Research needs for an improved assessment of risk from bigheaded carps

The risk assessment process also helped identify a host of research needs. Many of these emerged during the small group sessions of the expert workshop. They are described in detail within the individual watershed sections (Section 4 through Section 7), but some key areas are summarized here. First, there is a need to study the impacts of bigheaded carps on watersheds similar to those in Minnesota. This includes better understanding the dynamics influencing establishment and the impact of bigheaded carps on the native species present in Minnesota. It also includes improving the understanding of how bigheaded carps effect waterbodies dissimilar to those they currently inhabit, such as the coldwater Nemadji River. A key part of this is ensuring there is adequate baseline information to detect changes. Second, there is a need for further research on how native fish species affect the population dynamics of bigheaded carps. For example, there is a need for more research exploring native fish species predation on and competition with bigheaded carps. Third, there is a need for further research on how bigheaded carps affect the benthic community and how that influences broader ecosystem dynamics.

Some overarching additional research needs include the need to look at the economic aspect of bigheaded carps, to explicitly consider the differences between rivers and lakes, to look at additional fish species, to extrapolate these findings to different watersheds in the state, and to regularly update these findings. First, looking explicitly at the economic aspects of the risks from bigheaded carps and of management actions would help inform decision making. While such an economic analysis fell outside the scope of this risk assessment, the risks characterized here would provide a good starting point for that effort. Second, although the scale of this risk assessment was at the level of the watershed, including both rivers and lakes, there was a focus on rivers because of their importance to the establishment and resulting abundance of bigheaded carps. There is a need, however, to explicitly study how the risks to lakes within a watershed may differ from the risks to rivers.

Third, there is a need to assess additional fish species within each watershed. The scope allowed for assessing one game and one non-game fish species in each watershed. Although this exposed important variations across fish species and watersheds, examining additional fish species would strengthen this assessment. Fourth, there is a need to build upon the approach to and findings from this risk assessment to assess the risks to other watersheds in Minnesota. The scope and findings of this risk assessment revealed some of the variation of risk that exists across watersheds and the implications for management, but looking at additional watersheds would further aid decision making. Finally, there is a need to regularly update these findings to keep up with the relevant scientific literatures. There was low certainty within the risk characterizations because of the limitations of current knowledge, the plasticity of bigheaded carps, and the differing and dynamic habitats within a watershed. Updating these findings as knowledge advances can help improve the certainty of the risk characterizations.

9.2.2 Using risk assessment to inform invasive species management

Whereas previous risk assessments for bigheaded carps have taken place at a broad scale (Cudmore et al. 2012; Kolar et al. 2007), this risk assessment's finer scale revealed decision-relevant information for the state of Minnesota and important nuances in the risks posed by bigheaded carps. Most significantly, the severity of risk varied across watersheds and potential adverse effects. This information can help determine and justify appropriate management actions and can help achieve more realistic expectations of the likely impacts from bigheaded carps. Another essential aspect of this risk assessment was how it started with an explicit values-based discussion about what aspects of the watershed were most valued and most important to protect from bigheaded carps. This ensured that the characterizations of risk were assessing the potential for harm and not just inconsequential change. It also helped ensure that the results were as useful as possible and specific to the current decision making context. Risk assessment, such as the approach utilized here, is well suited to inform invasive species management as it provides a set of tools that can synthesize scientific knowledge, necessary values-based judgments, and a specific environmental context.

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11 Appendix A: Workshop Participants and Report Authors

All workshop participants took part in the workshop meeting and were provided the opportunity to review this report. Workshop participants who participated in writing the report are starred. As discussed in section 2.4, project researchers (Adam Kokotovich & David Andow) assembled and revised the different sections of the report and wrote the Executive Summary, Methodology, Overall Risk Characterization, Discussion, and Appendices. The overall conclusions in this report are based on the findings that emerged from the risk assessment, but represent the views of the project researchers.

Table A.1: Workshop participant and report authors (starred).

Participant	**Affiliation**
Luther Aadland*	MNDNR
David Andow*	Project Researcher; University of Minnesota
Kelly Baerwaldt	US Fish and Wildlife Service
Katie Bertrand*	South Dakota State University
Duane Chapman	US Geological Survey
Alison Coulter*	Southern Illinois University
Ryan Doorenbos	MNDNR
Shannon Fisher	Minnesota State University - Mankato
Nick Frohnauer*	MNDNR
Seth Herbst	Michigan Department of Natural Resources
Michael Hoff	US Fish and Wildlife Service
John Hoxmeier*	MNDNR
Byron Karns	National Park Service
Adam Kokotovich*	Project Researcher; University of Minnesota
Matt O'Hara*	Illinois Department of Natural Resources
Brad Parsons	MNDNR
Keith Reeves*	MNDNR
Ed Rutherford*	National Oceanic and Atmospheric Administration
Tony Sindt	MNDNR
Peter Sorensen	University of Minnesota
Elliot Stefanik	US Army Corps of Engineers
John Waters	MNDNR
Mike Weber*	Iowa State University
Jamison Wendel	MNDNR
Dave Zentner	Stop Carp Coalition

12 Appendix B: Consequence Table

		Consequence description				
		1 – Negligible	2 – Low	3 – Moderate	4 – High	5 – Extreme
Adverse effect	**Non-game fish**	Undetectable changes	Small decrease in population	Moderate decrease in population, with detectable changes in structure of food web	Large decrease in population leading to many new food web connections	Severe decrease in, or extirpation of, non-game fish species, resulting in major changes in ecosystem
	Game fish	Undetectable changes	Small decrease in population leading to a minor reduction in angling quality	Moderate decrease in population, with a moderate reduction in angling quality	Large decrease in population, resulting in significant reduction in angling quality and in occasional closing of the fishing season for its protection	Severe decrease in, or extirpation of, game fish species - likely ending the natural fishery
	Species diversity / Ecosystem resilience	Undetectable changes in the structure or function of the ecosystem	Minimally detectable changes in the structure of the ecosystem, but small enough that it would have little effect on the ability to withstand external stressors	Detectable changes in the structure or function of the ecosystem and its ability to withstand external stressors	Significant changes to the structure or function of the ecosystem leading to significantly decreased ability to withstand external stressors	Restructuring of the ecosystem leading to very little ability to withstand external stressors
	Recreational opportunity – Jumping Hazard	Undetectable change – no sighting of jumping carp	Rare sightings of jumping carp, but does not cause changes in recreational boating and fishing	Occasional sightings of jumping carp, causing minor changes in recreational boating and fishing	Regular sightings of jumping carp and occasional collisions, causing changes in recreational boating and fishing	Severe and persistent recreational hazard from jumping carp, causing major changes to recreational boating and fishing

13 Appendix C: Findings and Implications Workshop

Overview

On March 15, 2017 a workshop entitled "Risk Based Management for Bigheaded Carps" was held at the University of Minnesota to discuss the findings and implications of this risk assessment. During this workshop, project researchers provided the March 15th, 2017 draft of the risk assessment report and provided presentations on the findings from the risk assessment. To discuss the risk assessment findings and their implications for management, and to provide feedback on the risk assessment report, workshop participants filled out a survey and took part in small and large group discussions. About 50 people attended the workshop including interested members of the public and individuals from: 5 federal agencies, the Minnesota Department of Natural Resources, non-governmental organizations, many local units of government, and academia. The feedback garnered from this workshop informed the final version of the risk assessment report.

Three aspects of this workshop are summarized here. First, the findings from the 10 question survey completed by workshop participants are provided. Second, a summary of the small group discussions is provided. Finally, this appendix concludes with a discussion of one of the important issues facing the management of bigheaded carps that emerged at the workshop – the conflicts concerning barriers and deterrents.

Summary of survey findings

Questions from the survey are presented, with bulleted summaries of the answers. When available, sample qualitative answers are provided.

Question #1: Which of the following best describes your affiliation?

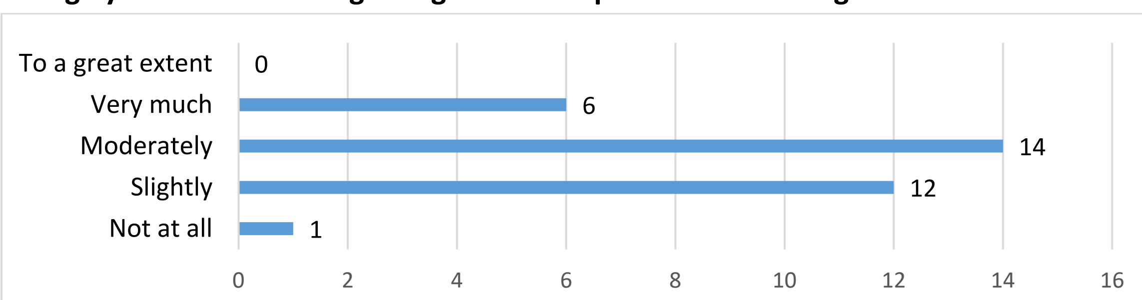
- Affiliations of respondents included: State agency (11); Federal agency (6); Academic institution (3); Stakeholder group (4); Interested individual (5); Local unit of government (4).

Question #2: What do you feel is the most important finding from the MN bigheaded carps risk assessment?

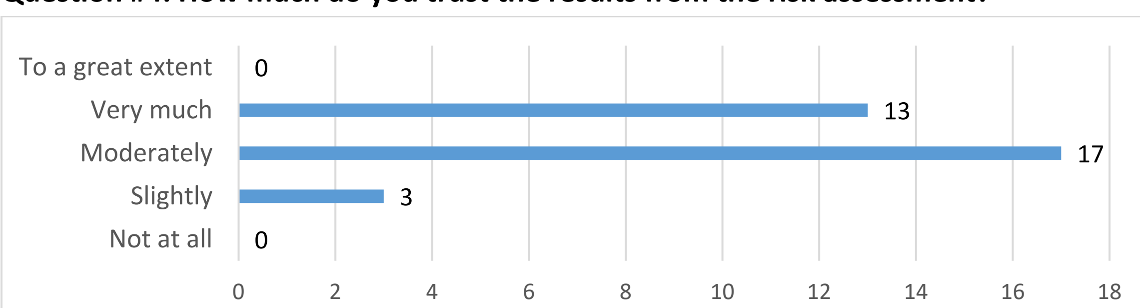
- Answers varied widely, but common themes included: 1) identifying the MN River-Mankato and Lower St. Croix River watersheds as higher risk; 2) recognizing the variation of risk across watersheds; 3) acknowledging the complexity and uncertainty present within these estimates; 4) acknowledging the importance of the potential for harm to native species from control measures.

Sample answers (each sentence comes from a different participant's response): The uncertainty and complexity impacting the findings. MN River and St. Croix River watersheds being at risk and need action soon. Understanding of the role of apathy and fear around the issue. No areas are the same nor should they be treated the same; Also our values differ and there is a need to be open and discuss in plain language. That a large group of people came together with varying perspectives to assess this, which is good. Acknowledging risk of control measures. There is still time, but establishment seems inevitable without action. The fish will not take over the entire state. Risk varies across watersheds and adverse effects. Understanding what is known and not known about Asian carp life history, especially as it applies to the waters of this state. Collaboration of experts and social science, brought up other aspects not usually considered by biological scientists. Damage to ecosystem resilience will likely be high, not so much for game fish. There is a lot of uncertainty and this uncertainty hampers our ability to make decisions and convince others to support these decisions.

Question #3: To what degree does the risk assessment and the discussions at this workshop change your understanding of bigheaded carps and their management?



Question #4: How much do you trust the results from the risk assessment?

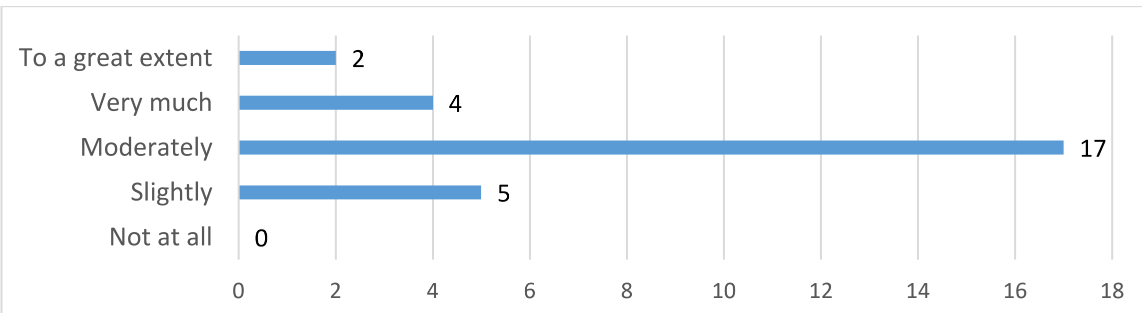


Question #5: How could they be more trustworthy?

- Answers largely identified the need to assess more fish species and watersheds, and to obtain more and better data.

Sample answers (each sentence comes from a different participant's response):
More species of fish included, since only one game and non-game looked at per watershed. More workshops, more perspectives, more watersheds looked at. More data from similar systems. Replicate assessments with other experts. Better data. Have participants provide sources. More quantitative analyses. I think this is as strong as it can be for the diverse group of parties involved. Translation into plain language. Being more up front with limitations.

Question #6a: How useful do you think these findings will be to the current management context?



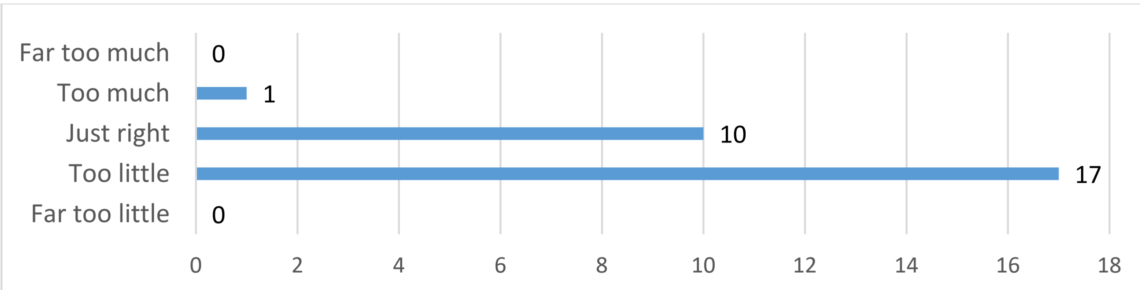
Question #6b: Why?

- Answers included justifications for why results would and would not be of use
- Justifications for why results would be of use included: 1) the importance of risk assessments for informing management decisions; 2) it is the first systematic analysis of risks for the state; 3) it provides justifications for continuing projects
- Justifications for why results would not be of use included: 1) the bureaucracy surrounding management will hamper its potential use; 2) the focus should be on prevention; 3) management comes down to resources

Samples answers (each sentence comes from a different participant's response):
Need risk assessment before any management decisions. Emphasis should remain on prevention, since once established management options usually fail. Citizens want to know how this carp thing applies to them. I think these discussions have been occurring at the management level with similar understandings, much comes down to $ and staff numbers. Provides estimates of risk but lacks risk of management options, particularly barriers. It provides context but no real action items. More work needs to be done to flesh out the bureaucracy within management and how decisions are made; Current management still lacks

true structured decision making. Best to know what you don't know. Because it's all we have to work with to date. I think it provides baseline data and justifications for continuing projects. They illuminate the need to act.

Question #7: Based on the risk assessment and discussions today, how would you characterize the current amount of management effort in Minnesota?



Question #8: What is the biggest remaining challenge facing the management of bigheaded carps?

- Answers emphasized: 1) scientific and political uncertainties; 2) the issues around barriers and deterrents, including whether they do more good than harm

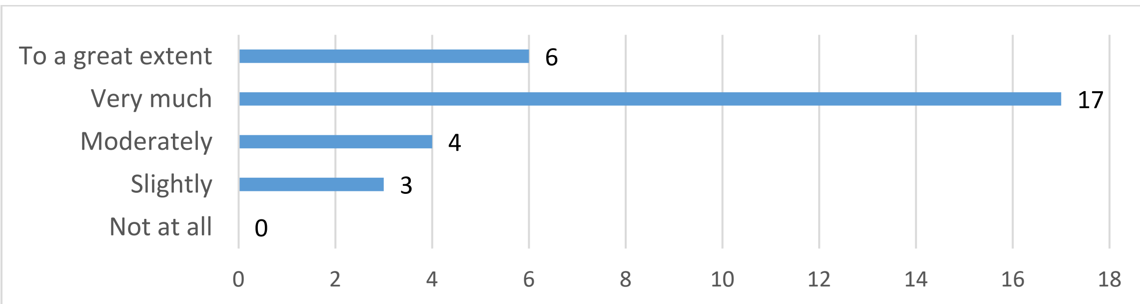
Sample answers (each sentence comes from a different participant's response): The debate between barriers and the resilience a diverse ecosystem needs to mitigate the threat. Uncertainty of everything: funding, research, food webs; Priorities of different organizations. Funding and quick response. Other AIS threats that grab the spotlight; Apathy. Getting other states on board. Funding strategies that don't damage ecosystems. Understanding and prioritizing management actions in and outside of MN based on collaborative approach. Funding and direction; what is our end game? Sharing information to bring results quicker. Data of how bigheaded carp will affect these basins. Implementing actions like barriers.

Question #9: What additional resources and/or information do we need to advance the management of bigheaded carps?

- Answers include a variety of research, politics, management, and society-related factors that could help advance the management of bigheaded carps

Sample answers (each sentence comes from a different participant's response): Database of research gathered together, to keep updating risk assessment. Sense of urgency. Resources for management actions. Well directed, cohesive management. Risk assessment on management options, including barriers. Research on river ecology, funding for temporary barriers to buy time. People, money, institutional support, and public support to continue adaptive and integrative management of Asian carp. Food web studies. Tag fish caught in Minnesota. More data. Identify most effective location for preventative actions. Zero in on end goals as managers. Quantitative estimation of potential impacts in watersheds.

Question #10: How important are meetings like these for the management of bigheaded carps?



Small group discussions

During the afternoon of the workshop small group sessions took place to discuss the implications of the risk assessment. Provided here is a summary of the key points that emerged during these discussions and that were not presented in the survey findings.

How do the risk assessment findings and this morning's events apply to your work, your organization and/or your views on bigheaded carps?

- Points raised in discussions emphasized how these findings can: 1) prioritize research activities and inform management, 2) help us understand what we do and do not know, 3) help provide better information to the public, and 4) help engage with the state legislature.

Based on the findings and this morning's events, what do we need to do going forward for the management of bigheaded carps? Are we on the right path or is an adjustment needed? What should be the focus of our management efforts?

- Points raised in the discussions concerning the needs going forward included: 1) scaling up the report to look at more species and watershed; 2) examining the effectiveness and non-target impacts of deterrents and barriers as management options; 3) continue to learn from other states; 4) better define management objectives, strategies, and priorities; 4) what is a realistic expectation for management instead of just 'we don't want them here'; 5) continue pursuing and evaluating deterrents at lock & dam #8 and #5;

What are the challenges going forward? Are additional information and resources needed? What is the largest challenge facing management?

- Points raised in the discussions concerning needs included: 1) communicating to public about what is being done; 2) leadership on the Mississippi River; 3) need to move faster and more definitively with management; 4) need to clarify uncertainty; 5) more data; 6) a local Asian carp task force; 7) a central hub for communication and information sharing, including funds to host it.
- Points raised in the discussions concerning challenges include: 1) educating the public; 2) the public's lack of faith in science; 3) how to communicate uncertainty in science; 4) sustained funding; 5) apathy & fear; 6) a lack of coordination between projects; 7) other environmental priorities; 8) the politicization of the issue; 9) conveying the need for impact and life history studies to funders.

Issues facing management: Barriers & deterrents

One of the remaining areas of conflict that became clear from the workshop survey and discussions concerned species-selective deterrents and non-selective barriers. First, there was miscommunication in terminology concerning the differences between species-selective deterrents and non-selective barriers, as some were using barrier to refer to both. Second, there were differing views about just how species-selective existing deterrent technology is, and of what level of efficacy (against bigheaded carps) and selectivity (so as not to hurt natives) is required before a deterrent technology should be put into use. Third, there were different views concerning what collateral damage on native species and ecosystem resilience from non-selective barriers or species-selective deterrents were acceptable when trying to reduce the likelihood of bigheaded carps spread. These two competing views can be seen in the following survey responses to the question asking about the biggest remaining challenge facing management:

> "So many unknowns, and fear pressuring action that is unnecessary and damaging to ecosystem health. Are known negative actions (i.e., dams, barriers) worth appeasing fears, when they are known to be more damaging than good? Explain to public that we are not even sure if they will have an impact or reach levels that might have a negative effect."

> "Knowing that acting in some capacity (even if barriers need refinement or all known effects on natives are incomplete) is better than inaction. Once they arrive in self-sustaining populations all the high level discussions that led up to the invasion/establishment will be for nothing. Finding a way to depoliticize this issue to free up state and regional and federal funding sources would be great"

These views indicate that there is a need for further study and deliberative discussions on these topics. The differences can be understood as conflicting types of risk profiles between two groups. Those who are skeptical of deterrents and barriers emphasized concerns about the likely impacts to native species that would occur if non-selective barriers or poorly working species-selective deterrents are used. This group also expressed concern that deterrents or barriers will not work as a permanent solution, and that if/when bigheaded carps make it past them, the deterrent or barrier damaged ecosystem will be more easily exploited. This group is most interested in management approaches based on strengthening ecosystem resilience and native predator populations.

Those supporting deterrents and barriers highlighted concerns about the likely impacts to native species from bigheaded carps, including the possibility that the impacts could be much worse than anticipated. This group expressed that the waterbodies in question are already impaired to the point where biotic resistance would not be an effective way to prevent establishment or lessen the severity of adverse effects. This group, then, asserted that species-selective deterrents (and potentially in some cases non-selective barriers) are the only real possible solution for avoiding the consequences from bigheaded carps, and that any effects on native species should be minimized as much as possible and then acknowledged as acceptable collateral damage.

The possible area of overlap between these two groups exists around species-selective deterrents. If there was truly a deterrent that was effective on bigheaded carps but had no impact on native species, this would likely be acceptable to all seeking to protect Minnesota's waters from bigheaded carps. Research continues on deterrents, and a few questions are important for deterrent-related decision-making: What level of deterrent efficacy on bigheaded carps would successfully prevent establishment further upstream? What level of species-selectivity is adequate to protect native species? What level of resources are worthwhile to invest to improve the efficacy and selectivity of selective deterrents? What levels of effectiveness on bigheaded carps and species-selectivity on native species would make a deterrent worthwhile? Given the potential for species-selective deterrents to address this conflict and prevent adverse effects, this area of research is promising.

Other research questions that can help address this conflict include: 1) To what degree can biotic resistance (by, for example, increasing ecosystem resilience and native predators) lessen the likelihood of establishment and lessen the severity of any resulting adverse effects from bigheaded carps? 2) What are the impacts of different deterrents and barriers on native species and bigheaded carps? 3) How would species-selective deterrents and non-selective barriers impact native species and how would they make it easier for bigheaded carps to thrive if/when they get above them?

There is also clearly a need for people with differing views on this issue to better understand each other and to understand the common ground that does exist concerning the desire to protect native species from harm. More engagement on the intersecting science and values-based questions concerning deterrents and barriers is needed to help advance bigheaded carps management in Minnesota.