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BINATIONAL ECOLOGICAL RISK ASSESSMENT OF BIGHEADED CARPS (*Hypophthalmichthys* spp.) FOR THE GREAT LAKES BASIN

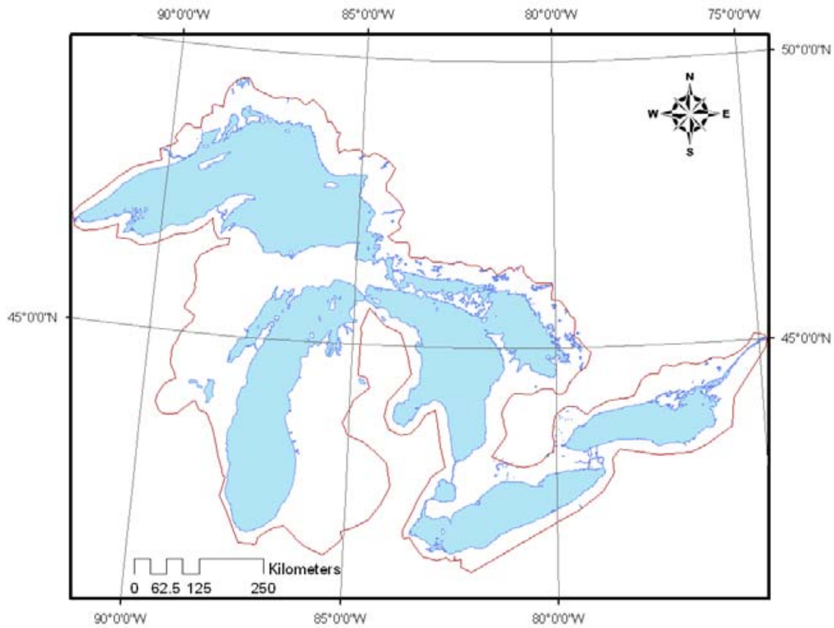

Figure 1: Map of the connected Great Lakes basin outlined in red (modified from Hedges et al*. 2011).*

*Bighead carp (*Hypophthalmichthys nobilis*) (from Missouririverfutures.com)*

*Silver carp (*H. molitrix*) (from Department of Fisheries and Allied Aquacultures, Auburn University, Alabama, USA)*

Context :

The intentional or accidental introduction of non-native species into Canadian waters poses a threat to native species and overall biodiversity. Non-native species can alter habitat, compete with native species for food or habitat, prey upon native species, and act as vectors for new diseases or parasites that could spread to native species. There is also a risk of introducing non-native genes into native populations through hybridization. Any of these effects could have further widespread, detrimental impacts on native species and communities.

Bigheaded carps (bighead and silver carps) were first imported into the United States in the 1970s for use as water quality control agents in man-made ponds and, subsequently, escaped those confined areas into natural waters in the 1990s (Chapman and Hoff 2011). For a detailed history on the use and introductions of these species in the United States, see Kelly et al*. (2011). Previous risk assessments identified broad, potential risks to Canada and the United States, including the Great Lakes (Mandrak and Cudmore 2004, Kolar* et al*. 2007). While these risk assessments provided insight into the risk faced by broad areas of North America, knowledge gaps were identified as a result of the lack of information, at the time, on these species in established populations outside of their native range. As bigheaded carps have moved farther north up the Mississippi River basin, concern for movement into the Great Lakes has increased. Now that further research has been conducted on the species in their introduced range, more available knowledge can be applied to our understanding of the risks associated with an invasion by these species. The purpose of conducting a new, targeted risk assessment was to determine the risk to the Great Lakes and to provide useful, scientifically defensible advice concerning prevention, monitoring, early detection, and management actions that are underway, or could be taken.*

SUMMARY

- The most likely entry point into the Great Lakes basin is the Chicago Area Waterway System (CAWS) into Lake Michigan. The effectiveness of the electrical barrier in the Chicago Sanitary and Ship Canal (CSSC) was not evaluated. Nevertheless, the complex nature of the CAWS and proximity of bigheaded carp populations led to the conclusion this is the most likely entry point.
- Once bigheaded carps have gained entry into the basin, they are expected to spread to other lakes within 20 years. The spread will be more rapid for lakes Michigan, Huron, and Erie, and potentially Lake Superior; longer for Lake Ontario.
- Bigheaded carps would find suitable food, and thermal and spawning habitats in the Great Lakes basin that would allow them to survive and become established. The areas that would be attractive and favorable are Lake Erie, including Lake St. Clair, and high productivity embayments of lakes Superior, Michigan, Huron and Ontario.
- There is a greater than 50% probability of successful mating each year with very few (< 10) adult females (and a similar number of adult males) within the basin of a Great Lake.
- Population growth is most sensitive to the survivorship of juveniles.
- The consequences of an established bigheaded carp population are expected to include changes in planktonic communities, reduction in planktivore biomass, reduced recruitment of fishes with early pelagic life stages, and reduced stocks of piscivores.
- To reduce the probability of introduction (either at the arrival, survival, establishment or spread stage), and delay or reduce subsequent ecological consequences, immediate prevention activities would be most effective, especially in conjunction with population management activities at the invasion front.

INTRODUCTION

The Great Lakes have not been immune to the arrival of aquatic invasive species. At least 69 non-native fish species have been introduced to the Great Lakes, half of which are considered established (Mandrak and Cudmore 2010). The invasion of destructive aquatic invasive species (AIS) (e.g., Sea Lamprey (*Petromyzon marinus*)) into the Great Lakes, and the resulting necessity for intensive management activities and associated costs, has promoted management strategies that now focus on the prevention of new aquatic invasive species (Ricciardi *et al.* 2011). The mandate of Fisheries and Oceans Canada's (DFO) Centre of Expertise for Aquatic Risk Assessment (CEARA) is to identify potential invaders to all parts of Canada, assess their ecological risk, and provide science advice towards preventing the introduction of those species considered to be high risk. As noted by Kolar *et al.* (2007), Chapman and Hoff (2011), and Cudmore and Mandrak (2011), two species that currently threaten to invade the Great Lakes are Bighead Carp (*Hypophthalmichthys nobilis*) and Silver Carp (*H. molitrix*), herein referred together as bigheaded carps (Figure 1).

The scope of the risk assessment was determined using information from Great Lakes researchers, managers, and decision-makers who participated in several preliminary workshops (November 2010, May 2011, June 2011). The risk assessment considered the available information known about bigheaded carps to assess the likelihood of arrival, survival, establishment, and spread, and the magnitude of the ecological consequences (up to 20 years and up to 50 years) to the connected Great Lakes basin (defined as the Great Lakes and its tributaries up to the first impassable barrier) (Figure 1). For this assessment, Lake St. Clair was considered to be part of the Lake Erie basin.

This ecological risk assessment focused only on the ecological consequences; the socio-economic consequences will be assessed separately using the results of the ecological risk assessment. The assessment also addressed only the current state, with management measures that are presently in place. It did not assess the level of risks associated with a variety of potential mitigating factors that are not currently in place. Targeted management questions were obtained from Great Lakes managers and decision-makers at the outset of the risk assessment process. This was done to ensure the risk assessment would provide as useful advice as possible to address the needs of managers and decision-makers on both sides of the border.

ASSESSMENT

Mandrak *et al.* (2012) divides the risk assessment process into two steps: 1) estimating the probability of introduction (using estimates of likelihood of arrival, survival, establishment, and spread); and, 2) the determination of the magnitude of the ecological consequences of an established population. The evaluation of the probability of introduction and the magnitude of the ecological consequences are based on a qualitative scale (see Tables 1 and 2, respectively), and includes a corresponding ranking of certainty (see Table 3).

Table 1. Likelihood as probability categories.

Likelihood	Probability Category
Very Unlikely	0.00 - 0.05
Low	0.05 - 0.40
Moderate	0.40 - 0.60
High	0.60 - 0.95
Very Likely	0.95 - 1.00

Table 2. Description of ecological consequence ratings.

Consequence Rating	Description
Negligible	Undetectable changes in the structure or function of the ecosystem.
Low	Minimally detectable changes in the structure of the ecosystem, but small enough that it would not change the functional relationships or survival of species.
Moderate	Detectable changes in the structure or function of the ecosystem.
High	Significant changes to the structure or function of the ecosystem leading to changes in the abundance of native species and generation of a new food web.
Extreme	Restructuring of the ecosystem leading to severe changes in abundance of ecologically important species (those considered dominant or main drivers in the ecosystem) and significant modification of the ecosystem.

Table 3. Relative certainty categories.

% Level	Certainty Category
± 10%	Very high certainty (e.g., extensive, peer-reviewed information)
± 30%	High certainty (e.g., primarily peer reviewed information)
± 50%	Moderate certainty (e.g., inference from knowledge of the species)
± 70%	Low certainty (e.g., based on ecological principles, life histories of similar species, or experiments)
± 90%	Very low certainty (e.g., little to no information to guide assessment)

The overall probability of introduction was ascertained by first determining the highest ranking between Overall Arrival and Spread, then taking this with the ranks of Survival and Establishment and using the lowest rank of the three. This is represented by the following formula:

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

This result and the magnitude of the ecological consequences are combined into a risk matrix to communicate an overall risk. Each lake was assessed for two different time periods: within 20 years; and, within 50 years.

CONCLUSIONS AND ADVICE

The likelihood of arrival by physical connections was very likely for Lake Michigan (with the Chicago Area Waterway System (CAWS) being the most likely route), low for Lake Erie, and very unlikely for Lake Superior; all with moderate certainty, except for Lake Michigan where certainty is high. (Table 4).

Arrival by human-mediated release was low for all lakes, except Lake Superior, which was ranked very unlikely; all with low certainty (Table 4).

Likelihood of survival was very likely for all lakes; all with high certainty, except for Lake Erie for which certainty was very high (Table 5).

Likelihood of establishment was very likely for all lakes, except Lake Superior, which was ranked moderate; all with high certainty, except for Lake Superior for which certainty was moderate (Table 6).

Likelihood of spread was very likely for all lakes, except Lake Ontario, which was ranked high; all with high certainty (Table 7).

Overall probability of introduction (Min [Max (Arrival, Spread), Survival, Establishment]) within the 20-year timeframe was very likely for lakes Michigan, Huron, and Erie (all with high certainty), high for Lake Ontario (high certainty), and moderate for Lake Superior (moderate certainty) (Tables 8 and 9).

Table 4. Overall probability of introduction rankings and certainties for each lake. Overall arrival is the combination of physical connections and overall human-mediated release. Greyed cells indicate "not applicable". (CAWS=Chicago Area Waterway System)

	Superior		Michigan		Huron		Erie		Ontario	
Element	**Rank**	**Cert**	**Rank**	**Cert**	**Rank**	**Cert**	**Rank**	**Cert**	**Rank**	**Cert**
CAWS			Very Likely	High						
Other Connections	Very Unlikely	Mod	High	Mod			Low	Mod		
Overall Physical Connections	**Very Unlikely**	**Mod**	**Very Likely**	**High**	**-**	**-**	**Low**	**Mod**	**-**	**-**
Bait	Very Unlikely	Low	Low	Low	Low	Low	Low	Low	Low	Low
Trade	Very Unlikely	Mod	Low	Mod	Very Unlikely	Low	Low	Low	Low	Mod
Overall Human-Mediated Release	**Very Unlikely**	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**
Overall Arrival	**Very Unlikely**	**Mod**	**Very Likely**	**High**	**Low**	**Low**	**Low**	**Mod**	**Low**	**Mod**

Table 5. Likelihood of survival rankings and certainties for each lake.

	Superior		Michigan		Huron		Erie		Ontario	
Element	**Rank**	**Cert**	**Rank**	**Cert**	**Rank**	**Cert**	**Rank**	**Cert**	**Rank**	**Cert**
Survival	Very Likely	High	Very Likely	High	Very Likely	High	Very Likely	Very High	Very Likely	High

Table 6. Likelihood of establishment rankings and certainties for each lake.

	Superior		Michigan		Huron		Erie		Ontario	
Element	**Rank**	**Cert**	**Rank**	**Cert**	**Rank**	**Cert**	**Rank**	**Cert**	**Rank**	**Cert**
Establishment	Mod	Mod	Very Likely	High	Very Likely	High	Very Likely	High	Very Likely	High

Table 7. Likelihood of spread rankings and certainties for each lake.

	Superior		Michigan		Huron		Erie		Ontario	
Element	**Rank**	**Cert**	**Rank**	**Cert**	**Rank**	**Cert**	**Rank**	**Cert**	**Rank**	**Cert**
Spread	Very Likely	High	Very Likely	High	Very Likely	High	Very Likely	High	High	High

Table 8. Maximum rank of overall arrival and spread (Max(Arrival, Spread)) for each lake.

	Superior		Michigan		Huron		Erie		Ontario	
Element	**Rank**	**Cert**	**Rank**	**Cert**	**Rank**	**Cert**	**Rank**	**Cert**	**Rank**	**Cert**
Overall Arrival	Very Unlikely	Mod	Very Likely	High	Low	Low	Low	Mod	Low	Mod
Spread	Very Likely	High	Very Likely	High	Very Likely	High	Very Likely	High	High	High
Max(Arrival, Spread)	Very Likely	High	Very Likely	High	Very Likely	High	Very Likely	High	High	High

Table 9. Overall probability of introduction rankings and certainties for each lake.

	Superior		Michigan		Huron		Erie		Ontario	
Element	**Rank**	**Cert**	**Rank**	**Cert**	**Rank**	**Cert**	**Rank**	**Cert**	**Rank**	**Cert**
Max(Arrival, Spread)	Very Likely	High	Very Likely	High	Very Likely	High	Very Likely	High	High	High
Survival	Very likely	High	Very Likely	High	Very Likely	High	Very Likely	Very High	Very Likely	High
Establishment	Mod	Mod	Very Likely	High	Very Likely	High	Very Likely	High	Very Likely	High
P(Intro)=Min [Max(Arrival, Spread), Survival, Establish]	Mod	Mod	Very Likely	High	Very Likely	High	Very Likely	High	High	High

The magnitude of the ecological consequences should bigheaded carps arrive, survive, establish, and spread in each lake was ranked for a 20-year and a 50-year time period. Within 20 years, the magnitude of the ecological consequences was ranked moderate for all lakes, except Lake Superior, which was ranked low. Within 50 years, the magnitude of the ecological consequences was ranked high for all lakes, except Lake Superior, which was ranked moderate (Table 10). All ranks for ecological consequences for all lakes in both time periods had moderate certainty (Table 10). These ranks indicate the escalating consequences expected as the invasion and population numbers increase over time.

Table 10. Magnitude of the ecological impacts and certainties to each lake within a 20-year and a 50-year timeframe.

	Superior		**Michigan**		**Huron**		**Erie**		**Ontario**	
Element	**Rank**	**Cert**	**Rank**	**Cert**	**Rank**	**Cert**	**Rank**	**Cert**	**Rank**	**Cert**
~20 years	Low	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod
~50 years	Mod	Mod	High	Mod	High	Mod	High	Mod	High	Mod

The results of the overall probability of introduction and magnitude of the ecological consequences were combined into a risk matrix to communicate risk in a 20 year (Figure 2a) and 50 year (Figure 2b) timeframe.

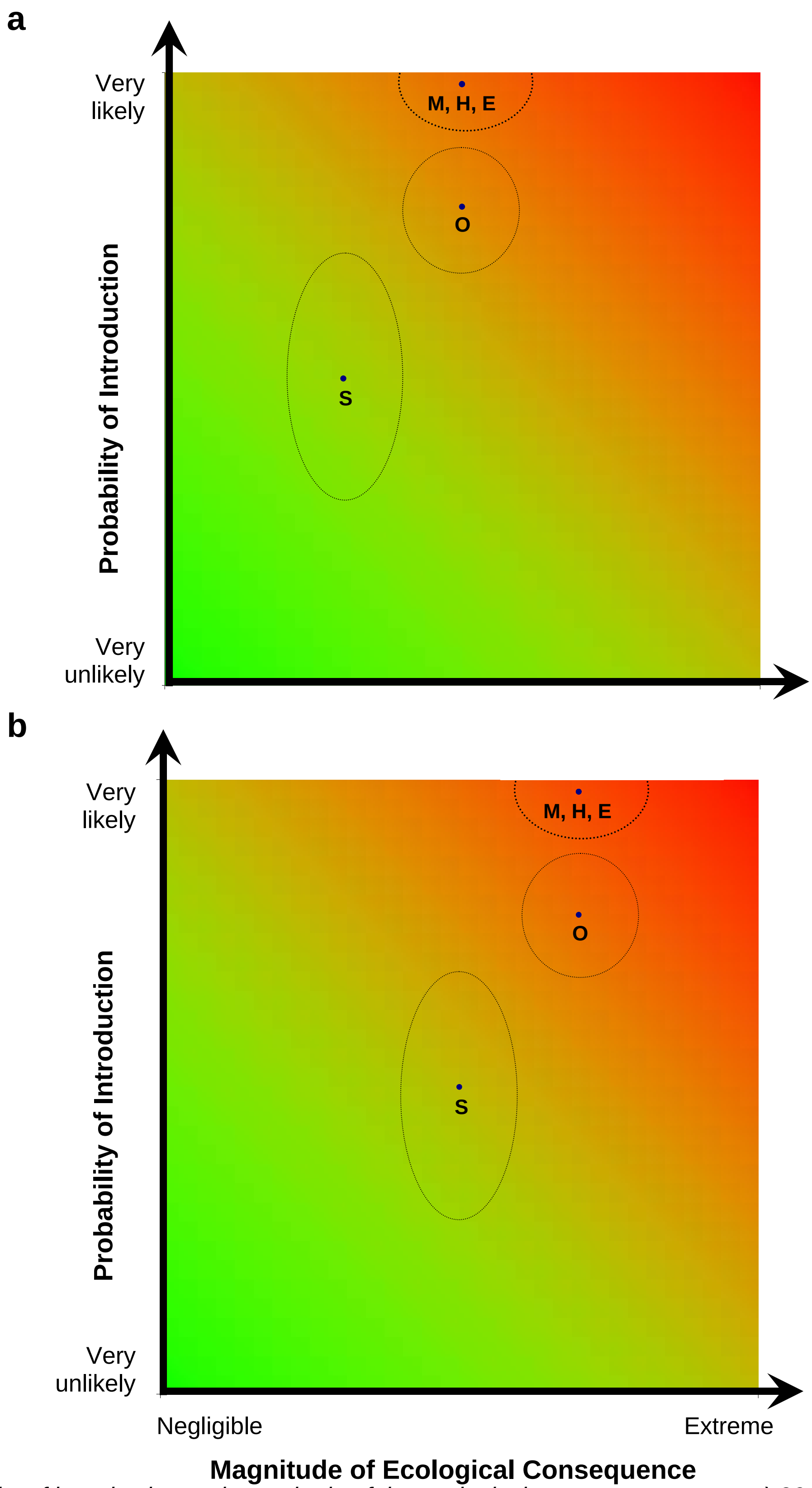

Figure 2. Probability of introduction and magnitude of the ecological consequences over a) 20 years and b) 50 years. S=Lake Superior, M=Lake Michigan, H=Lake Huron, E=Lake Erie, O=Lake Ontario; ellipses are representative of amount of certainty around rank.

There is an expected time lag associated with seeing the consequences of an established population of bigheaded carps in the Great Lakes. The situation currently being experienced in the Mississippi River basin is the result of an invasion that took decades, and the consequences are not yet at the level fully anticipated. Ongoing actions underway have prevented the invasion process from being further along than it currently is. Other management options exist, and further research can be conducted, to interrupt the trajectory of this invasion and to minimize the risk predicted within this assessment. Effective prevention and control actions implemented now have the potential to reduce probability of introduction into the lakes and, subsequently, the ecological consequences. This delay will provide time to conduct further research into prevention, eradication, and control options, as well as minimize and postpone overall costs of control and management efforts and costs associated with impacts. Prevention of arrival, survival, establishment, or spread is the most feasible and effective means to control the impact of bigheaded carp. As the bigheaded carp invasion towards the Great Lakes continues, an AIS program should include prevention activities as one of its key components. However, as this invasion is in such close proximity to the Great Lakes, prevention efforts should occur in conjunction with control and management of population numbers at the invasion front.

Specific management questions from Great Lakes managers and decision-makers were compiled and, where feasible, addressed during the ecological risk assessment process. These questions and advice are presented in Table 11.

Table 11. Summary of advice to management questions presented by Great Lakes managers and decision-makers.

Element	Management Question	Summary of Advice
Arrival	How risky are the various points of arrival?	In general, the physical connections represent higher likelihood than human-mediated releases; however, there is much lower certainty associated with the ranks of human-mediated releases. The highest likelihood of arrival into the basin is from the CAWS into Lake Michigan.
	How effective is the barrier?	A detailed evaluation of the effectiveness of the barrier was not conducted in this risk assessment.
Survival	Are the Great Lakes too cold?	No.
	Are the right environmental conditions available?	Yes.
	Is there enough food and where?	Yes. There is enough food, especially in Green Bay, Saginaw Bay, Lake St. Clair, and Lake Erie. Warm embayments in lakes Superior and Ontario should also provide suitable amounts of food.

Establishment	What number of individuals is needed to establish a population?	As few as 10 mature females and 10 (or fewer) mature males in the basin of a Great Lake have a greater than 50% chance of successfully spawning if the fish locate suitable spawning rivers (Currie *et al*. 2012).
	What is the potential biomass?	Bigheaded carps have the potential to become a dominant biomass in favourable locations.
	Where will they be most abundant?	Lake Erie, including Lake St. Clair, and high productivity embayments of lakes Superior, Michigan, Huron and Ontario.
	What characteristics make for suitable spawning tributaries?	Some general knowledge exists on the characteristics of suitable spawning tributaries; however, specific characteristics are identified as a critical knowledge gap (Cudmore *et al*. 2012) within the risk assessment.
	What/how many tributaries would support spawning and recruitment?	Suitable spawning tributaries are found in all lakes. **US:** 22 suitable spawning tributaries in American Great Lakes basin are unimpounded from mouth to at least 100km upstream. More detailed analyses of tributary characteristics for Lake Erie suggest that 7 out of 8 tributaries would provide suitable spawning habitat (Kocovsky *et al*. 2012). **Canada:** 41 suitable spawning rivers in Canadian Great Lakes basin are unimpounded from mouth to at least 100km upstream. More detailed analyses of tributary characteristics suggest that suitable spawning conditions exist in at least 49 Canadian Great Lake tributaries (Mandrak *et al*. 2011).
	Could they spawn directly in the Great Lakes?	This is identified as a critical knowledge gap within the risk assessment.
Spread	What is the timeframe and direction of spread?	Varies depending on arrival point within the basin, but predicted to be less than 10 years for spread with direction likely Michigan to Huron to Erie.
	How long before they reach Canadian waters?	Less than 5 years after arrival into the connected Great Lakes basin via Lake Michigan.

Consequences	What level of population would be an acceptable level of risk/impact?	This is outside the scope of this risk assessment.
	What are the impacts to recruitment – food, behavioural disruption?	Recruitment of fishes with pelagic early life stages will decline. Mechanisms are unclear.
	Will a fishery be lost? Loss of diversity, richness or production?	Fish community responses are variable and difficult to predict. Accordingly, impact on fisheries are difficult to predict and outside the scope of this risk assessment.
	Is there a variation of impacts with variation in abundance levels of bigheaded carps?	Yes. Higher abundance of bigheaded carps will lead to greater ecological consequences.
	Will there be a cumulative impact of two more planktivorous invaders?	Different changes in plankton communities predicted than seen with current planktivorous invaders. Cumulative impacts are difficult to predict.
	Need links of ecological impacts to use for socio-economic uses and activities	Select qualitative consequences have been identified; some specific quantitative information could not be completed within this risk assessment timeframe.
Overall	What is the timeframe of risk for each element?	If no additional management actions are taken: ▪ Arrival – impending; ▪ Survival – immediate upon arrival; ▪ Establishment – 5 to 20 years (short in southern basin, longer in Lake Superior); ▪ Spread – 5 to 20 years; and, ▪ Consequences – will build over time.
	What are the confounding issues?	Question is too broad to provide meaningful advice.
	Where are the most vulnerable areas?	Lake Erie, including Lake St. Clair, and high productivity embayments of lakes Superior, Michigan, Huron (including the Huron-Erie corridor), and Ontario. Overlap of identified spawning tributaries and potential points of arrival.
	Help inform rapid response?	See above points of arrival, abundant areas, spawning tributaries, and vulnerable areas.
	What are some mitigation options?	A discussion of mitigation options is outside the scope of this risk assessment; however, potential entry routes have been identified to inform prevention activities.

OTHER CONSIDERATIONS

Predictions and risk assessment on species that are currently not established in the Great Lakes are based on best available information. Research that is underway where results were not available, or research noted as a critical knowledge gap, may in the future, provide more information that would change the results of the risk assessment. The ecological risk assessment should be considered a living document that can be updated as needed.

The key area of low certainty in the rankings of the ecological risk assessment was the likelihood of arrival by human-mediated release for all lakes, which impacted likelihood of overall arrival into Lake Huron. This is a result of insufficient information on bait and trade as a route for the introduction of bigheaded carps into the Great Lakes basin. This, along with other knowledge gaps, was identified by the risk assessment authors and peer review meeting participants and noted in the meeting proceedings.

It is anticipated that other documents may arise from the ecological risk assessment to further communicate the results. These documents may be in the form of government reports or primary publications.

SOURCES OF INFORMATION

This Science Advisory Report is from the Fisheries and Oceans Canada, Canadian Science Advisory Secretariat, national advisory meeting of November 8-10, 2011 on the Binational Risk Assessment for Asian Carps in the Great Lakes. Additional publications from this process will be posted as they become available on the DFO Science Advisory Schedule at [http://www. dfo-mpo.gc.ca/csas-sccs/index-eng. htm](http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm).

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FOR MORE INFORMATION

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