ECOLOGICAL RISK ASSESSMENT OF GRASS CARP (*Ctenopharyngodon idella*) FOR THE GREAT LAKES BASIN

Adult Grass Carp, Ctenopharyngodon idella *(Courtesy of Asian Carp Program, Fisheries and Oceans Canada).*

Figure 1. The Great Lakes basin (image from the Great Lakes Commission).

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 widespread, detrimental impacts on native species and communities.

A responsibility of Fisheries and Oceans Canada (DFO) is to identify potential aquatic invasive species to all parts of Canada, assess their ecological risk, and provide science advice for preventing the introduction of those species considered to be high risk. Grass Carp, first introduced to North America in 1963 for vegetation control, has since escaped from impoundments and has made its way up the Mississippi River basin towards the Great Lakes. The threat to the Great Lakes has continued to increase, with recent occurrence records located in proximity to, and within, the Great Lakes basin. These findings have contributed to the urgency to better understand the current status and threat of Grass Carp in and to the Great Lakes basin.

In response to the increasing threat of Grass Carp introduction and to help prevent the arrival, establishment, and spread of Grass Carp to the Great Lakes, DFO's Asian Carp Program identified the need for a binational ecological risk assessment of Grass Carp to the Great Lakes basin.The purpose of this risk assessment is to determine the risk to the Great Lakes basin and to provide useful, scientifically defensible advice on prevention, monitoring, early detection, and management actions that are underway or could be taken. This assessment addresses only the current state of the system and management measures that were in place during the scoping of the risk assessment (baseline year = 2014) and focuses only on ecological consequences; socioeconomic consequences will be assessed separately using the results of this ecological risk assessment.

This Science Advisory Report is from the June 1–3, 2015 peer review of the Binational Ecological Risk Assessment for Grass Carp in the Great Lakes Basin. Additional publications from this meeting will be posted on the DFO Science Advisory Schedule as they become available.

SUMMARY

- Grass Carp (*Ctenopharyngodon idella*) is an herbivorous, freshwater fish that was first introduced in the United States in the early 1960s for use in biological control of aquatic vegetation. It has since escaped and dispersed through the Mississippi River basin towards the Great Lakes. To characterize the risk of Grass Carp to the Great Lakes basin, a binational ecological risk assessment of Grass Carp was conducted.
- This risk assessment covered both triploid (sterile) and diploid (fertile) Grass Carp and assessed the likelihood of arrival, survival, establishment, and spread, and the magnitude of the ecological consequences within 5, 10, 20 and 50 years from 2014 (i.e., the baseline year) to the connected Great Lakes basin (defined as the Great Lakes basin and its tributaries to the first impassable barrier; risk was assessed based on current climate conditions and at the individual lake scale but does not address a finer geographical scale (e.g., bay or sub-region).
- For triploid Grass Carp, the probability of occurrence (likelihood of arrival, survival, and spread) was assessed, and for diploid Grass Carp the probability of introduction (likelihood of arrival, survival, establishment and spread) was assessed.

Arrival:

- Grass Carp (both triploid and diploid) have arrived from outside the Great Lakes basin to two lake basins: lakes Michigan and Erie, but the pathways are not clear.
- The most likely point of direct arrival for triploid and diploid Grass Carp into the Great Lakes basin is through the Chicago-Area Waterway System (CAWS) to Lake Michigan.
- The most likely vector of arrival for triploid and diploid Grass Carp to Lake Erie is human-mediated release.
- Likelihood of arrival to Lake Ontario is low at 5 years for both triploid (human-mediated release) and diploid (physical connections) Grass Carp, and increases to moderate at 10 (triploid) and 50 (diploid) years. Likelihood of arrival to lakes Superior and Huron by 50 years is considered to be very unlikely to low for both triploid and diploid Grass Carp.
- Regulations and their effective enforcement are important factors that may affect the likelihood of arrival.

Survival:

- Based on thermal tolerance, food availability, predation, pathogens and diseases, adult and juvenile (both triploid and diploid) Grass Carp will survive in the Great Lakes; there are no known factors that would preclude survival.
- Survival at northern latitudes of Lake Superior is less certain based on some climate-based models.

Establishment:

- Triploid Grass Carp are not expected to establish because they are sterile (failed triploids are considered as diploids).
- Evidence exists for the conditions to support establishment of diploid Grass Carp, such as, but not limited to, existence of spawning habitat, potential for positive population growth, and overwinter survival of early life stages.

- Establishment requires relatively few diploid individuals if older age classes are introduced. Population growth is most sensitive to the survivorship of juveniles.
- Likelihood of establishment by 5 years is high for Lake Erie due to evidence of recruitment in Lake Erie.
- For lakes Michigan, Huron, Erie and Ontario, the likelihood of establishment is very likely by 10 years.
- In contrast, the likelihood of establishment in Lake Superior remains low at 50 years given the low probability of overwinter survival and inability to mature based on current climate, which will limit establishment.

Spread:

- No known impediments to spread exist among the lakes.
- Spread to other Great Lakes in the basin is a concern based on the arrival of Grass Carp in lakes Erie and Michigan.
- Expect significant lake-to-lake movement within 10 years (Lake Michigan to Lake Huron); movement will be influenced by habitat and food availability, especially across lakes Michigan, Huron, and Erie.
- Possible movement expected between lakes Huron and Superior and from Erie to Huron, but less likely between Ontario and Erie (Welland Canal).

Ecological Consequences:

- Consumption of aquatic vegetation by Grass Carp (both ploidies) may lead to consequences to elements of the biotic community (high potential consequence was predicted for 33 of 136 fishes assessed; and for 18 of 47 bird species assessed) and abiotic environment.
- The ecological consequences for triploid Grass Carp for all lakes were ranked as negligible at the lake-scale for all time periods because of inability to establish.
- It is important to note that effects may be greater within localized wetlands if Grass Carp (regardless of ploidy) aggregate in these areas.
- Ecological consequences depend on the predicted density of Grass Carp to occur in each lake.
- Lakes Michigan, Huron, Erie, and Ontario are most likely to experience increasing ecological consequences within 20–50 years.

Overall Risk:

- Under current conditions, the overall risk for triploid Grass Carp ranges from low (lakes Superior, Huron and Ontario) to medium (lakes Michigan and Erie) for all years.
- Under current conditions, the overall risk for diploid Grass Carp is low for all lakes within 5 years, but increases to high for Lake Ontario and extreme for lakes Michigan, Huron and Erie, at 50 years.
- If the rate of arrival increases, the onset and magnitude of risk will increase.
- Lakes Michigan and Erie are at greater risk relative to the other lakes.

Overarching Conclusions:

- Grass Carp has arrived to the Great Lakes basin (lakes Michigan and Erie) and the invasion process has begun.
- There is an expected time lag associated with the full ecological consequences of an established population of Grass Carp in the Great Lakes basin.
- Immediate preventative actions would be most effective, especially in conjunction with control activities where Grass Carp have arrived, to reduce the probability of establishment and delay or reduce subsequent ecological consequences.

INTRODUCTION

The Great Lakes have not been immune to the arrival of aquatic invasive species (AIS). As of 2016, there are over 180 non-native species reported in the Great Lakes basin (Figure 1; GLANSIS 2015). 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 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 AIS (Ricciardi et al. 2011).

A responsibility of Fisheries and Oceans Canada (DFO) is to identify potential invaders to all parts of Canada, assess their ecological risk, and provide science advice for preventing the introduction of those species considered to be high risk. Asian carps, which refers collectively to Grass Carp (*Ctenopharyngodon idella*), Bighead Carp *(Hypophthalmichthys nobilis*), Silver Carp (*H. molitrix*), and Black Carp (*Mylopharyngodon piceus*), have been identified by Mandrak and Cudmore (2004), Nico et al. (2005), Conover et al. (2007), Kolar et al. (2007), Chapman and Hoff (2011), and Cudmore and Mandrak (2011), as species that threaten to invade the Great Lakes basin.

DFO's Asian Carp Program (2012–2017) is specifically tasked with preventing the introduction, establishment, and spread of Asian carps to the Great Lakes. Risk assessments represent a key action to meet these goals of the program as it generates valuable science advice for managers and decision makers that enables informed decision-making and focuses management efforts. An earlier risk assessment of Asian carps in Canada, which included Grass Carp, identified broad potential risks to Canada, including the Great Lakes (Mandrak and Cudmore 2004). While this previous risk assessment provided insight into the risk faced by broad areas of Canada, knowledge gaps were identified. Given this, and the increasing threat of Grass Carp introduction, DFO, through the Asian Carp Program, identified the need for a peer-reviewed binational ecological risk assessment of Grass Carp for the Great Lakes basin. This project was vetted through the Asian Carp Regional Coordinating Committee and coordinated by the Great Lakes Fishery Commission. Experts from Fisheries and Oceans Canada, the U.S. Geological Survey (USGS) and the U.S. Fish and Wildlife Service participated as authors of the risk assessment.

The scope of this ecological risk assessment was informed by workshop participants consisting of Great Lakes researchers, managers, and decision makers who participated in two workshops (June 2014 and December 2014).Through these workshops, targeted management questions (Tables 1–4) were also obtained to ensure the risk assessment would provide as useful advice as possible to address the needs of managers and decision makers throughout the Great Lake basin. The risk assessment considered the available information known about Grass Carp to assess the likelihood of arrival, survival, establishment, and spread, and the magnitude of the ecological consequences within 5, 10, 20, and 50 years from 2014 (i.e., the baseline year) to the connected Great Lakes basin (defined as the Great Lakes and its tributaries up to the first impassable barrier (Neeson et al. 2015; Figure 2). For this assessment, Lake St. Clair was considered to be part of the Lake Erie basin. Although the risk assessment targets the Great Lakes basin as a whole, the risk assessment also takes into account each Great Lake separately, where appropriate. The two ploidies of Grass Carp found in North America, functionally sterile triploids (with three sets of chromosomes) and fertile diploids (with two sets of chromosomes), were considered separately in the risk assessment where appropriate. For the purposes of this risk assessment, fish that have failed triploid induction were considered diploid fishes.

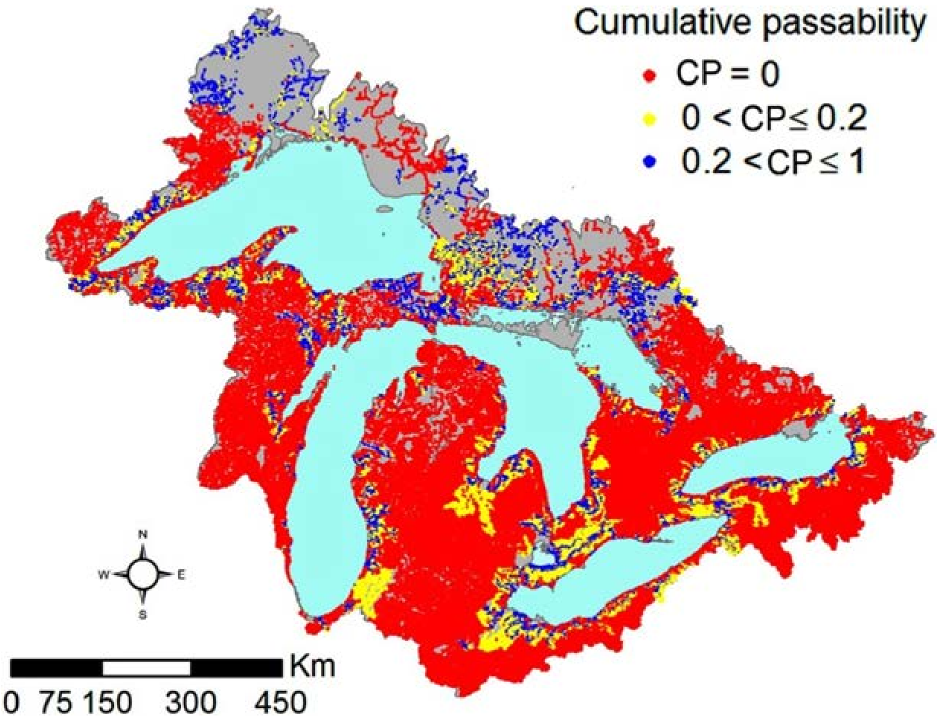

Figure 2. The cumulative passability (CP) of 6,692 dams and 232,068 road crossings in the Great Lakes basin. Nearly 87% of the total river channel length is at least partially inaccessible to adfluvial fishes (CP < 1), including 64% that is entirely inaccessible (CP = 0) (Neeson et al. 2015). Grey background represents areas without barriers or lacking barrier data. For the purposes of this risk assessment, the connected Great Lakes basin is defined as the Great Lakes and its tributaries up to the first impassable barrier (i.e., where yellow or blue changes to red). To address the unique circumstance of the Chicago-Area Waterway System (CAWS), the extent of the Great Lakes basin for this risk assessment ends at the Chicago Lock and O'Brien Lock and Dam, and the mouths of the Grand Calumet and Little Calumet Rivers.

This ecological risk assessment focused only on the ecological consequences; the socioeconomic consequences will be assessed separately using the results of the ecological risk assessment. It also addresses only the current state of the system and management measures that were in place during the scoping of the risk assessment (baseline year = 2014). It does not assess effectiveness of any measures currently in place, nor the level of risks associated with any potential management measures that are not currently in place. This document represents the science advice from the risk assessment on prevention, monitoring, early detection, and management actions that are underway or could be taken and is intended for use by decision makers who will use this and other information and advice for decision making.

ASSESSMENT

The format of this binational ecological risk assessment of Grass Carp for the Great Lakes basin follows guidance provided in the National Detailed-Level Risk Assessment Guidelines: Assessing the Biological Risk of Aquatic Invasive Species in Canada (Mandrak et al. 2012). This process serves to summarize the best available information and identify the relative risks posed to a specified area within a specified timeframe by a non-native species. Mandrak et al. (2012) divides the risk assessment process into two steps:

1) Estimating the probability of introduction (using likelihood of arrival, survival, establishment, and spread); and,
2) The determination of the magnitude of the ecological consequences if the species was introduced.

Following a similar approach to Mandrak et al. (2012), the Grass Carp risk assessment was divided into two steps:

1) Estimating the probability of occurrence for triploids (using likelihood of arrival, survival, and spread) or probability of introduction for diploids (using likelihood of arrival, survival, establishment, and spread) for each lake; and,
2) Determining the magnitude of ecological consequences of triploid and diploid Grass Carp based on the consequence thresholds associated with estimated population size and the area of submerged aquatic vegetation (SAV) in each lake.

The evaluation of the probability of occurrence, probability of introduction, and magnitude of the ecological consequences are based on qualitative scales and includes a corresponding ranking of certainty of data (see Tables 1–3 in Cudmore et al. 2017)

For triploid Grass Carp, the overall probability of occurrence was determined for each Great Lake by taking the highest ranking between overall arrival and spread, then comparing this rank with the rank of survival, and using the lowest rank of the two. The formula was modified from that presented in Mandrak et al. (2012) to remove the element of establishment, because triploid Grass Carp are functionally sterile and considered unable to form a self-sustaining reproducing population. This is represented by the following formula:

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

For diploid Grass Carp, the overall probability of introduction was determined for each Great Lake by taking the highest ranking between overall arrival and spread, then comparing this rank 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]

If either triploid or diploid Grass Carp was considered to have already arrived to a lake basin, this was denoted with an asterisk in the ranking table of the overall arrival for that Great Lake.

Ecological consequence ratings were based on predicted decreases in SAV area due to increasing Grass Carp densities (see Table 3 in Cudmore et al. 2017). The probability of occurrence and introduction was also considered in the authors' rankings of the magnitude of ecological consequences. The ratings were evaluated separately for each lake based on average Grass Carp densities across the lake, the SAV area currently in each basin, and recommended stocking densities for controlling SAV (see Cudmore et al. 2017). Currently, in each lake, Grass Carp densities are thought to be below thresholds required for a detectable impact. To estimate at what point in time Grass Carp densities might be large enough to have detectable impacts, the total number of Grass Carp required to exceed a consequence threshold was calculated as the product of the threshold densities (i.e., 5, 10, 15 Grass Carp per ha) and the current SAV area for each lake (see Table 16 in Cudmore et al. 2017). The number of years required to reach the threshold population sizes was calculated based on a population growth rate of 1.6 (C. Jerde, UNR, pers. comm.), assuming reproductive success in every second year and seeded with an initial population of 100 (lakes Superior, Huron, and Ontario) and 1,000 individuals (lakes Michigan and Erie) (see Table 16 in Cudmore et al. 2017). Although triploid Grass Carp would not reproduce and create a self-sustaining population, they could have effects for the duration of their life.

The probability of occurrence or probability of introduction and the magnitude of ecological consequences were then combined into a risk matrix to obtain an overall risk for each of triploid and diploid Grass Carp. Each lake was assessed for four different time periods, within 5, 10, 20, and 50 years of the baseline (i.e., 2014), to show any changes in the probability of occurrence or introduction and ecological consequences over these time periods.

The risk assessment rankings and ecological consequence ratings (see likelihood tables in Cudmore et al. 2017) for triploid and diploid Grass Carp are the product of consensus stemming from several steps. First, after reviewing the draft risk assessment research document, each author developed her/his own risk assessment tables for each element for each lake. The likelihood of each element along with the estimated certainty of data was then thoroughly discussed among the authors to reach consensus. This consensus output was presented at the peer-review meeting and was subsequently discussed, modified, and finalized by the authors with consensus input stemming from the peer-review meeting.

Sources of Uncertainty

Knowledge gaps were identified by the authors and additions were made at the peer-review meeting. These knowledge gaps influence the level of certainty when determining the risk of triploid and diploid Grass Carp to the Great Lakes basin and a specific knowledge gap may influence the certainty of data for one or more elements of the risk formulas (see above). Therefore, relative certainty categories reflecting the quality and quantity of data (see Table 2 in Cudmore et al. 2017) were used to qualify each of the rankings in the risk assessment (see likelihood tables in Cudmore et al. 2017). The most important sources of uncertainty are:

- Different life stages of Grass Carp were not assessed specifically for each step in the assessment. Information and knowledge on younger life stages is lacking.
- Given lack of measurement of total monitoring effort, the specific current status of Grass Carp in the Great Lakes basin and surrounding waters is unknown.
- The extent to which biological and behavioural differences exist between triploid and diploid Grass Carp (e.g., mortality, growth, spawning behaviour, movement) is unknown.
- Extent of trade of diploid and triploid Grass Carp is not well understood.
- There is little knowledge on the extent of illegal trade.
- There is little knowledge on the possibility of intentional stocking for cultural or nefarious reasons.
- Information is lacking on the occurrence of Grass Carp in the baitfish industry and bycatch in baitfish harvest, especially on the U.S. side of the basin.
- It is unknown whether Grass Carp would occur in areas of *Cladophora* abundance.

- There are a lack of data on the frequency of suitable spawning conditions in the Great Lakes basin.
- Information on cues to spawn is variable.
- Reproductive behaviour is largely unknown, including how individuals find each other for spawning, and whether a critical number of individuals are required to initiate spawning behaviour.
- The potential for lentic spawning (i.e., where eggs fall to substrate) needs to be further investigated; while it has not been observed in the native range, this does not mean it cannot happen in the introduced range.
- The relationship between overwinter survival (L_{crit} and proportion survival) to thermal survival from environmental niche models is unknown.
- The effect of predation and competition and resource limitation on overwinter survival is not known.
- Whether reproductive movements would enhance or limit spread because of the need to remain close to spawning rivers or due to aggregation of fish because of reproductive behaviour or response to reproductive pheromones.
- There is a lack of knowledge regarding individual movements given there is some variability with individual fish.
- No published studies have been undertaken to directly determine the extent of fish movement through the New York Canal System or the Trent-Severn Waterway.
- Understanding movement of fishes from Lake Erie to Lake Ontario through the Niagara River, by surviving the descent over Niagara Falls, is lacking.
- The depth limits of Grass Carp in lake systems are unknown.
- In general, there is a lack of information on ecological impacts in the wild.
- A comparison of macrophyte species preferences of Grass Carp to macrophyte species requirements of birds is not available.
- Species composition of macrophytes within submerged aquatic vegetation locations within the Great Lakes basin is not known.
- The potential influence of Grass Carp on Zebra Mussel is unknown.
- Further targeted research of the ecological changes associated with Grass Carp is needed, particularly with natural populations in temperate climates and lake systems.
- There is no information available to predict facilitated invasions of other species by Grass Carp and biotic interactions.
- Lack of understanding of lake-specific potential population biology (age to reproduction, spawning temperature patterns, etc.) to inform population growth models for each lake.

Further sources of uncertainty stem from knowledge gaps that limited modelling efforts. In particular, the models describing the probability of spread and establishment of AIS as a result of domestic ballast-water movement and spread of Grass Carp within and between basins both involved assumptions. Models describing the probability of spread and establishment of AIS as a result of domestic ballast-water movement were run for several invasiveness scenarios related to ballast uptake and establishment probability based on propagule density. However, the invasiveness scenarios used were not specifically developed for Grass Carp but represent generic scenarios that can be applied to reflect the ballast uptake and establishment characteristics of a given species. Therefore, uncertainty exists about which scenario best reflects the characteristics of Grass Carp spread as a result of ballast and represents a knowledge gap. Also, models of Grass Carp spread via natural dispersal were not constrained in large-scale dispersion by the low temperatures present in the northern Great Lakes and seasonality of movement that may occur due to the colder temperatures over winter. These factors introduce uncertainty into estimation of the rate of spread within and between basins.

Together, these knowledge gaps informed certainty rankings and resulted in very low to low certainty rankings for some risk elements due to the lack of data and the quality of data that are available. The key areas of uncertainty are:

- The extent and magnitude of human-mediated release (i.e., bait, stocking and trade) into all lakes for both triploid and diploid Grass Carp, where more information and data would strengthen the advice surrounding arrival from this potential entry route (see Table 7 in Cudmore et al. 2017).
- Magnitude of ecological consequences ratings for diploid Grass Carp in all lakes were given low certainty (see Table 17 in Cudmore et al. 2017); further targeted research of the ecological changes associated with Grass Carp is needed, particularly with natural populations in temperate climates and lake systems.

CONCLUSIONS AND ADVICE

Likelihood of Arrival

Entry pathways and vectors assessed were physical connections (canals and waterways, and intermittent or occasional connections around the watershed boundaries), human-mediated release (bait use, trade, stocking of private waters), and ballast water. Grass Carp already captured within the Great Lakes basin were used to inform the likelihood of arrival through the various vectors and pathways, but were not directly evaluated in the ranking assessment.

The likelihood of arrival by physical connections and laker ballast (considers potential for St. Lawrence River Grass Carp populations) was the same for both triploid and diploid Grass Carp, with laker ballast ranked as very unlikely with moderate certainty for all lakes (see Table 7 in Cudmore et al. 2017). For physical connections, Lake Michigan ranked as very likely, as the most likely point of direct arrival into the Great Lakes basin is through the CAWS; very unlikely to low for lakes Superior and Huron; and, low to moderate for lakes Erie and Ontario (see Table 7 in Cudmore et al. 2017).

Arrival by human-mediated release was similar for triploid and diploid Grass Carp; however, the likelihood was ranked higher for triploid Grass Carp for lakes Erie (very likely) and Ontario (low to moderate) due to the higher risk of triploid stocking. For both triploid and diploid Grass Carp, lakes Superior and Huron were ranked very low to low and low, respectively, while Lake Michigan was ranked high.

Overall likelihood of arrival for triploid and diploid Grass Carp was highest for lakes Michigan (physical connection to the CAWS where fish are resident) and Erie (stocking for triploid and stocking and bait for diploid). It is important to note that for this risk assessment, the invasion process for triploid and diploid Grass Carp is considered to be at the ‘arrival’ stage for lakes Erie and Michigan, as repeated detections of at least one Grass Carp in at least one part of the lake basin within a continuous 5-year period has occurred in each of these lakes (see Table 7 in Cudmore et al. 2017); however, the vector/pathway of arrival remains unknown. For the remaining Great Lakes, the invasion process is considered at 'pre-arrival' for both triploid and diploid Grass Carp (see Table 7 in Cudmore et al. 2017).

Likelihood of Survival

Survival is defined as individuals do not die upon arrival and adults live through winter months in the Great Lakes basin. Given a lack of information on differences between triploids and diploids pertaining to factors influencing likelihood of survival, both triploids and diploids were treated similarly in the assessment of survival, and the associated rankings and certainties are the same (see Table 9 in Cudmore et al. 2017).

Based on information on thermal tolerance, food availability, predation, pathogens, and diseases, the likelihood of survival was ranked very likely with very high certainty for all of the Great Lakes except for Lake Superior, which was ranked high with very high certainty (see Table 9 in Cudmore et al. 2017).

Likelihood of Establishment

Establishment was assessed independently of other elements in the introduction process and is evident by a self-sustaining population which is defined as the occurrence of individuals spawned within the Great Lakes basin subsequently reproducing. The establishment of triploid Grass Carp was ranked very unlikely with high certainty as they are considered functionally sterile for management purposes and would likely not become established in any of the Great Lakes regardless of the amount of time into the future (see Table 11a in Cudmore et al. 2017). Failed triploids are considered as diploids.

For diploid Grass Carp, the likelihood of establishment at the 5-year time period was ranked very unlikely (Superior, Huron, Ontario) to low (Michigan) for all lakes except for Lake Erie, which was ranked high given the recent evidence of Grass Carp recruitment in Lake Erie (see Table 11b in Cudmore et al. 2017). Certainty varied by lake at the 5-year time period from low to very high. Given the availability of suitable spawning and overwinter conditions the likelihood of establishment for later time periods (10, 20 and 50 years) was ranked very likely for all lakes except for Lake Superior (low) and certainty varied from moderate to high (see Table 11b in Cudmore et al. 2017).

Likelihood of Spread

The likelihood of spread (between lakes, e.g., into Lake Superior from other lakes) was assessed based on the best available scientific information about natural dispersal (i.e., volitional swimming of individual fish) and movement through canals, laker ballast, or human-mediated vectors (i.e., baitfish introductions). Spread is defined as the movement of individuals or expanding populations into new areas within the basin, between lakes; but not into the basin, as this is arrival. Triploid and diploid Grass Carp were treated the same, as inadequate information exists to make a substantive comparison in likelihood of spread between triploid and diploid fish based on individual movement. The rankings for the likelihood of spread into a lake were mainly informed by the current knowledge of Grass Carp occurrences in and around the Great Lakes basin and the spread model, which had the two most likely starting points for spread in the basin as southern Lake Michigan (at the CAWS) and south western Lake Erie (the Maumee River). As such, certainty was ranked as moderate for all lakes and time steps for both triploid and diploid Grass Carp.

The likelihood of triploid Grass Carp spreading to lakes Superior, Michigan, and Erie from another Great Lake was ranked very unlikely given the lack of triploid Grass Carp in adjacent lakes (see Table 12a in Cudmore et al. 2017). Lake Huron was ranked moderate (5 and 10 years) to high (20 and 50 years) given the occurrence of triploid Grass Carp in lakes Michigan and Erie and the results of the spread model by Currie et al. (2017). Spread to Lake Ontario was ranked very unlikely for 5 and 10 years and increased to low likelihood at 20 years given the occurrence of triploid Grass Carp in Lake Erie (see Table 12a in Cudmore et al. 2017).

Spread of diploid Grass Carp to lakes Superior, Michigan, Erie, and Ontario was ranked very unlikely to moderate, given the low opportunity for diploid fishes to spread to these lakes from the adjacent lake basins (see Table 12b in Cudmore et al. 2017). The likelihood of spread of both triploids and diploids to Lake Huron was ranked higher than all other lakes (see Table 12 in Cudmore et al. 2017) given its proximity to the increasing occurrences of both triploids and diploids (similar ploidy ratio of captures fishes) within western Lake Erie and southern Lake Michigan.

Overall Probability of Occurrence (triploid) and Introduction (diploid)

As the Great Lakes are interconnected, the overall probability of occurrence and introduction was ascertained by first determining the highest ranking between overall arrival and spread (see Table 13 in Cudmore et al. 2017).

For triploid Grass Carp, the probability of occurrence (Min [(Max (Arrival, Spread)), Survival]) was considered to be least likely for lakes Superior and Ontario, most likely in lakes Michigan and Erie, and of moderate to high likelihood for Lake Huron (see Table 14a in Cudmore et al. 2017). The increase in rank for lakes Superior and Ontario reflect the potential for arrival over time through stocking, while the increase for Lake Huron reflects the potential for spread from lakes Erie and Michigan (see Table 14a in Cudmore et al. 2017).

For diploid Grass Carp, the probability of Introduction (Min [(Max (Arrival, Spread)), Survival, Establishment]) by 5 years was driven mainly by the likelihood of establishment and ranked from very unlikely to low, except for Lake Erie (moderate) which was driven by the likelihood of arrival (see Table 14b in Cudmore et al. 2017). By 10 and 50 years, lakes Michigan and Huron were ranked very likely, respectively (see Table 14b in Cudmore et al. 2017). By 50 years, Lake Erie was ranked as high given the likelihood of arrival, while lakes Ontario and Superior were ranked moderate and low, respectively (see Table 14b in Cudmore et al. 2017). Overall, the increase in ranks over time reflects the potential accrual of Grass Carp through arrival, establishment and spread.

Magnitude of Ecological Consequences

The magnitude of ecological consequences of triploid Grass Carp in the Great Lakes was rated as negligible with moderate certainty (see Table 17a in Cudmore et al. 2017). This rating was based on the following: current densities have had an undetectable effect; the low likelihood of influx of triploids over time because of distance from intensive and permitted stocking facilities; and, the limitation of consequences to an individual's lifespan. Even if a substantial number of triploid Grass Carp were released into the Great Lakes, threshold values for ecological consequences would likely not be passed and ecological consequences would remain negligible at the lake-wide scale. However, it is important to note that effects may be greater within localized wetlands if Grass Carp populations aggregate in these areas.

We expect similar ecological consequences on an individual basis for triploids and diploids; however, the increase in the magnitude of ecological consequences over time for diploids is linked to growing population sizes. Thus, for diploid Grass Carp, increasingly higher ratings were given for lakes Michigan, Huron, Erie, and Ontario over time, reaching extreme by 50 years (see Table 17b in Cudmore et al. 2017). Lake Superior remained negligible over time (see Table 17b in Cudmore et al. 2017) given the low probability of introduction. Based on the assessment of the potential impacts of Grass Carp foraging, should Grass Carp establish in the Great Lakes, managing Grass Carp density may be a better approach than targeting larger individuals.

Overall Risk

The overall probability of occurrence and introduction and the magnitude of the ecological consequences were combined to obtain a final overall risk matrix for triploid (Figure 3) and diploid (Figure 4) Grass Carp for each lake taking into account 5, 10, 20, and 50 year time periods from the risk assessment baseline (i.e., 2014).

Overall risk for triploid Grass Carp was low (green) for all lakes for all time periods (Figure 3). The likelihood of occurrence was very likely for lakes Michigan and Erie for all time periods and it is noted that arrival is already considered to have occurred in these two lakes. Ranks for likelihood of occurrence increased for all other lakes over time. The magnitude of ecological consequences remained negligible for all lakes over all time periods, as triploids are functionally sterile for management purposes. Even if an influx of triploid Grass Carp to the Great Lakes basin was to occur (although not expected) it is not expected to surpass consequence thresholds for any of the lakes over any of the time periods, although localized impacts within certain areas of a lake may be significant.

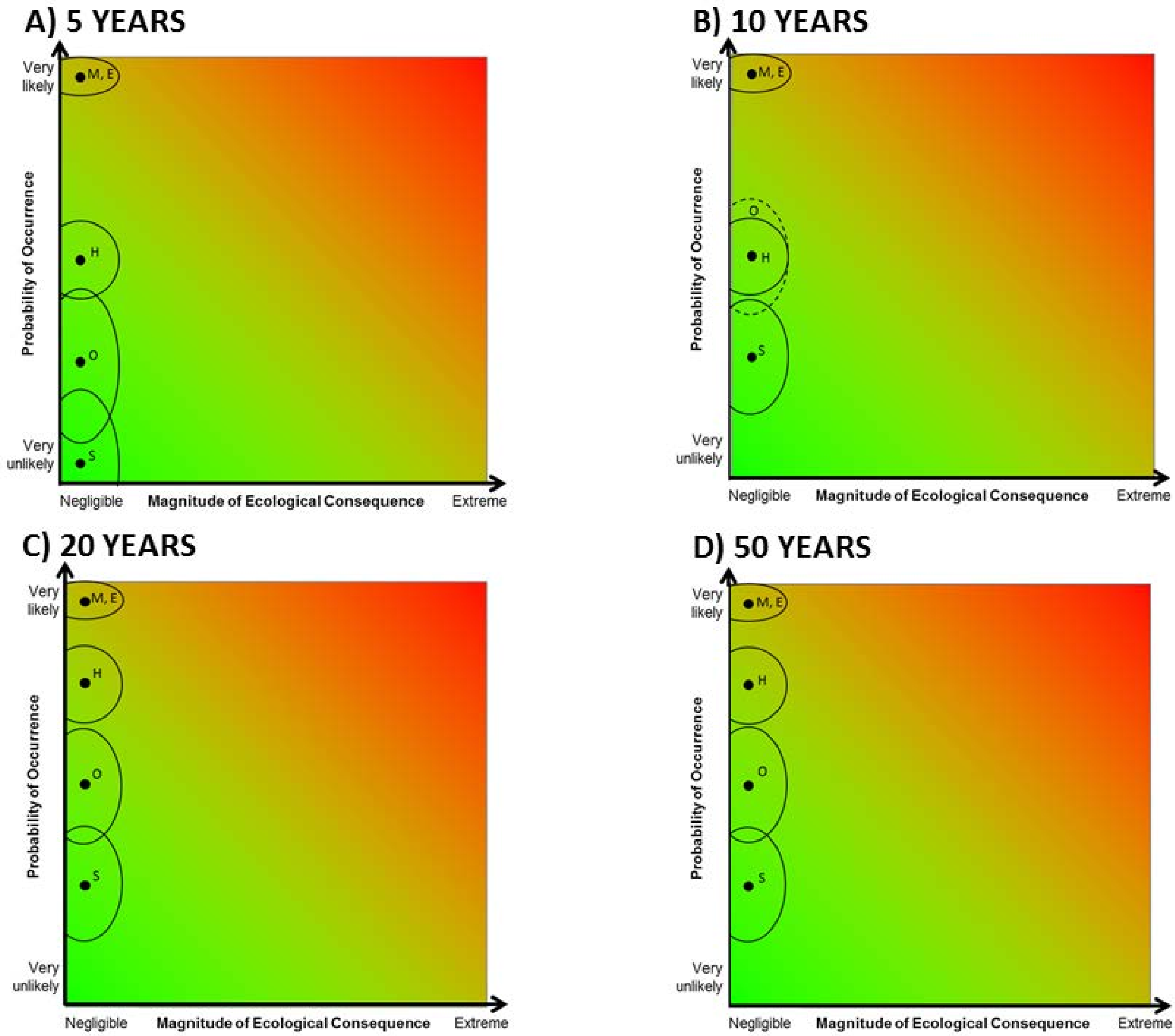

Figure 3. Probability of occurrence and magnitude of the ecological consequences for triploid Grass Carp over A) 5 years, B) 10 years, C) 20 years and D) 50 years from the baseline (i.e., 2014) as a graphic representation to communicate risk for triploid Grass Carp. S = Lake Superior, M = Lake Michigan, H = Lake Huron, E = Lake Erie, O = Lake Ontario; ellipses are representative of amount of certainty of data around ranks with broader ellipses representing greater uncertainty of data. Overall Risk: Green = Low Risk; Yellow = Medium Risk; Orange = High Risk; Red = Extreme Risk (Modified from Mandrak et al. 2012). Note: Grass Carp is considered to have already arrived to lakes Michigan and Erie.

Overall risk for diploid Grass Carp increases over time from low (green) to high (orange) and extreme (red) for all lakes except Lake Superior, which remains low (green) (Figure 4). The probability of introduction for lakes Michigan and Huron increases to very likely at 10 and 50 years, respectively, while lakes Erie and Ontario increase to high at 20 years, and moderate by 50 years, respectively (Figure 4). The magnitude of ecological consequences increases from negligible to extreme by 50 years for lakes Michigan, Huron, Erie, and Ontario (Figure 4), as they reach the estimated consequence density thresholds and based on the current Grass Carp occurrences and probability of introduction. Lake Superior remains negligible over time given the low likelihood of introduction (Figure 4).

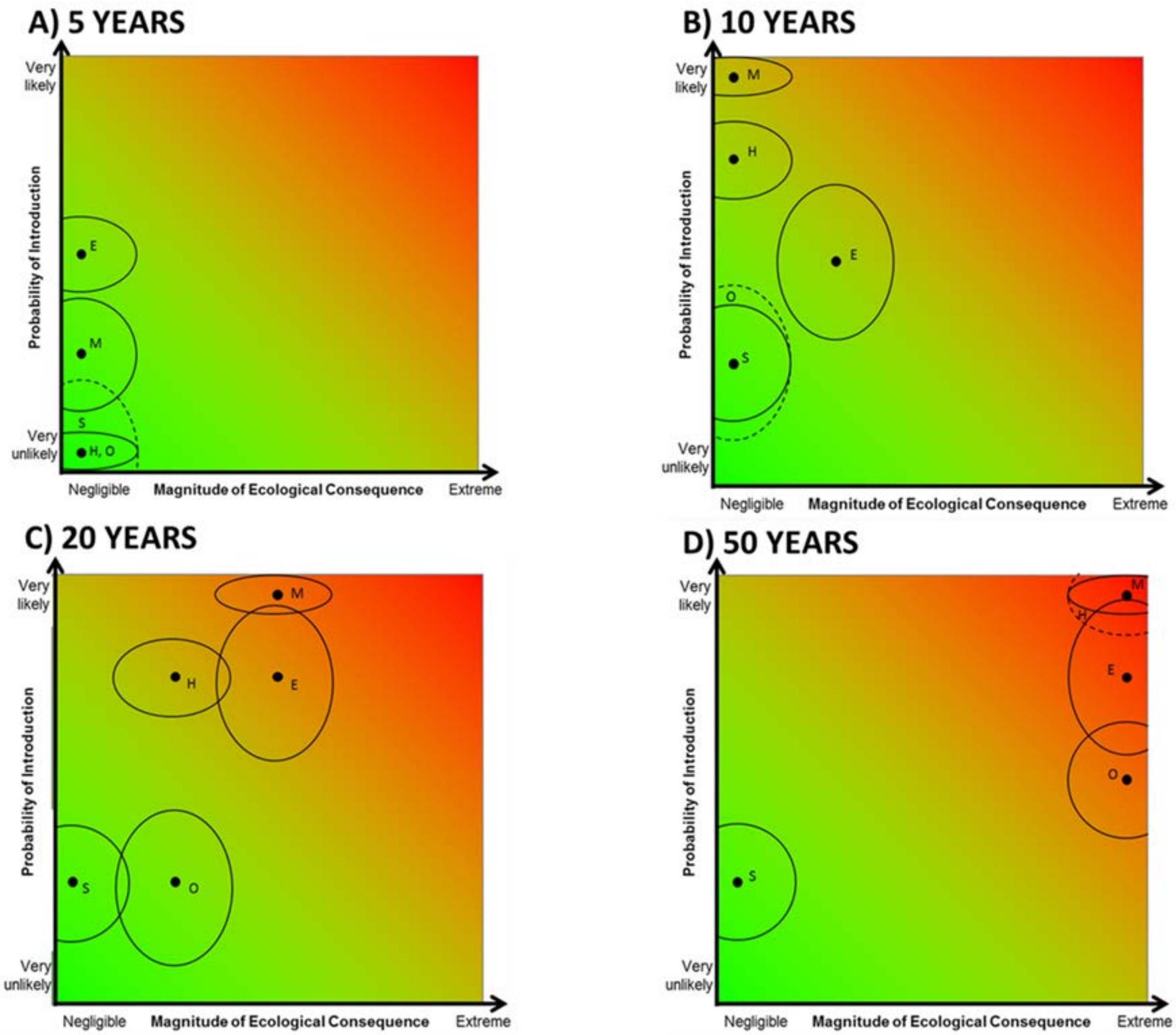

Figure 4. Probability of introduction and magnitude of the ecological consequences for diploid Grass Carp over A) 5 years, B) 10 years, C) 20 years and D) 50 years from the baseline (i.e., 2014) as a graphic representation to communicate risk for diploid Grass Carp. S = Lake Superior, M = Lake Michigan, H = Lake Huron, E = Lake Erie, O = Lake Ontario; ellipses are representative of amount of certainty of data around ranks with broader ellipses representing greater uncertainty of data. Overall Risk: Green = Low Risk; Yellow = Medium Risk; Orange = High Risk; Red = Extreme Risk (Modified from Mandrak et al. 2012). Note: Grass Carp is considered to have already arrived to lakes Michigan and Erie.

Targeted Management Questions

Specific management questions from Great Lakes managers and decision makers were also compiled and, where feasible, addressed during the ecological risk assessment process. These questions and science advice were categorized under the most appropriate risk assessment element (e.g., arrival, survival, establishment) and are presented in the following tables (Tables 1–6).

Arrival

Table 1. Summary of science advice to management questions presented by Great Lakes managers and decisions makers on arrival and location within the risk assessment document where the advice can be found.

Management Question	Summary of Answer
What are the comparative risks for the different pathways of arrival?	Physical connections and human-mediated release represent higher likelihood than laker ballast (very unlikely); however, it is important to note that lower certainty was generally associated with ranks for human-mediated release. See Section 2.1.4 and Table 7 of the risk assessment document (Cudmore et al. 2017).
Which pathway is highest risk for arrival?	The likelihood ranks varied by ploidy and lake; however, the most likely point of direct arrival into the Great Lakes basin is through the CAWS to Lake Michigan due to the proximity of established and invading Grass Carp populations within this connection, including in locations above the electric barrier. See Section 2.1.4 and Table 7 of the risk assessment document (Cudmore et al. 2017).
Pathways such as: illegal trade, interstate hauling, stocking, trade of live organisms, aquaculture facilities in basin, hydrologic connections and ballast water should be addressed.	Not all pathways were able to be addressed and for some only a partial assessment was possible due to lack of data. Those that were addressed in whole or in part include: physical connections, locations of Grass Carp producers and distributors, barge voids, bait use, trade and stocking, and laker ballast. Note that pathways were assessed in the context of arrival and spread; see Section 2.1 and 2.4 of the risk assessment document (Cudmore et al. 2017).
How many Grass Carp are in the Great Lakes?	This is unknown. Known captures of Grass Carp in the Great Lakes basin, as reported to USGS, are depicted in Figure 1 of the risk assessment document (Cudmore et al. 2017), but may simply be a reflection of search effort.
Where are they?	Known captures of Grass Carp in the Great Lakes basin, as reported to USGS, are depicted in Figure 1 of the risk assessment document (Cudmore et al. 2017). It is important that all Great Lakes jurisdictions report Grass Carp captures to USGS in a timely fashion.

Management Question	Summary of Answer
Where are they from?	Limited information exists on origin. For those assessed: Lake Erie - some diploid Grass Carp recruited from Great Lakes tributaries are the descendants of escaped or illegally introduced diploid fish, and captured triploid fish were escaped or intentionally introduced fish originating in aquaculture (Whitledge 2014). Lake Michigan - some Grass Carp assessed were consistent with aquaculture origin and implies escape or release of illegally imported Grass Carp (Whitledge 2014). Some in the CAWS that came from aquaculture are reproducing in the CAWS. See Section 2.1.1 of the risk assessment document (Cudmore et al. 2017).
What is their ploidy?	Known captures of Grass Carp in the Great Lakes basin with ploidy status as reported to USGS are depicted in Figure 4 of the risk assessment document (Cudmore et al. 2017). It is important that all Great Lakes jurisdictions report Grass Carp captures and submit samples for ploidy testing to USGS in a timely fashion. Established protocols for ploidy determination of wild caught fish should be followed (e.g., Asian Carp Regional Coordinating Committee Monitoring and Response Plan and Mississippi River Basin Panel on Aquatic Nuisance Species protocols). See USGS Nonindigenous Aquatic Species (NAS) database.
What are the detection limits?	Unknown.
What are the existing regulatory processes and law enforcement issues?	Regulations regarding Grass Carp are inconsistent across the basin making enforcement complicated. See Tables 4 and 5, and Figure 5 of the risk assessment document (Cudmore et al. 2017).
Are regulations by state and province effective?	Effectiveness of regulations was not assessed.

Management Question	Summary of Answer
What are the implications of interstate transport?	Did not address in this risk assessment given lack of information. See Mississippi Interstate Cooperative Resource Association report for more information (MICRA 2015).
How many diploids are in triploid legal trade?	Not well documented but see publications with measureable amounts of diploids (Whitledge et al. 2014, MICRA 2015). See Section 2.1.2.2 of the risk assessment document (Cudmore et al. 2017).

Survival

Table 2. Summary of science advice to management questions presented by Great Lakes managers and decisions makers on survival and location within the risk assessment document where the advice can be found.

Management Question	Summary of Answer
Are the Great Lakes too cold?	No. The environmental niche models assessed generally predicted survival of Grass Carp in even the northern-most areas of the Great Lakes.
Are the right environmental conditions available?	Yes.
What are the survival rates in the Great Lakes?	Survival rates are high for fish that have reached age 1+ (Jones et al. 2017).
What do they eat (preferences)?	Grass Carp feeds primarily on macrophytes as adults and is selective in its consumption of plant species, preferring submerged plants with soft leaves. Juvenile Grass Carp feed mainly on plants but, also consume animal prey (chironomids, cladocerans, copepods, insects and their aquatic larvae, crustaceans, and small fishes). See Section 2.2.3 of the risk assessment document (Cudmore et al. 2017).

Management Question	Summary of Answer
Is there enough food and where?	Yes. The Great Lakes as a whole are not dominated by low marsh habitat, but substantial areas with macrophytes that could be consumed by Grass Carp are present in all of the Great Lakes with a total wet weight biomass of approximately 2.5 to 4.5 million metric tonnes across the lakes. See Section 2.2.3 and Figure 20 of the risk assessment document (Cudmore et al. 2017).
What are the predation rates on Grass Carp at different life stages?	No research has directly assessed predation on Grass Carp in North America but Grass Carp are unlikely to be susceptible to most predators for very long relative to their lifespan given rapid growth rates. See Section 2.2.4 of the risk assessment document (Cudmore et al. 2017).
Are there diseases/pathogens that affect their survival?	Currently, there are no known significant diseases or pathogens present in the Great Lakes basin that would prevent the survival of Grass Carp. See Section 2.2.5 of the risk assessment document (Cudmore et al. 2017).
Do triploid and diploid differ in growth?	Unknown in natural/wild environments.

Establishment

Table 3. Summary of science advice to management questions presented by Great Lakes managers and decisions makers on establishment and location within the risk assessment document where the advice can be found.

Management Question	Summary of Answer
What number of individuals is needed to establish a population?	Model results (with assumptions) indicate very few 1+ age-class individuals may be needed to establish a population within 20 years and relatively low numbers of individuals are required regardless of probability of spawning suitability (Jones et al. 2017). See Section 2.3.2 and Figure 26 in the risk assessment document (Cudmore et al. 2017).
How does a combination of diploids and triploids influence the probability of establishment?	Unknown.
What egg survival rate is needed?	Unknown. Establishment model used fecundity, not rate of egg survival (Jones et al. 2017).

Management Question	Summary of Answer
Can juveniles survive overwinter?	Yes, models indicate that each Great Lake exhibits at least one location where survival is expected to occur with high confidence, but not in northern latitudes of lakes Superior and Huron (under current climate conditions). Furthermore, all sites where spawning was initiated have relatively high probability that at least one cohort, out of all the cohorts hatched across a 20-year period, will survive the winter period on the basis of temperature ($P > 0.75$). See Section 2.3.4 in the risk assessment document (Cudmore et al. 2017). See Jones et al. (2017).
Where will Grass Carp be most abundant?	Nearshore waters with SAV (but limited in northern latitudes under current climate conditions). See Figure 31 in the risk assessment document (Cudmore et al. 2017).
What characteristics make for suitable spawning tributaries and nursery habitat?	General knowledge exists on characteristics of suitable spawning tributaries and suitability of several Great Lakes tributaries for Asian carp has been assessed. See Section 2.3.1 in the risk assessment document (Cudmore et al. 2017). See also Mandrak et al. (in prep.).
Are nursery habitats close to spawning tributaries?	Yes. See Figure 24 (map of suitable Canadian spawning tributaries and the distribution of coastal wetlands) in the risk assessment document (Cudmore et al. 2017).

Management Question	Summary of Answer
What/how many tributaries would support spawning and recruitment?	Suitable spawning tributaries are found in all lakes. **U.S.**: 22 suitable spawning tributaries in U.S. Great Lakes are unimpounded from mouth to at least 100 km upstream. More detailed analyses of Lake Erie tributaries suggest 7 out of 8 would provide suitable spawning habitat and more recent evidence suggests that river length to spawn may be much shorter. See Kolar et al. (2007), Kocovsky et al. (2012), Murphy and Jackson (2013), Chapman et al. (2013), Garcia et al. (2013), George and Chapman (2015). **Canada:** 52 tributaries in Canadian Great Lakes are unimpounded from mouth to at least 80 km upstream. More detailed analyses of tributary characteristics suggest that suitable spawning conditions exist in at least 51 Canadian Great Lakes tributaries. Unlikely for Asian carps to mature within majority of Lake Superior tributaries. See Cudmore and Mandrak (2011), Mandrak et al. (in prep.).
Could they spawn directly in the Great Lakes?	The potential for lentic spawning (i.e., where eggs fall to substrate) is a knowledge gap that needs to be further investigated. No current evidence that they could spawn directly in the Great Lakes. See Section 2.3.1 in the risk assessment document (Cudmore et al. 2017).
Do triploids exhibit spawning behaviour?	Unknown.
Is there an Alleé effect and if so, how large is it?	Unknown.
What is the proportion of diploids in triploid stocking?	Not well documented, but see publications with measureable amounts of diploids (Whitledge et al. 2014, MICRA 2015). See Section 2.1.2.2 of the risk assessment document (Cudmore et al. 2017).

Spread

Table 4. Summary of science advice to management questions presented by Great Lakes managers and decisions makers on spread and location within the risk assessment document where the advice can be found.

Management Question	Summary of Answer
What is the timeframe and direction of spread, not only between but also within lakes?	Varies depending on arrival point and movement rates modelled, but predicted to be within 5–10 years to reach another basin and within 5 years from introduction location to completely occupy high-quality habitat within the lake (natural dispersal model only; Currie and Koops model in Currie et al. 2017). Direction of spread likely Michigan to Huron to Erie (CAWS introduction) and Erie to Ontario (Maumee River introduction) (Currie and Koops model in Currie et al. 2017).
How will spread differ depending on the point of arrival?	Two modelled arrival scenarios: southwestern Lake Michigan (near the CAWS) and western Lake Erie (near mouth of Maumee River); spread is faster from Lake Michigan than from Lake Erie with associated assumptions (Currie and Koops model in Currie et al. 2017). See previous question.
How do they spread?	Spread via natural dispersal, and movement through canals, laker ballast, and baitfish introductions were assessed. See Section 2.4 of the risk assessment document (Cudmore et al. 2017).
Have current fish captured in Great Lakes spread or were they placed in each lake? *Interpreted as: for the fish captured in the Great Lakes, what were their origins/how did they get there? (see question in Arrival above)*	It is assumed, based on best available information, that Grass Carp from lakes Michigan and Erie came from outside the Great Lakes basin; Grass Carp captured in Lake Huron likely spread from Lake Erie or were released; and, Grass Carp captured from Lake Ontario were directly released. However, firm evidence is lacking. See answers to similar questions in Arrival section above.
Is spread different for diploids and triploids?	Unknown.

Management Question	Summary of Answer
Can they spread through canals?	Movement studies suggest that migratory fishes can move through the St. Marys lock and dam complex and, thus, movement between Lake Superior and Huron basins appears possible. Conversely, there was no documented movement of fishes between the Lake Erie and Ontario basins through the Welland Canal. Although fishes did move between the canal and each lake, very few moved through the flight locks. Movement through other relevant canal systems is unclear. See Section 2.4.2 of the risk assessment document (Cudmore et al. 2017), and Currie et al. (2017).
How long before they reach Canadian waters?	Based on modelling results: less than 10 years after arrival into the connected Great Lakes basin via Lake Michigan and within one year if arrival is through western Lake Erie (Currie and Koops model in Currie et al. 2017). Note: 3 recent captures in Grand River, Ontario (2013: 2 captures; 2014: 1 capture).

Ecological Consequences

Table 5. Summary of science advice to management questions presented by Great Lakes managers and decisions makers on ecological consequences and location within the risk assessment document where the advice can be found.

Management Question	Summary of Answer
How many wetlands are there for Grass Carp to use?	Gertzen et al. (2017) estimated that approximately 2.5–4.5 million metric tonnes of aquatic vegetation exist in the Great Lakes at peak annual abundance (approximately August). See Figure 31 of the risk assessment document (Cudmore et al. 2017).
Are wetlands connected and would they be lost?	Modelling efforts predicted that complete elimination of vegetation would occur in few areas (typically less than 5% of areas) but substantial reductions in peak aquatic biomass were predicted in many scenarios (Gertzen et al. 2017). See Figure 32 of the risk assessment document (Cudmore et al. 2017).

Management Question	Summary of Answer
Will there be a shift in dominant plant species?	Potentially. Following depletion of preferred food items in one feeding ground, Grass Carp has been shown to move to another feeding ground. Within a few years of introduction, plants such as pondweed, hornwort, water milfoil, and duckweed disappeared, and toxic plants and nuisance hydrophytes became more abundant. See Section 3.1 of the risk assessment document (Cudmore et al. 2017)
Will plant composition change?	Potentially. Grass Carp can influence macrophyte composition through selective feeding behaviour. Grass Carp has a preference for plants with soft tissues and long, thin morphology (Wiley et al. 1986, Pine and Anderson 1991) because those plants are most easily consumed. See Section 3.1 of the risk assessment document (Cudmore et al. 2017).
Will there be changes to suspended solids?	Potentially. Grass Carp may contribute to increases in turbidity through its observed behaviour of consuming terrestrial vegetation (Kilgen and Smitherman1971, Terrell and Fox 1974) by digging into banks and uprooting riparian vegetation (D. Chapman, USGS, pers. comm.). See Section 3.0 and 3.4 of the risk assessment document (Cudmore et al. 2017). See also Wittmann et al. (2014).
Will there be changes to nutrient recycling?	Unknown. Coastal wetlands provide important nutrient sinks to help reduce eutrophication and if large populations of Grass Carp occur in the Great Lakes, they might further degrade vegetated wetlands resulting in the loss of ecosystem services including nutrient cycle control. See Section 3.4 of the risk assessment document (Cudmore et al. 2017). See also Wittmann et al. (2014).
Will there be changes to bank erosion?	Unknown. Grass Carp feeding behaviour may cause erosion to shore banks and increased turbidity in the adjacent waters.

Management Question	**Summary of Answer**
What are the effects on energy flow, and food-web effects?	Consequences other than loss of SAV were indirectly assessed, as changes to aspects of the biotic community and the abiotic environment are assumed to be indirectly related to the loss of SAV. See Section 3.6 of the risk assessment document (Cudmore et al. 2017).
What are the implications of losing/changing wetlands to native fishes?	Of 136 fishes in the Great Lakes assessed, the potential consequences are high for 33 fish species, moderate for 33 fish species, and low, nil or unknown for 70 fish species. Of the 33 species classified as potentially experiencing high undesirable effects, 85% may experience consequences across all life stages, and the remaining species may experience consequences across at least two life stages. See Section 3.3 of the risk assessment document (Cudmore et al. 2017). See also Gertzen et al. (2017).
Will critical habitat for threatened and endangered species be affected?	To be assessed in a socioeconomic risk analysis using information from Gertzen et al. (2017).
What are the implications of losing/changing wetlands to birds that use the wetlands?	High impact was predicted for 18 bird species based on nesting habitat requirements, and the use of aquatic vegetation, aquatic insects, and other aquatic invertebrates as food sources. The remaining 29 species are predicted to experience moderate impact, as the initial bird list was already restricted to birds using Great Lakes wetland habitat for important portions of their life (Gertzen et al. 2017). See Section 3.2 of the risk assessment document (Cudmore et al. 2017).
What level of population would be an acceptable level of risk/impact?	Acceptable level is a management decision – could use consequence table/section for advice on this.
Will the dynamics of the sport fishery change?	To be assessed in a socioeconomic risk analysis.

Management Question	Summary of Answer
Is there a variation of impacts with variation in abundance levels of Grass Carp?	Yes. Impact on vegetation biomass seemed to reach a tipping point at a density of ten 13.2 kg Grass Carp/ha. Predicted time to impact based on threshold population sizes varied depending on the initial population sizes. See Figures 32 and 33, and Table 16 in the risk assessment document (Cudmore et al. 2017).
Is there a variation of impacts with variation in ploidy?	Similar ecological consequences on an individual basis for triploids and diploids are likely; however, the increase in the magnitude of ecological consequences over time for diploids is linked to growing population sizes. Thus, for diploid Grass Carp, increasingly higher ratings were given for lakes Michigan, Huron, Erie, and Ontario over time, reaching extreme by 50 years. Compare Table 17a and 17b in the risk assessment document (Cudmore et al. 2017).
Need links of ecological impacts to use for socioeconomic uses and activities. Will fishing, beach use, etc. be affected?	Ecological consequences are provided in the risk assessment document (See Section 3.0, Cudmore et al. 2017). A separate socioeconomic assessment would need to be done.

Overall Risk

Table 6. Summary of science advice to management questions presented by Great Lakes managers and decisions makers on overall risk and location within the risk assessment document where the advice can be found.

Management Question	Summary of Answer
What is the timeframe of risk for each element and ecological consequence at each stage?	See risk tables in the risk assessment document (Cudmore et al. 2017).
What are the confounding issues?	See certainty of data ranks in risk tables and Section 5.0 (Considerations) in the risk assessment document (Cudmore et al. 2017). Key knowledge gaps and uncertainties are listed in the Assessment section of this report.
Where are the most vulnerable areas?	Vegetated nearshore areas. See Figure 32 of the risk assessment document (Cudmore et al. 2017).

Management Question	Summary of Answer
Will this help inform rapid response?	Yes, but how it will be used will be based on risk tolerance of managers using the science advice of overall risk. The science advice on overall risk and distribution maps from this risk assessment can be used to prioritize locations for response and other activities (e.g., monitoring).
What are some mitigation options?	Evaluation of mitigation options is outside the scope of this scientific risk assessment. This would be addressed in the next step in the risk assessment process – risk management.

Summary

Grass Carp has arrived to the Great Lakes basin (specifically lakes Michigan and Erie) and the invasion process has begun. Regulations and enforcement of regulations are two important factors that may affect the likelihood of arrival to the other lakes in the basin where Grass Carp have not arrived. There is an expected time lag associated with seeing the full ecological consequences of an established population of Grass Carp in the Great Lakes basin; however, immediate preventative actions would be most effective, especially in conjunction with control activities where Grass Carp have arrived, to reduce the probability of establishment and delay or reduce subsequent ecological consequences. Through the process of the risk assessment, significant gaps in knowledge have been identified that influence the certainty associated with some of the rankings; these are captured thoroughly in the risk assessment research document (Cudmore et al. 2017) and the proceedings (DFO 2017). These gaps provide direction for future research to decrease uncertainty and refine risk. Some of these knowledge gaps are considered key knowledge gaps and are listed below in Sources of Uncertainty section in this document.

OTHER CONSIDERATIONS

There is an expected time lag associated with seeing the full consequences of an established population of an invasive species, such as Grass Carp in the Great Lakes; however, this should not be interpreted that there is time to wait before acting. The opportunity to prevent these predicted consequences may not be indefinite. Ongoing management actions on both sides of the border continue while additional management options exist and further research can be conducted to interrupt the population trajectory and minimize the risk predicted within this assessment. We can, with effective prevention and control actions, continue to delay when these consequences would occur, and the level of impact, if Grass Carp became established in the Great Lakes. This delay will provide time to conduct further research into eradication and control options, and minimize and postpone overall costs of high 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 Grass Carp. As Grass Carp continue to threaten the Great Lakes, an AIS program should include prevention activities as one of its key components. However, given the proximity of Grass Carp to the Great Lakes basin, and that it is already considered to have arrived in some lakes, these efforts should occur in conjunction with control and management of population numbers at the invasion front. However, the concern for impact due to diploid Grass Carp is not the same for triploid Grass

Carp, as even if an influx of triploid Grass Carp to the Great Lakes basin was to occur (although not expected), it is not expected to cause significant impacts, although localized impacts within certain areas of a lake may be significant.

Risk assessments are based on best information available at the time of the assessment, and should identify knowledge gaps and uncertainties. Research underway, where results were not yet 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.

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 June 1-3, 2015 peer review of the Binational Ecological Risk Assessment for Grass Carp in the Great Lakes Basin. Additional publications from this meeting will be posted on the DFO Science Advisory Schedule as they become available.

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