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Ecological Consequences of Grass Carp, *Ctenopharyngodon idella,* in the Great Lakes Basin: vegetation, fishes and birds

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

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ABSTRACT

Grass Carp (*Ctenopharyngodon idella*), a large, herbivorous fish, was first introduced to North America in 1963 for aquatic macrophyte control. Grass Carp populations have since escaped from impoundments where they were stocked, entered rivers in central United States and continued making their way up the Mississippi River basin towards the Great Lakes. Grass Carp have also been spread by commerce in the United States, where sale of live diploid and certified triploid (reproductively sterile) Grass Carp is legal in several states. Between 2007 and 2012, 45 Grass Carp were caught in the Great Lakes basin and captures within the basin are continuing to occur with increasing frequency. The potential for Grass Carp to invade the Great Lakes is of increasing concern and Great Lakes managers need to understand the potential ecological consequences of Grass Carp to the Great Lakes basin. Using different approaches, the potential ecological impacts of Grass Carp on aquatic vegetation, native fishes, and bird communities in the Great Lakes basin were assessed. Under the evaluated scenarios, Grass Carp invasion typically predicted there would be a decline in low marsh biomass of less than 5% given the high amount of estimated submerged aquatic vegetation biomass across the Great Lakes. However, at the site-level, a greater range of variability was observed, with a large proportion of sites seeing a 50% decline in biomass, particularly at higher densities of large Grass Carp. The potential negative effect of Grass Carp on Great Lakes fishes was evaluated using spawning characteristics and habitat preferences for 136 fish species occurring in the Great Lakes Basin. The potential negative impact of Grass Carp, as predicted by overlap in spawning and habitat needs, was high for 33 fish species, moderate for 33 fish species and low, nil or unknown for 70 fish species. A total of 47 bird species were identified that use Great Lakes coastal wetlands in Canada as breeding habitat and that may experience consequences following the introduction of Grass Carp into the Great Lakes. Based on use of wetlands for feeding needs and nesting habitat, 18 species were predicted to experience high potential negative ecological consequences following Grass Carp introduction and the remaining 29 were predicted to experience moderate potential negative ecological consequences following Grass Carp introduction. In general, the predicted negative impacts of Grass Carp on aquatic vegetation, fishes and waterbirds are variable; however, the impacts may be extreme for certain sites and species in the Great Lakes.

Conséquences écologiques de la présence de la carpe de roseau, *Ctenopharyngodon idella*, dans le bassin des Grands Lacs : végétation, poissons et oiseaux

RÉSUMÉ

La carpe de roseau (*Ctenopharyngodon idella*) est un grand poisson herbivore qui a d'abord été introduit en Amérique du Nord en 1963 pour le contrôle de la macrophyte aquatique. Depuis, les populations de carpe de roseau se sont échappées des bassins où elles étaient retenues et ont remonté le bassin du Mississippi jusqu'aux Grands Lacs. La carpe de roseau s'est également propagée grâce au commerce américain, car la vente d'individus diploïdes vivants et triploïdes certifiés (stériles) de carpe de roseau est légale dans plusieurs États. Entre 2007 et 2012, 45 carpes de roseau ont été capturées dans le bassin des Grands Lacs, et les prises de ce poisson à cet endroit se poursuivent et sont de plus en plus fréquentes. La possibilité que la carpe de roseau envahisse les Grands Lacs est une préoccupation croissante, et les gestionnaires des Grands Lacs doivent comprendre les conséquences écologiques possibles de la présence de la carpe de roseau dans le bassin des Grands Lacs. Au moyen de différentes approches, on a évalué les impacts écologiques possibles de la carpe de roseau sur la végétation aquatique, les poissons indigènes et les communautés d'oiseaux du bassin des Grands Lacs. Les scénarios évalués prévoient qu'une invasion de la carpe de roseau engendrerait une diminution de moins de 5 % de la biomasse des zones de marées moyennes, étant donné la grande quantité estimée de la biomasse de végétation aquatique partout dans les Grands Lacs. Par contre, à l'échelle des sites, un plus grand degré de variabilité a été observé; une grande proportion des sites ont noté une diminution de 50 % de leur biomasse, particulièrement lorsque la densité de grandes carpes de roseau était plus forte. Les conséquences néfastes potentielles de la carpe de roseau pour les poissons des Grands Lacs ont été évaluées en fonction des caractéristiques de frai et des préférences en matière d'habitat de 136 espèces de poissons vivant dans le bassin des Grands Lacs. Les conséquences néfastes potentielles de la carpe de roseau, évaluées en fonction des besoins chevauchants en matière de frai et d'habitat, étaient élevées pour 33 espèces de poissons, modérées pour 33 espèces de poissons, et faibles, nulles ou inconnues pour 70 espèces de poissons. On a déterminé que 47 espèces d'oiseaux qui utilisent les zones humides côtières des Grands Lacs (au Canada) comme habitat de reproduction pourraient ressentir les effets néfastes de l'introduction de la carpe de roseau dans les Grands Lacs. En fonction de l'utilisation des zones humides à des fins alimentaires et de reproduction, on prédit que pour 18 espèces, la possibilité de conséquences écologiques néfastes liées à l'introduction de la carpe de roseau est élevée, et que pour les 29 autres espèces, elle est modérée. En général, les conséquences néfastes prévues de la carpe de roseau sur la végétation aquatique, les poissons et les oiseaux aquatiques sont variables; cependant, elles peuvent être extrêmes pour certains sites et certaines espèces des Grands Lacs.

GENERAL INTRODUCTION

Grass Carp (*Ctenopharyngodon idella*) is a sub-tropical to temperate fish species native to the large rivers of eastern Asia. Grass Carp is one of four species of Asian carps originally brought to North America in the 1960s for biological control in aquaculture facilities. Grass Carp, specifically, was brought to the southern United States in 1963 to evaluate its potential for control of aquatic vegetation. Numerous wild Grass Carp captures have since occurred throughout the United States and in the Great Lakes basin. The first was collected from the Lake Erie basin, Michigan in the early 1980s (Lee et al. 1980, Courtenay et al. 1984) and the first observed in Canadian (Ontario) waters was in Lake Erie, west of Point Pelee, in 1985 (Mandrak and Cudmore 2004). Evidence of recruitment in the Sandusky River, a tributary of Lake Erie, was found in 2012 (Chapman et al. 2013).

The Great Lakes are the world's largest freshwater system, an important tourist and recreational destination, and home to a multi-billion dollar fishing industry. Coastal wetlands in the Great Lakes provide numerous ecosystem services including nutrient cycling, erosion control, and habitat for fishes and breeding birds. Modelling has suggested that there is suitable habitat for Grass Carp throughout much of the Great Lakes, particularly in these ecologically and economically important shallow, vegetated coastal waters (Wittmann et al. 2014). Given the potential for Grass Carp to invade these habitats, identifying and quantifying the possible impacts of Grass Carp on coastal wetland habitats, native fishes and coastal bird communities is essential.

A risk assessment of Asian carps, which included Grass Carp, identified broad potential risks to Canada, including the Great Lakes (Mandrak and Cudmore 2004). While this risk assessment provided insight into the risk faced by broad areas of Canada, knowledge gaps were identified. Given this and the recent discovery of Grass Carp recruitment in Lake Erie, a binational ecological risk assessment of Grass Carp was proposed by Fisheries and Oceans Canada (DFO) and the Great Lakes Fishery Commission (GLFC) to the Asian Carp Regional Coordinating Committee (ACRCC), and was endorsed in early 2014.

The purpose of this research document is to support the binational ecological risk assessment by addressing the following questions:

1. What are the potential impacts of Grass Carp on the coastal wetland vegetation community?
2. What are the potential impacts of Grass Carp on the native fish community?
3. What are the potential impacts of Grass Carp on the wetland bird community?

This document is structured into three sections, each addressing one of the aforementioned questions. The first section (question 1, Section 1.0) provides an estimate of the potential magnitude of change in vegetation biomass and identifies areas within the Great Lakes basin where the greatest changes may occur if Grass Carp were introduced. Since shallow, vegetated waters are thought to be the most suitable for Grass Carp, this portion of coastal wetlands will likely be the most vulnerable to Grass Carp colonization. The second section (question 2, Section 2.0) evaluates the potential consequences of Grass Carp introduction on the native fish community of the Great Lakes. Given that changes in coastal wetland habitat are most likely, the portion of the fish community that uses this habitat may experience greater risk. The final section (question 3, Section 3.0) evaluates the direct and indirect effects of Grass Carp on the wetland bird community. Change in habitat conditions due to the introduction of Grass Carp will likely have a generally negative impact on birds utilizing coastal wetlands for feeding, nesting, and migratory stopovers.

1.0 EVALUATING THE POTENTIAL ECOLOGICAL CONSEQUENCES OF GRASS CARP ON COASTAL WETLANDS AND VEGETATION IN THE GREAT LAKES

Jonathan D. Midwood

INTRODUCTION

Coastal wetlands in the Great Lakes basin provide numerous ecosystem services and support a diverse array of flora and fauna. Indeed, the majority of Great Lakes fishes use this habitat at some point during their life cycle (Jude and Pappas 1992, Wei et al. 2004). Despite their ecological importance, coastal wetlands are still under threat from watershed alteration, water level declines and invasion of non-indigenous species. Grass Carp (*Ctenopharyngodon idella*), a species that was originally introduced into small ponds and lakes for bio-control of aquatic macrophytes in North America, is threatening to invade coastal wetlands in the Great Lakes. Given this risk, identifying and quantifying the possible impacts of Grass Carp on coastal wetland habitats is important.

With an aim of supporting the development of a risk assessment of the colonization of Grass Carp in the Great Lakes basin, this section provides;

a. an outline of the development of a low marsh inventory for the Great Lakes, encompassing areas that are permanently inundated and may support submerged aquatic vegetation (SAV),

b. an outline of the approaches used to estimate vegetation biomass in Great Lakes low marsh habitat, and;

c. an evaluation of the potential impacts of Grass Carp feeding on vegetation biomass.

Combined, this section provides an estimate of the potential magnitude of change in vegetation biomass and it identifies areas within the Great Lakes basin where the greatest changes may occur.

METHODS AND RESULTS

Great Lakes Low Marsh Inventory (GLLMI) Creation

One of the first steps towards assessing the potential impacts of Grass Carp colonization is to create a spatial layer that maps the extent of coastal wetland habitat within the Great Lakes. The existing wetland inventories for the Great Lakes collectively provide excellent coverage; however, they include habitat within wetlands that may not be directly impacted by Grass Carp (e.g., wet meadows and swamps). In contrast, shallow, vegetated waters are thought to be the most suitable for Grass Carp (Wittmann et al. 2014) and therefore the most likely portion of a wetland that will be exploited. For the purpose of this section, we will refer to these areas as “low marsh” defined as “areas that are permanently inundated, support SAV, and support fish spawning and foraging”. All analyses and discussion are focused solely on this component of Great Lakes wetland habitat.

Existing inventories of Great Lakes coastal wetlands were integrated into a GIS to create a comprehensive inventory of low marsh habitat termed the Great Lakes Low Marsh Inventory (GLLMI). Five inventories, covering different scales and areas of the Great Lakes, were selected for inclusion: Great Lakes Coastal Wetland Inventory (GLCWI; Ingram et al. 2004), Michigan Tech Coastal Wetland Inventory (MTCWI; EPA/MTRI 2015), Ontario Great Lakes Coastal Wetland Atlas (OGLCWA; Ball 2003), McMaster Coastal Wetland Inventory (MCWI; Midwood et al. 2012), and for the United States of America, the United States National Wetland Inventory

(USNWI; U.S. Fish and Wildlife Service 2009). The GLCWI is one of the most comprehensive basin-wide inventories and was developed using different sources (e.g., OGLCWA) as well as new delineations from aerial photographs or satellite imagery. The MTCWI used satellite images collected between 2007–2011 to develop a continuous map of land cover around the entire Great Lakes with generally high classification accuracy (up to 94%), and very good spatial accuracy (6–25 m). This inventory classifies aquatic vegetation into Aquatic Bed, *Schoenplectus* spp., *Typha* spp., and Emergent Wetland. The OGLCWA includes coastal and inland wetlands in Ontario and was developed using several different sources (e.g., Ontario Ministry of Natural Resources evaluated wetlands, and Environment Canada's Great Lakes Environmental Sensitivity Atlas). The MCWI was developed specifically for eastern and northern Georgian Bay using high-resolution satellite imagery. To fill in any gaps along the shoreline of the United States of America, the USNWI was also included.

Polygons from all of the inventories were merged together and then split into distinct units and assigned a unique identifier. These polygons were then clipped using a comprehensive water layer to ensure only parts of the wetlands that were low marsh habitat (i.e., inundated) were included. In the Great Lakes, over 40 thousand wetlands units were identified in the GLLMI for a total area of low marsh habitat of 114,800 ha (Table 1.1; Figure 1.1). There were clearly parts of the Great Lakes where low marsh habitat was concentrated (Figure 1.1) including: Bay of Quinte and eastern Lake Ontario, Long Point Provincial Park in Lake Erie, Lake St. Clair, Green Bay in Lake Michigan, Georgian Bay and Saginaw Bay in Lake Huron, and the western end of Lake Superior.

Table 1.1. Summary of low marsh units and area in the GLLMI by Great Lake.

Lake	# Low Marsh Units	Total Area (ha)	Max. Low Marsh Area (ha)	# Wetlands > 500 ha
Erie	3,509	27,840	11,976	6
Huron	21,280	41,668	5,781	6
Michigan	4,925	13,426	1,748	2
Ontario	5,705	21,720	1,740	9
Superior	8,301	10,166	557	1

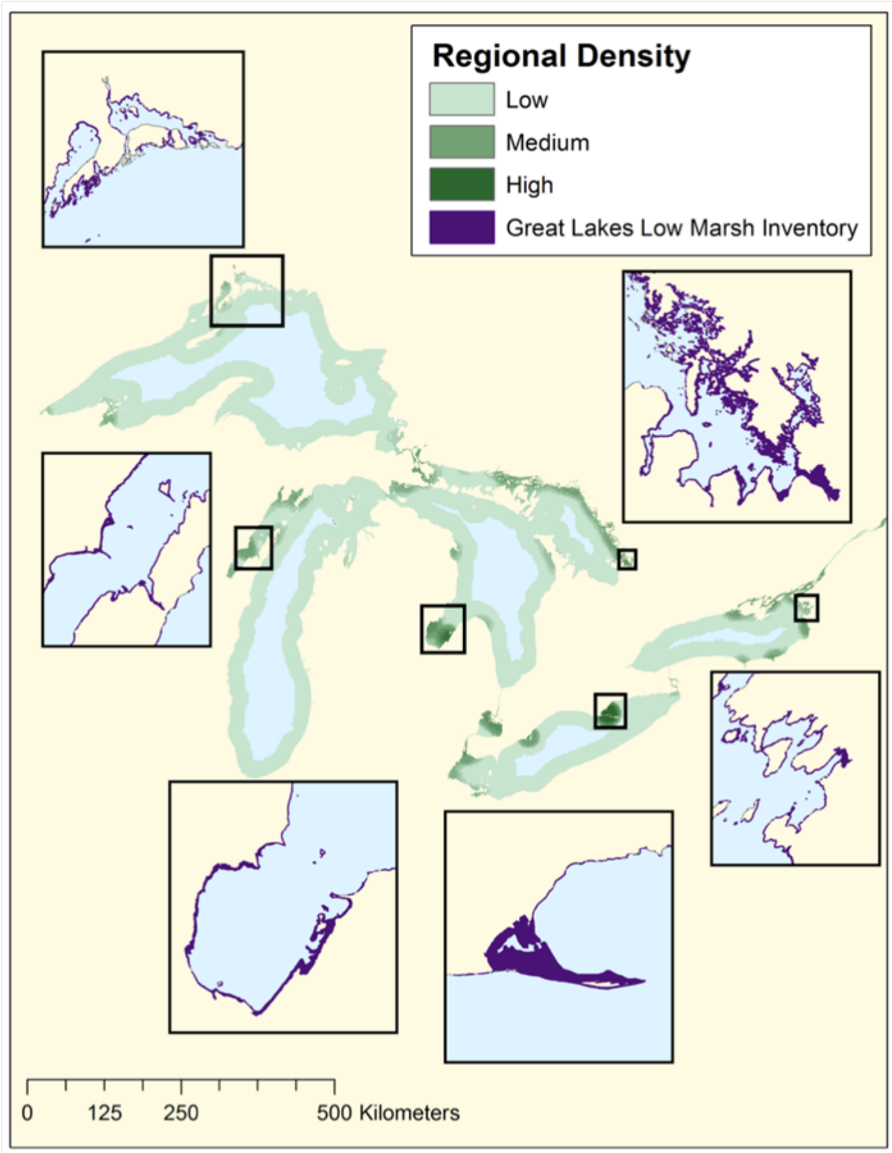

Figure 1.1. The distribution of the Great Lakes Low Marsh Inventory (GLLMI). Low marsh habitat is shown in purple in the insets. The darker areas in green represent parts of the Great Lakes with higher densities of coastal marshes by area.

The largest wetland (Long Point Provincial Park) was found in Lake Erie; however, Lake Huron had the largest number of wetland units and the largest total area of wetlands (over 40,000 hectares). There were 24 wetlands across the Great Lakes that were greater than 500 hectares in size. Lake Ontario had the most and these were concentrated in the Bay of Quinte (3), along the south-eastern shoreline (4), and in the Niagara and St. Lawrence Rivers. Long Point, Rondeau Bay and the wetlands in Lake St. Clair were some of the largest wetlands in Lake Erie. For lakes Huron and Michigan, Matchedash Bay, Saginaw Bay and Green Bay were among the largest single units. Finally, for Lake Superior, the sole unit greater than 500 hectares was found along the northern shore, north-east of Thunder Bay.

Integrating additional habitat into the Great Lakes Low Marsh Inventory (GLLMI+MLC-7K)

Despite the integration of several comprehensive inventories, it is still possible that the GLLMI underestimates the amount of low marsh habitat in the Great Lakes. This is due to the focus of most wetland mapping efforts on areas less than 2-m deep (represents the transitional littoral zone) as well as methodological challenges (e.g., mapping vegetation in dystrophic or turbid waters using remote sensing techniques). For example, in areas with clear water, the euphotic zone is larger and rooted angiosperms can grow to depths greater than 10 m (Middelboe and Markager 1997). Rokitnicki-Wojcik (2009) found that inclusion of deeper habitats increased total wetland area in eastern Georgian Bay coastal wetlands by 50–75%, suggesting that there may be a significant portion of habitat absent in current inventories.

Given these challenges, spatial modelling was used to identify new areas of low marsh habitat that may not have been mapped by satellite imagery. This approach for mapping new low marsh habitat employed maximum likelihood classification (MLC). The Aquatic Bed layer from the MTCWI was used as the base for the development of training and testing sets. The centroids for each of the 94,377 polygons in the MTCWI Aquatic Bed layer were determined and converted into a point shapefile. From this new point file, 20,000 points were randomly selected (~21%) to serve as a training set. Another 20,000 randomly selected points that were not part of the training dataset were used to develop a testing dataset to provide an estimate of the classifications ability to detect already mapped Aquatic Beds. A second class (open water) was included in the training dataset. For this class, 20,000 points that fell within the water layer were randomly selected (Figure 1.2). Areas in the water layer that overlapped with the GLLMI were excluded from this selection so as to provide greater differentiation between the open water and Aquatic Beds classes. The training dataset was used to classify bathymetry (from NOAA 2014) and fetch rasters for each Great Lake into either Aquatic Beds or open water. To refine the MLC approach, the presence of potential Aquatic Beds was also classified separately based solely on areas where fetch was less than 7 km (after Mortsch et al. 2006). The resulting classification, herein MLC-7K, combined the MLC bathymetry raster and the fetch-7 km threshold raster.

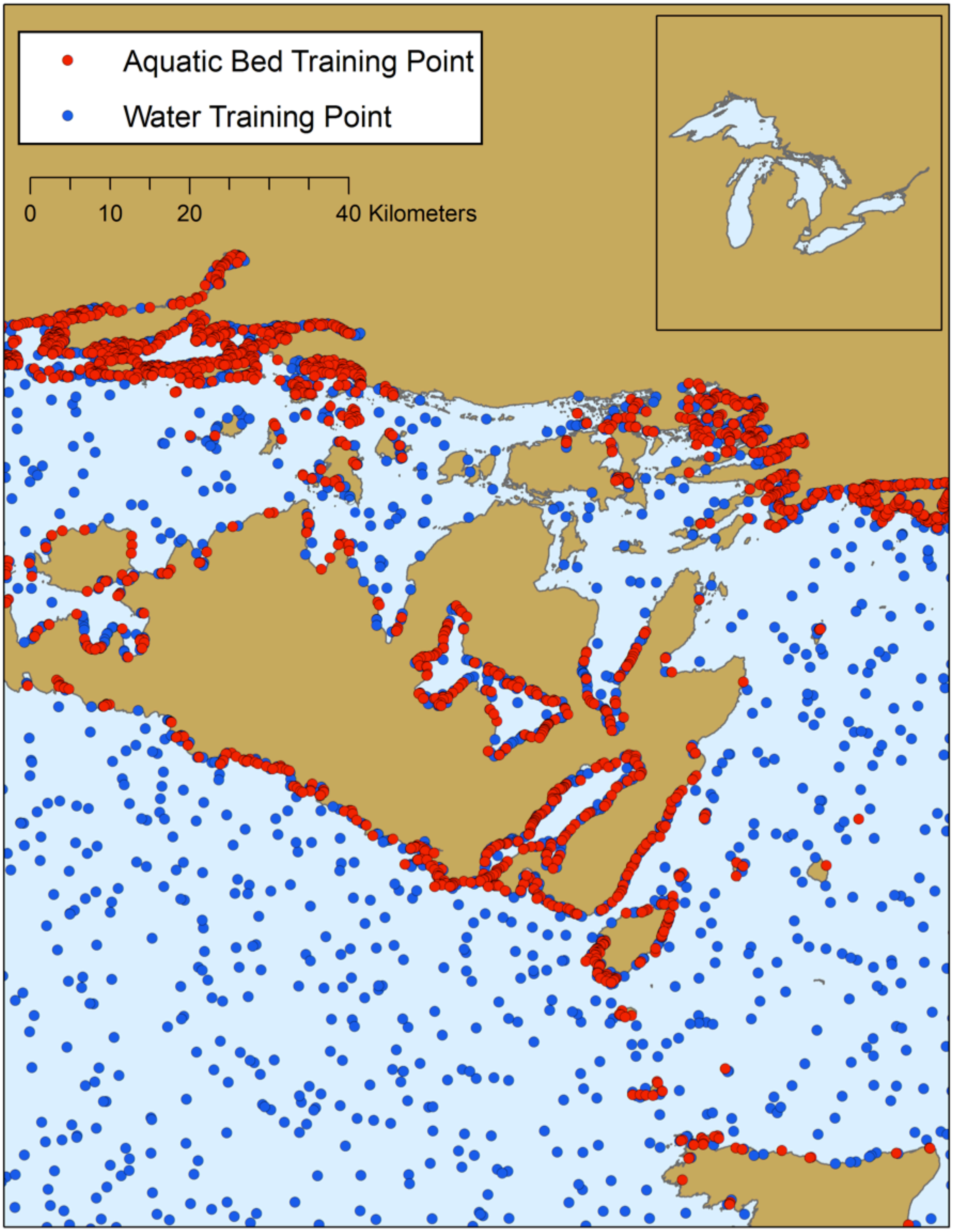

Figure 1.2. Example of the distribution of the training data used in the maximum likelihood classification to predict where Aquatic Bed habitat may occur.

The MLC-7K was combined with the GLLMI to create a new inventory. The result was the $GLLMI_{MLC7K}$, which increased the predicted amount of low marsh habitat by 500% (571,660 ha) and resulted in a decrease in the number of unique wetland units from 43,720 to 29,296 (Figure

1.3). These very large increases in Aquatic Bed habitat should be taken with some caution as the overall and Lake-specific accuracies for the MLC-7K were quite low (typically much less than 65%). The overall accuracy for predicting the location of Aquatic Bed habitat was 56%, which is far below what has been reported in more successful classifications (e.g., 90% in Wei and Chow-Fraser 2007 or 87% in Midwood and Chow-Fraser 2010). The low classification accuracy is likely related to the complexity of the variables that dictate the presence of aquatic vegetation at the scale of the entire Great Lakes basin, paired with the coarse resolution of the input and output data layers. An important caveat to the work here is that wetland inventory development and habitat classification is ongoing within the Great Lakes and this inventory is by no means a perfect representation of all low marsh habitats.

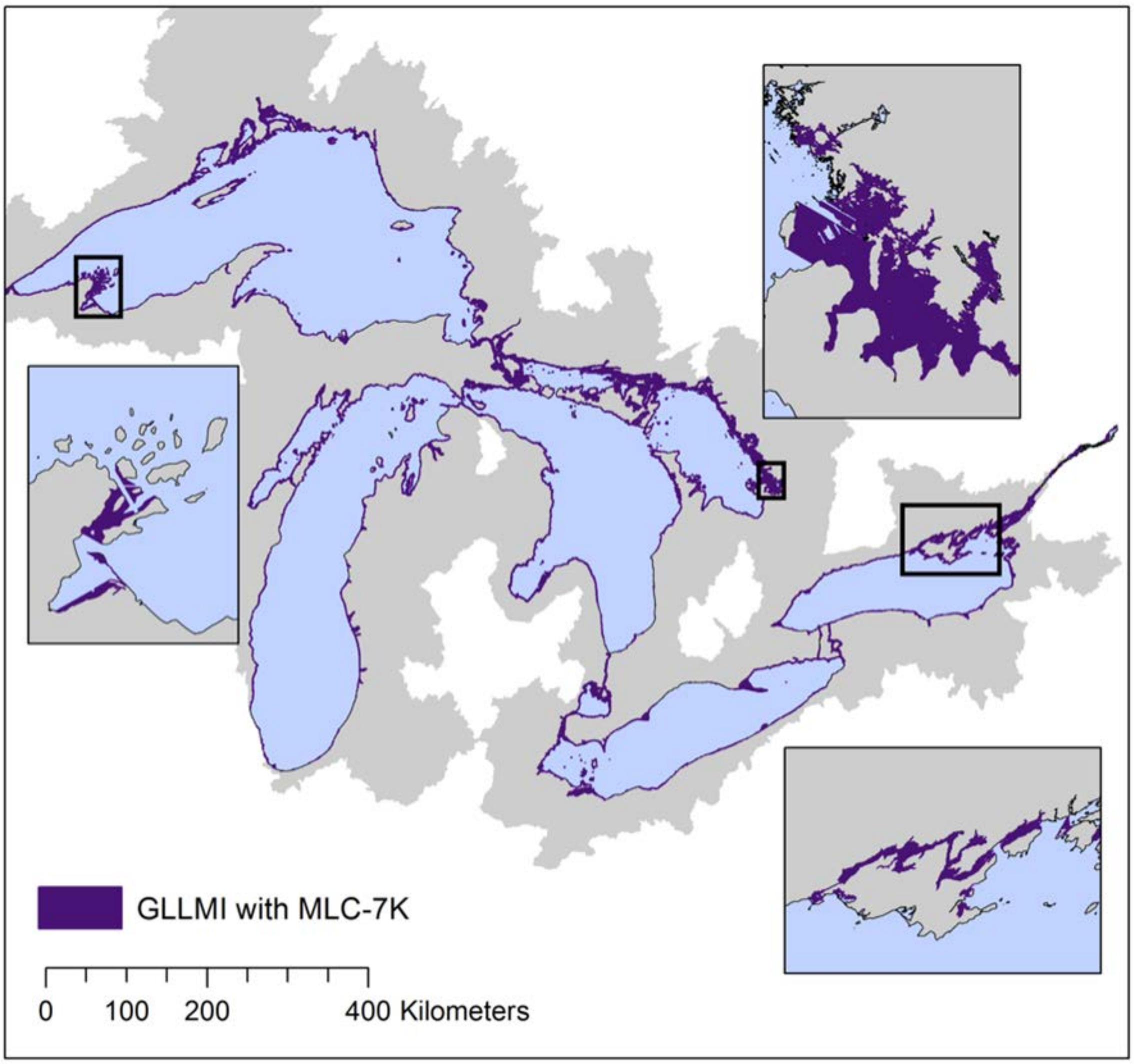

Figure 1.3. Output from the MLC-7K classification after it has been merged with the GLLMI. Areas of interest in Severn Sound and the Bay of Quinte are shown in the insets. These are two of the largest areas of aquatic bed habitat based on this classification.

To account for some of the inherent uncertainty in predicting the distribution of low marsh habitat and the SAV component of this habitat in particular, both the GLLMI and $GLLMI_{MLC-7K}$ were used as estimates of the spatial distribution of low marsh habitat and consequently macrophyte biomass. The GLLMI on its own likely underestimates the total extent of low marsh habitat within the Great Lakes, particularly the spatial coverage of SAV. In contrast, the $GLLMI_{MLC-7K}$ almost certainly represents an overestimation of the spatial distribution of low marsh habitat. Regardless of the inherent caveats with each of the inventories, using both will result in a range of estimates that are likely above ($GLLMI_{MLC-7K}$) and below (GLLMI) what actually occurs in the Great Lakes.

Estimating vegetation biomass in Great Lakes low marsh habitat

A variety of methods can be used to estimate SAV cover and/or biomass including: remote sensing, field surveys, modelling, and hydroacoustic surveys. Past studies that have estimated SAV biomass present two main challenges. First, mapping efforts and models are typically focused on a single region (e.g., Lake Okeechobee, Havens et al. 2002 or Chesapeake Bay, Cerco and Moore 2001); therefore the appropriateness of applying these approaches to the Great Lakes is unknown. Second, many of the techniques require environmental data that are not available at the scale of the Great Lakes. For example, neither sediment composition nor percent cover of SAV data are available basin-wide for the Great Lakes. Model selection is therefore limited to variables that are available basin-wide.

Three approaches were used to estimate the amount of biomass (g/m^2 dry weight) within each low marsh unit in both the GLLMI and $GLLMI_{MLC-7K}$, as well as under two different water level scenarios Base (chart datum) and Base+1 (1 m above chart datum). The three simple approaches were obtained from the literature. The first approach, herein referred to as CK85, used Secchi depth to determine the maximum biomass (Z_b) and then applied predefined biomasses to depth intervals around Z_b (Chambers and Kalff 1985). The second approach, herein referred to as H97, applied a predefined biomass at 1-m depth intervals (Hudon 1997). The third approach, herein referred to as H00, used an equation that linked water depth to biomass (Hudon et al. 2000).

The first approach for estimating biomass relied on Secchi depth to estimate the depth of maximum biomass (Z_b). Unfortunately, no comprehensive spatial layer of Secchi depth exists for the Great Lakes. Spatial and temporal maps of the light extinction coefficient (Kd) are available for parts of the upper Great Lakes (i.e., Michigan, Huron and Superior; MTRI 2015); however, these layers do not cover the nearshore area and therefore cannot be used to estimate biomass in low marsh habitat. Given the absence of direct Secchi depth data for the entire Great Lakes nearshore, Secchi depth was ranked relative to the proportion of non-natural land cover in a watershed. Secchi depths were used in the equation $0.54(\log_{10}(\text{Secchi depth})) + 1.15$ (Chambers and Kalff 1985) to predict maximum depth of biomass (Z_b) in each watershed. SAV biomass is known to follow an approximately normal distribution around Z_b (Capers and Les 2005). Therefore, based on Z_b, five biomass intervals were established with biomass in each interval linked to estimates of biomass in Hudon (1997) (Table 1.2). The results from this model are herein referred to as CK85-Base or CK85-Base+1, depending on the bathymetry model used (Table 1.3; Figures 1.4 and 1.5).

Table 1.2. Interval depth and biomass for the application of a model of the depth of maximum biomass. Biomass intervals were adapted from Hudon (1997) and the interval depths were derived to approximate a normal distribution. Z_b is the depth of maximum biomass.

Biomass Interval	Interval Depths (m)	Biomass (g/m^3)
1	0.0–0.4(Z_b)	103
2	0.4(Z_b)–0.8(Z_b)	266
3	0.8(Z_b)–1.2(Z_b)	629
4	1.2(Z_b)–1.6(Z_b)	266
5	1.6(Z_b)–2.0(Z_b)	103

Table 1.3. Total biomass estimates for the each Great Lake based on the three models and the two different water level scenarios.

GLLMI Inventory

Lake	CK85-Base	CK85-Base+1	H97-Base	H97-Base+1	H00-Base	H00-Base+1
ER	20,201	65,369	47,510	116,562	33,326	65,123
HU	57,575	47,661	79,468	66,844	57,256	47,170
MI	15,414	14,955	21,924	21,150	17,792	16,848
ON	15,582	26,524	28,454	42,884	21,408	33,333
SU	11,506	9,609	14,456	12,704	10,707	9,433

GLLMI$_{MLC-7K}$ Inventory

Lake	CK85-Base	CK85-Base+1	H97-Base	H97-Base+1	H00-Base	H00-Base+1
ER	65,351	136,037	140,707	218,221	87,663	121,001
HU	198,683	190,140	311,224	239,489	244,394	184,321
MI	41,128	37,816	62,651	54,442	55,650	46,691
ON	54,123	59,388	81,165	95,449	57,102	72,353
SU	87,628	72,289	113,351	95,727	79,960	69,499

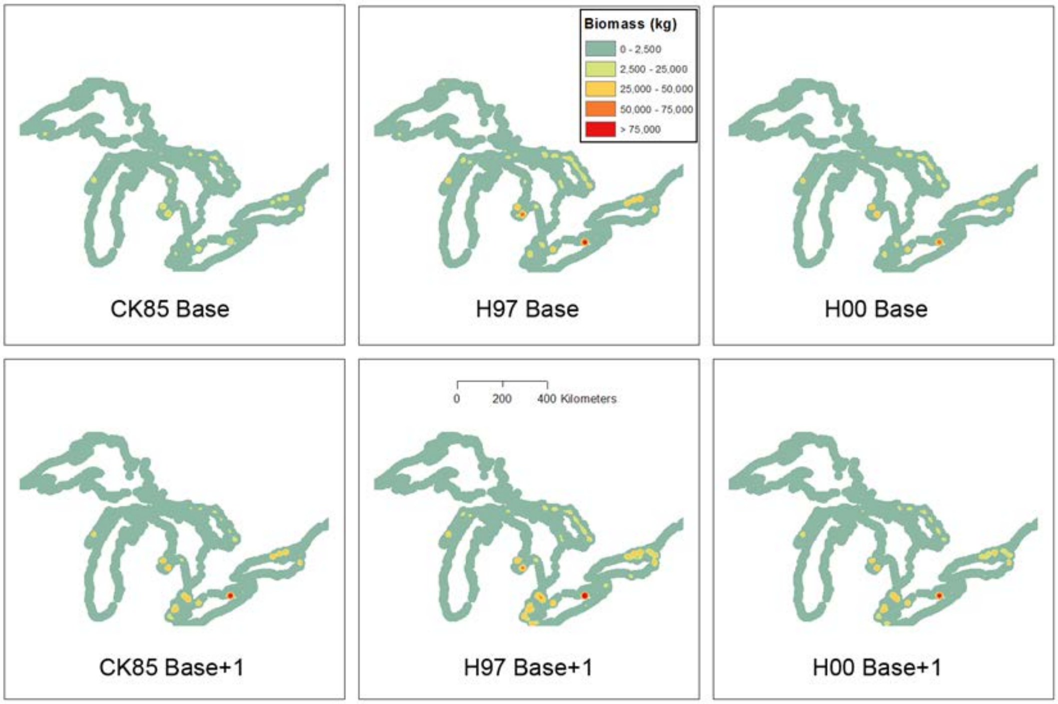

Figure 1.4. Kernel density estimates for the GLLMI using three models under two different water level scenarios.

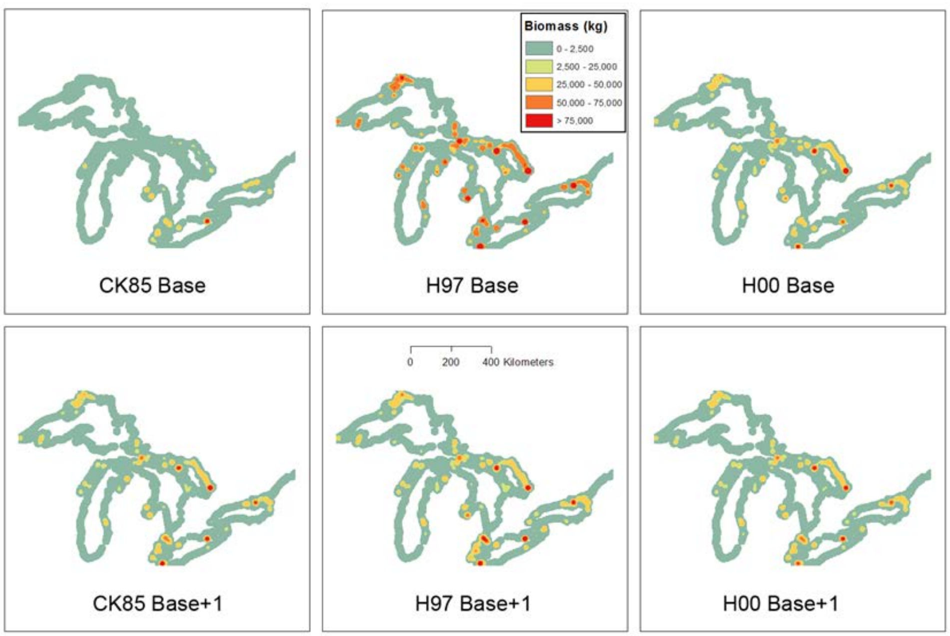

Figure 1.5. Kernel density estimates for the $GLLMI_{MLC-7K}$ using three models under two different water level scenarios.

The second approach used only depth at intervals of 1-m to predict vegetation biomass (Table 1.4; Hudon 1997). For each Great Lake, depths that fell within each interval, as determined from their bathymetry layer, were classified with the associated biomass. For every polygon in both inventories, the total biomass contained within that polygon was calculated. Results from these models are herein referred to as H97-Base or H97-Base+1 (Table 1.3; Figures 1.4 and 1.5).

Table 1.4. Aquatic vegetation biomass as a function of depth interval. Adapted from Hudon (1997).

Depth Interval (m)	Biomass (g/m²)
<0.03	0
0.03–1.00	629
1.01–2.00	266
2.01–3.00	166
3.01–4.00	124
4.01–5.00	103
>5.00	0

The final approach was again based solely on depth; however, it employed an equation for predicting the amount of biomass per m^2 from Hudon et al. (2000):

$\log_{10}(\text{Biomass}) = -0.65 - 0.75(\log_{10}(\text{Depth})) - 0.23(\log_{10}(\text{Depth})^{2})$

This equation was applied to the bathymetry layer for each Great Lake and the total biomass contained within each polygon in both inventories was calculated. Results from this approach are herein referred to as H00-Base or H00-Base+1 (Table 1.3; Figures 1.4 and 1.5).

The three biomass models predicted a wide range of estimates for macrophyte biomass in low marsh habitat in the Great Lakes (Table 1.3). They were, however, consistent in the order of magnitude of this biomass, ranging from a low of approximately 100,000 to a high of over 700,000 metric tonnes. For all models, there was a high level of agreement in the areas that were identified as containing the greatest amount of biomass. These areas tended to be shallow protected areas and included: Long Point and Rondeau Bay in Lake Erie, Bay of Quinte in Lake Ontario, Saginaw Bay and eastern Georgian Bay in Lake Huron, and Green Bay in Lake Michigan (Figures 1.4 and 1.5).

Assessing the ecological consequences of Grass Carp on Great Lakes low marsh habitat

Model Components

Three key metrics from a bioenergetics model for Grass Carp (Jones et al. 2017) were used to evaluate their potential impacts on low marsh habitat: daily consumption rate, annual consumption rate and the feeding window (seasonal start and end of feeding). The daily consumption rate was calculated using Equation 1 and annual consumption rates were estimated based on outputs from the bioenergetics model (Table 1.5).

Eq. 1 $C_{max} = 1.8955W^{-0.3676}$

For the feeding window, Grass Carp feeding was set to start on April 20th and end on November 20th, with a brief cessation of feeding for spawning from June 24th until July 7th (Jones et al. 2017). Since consumption rate is directly linked to the size of the Grass Carp, six different sizes of Grass Carp were evaluated, roughly relating to Grass Carp that were 2, 4, 6, 8, 10, and 12 years old (Table 1.5). Finally, eight different Grass Carp densities were evaluated ranging from 2–16/ha in increments of 2. This range falls within the range of stocking densities of Grass Carp in areas where they are used to control aquatic vegetation (Pípalová 2006, Cassani et al. 2008, Wittmann et al. 2014).

Since the results from the vegetation biomass models were in g-dry weight and the inputs of vegetation food sources for the bioenergetics model are in g-wet weight (g-WW), a conversion was necessary. The biomass model output was converted to g-wet weight by dividing by 0.16. This value was selected based on estimates of aquatic macrophyte water content of approximately 84% (Hakanson and Boulian 2002). For the remainder of the section, biomass is reported as wet weight.

Table 1.5. Parameters derived from a bioenergetics model for Grass Carp (Jones et al. 2016) that were used to model consumption at various densities of different ages of Grass Carp.

Age (y)	Estimated Mass (kg)	Annual Consumption (g W/year)
2	1.6	27
4	4.5	52
6	9.5	65
8	13.2	72
10	16.0	78
12	18.0	83

Basin-wide Evaluation

Basin-wide impacts of Grass Carp were evaluated for the six different biomass models (CK85-Base, CK85-Base+1, H97-Base, H97-Base+1, H00-Base, and H00-Base+1). Analyses were conducted separately for all combinations of the six masses and the eight densities of Grass Carp. First, the total area of low marsh habitat (in hectares) and the total biomass of aquatic vegetation (in g-WW) were determined for both the GLLMI and $GLLMI_{MLC\text{-}7K}$. Based on the total area of low marsh habitat, the total number of Grass Carp that would be feeding within the basin was then determined from the associated density. An overall estimate of total consumption of biomass by Grass Carp was then calculated and this value was subtracted from the total biomass.

The estimated basin-wide annual consumption for Grass Carp ranged from a low of 6.2×10^9 to a high of 7.6×10^{11} g-WW (6,200 to 76,000 metric tonnes). Not surprisingly, the largest estimates of consumption were linked to the highest densities of the largest Grass Carp (e.g., 16 Grass Carp of 18-kg per hectare). This trend was consistent for both the GLLMI and $GLLMI_{MLC\text{-}7K}$ (Figures 1.6 and 1.7) inventories. Despite the magnitude of consumption at high densities of Grass Carp, it typically constituted less than 25% of the overall biomass estimated to be available in the basin.

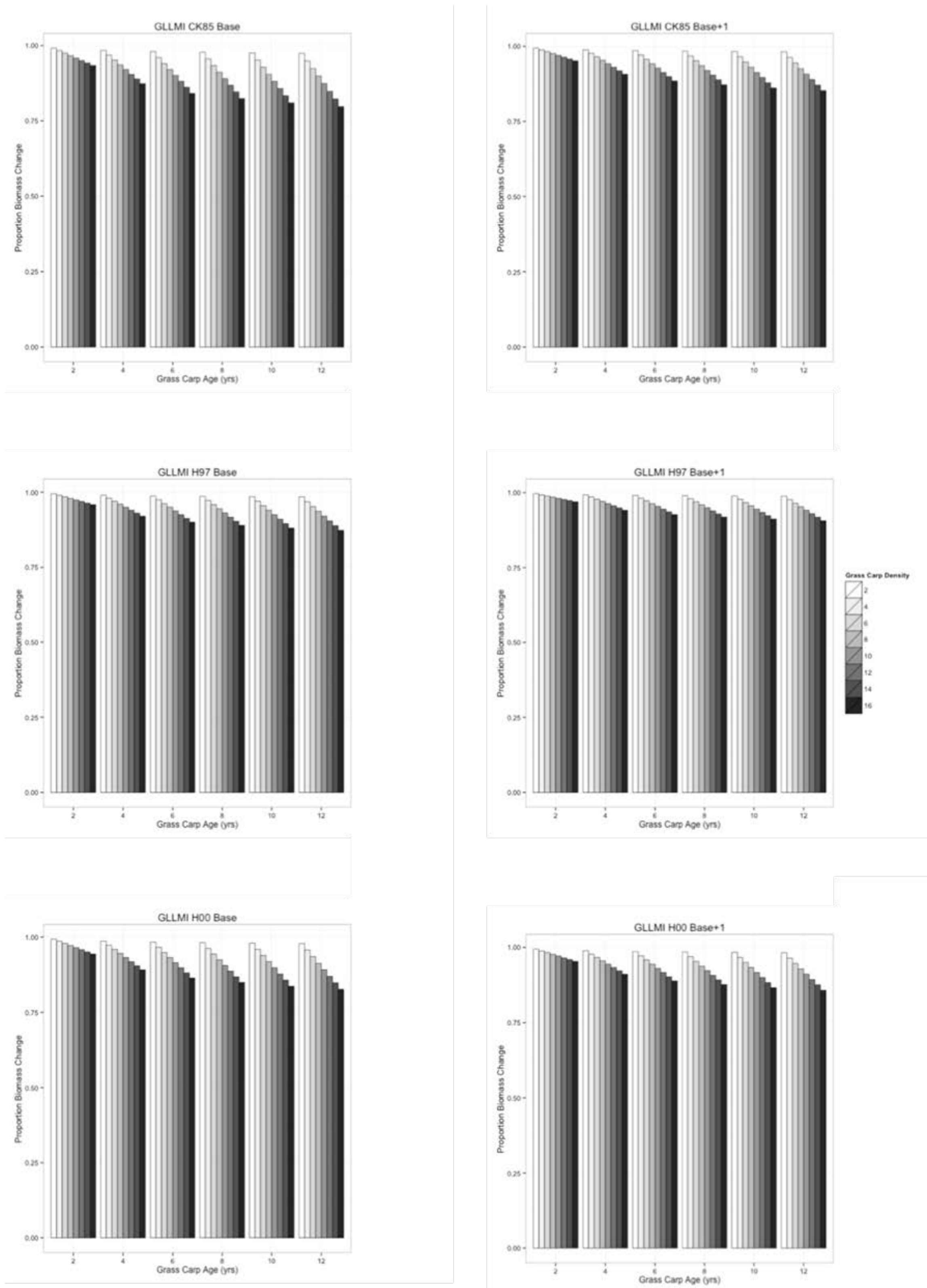

Figure 1.6. Basin-wide changes in biomass under the various Grass Carp densities and ages for the GLLMI inventory.

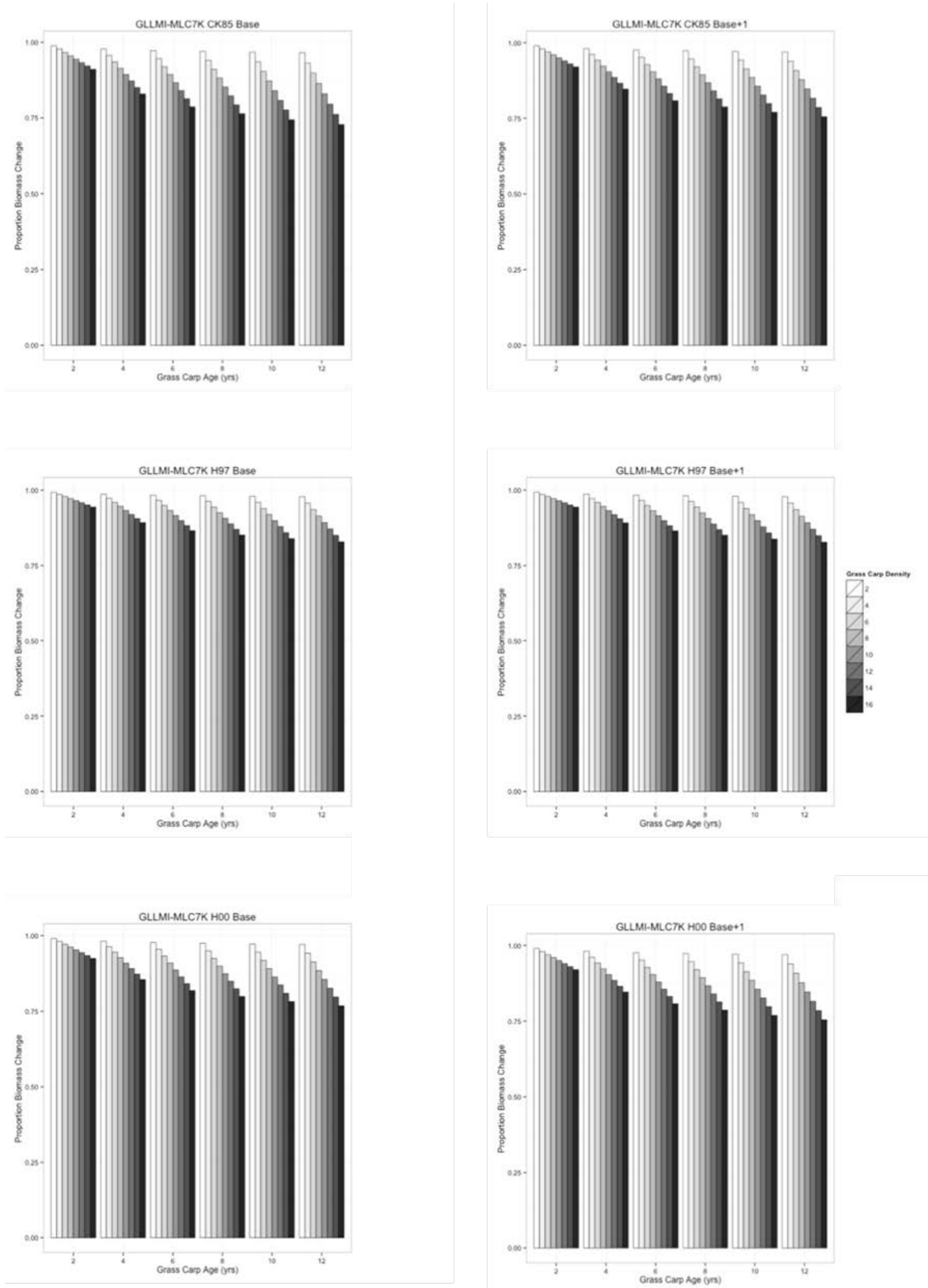

Figure 1.7. Basin-wide changes in biomass under the various Grass Carp densities and ages for the GLLMI$_{MLC\text{-}7K}$ inventory.

The $GLLMI_{MLC\text{-}7K}$ had a much greater low marsh area than the GLLMI; however, on a per-unit area basis, this inventory had lower estimates for vegetation biomass. As a result, the predicted influence of Grass Carp consumption on basin-wide biomass was greater for the $GLLMI_{MLC\text{-}7K}$ than it was for the GLLMI. This was driven largely by the larger number of Grass Carp that would be present in the $GLLMI_{MLC\text{-}7K}$ as a function of its area. For example, at the maximum density of 16/ha and largest Grass Carp size (18.0 kg), for the $GLLMI_{MLC\text{-}7K}$ the various models suggested that between 73 and 83% of the total biomass would remain. In the same scenario, models based on the GLLMI suggested that between 80 and 91% of the vegetation biomass would remain.

Lake and Watershed Evaluation

The total proportional change in vegetation biomass for each Great Lake was calculated for 18-kg Grass Carp under all eight fish densities. Similarly, proportional change was calculated at the tertiary watershed scale for the same scenarios.

Within each Lake, there was a range of proportional changes that were dependent on the biomass model that was used (Table 1.6). Lake Erie tended to show the greatest variability with proportional changes between 0.006 and 0.037 for 2/ha density and 0.051 and 0.293 for the 16/ha density; Lake Erie also had high variability in remaining vegetation biomass estimates. For all models, the lowest estimates for change under the 16/ha scenario predicted between 5-25% change and higher estimates ranged from 18–40% (Table 1.6).

Table 1.6. proportional change in biomass for each lake under high and low densities of 18 kg Grass Carp. The brackets show the biomass model from which the proportion was derived.

GLLMI Inventory

Lake	2 18 kg/ha		16 18 kg/ha	
	Low	**High**	**Low**	**High**
Erie	0.006 (H97B1)	0.037 (CK85B)	0.051 (H97B1)	0.293 (CK85B)
Huron	0.014 (H97B)	0.023 (H00B1)	0.111 (H97B)	0.188 (H00B1)
Michigan	0.016 (H97B)	0.024 (CK85B1)	0.130 (H97B)	0.191 (CK85B1)
Ontario	0.013 (H97B1)	0.037 (CK85B)	0.108 (H97B1)	0.296 (CK85B)
Superior	0.019 (H97B)	0.029 (H00B1)	0.149 (H97B)	0.229 (H00B1)

GLLMI$_{MLC-7K}$ Inventory

Lake	2 18 kg/ha		16 18 kg/ha	
	Low	**High**	**Low**	**High**
Huron	0.023 (H97B)	0.039 (H00B1)	0.185 (H97B)	0.312 (H00B1)
Michigan	0.018 (H97B)	0.030 (CK85B1)	0.143 (H97B)	0.238 (CK85B1)
Ontario	0.019 (H97B1)	0.034 (CK85B)	0.152 (H97B1)	0.268 (CK85B)
Superior	0.031 (H97B)	0.051 (H00B1)	0.250 (H97B)	0.408 (H00B1)

At the tertiary watershed level, for the GLLMI proportional change ranged from 0.004 to 0.150 under the 2/ha density and 0.034 to 1.00 under the 16/ha density. The GLLMI$_{MLC-7K}$ showed a similar range for the 16/ha density (0.040 to 1.00), but was more variable for the 2/ha density (0.005 to 0.864). At the higher Grass Carp density, there was a clear north-south structure of tertiary watershed impacts with sites in Lake Erie and southern Lake Michigan-Huron seeing the largest proportional changes in biomass (Figures 1.8 and 1.9).

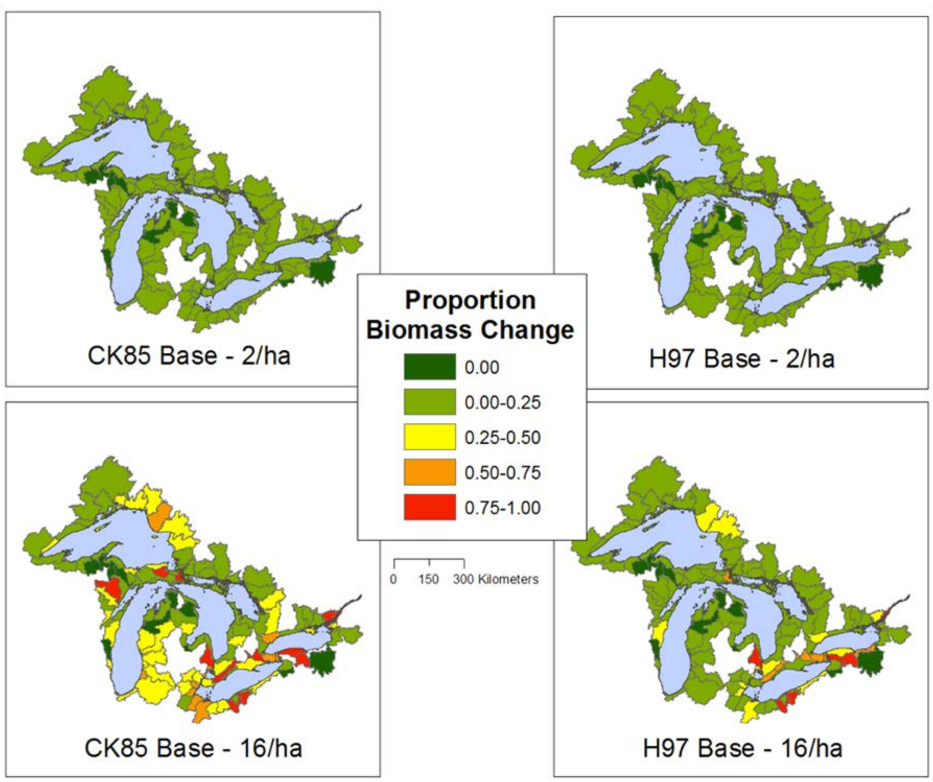

Figure 1.8. Watershed-level proportional changes in biomass for the GLLMI. The values refer to only wetlands in direct contact with a Great Lake or connecting waterway, but the entire watershed is shaded to better show differences in the basin. The CK85 Base model was selected since it was typically showed the largest changes and the H97 Base model was selected because it typically had the smallest changes.

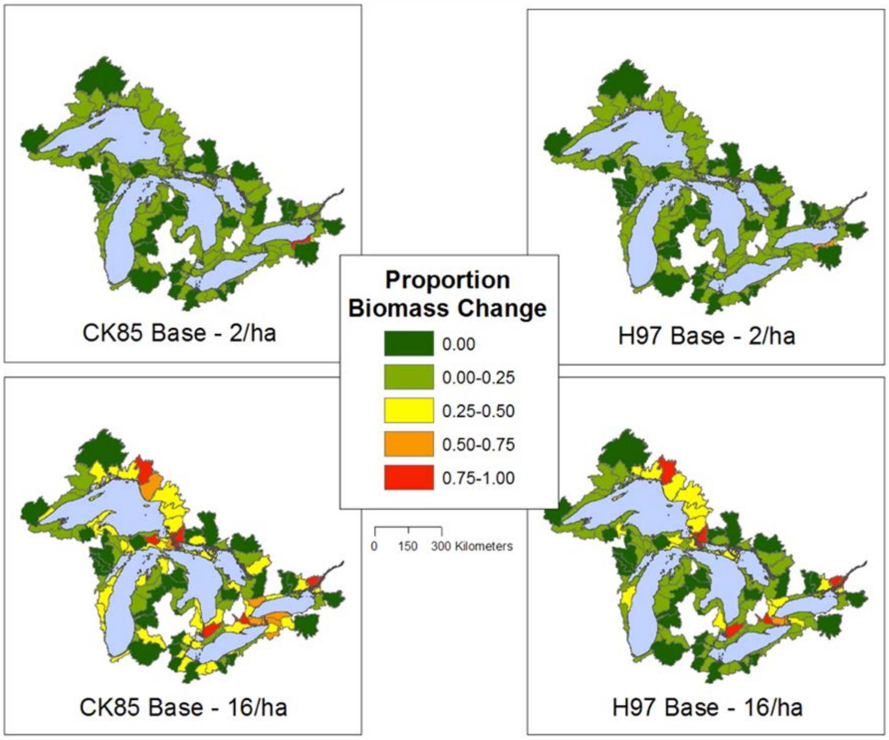

Figure 1.9. Watershed-level proportional changes in biomass for the $GLLMI_{MLC-7K}$. The values refer to only wetlands in direct contact with a Great Lake or connecting waterway, but the entire watershed is shaded to better show differences in the basin. The CK85 Base model was selected since it was typically showed the largest changes and the H97 Base model was selected because it typically had the smallest changes.

Site-level Evaluation

A similar analytical approach as the basin-wide evaluation was used for each low-marsh unit in both the GLLMI and $GLLMI_{MLC-7K}$. The proportional change in overall vegetation biomass for each low marsh unit in each inventory and biomass model was evaluated under all combinations of the eight different Grass Carp densities and the six different Grass Carp sizes. Also, the proportion of low marsh units for each inventory and biomass unit that would lose 50% and 100% of their vegetation biomass as a result of Grass Carp consumption was determined. Finally, a density histogram was plotted to look at the frequency of sites with low to high proportional changes in vegetation biomass. This was only completed for the highest density (16/ha) of the largest Grass Carp (18.0 kg).

Under all biomass models for both the GLLMI and $GLLMI_{MLC-7K}$, vegetation was completely depleted at only a small proportion of sites (typically <5%). The greatest incidence of depletion was for the H00 model (at both Base and Base+1), particularly when there were 10 or more 13.2 kg Grass Carp per hectare. However, for this model the maximum observed proportional loss of biomass was still less than 10%.

In contrast, all of the models showed a large proportion of sites experiencing a 50% reduction in biomass, peaking at 62% of sites for CK85 Base (16 18 kg Grass Carp per hectare; Figures 1.10 and 1.11). Once again, the greatest change was observed when the density exceeded 10 13.2 kg Grass Carp per hectare. Indeed, 13.2 kg Gras Carp at a density of 10/ha seems to represent a transitional zone. For example, the proportion of sites with a 50% change when 9.5 kg Grass Carp are present ranges from 0.02 to 0.08 but when they increase to 13.2 kg the range increases to 0.20 to 0.31.

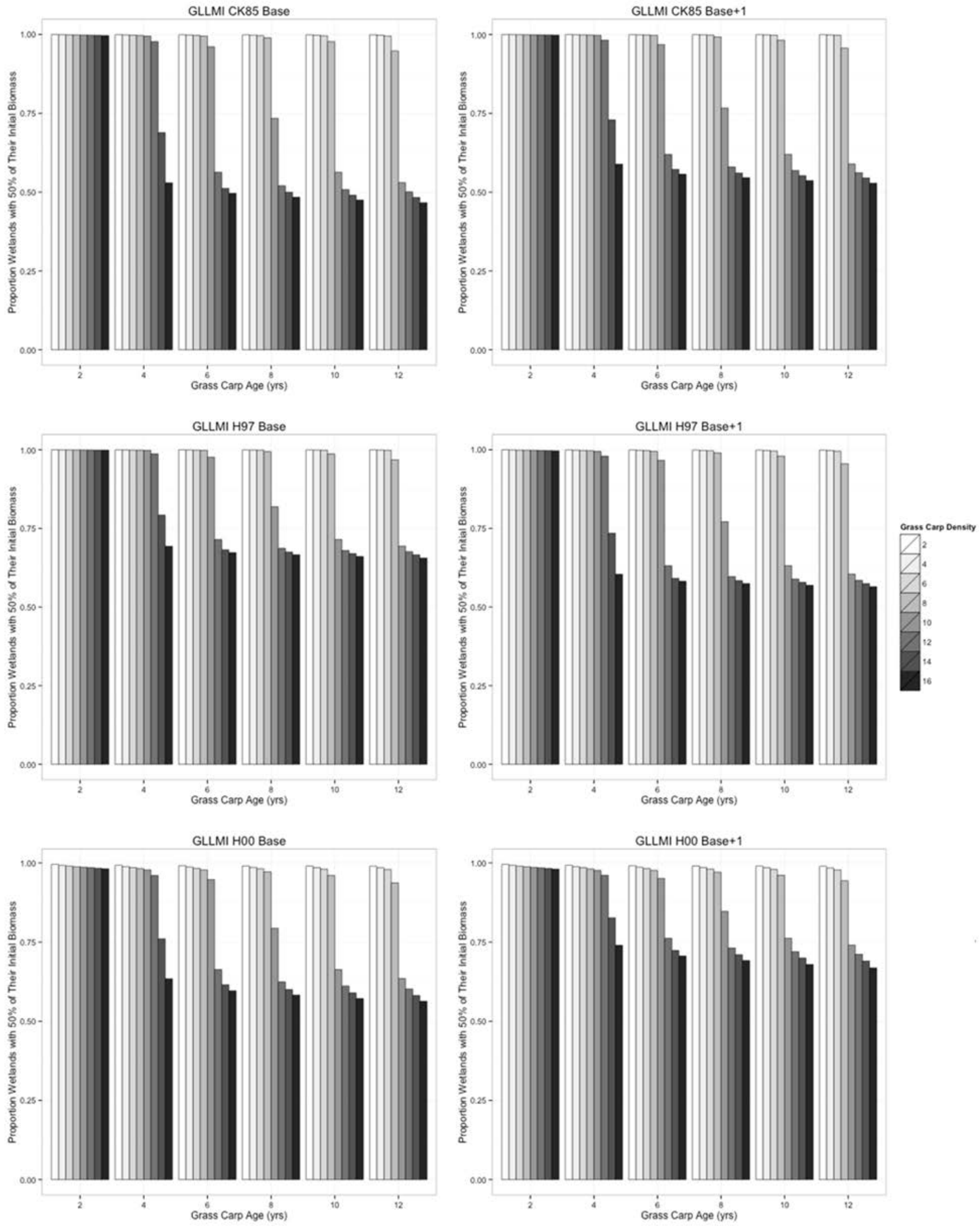

Figure 1.10. Site-level changes in biomass under the various Grass Carp densities and ages for the GLLMI.

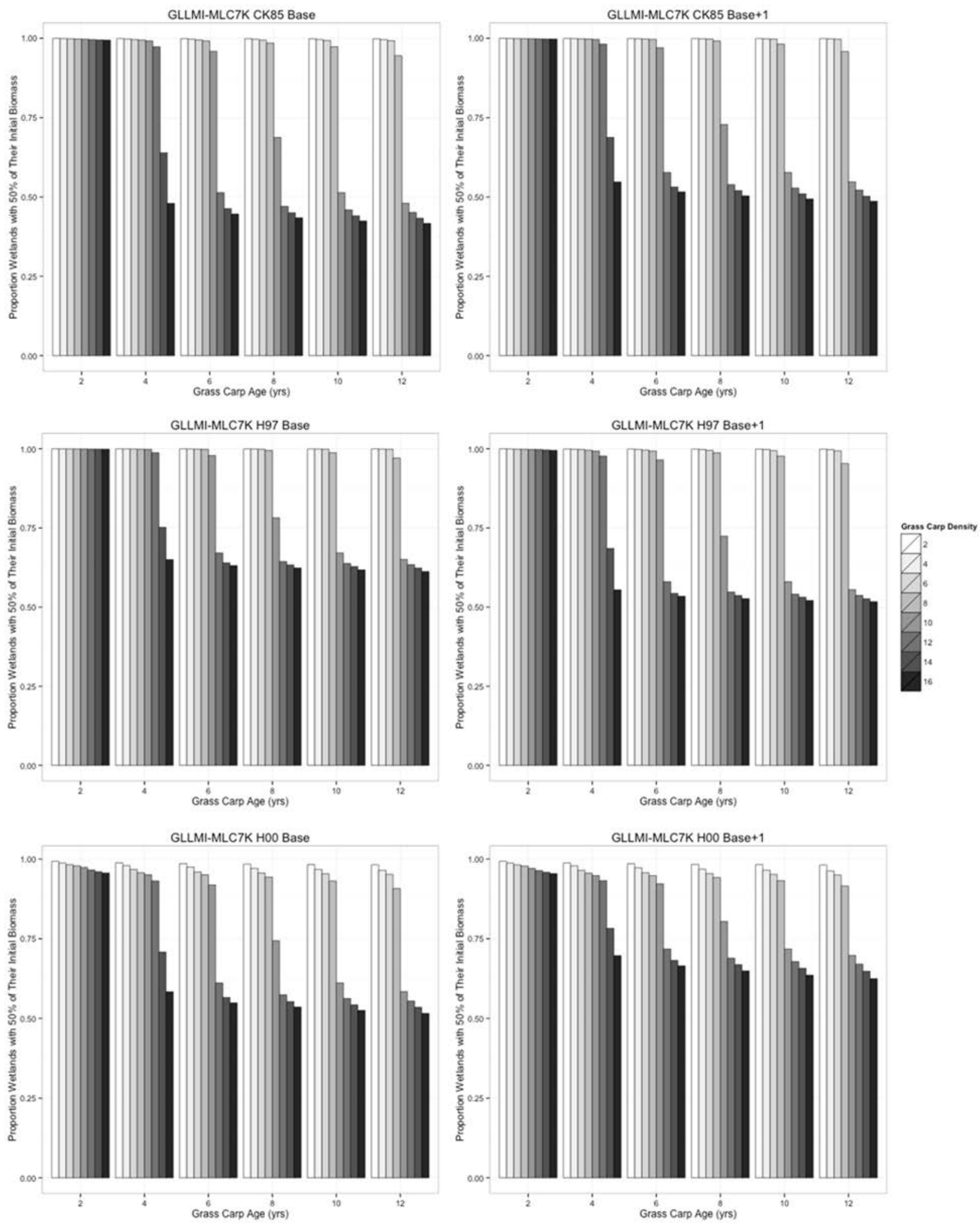

Figure 1.11. Site-level changes in biomass under the various Grass Carp densities and ages for the $GLLMI_{MLC\text{-}7K}$.

In the density histograms, there was a clear bi-modal distribution for all densities of 18.0 kg Grass Carp (Figures 1.12 and 1.13). For both inventories and all biomass models, the separation between the peaks became increasingly distinct as the density of Grass Carp increased. This suggests that within Great Lakes there are two distinct types of low marshes that have variable levels of susceptibility to Grass Carp foraging. The group that appears more resistant is likely associated with areas that have a high vegetation biomass that is concentrated in a small area.

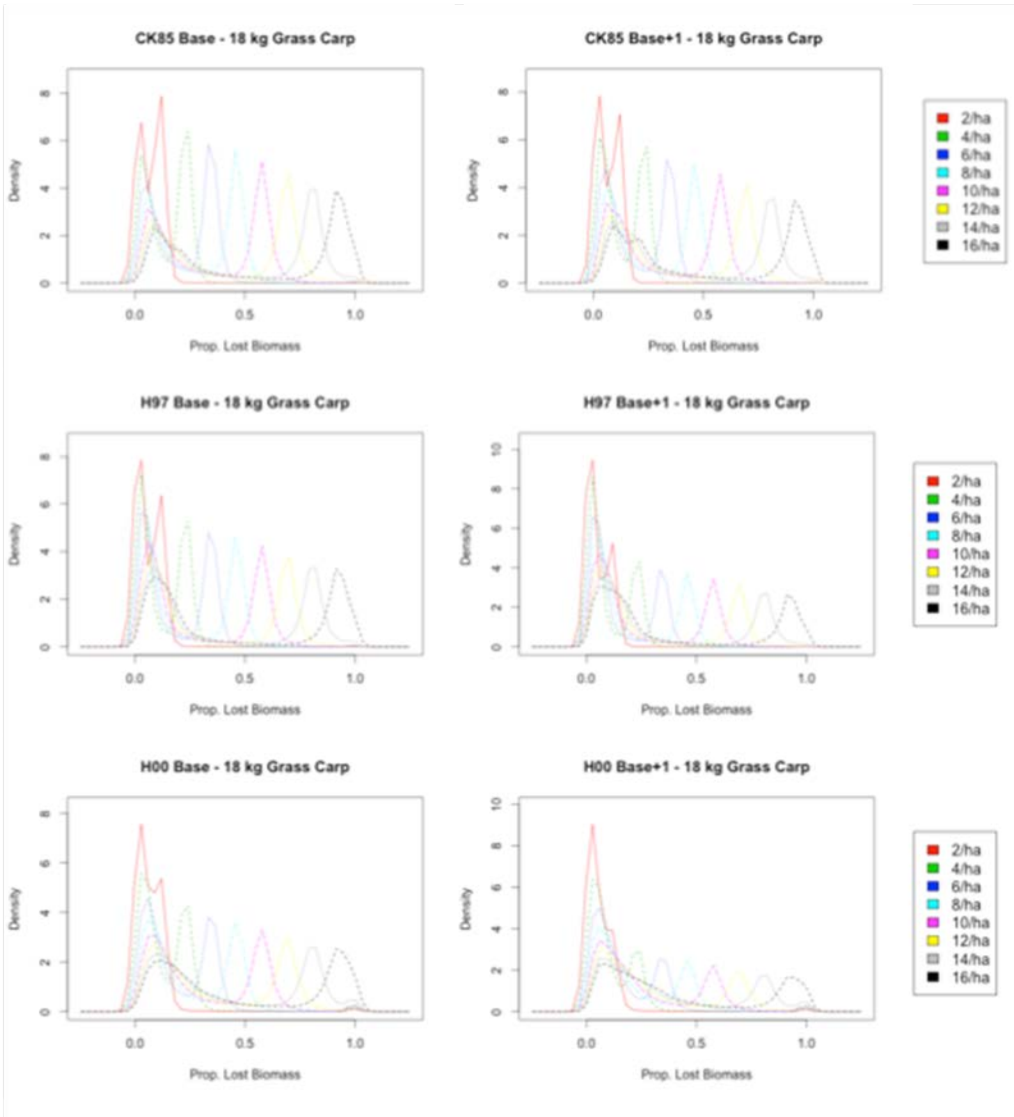

Figure 1.12. Density histogram showing the distribution of sites based on their proportional loss of biomass as a result of Grass Carp foraging in the GLLMI.

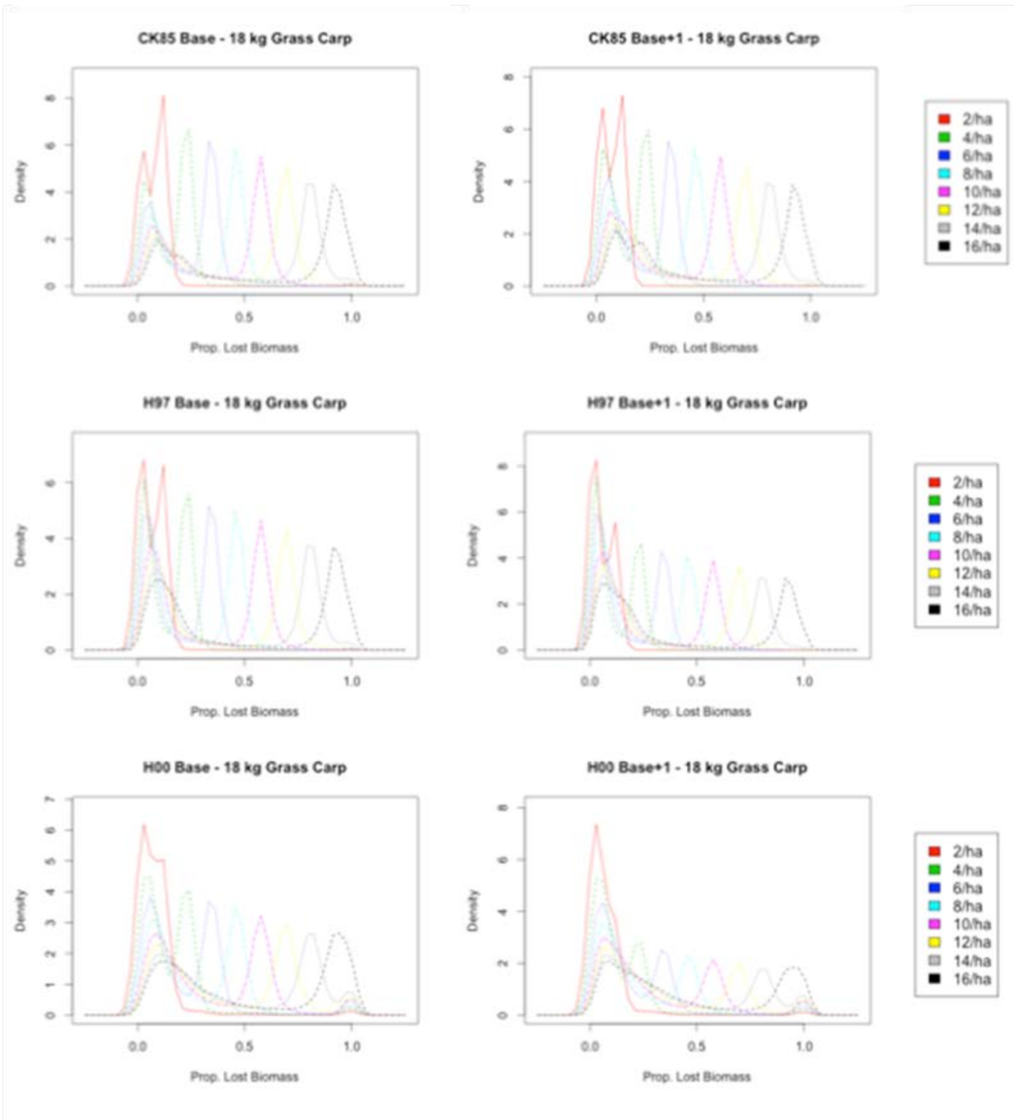

Figure 1.13. Density histogram showing the distribution of sites based on their proportional loss of biomass as a result of Grass Carp foraging in the $GLLMI_{MLC\text{-}7K}$.

Breakpoints in seasonal vegetation biomass

While it is clear that the total annual vegetation biomass consumed by Grass Carp will influence their impact on low marsh habitat, the timing of the start of their feeding will also play a role. The vegetation biomass models outlined in this section are estimates of the peak biomass in a given year. Therefore, at the start of the growing season, vegetation biomass will effectively be zero, rising throughout the spring and early summer, before peaking mid-summer and then senescing through the fall and into the early winter.

To account for this seasonal variability, the biomass in each wetland at the time when Grass Carp begin to feed (April 20th) needed to be determined. Since aquatic vegetation grows exponentially until it reaches its peak biomass, the relative growth rate (RGR = $\ln(W_2/W_1)$/days) was used to back-calculate the amount of biomass in each wetland on April 20th, with peak biomass set to occur on August 15th (as reported for lakes in Quebec's eastern Townships; Rooney and Kalff 2000). W_1 represents the biomass on April 20th and W_2 the biomass on August 15th. A variety of RGRs have been reported in the literature for aquatic vegetation, and these are dependent on local conditions (e.g., nutrient composition [Forchhammer 1999], species [Madsen and Cedergreen 2002], and climate). For this section, four different RGRs ranging from 0.025 g/day to 0.11 g/day were used (Sand-Jensen and Madsen 1999, Forchhammer 1999; Madsen and Cedergreen 2002).

Breakpoints for each of the four RGRs were determined for Grass Carp masses ranging from 0.1-kg to 18-kg based on consumption rates. These breakpoints represent the theoretical vegetation biomass that needs to be established prior to the start of Grass Carp feeding in order to balance their feeding and not result in a complete loss of vegetation. Invariably, Grass Carp feeding will reduce biomass, but this early season feeding is likely of particular importance since it can make it challenging for aquatic vegetation to become established. Only RGR 0.04, an average condition, was used for the remaining evaluation (Figure 1.14).

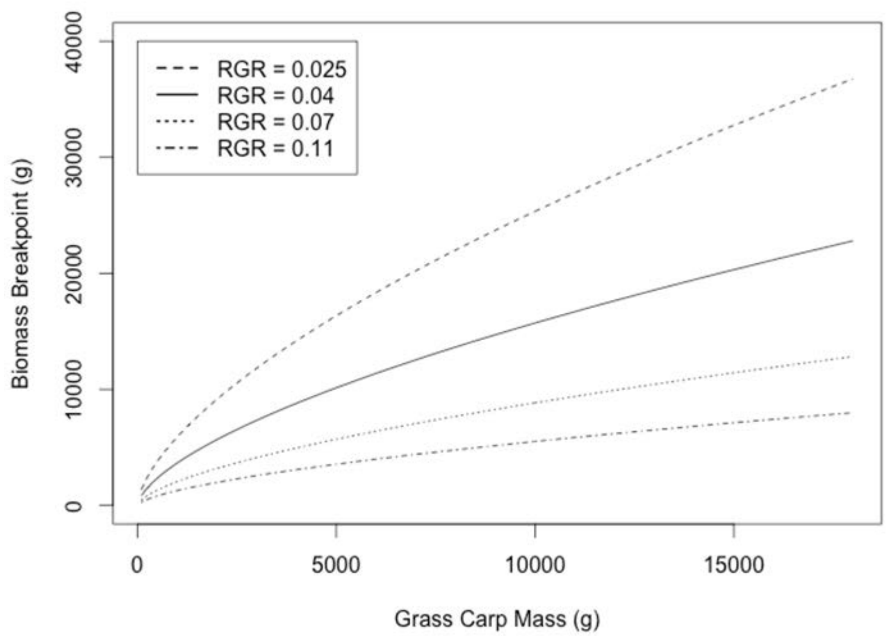

Figure 1.14. Breakpoints for the various relative growth rates (RGRs). The breakpoint represents the minimum amount of biomass that must be present prior to the start of Grass Carp feeding in order for aquatic macrophytes to remain at a given site.

To link these theoretical breakpoints for RGR 0.04 to low marsh areas in the Great Lakes, the proportion of units in the GLLMI and $GLLMI_{MLC-7K}$ that fell below the calculated breakpoints for 1.6 kg, 4.5 kg, 9.5 kg, 13.2 kg, 16 kg and 18 kg Grass Carp were determined. These proportions were calculated for all six of the vegetation biomass models. Density of Grass Carp was not considered in this analysis, instead only a single Grass Carp was assumed to be present at the start of the growing season.

For both inventories, the proportion of wetlands that fell below the breakpoint increased with increasing Grass Carp size until approximately 13.2 kg, at which point it began to level-off (Figures 1.15 and 1.16). This levelling off is related to the predicted decrease in consumption rate for larger Grass Carp.

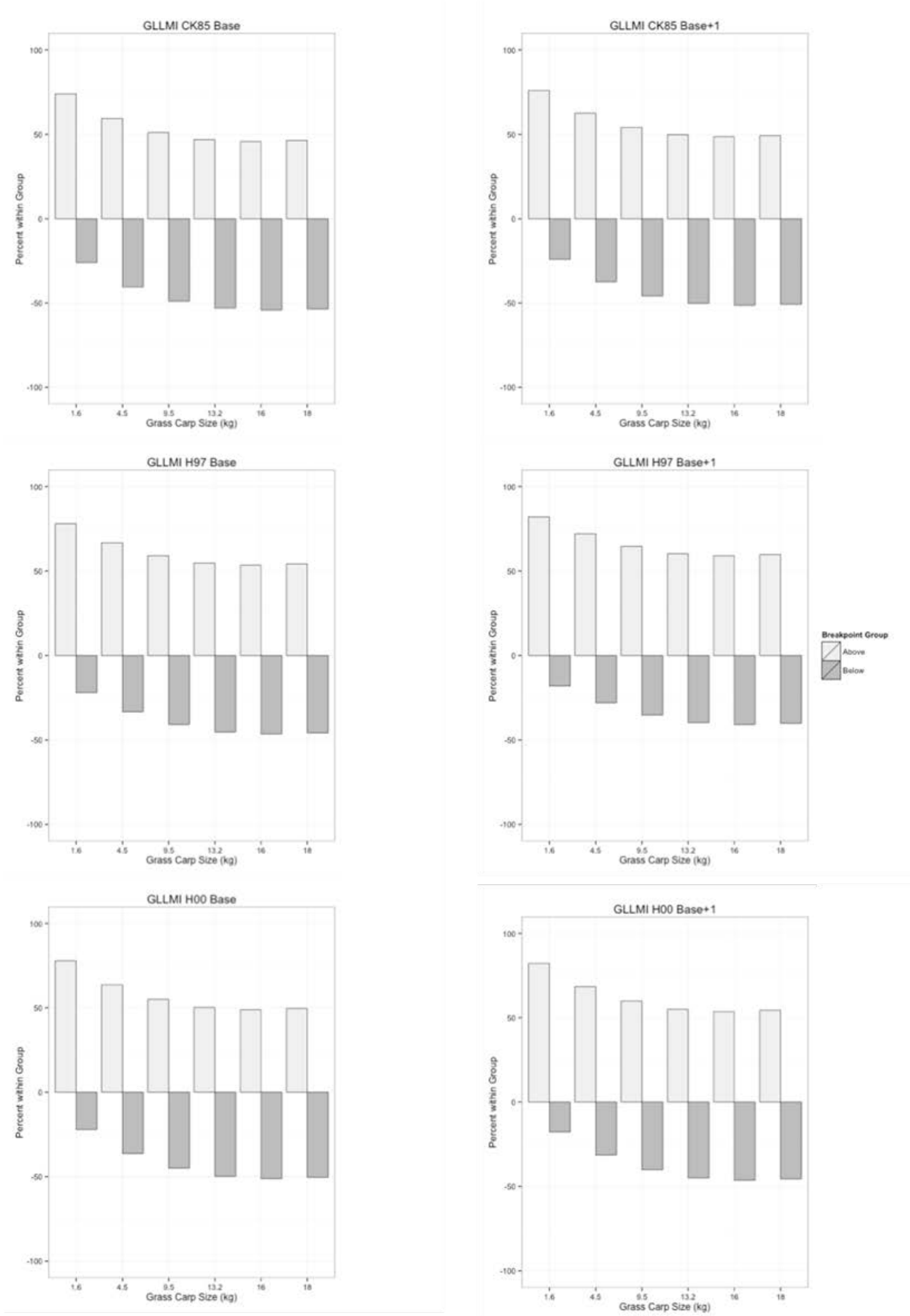

Figure 1.15. Percentage of low marsh units that were either above or below the established breakpoint at the start of Grass Carp feeding (April 20th) for the various biomass models in the GLLMI.

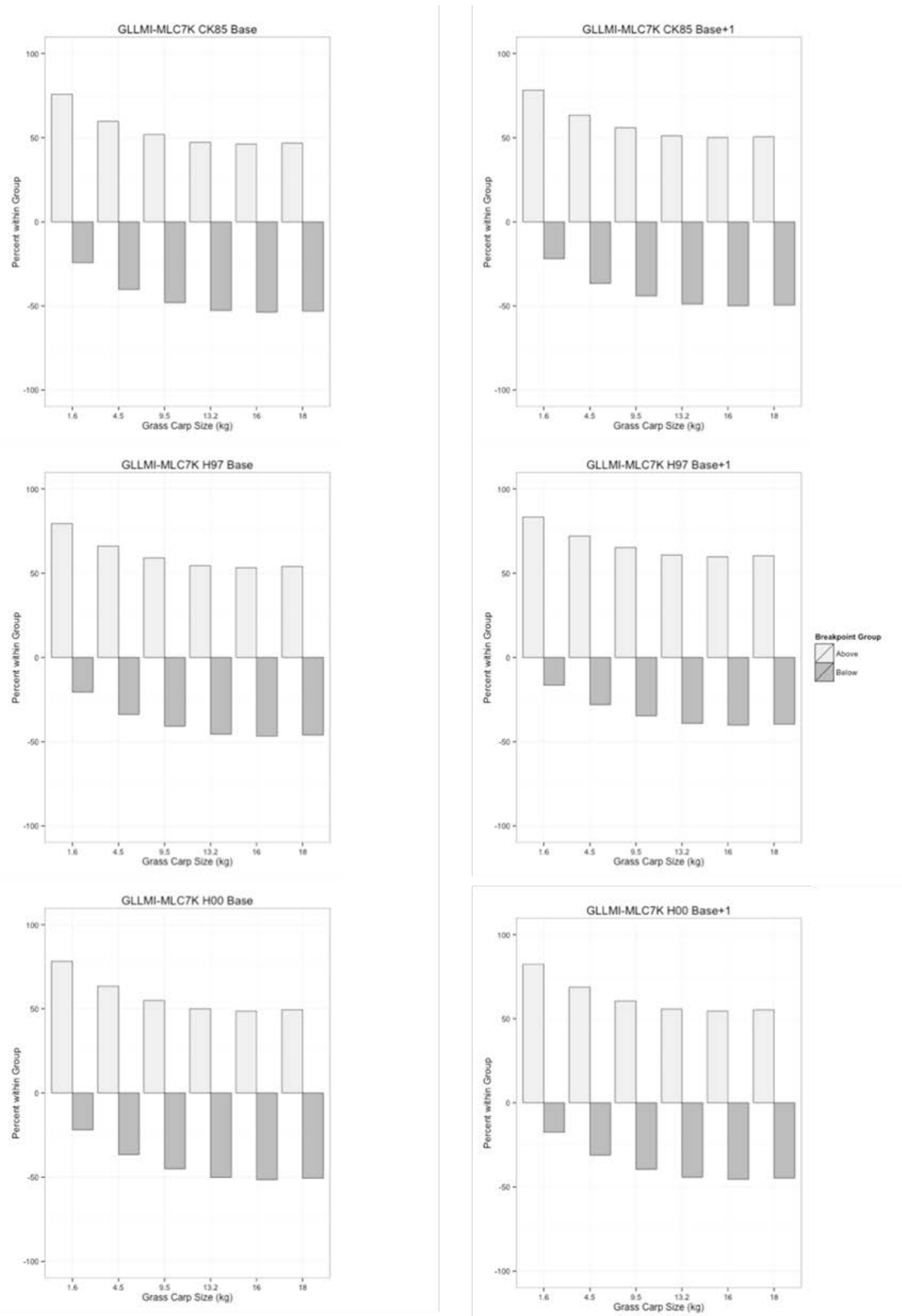

Figure 1.16. Percentage of low marsh units that were either above or below the established breakpoint at the start of Grass Carp feeding (April 20^th^) for the various biomass models in the $GLLMI_{MLC\text{-}7K}$.

DISCUSSION

The results of the present section suggest that there are a large number of low marsh units (30,000–45,000) that cover a large area (150,000 to 550,000 hectares) within the Great Lakes and that these areas support a massive amount of vegetation biomass estimated at between 2.5 and 4.5 million metric tonnes of wet weight. It is therefore not surprising that at a basin-wide scale, the evaluated scenarios of Grass Carp invasion typically predicted there would be a decline in vegetation biomass of less than 5%. However, at the site-level, a greater range of variability was observed, with a large proportion of sites seeing a 50% decline in vegetation biomass, particularly at higher densities of large Grass Carp.

Within the Great Lakes and their connecting waterbodies, at higher densities of large Grass Carp (18 kg), the most vulnerable areas appear to be focused in Lake Erie, and southern lakes Michigan, Huron and Ontario. For the present section, however, only impacts from the largest Grass Carp group were evaluated, which will clearly show the highest level of change. Therefore a range of 5–40% change is a worst-case scenario. That being said, biomass changes in the low end of this range could still have serious negative consequences for native aquatic species.

The potential negative impacts from Grass Carp invasion were most apparent for the breakpoint analysis, whereby a large proportion of sites would see significant declines in vegetation biomass in the presence of a single Grass Carp early in the season. Combined foraging of multiple Grass Carp (a more likely scenario) would be even more severe and likely result in a high loss of vegetation biomass at a substantial number of sites.

From the assessment of the potential impacts of Grass Carp foraging, there is some indication that since consumption rates in the Grass Carp begin to level off as they grow the density of Grass Carp is a more important factor in dictating the extent of their impact on vegetation biomass. Indeed, the largest changes were found at densities greater than 10/ha for the majority of size groups. Should they become established in the Great Lakes, managing Grass Carp density may be a better approach than targeting larger individuals.

Finally, a key element currently missing from this analysis is an evaluation of the spatial distribution of vulnerable sites (low marsh units). As previously noted, highly impacted low marsh habitat was found throughout the Great Lakes basin. This suggests that if Grass Carp are able to establish in all lakes, there will be portions of these systems that are heavily impacted. The fact that there were still low marsh areas that did not appear to be as negatively affected is promising and suggests that some sites may produce sufficient vegetation biomass that can serve as a buffer to Grass Carp foraging. That being said, the work here only focuses on the impact over a single season and the cumulative effects of repeated foraging may eventually deplete this reserve vegetation biomass.

The scenarios presented here and their potential impacts come with several important caveats. First, the Grass Carp consumption models do not currently incorporate changes in temporal foraging rates. Rather, a single value was applied across all days when foraging occurred (the 14-day spawning run was however removed); this will likely result in a slight overestimate of consumption for the breakpoint analysis. However, for the basin, lake, watershed and site-level analyses, a single value for annual consumption was applied for each age/size group. This value was based on an estimated mean annual consumption rate for that size based on the bioenergetics model. Additionally, the consumption rates were applied evenly across the entire Great Lakes basin and therefore do not account for any variability in climate. Since water temperature influences the consumption rate of Grass Carp, their overall consumption in northern latitudes is likely an overestimate. Finally, the vegetation biomass models are estimates of the peak potential biomass. Therefore, at the start of the growing season, biomass will effectively be zero, rising throughout the spring and early summer, before peaking mid-summer and then senescing through the fall and into the early winter. The start, peak and ending of vegetation growth is highly dependent on water temperatures and consequently there will be extensive interannual variability in biomass that is not directly considered in this report.

2.0 EVALUATING THE POTENTIAL ECOLOGICAL CONSEQUENCES OF GRASS CARP ON THE GREAT LAKES FISH COMMUNITY

Erin L. Gertzen and Marten A. Koops

INTRODUCTION

Grass Carp (*Ctenopharyngodon idella*) is currently widespread in parts of the United States and poses an imminent threat to the Great Lakes. As part of the binational Great Lakes Risk Assessment for Grass Carp, an evaluation of the potential impacts of Grass Carp introduction on the native fish community of the Great Lakes is important. Predicting such impacts can help assess the level of risk anticipated if Grass Carp invade the Great Lakes.

Grass Carp prefer shallow water habitat and areas with large amounts of aquatic vegetation (Wittmann et al. 2014). They are an herbivorous fish and consume large amounts of aquatic vegetation. While few Great Lakes fish species consume aquatic vegetation and would compete directly with Grass Carp for food, well over half of the Great Lakes fish community uses aquatic vegetation for important life history needs such as spawning, refuge and forage habitat (Jude and Pappas 1992). A meta-analysis of the impacts of Grass Carp on various biotic and abiotic metrics found a weak positive and variable relationship between Grass Carp presence and fish population and community metrics in small pond systems (Wittmann et al. 2014). Information on impacts in novel, large lake systems such as the Great Lakes are unknown. It is likely that the consequences of Grass Carp on the Great Lakes fish community would be indirect and mediated through Grass Carp's effect on aquatic vegetation. Therefore, this section evaluates the potential impacts of Grass Carp on the fish community using two methods:

a. a classification of the fish community into low, medium and high potential impact groups based on how much each species relies on shallow, vegetated habitat throughout its life, and
b. a literature review of the relationship between fish population and community metrics and aquatic vegetation.

Together, these should provide an insight on the potential consequences of Grass Carp introduction on the Great Lakes fish community.

METHODS

Review of Great Lakes fishes habitat needs and classification into 'potential consequences following Grass Carp introduction' groups

In this review, important information on the characteristics and habitat of Great Lakes fish species were compiled (Table 2.1). This information, including variables ranging from species at risk status to trophic level and habitat associations, is aimed at helping managers evaluate the potential consequences of Grass Carp on the Great Lakes fish community. Each variable and the data sources are described below.

Status:

- Status describes any important designations the species has including listing under the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and whether the species is non-native to the Great Lakes region. A blank entry means the species is native to the Great Lakes region and has not been evaluated under COSEWIC.
- Table codes:
    - DD = listed as data deficient under COSEWIC – inadequate information to make an assessment of risk
    - END = listed as endangered under COSEWIC
    - INT = introduced species
    - NAR = listed as not at risk under COSEWIC – assessed and found not be not at risk
    - SC = listed as special concern under COSEWIC
    - THR = listed as threatened under COSEWIC
- Source: Environment Canada (2016)

General Habitat:

- General Habitat describes broadly the types of water bodies the species inhabits. Species that inhabit lacustrine and riverine areas of the Great Lakes basin may overlap with Grass Carp during different life history events (e.g., resident adult lake habitat vs spawning river habitat).
- Table codes:
    - L = lacustrine
    - R = riverine
    - M = marine
    - E = estuarine
- Source: Eakins (2015)

Great Lake Presence:

- Great Lake Presence indicates which of the five Great Lakes the species is found in. This column provides a reference to enable refinement of the fish list or potential effects of Grass Carp by lake.
- Table codes:
    - S = Lake Superior
    - M = Lake Michigan
    - H = Lake Huron
    - E = Lake Erie
    - O = Lake Ontario
- Source: Nick Mandrak, DFO, pers. comm.

Thermal Guild:

- Thermal Guild describes the general thermal habitat preferred by adult fish.
- Table codes:
    - Cold = coldwater (<19 °C)
    - Cool = coolwater (19–25 °C)
    - Warm = warmwater (>25 °C)
- Sources: Coker et al. (2001), Eakins (2015)

Trophic Guild:

- Trophic Guild describes the types of foods the species consumes and its position in the food chain.
- Table codes:
    - C = carnivore – consumes fish and/or other vertebrates
    - D = detritivore – consumes detritus
    - H = herbivore – consumes plant matter
    - I = invertivore – consumes invertebrates
    - P = planktivore – consumes plankton
- Source: Eakins (2015)

Economic Use:

- Economic Use describes the economic value, if any, of the fish species related to angling or a fishery.
- Table codes:
    - B = bait fish – used for angling sport fish(es)
    - C = commercial fishery (current or historic)
    - F = forage fish – important for other economically important fish(es)
    - O = coarse fish – less valuable fish species
    - P = pan fish – smaller fish that may be angled
    - S = sport fishery
- Source: Eakins (2015)

Jude and Pappas Class:

- Jude and Pappas Class uses a 1992 ranking of Great Lakes fish species from 1 to 113 based on observed frequency of occurrence in open water, coastal zone and wetland habitat. The Great Lakes fishes were reclassified following Trebitz and Hoffman (2015).
- Table codes:
    - open water = fishes ranked 1–31 by Jude and Pappas (1992)
    - coastal = fishes ranked 32–66 by Jude and Pappas (1992)
    - weak wetland = fishes ranked 67–90 by Jude and Pappas (1992)
    - strong wetland = fishes ranked 90–113 by Jude and Pappas (1992)
- Sources: Jude and Pappas (1992), Trebitz and Hoffman (2015)

Depth Affinity:

- Depth Affinity describes the water depths a fish uses across its life. Water depth associations for Great Lakes fishes have been reviewed and presented in the literature (e.g., Lane et al. 1996a, b, c). Using this information, we assigned each life stage (spawning, nursery, adult) of fishes to a shallow (<10 m), broad (0–20+ m) or pelagic (deeper depths). We joined data across life stages to describe the overall depth affinity for the species.
- Table codes:
    - shallow = all three life stages exclusively use water depths less than 10 m
    - mixed = one or two life stages exclusively use water depths less than 10 m
    - broad = all life stages have broad water depth affinities and use a range of depths from 0 to 20+ m
    - pelagic = the species uses predominantly pelagic habitat
- Sources: Lane et al. (1996a, b, c), Cudmore-Vokey and Crossman (2002), Eakins (2015)

Balon Reproductive Guild:

- Balon Reproductive Guilds describe the type of spawning behaviour and habitat preferences exhibited by species during spawning.
- Table codes (see Appendix B in Coker et al. (2001) and Balon (1975) for further descriptions of reproductive guild codes):
    - A.1.1=nonguarder, open substrate: pelagophil;
    - A.1.2= nonguarder, open substrate: litho-pelagophil;
    - A.1.3= nonguarder, open substrate: lithophil;
    - A.1.4= nonguarder, open substrate: phyto-lithophil;
    - A.1.5= nonguarder, open substrate: phyophil;
    - A.1.6= nonguarder, open substrate: psammophil;
    - A.2.3= nonguarder, brood hider: lithophil;
    - B.1.3=guarder, substrate chooser: lithophil;
    - B.1.4=guarder, substrate chooser: phytophil;
    - B.2.2=guarder, nester: polyphil;
    - B.2.3=guarder, nester: lithophil;
    - B.2.4=guarder, nester: ariadnophil;
    - B.2.5=guarder, nester: phytophil;
    - B.2.7=guarder, nester: speleophil.
- Source: Coker et al. 2001 (Smallmouth Buffalo from Simon [1999] and Ghost Shiner from Eakins [2015])

Vegetation Affinity – Spawn, Nursery and Adult:

- Vegetation Affinity during early (spawning), young-of-the-year (nursery) and adult life stages describes how associated the species is with emergent and submergent aquatic vegetation. Vegetation associations for Great Lakes fishes have been reviewed and presented in the literature (e.g., Lane et al. 1996a, b, c). Using this information, we assigned each life stage (spawning, nursery, adult) of fishes to a "high" vegetation affinity if they had a high association with either emergent or submergent vegetation, a "medium" vegetation affinity if they had a medium association with either emergent or submergent vegetation (and no high affinity for a vegetation type), a 'low" vegetation affinity if they had a low association with either emergent or submergent vegetation (and no high or medium affinity for a vegetation type), a 'nil' vegetation affinity if their habitat associations had been reviewed but no association with vegetation was observed, and a '-' if no information on their vegetation affinity was available in the literature.
- Table codes:
    - H = high vegetation affinity
    - M = medium vegetation affinity
    - L = low vegetation affinity
    - N = nil observed use of vegetation
    - \- = no information on vegetation affinity
- Sources: Lane et al. (1996a, b, c), Cudmore-Vokey and Crossman (2002), Eakins (2015)

Using the information described above, we classified all Great Lakes fish species into groups describing the potential negative consequences they could experience following Grass Carp introduction into the Great Lakes (Table 2.1). The classification is based on habitat and life history needs that overlap with the habitats preferred by Grass Carp.

The classification index is the sum of five variables:

1. Balon Reproductive Guild:
    - 1 if vegetation is used by the reproductive guild: A.1.4, A.1.5, B.1.4, B.2.5

- 0 otherwise

2. Depth Affinity:
    - 1 if shallow water depth affinity (all life stages use shallow water [<10 m])
    - 0.5 if mixed depth affinity (some life stages use shallow water)
    - 0 otherwise
3. Spawning Vegetation Affinity:
    - 1 if high vegetation affinity
    - 0.7 if medium vegetation affinity
    - 0.3 if low vegetation affinity
    - 0 otherwise
4. Nursery Vegetation Affinity:
    - 1 if high vegetation affinity
    - 0.7 if medium vegetation affinity
    - 0.3 if low vegetation affinity
    - 0 otherwise
5. Adult Vegetation Affinity:
    - 1 if high vegetation affinity
    - 0.7 if medium vegetation affinity
    - 0.3 if low vegetation affinity
    - 0 otherwise

The classification rules to describe the potential consequences of Grass Carp on a fish species are:

- Potential Consequences Sum = Balon Reproductive Guild + Depth Affinity + Spawning Vegetation Affinity + Nursery Vegetation Affinity + Adult Vegetation Affinity
- If Potential Consequences Sum is ≥4 Then Potential Consequences Class = High
- If Potential Consequences Sum is <4 and ≥3 Then Potential Consequences Class = Moderate
- If Potential Consequences Sum is <3 and >0 Then Potential Consequences Class = Low
- If Potential Consequences Sum is 0 Then Potential Consequences Class = Nil
- Exceptions:
    - If Potential Consequences Class = High and maximum vegetation affinity is Medium Then Potential Consequences Class = Moderate
    - If Potential Consequences Class = Low and maximum vegetation affinity is High Then Potential Consequences Class = Moderate
    - If Potential Consequences Class = Low and Trebitz and Hoffman (2015) list species as an important coastal fishery species Then Potential Consequences Class = Moderate
- The Potential Consequences on fishes may occur across all life stages or during only one or two life stages if a species experiences ontogenetic shifts in habitat and life history needs.

Table 2.1. Classification of the potential effects of Grass Carp on Great Lakes fishes based on overlap in habitat and life history traits.

Petromyzontidae

Species Name	Common Name	Potential Effect		General Habitat	Great Lake Presence	Thermal Guild	Trophic Guild	Economic Use	Jude & Pappas Class	Depth Affinity	Balon Reprod Guild	Vegetation Affinity		
		Class	Life stage(s)									Spawn	Nursery	Adult
Ichthyomyzon castaneus	Chestnut Lamprey	nil	-	L, R	S,M,H	cool	H, C	-	coastal	broad	A.2.3	-	-	-
Ichthyomyzon fossor	Northern Brook Lamprey	L	-	R	S,M,H,E	cool	H	-	-	broad	A.2.3	-	L	L
Ichthyomyzon unicuspis	Silver Lamprey	L	-	L, R	All	cool	H, D, C	-	-	broad	A.2.3	-	L	N
Lethenteron appendix	American Brook Lamprey	L	-	R	All	cold	H	-	-	broad	A.2.3	-	L	L
Petromyzon marinus	Sea Lamprey	L	-	L, M	All	cool	H, D, C	-	open	broad	A.2.3	-	L	N

Acipenseridae

Species Name	Common Name	Potential Effect		General Habitat	Great Lake Presence	Thermal Guild	Trophic Guild	Economic Use	Jude & Pappas Class	Depth Affinity	Balon Reprod Guild	Vegetation Affinity		
		Class	Life stage(s)									Spawn	Nursery	Adult
Acipenser fulvescens	Lake Sturgeon	L	-	L, R	All	cool	I, H	C	open water	mixed	A.1.2	N	L	N

Lepisosteidae

Species Name	Common Name	Potential Effect		General Habitat	Great Lake Presence	Thermal Guild	Trophic Guild	Economic Use	Jude & Pappas Class	Depth Affinity	Balon Reprod Guild	Vegetation Affinity		
		Class	Life stage(s)									Spawn	Nursery	Adult
Lepisosteus oculatus	Spotted Gar	H	All	L, R	M,E,O	warm	C	-	weak wetland	shallow	A.1.5	H	H	H
Lepisosteus osseus	Longnose Gar	H	All	L, R	All	warm	C	O	weak wetland	shallow	A.1.5	H	H	H

Amiidae

Species Name	Common Name	Potential Effect		General Habitat	Great Lake Presence	Thermal Guild	Trophic Guild	Economic Use	Jude & Pappas Class	Depth Affinity	Balon Reprod Guild	Vegetation Affinity		
		Class	Life stage(s)									Spawn	Nursery	Adult
Amia calva	Bowfin	H	All	L, R	M,H,E,O	warm	C	O	weak wetland	shallow	B.2.5	H	H	H

Hiodontidae

Species Name	Common Name	Potential Effect		General Habitat	Great Lake Presence	Thermal Guild	Trophic Guild	Economic Use	Jude & Pappas Class	Depth Affinity	Balon Reprod Guild	Vegetation Affinity		
		Class	Life stage(s)									Spawn	Nursery	Adult
Hiodon tergisus	Mooneye	nil	-	L, R	M,H,E,O	cool	I	-	coastal	pelagic	A.1.2	-	N	N

Anguillidae

Species Name	Common Name	Potential Effect		General Habitat	Great Lake Presence	Thermal Guild	Trophic Guild	Economic Use	Jude & Pappas Class	Depth Affinity	Balon Reprod Guild	Vegetation Affinity		
		Class	Life stage(s)									Spawn	Nursery	Adult
Anguilla rostrata	American Eel	L	-	L, R	All	cool	I, C	C	coastal	broad	A.1.1	-	-	H *any crevice

Clupeidae

Species Name	Common Name	Potential Effect		General Habitat	Great Lake Presence	Thermal Guild	Trophic Guild	Economic Use	Jude & Pappas Class	Depth Affinity	Balon Reprod Guild	Vegetation Affinity		
		Class	Life stage(s)									Spawn	Nursery	Adult
Alosa pseudoharengus	Alewife	L	-	L, M	All	cold	P	F, B	coastal	pelagic	A.1.4	L	L	N
Dorosoma cepedianum	Gizzard Shad *	M	All	L, R	M,H,E,O	cool	H	F	weak wetland	pelagic	A.1.2	H	H	N

Cyprinidae

Species Name	Common Name	Potential Effect		General Habitat	Great Lake Presence	Thermal Guild	Trophic Guild	Economic Use	Jude & Pappas Class	Depth Affinity	Balon Reprod Guild	Vegetation Affinity		
		Class	Life stage(s)									Spawn	Nursery	Adult
Campostoma anomalum	Central Stoneroller	L	-	R	M,H,E,O	cool	H	B	strong wetland	shallow	A.2.3	N	M	M
Carassius auratus	Goldfish	H	All	L, R	All	warm	I, H	-	weak wetland	shallow	A.1.5	H	H	H
Chrosomus eos	Northern Redbelly Dace	H	Spawn, Adult	L, R	All	cool	I, P	F, B	-	shallow	A.1.5	H	N	H
Chrosomus neogaeus	Finescale Dace	M	Spawn, Adult	L, R	All	cool	I, P	F, B	-	shallow	A.1.4	N	N	H
Clinostomus elongatus	Redside Dace	nil	-	R	All	cool	I	-	-	-	A.1.3	-	-	N
Couesius plumbeus	Lake Chub	L	-	L, R	S,M,H,O	cold	I, P	F, B	open water	mixed	A.1.3	N	N	N
Cyprinella spiloptera	Spotfin Shiner	L	-	R	M,H,E,O	warm	I, H	F, B	weak wetland	shallow	A.1.4	L	L	L
Cyprinus carpio	Common Carp *	H	All	L, R	All	warm	I, D	O, C	coastal	shallow	A.1.5	H	H	H
Hybognathus hankinsoni	Brassy Minnow	H	All	L, R	All	cool	P, D	F, B	-	shallow	A.1.4	H	M	M
Luxilus chrysocephalus	Striped Shiner	M	Adult	R	M,H,E,O	cool	I	F, B	strong wetland	mixed	B.2.3	N	M	H
Luxilus cornutus	Common Shiner	L	-	R	All	cool	I	F, B	strong wetland	shallow	B.2.3	L	M	M
Lythrurus umbratilis	Redfin Shiner	H	All	R	M,H,E,O	cool	I	F	-	shallow	A.1.4	N	H	H
Macrhybopsis storeriana	Silver Chub	L	-	L, R	E	cool	P, I	F	-	mixed	A.1.4		L	M
Margariscus nachtriebi	Northern Pearl Dace	L	-	L, R	All	cool	I, C	F, B	-	shallow	A.1.3	L	L	L
Nocomis biguttatus	Hornyhead Chub	L	-	R	All	cool	I, H	B	-	shallow	A.2.3	L	-	N
Nocomis micropogon	River Chub	nil	-	R	M,H,E,O	cool	P, I	B	-	-	A.2.3	-	-	N
Notemigonus crysoleucas	Golden Shiner	H	All	L	All	cool	I, H	F, B	weak wetland	shallow	A.1.5	H	H	H
Notropis anogenus	Pugnose Shiner	H	All	L, R	M,H,E,O	cool	D	-	strong wetland	shallow	A.1.3	H	H	H
Notropis atherinoides	Emerald Shiner	L	-	L, R	All	cool	P	F, B	coastal	broad	A.1.1	L	M	N
Notropis bifrenatus	Bridle Shiner	H	Spawn, Adult	L, R	O	cool	P	F	open water	shallow	A.1.5	H	L	H
Notropis buchanani	Ghost Shiner	nil	-	R	E	warm	I	-	-	-	A.1.2	-	-	N
Notropis heterodon	Blackchin Shiner	H	All	L, R	All	cool	I	F, B	strong wetland	shallow	A.1.5	H	H	H
Notropis heterolepis	Blacknose Shiner	H	All	L, R	All	cool	I, H	B	strong wetland	shallow	A.1.6	H	H	H
Notropis hudsonius	Spottail Shiner	M	YOY, Adult	L, R	All	cool	I, P	F, B	coastal	broad	A.1.6	M	H	H
Notropis rubellus	Rosyface Shiner	L	-	R	All	warm	I, D, H	F	-	shallow	A.1.3	N	L	N
Notropis ludibundus	Sand Shiner	L	-	L, R	All	warm	I, D	F, B	weak wetland	mixed	A.1.6	L	M	L
Notropis volucellus	Mimic Shiner	H	Spawn, YOY	L, R	All	warm	I, H	F, B	coastal	shallow	A.1.4	H	H	L
Opsopoeodus emiliae	Pugnose Minnow	H	All	L, R	M,E	warm	D	-	strong wetland	shallow	A.1.5	M	H	H
Pimephales notatus	Bluntnose Minnow	M	Adult	L, R	All	warm	D	F, B	strong wetland	shallow	B.2.7	M	M	H
Pimephales promelas	Fathead Minnow	M	Adult	L, R	All	warm	D, I	F, B	weak wetland	shallow	B.2.7	M	M	H
Rhinichthys atratulus	Blacknose Dace	L	-	R	All	cool	I	F, B	weak wetland	shallow	A.1.3	N	N	N
Rhinichthys cataractae	Longnose Dace	L	-	L, R	All	cool	I	F, B	coastal	shallow	A.1.3	N	L	L
Scardinius erythrophthalmus	Rudd	H	Spawn, Adult	L, R	E,O	cool	I, H	-	-	shallow	A.1.5	H	-	H
Semotilus atromaculatus	Creek Chub	L	-	R	All	cool	I, C	B	coastal	shallow	A.2.3	N	M	M
Semotilus corporalis	Fallfish	L	-	L, R	O	cool	I, C	B	coastal	shallow	A.2.3	N	L	N

Catostomidae

Species Name	Common Name	Potential Effect		General Habitat	Great Lake Presence	Thermal Guild	Trophic Guild	Economic Use	Jude & Pappas Class	Depth Affinity	Balon Reprod Guild	Vegetation Affinity		
		Class	Life stage(s)									Spawn	Nursery	Adult
Carpiodes cyprinus	Quillback	L	-	L, R	M,H,E,O	cool	I, D	O	weak wetland	shallow	A.1.6	N	M	M
Catostomus catostomus	Longnose Sucker	M	YOY	L, R	All	cold	I	O, C	open water	mixed	A.1.3	N	H	M
Catostomus commersonii	White Sucker *	M	All	L, R	All	cool	I, D	F, B, O	coastal	mixed	A.1.3	L	H	M
Erimyzon sucetta	Lake Chubsucker	H	All	L, R	M,H,E,O	warm	I, H	-	weak wetland	shallow	A.1.5	H	H	H
Hypentelium nigricans	Northern Hog Sucker	M	YOY	R	M,H,E,O	warm	I, H	B	coastal	shallow	A.1.3	N	H	N
Ictiobus cyprinellus	Bigmouth Buffalo	H	Spawn, Adult	L, R	M,H,E	warm	I	O	strong wetland	shallow	A.1.5	H	M	H
Ictiobus niger	Black Buffalo	?	?	L, R	M,H,E	warm	I, H	-	-	-	A.1.5	-	-	-
Ictiobus bubalus	Smallmouth Buffalo	L	-	L, R	M,E	warm	I	-	-	-	A.1.2	M	M	M
Minytrema melanops	Spotted Sucker	M	YOY	L, R	M,H,E	warm	I	-	strong wetland	shallow	A.1.3	N	H	L
Moxostoma anisurum	Silver Redhorse	M	YOY	L, R	All	cool	I	-	open water	shallow	A.1.3	N	H	N
Moxostoma duquesneii	Black Redhorse	M	YOY	R	M,H,E,O	warm	I	-	coastal	shallow	A.1.3	-	H	L
Moxostoma erythrurum	Golden Redhorse	M	YOY	R	M,H,E,O	warm	I	-	coastal	shallow	A.1.3	-	H	N
Moxostoma macrolepidotum	Shorthead Redhorse	L	-	L, R	All	warm	I	-	coastal	shallow	A.1.3	N	N	L
Moxostoma valenciennesi	Greater Redhorse	L	-	L, R	M,H,E,O	warm	I	-	-	shallow	A.1.3	N	N	N
Moxostoma carinatum	River Redhorse	nil	-	R	M,H,E,O	cool	I	-	strong wetland	-	A.1.3	N	N	N

Ictaluridae

Species Name	Common Name	Potential Effect		General Habitat	Great Lake Presence	Thermal Guild	Trophic Guild	Economic Use	Jude & Pappas Class	Depth Affinity	Balon Reprod Guild	Vegetation Affinity		
		Class	Life stage(s)									Spawn	Nursery	Adult
Ameiurus melas	Black Bullhead *	M	All	L, R	All	warm	I, C	O	weak wetland	shallow	B.2.3	H	M	H
Ameiurus natalis	Yellow Bullhead	H	All	L, R	All	warm	I, C	O	weak wetland	shallow	B.2.7	H	H	H
Ameiurus nebulosus	Brown Bullhead *	M	All	L, R	All	warm	I, H, C	O, C	strong wetland	shallow	B.2.7	M	H	H
Ictalurus punctatus	Channel Catfish *	M	All	L, R	M,H,E,O	warm	I, C	C, S	coastal	shallow	B.2.7	L	L	N
Noturus flavus	Stonecat	L	-	R	All	warm	I, C	-	coastal	shallow	B.2.7	N	L	N
Noturus gyrinus	Tadpole Madtom	M	YOY, Adult	L, R	M,H,E,O	warm	I, P	-	weak wetland	mixed	B.2.7	M	H	H
Noturus miurus	Brindled Madtom	M	YOY, Adult	L, R	E,O	warm	I	-	weak wetland	shallow	B.2.7	M	H	M
Noturus stigmosus	Northern Madtom	?	?	R	E	warm	I	-	-	-	B.2.7	-	-	N
Pylodictis olivaris	Flathead Catfish	?	?	L, R	M,H,E	warm	I, C	-	coastal	-	B.2.3	-	-	-

Esocidae

Species Name	Common Name	Potential Effect		General Habitat	Great Lake Presence	Thermal Guild	Trophic Guild	Economic Use	Jude & Pappas Class	Depth Affinity	Balon Reprod Guild	Vegetation Affinity		
		Class	Life stage(s)									Spawn	Nursery	Adult
Esox americanus vermiculatus	Grass Pickerel	H	All	L, R	All	warm	I, C	-	strong wetland	shallow	A.1.5	H	H	H
Esox lucius	Northern Pike *	H	All	L, R	All	cool	C	C, S	coastal	shallow	A.1.5	H	H	H
Esox masquinongy	Muskellunge	H	All	L, R	All	warm	C	C, S	coastal	mixed	A.1.5	H	H	H

Umbridae

Species Name	Common Name	Potential Effect		General Habitat	Great Lake Presence	Thermal Guild	Trophic Guild	Economic Use	Jude & Pappas Class	Depth Affinity	Balon Reprod Guild	Vegetation Affinity		
		Class	Life stage(s)									Spawn	Nursery	Adult
Umbra limi	Central Mudminnow	H	All	R	All	cool	I	F, B	strong wetland	shallow	A.1.5	H	H	H

Osmeridae

Species Name	Common Name	Potential Effect		General Habitat	Great Lake Presence	Thermal Guild	Trophic Guild	Economic Use	Jude & Pappas Class	Depth Affinity	Balon Reprod Guild	Vegetation Affinity		
		Class	Life stage(s)									Spawn	Nursery	Adult
Osmerus mordax	Rainbow Smelt	L	-	L, M	All	cold	I, C	F, B, C, S	coastal	pelagic	A.1.3	L	N	N

Salmonidae

Species Name	Common Name	Potential Effect		General Habitat	Great Lake Presence	Thermal Guild	Trophic Guild	Economic Use	Jude & Pappas Class	Depth Affinity	Balon Reprod Guild	Vegetation Affinity		
		Class	Life stage(s)									Spawn	Nursery	Adult
Coregonus artedi	Lake Herring/Cisco	L	-	L	All	cold	P, I	F, B, C, S	open water	pelagic	A.1.2	N	L	N
Coregonus clupeaformis	Lake Whitefish	L	-	L, R	All	cold	I, C	C, S	open water	broad	A.1.3	N	L	N
Coregonus hoyi	Bloater	nil	-	L	S,M,H	cold	P, I	C, F	open water	pelagic	A.1.2	N	N	N
Coregonus kiyi	Kiyi	nil	-	L	S	cold	P	C	open water	pelagic	A.1.2	N	N	N
Coregonus zenithicus	Shortjaw Cisco	nil	-	L	S,H	cold	P	C	open water	pelagic	A.1.1	N	N	N
Oncorhynchus gorbuscha	Pink Salmon	nil	-	L, M	All	cold	I	S	open water	pelagic	A.2.3	-	N	N
Oncorhynchus kisutch	Coho Salmon	nil	-	L, M	All	cold	I, C	S	open water	pelagic	A.2.3	-	N	N
Oncorhynchus mykiss	Rainbow Trout	L	-	L, R	All	cold	I, C	S	open water	broad	A.2.3	N	L	N
Oncorhynchus tshawytscha	Chinook Salmon	nil	-	L, M	All	cold	I, C	S	open water	pelagic	A.2.3	-	N	N
Prosopium coulterii	Pygmy Whitefish	nil	-	L, R	S	cold	I	-	open water	broad	A.1.3	N	N	N
Prosopium cylindraceum	Round Whitefish	nil	-	L, R	S,M,H,O	cold	I, C	C	open water	broad	A.1.3	N	N	N
Salmo trutta	Brown Trout	L	-	L, R	All	cold	I, C	S	open water	mixed	A.2.3	N	N	N
Salvelinus fontinalis	Brook Trout	nil	-	L, R	All	cold	I, C	S	open water	shallow	A.2.3	N	N	N
Salvelinus namaycush	Lake Trout	nil	-	L	All	cold	I, C	C, S	open water	broad	A.2.3	N	N	N

Percopsidae

Species Name	Common Name	Potential Effect		General Habitat	Great Lake Presence	Thermal Guild	Trophic Guild	Economic Use	Jude & Pappas Class	Depth Affinity	Balon Reprod Guild	Vegetation Affinity		
		Class	Life stage(s)									Spawn	Nursery	Adult
Percopsis omiscomaycus	Trout-Perch	L	-	L, R	All	cold	I, C	F, B	coastal	broad	A.1.3	L	N	N

Gadidae

Species Name	Common Name	Potential Effect		General Habitat	Great Lake Presence	Thermal Guild	Trophic Guild	Economic Use	Jude & Pappas Class	Depth Affinity	Balon Reprod Guild	Vegetation Affinity		
		Class	Life stage(s)									Spawn	Nursery	Adult
Lota lota	Burbot	nil	-	L, R	All	cold	I, C	O	open water	broad	A.1.2	N	N	N

Atherinidae

Species Name	Common Name	Potential Effect		General Habitat	Great Lake Presence	Thermal Guild	Trophic Guild	Economic Use	Jude & Pappas Class	Depth Affinity	Balon Reprod Guild	Vegetation Affinity		
		Class	Life stage(s)									Spawn	Nursery	Adult
Labidesthes sicculus	Brook Silverside	M	Spawn	L, R	M,H,E,O	warm	P, I	F	coastal	pelagic	A.1.4	H	L	M

Fundulidae

Species Name	Common Name	Potential Effect: Class	Potential Effect: Life stage(s)	General Habitat	Great Lake Presence	Thermal Guild	Trophic Guild	Economic Use	Jude & Pappas Class	Depth Affinity	Balon Reprod Guild	Vegetation Affinity: Spawn	Vegetation Affinity: Nursery	Vegetation Affinity: Adult
Fundulus diaphanus	Banded Killifish	H	All	L, R	M,H,E,O	cool	I, P	B	strong wetland	shallow	A.1.5	H	H	H
Fundulus notatus	Blackstripe Topminnow	H	All	R	M,E	warm	H, I	-	-	-	A.1.5	-	-	H

Gasterosteidae

Species Name	Common Name	Potential Effect: Class	Potential Effect: Life stage(s)	General Habitat	Great Lake Presence	Thermal Guild	Trophic Guild	Economic Use	Jude & Pappas Class	Depth Affinity	Balon Reprod Guild	Vegetation Affinity: Spawn	Vegetation Affinity: Nursery	Vegetation Affinity: Adult
Apeltes quadracus	Fourspine Stickleback	M	All	L, E, M	S	cool	P	-	-	mixed	B.2.4	H	M	M
Culaea inconstans	Brook Stickleback	M	YOY	L, R	All	cool	P, I	F, B	weak wetland	mixed	B.2.4	H	M	M
Gasterosteus aculeatus	Threespine Stickleback	L	-	L, R, E, M	All	cool	I	F	open water	mixed	B.2.4	L	L	M
Pungitius pungitius	Ninespine Stickleback	M	Spawn, Adult	L, R, E, M	All	cool	P	F, B	open water	broad	B.2.4	H	M	H

Cottidae

Species Name	Common Name	Potential Effect: Class	Potential Effect: Life stage(s)	General Habitat	Great Lake Presence	Thermal Guild	Trophic Guild	Economic Use	Jude & Pappas Class	Depth Affinity	Balon Reprod Guild	Vegetation Affinity: Spawn	Vegetation Affinity: Nursery	Vegetation Affinity: Adult
Cottus bairdii	Mottled Sculpin	L	-	L, R	All	cold	I	F, B	open water	shallow	B.2.7	N	L	M
Cottus cognatus	Slimy Sculpin	nil	-	L, R	All	cold	I	F, B	open water	broad	B.2.7	N	N	N
Cottus ricei	Spoonhead Sculpin	L	-	L, R, E	S,M,H	cold	I	F	open water	broad	B.2.7	N	N	L
Myoxocephalus thompsonii	Deepwater Sculpin	L	-	L	All	cold	I	F	open water	broad	B.2.3	N	N	L

Moronidae

Species Name	Common Name	Potential Effect: Class	Potential Effect: Life stage(s)	General Habitat	Great Lake Presence	Thermal Guild	Trophic Guild	Economic Use	Jude & Pappas Class	Depth Affinity	Balon Reprod Guild	Vegetation Affinity: Spawn	Vegetation Affinity: Nursery	Vegetation Affinity: Adult
Morone americana	White Perch *	L	-	L, R, E, M	All	warm	I, C	C, P	weak wetland	mixed	A.1.4	M	M	N
Morone chrysops	White Bass *	M	All	L, R	All	warm	I, C	C	strong wetland	mixed	A.1.4	L	M	N

Centrarchidae

Species Name	Common Name	Potential Effect: Class	Potential Effect: Life stage(s)	General Habitat	Great Lake Presence	Thermal Guild	Trophic Guild	Economic Use	Jude & Pappas Class	Depth Affinity	Balon Reprod Guild	Vegetation Affinity: Spawn	Vegetation Affinity: Nursery	Vegetation Affinity: Adult
Ambloplites rupestris	Rock Bass *	M	All	L, R	All	cool	I, C	P	weak wetland	shallow	B.2.3	L	H	H
Lepomis cyanellus	Green Sunfish *	H	All	L, R	All	warm	I, C	P	strong wetland	shallow	B.2.3	H	H	H
Lepomis gibbosus	Pumpkinseed *	H	All	L, R	All	warm	I, C	P	weak wetland	shallow	B.2.2	H	H	H
Lepomis gulosus	Warmouth	H	All	L, R	M,H,E	warm	I, C	-	coastal	shallow	B.2.5	H	H	H
Lepomis humilis	Orangespotted Sunfish	M	YOY, Adult	L, R	E	warm	I	-	coastal	shallow	B.2.3	L	H	M
Lepomis macrochirus	Bluegill *	H	All	L, R	All	warm	I	P	weak wetland	shallow	B.2.3	H	H	H
Lepomis peltastes	Northern (Longear) Sunfish	M	Ad	L, R	M,H,E,O	warm	I	-	coastal	shallow	B.2.3	M	M	H
Micropterus dolomieu	Smallmouth Bass *	M	All	L, R	All	cool	I, C	S	coastal	shallow	B.2.3	L	N	L
Micropterus salmoides	Largemouth Bass *	H	All	L, R	All	warm	I, C	S	weak wetland	shallow	B.2.5	H	H	H
Pomoxis annularis	White Crappie	H	All	L, R	M,H,E,O	warm	I, C	P	strong wetland	shallow	B.1.4	M	H	H
Pomoxis nigromaculatus	Black Crappie *	H	All	L, R	All	cool	I, C	P	coastal	shallow	B.2.5	H	H	H

Percidae

Species Name	Common Name	Potential Effect		General Habitat	Great Lake Presence	Thermal Guild	Trophic Guild	Economic Use	Jude & Pappas Class	Depth Affinity	Balon Reprod Guild	Vegetation Affinity		
		Class	Life stage(s)									Spawn	Nursery	Adult
Ammocrypta pellucida	Eastern Sand Darter	L	-	L, R	E	warm	I	-	-	mixed	A.1.6	N	L	N
Etheostoma blennioides	Greenside Darter	M	Spawn, YOY	R	M,H,E,O	warm	I	F	-	shallow	A.1.5	L	M	L
Etheostoma caeruleum	Rainbow Darter	L	-	R	M,H,E,O	cool	I	F, B	weak wetland	shallow	A.2.3	L	N	N
Etheostoma exile	Iowa Darter	M	All	L, R	All	cool	I	B	strong wetland	shallow	A.1.4	M	M	M
Etheostoma flabellare	Fantail Darter	L	-	R	All	cool	I	F, B	strong wetland	shallow	B.2.7	N	M	L
Etheostoma microperca	Least Darter	H	All	L, R	All	warm	I	-	-	shallow	A.1.5	H	H	H
Etheostoma nigrum	Johnny Darter	L	-	L, R	All	cool	I	F, B	coastal	mixed	B.2.7	N	M	M
Etheostoma olmstedi	Tessellated Darter	L	-	L, R	O	cool	I	F, B	-	shallow	B.2.7	N	M	M
Gymnocephalus cernuus	Ruffe	L	-	L, R	S,M,H	cool	I	-	coastal	mixed	A.1.4	M	N	N
Perca flavescens	Yellow Perch *	M	All	L, R	All	cool	I, C	F, C, P	coastal	broad	A.1.4	M	M	M
Percina caprodes	Logperch	L	-	L, R	All	warm	I	F, B	strong wetland	mixed	A.1.6	N	M	M
Percina copelandi	Channel Darter	L	-	L, R	H,E,O	warm	I, H	-	open water	mixed	A.2.3	N	L	N
Percina maculata	Blackside Darter	L	-	R	M,H,E,O	cool	I	F, B	coastal	shallow	A.2.3	N	M	L
Percina shumardi	River Darter	L	-	L, R	M,H,E	warm	I	B	strong wetland	shallow	A.2.3	N	N	N
Sander canadensis	Sauger	L	-	L, R	S,M,H,E	cool	I, C	C, S	open water	mixed	A.1.3	L	N	L
Sander vitreus	Walleye *	M	All	L, R	All	cool	I, C	C, S	coastal	mixed	A.1.2	L	L	L

Sciaenidae

Species Name	Common Name	Potential Effect		General Habitat	Great Lake Presence	Thermal Guild	Trophic Guild	Economic Use	Jude & Pappas Class	Depth Affinity	Balon Reprod Guild	Vegetation Affinity		
		Class	Life stage(s)									Spawn	Nursery	Adult
Aplodinotus grunniens	Freshwater Drum *	M	All	L, R	All	warm	I, C	O, C	weak wetland	broad	A.1.1	L	M	L

Gobiidae

Species Name	Common Name	Potential Effect		General Habitat	Great Lake Presence	Thermal Guild	Trophic Guild	Economic Use	Jude & Pappas Class	Depth Affinity	Balon Reprod Guild	Vegetation Affinity		
		Class	Life stage(s)									Spawn	Nursery	Adult
Neogobius melanostomus	Round Goby	L	-	L, R	All	cool	I	-	-	mixed	B.1.3	L	M	M
Proterorhinus semilunaris	Tubenose Goby	M	All	L, R	S,H,E	cool	I	-	-	mixed	B.2.7	M	M	H

Description of table codes:
Common Name *: Important coastal fishery species in the Great Lakes (Trebitz and Hoffman 2015).
Potential Effect – Class: H=high, M=moderate, L=low, nil=none anticipated. Level of potential effects of Grass Carp (see main text for classification rules).
Potential Effect Life Stage(s): Spawning, YOY and/or Adult. The life stage(s) where Grass Carp effects may be observed. No life stage is assigned in the case of low or nil anticipated effected.
General Habitat: L=lacustrine, R=riverine, M=marine, E=estuarine. Source: Eakins (2015).
Great Lake Presence: S=Lake Superior, M=Lake Michigan, H=Lake Huron, E=Lake Erie, O=Lake Ontario. Source: N. Mandrak, DFO, pers. comm.
Thermal Guild: cold, cool, warmwater. Sources: Coker et al. (2001), Eakins (2015).
Trophic Guild: C=carnivore, D=detritivore, H=herbivore, I=invertivore, P=planktivore. Source: Eakins (2015).
Economic Use: B=bait, C=commercial, F=forage, O=coarse, P=pan, S=sport. Source: Eakins (2015).
Jude & Pappas Class*:* Ranking of Great Lakes fish species from 1 to 113 based on frequency of occurrence in open water, coastal zone and wetlands. Reclassified following Trebitz and Hoffman (2015) where 1-31=open water, 32-66=coastal, 67-90=weak wetland, and 91-113=strong wetland fishes. Source: Jude and Pappas (1992), Trebitz and Hoffman (2015).

Depth Affinity: shallow, mixed, broad or pelagic based on depth preferences across spawning, nursery and adult habitat. Shallow if all life stages use depths <10 m, mixed if some life stages use depths <10 m, broad if all life stages use wide range of depths, and pelagic if species using pelagic habitat. Sources: Lane et al. (1996a, b, c), Cudmore-Vokey and Crossman (2002), Eakins (2015).
Balon Reproductive Guild: A.1.1=nonguarder, open substrate: pelagophil; A.1.2= nonguarder, open substrate: litho-pelagophil; A.1.3= nonguarder, open substrate: lithophil; A.1.4= nonguarder, open substrate: phyto-lithophil; A.1.5= nonguarder, open substrate: phyophil; A.1.6= nonguarder, open substrate: psammophil; A.2.3= nonguarder, brood hider: lithophil; B.1.3=guarder, substrate chooser: lithophil; B.1.4=guarder, substrate chooser: phytophil; B.2.2=guarder, nester: polyphil; B.2.3=guarder, nester: lithophil; B.2.4=guarder, nester: ariadnophil; B.2.5=guarder, nester: phytophil; B.2.7=guarder, nester:speleophil. See Appendix B in Coker et al. (2001) and Balon (1975) for further descriptions of reproductive guild codes. Source: Coker et al. (2001) (Smallmouth Buffalo from Simon (1999) and Ghost Shiner from Eakins (2015)).
Vegetation Affinity – Spawn, Nursery and Adult: H=high, M=medium, L=low, N=nil observed use, - = no information. Based on affinity for emergent **or** submergent vegetation from literature sources. Sources: Lane et al. (1996a, b, c), Cudmore-Vokey and Crossman (2002).

Review of the relationship between Great Lakes fishes and aquatic vegetation

We conducted a literature review to complement the classification of Great Lakes fishes into Potential Consequences groups and to further answer the question 'what are the impacts Grass Carp would have on the Great Lakes fish community?' Wittmann et al. (2014) reviewed the experimental evidence of Grass Carp impacts on fish communities in the United States. A meta-analysis of the data showed impacts on both water quality and biota, however few quantifiable fish studies were available and the impact on fishes of the studies that were be included was variable (-0.21–0.43, 95% confidence intervals) and the cumulative effect size was positive but non-significant (effect size = 0.11, df = 17).

In the absence of clear trends or a large body of research on the impacts of Grass Carp on fishes, and with a complete absence of information on the potential consequences of Grass Carp on fishes within the unique landscape of the Great Lakes, we opted to investigate how Grass Carp may mechanistically change the Great Lakes fish community through its effect on aquatic vegetation. To this end, we conducted a literature review on empirical evidence of the relationship between Great Lakes fishes and aquatic vegetation. A few studies outside of the Great Lakes were also included in the review. Aquatic vegetation is important to fulfill life history needs such as spawning, refuge and forage habitat for over half of Great Lakes fishes (Jude and Pappas 1992).

RESULTS AND DISCUSSION

Review of Great Lakes fishes habitat needs and classification into 'potential following Grass Carp introduction' of Grass Carp' groups

The characteristics and habitat needs of 136 fish species from 25 families that currently reside in the Great Lakes and their tributaries were included in this section (Table 2.1). Of those species, 18 are non-native to the Great Lakes and 25 are listed as special concern, threatened or endangered under COSEWIC (Table 2.2). Eighteen fish species are part of economically important coastal fisheries (Trebitz and Hoffman 2015) and many others are used for recreational and commercial fisheries.

Table 2.2. Fish species at risk in the Great Lakes as listed by COSEWIC (Environment Canada 2016).

Species	Status	Date
American Eel	Threatened	2012
Black Redhorse	Threatened	2005
Blackstripe Topminnow	Special Concern	2012
Bridle Shiner	Special Concern	2013
Channel Darter	Threatened	2002
Deepwater Sculpin	Special Concern	2006
Eastern Sand Darter	Threatened	2009
Grass Pickerel	Special Concern	2014

Species	Status	Date
Kiyi (Upper Great Lakes)	Special Concern	2005
Lake Chubsucker	Endangered	2008
Lake Sturgeon	Threatened	2006
Northern Brook Lamprey	Special Concern	2007
Northern Sunfish	Special Concern	2016
Northern Madtom	Endangered	2012
Pugnose Minnow	Threatened	2012
Pugnose Shiner	Threatened	2013
Redside Dace	Endangered	2007
River Redhorse	Special Concern	2006
River Darter	Endangered	2016
Shortjaw Cisco	Threatened	2003
Silver Chub	Endangered	2012
Silver Lamprey	Special Concern	2011
Spotted Gar	Endangered	2015
Spotted Sucker	Special Concern	2014
Warmouth	Endangered	2015

The potential negative ecological consequences of Grass Carp on Great Lakes fishes is high for 33 fish species, moderate for 33 fish species and low, nil or unknown for 70 fish species. Of the 33 species that were classified as potentially experiencing high negative consequences, 85% may experience consequences across all life stages and all species may experience consequences across at least two life stages.

Review of the relationship between Great Lakes fishes and aquatic vegetation

Analysing trends from the non-exhaustive literature review is difficult because of inconsistencies in research questions, study designs and analysis methods across the various studies (Table 2.3). In general, a relationship between submerged aquatic vegetation and individual fish species metrics (e.g., Largemouth Bass abundance) is evident; however, there is no clear relationship between submerged aquatic vegetation and larger scale fish community metrics (e.g., community-wide biomass). Given that Grass Carp impacts to the Great Lakes fish community would likely manifest through changes they make to aquatic vegetation, similar changes may be expected with Grass Carp invasion to the Great Lakes.

Table 2.3. Review of empirical relationships between Great Lakes fishes and aquatic vegetation.

Population-specific relationships

Species/Group	Dependent Variable	Independent Variable	Relationship	Location	Reference
Pumpkinseed	Biomass	Macrophyte category (0%, <33%, 33-66%, >66% cover)	+ ANOVA	Bay of Quinte, Lake Ontario	Randall et al. 2012
Pumpkinseed	Growth index	Macrophyte category	NS	Bay of Quinte, Lake Ontario	Randall et al. 2012
Pumpkinseed	Average weight	Macrophyte category	NS	Bay of Quinte, Lake Ontario	Randall et al. 2012
Pumpkinseed	Production index	Macrophyte category	+ ANOVA	Bay of Quinte, Lake Ontario	Randall et al. 2012
Yellow Perch	Biomass	Macrophyte category	+ ANOVA	Bay of Quinte, Lake Ontario	Randall et al. 2012
Yellow Perch	Growth index	Macrophyte category	NS	Bay of Quinte, Lake Ontario	Randall et al. 2012
Yellow Perch	Average weight	Macrophyte category	NS	Bay of Quinte, Lake Ontario	Randall et al. 2012
Yellow Perch	Production index	Macrophyte category	+ ANOVA	Bay of Quinte, Lake Ontario	Randall et al. 2012
Largemouth Bass	CPUE	Submerged vegetation (% cover) < 66.4%	+ CART regression	Indiana lakes	Middaugh et al. 2013
Largemouth Bass	Length	Surface vegetation (% cover) > 24.4%	+ CART regression	Indiana lakes	Middaugh et al. 2013
Largemouth Bass	CPUE	Submerged vegetation (% cover) <7.8%	+ CART regression	Indiana lakes	Middaugh et al. 2013
Largemouth Bass	Abundance	Milfoil % cover (50% loss)	NS	US lake	Unmuth et al. 1999 in Smokorowski and Pratt 2007
Largemouth Bass	Growth index	Removal of vegetation (50-100%)	NS	3 Minnesota lakes	Cross et al. 1992
Largemouth Bass	First year growth	Removal of vegetation (50-100%)	+	3 Minnesota lakes	Cross et al. 1992
Bluegill	CPUE	Surface vegetation (% cover) > 40%	+ CART regression	Indiana lakes	Middaugh et al. 2013
Bluegill	CPUE	Surface vegetation (% cover) > 17.8%	+ CART regression	Indiana lakes	Middaugh et al. 2013
Bluegill	Abundance	Milfoil % cover (50% loss)	NS	US lake	Unmuth et al. 1999 in Smokorowski and Pratt 2007
Bluegill	Growth index	Milfoil % cover (50% loss)	-/+	US lake	Unmuth et al. 1999 in Smokorowski and Pratt 2007
Bluegill	Growth index	Removal of vegetation (50-100%)	NS	3 Minnesota lakes	Cross et al. 1992
Northern Pike	Growth index	Removal of vegetation (50-100%)	NS	3 Minnesota lakes	Cross et al. 1992

Community-wide relationships

Species/Group	Dependent Variable	Independent Variable	Relationship	Location	Reference
Fish community	Richness	Macrophyte category	+ ANOVA	3 locations in Great Lakes	Randall et al. 1996
Fish community	Abundance	Macrophyte category	+ ANOVA	3 locations in Great Lakes	Randall et al. 1996
Fish community	Average weight	Macrophyte category	- ANOVA	3 locations in Great Lakes	Randall et al. 1996
Fish community	Production index	Macrophyte category	+ ANOVA	Bay of Quinte, Lake Ontario	Randall et al. 2012
Fish community	IBI	Wetland macrophyte index	+ Regression	Great Lake wetlands	Cvetkovic et al. 2010
Fish community	IBI	SAV IBI	+ Quadratic regression	Lake Ontario wetlands	Grabas et al. 2012

Species/Group	Dependent Variable	Independent Variable	Relationship	Location	Reference
Fish community	Productivity	Pre-post vegetation loss	NS	Estuarine lake	Whitfield 1986 in Smokorowski and Pratt 2007
Fish community	CPUE	Pre-post vegetation loss	-	Estuarine lake	Whitfield 1986 in Smokorowski and Pratt 2007
Fish community	Abundance effect	post-post vegetation comparison across sites	NS	Lake/stream meta-analysis	Smokorowski and Pratt 2007
Fish community	Abundance effect	Pre-post vegetation loss	+ Hedges d	Lake/stream meta-analysis	Smokorowski and Pratt 2007
Fish community	Biomass effect	Pre-post vegetation loss	NS	Lake/stream meta-analysis	Smokorowski and Pratt 2007
Fish community	Biomass	Pre-post vegetation loss	NS	Estuarine lake	Whitfield 1986 in Smokorowski and Pratt 2007
Turbidity tolerant species	% Community	Emergent, submergent/floating, open water	- SAV/emergents	Great Lake wetlands	Trebitz et al. 2009
YOY	% Community	Emergent, submergent/floating, open water	+ SAV/emergents	Great Lake wetlands	Trebitz et al. 2009
Game and pan fish	% Community	Emergent, submergent/floating, open water	+ SAV/emergents	Great Lake wetlands	Trebitz et al. 2009
Nest guarders	% Community	Emergent, submergent/floating, open water	+ SAV/emergents	Great Lake wetlands	Trebitz et al. 2009
Vegetation spawners	% Community	Emergent, submergent/floating, open water	+ emergents	Great Lake wetlands	Trebitz et al. 2009
Fish community	Richness	Emergent, submergent/floating, open water	+ SAV	Great Lake wetlands	Trebitz et al. 2009
Fish community	Richness	Substrate type with/without vegetation	+ ANOVA	Lake Erie	Ross 2013
Fish community	Richness	Armor stone vs. not with/without vegetation	+ ANOVA	Lake Erie	Ross 2013

Grass Carp introduction studies

Species/Group	Dependent Variable	Independent Variable	Relationship	Location	Reference
Fish community	Species diversity	Pre-post vegetation loss	-	Two small lakes	Ware and Gasaway 1978 in Smokorowski and Pratt 2007
Fish community	Biomass	Pre-post vegetation loss	NS	Texas reservoir	Bettoli et al. 1993 in Smokorowski and Pratt 2007
Fish community	Biomass	Pre-post vegetation loss	NS	100 Arkansas waters	Bailey 1978 in Smokorowski and Pratt 2007
Fish community	Biomass	Pre-post vegetation loss	-	Two small lakes	Ware and Gasaway 1978 in Smokorowski and Pratt 2007
Planktivores	Biomass	Pre-post vegetation loss	+ dominance	Texas reservoir	Bettoli et al. 1993 in Smokorowski and Pratt 2007
Phytophils	Biomass	Pre-post vegetation loss	- dominance	Texas reservoir	Bettoli et al. 1993 in Smokorowski and Pratt 2007

3.0 EVALUATING THE POTENTIAL ECOLOGICAL CONSEQUENCES OF GRASS CARP ON THE GREAT LAKES WETLAND BIRD COMMUNITY

Nichole Wiemann, Erin L. Gertzen and Marten A. Koops

INTRODUCTION

Birds provide a wide variety of ecosystem services that make them a fundamental aspect of most ecosystems (Sekercioglu 2006, Meyer et al. 2006). This is also true of birds in Great Lakes coastal wetlands. Birds are important players in seed dispersal, pollination, food web dynamics, carcass and waste disposal, nutrient deposition, and ecosystem engineering (Sekercioglu 2006). Some species are also hunted for sport (e.g., Mallard [*Anas platyrhynchos*] and Sandhill Crane [*Grus canadensis*]) while others are very popular for hobby observation by birders. These valuable birds rely on coastal wetland habitat in the Great Lakes and may be threatened by Grass Carp (*Ctenopharyngodon idella*) introduction. In a meta-analysis of Grass Carp impacts in ponds, Wittmann et al. (2014) found a positive but non-significant effect of Grass Carp on birds. In the Great Lakes, Grass Carp are expected to consume a large quantity of aquatic vegetation, which may change the coastal wetland ecosystems the water bird community relies on.

Grass Carp introduction may have a variety of direct and indirect consequences on Great Lakes water bird populations. The most direct impact would be Grass Carp directly competing with wetland birds for submergent aquatic vegetation (SAV) as a food source. Dozens of Great Lakes wetland birds rely on aquatic vegetation as a part of their diet (McKnight and Hepp 1995). Grass Carp's preferential consumption of native vegetation may allow for the expansion of non-native vegetation species into recently grazed habitat (McKnight and Hepp 1995), and in turn this may yield lower quality habitat and a decrease in preferred vegetation for bird species that consume SAV (Clayton and Wells 1999). Indirectly, a loss of vegetation in wetlands may decrease habitat for certain fish and aquatic invertebrate species that are important prey sources for many wetland birds. Vegetated areas are often used by fishes as both spawning locations and as refuge and foraging habitat (see section 2), therefore a loss of this habitat may indirectly affect the food supply for piscivorous birds (Clayton and Wells 1999). Aquatic invertebrates are also an important food item for many species of waterfowl (Krull 1970, McKnight and Hepp 1995) and a change in habitat characteristics may result in a decrease in population numbers or a change in invertebrate species composition to a community of less suitable prey items for wetland birds (Hickie 1985, Clayton and Wells 1999).

Due to the expected decreased in coastal wetland macrophytes following Grass Carp introduction (see section 1), changes in nutrient cycling may increase the prevalence of algal blooms in the system (Lynch 2009). Increase algal presence will reduce sunlight penetration into the water and the resulting changes in water chemistry may have negative effects on aquatic organisms present in the waterbody. In addition, increased turbidity in the water will negatively impact bird species that hunt by sight such as herons, diving ducks, and kingfishers (Poole 2005). At a large scale, the change in habitat conditions due to the introduction of Grass Carp will likely have a negative impact on birds utilizing coastal wetlands for feeding, nesting, and migratory stopovers.

METHODS

Development of a wetland bird list for the Canadian Great Lakes

To assess how Grass Carp may affect the Great Lakes wetland bird community, we first compiled a list of birds that rely on coastal wetlands for survival and reproduction. Focusing on the Canadian side of the Great Lakes, a wetland bird list was compiled from a variety of sources, including: Meyer et al. (2006); Steen et al. (2006); and expert opinion (Lyndsay Cartwright, TRCA; Ted Barney, Long Point Waterfowl; Jeff Krete, Ducks Unlimited Canada; and Mark Gloutney, Ducks Unlimited Canada). Bird Conservation Region (BCR) reports were also used for regions 8 (Boreal Softwood Shield), 12 (Boreal Hardwood Transition), and 13 (Lower Great Lakes/St. Lawrence Plain, Ontario) which encompass the entirety of the Canadian Great Lakes region (Environment Canada 2014a, b, c). Individual species were assessed based on four main parameters for inclusion in the list: residence status in the Great Lakes region, nesting habitat, dependence on coastal wetlands for foraging, and expert opinion. The final bird list includes 47 species that use Great Lakes coastal wetlands in Canada as breeding habitat and that may overlap with Grass Carp. Migratory species were not taken into account in the compilation of the final species list as the focus was kept on birds having a residential season in the Great Lakes coastal wetlands and the addition of migratory species would have made the list unmanageable. The exception is the Tundra Swan, as nearly 100% of the eastern population migrates through the Great Lakes (Ted Barney, Long Point Waterfowl, pers. comm.).

Review of Great Lakes wetland bird characteristics

Each bird species was assessed based on four parameters to identify their risk potential to Grass Carp introduction: nesting habitat, and their reliance on aquatic vegetation, aquatic insects, and aquatic non-insect invertebrates as food sources.

To begin, each species was classified into four general groups: land birds, water birds, waterfowl, and shorebirds. Classifications for each bird were obtained from Appendix 1 of the BCR Reports (Environment Canada 2014a, b, c). This initial classification is useful because species belonging to a single group often experience similar population trends and threats, and have similar conservation strategies. Residence status in the Great Lakes region was then determined. Each species was classified into three potential groups based on their residence time in the Great Lakes coastal wetlands: breeding (B), migratory (M), and overwintering (W). Some bird species were classified into more than one of the residence groups depending on their life history patterns. Residence status was also taken from BCR reports; each Bird Conservation Region was assessed separately but for ease of reading, we condensed the information into a single column.

For all species that breed in the Great Lakes region, nesting habitat was assessed using breeding habitat preference information from Birds of North America (Poole 2005). All species were sorted into one of three groups depending on their nesting preferences: obligate use of coastal wetlands (OBL), facultative use of coastal wetlands (FAC), and not dependent on coastal wetlands (ND). Wetland obligate breeders require wetlands for successful breeding while wetland facultative breeders can use wetland and non-wetland habitat for breeding. As they are migratory through the Great Lakes region, Tundra Swan nesting habitat is not applicable to the ranking system. Nesting habitat was determined using the best available information and some uncertainty on proper classification remains.

The dietary preferences of each species on the bird list were assessed to estimate the potential consequence of a change in food sources in the event of Grass Carp introduction. Reliance on aquatic vegetation, aquatic insects, and aquatic non-insect invertebrates was assessed. Grass

Carp, when present in high abundance, can have significant effects on the quantity and quality of submerged aquatic vegetation (SAV) available. Such vegetation is an important food source for many Great Lakes wetland birds (McKnight and Hepp 1995). Aquatic insects, whose habitat is tied closely to the SAV community in coastal wetlands, are often consumed by wetland birds and are of high importance to both egg-laying females and newly hatched ducklings (Clayton and Wells 1999; Krull 1970; Beard 1953). Non-insect aquatic invertebrates, which include crustaceans, molluscs, and gastropods, are also highly associated with SAV habitat (Clayton and Wells 1999). The diet of each bird species was determined from species accounts on Birds of North America (Poole 2005). Each type of food source was quantified as either a major, minor, or occasional/rare part of each bird species' diet. When possible, diet was assessed using information on food sources while present in the Great Lakes region and not while migrating or overwintering in other locations. It should be noted that in some cases there was little available information on a particular bird species' diet, and in other cases information was not available on the diet of the bird species while it is present in Great Lakes coastal wetlands. Regional dietary information is important as bird diet can vary greatly depending on the season; however every attempt was made to ensure that this information is as accurate as possible.

Ranking of bird species into magnitude of ecological consequences classes

The information collected on the bird community in coastal wetlands on the Canadian side of the Great Lakes was organized into a table. Based on this information, scores were assigned in an attempt to differentiate the birds into categories describing potential high and moderate negative ecological consequences following Grass Carp introduction. Scores were given based on the following parameters: nesting habitat, and consumption of aquatic vegetation, aquatic insects, and aquatic non-insect invertebrates as part of their diet. The ecological consequences class is the sum of four variables:

1. Nesting habitat in the Great Lakes region:
    - 1 if wetland obligate (OBL)
    - 0.5 if wetland facultative (FAC)
    - 0 if not dependent on wetlands (ND)
2. Aquatic vegetation as part of their diet:
    - 1 if major component of diet (M)
    - 0.5 if minor component of diet (n)
    - 0 if occasional/rare part of diet (o) or if not part of diet
3. Aquatic insects as part of their diet:
    - 1 if major component of diet (M)
    - 0.5 if minor component of diet (n)
    - 0 if occasional/rare part of diet (o) or if not part of diet
4. Non-insect aquatic invertebrates as part of their diet:
    - 1 if major component of diet (M)
    - 0.5 if minor component of diet (n)
    - 0 if occasional/rare part of diet (o) or if not part of diet

The score for each species was then summed. A score of 3 or higher out of a possible 4 was determined to be the cut-off for the "high" potential negative ecological consequences class. Species with a score of 3 or higher would be affected across multiple breeding and foraging needs. This score was chosen as it means that either three major food sources of the wetland bird are affected or two major food sources as well as their nesting habitat are affected. The remainder of the species on the list (score of less than 3) are deemed to belong to the "moderate" potential negative ecological consequences class; birds were not added to the list unless it was assumed they would be at least moderately affected due to their reliance on coastal wetlands. Birds not included on the wetland birds list could be considered to belong to the “low” or “nil” potential negative ecological consequences classes.

RESULTS AND DISCUSSION

47 bird species were identified that use Great Lakes coastal wetlands in Canada as breeding habitat and that may potentially experience negative effects following the introduction of Grass Carp into the Great Lakes (Table 3.1). Of the 47 species, 18 were classified as potentially experiencing high potential negative ecological consequences based on their nesting habitat, and the utilization of aquatic vegetation, aquatic insects, and non-insect aquatic invertebrates as food sources (Table 3.1). The remaining 29 species were classified as potentially experiencing moderate negative ecological consequences (Table 3.1).

The wetland bird community uses coastal aquatic vegetation for a range of services and needs. Ten bird species are obligate wetland nesters and consume aquatic vegetation, insects and other invertebrates as major components of their diet Table 3.1). Another ten species require three of the four indicators (Table 3.1) Fifteen bird species use all aquatic food sources to some extent, while 17 species use aquatic vegetation (submerged, emergent and floating vegetation) as a major food source and six species use aquatic vegetation as a minor food source (Table 3.1). Twenty three species consume aquatic insects as a major part of their diet while 22 species consume non-insect aquatic invertebrates as a major portion of their diet (Table 3.1). Of the 47 species, five are listed as special concern, threatened or endangered by COSEWIC or by The Committee on the Status of Species at Risk in Ontario (COSSARO) (Table 3.2).

Table 3.1. Great Lakes coastal wetland bird community classification into potential impact categories due to Grass Carp introduction.

Common Name	Scientific Name	Bird Type	Residence Status	Nesting Habitat	Aquatic Vegetation	Aquatic Insects	Aquatic Invertebrates	Impact Score
American Bittern	*Botaurus lentiginosus*	WB	B	OBL	-	M	n	2.5
American Black Duck	*Anas rubripes*	WF	B, W	ND	M	n	n	2
American Coot	*Fulica Americana*	WB	B	OBL	M	n	n	3
American Wigeon	*Anas Americana*	WF	B	ND	-	M	M	2
Bald Eagle	*Haliaeetus leucocephalus*	L	B, W	ND	-	-	n	0.5
Belted Kingfisher	*Ceryle alcyon*	L	B, W	ND	-	n	n	1
Black Tern	*Chlidonias niger*	WB	B	OBL	-	M	-	2
Black-crowned Night Heron	*Nycticorax nycticorax*	WB	B	FAC	n	M	M	3
Blue-winged Teal	*Anas discors*	WF	B	ND	M	M	M	3
Bufflehead	*Bucephala albeola*	WF	B, M	ND	-	M	M	2
Canada Goose†	*Branta Canadensis*	WF	B, M, W	ND	M	-	-	1
Canvasback	*Aythya valisineria*	WF	B, M, W	FAC	M	M	M	3.5
Caspian Tern	*Hydroprogne caspia*	WB	B	FAC	-	o	o	0.5

Common Name	Scientific Name	Bird Type	Residence Status	Nesting Habitat	Aquatic Vegetation	Aquatic Insects	Aquatic Invertebrates	Impact Score
Common Gallinule	*Gallinula chloropus*	WB	B	OBL	M	n	M	3.5
Common Loon	*Gavia immer*	WB	B	ND	-	-	n	0.5
Common Tern	*Sterna hirundo*	WB	B	ND	-	M	M	2
Forster's Tern	*Sterna forsteri*	WB	B	OBL	-	-	-	1
Gadwall	*Anas strepera*	WF	B	ND	M	n	M	2.5
Great Blue Heron	*Ardea Herodias*	WB	B, W	FAC	-	-	n	1
Great Egret	*Ardea alba*	WB	B	FAC	-	-	n	1
Green Heron	*Butorides striatus*	WB	B	FAC	-	n	n	1.5
Green-winged Teal	*Anas crecca*	WF	B	ND	M	M	M	3
King Rail	*Rallus elegans*	WB	B	OBL	-	M	M	3
Least Bittern	*Ixobrychus exilis*	WB	B	OBL	n	M	n	3
Lesser Scaup	*Aythya affinis*	WF	B, M, W	ND*	n	-	M	1.5
Mallard	*Anas platyrhynchos*	WF	B, W	ND	-	M	M	2
Marsh Wren	*Cistothorus palustris*	L	B	OBL	-	M	n	2.5
Mute Swan	*Cygnus olor*	WF	B	FAC*	M	o	o	1.5
Northern Harrier	*Cistothorus palustris*	L	B, W	FAC*	-	-	-	0.5
Northern Shoveler	*Anas clypeata*	WF	B	ND*	-	n	M	1.5
Northern Pintail	*Anas acuta*	WF	B	ND	M	M	M	3
Pied-billed Grebe	*Podilymbus podiceps*	WB	B	OBL	-	M	M	3
Redhead	*Aythya Americana*	WF	B, W	FAC*	M	M	M	3.5
Red-necked Grebe	*Podiceps grisegena*	WB	B, M	OBL	-	M	M	3
Red-winged Blackbird	*Agelaius phoeniceus*	L	B, W	FAC	-	M	-	1.5
Ring-necked Duck	*Aythya collaris*	WF	B	FAC*	M	M	M	3.5
Sandhill Crane	*Grus Canadensis*	WB	B	OBL	M	n	n	3
Sedge Wren	*Cistothorus palustris*	L	B	ND	-	-	-	0
Sora	*Prozana carolina*	WB	B	OBL	M	n	M	3.5
Swamp Sparrow	*Melospiza georgiana*	L	B, W	OBL	M	M	-	3
Trumpeter Swan	*Cygnus buccinator*	WF	B	FAC*	M	o	-	1.5
Tundra Swan	*Cygnus columbianus*	WF	M, W	N/A	M	-	n	1.5

Common Name	Scientific Name	Bird Type	Residence Status	Nesting Habitat	Aquatic Vegetation	Aquatic Insects	Aquatic Invertebrates	Impact Score
Virginia Rail	*Rallus limicola*	WB	B	OBL	o	M	M	3
Wilson's Snipe	*Gallinago delicata*	S	B	FAC	n	M	n	2.5
Wood Duck	*Aix sponsa*	WF	B	ND	n	-	M	1.5
Yellow Rail	*Coturnicops noveboracensis*	WB	B	OBL	n	n	M	3
Yellow-headed Blackbird	*Xanthocephalus xanthocephalus*	L	B	OBL	-	M	-	2

Description of table codes:
Bird Type: L=land bird, S=shore bird, WB=water bird, WF=waterfowl
Nesting Habitat in the Great Lakes: OBL=wetland obligate, FAC=wetland facultative, ND=not wetland dependent
Aquatic Vegetation: M = major part of diet; n = minor part of diet; o = occasional/rare part of diet, - = not consumed
Aquatic Insects: M = major part of diet; n = minor part of diet; o = occasional/rare part of diet, - = not consumed
Aquatic Invertebrates: M = major part of diet; n = minor part of diet; o = occasional/rare part of diet, - = not consumed
* uncertainty
† Temperate-breeding Eastern Canada population of Canada Goose

Table 3.2. Species at risk status for the Canadian Great Lakes water bird community, as listed by COSEWIC or COSSARO.

Species	Status	Listing Agency	Date
Bald Eagle	Special Concern	COSSARO	-
Black Tern	Special Concern	COSSARO	-
King Rail	Endangered	COSEWIC	1994; re-examined 2011
Least Bittern	Threatened	COSEWIC	2001; re-examined 2009
Yellow Rail	Special Concern	COSEWIC	1999; re-examined 2001, 2009

The review and classification provided in this section are intended to help describe how Great Lakes wetland birds and Grass Carp may overlap in their habitat and life history needs. While it is an initial attempt to describe the relationship between wetland birds and Grass Carp, it may not describe the entire picture. For example, bird species not directly inhabiting the coastal wetlands for nesting and foraging were not included but may still be affected by changes. Therefore this classification may be underreporting the potential impact. Another area of uncertainty is associated with other potential ecosystem changes that are not taken into account, such as indirect changes on parameters other than food (e.g., reduced water clarity impacting water visibility which is important for birds that hunt by sight). Nevertheless, this section provides a review of the importance of coastal wetlands to the Great Lakes bird community in Canada.

GENERAL CONCLUSIONS

The research presented here in support of the Grass Carp risk assessment predicted that if introduced to the Great Lakes basin, Grass Carp will have an impact on the coastal wetlands and associated community, including native fish and bird species. More specifically, the following main summary points are:

Impact on coastal wetland vegetation

- On a basin-wide scale, the evaluated scenarios of Grass Carp invasion typically predicted there would be a decline in biomass of less than 5%.

- At the site-level, a greater range of variability was observed, with a large proportion of sites seeing a 50% decline in biomass, particularly at higher densities of large Grass Carp.
- Combined foraging of multiple Grass Carp would be even more severe and likely result in a high loss of biomass at a substantial number of sites.

Impact on native fish communities

- Out of 136 fish species included in this report, the potential negative ecological consequences of Grass Carp on Great Lakes fishes is high for 33 fish species, moderate for 33 fish species and low, nil or unknown for 70 fish species.
- Of the 33 species that were classified as potentially experiencing high negative consequences, 85% may experience consequences across all life stages and all species may consequences impacts across at least two life stages.
- Within the literature, a relationship between submerged aquatic vegetation and individual fish species metrics (e.g., Largemouth Bass abundance) is evident; however, there is no clear relationship between submerged aquatic vegetation and larger scale fish community metrics (e.g., community-wide biomass).

Impact on coastal wetlands bird communities

- Of the 47 bird species, 18 are expected to experience high potential negative ecological consequences following Grass Carp introduction based on their nesting habitat, and the utilization of aquatic vegetation, aquatic insects, and non-insect aquatic invertebrates as food sources.
- The remaining 29 bird species are expected to experience moderate potential negative ecological consequences following Grass Carp introduction.

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