A 3-dimensional Model for Understanding Bigheaded Carp Habitat Suitability in Lake Michigan

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Abstract

Bighead Carp *Hypophthalmichthys nobilis* and Silver Carp *H. molitrix* (collectively, bighead<u>ed</u> carp [BHC]) threaten to enter Lake Michigan (LM), but it is uncertain whether there is sufficient food to support these planktivores. Previous studies suggest that suitable BHC habitat is limited to a few productive nearshore areas. However, those studies did not consider the influence of BHC's diet plasticity or the presence of spatially-discrete subsurface prey resources. Here we used simulated outputs of prey biomass (phytoplankton, zooplankton, and detritus) and water temperature from a three-dimensional biophysical model to evaluate growth rate potential (GRP, quantitative index of habitat suitability) of adult BHC. We defined suitable habitat as areas capable of supporting growth or at least weight maintenance (GRP ≥ 0 $g \cdot g^{-1} \cdot d^{-1}$). Additionally, we simulated effects of different meteorology (warm year [1998], cool year [1997], and a reference year [2010]), tributary total phosphorus loads (0 MTA, 3300 MTA, and 5600 MTA), and the presence/absence of dreissenid mussels on BHC habitat based on 9 scenario outputs from the biophysical model. Our results show that suitable BHC habitat may be greater than previously predicted owing to the availability of subsurface prey and the fishes' flexible diets, suggesting that LM's productivity would not limit BHC establishment. Furthermore, our results indicate that a warming climate and/or increases in nutrient loads can lessen the negative effects of dreissenid filtration on BHC habitat suitability. Our use of a spatially-explicit, 3D biophysical model to predict BHC habitat suitability is a novel risk assessment tool for aquatic invasive species.

Keywords: Asian carp, bioenergetics, habitat suitability, risk assessment, invasive species

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Executive Summary

The disruptive effects of Asian Carp—specifically the plankton-feeding Bighead and Silver Carp (collectively referred to as bighead<u>ed</u> carp)—throughout the Mississippi River Basin has sparked concerns regarding how they might impact the Great Lakes. However, as the invasion front moves closer to Lake Michigan, the ability of bigheaded carp to survive in the cold, food-limited waters of the lake has come into question. Prior to this research, models suggested that bigheaded carp would only be able to survive and grow in the most productive nearshore habitats (e.g. Green Bay). However, these studies did not evaluate subsurface environments in the lake, such as the deep chlorophyll layer, or consider prey resources outside of phytoplankton and/or zooplankton, whereas bigheaded carp are known to consume a broader array of food types including organic detritus and bacteria. Our project aimed first to address these gaps through comprehensively evaluating current habitat suitability using a three dimensional (3-D) growth rate potential model. This approach measures habitat quality (indexed by fish growth rate potential) and quantity based on water temperature, prey abundance, and bigheaded carp physiology. We defined suitable habitat as areas where BHC would maintain weight or grow.

After assessing current habitat suitability, we then used 9 scenario datasets that were characterized by different meteorology (cool [1997], recent [2010], and warm [1998] years), tributary nutrient loads (none [0 MTA], recent/low [3300 MTA], and high [5600 MTA]), and the presence/absence of dreissenid mussels to understand the effects these stressors had on bigheaded carp habitat quality individually and interactively. Scenarios with mussels present were based on mussel population densities from 2010. While the no loads (0 MTA) scenario is not realistic, it allowed us to isolate the effect of the mussels and nutrient loads. The high loads scenario (5600 MTA) reflects Lake Michigan's loading target outlined in the Great Lakes Water Quality Agreement.

Our approach used simulated environmental and biological data from a 3-D biophysical model that provided input into the fish growth rate potential model. The biophysical model simulated daily physical characteristics (e.g. currents and thermal structure) and lower food web dynamics (e.g. plankton dynamics, decomposition of organic matter, and mussel grazing and excretion) in the lake for an entire year, and, therefore, provided a highly-resolved spatial environment to evaluate fish growth potential. The added resolution and capacity offered by this dataset facilitated a spatially-explicit evaluation of habitat quality throughout the entire lake, including subsurface environments, while also accounting for the ability of bigheaded carp to feed on an alternative prey item, detritus, as well as their preferred prey: phytoplankton and zooplankton.

Our evaluation of current conditions indicate that habitats with the highest quality were concentrated near river mouths and in eutrophic areas of Green Bay, which is in agreement with previous studies. However, in contrast to previous studies, we found suitable offshore habitat for Bighead Carp, but Silver Carp habitat was largely limited to Green Bay and productive river mouths (Figure 1).

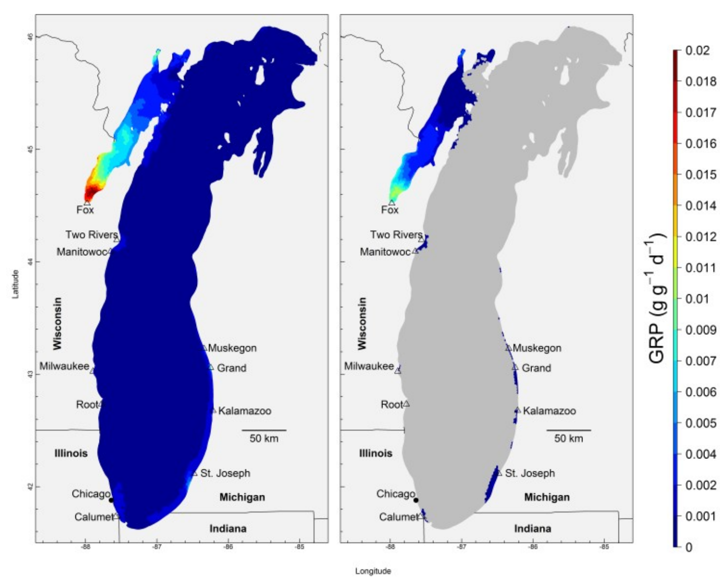

Figure 1. Map of Bighead Carp (left) and Silver Carp (right) average habitat quality in the summer (June-Aug) in Lake Michigan with references to major tributary mouths (triangles with the name of the tributary) and surrounding cities and states. Grey habitat within the lake indicates areas where growth potential was negative, and thus deemed not suitable.

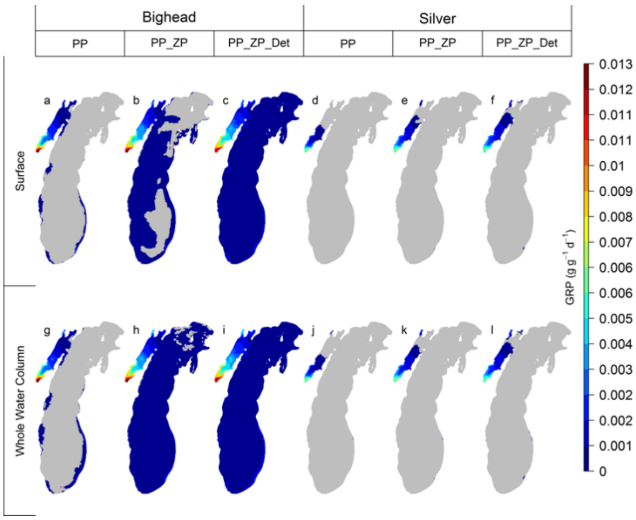

Figure 2. Average (April–Nov) bigheaded carp habitat quality (indexed by growth rate potential) in Lake Michigan under different feeding scenarios (PP = Phytoplankton only diet [a, d, g, & j]; PP_ZP = Phytoplankton + Zooplankton [b, e, h, & k]; PP_ZP_Det = Phytoplankton, Zooplankton, and Detritus [c, f, i, & l]). Top row: Fish were allowed to feed only at surface (top 1 m). Bottom row: Fish were allowed to feed throughout the water column. Grey habitat indicates areas where growth potential was negative, and thus deemed not suitable.

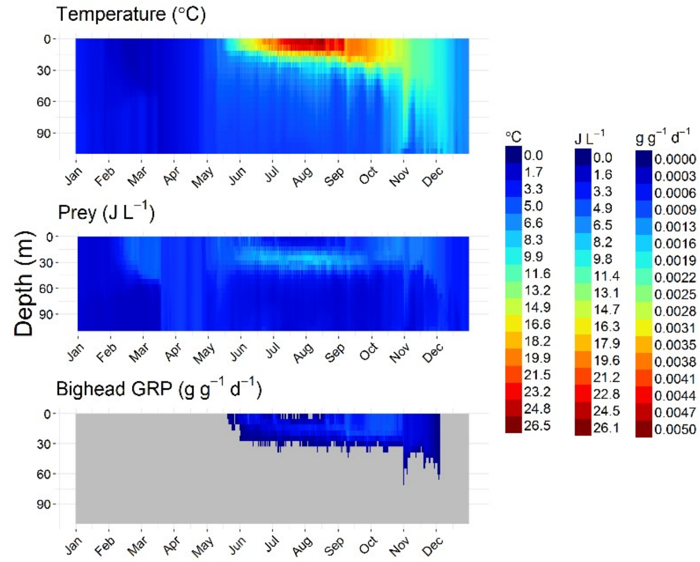

Figure 3. Vertical distribution of temperature (top), prey (middle), and Bighead Carp habitat quality (bottom) at an offshore site near Muskegon, MI throughout the year. Grey habitat indicates areas where growth potential was negative, and thus deemed not suitable. The biophysical model simulated the effects of stratification on thermal structure and prey distribution—with a deep chlorophyll layer forming in summer months that was capable of supporting Bighead Carp growth.

We were able to evaluate the importance of diet flexibility and subsurface habitat by sequentially broadening the diet of the fish and controlling the depth to which it could feed (only at the surface or throughout the water column). We found that diet flexibility and subsurface habitat had stronger effects on Bighead Carp than on Silver Carp (Figure 2). We also found that subsurface prey concentrations during late summer stratification, primarily in the deep chlorophyll layer, provides maximum habitat quality in offshore areas of the lake (Figure 3).

Our scenario evaluation indicates a warmer winter-spring period or increased nutrient loads can improve habitat suitability despite the presence of dreissenid mussels. The filtering activity of dreissenid mussels reduces bigheaded carp habitat quality by reducing the plankton supply, particularly in the spring when the lake is mixing and mussels have access to food throughout the water column. When the lake is stratified in the summer, bigheaded carp habitat quality improves due to warmer water temperatures and a greater availability of prey in the upper water column that is separated from the mussels. By inducing earlier summer stratification, we found that a warmer climate reduces the duration of time mussels and bigheaded carp would be competing for food in the water column, which led to a longer growing season (days with suitable habitat present) for Bighead Carp in most of the lake (Figure 4).

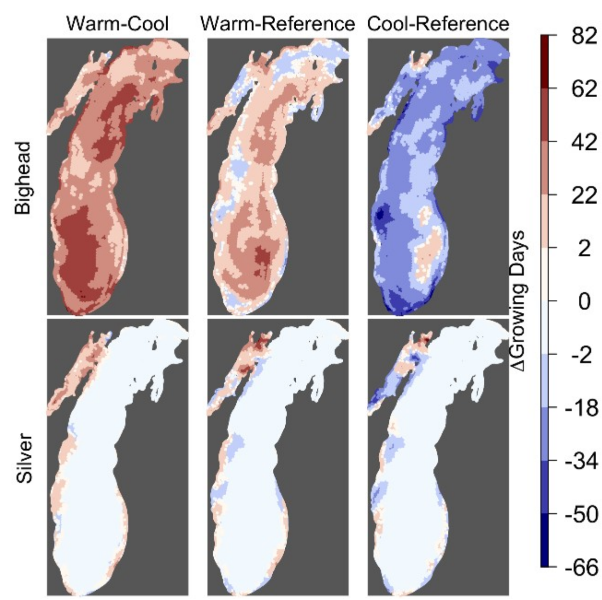

Figure 4. Change in total growing days (days with GRP ≥ 0 $g{\cdot}g^{-1}{\cdot}d^{-1}$) throughout the year between meteorological scenarios for bigheaded carp. Mussels were present in each scenario.

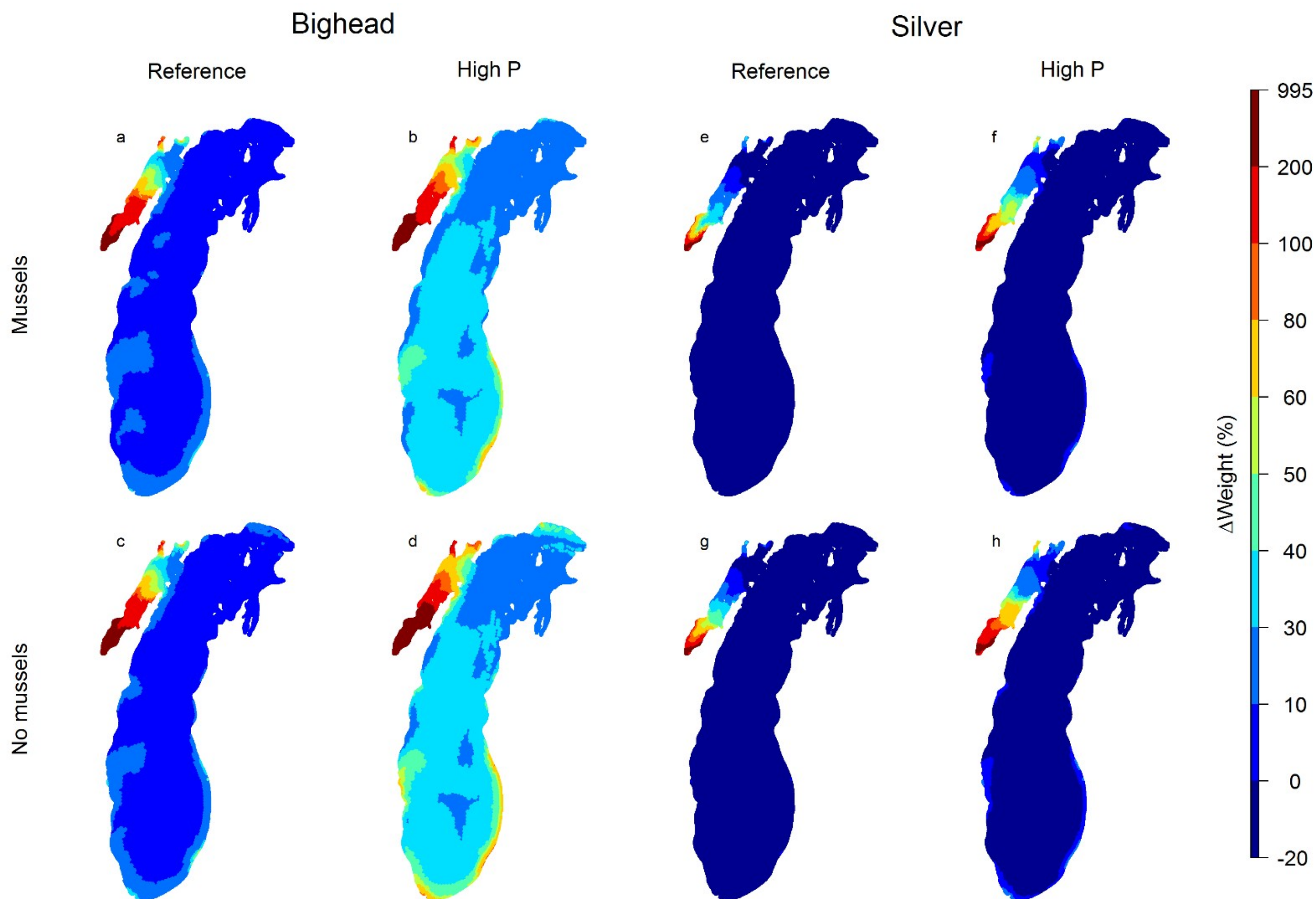

Figure 5. Bighead and Silver carp annual growth potential (% weight change from initial weight) in low load (“reference”, 3300 MTA) and high load (5600 MTA) scenarios and in the presence (top row) or absence (bottom row) of mussels. Note that initial weight was set at 5480 g for Bighead Carp and 4530 g for Silver Carp.

Our results also demonstrate the importance of nutrient inputs to bigheaded carp habitat suitability (Figure 5). Here we compare bigheaded carp cumulative growth (%) over the course of a year under four scenarios characterized by two levels of phosphorus loads (low [3300 MTA, Fig. 5: “Reference”], and high [5600 MTA, Fig. 5: “High P”]) and two levels of mussel populations (absent and current). The model indicates that high phosphorus loads would make nearshore habitat quality more conducive for bigheaded carp growth, even in the presence of mussels (Figure 5b, f).

Comparing the scenario representative of current lake conditions (low nutrients and mussels present (Fig 5a, e)) to the high load, mussels absent scenario (Fig. 5d, h) illustrates how Lake Michigan’s suitability for bigheaded carp has declined since the 1980’s when nutrient loads were higher and mussels were not yet in the lake. Still, some nearshore areas under the current nutrient loading regime provide suitable conditions for growth throughout the year (Figure 5a, e).

Overall, our assessment of Lake Michigan’s current suitability for bigheaded carp demonstrates that suitable habitat is more expansive than predicted by previous studies. Furthermore, our evaluation of climate and nutrient scenarios indicated that establishment risk will likely increase as the climate continues to warm or if nutrient inputs to the lake were to increase. Maps generated by our model identified the potential for cross-lake and nearshore migration corridors that may facilitate and accelerate lake-wide movements towards more productive habitats. In addition to providing intuitive maps for communicating risk, this research demonstrates the utility of three-dimensional simulated datasets for assessing the potential distribution of habitat for invasive species in the Great Lakes.