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Research Article

Assessment of dreissenid biodeposits as a potential food resource for invasive Asian carp

Karl R. Anderson*, Duane C. Chapman and Cari-Ann Hayer
U. S. Geological Survey, Columbia Environmental Research Center, 4200 New Haven Road, Columbia, MO 65201, USA
E-mail addresses: karlanderson@usgs.gov *(KRA),* dchapman@usgs.gov *(DCC)*
**Corresponding author*

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Abstract

Silver carp (*Hypophthalmichthys molitrix*) and bighead carp (*H. nobilis)* are poised to invade the Laurentian Great Lakes. Zebra mussels (*Dreissena polymorpha*) and quagga mussels (*D. rostriformis bugensis*) have shifted nutrient pathways towards the benthos, partly through deposition of feces and rejected food particles called biodeposits. When biodeposit material was fed to bighead and silver carp, they fed on the material, but on average lost weight. Energy density between fed and unfed fish did not differ, but a few individual fish did gain weight on the biodeposits diet. Our results demonstrate that biodeposits might be considered a supplemental food for bigheaded carps.

Key words: invasive species, Asian carp, biodeposits, dreissenid mussels

Introduction

Bighead carp [*Hypophthalmichthys nobilis* (Richardson, 1845)] and silver carp [*H. molitrix* (Valenciennes, 1844)], together the bigheaded carps, are filter feeding, planktivorous, Asian carps that have become increasingly abundant in the Mississippi River Basin since their introduction in the 1970s. There is growing concern that bigheaded carps will enter into Lake Michigan through the Chicago Area Waterway System (CAWS) then spread to the remaining Laurentian Great Lakes (Cuddington et al. 2014). This invasion could damage high value fisheries and alter aquatic ecosystem population dynamics (Cudmore et al. 2012). Cooke and Hill (2010) suggest that many areas of the Great Lakes, especially Lake Michigan, do not provide sufficient algal foods for these fish due to low phytoplankton availability. However, alternatives to planktonic foods may exist that could support invasive carp.

The Great Lakes, particularly Lake Michigan, have seen changes in nutrient cycling due to the invasion of the zebra mussel [*Dreissena polymorpha* (Pallas, 1771)] and the quagga mussel [*D. rostriformis* (Andrusov, 1897); Nalepa et al. 2009]. Through filter feeding, dreissenid mussels increase water transparency and direct nutrients to the benthos as feces and as biodeposits. Biodeposits consist of pseudofeces (rejected semi-consolidated mucous-bound agglomerates of organic and inorganic material; Reeders and Bij de Vaate 1990) and feces. Madenjian (1995) estimated that zebra mussels deposit up to 1.4 × 10^6 metric tons of biodeposits in as little as six months in western Lake Erie. The biodeposits of dreissenid mussels are so large that they have caused lake-wide changes in nutrient dynamics and benthic ecosystems (Sousa et al. 2014; Turner 2010).

While bigheaded carps are predominately pelagic planktivores, they have been documented feeding on benthic detritus (Calkins et al. 2012). In experimental ponds, adult bighead carp sometimes fed by agitating the substrate and filter feeding in the resultant sediment plume (D. Chapman, personal observation). The ability of bigheaded carps to obtain their energy from both pelagic and benthic pathways could promote their establishment within the Great Lakes. Our goal was to experimentally determine if bighead and silver carp would consume dreissenid biodeposits and benefit from them.

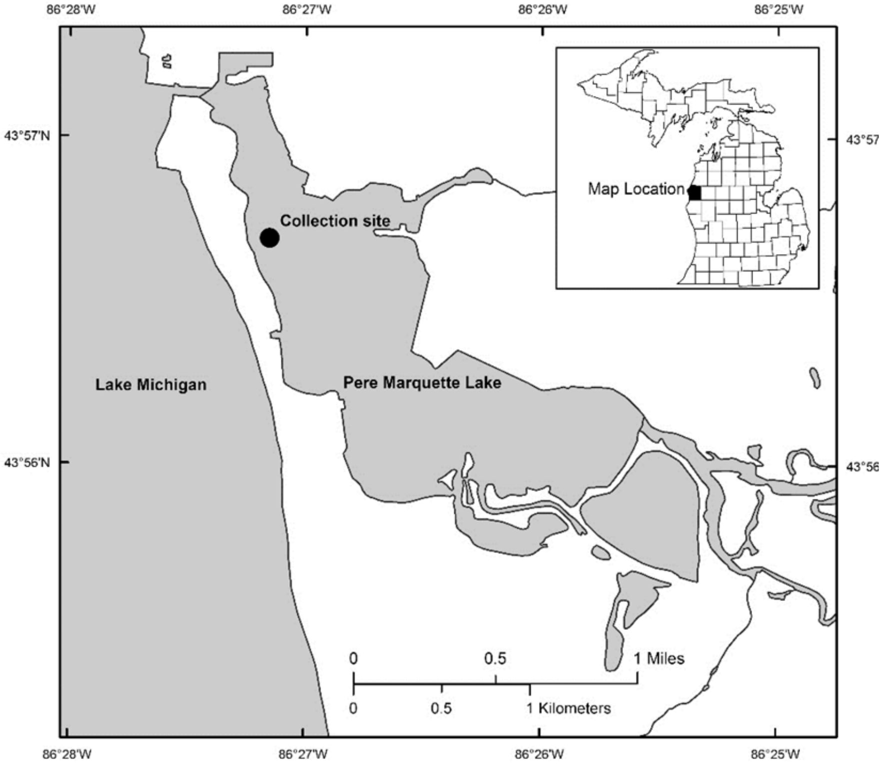

Figure 1. Collection location of biodeposits in Pere Marquette Lake near Ludington, MI from June 12–15, 2012.

Methods

Biodeposits were collected in Pere Marquette Lake on June 12–15 2012, approximately 1 km from the entrance to Lake Michigan (43.944884ºN; 86.452551ºW; Figure 1). The site was chosen for its underwater structures that support a large population of dreissenid mussels and create a surface from which it was possible to collect biodeposits with little non-biodeposit sediment. Scuba divers collected biodeposits using a diaphragm pump. The biodeposits were agitated lightly by hand causing lighter particles to suspend, allowing them to be sucked into the vacuum hose, mimicking the activity of detritus-feeding bigheaded carp and minimizing the proportion of inorganic sediment in the collections. The actual proportions of inorganic sediment and biodeposit material in the collected sample are unknown. Collected water was filtered through a 75μm mesh into 9.5 L plastic containers. Containers were frozen at −20°C within three hours of collection and maintained at this temperature until needed. Prior to the start of the experiment, the containers were thawed in a 4°C walk-in refrigerator. Biodeposits were filtered from the remaining water using cotton cloth and spooned into 1000 ml Nalgene containers, refrozen, and thawed as needed.

Bighead and silver carp have not been detected from Lake Michigan and thus local fish were unavailable for use in this experiment. Instead we collected bigheaded carp from the Missouri River in central Missouri near Rocheport, MO in 2011. Fish were then maintained in outdoor ponds at the Columbia Environmental Research Center (CERC), Columbia, MO.

The experiment took place indoors from July 16 to August 13 2012 at the Columbia Environmental Research Center in five 416-L polyethylene, opaque, open top, flat bottom, cylindrical tanks (76 cm diameter, 91 cm height). Tanks were supplied with 19 °C well water at approximately one volume replacement per hour. A YSI 6920v2 multi-parameter sonde was put in each tank and measured temperature (°C), pH, specific conductivity (µS/cm), and dissolved oxygen (mg/L) at 1 hour intervals (24 hours per day; YSI 6920v2; YSI Incorporated, Yellow Springs, OH, USA). Ammonia concentration (NH_3, mg/L) was monitored at 48 hour intervals using an ion selective probe (Hach HQ440D; Hach Company, Loveland, CO, USA).

Table 1. Average water quality parameters (± SD) in each tank over the duration of the study.

Treatment –Tank Number	Temperature °C	pH	Dissolved Oxygen mg/L	Specific Conductivity µS/cm	Ammonia NH_3 mg/L
Control-1	19.22 ± 0.14	7.95 ± 0.03	8.41 ± 0.15	674 ± 50	0.055 ± 0.015
Control-2	19.34 ± 0.22	7.89 ± 0.04	8.54 ± 0.24	683 ± 75	0.069 ± 0.021
Biodeposits-1	19.29 ± 0.22	7.89 ± 0.04	8.50 ± 0.34	682 ± 70	0.057 ± 0.017
Biodeposits-2	19.34 ± 0.23	7.91 ± 0.05	8.48 ± 0.22	680 ± 67	0.066 ± 0.020
Biodeposits-3	19.36 ± 0.24	7.84 ± 0.02	8.23 ± 0.22	682 ± 74	0.076 ± 0.013

Fish were tagged with individually identifiable elastomer tags (Northwest Marine Technology, Inc) to track growth of each individual fish. Eight bighead carp and eight silver carp were added to each of the five tanks on day 0 (80 fish total). Initial average weight and length for bighead carp (± S.D.) was 178.6 ± 36.7 g and 266 ± 15 mm. Initial average weight and length for silver carp was 122.2 ± 19.4 g and 244 ± 13 mm. Scale accuracy was ± 0.2 g and length was measured to the nearest millimeter.

The experiment consisted of a training phase (days 1–11), one rest day (day 12), an experimental or feeding phase (days 13–25), and a final rest day (day 26). The training phase was necessary because bigheaded carps are sometimes slow to take advantage of new food types (Bialokoz and Krzywosz 1981). Fish were not fed on the rest days to ensure empty intestinal tracks when the fish were weighed.

In the training phase, fish were fed frozen rotifers (http://www.brineshrimpdirect.com) at 6% body weight per day for days 1–3. From days 4–11, fish were trained on an increasing ratio of biodeposits to frozen rotifers until 100% biodeposits were fed on day 11. Frozen rotifers and biodeposits sank to the bottom of the tanks quickly after adding them. During the training phase, video cameras (Hero2, GoPro®, San Mateo, CA, USA) were placed in tanks 30 minutes before feeding and remained in tanks for two hours to record and observe feeding behavior.

After the first rest day, fish were weighed and measured, representing initial weight and length. Four fish of each species from each tank were retained for quantification of energy density (see below). The remaining fish were replaced in their tanks for the experimental phase. During this phase, fish in three tanks were fed 100% biodeposits (no frozen rotifers) at 10–11% initial body wt. per day (biodeposits-1, biodepoits-2, and biodepoits-3). Fish in two tanks remained unfed during the feeding phase to serve as controls (i.e., control-1 and control-2). Thawed biodeposits were weighed before each feeding and placed into tanks by spoon. After the feeding phase and second rest day, the final length and weight of the remaining fish were recorded.

Changes in fish weights from initial weight to final weight were transformed to percentage of weight gain calculated from the following formula: Percentage of weight gain (%) = ((final weight – initial weight)/initial weight) × 100% (Chiu et al. 2015). Percentages of weight gains were described with comparative descriptive statistics.

After the second rest day, the remaining fish (N=40) were removed and processed for energy density. Energy density (J/g wet weight) is a measure of the stored energy of a fish or its prey and it changes in response to starvation (energy density decreases) or plentiful food (energy density increases; Breck 2008). All fish (i.e., those removed after the first and second rest days) were euthanized immediately after removal with tricaine methane sulfonate (MS-222; Western Chemical Inc., Ferndale, WA, USA) and frozen at −20°C until processing. For energy density, frozen fish were homogenized and 50 g subsamples were freeze dried (Virtis Genesis 35EL freeze dryer, SP Industries, Gardiner, NY, USA). Energy content of freeze-dried fish (N = 80) and five samples of biodeposits were analyzed using an adiabatic bomb calorimeter (Parr Instrument Company, Moline, IL, USA). Energy density changes were described with comparative descriptive statistics and values outside a standard deviation of the mean between the mean initial values for all fish and post values for all fish were considered as a change.

Results

Water quality variables remained within ranges amenable to fish health (Boyd 1979; Table 1). Average moisture content and energy density of biodeposits (± SD) were 84 ± 3.6% and 979 ± 154 j/g wet mass, respectively.

Underwater video during the last day of the training phase, when fish were fed 100% biodeposits, showed both species actively feeding (http://dx.doi.org/10.5066/F70K26N7). Fish quickly swam into the plume of added biodeposits, stopped, and displayed increased buccal ventilation. We consider this pump filtration,

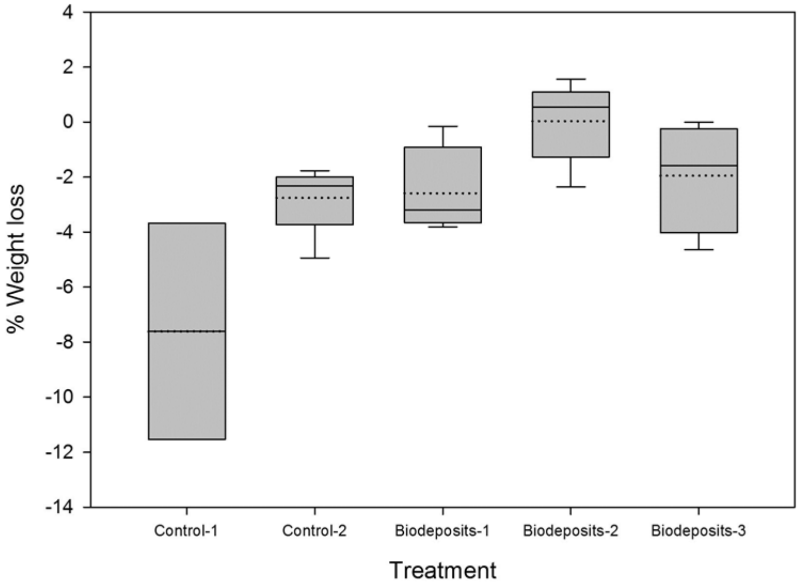

Figure 2. Box plot of percent body weight change of silver carp in control tanks and feeding tanks. Box plots show 10th, 25th, median (solid line), average (dotted line), 75th, and 90th percentiles with error bars**.**

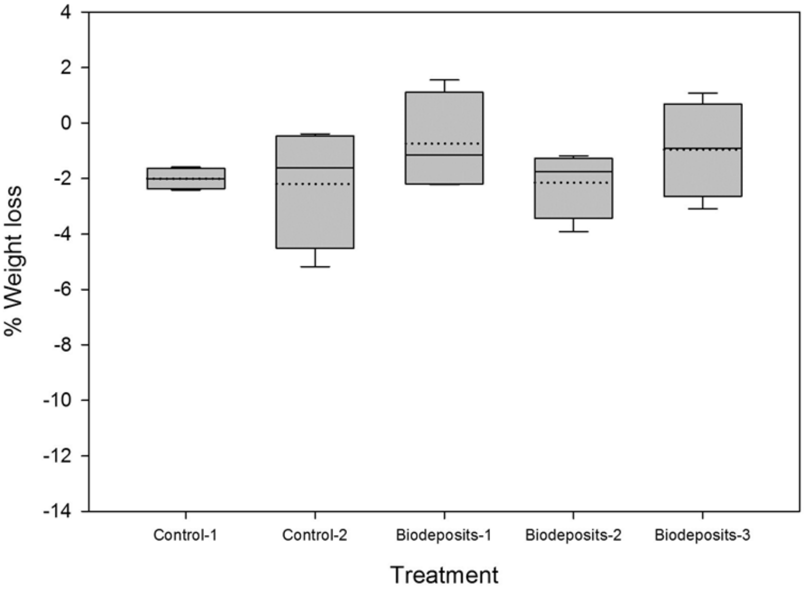

Figure 3. Box plot of percent body weight change of bighead carp in control tanks and feeding tanks. Box plots show 10th, 25th, median (solid line), average (dotted line), 75th, and 90th percentiles with error bars.

which is exhibited by wide opening of the mouth and rapid opening and closing of the opercula. Silver carp exhibited both pump filtration and benthic feeding during the training phase. Bighead carp fed by pump filtration, but were not observed feeding on substrate. However, both bighead and silver carp were observed pump filtering in the plume of material produced by benthic-feeding silver carp.

In the tanks where carp were fed biodeposits, three silver carp gained weight, one maintained weight, and nine lost weight by the end of the experiment. All silver carp in the control tanks lost weight. During the initial weighing of all fish, two silver carp from control tank 1 were inadvertently placed into feeding tank 2 and one silver carp from feeding tank 2 was inadvertently placed into control tank 2. This resulted in one feeding and one control tank having 5 instead of 4 fish and one control tank having 2 fish. Silver carp in control tank 1 (N = 2) lost a median of 7.6 % body weight while silver carp in control tank 2 (N = 5) lost an average of 2.8 % body weight (Figure 2). Silver carp in feeding tanks

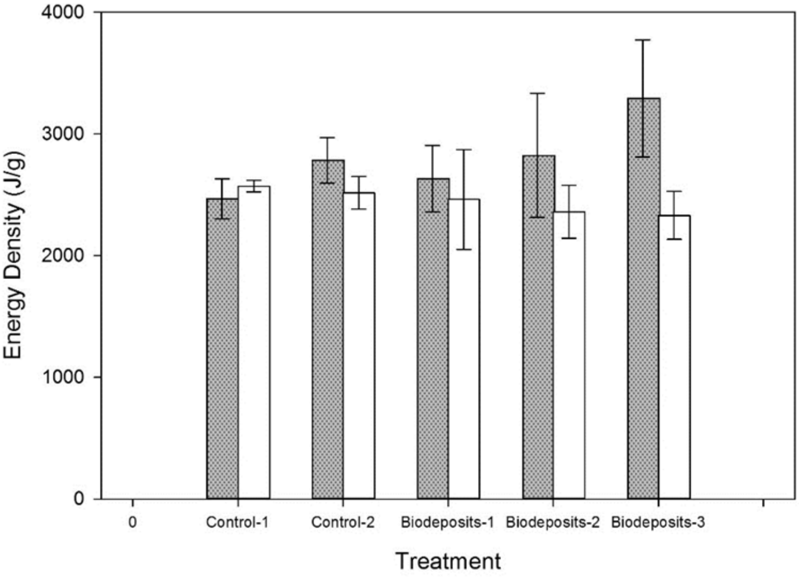

Figure 4. Average energy density in J/g wet weight of silver carp with standard deviation bars. Dotted bars (left) represent energy density of fish removed before the feeding experiment and white bars (right) represent the average energy density of fish after the feeding experiment.

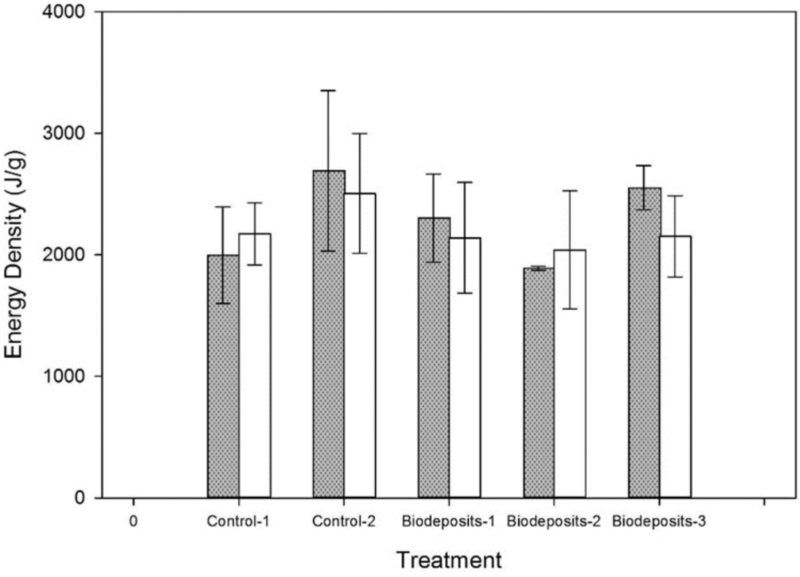

Figure 5. Average energy density in J/g wet weight of bighead carp with standard deviation bars. Dotted bars (left) represent energy density of fish removed before the feeding experiment and white bars (right) represent the average energy density of fish after the feeding experiment.

1 and 3 (both N = 4) lost an average of 2.59 % and 1.95 % body weight respectively (Figure 2) while those in feeding tank 2 (N = 5) gained an average of 0.03 % body weight (Figure 2).

Two bighead carp gained weight and ten bighead carp lost weight in the feeding tanks. All bighead carp in the control tanks lost weight. Bighead carp in control tank 1 (N = 4) lost an average of 2 % body weight while those in control tank 2 (N = 4) lost 2.2 % body weight on average (Figure 3). Bighead carp in feeding tanks 1, 2 and 3 (N = 4 in each tank) lost an average of 0.7 %, 2.1 % and 1 % body weight respectively (Figure 3).

The average energy density (± SD) of silver carp before and after the experiment were all within a standard deviation of each other except for the fish in biodeposit-3 tank in which fish after the experiment had on average 34 % less J/g than when tested before the experiment (Figure 4). The average energy density of all bighead carp before and after the experiment were within one standard deviation of each other (Figure 5).

Discussion

Biodeposits are a poor resource for bigheaded carp, in that they have an energy density approximately 40 % less than phytoplankton and 25–40 % less than zooplankton reported in Lake Erie studies (Chipps and Bennet 2000; Hambright et al. 2002). Two bighead and three silver carp in this study did gain weight while all control fish lost weight. We fed at approximately 10 % of body weight per day. However, bigheaded carps can consume 20 % to over 100 % of their body weight daily (Bialokoz and Krzywosz 1981). The collection of biodeposits is difficult so the supply available was limited and, as a result, we do not believe that the fish were fed ad libitum in this study. In the Great Lakes, where dreissenid biodeposits are abundantly available (Madenjian 1995), bigheaded carps in natural conditions would not be limited to the rations provided in this study.

Average energy density in one tank of silver carp dropped enough during the study to be outside a standard deviation of the average, but energy density did not differ substantially in most cases. Bigheaded carps in this study lost weight and energy density very slowly. In an unrelated experiment, unfed and undisturbed bighead carp of similar size (58 g average) held at 18 °C, lost only 0.7 % body weight and 1.57 % of their energy density over 15 days (unpublished data). This is an indication that bigheaded carps may be able to endure long periods of low food availability if energy demands during that period are not excessive.

We cannot determine from this study whether bigheaded carp could survive in the Great Lakes entirely with biodeposits-based detritivory. It is more likely they would consume a mixed diet with some higher nutritional value food. Lake Michigan is oligotrophic and has low availability of planktonic food, which is the typical diet of bigheaded carps (Barbiero et al. 2012). The invasion of dreissenid mussels has further decreased the abundance of potential planktonic foods, but has created another potential source of food, if bigheaded carps are capable of adapting to it. This study shows that a small proportion of fish gained weight in a short period but most did not and lost weight. In Lake Balaton, Hungary, which has a high density of dreissenid mussels and is currently mesotrophic to oligotrophic (like Lake Michigan), bigheaded carps exhibit excellent condition despite the lake's low productivity and scarce food resources (Boros et al. 2014). If bigheaded carps were to gain access to Lake Michigan, they would have access to much greater quantities of biodeposits than were available in this study, and would have a much greater opportunity to adapt to this alternative food source than we provided here. In addition, dreissenid mussel veligers are known to reach very high densities (15–35 k/m^3/L; Nalepa et al. 2010). Bigheaded carps that filter-feed on resuspended biodeposits would also consume veligers during their filtering process if they were present. In Lake Balaton, veligers constituted the majority of the animal portion of the diet (Dr. István Tátrai, personal communication). In this study, our collection process would not have allowed inclusion of substantial numbers of veligers because it was not a peak reproduction period for dreissenid mussels (Nalepa et al. 2010).

Calkins et al. (2012) found that 73 % of silver carp guts sampled contained detritus and sand, suggesting that benthic feeding is common. Adult bighead carp have been observed feeding on detritus in Missouri research ponds: a small group of adult fish fed in the sediment plume created when one of the fish fanned the sediment. When the sediment cloud dissipated the same, or another, fish would fan the sediment again and the process was repeated (D. Chapman, personal observation). Juvenile bighead carp in this experiment did not replicate that behavior, but we did observe similar benthic feeding by juvenile silver carp, with both species feeding on the plume created. Some fish responded quickly and fed when biodeposits were added and others did not. Fish that gained weight in this study may have been those that accepted the biodeposits diet, or they may have been the dominant fish in the tanks. It is well known that in-tank interactions and dominance hierarchy formation can lead to the suppression of growth in subordinate fish (McCarthy et al. 1992).

Future studies should provide much more biodeposit material over a longer period of time. Adult fish testing would also be useful but would require larger tanks, ponds, or lake enclosures with a large dreissenid mussel population as a biodeposit source. These items should be considered if follow-up experiments are performed in the future. However, this study does provide evidence that bigheaded carps can consume this abundant resource in the Great Lakes, and may benefit from it.

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