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Evaluation of Diets from Adult Cisco in Grand Traverse Bay, Lake Michigan

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Abstract.—The lack of information on Cisco *Coregonus artedi* diet creates a knowledge gap that limits fisheries managers' ability to understand energy transfer in the rapidly changing Lake Michigan ecosystem. In order to examine diet and determine what niche Cisco inhabit in the food web of Grand Traverse Bay, Lake Michigan, we sampled Cisco in June, September, and October of 2014 at sites located near Elk Rapids. Diet analysis revealed that Cisco consume predominantly Round Goby *Neogobius melanostomus* and Diptera *Chironomidae* pupa in the spring and Alewives *Alosa pseudoharengus* and spiny waterfleas *Bythotrephes longimanus* in the fall. The almost exclusive consumption of these prey items in their respective seasons suggests that a feeding shift from benthic to pelagic prey items exists in Cisco foraging from spring to fall. This diet shift indicates that Cisco may provide a linkage between benthic prey items and pelagic piscivores. Abundance of prey items that were not historically present in their diet suggests that Cisco may have adapted their feeding strategy to food web changes and integrated into the contemporary fish community that exists in Grand Traverse Bay. Fisheries managers should consider Cisco rehabilitation as a potential tool for restoring food web pathways in Lake Michigan. However, efforts at rehabilitation must be continued with the understanding that the prey composition is predominantly nonnative, and that new pathways of energy transfer will require Cisco stocks that can adapt to ongoing ecosystem changes.

Introduction

Coregonids were once diverse and abundant in the Laurentian Great Lakes, which provided habitat for seven deepwater species and one shallower water species, the Cisco *Coregonus artedi* (Eshenroder and Burnham-Curtis 1999; Koelz 1929; Scott and Crossman 1973; Smith 1964; Todd and Smith 1992; Wells and McLain 1973). By the 1960s, the majority of the Ciscos in Lake Michigan were severely depleted or extirpated as a result of exploitation, predation by Sea Lampreys *Petromyzon marinus*, and interactions with other invasive species (Smith 1964; Wells and McLain 1973; Zimmerman and Krueger 2009). Cisco have persisted, albeit at very low levels (Fitzsimons and O'Gorman 2006), since that time. Cisco have significant commercial value for their flesh and roe, and once supported one of the highest valued fisheries in Lake Michigan (Brown et al. 1999b; Wells and McLain 1973; Zimmerman and Krueger 2009). At its highest from 1883 to 1908, commercial harvest of Cisco reached 1.09 million

kg annually (Wells and McLain 1973). However, in the early 1900s Cisco began to decline along with the other coregonid species, and commercial harvest has since declined to lower than 907 kg annually (Baldwin et al. 2009). Similar to other Lake Michigan coregonids, the decline of the Cisco is largely attributed to interactions with invasive species, exploitation, and habitat degradation. Cisco survival was reduced by the invasive Alewife and Rainbow Smelt *Osmerus mordax*, which consume larvae and compete with young-of-the-year for zooplankton (Bunnell et al. 2006; Smith 1970; Wells and McLain 1973). The population was affected by habitat degradation in key spawning areas, such as Green Bay (Fitzsimons and O’Gorman 2006; Madenjian et al. 2008; Wells and McLain 1973), where pollution in the southern part of the bay produced a bottom covered in anoxic gray sludge that altered Cisco spawning habitat and greatly reduced their abundance (Madenjian et al. 2011; Wells and McLain 1973).

In Lake Michigan, Cisco commercial catch rates were close to zero after the crash in the 1960s and did not start to increase until the mid-1990s (Fitzsimons and O’Gorman 2006). Since then, an increase in Cisco abundance in Grand Traverse Bay has been observed, with sport harvest increasing three- to seven-fold during the period 1995–1998. Recent bottom gill-net assessment in Elk Rapids has also shown a steady increase in abundance since assessment began in 2007, with a peak catch of 90 Cisco per 305 m of graded mesh gill net in 2013 (R. M. Claramunt, Michigan Department of Natural Resources, Fisheries Division, unpublished data).

Historically, Cisco have been described as offshore planktivores (Brown et al. 1999a) that consume native invertebrates *Mysis relicta* and *Diporeia* species, copepods, zooplankton, and invasive spiny waterfleas *Bythotrephes longimanus* (Anderson and Smith 1971; Coulas et al. 1998; Fitzsimons and O’Gorman 2006; Link et al. 1995; Link and Hoff 1998). However, we found that much of the information on Cisco diet is out of date or was collected from populations far removed from Lake Michigan, indicating current and accurate information on this topic is needed. In the Great Lakes region, rehabilitation of Cisco is a priority goal of fishery managers (Stockwell et al. 2009; Zimmerman and Krueger 2009). Due to the connectedness and complexity of aquatic communities in the Great Lakes, acquiring and organizing biological information is crucial when considering the rehabilitation of species (Zimmerman and Krueger 2009). Therefore, our objective was to describe Cisco diets to help fisheries managers better understand their niche in the food web of Grand Traverse Bay, Lake Michigan.

Methods

Study Area

We collected Cisco from four sites located in East Grand Traverse Bay (Lake Michigan), just north of Elk Rapids, Michigan (Figure 1). Our decision to collect Cisco from Grand Traverse Bay was supported by the proximity of collection sites to deep water and the knowledge that there is a remnant Cisco population in the area. The bay has a maximum depth of 180 m (Holcombe 1996); the four collection sites are located within 3 km of the deepest part of Grand Traverse Bay. In this area of the bay, fish can move easily and quickly to deeper or shallower depths.

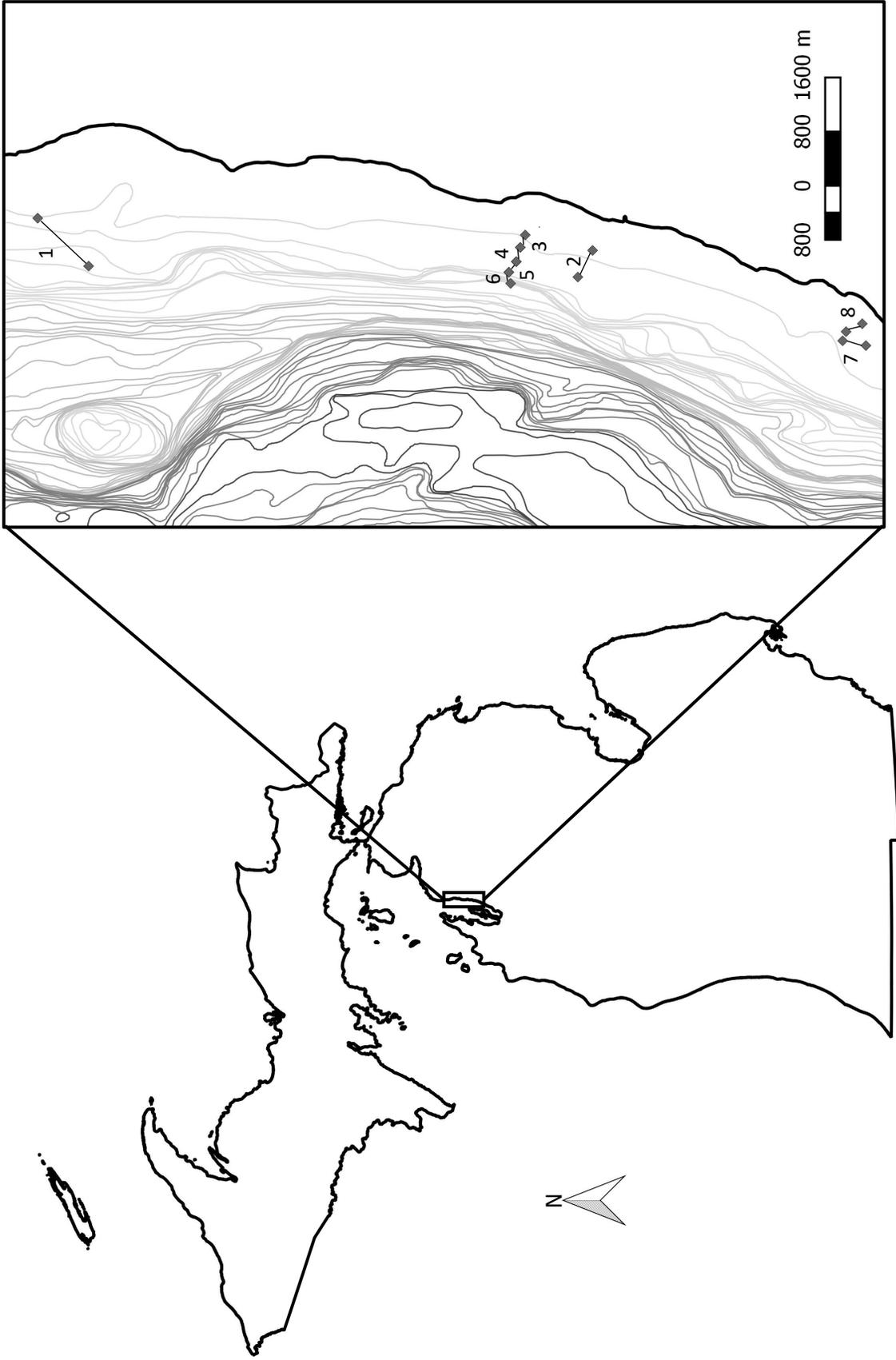


Figure 1.—Collection sites in Grand Traverse Bay, Lake Michigan. Nets set at each of four sites labelled 1–8 are referred to in Appendix A.

Field Collection

We set a total of eight graded-mesh monofilament gill nets on four different sampling days (1 net, June 23; 1 net, September 16; 4 nets, September 24; 2 nets, October 14) from June through October 2014 with 7 of the 8 nets set in the fall (Appendix A). The gill nets were 1.8-m tall, graded 6.35–11.43 cm in 1.3 cm increments; the net set in June was 1,219-m long and the remainder of the nets were 152.4 m (Appendix A). The gill nets were 1.8-m deep and were set less than 2,000 m from shore on the bottom in depths ranging from 3.1 m to 21.0 m for one net night. Greater effort (length of gill net fished) occurred in the spring as nets were set from the S/V Steelhead where it was feasible to handle more gear. Water temperatures ranged from a low of 13.3°C in June to a high of 18.2°C in September; temperatures dropped in October but not to the level observed in June.

Diet Analysis

All Cisco were stored on ice in the field and returned to the laboratory where their stomachs were removed, labelled, and frozen for later processing. Diet analysis was guided by the 1996 Protocol for Conducting Diet Studies of Lake Michigan Piscivores (Elliott et al. 1996); specific information is described below. All diet items were removed, identified, counted, and measured in the laboratory. Stomach contents were viewed under a Nikon SM-5 stereoscopic microscope with 8–35x magnification. Complete prey fish were identified to species, measured (total length, mm), and weighed individually (wet weight, g). For partially digested or incomplete fish with a full vertebral column, we measured standard length if the snout through the end of the vertebral column was intact or vertebral length if just the full vertebral column remained. For fish with an incomplete vertebral column, the existing length of the vertebral column and vertebrae count were used to estimate the total length of the fish. Regression equations (Table 1; Elliott et al. 1996) were applied to estimate total length and wet weight for incomplete fish. We identified all invertebrates to order; if over 100 invertebrates were present, they were subsampled using a 9 x 9 unit sectioned clear dish. Invertebrates of the same order were weighed together.

Table 1.—Regression equations for prey fish total length and wet weight estimation. Vertebrae count and incomplete vertebrae length are for fish without a complete vertebral column. Compiled from Elliott et al. (1996); Round Goby equations from J. Jonas (Michigan Department of Natural Resources, Fisheries Division, unpublished data).

Prey fish species	Total length (TL) to wet weight	Standard length (SL) to total length	Vertebral length (VL) to total length	Vertebrae count (VC) and incomplete vertebrae length (IVL) to total length
Alewife	$4.0 \times 10^{-6} \times TL^{3.1}$	$1.26 \times SL - 3.6$	$1.7 \times VL - 3.9$	$\left(1.7 \left(48 \left(\frac{IVL}{VC}\right)\right)\right) - 3.9$
Rainbow Smelt	$2.5 \times 10^{-6} \times TL^{3.2}$	$1.2 \times SL - 5.3$	$1.5 \times VL - 4.6$	$\left(1.5 \left(63 \left(\frac{IVL}{VC}\right)\right)\right) - 4.6$
Round Goby	$6.0 \times 10^{-6} \times TL^{3.2}$	$1.2 \times SL + 2.9$	$1.6 \times VL + 9.0$	$\left(1.6 \left(32 \left(\frac{IVL}{VC}\right)\right)\right) + 9.0$

Age Determination

We removed dorsal fin rays from each Cisco to determine age. Fin rays were placed in an envelope labelled with an identifying number and dried. Two to five small sections (about 0.5 mm thick) of the fin rays were cut with a Dremel MultiPro saw at the base of the fin, parallel to what would be the body of the fish. These sections were placed in a small drop of mineral oil under a Nikon SMZ1000 microscope equipped with an Insight 4.2 camera. We used 40x magnification to capture images of most fin ray sections; some larger sections required lesser magnification. All fin ray sections were imaged and edited to capture the best display of annuli, which were subsequently counted to determine age of each Cisco collected. Since the most recent annulus may not be visible on fin ray sections from fish collected in spring (Jearld 1983; Wesley 1996), we counted the edge of the fin ray section as an annulus for all spring-collected Cisco. All visible annuli were counted for fall-collected Cisco. Images were taken using both bright field reflected and transmitted light. Multiple images were aged to establish consistency in age assignments and reduce bias that may be associated with imaging practices.

Data analysis.—We used four metrics to characterize observations of stomach contents for Cisco: percentage of empty stomachs, index of ration, percent prey composition, and prey fish size. The percentage of empty stomachs in a sample provided a gross indication of the amount of food available in the ecosystem for the predator. Ration was determined from each individual Cisco, including those with empty stomachs, and calculated by taking the sum of the weight of each prey category consumed per fish and then averaging the total weight of each prey category for the spring and fall samples separately (Elliott et al. 1996). Percent prey composition was calculated from the ratio of the average wet weight for each prey category across all Cisco to the total wet weight of all stomach contents with results presented for each season independently. Percent composition was calculated only from fish that consumed some prey item (i.e., non-empty stomachs).

Results

A total of 67 Cisco were caught in the spring, and 23 Cisco were captured in the fall (Appendix A). All Cisco were over 300 mm total length; the average age was 4.8 years with a range of 1 to 9 years. Of the Cisco captured, 97% were mature, and there was not a recognizable difference in percent maturity from spring to fall. Overall, 6.7% of all stomachs were empty. There was a slight difference between the spring and fall samples, with a higher percentage of empty stomachs observed in the spring (7.5%) compared to the fall (4.3%).

In the spring sample, the Cisco consumed an average of 3.76 g Round Goby, 0.02 g Threespine Stickleback *Gasterosteus aculeatus*, 0.01 g Rainbow Smelt, 0.40 g Diptera, 7.31×10^{-4} g larval Ephemeroptera, and 4.48×10^{-5} g Amphipoda. The Cisco sampled in the fall consumed an average of 2.61 g Alewife, 0.20 g Round Goby, 0.64 g spiny waterflea, and 4.78×10^{-4} g Diptera (Figure 2). Cisco diet compositions during spring were 89.64% Round Goby, 9.63% Diptera, .48% Threespine Stickleback, .02% Ephemeroptera larvae, 0.24% Rainbow Smelt, and 0.00% Amphipoda. In the fall, Cisco diets were composed of 75.64% Alewife, 18.55% spiny waterflea, 5.80% Round Goby, and 0.01% Diptera.

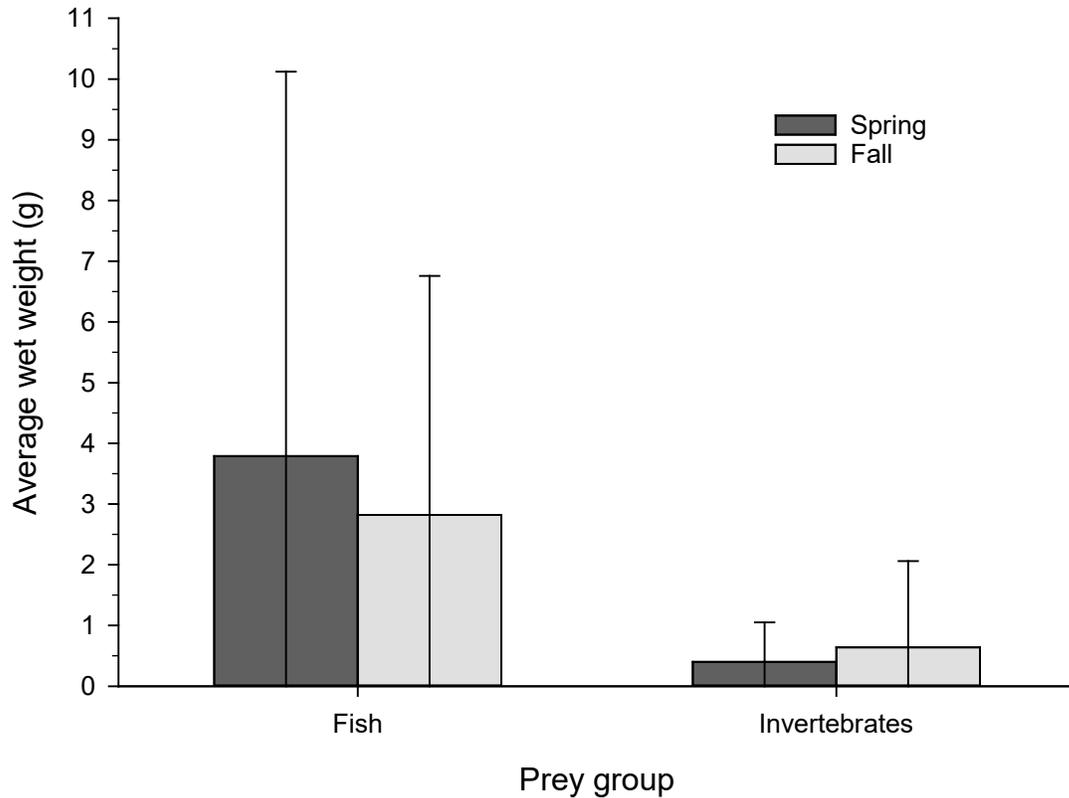


Figure 2.—Average \pm SD ration of Cisco collected in Grand Traverse Bay, Lake Michigan. Error bars represent standard error. Due to the almost exclusive consumption of Round Goby and Diptera in the spring and Alewife and spiny waterflea in the fall, spring fish are Round Goby and fall fish are Alewife. Similarly, data labelled invertebrates are Diptera in the spring and spiny waterflea in the fall.

In the spring, 9% of the Cisco sampled consumed Round Goby exclusively, 37% consumed Diptera exclusively, and 36% consumed a combination of both. In the fall, 52% of the sample consumed Alewife exclusively, 26% consumed only spiny waterfleas, and 13% consumed both fish and invertebrates. Excluding Diptera, all of the primary food items (Round Goby, Alewives, and spiny waterfleas) are species that are not native to the Great Lakes.

Consumed prey fish ranged from 23 to 91 mm total length. The length of fish consumed in spring ranged from 23 to 91 mm and in the fall was 24 to 70 mm. Prey fish consumed by Cisco collected during the spring were almost exclusively Round Goby, which have wider size ranges than young-of-the-year Alewives, which were consumed in the fall. Cisco diets showed an increase in both size and percent composition from spring to fall for young-of-the-year Alewife.

Discussion

Our results showed that Cisco in Grand Traverse Bay shifted their feeding patterns from predominantly Round Goby and Diptera in the spring to Alewives and spiny waterfleas in the fall. The Diptera we examined were identified as midge *Chironomidae* species pupae. The nearly exclusive consumption of midge pupae and Round Goby highlights that the predominant prey items in the spring originate from benthic sources (Janssen and Jude 2001; Saether 1979). Alternatively, the primary prey items consumed in the fall, spiny waterfleas and Alewives, are pelagic (Kerfoot et al. 2011;

VanderZanden and Rasmussen 1996). If this shift in the habitat of Cisco from the benthic zone in the spring to the pelagic zone in the fall is consistent and widespread, then it may represent the restoration of a critical linkage between benthic prey items and pelagic piscivores.

Past literature (Anderson and Smith 1971; Coulas et al. 1998; Brown et al. 1999a; Fitzsimons and O’Gorman 2006; Link et al. 1995; Link and Hoff 1998) has documented that Cisco primarily consume plankton and invertebrates. However, the Cisco that we sampled exhibited different dietary preferences than what has historically been documented from earlier Great Lakes diet studies. Currently, Cisco encounter a very different food web than what existed before the population collapsed in the 1960s. After the collapse, several nonnative species became abundant in Lake Michigan, including Alewife, Round Goby, and spiny waterflea (Lehman 1987; Madenjian et al. 2002; Wells and McLain 1973), all of which were abundant in the diets of the Cisco we observed. The predominance of nonnative prey items suggests that Cisco in Grand Traverse Bay were able to adapt their feeding strategy to take advantage of food web changes in Lake Michigan. The diversity of prey types consumed, the low percentage of empty stomachs, and the large range in sizes of prey fish in our study indicate that this adaptation has resulted in abundant prey options for Cisco in Grand Traverse Bay.

The adaptation of Cisco to nontraditional food sources raises some questions relating to the Lake Michigan fish community. It is unknown whether Cisco choose nonnative prey items because they are more abundant, or if Cisco would select traditional native prey items if they were equally abundant to nonnative prey. Additionally, our study cannot provide conclusive information regarding the role of Cisco in the fish community. The results from this study are based on limited sample sizes from one year, with data gaps between the spring and fall and also during winter months. The low sample sizes are based on the reality that Lake Michigan Ciscos are only now showing signs of population recovery and, even with targeted sampling, Ciscos are very difficult to sample during the winter and midsummer months.

More spatially and temporally extensive data would be useful to confirm our observations and determine if there are other diverse patterns in Cisco feeding ecology. Logistical constraints prevented us from using optimal methods for conducting a diet study. Active sampling with trawls is recommended for conducting diet studies, as they provide a more accurate representation of what fish are consuming at the time of capture and reduce biases resulting from prey digestion. However, successful trawling requires a high abundance in a specific location, as well as appropriate sampling conditions (e.g., bottom type), and was not possible considering the limited knowledge of where Cisco currently exist in Lake Michigan. Our study is limited to Cisco in Grand Traverse Bay; therefore, we recommend further investigation to determine if the information collected in this region is relevant elsewhere. Grand Traverse Bay appears to be a unique area, home to the largest known contemporary population of Cisco in Lake Michigan. Determination of the characteristics of Grand Traverse Bay that make it a suitable habitat for Cisco would aid those considering rehabilitation of Cisco in Lake Michigan.

Our preliminary findings suggest that Ciscos have adapted and integrated into the new fish community existing in Grand Traverse Bay. Our recommendation to fisheries managers is that they consider Cisco rehabilitation as a critical link to restoring food web pathways in Lake Michigan; however, progress towards rehabilitation must be with the understanding that the prey composition is predominantly nonnative. Additionally, those interested in rehabilitation may consider that since Cisco can also serve as prey (Zimmerman and Krueger 2009), new pathways of energy transfer may be created as a result of expansion of the Cisco population in Lake Michigan. Ongoing ecosystem changes highlight the need for efforts at rehabilitation to use Cisco stocks that can continue to adapt to current and future changes in the environment.

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Appendix A.–Field collection information for Cisco captured for this study. CPUE is fish/305m of gill net.

Site	Net	Date	Season	Depth (m)		Effort (m)	Catch (# of fish)	CPUE	Coordinates	
				start	end				start	end
2	1	6/23/2014	Spring	4.0	16.8	1,219.2	67	17	45° 0' 53.8452" N,	45° 0' 29.9622" N,
									85° 23' 35.4546" W	85° 24' 8.0958" W
3	2	9/16/2014	Fall	4.0	7.9	457.2	3	2	44° 56' 28.2042" N,	44° 56' 35.3646" N,
									85° 24' 0.0138" W	85° 24' 17.9094" W
3	3	9/24/2014	Fall	6.4	6.4	152.4	0	0	44° 57' 0.4206" N,	44° 57' 2.808" N,
									85° 23' 49.275" W	85° 23' 57.6276" W
4	4	9/24/2014	Fall	6.4	6.7	152.4	2	4	44° 57' 2.808" N,	44° 57' 4.7952" N,
									85° 23' 57.6276" W	85° 24' 7.1712" W
5	5	9/24/2014	Fall	6.7	12.5	152.4	4	8	44° 57' 4.7952" N,	44° 57' 8.373" N,
									85° 24' 7.1712" W	85° 24' 14.3316" W
6	6	9/24/2014	Fall	12.5	21.0	152.4	1	2	44° 57' 8.373" N,	44° 57' 7.578" N,
									85° 24' 14.3316" W	85° 24' 21.888" W
4	7	10/14/2014	Fall	3.1	4.6	152.4	7	14	44° 54' 17.6364" N,	44° 54' 28.7712" N,
									85° 25' 5.556" W	85° 25' 2.2152" W
8	8	10/14/2014	Fall	3.1	4.3	152.4	6	12	44° 54' 19.3068" N,	44° 54' 27.1002" N,
									85° 24' 50.8032" W	85° 24' 56.0916" W