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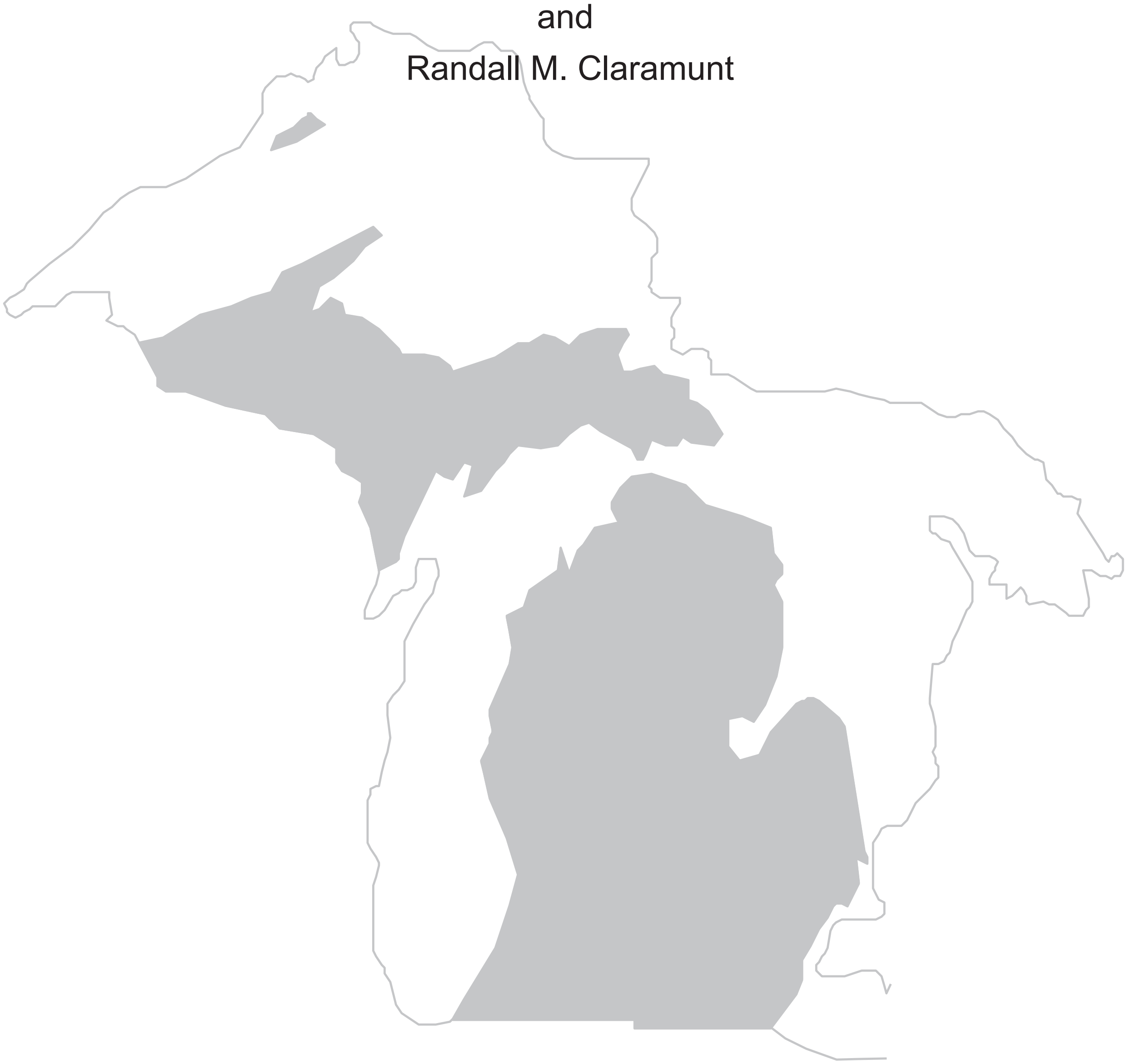

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Assessment of Chinook Salmon Diets in Lake Michigan from 1994 to 2013: An Auxiliary Indicator of Predator-Prey Balance

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Abstract–Chinook Salmon *Oncorhyncus tshawytscha* are the predominant piscivore in Lake Michigan and an annual assessment of their diet is important to determine their health in response to food web changes. The objective of this report was to use analyses of Chinook Salmon diets to show how changes in the food web from 1994 to present may affect salmon and their relationship with Lake Michigan prey populations. We examined factors including the percent of empty stomachs for a given year, alternative prey use (fish and non-fish), size structure of predator and prey populations, number of prey items per salmon stomach, and total ration as indicators of the availability of prey for a particular year and of the health of Chinook Salmon populations. Large changes in prey fish populations have been observed and the most recent diet data for Chinook Salmon indicate that there is a shift to feeding on smaller Alewife *Alosa pseudoharengus*, the dominant prey of Chinook Salmon. During 1994–1996, the size of the Alewife being preyed upon increased with increasing size of Chinook Salmon. However, 2012 and 2013 the size of Alewife eaten by Chinook Salmon did not increase with increasing predator size. In 2012 and 2013, Alewife constituted over 98 percent of the diet of Chinook Salmon collected for this study. Even with the decreased size of the available Alewife, Chinook Salmon consistently chose them as their primary prey item. Our results indicate that an annual assessment is useful to better understand how the predator-prey relationship between Chinook Salmon and Alewife is changing and what effect this changing relationship may have on the fishery.

Introduction

Chinook Salmon *Oncorhyncus tshawytscha* were introduced into Lake Michigan in 1967 as a way to control the rising Alewife *Alosa pseudoharengus* populations as well as a way to create a viable sports fishery. Over-abundance of salmon, via natural reproduction and continued stocking, has contributed to a declining Alewife population over the past 20+ years (Jones et al. 1993; Claramunt et al. 2012 a,b). Tsehaye et al. (2014 a,b) also support the hypothesis that Chinook Salmon were the main contributors to the decline in the Alewife population and that Chinook Salmon were responsible for over 60% of all Alewife predation since 1980. The results from Tsehaye et al. (2014 a,b) also demonstrate that salmonine predation on alternative prey (e.g. Rainbow Smelt *Osmerus mordax*) did not have a strong effect on alternative prey abundance in recent years. However, the predator-prey relationship between salmonine and Alewife indicates the importance of top-down control in the pelagic fish communities in Lake Michigan. A continued dominance of Alewife in the diet of Chinook Salmon, even while alewife abundance declined substantially has caused concern that Chinook Salmon may not be able to alter their diet from Alewife, which is their primary food source (Jude et al. 1987; Rybicki and Clapp 1996; Warner et al. 2008; Jacobs et al. 2013).

Several studies have examined the importance of Alewives in Chinook Salmon diets. Jacobs et al. (2013) found that Chinook Salmon were the primary predators in Lake Michigan, and that their diet is related to the abundance of alewives which can change from year to year. During 1994–96, diet analyses from Chinook Salmon showed that they fed on presumably more abundant large Alewives and that there was a higher abundance of alternative prey fishes in diets (e.g., Bloaters *Coregonus hoyi*). In 2009 and 2010, however, the diets of Chinook Salmon showed an abundance of smaller Alewives and less abundant alternative prey fish (Jacobs et al. 2013). Jude et al. (1987) stated that Chinook Salmon prefer Alewives over Bloater and Rainbow Smelt and do not alter their diet based on the abundance of alternative prey species. Warner et al. (2008) found that salmon select Alewife over other species (such as Bloater or Rainbow Smelt) and that the size of the age 1 Chinook Salmon determined the preference for smaller Alewife over larger ones. Rybicki and Clapp (1996) conducted a similar study to determine Chinook Salmon diet composition based on factors including salmon size and age, season, and water depth, and to determine if diet was influenced by bacterial kidney disease and foraging patterns. They found that the diets of Chinook Salmon do change with increasing size but that diet remains primarily fish throughout the year. Younger Chinook Salmon consumed a greater variety of fish prey including Alewife, Smelt, and Bloater. As Chinook Salmon reach larger sizes, their reliance on Alewives increases quickly.

Based on previous studies, we predict that Chinook Salmon will primarily consume Alewives as prey. However, we also hypothesize that variation in stomach contents can be an indicator of changes in the prey fish community. Because Chinook Salmon are the dominant piscivore in Lake Michigan, a better understanding their feeding habits and the status of their dominant (and alternative) prey can help us better manage the pelagic fish community. Diet indices can highlight potential threats and possibly indicate if changes in our fisheries management plans should be made to better balance Chinook Salmon and their prey to maintain a viable fishery.

Methods

Study Area and Sample Collection

Chinook Salmon collected for this study were obtained between the years 1994–2013. Diet samples from Chinook Salmon were only collected from Lake Michigan and were collected within statistical districts MM-3 through MM-8 and WM-3 through WM-6 (Schneeberger et al. 1998). Samples were obtained from sport fishing boats, fishing tournaments, and survey vessels in Lake Michigan. Jacobs et al. (2013) did a comparison for sport and gill net surveys to test if collection methods showed differences in diet content. They found that there was a difference in the percentage of non-empty stomachs between small sport-caught Chinook Salmon and small survey caught Chinook Salmon. Approximately 40% of the smaller sport caught were nonempty, whereas 28% of the small survey-caught fish were non-empty. They did not, however, find a significant difference in larger non-empty sport (52%) and survey (46%) caught Chinook Salmon stomachs. Sport-caught salmon seemed to be representative of the adult population and therefore Jacobs et al. (2013) recommended that after 2012 sport caught salmon be used as the primary source for diet data.

Sample Processing

The processing of the samples was similar to Jacobs el al. (2013), following protocols established in Elliott et al. (1996). After collection, stomachs were removed from the salmon and transferred into plastic bags where they were frozen for later analysis. For contents analysis, stomachs were thawed and the prey items were removed from the stomachs and sorted by species to determine percent diet composition. Measurements of individual diet items were also taken. We attempted to establish total length (TL) in mm for the prey items when possible; if TL was not measurable, then vertebral length (VL) in mm was used to determine TL using formula provided in Elliott et al. (1996). (For example, the formula for Alewife is shown here):

$$TL = (VL \times 1.66) - 3.90.$$

If the vertebral column was not complete, then the length of the remaining vertebrae was taken and the individual vertebrae were counted and used to determine an estimated TL of the prey using formula from Elliott et al. (1996). (Alewife-specific example shown here):

$$TL = (((VL / \text{number of vertebrae}) \times 48) \times 1.66) - 3.9.$$

Each prey item was also weighed (grams) to permit calculation of total and species-specific ration values according to Elliott et al. (1996). Once this information was obtained, it was entered into Microsoft Access © for data storage and analysis.

Data Analysis

This study generally followed procedures described in the Lake Wide Assessment Plan (LWAP; Elliott et al. 1996; Schneeberger et al. 1998) for the analysis of the data with the exception of collection methods and summary of data by age class. The plan was established to provide assessment approaches for key predators in Lake Michigan, and Chinook Salmon is one of the key indicator species. Some modifications to LWAP procedures were implemented to account for results of more recent methodological publications. For example, the LWAP assumes diet samples are collected from survey caught fish. For Chinook Salmon, however, there are insufficient samples of Chinook Salmon diets from surveys and angler caught fish adequately represent feeding conditions (Jacobs et al. 2013). In addition, LWAP recommends age-based estimates of diet indicators. However, Chinook Salmon size-at-age can vary substantially from year to year and predator-prey dynamics are size-based. Therefore, we followed methods described in Jacobs et al. (2013) and used size-based stratification (small (<500mm) and large (>500mm)) for Chinook Salmon to compare feeding conditions. For each year and size category, we calculated the overall diet proportions by estimating the individual diet proportions by mass or number of prey items and then averaging over all of the Chinook Salmon in the particular size category for that year. We estimated the long-term average (±SE) calculated based on the average and variation among annual values and range (minimum and maximum of annual values) for each diet index variable. We then compared the 2013 data point with the previous year (2012) and the long-term average for biological reference. We reported mean (±SE) number of prey per stomach for individual years to assist in judging differences among years.

Results

Between the years of 1994–2013, we collected a total of 4,889 stomachs, an average of 244 per year. The years with the highest and lowest number of samples were 1995 and 2008, respectively (Figure 1). We sampled 261 stomachs in 2013, slightly lower than in 2012 (443 stomachs) and similar to the long term average.

Percent of Empty Stomachs

The average percentage of empty Chinook Salmon stomachs was 41.25% ± 2.5% (Figure 1). The years with the highest percent empty stomachs collected were 2005 and 2008, with over 55% of stomachs empty. Between 2011 and 2013, the percentage of stomachs empty remained steady between 35% and 40%.

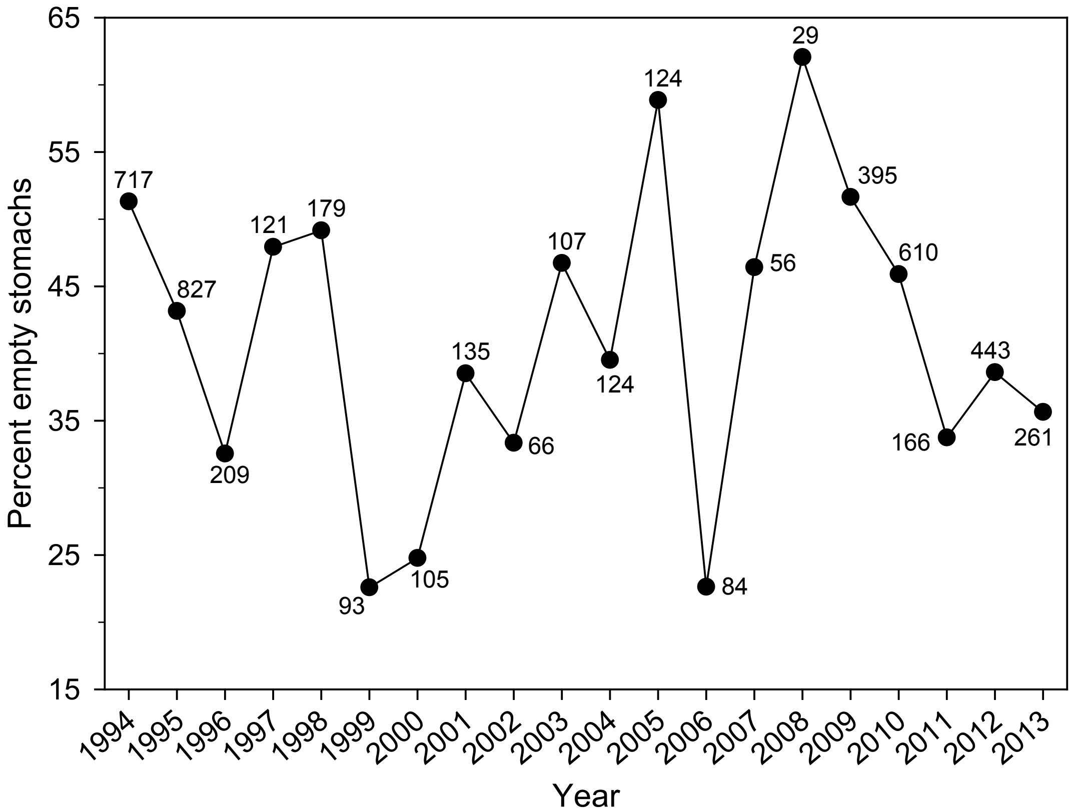

Figure 1.–Percent empty stomachs for Chinook Salmon collected between 1994 and 2013. Data labels for each point in the time series represent the number of Chinook Salmon stomachs examined each year.

Between 1994 and 2003, Chinook Salmon above and below 500 mm were similar in the percentage of empty stomachs observed; however, between 2004 and 2008 fish above 500 mm generally had a higher percentage of empty stomachs. This pattern reversed between the years 2009 and 2012, when fish less than 500 mm had a greater percentage of empty stomachs (Figure 2). Percent empty stomachs was also closely related to the percentage of Alewives in Chinook Salmon stomachs; as the percentage of Alewives in Chinook Salmon stomachs increased, the percentage of empty stomachs decreased (Figure 3).

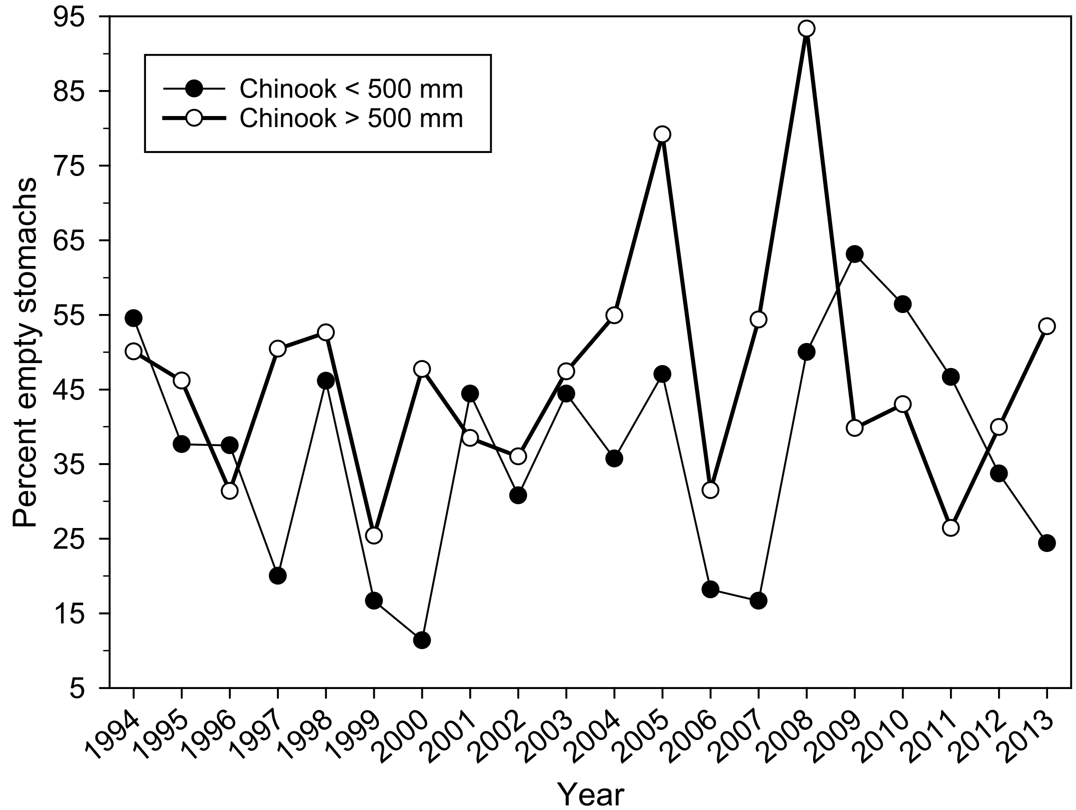

Figure 2.–Percent empty stomachs for Chinook Salmon greater than 500mm and less than 500mm in total length from samples collected between 1994 and 2013.

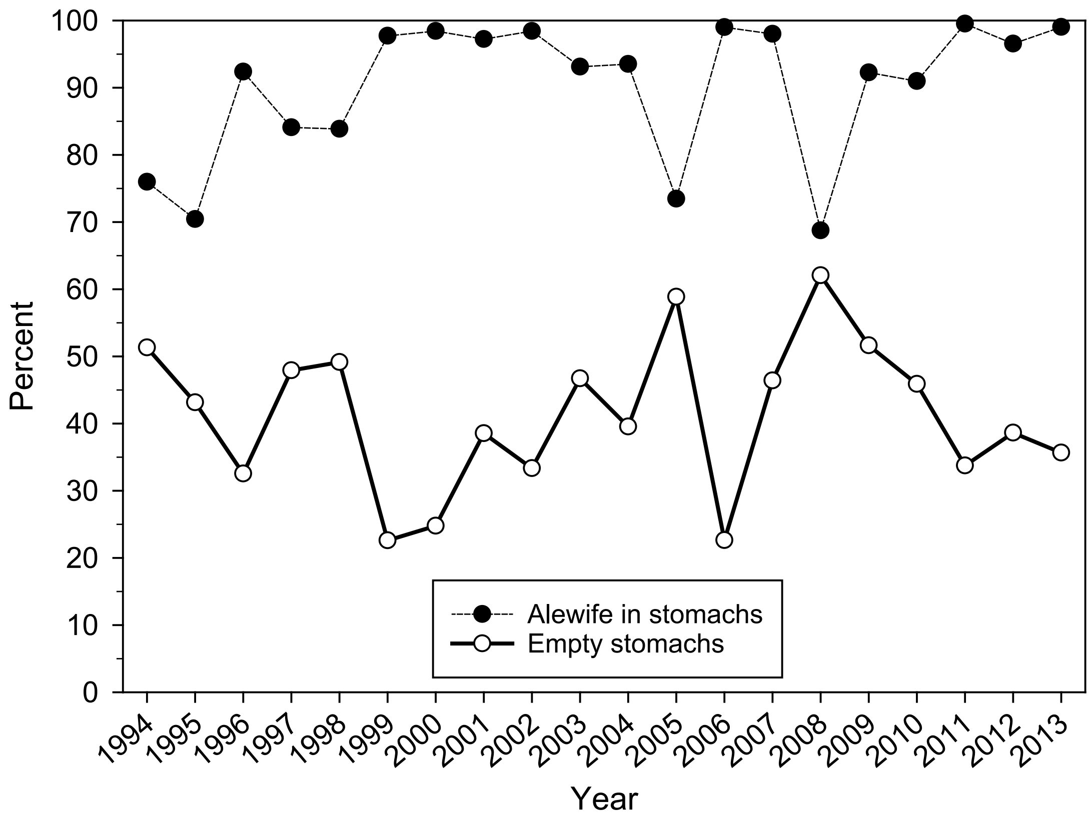

Figure 3.–Percent of empty stomach Chinook Salmon stomachs compared to the percent diet composition of Alewives in non-empty stomachs.

Numerical Composition

Throughout the study, the average (±SE) number of fish prey per stomach for Chinook Salmon less than 500 mm TL was always less than the average number of fish prey per stomach for Chinook Salmon greater than 500 mm TL, except in 2013 (Figure 4). In 2013, Chinook Salmon less than 500 mm TL had a higher average number of prey per stomach (3.90 ± 0.5 prey per stomach) than Chinook Salmon greater than 500 mm TL (3.48 ± 0.7 prey per stomach).The overall mean of prey per stomach between 1994 and 2013 for all sizes of Chinook Salmon combined was 2.32 ± 0.2 per stomach. The year with the highest prey average per stomach was 1999, with 4.01 ± 0.4 prey per stomach; the year with the lowest average was 2008, with 1.19 ± 0.1 prey per stomach. The average prey per stomach in 2013 was 3.75 ± 0.4, which was slightly higher than the overall average and also higher than 2012 (2.14 ± 0.1 prey per stomach).

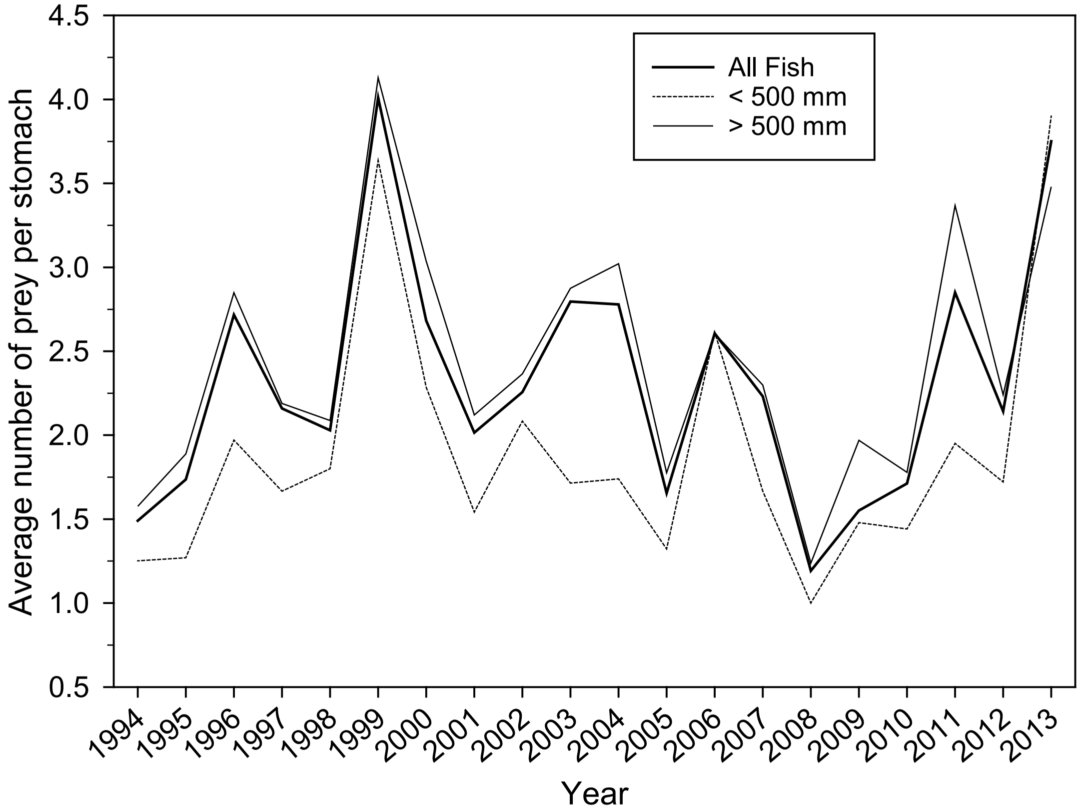

Figure 4.–Average number of prey fish per Chinook Salmon stomach for salmon above and below 500mm total length and for all salmon collected from 1994 to 2013. Fish with empty stomachs were excluded from the analysis.

Prey Species Composition

For the years 2012 and 2013, Alewives dominated the prey species found in Chinook Salmon stomachs of all Chinook Salmon sizes. In 2013, 99% (by number) of prey found in Chinook Salmon stomachs were Alewives (and in 2012 Alewives constituted 96% of the number of prey consumed). In 2013, other prey consumed included Bloaters, Round Goby, and invertebrates. In 2012, Rainbow Smelt, Yellow Perch *Perca flavescens*, and invertebrates were the other prey items consumed by Chinook Salmon. During 2012–2013, Alewife represented over 99% of total prey weight consumed by Chinook Salmon (Table 1).

From 1994 to 2013, the average ration (combined weight of all stomach contents for an individual salmon) for Chinook Salmon greater than 500 mm TL gradually decreased through the years, with some fluctuation (Figure 5). Overall, the prey weight in stomachs of Chinook Salmon above 500 mm TL was much lower in 2013 than in previous years. For Chinook Salmon below 500 mm TL, the prey weight fluctuated from year to year with peaks in prey weight in 2002 and 2007, but with no obvious increasing or decreasing trend. For all Chinook Salmon sizes combined, the average prey weight (grams) between 1994 and 2013 was 6.95 ± 2.7. The year with the highest average weight was 2002 (12.33g) and the year with the lowest average was 2011 (2.91 g). Average prey weight in 2013 was only 3.73 g, which was only about half of the long-term average. In contrast, average prey weight was 6.15 g in 2012.

Table 1.–Percent prey items (by number) found in Chinook Salmon stomachs for 1998–99, 2005–06, and 2010–13.

	Percent in stomach				
Year	Alewife	Rainbow Smelt	Bloater	Round Goby	Other
1998	83.9	2.8	3.2	0.0	10.2
1999	97.7	0.0	0.8	0.0	1.4
2005	73.5	0.8	6.1	9.1	10.6
2006	99.0	0.0	0.0	0.0	1.0
2010	91.0	2.8	0.7	0.5	5.0
2011	99.5	0.0	0.0	0.0	0.5
2012	96.6	0.1	0.0	0.0	3.3
2013	98.8	0.0	0.2	0.3	0.7

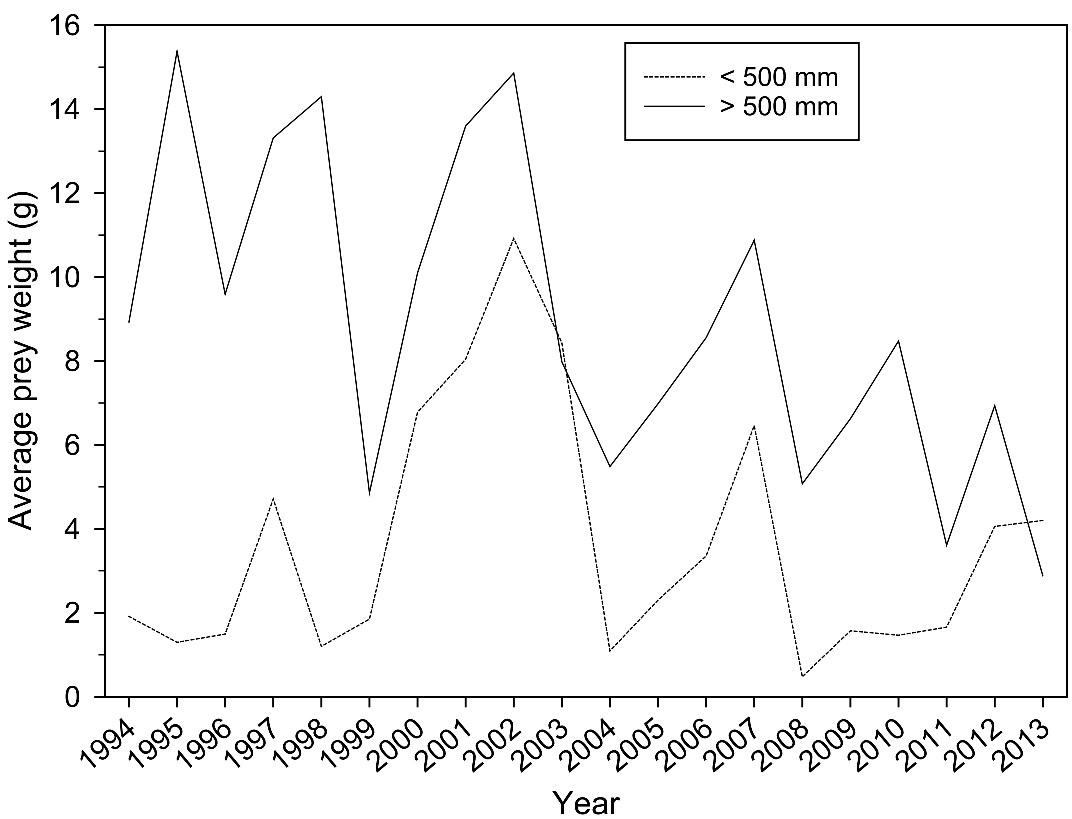

Figure 5.–Average prey fish weight (g) consumed by Chinook Salmon above and below 500 mm total length between 1994 and 2013.

For all sizes of Chinook Salmon combined, the average weight of Alewife per Chinook Salmon between 1994 and 2013 was 8.49 g ± 2.0. The highest Alewife average weight was observed in 2002 (14.83 g) and the lowest in 2011 (3.31 g; Figure 6). Average Alewife weight in 2013 was 3.73 g, significantly lower than the long-term average of 8.49 g. In contrast, average Alewife weight was 6.67 g in 2012. The weight of Alewife weight in stomachs fluctuated among years, with a gradual decline in weight of Alewife in the stomachs from 7.39 g in 1994 to 3.73 g in 2013.

Total length (TL) of Alewife found in the diet of Chinook Salmon showed a similar pattern as weight. Between 1994 and 2013, Alewife consumed by Chinook Salmon averaged 131.4 mm ± 4.9 (Figure 7). The average in 2013 (137.5 mm) was slightly higher than the long-term average, but was lower than it was in 2012 (141.3 mm).

Chinook Salmon collected for the study averaged 602.1 mm ± 15.1 in TL (Figure 8). The largest Chinook Salmon (990 mm) was caught in 1998, and the smallest (115 mm) was caught in 2013. The average Chinook Salmon length from 2013 was 470.8 mm, smaller than both the overall average and that observed in 2012 (679.8 mm).

Size-specific consumption of Alewife by Chinook Salmon has changed over the course of this study. Between 1994 and 1996 when Chinook Salmon TL increased, their consumption of larger Alewife also increased (Figure 9). In 2009 and 2010, results showed that larger Chinook Salmon still consumed larger Alewife but not as strongly as in previous years. This could be due to a decline in the availability of larger Alewife. Lastly, in 2012 and 2013 there was no relationship between Chinook Salmon TL and Alewife TL (Figure 9). Small Alewife were consistently consumed by Chinook Salmon, likely indicating a decline in large Alewife abundance.

Figure 6.–Average weight (g) of Alewives consumed by Chinook Salmon between 1994 and 2013.

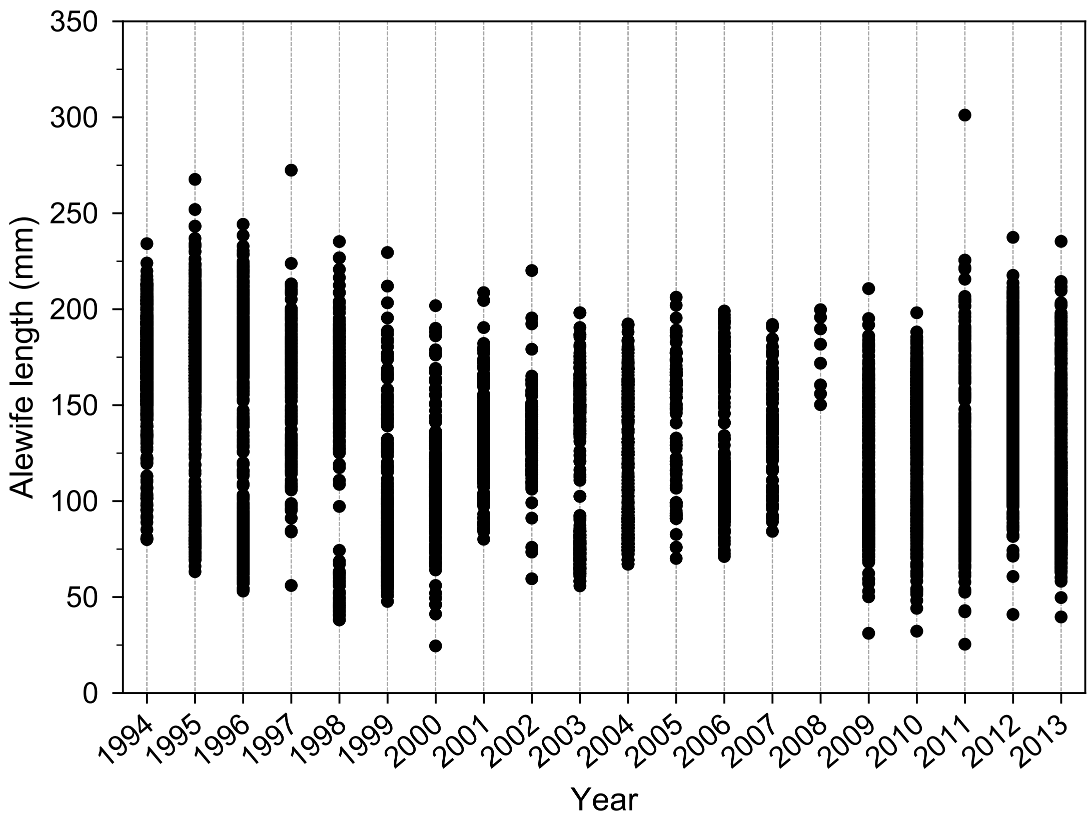

Figure 7.–Total length (mm) of all Alewife consumed by Chinook Salmon between 1994 and 2013.

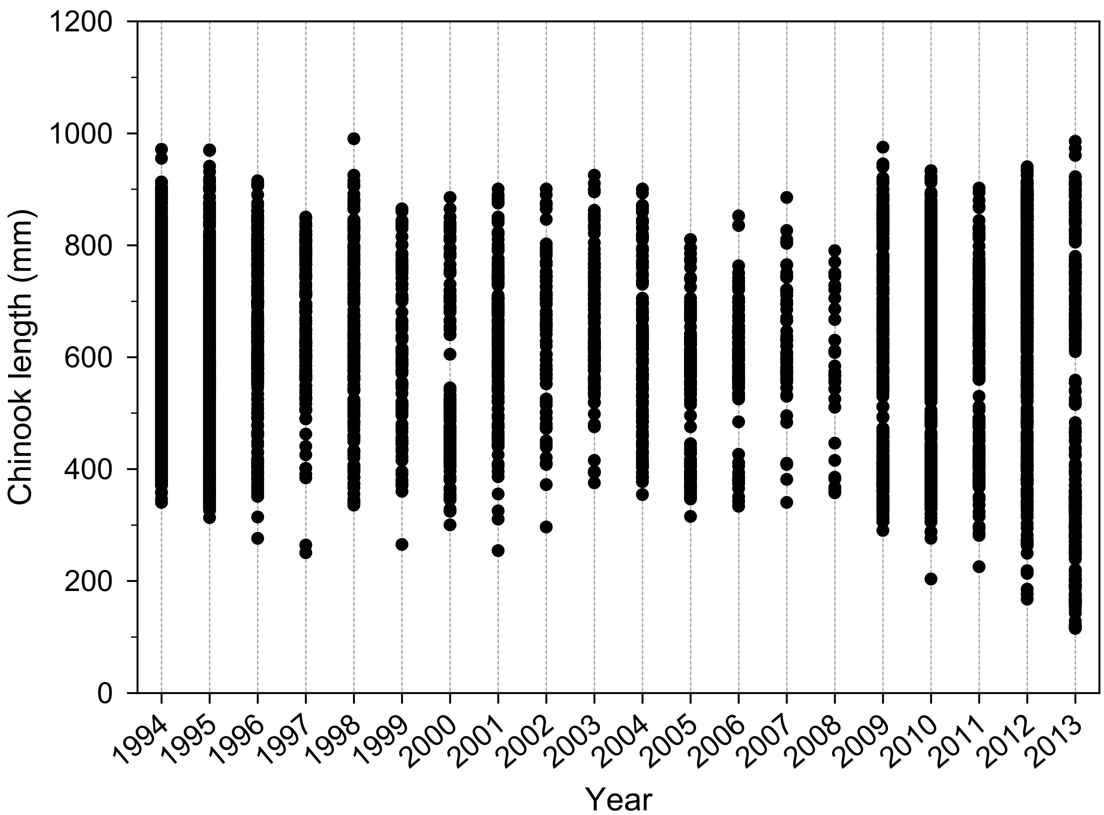

Figure 8.–Total length (mm) of all Chinook Salmon collected for stomach content analysis between 1994 and 2013.

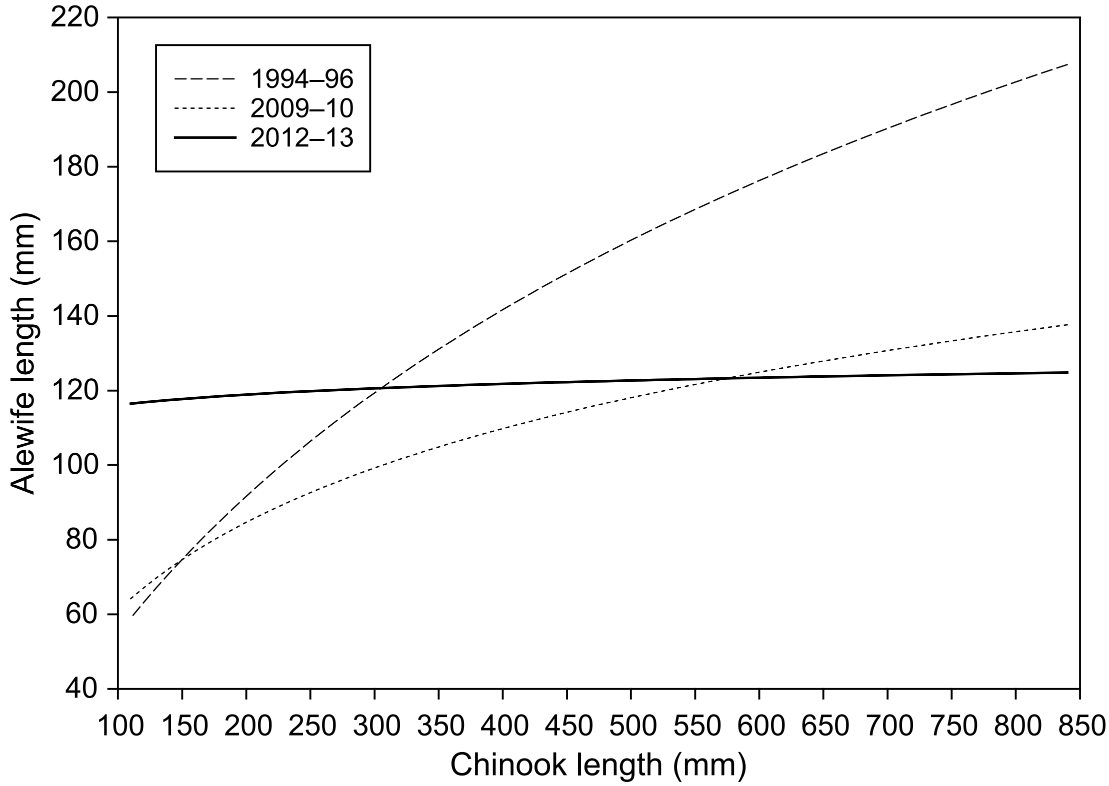

Figure 9.–Relationship between Chinook Salmon TL (mm) and Alewife TL (mm) over the time series including three periods (1994-1996, 2009-2010, and 2012-2013).

Discussion

As previous studies have documented (Jude et al. 1987; Rybicki and Clapp 1996; Warner et al. 2008; Jacobs et al. 2013), we found that Chinook Salmon fed predominantly on Alewives. Other prey species were observed in the stomachs examined – such as Bloater, Rainbow Smelt, and Yellow Perch – but Alewife was the dominant item in Chinook Salmon diets. In addition to being consistent with previous diet studies, our findings are supported by modeling estimates of Chinook Salmon consumption of alewives in Lake Michigan (Tsehaye et al. 2014 a,b).

The relative abundance of other prey species (e.g., Rainbow Smelt or Bloaters) can be indexed by tracking the percent of the diet that consists of alternate prey items (Figure 10). This index suggests that Bloaters can be a good alternate prey when Alewives are in low abundance and Bloater abundance is relatively high (e.g., 1994–1995 and 2005). In addition, Chinook Salmon diets containing significant amounts of other, non-fish prey items, such as Mysis and *Bythotrephes longimanus*, can be an indicator of very poor salmon feeding conditions (e.g., 1995, 1997, and 2008; Figure 10).

Our results also demonstrate that diet analyses can provide useful indices of the changing availability of prey from year to year. Prey fish surveys conducted by the Great Lakes Science Center, United States Geological Survey, and the Michigan Department of Natural Resources indicate that prey fish populations have changed substantially in Lake Michigan (Claramunt et al. 2012b; Madenjian et al. 2014; Warner et al. 2014). In support of the prey fish surveys, a simple Chinook Salmon diet analysis, such as the percent of empty stomachs, can be a robust indicator of feeding conditions. In the early to mid-2000s, the number of Chinook Salmon collected each year was lower than earlier or later in the

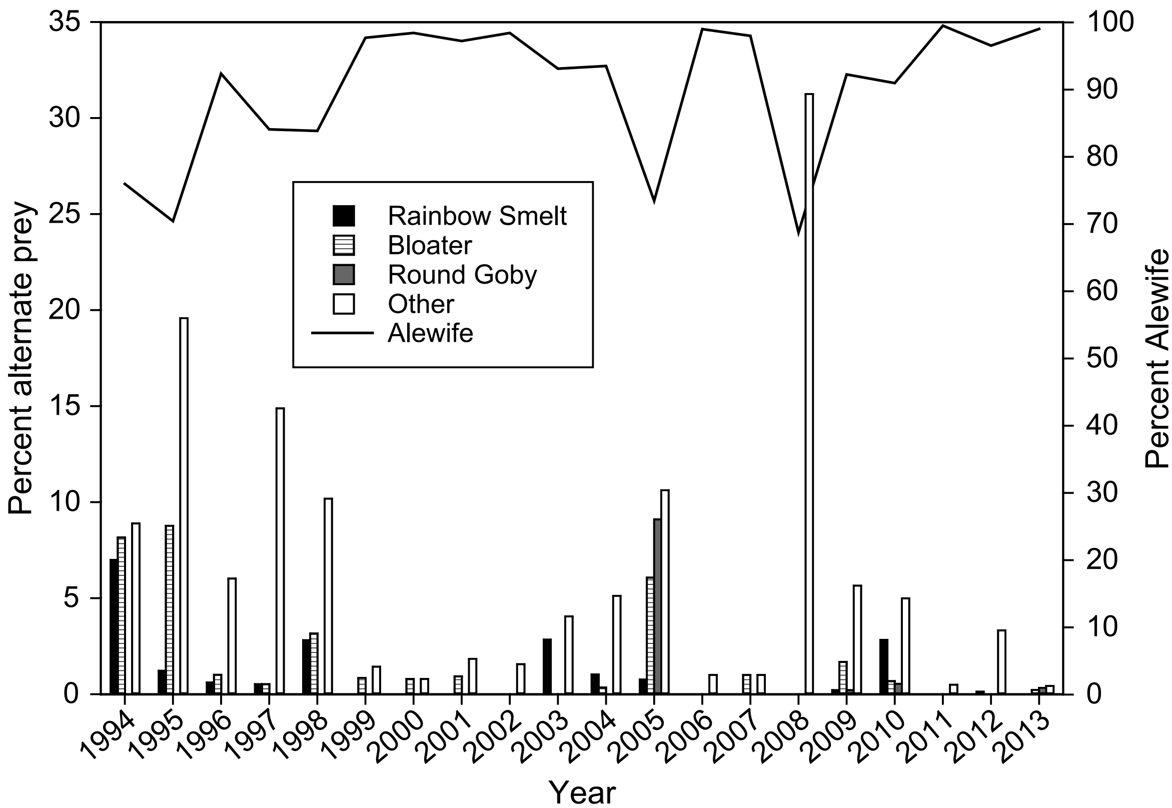

Figure 10.–Percentage (by number) of prey items found in Chinook Salmon stomachs between 1994 and 2013. Percent Alewives is shown as a separate line with values portrayed on the right-hand vertical axis. Empty stomachs were excluded from this analysis.

study. Even with this period of lower sample sizes, the percent of empty stomachs seemed to serve as a good indicator of Alewife year-class strength. In general, we found a declining percentage of empty stomachs for Chinook Salmon after a strong Alewife year class. For example, following the years 1998, 2005, and 2010, the percentages of empty Chinook Salmon stomachs decreased substantially as the percentage of Alewives in salmon stomachs increased (Table 1, Figures 1 and 10). The diet contents suggest that 1998, 2005, and 2010 produced strong year classes of Alewives and the findings are supported by prey fish surveys conducted independently of diet analyses (Madenjian et al. 2014; Warner et al. 2014).

The weight of prey items in non-empty stomachs provides an informative index of prey quality (e.g., multiple older year classes of Alewives) when data analysis is limited to larger salmon (greater than 500 mm TL), but significant trends were not apparent in data from smaller, younger salmon (see Figure 5). A more direct and easier to interpret index of prey quality is the average TL of prey (i.e., Alewife) in Chinook Salmon stomachs. Size structure of prey populations can provide an index of both prey availability and quality. In recent years, prey size in salmon stomachs has not been strongly related to Chinook Salmon size (see Figure 9) and the lack of a predator-prey size relationship is indicative of a major decline in larger Alewives in Lake Michigan (Madenjian et al. 2014). The condition or energy content of Alewives has also been declining in recent years (Flath and Diana 1985, Madenjian et al. 2003); thus an annual assessment of Chinook Salmon diet is critical to determining whether smaller, lower quality Alewife can support Lake Michigan Chinook Salmon populations.

As described in this study, an annual assessment of Chinook Salmon diets can provide critical indices to inform managers concerning the predator-prey dynamic in Lake Michigan. However, managers would prefer a more rapid distribution of results than is afforded by publication in a journal or as an agency technical report. In response to managers concerns, our review and the most recent results (e.g., 2013 diet indices) were provided to fisheries managers in a management brief format (yearly fact sheet) for rapid distribution (See Appendix A). The yearly fact sheet produced from the assessment will give managers the ability to evaluate annual changes and take action such as stocking adjustments or regulation modifications (e.g., in the daily bag limits for the fishery; Claramunt et al. 2009). We recommend use of the management brief approach (fact sheet) for this and other DNR predator fish diet studies, because it can be prepared soon after the completion of the sample processing and analysis, and can be easily distributed to managers and the public for more rapid communication of fisheries assessment data.

Acknowledgments

This study was funded by Federal Aid in Sport Fish Restoration Grant F-81 (Study 230485) to the Michigan Department of Natural Resources (R. Claramunt). Additional funding was provided through the MDNR Game and Fish Protection Fund. We thank Chuck Bronte and the United States Fish and Wildlife Service for helping coordinate Chinook Salmon collections at fishing tournaments and for biological data management. We also thank Nick Arend (USFWS), David Clapp, Tracy Kolb and David Warner (USGS) for contributing useful comments on earlier versions of this manuscript, and to Chuck Madenjian (USGS) and Robert Elliott (USFWS) for providing a formal external review. James Bence (MSU) was the technical editor for this report.

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Approved by Gary E. Whelan

Appendix A.–Lake Michigan Chinook Salmon diets: annual evaluation, 2013. (Reduced to fit.)

Lake Michigan Chinook Salmon Diets: Annual Evaluation, 2013

By Michael L. Diefenbach and Randall M. Claramunt

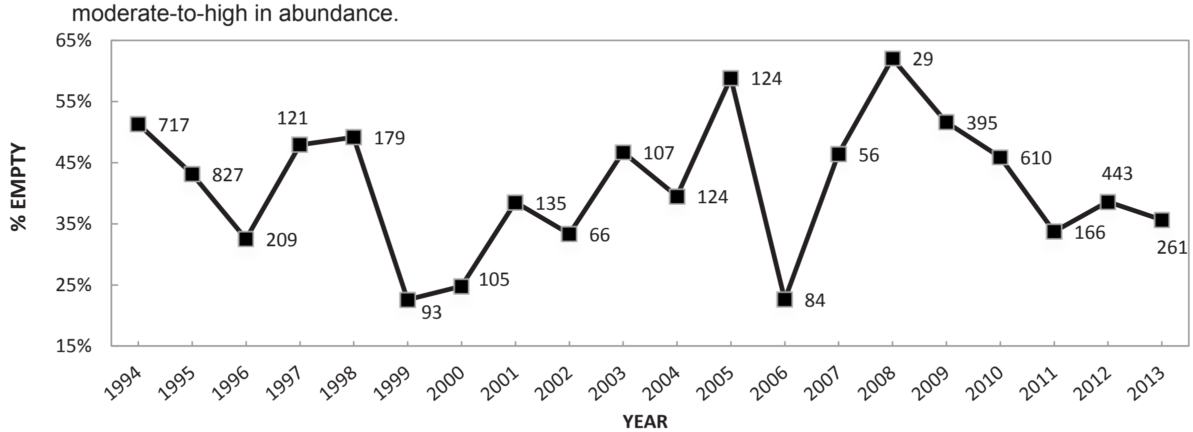
(Note: This study was funded by Federal Aid in Sport Fish Restoration Grant F-81 (Study 230485) to the Michigan Department of Natural Resources. This is a short summary of current findings from this long-term assessment study; more detailed information is available from the MDNR Charlevoix Fisheries Research Station. Additional funding for this work was provided through the MDNR Game and Fish Protection Fund.)

Background:

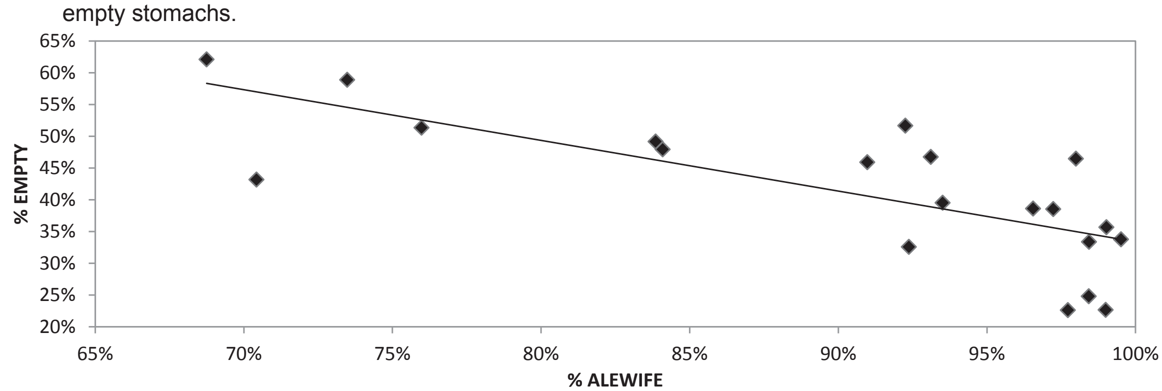
Chinook Salmon *Oncorhyncus tshawytscha* were introduced into Lake Michigan in the late 1960s as a way to control the rising Alewife *Alosa pseudoharengus* populations as well as create a viable sports fishery. Maintaining salmon populations, which was the successful solution to the overabundant Alewife problem in the 1960s, has now become the challenge of today. An annual assessment of diet contents is important because it can show the ongoing relationship between Chinook Salmon and Alewife. Chinook Salmon are important to Lake Michigan and knowing the status of their prey availability and feeding habits can help us better manage them in the future.

Major Findings:

1. Prey Availability: Simple diet indices, such as the average **percent of empty stomachs** in a given year, can be a good indicator of Alewife year class strength. For example, the lowest percentages of empty stomachs were in years following the 1998, 2005, and 2010 Alewife year classes. In 2013, the percent of empty stomachs decreased, likely as a result of the 2012 year class of Alewives, which was estimated to be moderate-to-high in abundance.



2. Comparing the percentage of empty stomachs to the percentage of Alewives in non-empty stomachs, a trend emerges showing that as the percentage of Alewives in the stomachs increase, the percentage of empty stomachs for that year decreases. This also can be a good indicator of the preference and the reliance that Chinook Salmon have for Alewives. When Alewives are abundant, then Chinook Salmon tend to have less empty stomachs.



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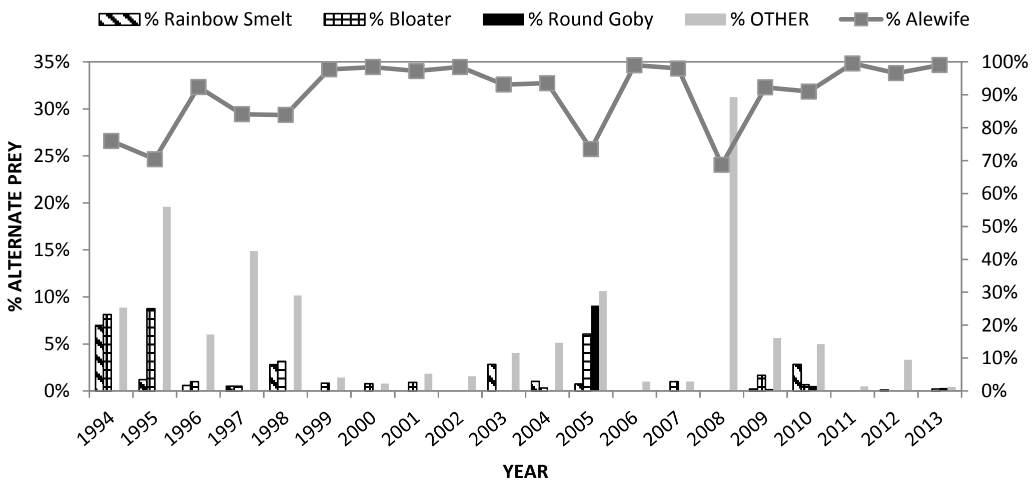
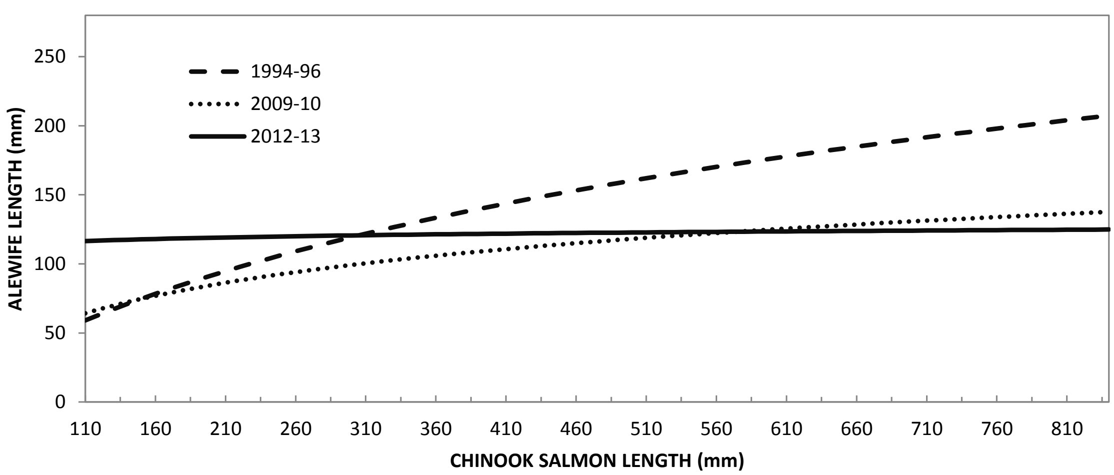
3. Prey Fish Community: Even though Chinook Salmon prefer to eat Alewives, the relative **abundance of other prey species** (e.g., **Rainbow Smelt** or B**loaters**) can be indexed by tracking the percent of the diet that consists of alternate prey items. This index suggests that Bloaters can be a good alternate prey when Alewives are in low abundance and Bloater abundance is relatively high (e.g., 1994-1995 and 2005). In addition, feeding on **other** non-fish prey items, such as Mysis and *Bythotrephes longimanus*, can be an indicator of very poor salmon feeding conditions (e.g., 1995, 1997, and 2008).



4. Prey Quality: By comparing **Salmon size to the size of alewives consumed** by Chinook Salmon, fisheries managers have a good index of the health of the prey fish population. Historically, the average size of Alewife consumed tended to increase with Chinook Salmon size. However, recently (2012-2013) there is little relationship between predator and prey size, suggesting that large Alewives are scarce in the Lake Michigan prey fish population.



Findings from the 2013 Chinook Salmon diet analyses:

- Prey availability in Lake Michigan improved from 2012 to 2013 based on a decrease in percent of empty stomachs
- However, prey size continued to decrease suggesting that larger Alewives are less abundant or available to adult Chinook Salmon
- Chinook Salmon in Lake Michigan are highly selective for Alewives and in 2013 they comprised over 99% of the diet composition suggesting that alternate prey fish are less of a factor due to a higher abundance of Alewives.