Section A. Summary.

Title of Project and Report Type: ASSESSING NEARSHORE – OFFSHORE CONNECTIVITY IN THE LAKE MICHIGAN FOOD WEB USING MULTIPLE TROPHIC INDICATORS

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Abstract

Lake Michigan has recently experienced a food web re-assembly, whereby non-native species have replaced many native forage species within the food web. We investigated how these ecosystem-wide changes affect prey utilization by top predators using stomach content, fatty acid profiles, and stable isotope ratios to provide comprehensive descriptions of responses at the top of the food web. This three-pronged approach yields both short and long term views of fishes foraging habits. Stomach content analysis indicated that Alewife remain the large portion of salmonid diets in Lake Michigan. Combined results (stomach content plus biochemical methods) indicated that Chinook Salmon continue to specialize on Alewife, whereas Lake Trout are capable of incorporating other prey fish species into their diets when abundant and available. We also note a potential gear-bias in the diets of Rainbow Trout, in that stomach contents indicated high reliance on terrestrial invertebrates but biochemical similarities to other salmonids suggest this pattern could be exaggerated by how fish samples were collected.

Keywords

Lake Michigan, food web, trophic ecology, trophic indicators

Lay Summary

Non-native species introduced through human activities have altered the food web of Lake Michigan. To better understand how these introductions have effected salmon, we examined the diets of salmon caught by anglers throughout Lake Michigan. Some species (Chinook and Coho), relied heavily on Alewife as prey whereas other species (Lake Trout and Rainbow Trout) had more varied diets. Lake Trout diet composition depended on where they were in the lake and what season it was when they were caught. Chinook Salmon on the other hand either consumed Alewife or when they had trouble finding Alewife they had empty stomachs. Interestingly, Rainbow Trout stomachs contained large quantities of terrestrial invertebrates, which is likely a reflection of being caught by anglers, rather than what they derive most of their energy from. These results indicate the Chinook Salmon relies on Alewife for prey whereas other species of salmon are able to take advantage of different resources, when available.

Section B. Accomplishments

Introduction

Lake Michigan is in a state of transition. While Lake Michigan and all of the Laurentian Great Lakes are likely never at a steady state with regard to physical, chemical, and biological dynamics, the lake has recently experienced changes in chemistry and biological community composition that are exceptionally large both in relative magnitude and in spatial context. Early studies of these changes highlighted the expansion of dreissenid mussel populations and the potential effects of this expansion on benthic organisms (Fahnenstiel et al. 2010; Nalepa et al. 2009). More recently, a number of other transitions have been documented, indicating that not only has the relative abundance of some biota changed, but fundamental aspects of ecosystem functioning have been altered. For example, pelagic plankton abundance has declined more than would be expected based on nutrient loads and standing stocks (Chapra and Dolan 2012), and the late winter/spring phytoplankton bloom, which represented a large portion of the annual energy supply to benthic invertebrates, has virtually disappeared (Fahnenstiel et al. 2010). In contrast, nearshore benthic algal growth has increased, and is disproportionately high relative to nutrient loading (Auer et al. 2010).

Alterations in the magnitude and spatial distribution of carbon fixation at the base of the food web have been accompanied by major changes at higher trophic levels. Yellow Perch populations have declined dramatically (Marsden and Robillard 2004). While the precise cause of this decline remains unclear, lower zooplankton densities and competition with Alewife and Round Goby are certainly factors that inhibit the recovery of perch populations. Growth rates and condition of Alewife and Lake Whitefish have decreased (Pothoven and Madenjian 2008), and the energy density of Deepwater Sculpin has declined (Pothoven et al. 2011). Chinook Salmon catches have remained relatively high, but natural recruitment has been low (Claramunt et al. 2012).

Most of the above changes have been accompanied by changes in feeding behavior. For example, gut content analyses indicate that Alewife reliance on profundal benthic invertebrates has decreased, while Lake Whitefish have become a major consumer of dreissenids due to the loss of their more preferred food items such as Diporeia (Bunnell et al. 2015; Pothoven et al. 2011; Pothoven and Madenjian 2008). Chinook Salmon have always relied heavily on Alewife, but that dependence appears to have become even stronger with the decline of other forage fish (Jacobs et al. 2013). Alewife populations are at historic lows (with occasional exceptions, such as the strong 2010 year-class), and the resulting precarious condition of the forage base has prompted a recent reduction in Chinook Salmon stocking numbers. Round Goby populations expanded greatly in the mid-2000s to high densities particularly off the Illinois shoreline and the shallow rocky areas of Lake Michigan's Northeast (USGS 2017). The trophic role of this relatively new species is uncertain. Round Goby appear to have become an important prey fish in some parts of the Great Lakes (Dietrich et al. 2006; Hensler et al. 2008; Johnson et al. 2005; Truemper et al. 2006), and there is evidence that it may be an important food item for Lake Trout in some parts of Lake Michigan (Happel et al. 2017b), but its general role in the Lake Michigan food web remains unclear. If this species does become an important forage fish in Lake Michigan, it could be a major vector by which nearshore, benthic energy is transferred to the pelagic food web.

Previous studies focusing on alterations within Lake Michigan's nearshore areas illustrated a consistent difference in how energy flows between the eastern and western sides of the Lake Michigan's basin (Foley et al. 2016; Happel et al. 2015a; Happel et al. 2015b). These were followed by a pilot study looking at how these lower trophic level differences assimilate into Lake Trout, an upper trophic level predator (Happel et al. 2017b). Lake Trout diets were shown to reflect similar eastern-western differences through stomach contents and fatty acid profiles (Happel et al. 2017b). Such results highlight the idea of spatial and temporal variability in food webs within Lake Michigan, and that such variability affects both lower and upper trophic levels. In order to better understand spatial and temporal aspects of Lake Michigan's upper trophic level we sought to describe trophic ecologies of the salmon and trout species caught by anglers. Our aims were to 1.) Describe temporal and spatial aspects of each species diet, 2.) Compare diets among species, 3.) Utilize biochemical markers to assess each species reliance on nearshore vs offshore productivity within the auspices of the above temporal and spatial investigations.

Project Narrative

1. Methods

1.1. Field Collections

Previous surveys indicate spatial differences in nearshore fish community composition across relatively large scales (East vs. West), and since pelagic large predators such as salmon migrate large distance(s?) we focused our efforts into four quadrants (Northwest, Northeast, Southeast, and Southwest) of the lake. In lieu of coordinated sampling efforts offshore, we capitalized on efforts of charter fishermen and anglers to provide individual fishes for sampling. The US Fish and Wildlife Service's Coded Wire Tag Program coordinates teams of technicians across Lake Michigan. Such teams typically collect fish heads for monitoring the stocking program in the lake, however we were able to share biological data and use the teams to collect stomachs, belly flap tissues (for fatty acid analysis) and muscle plugs (for stable isotope analysis). Fish tournaments and derbies offered the highest returns of fishes, of which USFWS technicians were able to collect samples from landed fishes at fish cleaning stations. All samples were stored individually in ziplock baggies labeled with unique identifying numbers, kept on ice, and stored in freezers of at least -20 °C at the end of each sampling day.

1.2. Laboratory Analysis

For stomach content analysis, stomachs were thawed prior to being dissected. After dissection, stomach contents were organized into readily identifiable fishes, well digested fishes, invertebrates, and unknown groups. Readily identified fishes were weighted, and a measure of standard length, backbone length, or partial vertebral length were recorded. For well-digested fishes, identification using cleithra was attempted after weighing the specimen. If cleithra was not obtained, vertebral counts and structure were used for identification. If partial vertebral length measurements were obtained, counts of vertebrae were recorded. If cleithra could be located, measurements of cleithra length were obtained. Such measurements allow the reconstruction of prey fish size prior to consumption if desired. For invertebrate species, eye pairs were counted if low in abundance, and weighed as unique groups. For stomachs where invertebrates were highly abundant or difficult to separate into alike groups, the whole invertebrate mass was recorded, and a 1-gram subsample was described using counts (i.e, 4 ladybeetles and 3 terrestrial moths). Few aquatic insects were found.

For fatty acid analysis, lipids were extracted according to Folch et al. (1957) allowing a measure of the lipid content of each tissue sample. Fatty acid methyl esters (FAME) were prepared according to Metcalfe and Schmitz (1961), separated by gas chromatography/mass spectrometry (Agilent 7890A GC and 5975C inert XL EI/CI MSD, Agilent Technologies, Inc., Santa Clara, California, USA) and quantified as previously described (Czesny et al. 2011). Fatty acid data are expressed as percent composition by mass for each individual (Happel et al. 2017a).

For stable isotope analysis, all samples were either processed immediately upon returning to the laboratory or were frozen (-20 °C) until further analysis. Fish muscle tissues were dried and ground into a fine powder. Dried subsamples of fish tissue were packed in tin capsules for stable isotope analysis. Stable isotope measurements and measurements of tissue C and N concentrations were made using an isotope ratio mass spectrometer (Finnigan MAT delta S SIR-MS) with an elemental analyzer front end and ConFlo II interface. After every 12th sample, an acetanilide control was run to ensure instrument calibration. ^{13}C:^{12}C ratios (presented as $\delta^{13}C$ values) were measured relative to the PDB carbonate standard and ^{15}N:^{14}N ratios (presented as $\delta^{15}N$ values) were measured relative to atmospheric air concentrations. Results were expressed in per mil (‰) differences between the isotope ratio of the sample and that of the standard. $\delta^{13}C$ values were calculated as $\delta^{13}C = [(^{13}C_{sample}/^{12}C_{sample}) / (^{13}C_{PDB}/^{12}C_{PDB})-1]x1000$, and $\delta^{15}N$ values were calculated as $\delta^{15}N = (^{15}N_{sample}/^{14}N_{sample}) / (^{15}N_{Air}/^{14}N_{Air})-1]x1000$. Before additional analyses were performed on fish tissues, lipid corrections were applied to $\delta^{13}C$. In addition to the Illinois-Indiana Sea Grant funded sampling, data on prey species of Alewife and Round Goby were obtained from B. Turshak and H. Bootsma at the University of Wisconsin to help interpret our data.

1.3. Statistical Analysis

Stomach content data were analyzed as percent composition based on weight mass rather than reconstructed pre-consumption prey masses. As the stomach contents of one fish at one time may be highly variable, and unlikely to represent the average consumption for a location/time point we pooled stomach samples according to recommendations in (Elliott et al. 1996). For this, stomach content were expressed as masses, each fish was assigned classifiers on season

(Feeding/Spring = week 31 and earlier [roughly July 31], vs Summer = week 32 and later), and size (Small < 650 mm or Large >= 650 mm). Stomachs were summed for each species by region, season, and size classification into biweek intervals. Any interval with only one or two fish contributing to the biweek was dropped from analysis, keeping all biweeks with three fish or more as the sample unit for our analysis. Each biweek sample was transformed into percentages and averaged to create summaries for each species, size class, region, and season. We express these average percentages as a function of the average ration for the respective species, size class, region, and season. Average percentages were also used to evaluate competition among species for each size class, region, and season using Schoener's Index of similarity (Schoener 1983).

Fatty acid data were analyzed using boxplots to describe differences using previously identified putative tracers of either Alewife (higher DHA or 18:1n-9) or Round Goby (Higher EPA or 16:1n-7). Multivariate ordination techniques in R were used to assess similarities among species fatty acid profiles and to explore temporal and spatial differences within species. Specifically, linear discriminant analysis was used to separate a priori groupings (i.e., species, region, season) and assess how similar or different groups are from each other.

Advanced analysis of fatty acid profiles was conducted using previously described fatty acid profiles of Alewife and Round Goby from Lakes Michigan and Ontario over multiple years. Discriminate axes between these prey species' fatty acid profiles were constructed as a training set, these axis were then used to place individual salmonid's fatty acid profile on a scale of how similar each is to either prey species' fatty acid profiles. Such analysis gives a crude assessment of how reliant each individual salmonid is on each prey species.

Stable isotope values were placed into bi-plot graphs based on the region each was sampled from. Graphs were made of the mean and standard error of large and small, and spring vs summer captures for each region. More depleted carbon ratios (more negative) is indicative more offshore productivity in the food web, whereas more enriched carbon ratios (less negative) indicates greater benthic and nearshore reliance. Lakewide averages for Alewife and Round Goby carbon and nitrogen stable isotopes were added to each plot to aide in interpretation of each salmonids isotope values (2016 GLFT, unpublished data; Bootsma, Czesny, Hook, Leonhardt, Rinchard, and Turschak).

2. Results and Conclusions

2.1. Overall Sample Numbers

In 2015 a total of 1,644 fish were sampled for this project (Table 1). All fish had stomach contents analyzed yielding information on the contents of 1,644 stomachs. A total of 933 samples of belly flap tissues were analyzed for fatty acid composition, and 499 samples of muscle tissues were analyzed for stable isotope ratios. Throughout the datasets, the largest number of fish captured were from the southwest quadrant of the lake, which is also where the highest population of anglers on the lake is (Simpson et al. In Press).

<u>Table 1</u> Sample Numbers of fish analyzed for stomach content, fatty acid, and stable isotope analyses. BNT – Brown Trout, CHS – Chinook Salmon, COS – Coho Salmon, LAT – Lake Trout, RBT – Rainbow Trout.

	Spring					Summer				
	BNT	CHS	COS	LAT	RBT	BNT	CHS	COS	LAT	RBT
Stomach Content Analysis										
NE										
Large	1	5	-	12	2	1	3	5	3	-
Small	-	6	2	4	4	1	-	5	5	-
NW										
Large	2	65	2	37	29	2	39	9	21	11
Small	10	50	12	23	35	10	36	13	11	17
SE										
Large	4	35	1	26	17	2	58	20	23	30
Small	9	9	17	21	17	2	10	18	22	5
SW										
Large	20	77	23	78	40	8	50	20	101	30
Small	30	57	40	61	41	12	24	40	21	13
Fatty Acid Analysis										
NE										
Large	2	9	-	17	6	3	10	1	3	1
Small	10	14	14	29	15	2	6	18	13	3
NW										
Large	-	37	-	18	10	1	50	1	14	12
Small	11	30	8	26	23	10	36	20	18	22
SE										
Large	2	9	1	5	3	-	30	-	25	8
Small	15	6	11	29	13	1	6	24	26	14
SW										
Large	5	12	1	12	5	3	11	2	8	7
Small	7	24	15	20	11	6	11	11	5	5
Stable Isotope Analysis										
NE										
Large	-	-	-	2	7	1	13	4	8	1
Small	-	-	-	6	12	1	17	16	11	-
NW										
Large	-	17	-	-	7	-	-	-	2	-
Small	1	5	-	-	6	1	-	1	2	-
SE										
Large	2	-	-	-	3	-	14	-	22	7
Small	22	4	-	-	2	3	10	37	7	9
SW										
Large	1	15	-	7	11	-	22	3	12	9
Small	4	37	12	18	12	4	10	21	6	7

2.2. Stomach Content Analysis

Of all of the stomachs dissected, 44% were empty. Rainbow Trout had a higher percentage of empty stomachs in the summer period (52%) than in the spring (21%). A similar trend was evident with Lake Trout (64% summer vs 42% spring) and Brown Trout (61% summer vs 37% spring). The percentage of empty stomachs for Chinook Salmon was 50% for both spring and summer periods, and Coho Salmon had relatively low percentages of empties (40% spring and 32% summer) in both seasons. Although we do note that empty stomachs were generally more prevalent on the Eastern side of the lake than on the Western side for Chinook Salmon.

Across the salmonids analyzed, rations appear to be larger in southern waters, especially the Southeast, than in northern areas of the lake. As expected, Alewife were the primary fish prey for salmonids in Lake Michigan in 2015 (Fig. 1). Chinook Salmon, Coho Salmon, and Brown Trout had the highest percentages of Alewife consumed in their stomachs regardless of size, season, or region of the lake.

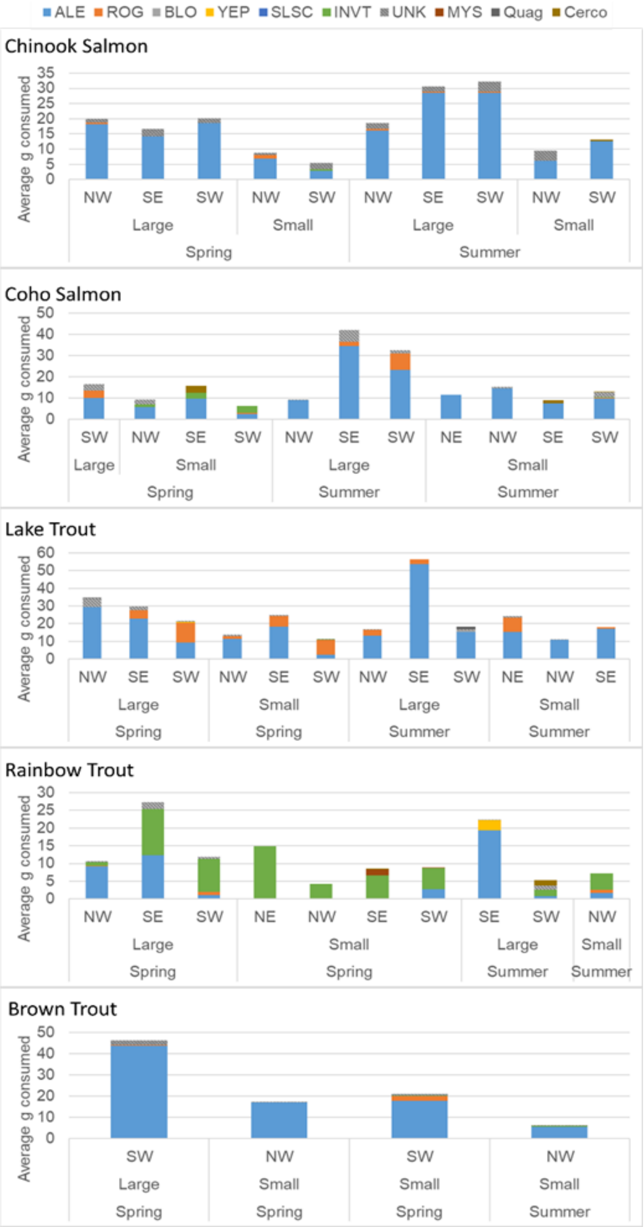

Fig 1. Stomach content for each salmonid included in our analysis expresses percentages of the average ration consumed for each period. Exact method for summarizing stomach data are outlined in the text.

Rainbow Trout consumed the highest proportion of terrestrial invertebrates out of the species assessed. Invertebrates were primarily stinkbugs, moths, beetles, lady beetles, and houseflies. It is likely that the Rainbow Trout stomach data represent a bias due to fishing efforts focused on scumlines which aggregate terrestrial invertebrates and Rainbow Trout are known to favor such locations for feeding.

Lake Trout stomach content varied by location, with greater proportions of Round Goby consumed in southern regions of Lake Michigan. This is somewhat consisted with results from 2011 although increased consumption of Round Goby appears to occur in the Southwest and in the Spring (Happel et al. 2017b). It is possible that the higher consumption of Round Goby in the southern part of lake in the spring is driven by Round Goby migrating from offshore to nearshore as waters warm up in the spring.

Schoener's indices indicate that the least amount of diet overlap occurs when species are compared to Rainbow Trout (Table 2). This is due to the amount of terrestrial invertebrates found in the stomachs of Rainbow Trout. Lake Trout and Coho Salmon diet compositions overlapped significantly with Chinook Salmon in most areas of the lake except the Southwestern region in the Spring. This is likely explained by the increased consumption of Round Goby in this region in the spring period by Lake Trout and the inclusion of terrestrial invertebrates by Coho Salmon.

Table 2. Schoener's index between species depending on size, region of capture, and season of capture. Schoener's indices were not calculated between differing size classes, regions, nor season of captures. Cells highlighted red indicate areas of significant overlap (index > 0.60) where as others are highlighted green. Brown Trout were not included in this analysis due to low sample numbers.

			CHS			LAT		COS
			LAT	COS	RBT	COS	RBT	RBT
Spring	Large	NE	NA	NA	NA	NA	NA	NA
		NW	0.91	NA	0.90	NA	0.88	NA
		SE	0.84	NA	0.52	NA	0.52	NA
		SW	0.47	0.69	0.15	0.67	0.20	0.23
	Small	NE	NA	NA	NA	NA	NA	NA
		NW	0.9	0.7	0.0	0.69	0.00	0.14
		SE	NA	NA	NA	0.63	0.00	0.20
		SW	0.26	0.50	0.41	0.31	0.22	0.81
Summer	Large	NE	NA	NA	NA	NA	NA	NA
		NW	0.83	0.88	NA	0.80	NA	NA
		SE	0.94	0.89	0.87	0.87	0.87	0.83
		SW	0.89	0.77	0.27	0.77	0.21	0.20
	Small	NE	NA	NA	NA	0.63	NA	NA
		NW	0.67	0.71	0.24	0.96	0.24	0.24
		SE	NA	NA	NA	0.84	NA	NA
		SW	NA	0.79	NA	NA	NA	NA

2.3. Lipid and Fatty Acid Analysis

Lipid content of tissue samples were highest in Brown Trout and Lake Trout (~35%) whereas for other salmonids mean values were around 15% (Fig. 2). As samples were of bellyflaps instead of muscle tissues for lipid analysis, we did not use lipid analysis as a measure of condition factor and further conclusions were minimal at this point in time.

A ratio of DHA to EPA was suggested as a means of tracing pelagic (i.e., Alewife) vs benthic (i.e., Round Goby) foraging (Czesny et al. 2011) and similarly for a ratio of 18:1n-9 to 16:1n-7 (Happel et al. 2017c). As such, these ratios were calculated and explored as boxplots to assess each species reliance on the two prey species (Fig. 2). We note that Brown Trout and Lake Trout trend slightly more towards indicators of Round Goby (higher 16:1n-7 and EPA) than other species analyzed. This corresponds to higher Round Goby masses in Lake Trout stomachs but does not seem to match stomach content analysis of Brown Trout.

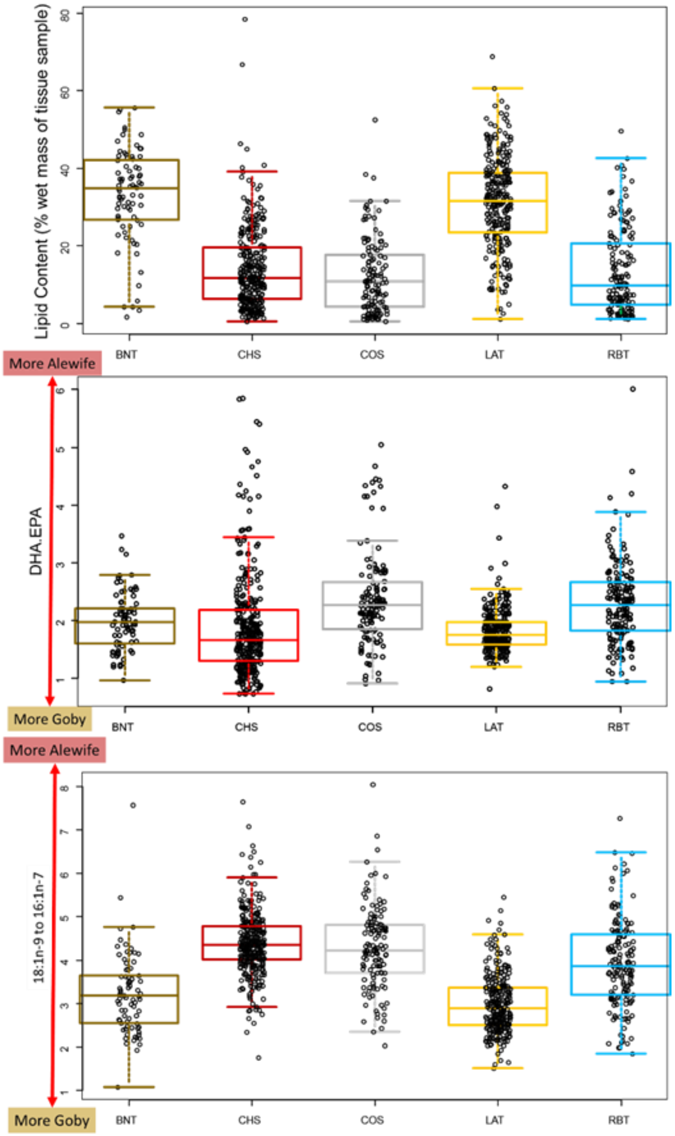

Fig 2. Summary data of lipid content (% wet weight) and fatty acid ratios used to evaluate reliance on Alewife vs Round Goby consumption.

Classification of each sample during DFA indicated that each species was relatively distinct and a majority of samples were classified to the correct species (Table 3). Of those misclassified, Coho and Chinook Salmon were more often misclassified as each other. Also, 18% of Rainbow Trout fatty acid profiles were misclassified as Coho Salmon.

Plots of mean sample locations from DFA indicated a triangle-like association where Chinook Salmon, Lake Trout, and Rainbow Trout comprise the corners and Brown Trout and

Coho Salmon samples are within the boundaries (Fig. 3). This configuration is consistent for each size and season that was assessed, and suggest the three corners represent different consumption patterns, and to a lesser degree taxonomic differences in how fatty acids are assimilated into consumers’ tissues. Error bars for Chinook Salmon were generally smaller and means for each region were generally closer in proximity than those for other species indicating that diet compositions are relatively invariant. Conversely, error bars for Lake Trout and Rainbow Trout appeared much larger; especially for those from southern regions indicating diets in these regions may be more plastic and vary individualistically.

Table 3. Classification matrix from discriminant function analysis on salmonid fatty acid profiles.

		Predicted species				
		BNT	CHS	COS	LAT	RBT
Species identity	BNT	54	3	8	12	1
	CHS	2	267	23	7	2
	COS	8	10	90	5	14
	LAT	4	6	1	254	3
	RBT	2	5	29	10	112

Results from the training of DFA with prey species and then classifying the salmonids indicated a much greater similarity between Chinook Salmon samples and the fatty acid profile of Alewives (Fig. 4). For Lake Trout, a greater inclusion of Round Goby in the diets of those from the Spring period was indicated, followed by a greater reliance on Alewife during the Summer periods. Such results mirror those of the stomach contents analyzed, that Alewife appear to be the largest contributor to stomach content biomass and thus energy assimilated.

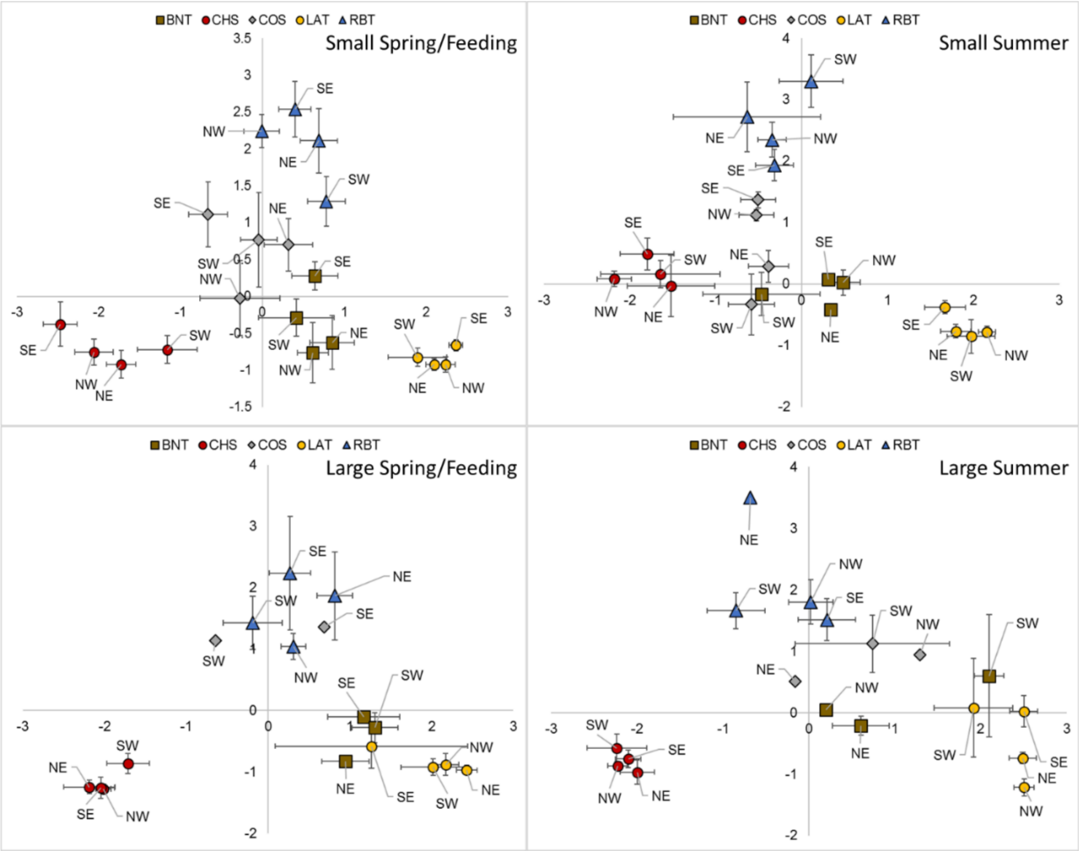

Fig 3. Averaged (± SE) sample locations from linear discriminant function analysis of fatty acid profiles.

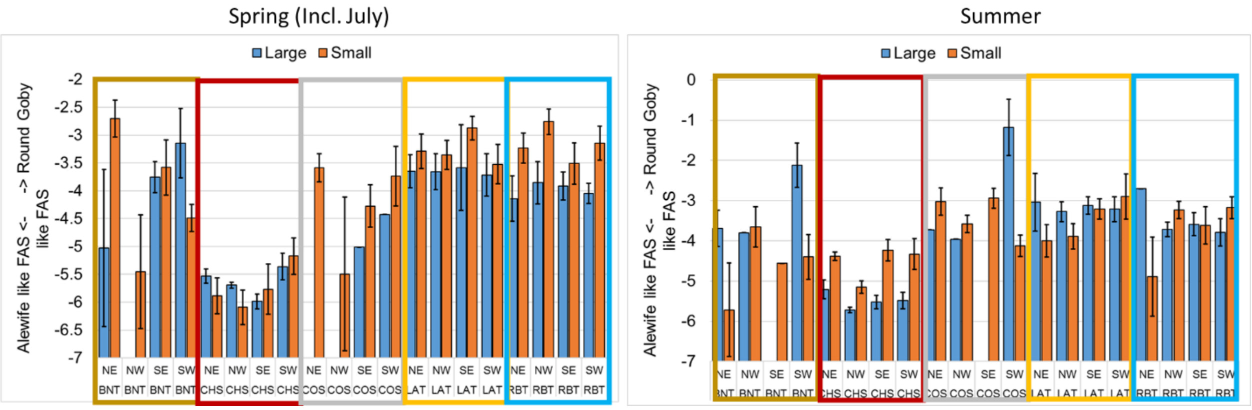

Fig 4. Results of discriminant function analysis used to evaluate how similar species fatty acid profiles are to Alewife (negative) vs Round Goby (positive).

2.3. Stable Isotope Analysis

It is worth mentioning that lake-wide averages for prey species are currently under evaluation by the colleagues that provided the data and regional and depth-related differences in prey resource signatures may affect interpretations. For example, it is likely that the lake-wide Round Goby signature provided is more depleted than is the case for specific regions. Regardless, the inclusion of prey signature data is important to provide points of reference as consumer isotopes depend on prey signatures. Further, accounting for regional differences in prey resources when consumers migrate between the same regions will provide an interesting challenge to those working with stable isotope mixing models. As such, we forego implementing mixing models on our data at this moment, and instead rely on interpretations of biplots.

Chinook Salmon and Lake Trout had the most depleted carbon signatures of the salmonid groups (Fig. 5). Depleted carbon signatures suggest a greater reliance on in-lake pelagic productivity, whereas more enriched signatures indicate greater benthic or terrestrial origins of carbon. Also, Lake Trout samples were more enriched in nitrogen than other salmonid samples, something that has been noted through several datasets (B. Turshak, personal communication). It is thought that the consumption of demersal species (i.e., sculpin, *Mysis*, *Diporeia*) from deep depths leads to the enrichment of Lake Trout nitrogen ratios vs. other salmon who do not feed at such depths. For comparison, Rainbow Trout and Coho Salmon had more depleted nitrogen ratios and slightly more enriched carbon ratios which may be caused by the incorporation of terrestrial insects into the diet as stomach and fatty acid profiles also suggested.

In general, ratios of stable carbon isotopes found in Lake Michigan's salmonid community varied only between -24 and -22 which is a relatively small window compared to other systems studied (Mumby et al. 2017; Turschak et al. 2014). Two inter-connected theories can account for this; 1.) salmonids share a common prey and rely on it for a large proportion of their energetic needs, or 2) being at the top of the food chain causes an assimilation of carbon ratios leading to a narrowing in the range of carbon isotope ratios seen at higher trophic level than lower levels.

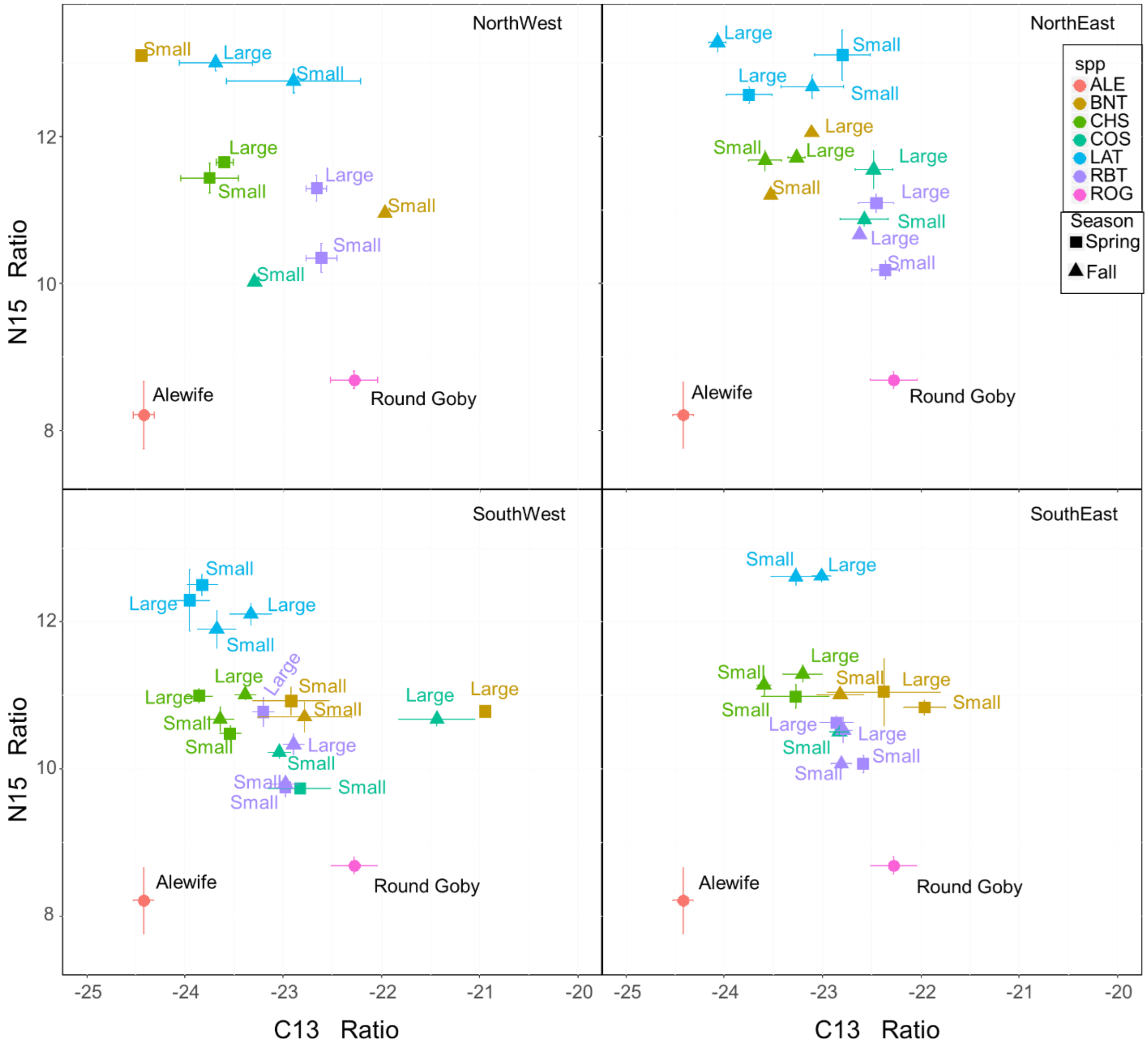

Fig 5. Biplots of stable isotope ratios for salmonids from Lake Michigan. Samples of Alewife and Round Goby represent lakewide averages of samples collected in 2016 (2016 GLFT, unpublished data; Bootsma, Czesny, Hook, Leonhardt, Rinchard, and Turschak).

3. Potential Applications, Benefits and Impacts

Understanding energy flow pathways in the Lake Michigan food web is a prerequisite to making wise decisions regarding stocking and management. Recently, management agencies have decided to reduce stocking numbers of several salmonid species to the lake. This decision is a response to the reduced numbers of forage fish combined with increased natural reproduction of Chinook Salmon and Lake Trout (Hanson et al. 2013; Landsman et al. 2017). Stocking reductions are an attempt to prevent a crash of salmon numbers like that observed in Lake Huron and to avoid corresponding significant economic impacts (Dettmers et al. 2012). However, uncertainty remains regarding the carrying capacity of Lake Michigan. The declines in abundance of plankton and pelagic forage fish appear to have reduced the lake's overall carrying capacity, but it is unlikely that all fish species are equally affected. Recent work looking at stomach content compositions indicated that some species are Alewife specialists and may be more responsive to changes in Alewife population numbers. For example both our current study and previous work from the Great Lakes region indicate that Chinook Salmon stomach content rarely deviate from Alewife as the most abundant (numerically and by biomass) (Happel et al. 2017c; Jacobs et al. 2013; Roseman et al. 2014). In contrast, Lake Trout appear to be capable of taking advantage of other resources if available, this especially seems true for the expanding Round Goby populations (Happel et al. 2017b; Happel et al. 2017c), similarly higher abundances of Rainbow Smelt yield higher consumption of Rainbow Smelt by Lake Trout (Happel et al. 2017b; Roseman et al. 2014).

An interesting result is the abundance of terrestrial invertebrates in Rainbow Trout stomachs. We suspect that this led to the slight difference in fatty acid profiles seen in the Rainbow Trout compared to Chinook Salmon or Lake Trout. We also suspect that Rainbow Trout do not rely as heavily on terrestrial resource as suggested by stomach content and this result is likely partially due to sample collection relying on angler caught fishes. Anglers focus on scumlines that develop in the spring when warm water pulls surface water offshore prior to sinking, dragging with it incidental landings of terrestrial insects. These insects collect at the down-welling point and Rainbow Trout are known to take advantage of this area of the water. As such, our samples are likely skewed by Rainbow Trout caught at these scumlines where high concentrations of terrestrial insects are located.

By identifying current trophic pathways and the ability of various species to utilize alternative energy sources, such as Round Goby or terrestrial insects, we will be able to better quantify how the recent reallocation of nutrient and energy resources is affecting individual fish species and the fish community as a whole. This information can be used to inform management decisions related to stocking and fishing regulations for individual species. In particular, the abundance of Round Goby consumption by Lake Trout in the spring is being discussed as becoming incorporated into lakewide mass-balance models to help model food web responses.

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Section C. Outputs

Media Coverage

Interviews

"Invasive Species are Changing Lake Trout Diets" by Kevin Bunch in "Great Lakes Connection", December 7, 2017, International Joint Commission Online publication. http://ijc.org/greatlakesconnection/en/2017/12/invasive-species-are-changing-lake-trout-diets/

Presentations:

Presentations

Happel, A., Czesny, S.J., Rinchard, J., Bronte, C.R., Kornis, M.S. (oral presentation). Diet compositions of five salmonid species in Lake Michigan during 2015. *International Association of Great Lakes Research*. Detroit, MI. May 18th, 2017.

Happel, A., Czesny, S.J., Rinchard, J., Bronte, C.R., Kornis, M.S. (oral presentation). Diet compositions of five salmonid species in Lake Michigan during 2015. *Annual meeting of Illinois Chapter of the American Fisheries Society*. Moline, IL. Feb. 22nd, 2017.

Maier, C., Barker, N., Edwards, M., Czesny, S. and Rinchard, J., 2017 (oral presentation). Fatty acid signatures of predatory fish from Lake Michigan. *44th Annual Fall Scientific Paper Session of the Rochester Academy of Science*, Rochester (New York, USA), November 11, 2017.

Maier, C., Barker, N., Edwards, M., Czesny, S. and Rinchard, J., 2017 (poster presentation). Fatty acid signatures of predatory fish from Lake Michigan. *2017 SUNY Undergraduate Research Conference*, Fredonia (New York, USA), April 22, 2017.

Maier, C., Edwards, M., Barker, N., Czesny, S. and Rinchard, J., 2017 (oral presentation). Fatty acid signatures of predatory fish from Lake Michigan. *Brockport Scholars Day*, Brockport (New York, USA), April 12, 2017.

Maier, C., Barker, N., Edwards, M., Czesny, S. and Rinchard, J., 2017 (poster presentation). Fatty acid signatures of predatory fish from Lake Michigan. *2017 Annual Meeting of the New York Chapter of the American Fisheries Society*, Buffalo (New York, USA), February 1-3, 2017.

Barker, N., Maier, C., Edwards, M., Czesny, S. and Rinchard, J., 2016 (poster presentation). Variations in fatty acid signatures of brown trout and coho salmon from Lake Michigan. *43rd Annual Fall Scientific Paper Session of the Rochester Academy of Science*, Rochester (New York, USA), November 12, 2016.

Maier, C., Barker, N., Edwards, M., Czesny, S. and Rinchard, J., 2016 (poster presentation). Fatty acid signatures of predatory fish from Lake Michigan. *43rd Annual Fall Scientific Paper Session of the Rochester Academy of Science*, Rochester (New York, USA), November 12, 2016.

Edwards, M., Maier, C., Barker, N., Czesny, S. and Rinchard, J., 2016 (poster presentation). Fatty acid signatures of Lake Michigan rainbow trout. *43rd Annual Fall Scientific Paper Session of the Rochester Academy of Science*, Rochester (New York, USA), November 12, 2016.

Undergraduate/Graduate students

Supported Nathan Barker, Michele Edwards, Chris Maier who all conducted a Summer Undergraduate Research Internship in Dr. Rinchard's lab.

Partially supported Austin Happel through his final stages as a Ph.D. student at University of Illinois.

Project Partnerships:

This project was a springboard to broader partnership and collaboration among academic (UWM, Purdue, SUNY, UI) as well as state and federal (MI DNR, IL DNR, USFWS, USGS) entities trying to gain a better understanding of prey resource utilization by top predators and optimizing strategies for sustainable management of fisheries in Lake Michigan.

Related Projects:

The New Lake Michigan Food Web: Establishing links between nearshore food sources and pelagic piscivores. Funding Agency: Great Lakes Fishery Trust. Co-PIs; Bootsma, Czesny, Hook, Rinchard. Collaborative Project among UW Milwaukee, University of Illinois, Purdue University, and SUNY. Total new funding of $374,132 (including $109,360 match).

Awards and Honors NA
Patents/Licenses NA