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Interpreting Predator – Prey Interactions in Cayuga Lake Fishes Using Fatty Acid Signature Analysis

Jeremy Kraus
The College at Brockport, jkrau1@brockport.edu

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Jeremy W. Kraus

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Abstract

Fatty acids are transferred from prey to predator and can be used to assess trophic interactions in aquatic food webs. Therefore, to better understand Cayuga Lake food web dynamics, fatty acid signatures (FAS) of lake trout (*Salvelinus namaycush*) were compared to two major prey species in the lake; alewife (*Alosa pseudoharengus*) and round goby (*Neogobius melanostomus*). The main objectives of the study were to assess FAS dissimilarity between prey species and then compare each prey FAS to lake trout FAS. Fish were collected in 2014 and 2015 using seine nets (alewife, n = 255 and round goby, n = 448) and gillnets (lake trout, n = 60). Mean total lipid content in alewife was significantly higher than round goby (5.7 vs. 3.1%, Mann-Whitney U test = 19.666, df = 1, $P < 0.05$). The FAS of both prey species differed significantly (ANOSIM, overall $R = 0.594$; $P < 0.05$); concentration of 18:1n-9 was highest in alewife, whereas 22:6n-3, 20:5n-3, 16:1n-7, and 18:3n-3 concentrations were highest in round goby. Intraspecies (spatio-temporal) FAS variations were found for each prey species, but these variations were less significant than those observed between species. Although round goby in lake trout diet appeared to increase in 2015, comparisons of FAS of lake trout and both prey species suggest that lake trout diet is composed primarily of alewife.

1. Introduction

1.1. Cayuga Lake History and Ecology

The longest (61.4 km) and second deepest (132.6 m) of the Finger Lakes, Cayuga Lake is a glacial relic in Central New York. Its geographic location is 42° 41’ 30” N and 76° 41’ 22” W, at an elevation of 116.4 m above sea level, with a 2033 km² catchment area (Oglesby 1978). Cayuga Lake developed from a large river valley, carved by glacial scouring, approximately 10,000 years ago. A few common characteristics of the Cayuga Lake basin are steep slopes, lined with water-carved gorges, and multiple waterfalls. The Cayuga Lake watershed boasts Taughannock Falls, one of the tallest waterfalls (65.53 m) in the northeastern United States. The ancient Cayuga River Basin once dipped and flowed to the south, but was changed so drastically by glacial force that it now flows north. A terminal moraine, deposited 16 km south of Ithaca, marks the furthest point of glacial advance in the region. The moraine also forms the watershed boundary between Cayuga Lake and the Susquehanna River. As the 1.6 km thick glacier melted, massive volumes of water carved into the hillsides, leaving the lake and its gorges behind. The Finger Lakes now lie in deeply carved basins flowing north to Lake Ontario. In 1910, after 10,000 years of formation, the first scientific data on Cayuga Lake were collected when Birge and Juday began limnological studies (Oglesby 1978). Since then, few ecological studies have been conducted on Cayuga Lake.

Before ecological studies were conducted on Cayuga Lake, many fish were introduced, making it difficult to know which species today occurred naturally. Early records kept by missionaries and deductive reasoning have been used to shed light on the matter. Historically, American eels (*Anguilla rostrata*) and Atlantic salmon (*Salmo salar*) were abundant, along with cisco or lake herring (*Coregonus artedii*) and lake trout (*Salvelinus namaycush*). The eel’s

migration path to Cayuga Lake from the Atlantic Ocean has been hindered through engineered waterways and dams. Today, far fewer eels migrate successfully relative to 70 years ago, before the construction of the Moses-Saunders Dam on the St. Lawrence River. One of my fondest fishing memories is of my father catching an American eel in the early 2000's from Taughannock Falls State Park.

From personal experience and an angling perspective, the fishing effort for Atlantic salmon is greater than for lake trout. Atlantic salmon were decimated from New York lakes (including Cayuga) before the turn of the 20th century (Smith 1985). Not until 1948, did state-run programs to reestablish and sustain a fishery of inland Atlantic salmon begin (Smith 1985). In recent years, the stocks of salmon have done well in Cayuga Lake, with 2017 being a banner year with lots of adult fish reportedly caught (Personal Communication, Michael Speziale New York State Department of Environmental Conservation (NYSDEC) 2017).

Lake trout and Atlantic salmon have suffered similar fates in Cayuga Lake. Both species were nearly wiped out, and management programs established over 80 years ago are still working to maintain healthy populations in Cayuga Lake, across the state of New York, and the Great Lakes generally. Much of the decline in native species is credited to the development of fish culture in the 1860's; followed by successful transport and introduction of non-native species to United States waterways. With the completion of the Erie Canal system in the 1820s, fish such as sea lamprey (*Petromyzon marinus*) and alewife (*Alosa pseudoharengus*) migrated from previously isolated water bodies into Cayuga Lake (Youngs and Oglesby 1972). These introductions have led to the displacement of native forage species, such as cisco, and caused problems (historic and current) for native predatory fisheries.

Sea lamprey are known best for their parasitic life stage, in which they attach and suck body fluids from large native predatory fish such as lake trout and Atlantic salmon. This interaction has had a historically significant impact on the lake trout and salmon fisheries throughout the Great Lakes, making the lamprey a predator on its own. Currently, the sea lamprey population in Cayuga Lake seems to be successfully controlled via lampricide application (Kielbasinski 2014). Lampreys have also been identified as a food source of lake trout, albeit uncommonly (Personal Communication, John Gaulke 2015).

Alewife was one of the first introductions to the lake, likely through the canal systems or early fish culture activity (Youngs and Oglesby 1972). Alewife have directly impacted lake trout and the structure of the forage fish populations and/or communities in the lake for nearly two centuries. The competitive nature of alewife has likely aided the extirpation of cisco, a planktivore and forage fish in Cayuga Lake (Youngs and Oglesby 1972). Fluctuations in forage fish diversity and abundance ultimately affected the status of lake trout. Since the 1930s, the lake trout fishery in Cayuga Lake has been maintained by the NYSDEC stocking programs (Kielbasinski 2014). Stocking programs are in place to support populations of fish that are unable to reproduce naturally. Lake trout and other salmonid species with a diet consisting mostly of alewife experience reproductive failure due to thiamine deficiency in their eggs; this leads to Cayuga Syndrome (or Early Mortality Syndrome (EMS)) in fry (Fisher et al. 1995, Riley *et al.* 2011). This accounts for erratic swimming and death of lake trout and other salmonid species' fry, usually before exogenous feeding takes place. Alewife contain high levels of thiaminase, a degradative enzyme of thiamine, which is an essential vitamin (B_1) for lake trout reproduction and fry development (Honeyfield *et al.* 2012). Palatability, relative abundance (high optimal forage value), and predictable diel migration are likely reasons why alewife have been such a

favored food source for lake trout. When brood stock diet consists of mostly alewife, lake trout embryos succumb to Cayuga Syndrome (Fitzsimons *et al.* 2005, Riley *et al.* 2011). The presence of alewife along, with sport fishery demand and lamprey predation, has led to lake trout population decline in Cayuga Lake, as well as many Great Lake populations.

Rainbow smelt (*Osmerus mordax*) and round goby (*Neogobius melanostomus*) are two additional species consumed by lake trout in Cayuga Lake (Youngs and Oglesby 1972). Round goby are the most recent introduction to the lake, whereas rainbow smelt have been present for nearly 100 years. Rainbow smelt were introduced to Cayuga Lake in the 1920's as a sport fishery and forage base, becoming well established thereafter (Youngs and Oglesby 1972). In April, rainbow smelt tend to school in and around the mouths of tributaries. During that period, lake trout forage heavily on rainbow smelt due to their increased availability and ease of access. However, there is little documentation on whether lake trout feed on rainbow smelt year-round in Cayuga Lake. Rainbow smelt stocks in the Finger Lakes are low compared to 30 years ago (Rudstam *et al.* 2013), which may make them a less preferred food source to lake trout. Consumption of year-of-the-young alewife by rainbow smelt, out of foraging habit or territoriality, directly and negatively impacts their reproductive success due to thiaminase (Chalupnicki *et al.* 2010). Rainbow smelt interaction (by eating each other's fry) and competition for resources and space with alewife may have contributed significantly to their decline in Cayuga Lake (Chalupnicki *et al.* 2010).

Round goby, the newest addition to the Cayuga Lake ecosystem, creates an opportunity to develop an understanding of its impact on lake trout and its long-established forage base. The round goby is a notoriously invasive species introduced from the Ponto-Caspian Sea. It is not clear when the species was introduced in Cayuga Lake, although I

caught and reported a round goby on 26 June 2013 at Taughannock Falls State Park (Figure 1). Round goby likely spread to Cayuga Lake using the NYS Barge (Erie) Canal system as a convenient vector. They are known for their reproductive success, voracious appetite, and generalist foraging habits. As predominantly benthic organisms, they feed on invertebrates like dreissenid mussels, which could shift the flow of energy to the benthic zones of the lake (Kornis *et al.* 2012). Zebra and quagga mussels (*Dreissena polymorpha* and *D. rostriformis bugensis*) have been observed in the lake since 1991 and 1994, respectively (Cornell University, Lake Source Cooling Environmental Impact Statement, 2000). The presence of round goby is positively correlated with submerged aquatic vegetation in the coastal Great Lakes (Kornis *et al.* 2012). Round goby have also been found in a wide variety of habitats, from shallow coastal areas to as deep as 130 m (Kornis *et al.* 2012). In Summer 2013, the NYSDEC officially confirmed the presence of round goby in Cayuga Lake, therefore round goby became established over the past few years. In the Great Lakes, round goby is a known lake trout prey species (Dietrich *et al.* 2006) and this interaction is also occurring in Cayuga Lake (Personal Communication, Emily Zollweg-Horan NYSDEC 2017). In addition to providing forage for lake trout, round goby could also compete directly with alewife and rainbow smelt by consuming similar prey and eating each other's eggs and fry (Chalupnicki *et al.* 2010). It is possible that a shift in lake trout diet to round goby would supplement thiamine and reduce reproduction problems (Fitzsimons *et al.* 2009). Since it is such a new introduction, its current impact on lake trout and the food web of Cayuga Lake are still unknown.

Lake trout are native predators in deep temperate lakes of New York State and are reliable indicators of healthy ecosystems (Rush *et al.* 2012). Historically, the primary prey fish interaction of lake trout in Cayuga Lake was with alewife (Youngs and Oglesby 1972). Since the 1930's lake

trout have been captured in Cayuga Lake for eggs by the NYSDEC Fish Culture Section, and the roughly 260,000 lake trout eggs collected each year represent a large portion of the State's stocked fish (Kielbasinski 2014). NYSDEC culturists capture both adult males and females to artificially spawn them and release them unharmed shortly after. Immediately after fertilization, eggs are treated with thiamine to prevent Cayuga syndrome, also known as early mortality syndrome (EMS), and iodophor solution for disinfection before transport to the NYSDEC Hatchery in Bath, NY for incubation. The lake trout hatched through this process are used to stock lakes in a statewide restoration effort.

1.2. Fatty Acid Signatures

Fatty acid signatures (FAS) have been previously used in aquatic environments to study feeding ecology and food web dynamics (Budge *et al.* 2012). Fatty acids are energy-rich dietary nutrients, often functioning as fuel in metabolic functions. Apart from being rich in energy; fatty acids help maintain cell membrane fluidity and structure, aid in development, immune response, and reproduction in fish. The International Union of Physical and Applied Chemists (IUPAC) has standardized the characterization and naming of fatty acid molecules for ease of identification. Fatty acid molecule identification is based on the number of carbon atoms, double bonds (degree of unsaturation), and the position of the first double bond in the carbon chain relative to the methyl end (Glencross 2009). For example, docosahexaenoic acid (DHA) has an IUPAC formula of 22:6n-3, meaning the molecule has 22 carbons and 6 double bonds, the first of which is located after the third carbon from the methyl terminus.

The practicality of FAS for assessing food web interactions among organisms is due to the prevalence of fats stored in tissues (Lovern 1935). Lipid molecules are passed unchanged

along the food chain allowing accurate identification and comparison, assuming FAS are distinguishable among species (Czesny *et al.* 2011). FAS are diet-dependent and can vary due to locality or migration patterns and seasonality (Czesny et al. 2011, Bayes *et al.* 2014). The use of fatty acids in fisheries ecology research has become increasingly popular in the last decade, from marine studies on great white sharks (binomial) to planktonic freshwater crustaceans (cf. Brett *et al*. 2007, Joensen and Grahl-Nielsen 2014, Pethybridge *et al*. 2014, Pattridge 2016, Happel *et al*. 2017).

1.3. Objectives and Hypotheses

The main objective of my study was to determine predator-prey interactions in Cayuga Lake using fatty acid signatures. Specifically, lake trout interactions with alewife and round goby were examined through species FAS comparison. Due to the underrepresentation of rainbow smelt in my sampling efforts, I omitted them from my study. Observation of stomach contents in predators and historical data have indicated how fluctuation in prey availability and diversity affect food web dynamics among salmonids (Brandt 1986). The use of fatty acids brings a new perspective to our understanding the feeding ecology of one of Cayuga Lake's top predators.

The specific objectives and hypotheses of my study included:

1. Establish FAS of alewife and round goby and evaluate interspecies differences. This step was critical because if the FAS of both species are similar, they could not be used to assess predator-prey interactions.

Ho: FAS between prey will be similar.

Ha: FAS between prey will be significantly distinct.

2. Evaluate potential spatio-temporal difference in FAS within each prey species. If spatio-temporal differences in FAS existed within each species and were larger than interspecies differences, time and location would need to be considered when assessing predator-prey interactions.

Ho: FAS within each prey species will not be significantly distinct spatially (Taughannock Falls State Park, Deans Cove State Boat Launch, Long Point State Park, and Myers Park) and temporally (Spring, Summer, and Fall).

Ha: FAS within each prey species will be significantly distinct spatially (Taughannock Falls State Park, Deans Cove State Boat Launch, Long Point State Park, and Myers Par) and temporally (Spring, Summer, and Fall).

3. Determine FAS of lake trout and compare them to FAS of each prey fish species.

Ho: FAS can be used to assess diet of lake trout in Cayuga Lake.

Ha: FAS cannot be used to assess diet of lake trout in Cayuga Lake.

2. Materials and Methods

2.1. Prey Fish

Prey fish (alewife and round goby) were captured for lipid and fatty acid analyses at four nearshore locations (Deans Cove State Boat Launch, Taughannock Falls State Park, Myers Park, and Long Point State Park) along Cayuga Lake (Figure 2) throughout the year (Fall 2014, Spring, Summer, and Fall 2015). Most fish were collected at or after dusk (time varied with season; 19:00 Fall and 21:00 Spring and Summer), except for a few midday sampling trips in the late Spring and early Summer of 2015. Collections were conducted using seine nets. Seines 25 and 10 m in length were dragged perpendicular to shore for 50 m. The nets were pulled to shore and picked

for alewife and round goby between each haul; each species was sorted into plastic bags and placed on ice. Once sampling was completed, all fish collected were transported back to the lab and stored at -80°C until further processing and biochemical analysis. Prey were thawed, measured (mm), weighed (g), and sexed (when possible) before chemical analysis.

2.2. Lake Trout

Thirty lake trout (15 males and 15 females) were sampled in Fall 2014 and 2015 during the annual NYSDEC lake trout egg take at Taughannock Falls State Park. Five monofilament gill nets were set just off the bottom, perpendicular to shore, in approximately 30 m of water. Each net was 45.72 m long with a 15.24 cm bar. Nets were set at dusk, left overnight, and pulled at 07:30 to avoid overstressing captured fish. Pulled nets were racked into lugs as the fish were picked out and placed in aerated live wells. Immediately upon capture, lake trout were sexed by gently pressing the belly to indicate the presence of eggs or sperm. If gametes were observed, fish were killed and kept until 15 of each sex were collected. Two large coolers with ice were used to hold and chill the lake trout as they were collected and transported back to the lab for processing.

Upon arrival at the lab, the lake trout were individually weighed (g) and measured for standard and total length (mm). Scales, stomachs, and belly flap tissue were collected for aging, diet analysis, and lipid/fatty acid analysis, respectively.

2.2.1. Condition factor

The condition factor (K) of each fish was calculated using the formula, $K = 100 \times W / L^3$, where W is the weight (g) and L is the total length (cm) (Nash *et al.* 2006).

2.2.2. Age

Scales, stored in envelopes, were washed, pressed between two microscope slides, and examined under an inverted microscope (Bausch and Lomb Optical Co., Rochester, NY). The scales were read at low magnification (4X). After visually scanning a representative sample of the mounted scales, a clean, clear scale from each fish was selected and annuli (year markings) were counted to determine the age of each fish.

2.2.3. Stomach Content Analysis

Stomachs were preserved in 70% isopropanol before analysis. Prey items were identified to the lowest possible taxonomic level using a dissecting microscope. Although no key was used for identification; the shape, color, and size of remains found in stomachs were indicative of each species identified. The mass (g) of fish remains was measured and all other identifiable contents were tallied.

2.3. Fatty Acid Analysis

Prior to grinding, the skin from the lake trout belly flap was removed. Belly flaps were processed in a coffee grinder (Jarden Corporation, Rye, NY) for approximately 1 min or until pasty in consistency. The same grinding procedure used for the prey fish, except that whole fish were processed. The homogenized tissues were collected and stored in plastic test tubes at -80°C before biochemical analysis. The grinder was cleaned thoroughly between each sample to assure quality control.

2.3.1. Lipid Extraction

A weighed amount of ground sample was placed in threaded glass test tubes for lipid extraction. Each sample tube received a 20 mL aliquot of solvent mixture (2:1 chloroform-methanol with 0.01% butylated hydroxytoluene) to begin the extraction (Folch *et al.* 1957).

Each tube was sealed with a lid and placed in a cooler of ice. Using a PowerGen 500 homogenizer (Fisher Scientific, Waltham, MA) or an Omni International General Laboratory Homogenizer (GLH) 850 (Omni International, Kennesaw, GA), the ground tissue and solvent mixture in each tube was homogenized (at speed setting 4) on ice for one minute, recapped, and stored back in the ice cooler. The probes were rinsed four times between each sample to ensure no cross contamination; twice in beakers containing deionized (DI) water and twice in the solvent mixture, respectively. The rinsing beakers were replenished with fresh water and solvent regularly to assure proper probe cleaning. Each sample was then vacuum filtered through 1 μm Whatman filters (Whatman International Ltd., Piscataway, NJ) and rinsed with solvent to separate the tissue from the lipid containing solvent. The filter was discarded and filtrate was transferred to larger threaded glass tubes and 4 mL of magnesium chloride hexahydrate solution (6 g $MgCl_26H_2O$ in 1000 mL DI water) was added. Each tube was filled with nitrogen gas (N_2), capped, vortexed for one minute, refilled with N_2 gas, sealed, and stored under the fume hood overnight. Then using a Pasteur pipette, the organic layer (bottom layer) was transferred to a clean threaded tube and evaporated under N_2 in a warm water bath (30-35°C). The lipid extract, free of water, was transferred into pre-weighed threaded test tubes. The solvent mixture was continuously evaporated under N_2 until only the lipid remained. Using an analytical balance, the initial tube weight (g) subtracted from the final weight plus lipid (g), yields the total weight of lipid. The total lipid content in percent (%) was determined and expressed as the percentage of the total sample wet weight.

2.3.2. Fatty Acid Transmethylation

The lipid extract was subject to the transmethylation process before analysis using gas chromatography/mass spectrometry (GC/MS) (Metcalfe and Schmitz 1961). Fatty acid

methyl esters (FAMEs) were made by chemically cleaving the hydroxyl group from the terminus of each fatty acid chain and adding methyl groups. Nonadecanoic acid (19:0) was used as the internal standard and added to each sample based on the amount of total lipids present (8 mg/50 mg of lipids). Total lipids were subject to saponification using 1.5 mL of sodium hydroxide (NaOH 0.5 M in methanol) and 1 h incubation at 80°C. This effectively adds a hydroxyl group to the carboxyl terminus of each lipid molecule. After cooling to room temperature, 2 mL of borontrifluoride methanol was added, replacing hydroxyl groups with a methyl groups. Each threaded sample tube was filled with N_2, capped, incubated for 30 min at 80°C, and allowed to cool to room temperature. One mL hexane was added to each tube, then the tubes were capped and vortexed. One mL DI water was then added to each tube, and the tubes were capped and vortexed again. The hexane phase was transferred by Pasteur pipette into a clean, covered, threaded tube containing a small amount of anhydrous sodium sulfate. To ensure the complete transfer of all fatty acids in the supernatant, an additional 1 mL of hexane was added; the tubes were capped, vortexed, and transferred into each corresponding vial. After vortexing 20 s, the hexane phase was transferred to 4 mL threaded vials previously rinsed with hexane, leaving the anhydrous sodium sulfate as waste. The transmethylated samples were then stored at -80°C until gas chromatogram/mass spectrometer (GC/MS) injection.

2.3.3. Gas Chromatography/Mass Spectrometry Analysis (GC/MS)

Fatty acid profiling was completed using an Agilent Technologies 7890A GC system with Agilent Technologies 7693 Autosampler and Agilent Technologies 5975C inert XL EI/CI MSD with Triple-Axis detector (Agilent Technologies, Inc., Santa Clara, CA). The capillary column used was an Omegawax 250 Fused Silica Capillary Column with 30 m x 0.25 mm x

0.25 μm film thickness (Supelco, Bellefonte, PA). Helium was used as a carrier gas. The oven ramp temperature was programmed for 175°C to 205°C, increasing 2°C per min over 26 minutes, and then held at 205°C for 24 min. The flow rate of helium carrier gas was 1.8 mL per min. The source and analyzer temperature of the MS was set at 230°C. The individual fatty acid methyl esters (FAMEs) were identified by comparing the retention times of authentic standard mixtures (FAME mix 37 components, Supleco) with known spectrographic patterns of FAMEs. Spectrographic patterns for FAMEs were attained from the NIST Mass Spectral Library provided with the GC/MS and the American Oil Chemists' Society (AOCS) mass spectral library provided at http://lipidlibrary.aocs.org/index.html. Individual FAMEs were identified by their retention times and their peak areas were quantified in proportion to that of the internal standard. The composition of each was calculated and reported as a percentage of the total FAMEs.

Quality assurance was implemented by maintaining a strict protocol that remained consistent with all individuals involved in the project; it included recording all procedures and data in detail, as well as specific quality control measures like the use of a blank when running the GC/MS. Blanks consisting of pure hexanes were injected every 15 samples to assure the column remained clean and chromatograms recorded an even baseline without static. Predetermined retention times and expected peak areas were utilized to identify unique FAMEs. Any shifts in retention times were noted and adjustments were made manually to correct for the column breaking down over time. After the initial integration and peak area calculations, the data were reviewed multiple times to ensure accuracy.

2.4. Statistical Analysis

Univariate and multivariate statistical methods were used to analyze inter- and intra-specific variation between prey species lipids and FAS based on time of the year (Spring/Summer/Fall) and sample site (Deans Cove State Boat Launch, Taughannock Falls State Park, Myers Park, and Long Point State Park). Data collected for seasons and sites were initially grouped by species for each site during each season (i.e. alewife; Taughannock and Spring). Although pseudoreplication is present, data were tested for differences and combined at the seasonal and site levels to compare (average lipid and FAS) differences within prey species. To further explain, all the sites were combined per collection season (Spring - Deans Cove, Taughannock, Myers Park, and Long Point; Summer - Deans Cove, Taughannock, Myers Park, and Long Point; Fall - Deans Cove, Taughannock, Myers Park, and Long Point) to compare average seasonal data within each prey species. The same was done regarding the site comparisons; sites were compared based on the average of all seasonal data within each species (Deans Cove - Spring, Summer, and Fall; Taughannock - Spring, Summer, and Fall; Myers Park - Spring, Summer, and Fall; Long Point - Spring, Summer, and Fall).

Yearly variation (Fall of 2014 and 2015) in lake trout lipid and FAS were assessed and ultimately FAS similarities between prey and lake trout were evaluated. Statistical analyses were performed with IBM SPSS Statistics 23 (International Business Machines Corp., Armonk, NY) and PRIMER v6 (Primer-E, Plymouth, U.K.) using arcsin transformed lipid percent data and untransformed data from 27 unique fatty acids expressed as percentage of the total FA detected.

Assumptions (normality and homogeneity of variance) were not met for a parametric T test, so a non-parametric Mann-Whitney U test was performed using SPSS to compare the lakewide average % lipids (± standard deviation) between round goby and alewife. Significance of a Mann-Whitney U indicated a difference between the species' average % lipids ($P < 0.05$).

Independent spatio-temporal (4 sites and 3 seasons) comparisons for each alewife and round goby samples using Kruskal-Wallis tests as a non-parametric alternative to 3-way ANOVA. Tamhane's post-hoc test was used to explain significant mean lipid % differences within each species (among sites and seasons). Independent sample T tests (SPSS 23) were used to compare lake trout lipids, length, weight, age, and condition factor between years; the t test is significant when $P < 0.05$, rejecting the null hypothesis of no significant difference between years.

Using Bray-Curtis matrices, non-metric multidimensional scaling (nMDS) was used to visually assess FAS groupings within and between prey species and between lake trout collection years. After unique FAS between prey species were determined, a second nMDS was created comparing the prey species to lake trout. Stress values (nMDS) are indicative of how dependably the high-dimensional relationships among the samples are represented in ordinal plots; lower stress values (< 0.2) represent higher dimensionality with low prospect of misinterpretation. Shepard diagrams (Dr. Jacques Rinchard, Multivariate Statistics Course, Spring 2016) were made to visually asses the stress levels of the nMDS analyses, where point departure from the best fit regression line represents increasing stress.

Non-parametric, one-way analysis of similarities (ANOSIM) were used to assess differences in FAS between prey species (alewife and round goby), and then between prey species and lake trout, assuming differences between prey. ANOSIM uses a Bray-Curtis resemblance matrix based on untransformed data and is described by a Global R value at a significance level of 0.001; the closer the R value is to 1, the more distinction there is within clusters at that significance level. The difference rule used for interpreting R values was as follows: $0.75 < R < 1$ - highly different; $0.5 < R < 0.75$ - different; $0.25 < R < 0.5$ - different with some overlap; $0.1 < R < 0.25$ - similar with some differences (or high overlap); and $R < 0.1$ – similar.

FASs were analyzed using SIMPER (similarity percent) analysis to assess which fatty acids contribute more to the similarity/dissimilarity within and between species. SIMPER analysis outputs provide average (%) of fatty acid contribution to the total fatty acid signatures. For example, Table 3 shows fatty acid 18:1n-9 contributing 18.82 % to alewife FAS and 11.03% to round goby FAS, this fatty acid contributed 18.66% to the overall FAS comparison and had the most difference between the two species (4.03% dissimilarity).

3. Results

3.1. Prey Fish

A total of 255 alewife and 448 round goby were collected from the four sites (Deans Cove State Boat Launch, Taughannock Falls State Park, Myers Park, and Long Point State Park) along Cayuga Lake in Fall 2014, Spring, Summer, and Fall 2015 (Tables 1 and 2). Data from Fall 2014 and 2015 were combined for alewife and round goby in both tables and for statistical analyses because neither species were significantly different (Appendix 1).

3.1.1. Interspecies Variations in Lipid and FAS

i. Prey Lipid Analysis

For all samples collected lake-wide, the whole-body lipid content was significantly higher in alewife than round goby (5.7 ± 2.5% vs. 3.1 ± 1.2%; Mann-Whitney U test: $U = 19.666$, $df = 1$, $P < 0.05$). Spatial and seasonal differences between mean % lipid content of the two species are shown in Figures 3, 4, and 5. There was no difference between 2014 and 2015 average lipid % for each species in the Fall, so the two years were combined (Appendix 1). In both species, lipid content varied among season and location but Fall samples contained significantly higher lipid content (Kruskal-Wallis; $H = 31.949$, $df = 2$;

$P < 0.05$ and $H = 19.287$, $df = 2$, $P < 0.05$ for alewife and round goby, respectively). Significantly higher lipid content was found in alewife collected from Taughannock and round goby from Deans Cove (Kruskal-Wallis; $H = 14.984$, $df = 3$, $P < 0.05$ and $H = 20.714$, $df = 3$, $P < 0.05$ for alewife and round goby, respectively). Although there were some significant differences in lipid content among season and location, the difference between species was more substantial.

ii. Prey FAS Analysis

Twenty-seven fatty acids were routinely identified and quantified in both prey species (Tables 1 and 2). The most abundant fatty acids were generally similar between species, but at highly variable concentrations. Saturated fatty acids were predominantly represented by palmitic acid (16:0), whereas monounsaturated fatty acids were mostly represented by palmitoleic acid (16:1n-7) and oleic acid (18:1n-9). Among polyunsaturated fatty acids, most dominant were docosahexaenoic acid (DHA or 22:6n-3), eicosapentaenoic acid (EPA or 20:5n-3), arachidonic acid (ARA or 20:4n-6), linoleic acid (18:3n-3) and linolenic acid (18:2n-6).

Fatty acid signature significantly differed between both species (ANOSIM, overall $R = 0.596$, $P < 0.05$). Therefore, fatty acid profiles clustered based on species in nMDS space (Figure 4). Similarity between fatty acid signatures within species reached 89.8 and 83.6% for alewife and round goby, respectively, whereas FAS dissimilarity reached 21.6% (SIMPER analysis, Table 3). The primary fatty acids responsible for the dissimilarity between species were 18:1n-9, 22:6n-3, 20:5n-3, 16:1n-7, and 18:3n-7. These fatty acids make up > 50% of differences in abundance between alewife and round

goby. The content of 18:1n-9 was much higher in alewife than in round goby, whereas round goby had higher percentages of 22:6n-3, 20:5n-3, 16:1n-7, and 18:3n-3.

3.1.2. Intraspecies (Spatio-Temporal) Variations FAS

i. Alewife Spatio-Temporal FAS Analysis

Spatio-temporal grouping within alewife FAS show slight (insignificant) seasonal differences and no significant spatial differences in FAS (ANOSIM (for interpretation refer to methods: section 2.4, paragraph 4); overall $R = 0.266$ and 0.037, respectively, $P > 0.001$). Tables 4 and 5 and Figures 4 and 5 show what seasons were responsible for minor differences in seasonal alewife FAS. Although there were no significant FAS differences seasonally or spatially, Tables 6 and 7 contain the five most influential fatty acids, respectively. Similarity within seasons and sites for alewife FAS were all close to 90 % (Table 6 and 7). Any spatial and seasonal overlapping within alewife samples were insignificant compared to FAS dissimilarities between prey species (Table 12 and Figure 8).

ii. Round Goby Spatio-Temporal FAS Analysis

Spatio-temporal grouping within round goby FAS show significant seasonal differences, but no significant spatial differences (ANOSIM; overall $R = 0.653$ and 0.065, $P < 0.001$ and $P > 0.001$, respectively. Tables 4 and 5 and Figures 6 and 7 show how seasonal differences contributed to combined difference within round goby FAS. Significant seasonal differences were characterized by three groups of five abundant fatty acids (Tables 8a, 8b, and 8c), making up about 50% of signatures: Fall and Spring, Fall

and Summer, and Spring and Summer with 17.7, 20.6, and 17.2% dissimilarities, respectively (SIMPER analysis, Tables 8a, 8b, and 8c). Although no spatial difference was found in round goby FAS, Table 9 contains the five most influential fatty acids samples based on location. Similarity among round goby FAS within Deans Cove, Long Point, Myers Park, and Taughannock were 84.8, 83.3, 84.8, and 83.4%, respectively (SIMPER analysis, Table 9). Although there was seasonal variation in fatty acid signatures, the differences were insignificant, as compared to dissimilarities between prey species (Table 12 and Figure 8).

3.2. Lake Trout

A total of 60 lake trout were collected in the Fall from Taughannock; 30 in 2014 and 2015 (15 males and 15 females for each year). Mean and standard deviation of lake trout length, weight, condition factor (K), and age were determined for each sex and collection year and are reported in Table 10. There was no significant difference in length or weight between lake trout collected in 2014 and 2015 (t test; $t = 1.055$, $df = 58$, $P > 0.05$ and $t = 1.525$, $df = 58$, $P > 0.05$ for length and weight, respectively). Lake trout collected in 2015 were significantly older on average than those collected in 2014 (t test; $t = 6.234$, $df = 58$, $P < 0.05$). The condition factor did not differ significantly between lake trout year classes (t test; $t = -1.234$, $df = 58$, $P > 0.05$). Lake trout stomachs contained different food items: 5 stomachs contained alewife, 10 had lake trout eggs, 1 had eggs and alewife together, 4 contained unidentified bits of tissue, and 39 were empty.

3.2.1. Intraspecific Lake Trout Lipid Comparison

Lake trout collected in 2015 had significantly higher mean lipid % than lake trout collected in 2014 (t test; $t = 5.251$, $df = 58$, $P < 0.5$) (Figure 9 and Table 10).

3.2.2. Intraspecific Lake Trout FAS Comparison

Five abundant fatty acids characterized > 50% of lake trout fatty acid signatures; 18:1n-9, 16:0, 22:6n-3, 16:1n-7, and 20:5n-3 (Table 11). FAS significantly differed between year (ANOSIM; global $R = 0.604$, $P < 0.05$). The dissimilarity between FAS between lake trout sample years was 6.7% (SIMPER analysis, Table 11). The major fatty acids responsible for yearly variation in FAS were 16:0, 18:1n-9, 16:1n-7, 14:0, and 18:2n-6. Lake trout collected in 2014 had higher abundance of 16:0, 14:0, and 18:2n-6 and lower abundance of 18:1n-9 and 16:1n-7 in comparison to 2015 lake trout. FAS difference between years can be seen in the nMDS plot (Figure 10).

3.3. Comparison of lake trout FAS to prey FAS

My data indicate that interspecific differences in FAS between prey species are more substantial than intraspecific spatial or seasonal variation in FAS. Therefore, because prey FAS differ, alewife and round goby can be used to assess the diet of lake trout in Cayuga Lake. There was a significant difference among alewife, round goby, and lake trout FAS (ANOSIM; overall $R = 0.579$, $P < 0.001$, Figure 11). Of three pairwise comparisons among species, lake trout and alewife FAS were most similar (ANOSIM, Table 12). Intraspecific similarity for fatty acid signatures reached 89.8, 83.6, and 94.3% for alewife, round goby, and lake trout, respectively; lake trout and alewife had lesser percent dissimilarity (14.8%) than lake trout and round goby (25.7%) (SIMPER analysis, Tables 13 and 14). The five most influential fatty acids separating alewife and lake trout samples were 18:1n-9, 16:0, 20:5n-3, 22:6n-3, and 16:1n-7; conversely, 18:1n-9, 20:5n-3, 22:6n-3, 16:0, and 18:0 were most influential to discriminate round goby from lake trout. Fatty acids 18:1n-9 and 16:1n-7 were more abundant in lake trout compared to alewife,

which were better represented by 20:5n-3, 16:0, and 22:6n-3. The only fatty acid to have higher abundance in lake trout compared to round goby was 18:1n-9. Overall, alewife has more fatty acid similarity and therefore a more prevalent role as lake trout forage.

4. Discussion

My results support the hypotheses that there are significant differences between the prey species lipid % and [more importantly] FAS, which allows valid comparison of prey and predator FAS. The prey - predator analysis reflected more similarity between alewife and lake trout FAS than for round goby and lake trout.

4.1. Lipids in Prey & Lake Trout

The lipid content in fish gives some insight on comparing the diets within and among trophic levels. It has been noted that lipid content in predatory fish is directly related to that of their prey, and decreased growth rate could be caused by reduced lipid content in prey species. (Madenjian *et al*. 2000).

4.1.1. Prey

The total lipids in alewife (5.7 %) were significantly higher than round goby (3.1%). High lipid content in alewife is common among alewife populations (Czesny *et al*. 2011, Fitzsimons *et al*. 2011, Happel *et al*. 2017). There was a strong similarity between overall lipid % in prey samples collected in Lake Ontario (alewife = 7.7% and round goby = 3.1%) (Happel *et al*. 2017) and those collected from Cayuga Lake. The Cayuga Lake alewife samples I collected were slightly lower in overall lipid % than the Lake Ontario study, whereas round goby had the exact same lipid % overall. The lower lipid % in alewife in my study was likely due to the

lack of samples collected in the Fall sample season. Similar studies indicate a spike in alewife lipid content in the Fall season, potentially due to increased feeding in preparation for Winter months (Madenjian *et al*. 2000, Happel *et al*. 2017).

4.1.2. Lake Trout

Belly flap lipid content differed between sampling years, possibly due to increased age and length of fish collected in 2015 compared to 2014. If lake trout – prey fish interactions continue in similar fashion annually then it makes sense that older and longer fish would contain higher lipid content than younger fish. Compared to a similar study in Lake Michigan, the lipid content of lake trout collected in Cayuga Lake is much higher (Madenjian *et al.* 2000). The lower lipid content of Lake Michigan lake trout could be a consequence of collection date and the prey community dynamics at the time. A more recent study on predatory fish in Lake Ontario showed mean lake trout lipids being higher (34.8%) than those collected for this study (27.2%) (Pattridge 2016). Research suggests high variability in lake trout lipids, depending on lake and the time of collection.

4.2. FAS Comparison: Prey

Positive FAS discrimination between prey was a critical step, preceding interaction assessments between prey and predator. There was very little overlap between species FAS and differences within species had little influence on between species discrimination. Overlap in FAS between alewife and round goby occurred in the Fall; all alewife collected then were juveniles, which suggests that small alewife may compete with goby for similar resources close to the bottom and nearshore. An investigation of what invertebrates inhabit these areas in the Fall could

help explain the interactions and why the overlap occurred. Compared to Happel *et al.* (2017), Lake Ontario prey contained similar contributing (16:1n-7, 18:1n-9, and 22:6n-3) and the same top differentiating fatty acids (18:1n-9 and 16:1n-7) to those in Cayuga Lake sample fish; both studies resulted in 18:1n-9 being highest in alewife and 16:1n-7 in round goby.

4.3. FAS Comparison: Lake Trout

There were FAS differences in lake trout between sampling years (2014 and 2015), possibly due to increasing incorporation of round goby in the diet. The round goby is a relatively new species to the lake (2013) and from year to year, lake trout consumption of round goby may be increasing. The major fatty acid difference between lake trout years was in 16:0, with 14.2% in 2014 and 11.6% in 2015. In my samples, round goby had lower mean % 16:0 than alewife, which could explain the difference between annual lake trout FAS if round goby were more preferred prey. A study by Czesny *et al.* (2011) had similar results for 16:0 abundances in Lake Michigan alewife (19.0%) and round goby (14.7%) compared to my study. The similarity in 16:0 abundance of Cayuga Lake alewife (17.3%) and round goby (16.0%) provides insight on the consistent nature of prey fish signatures across different lakes. I would expect to see similar trends among larger lakes with similar fish assemblages. Conversely, the proportion of 16:1n-7 (the discriminating FA in round goby) increased in lake trout slightly from 6.1% in 2014 to 7.0% in 2015. Fatty acids associated with eating round goby (16:0 and 16:1n-7) caused the major differences between lake trout sample years. FAS comparison results and creel stomach content analyses suggest that round goby has become an increasingly important part of lake trout diet in Cayuga Lake since their introduction.

4.4. FAS Comparison: Prey and Lake Trout

The major prey item for lake trout in Cayuga Lake is still alewife per the FAS analysis, but it is apparent that round goby assimilation is becoming more common. In Lake Ontario, it is accepted that alewife make up a majority of the diet in trout and salmon due to their high lipid content and the abundance of oleic acid (18:1n-9) seen in salmonid species (24.6% in lake trout) (Happel *et al.* 2017). These results also pertain to Cayuga lake trout (18:1n-9 = 24.5%). Additionally, it has been well documented that lake trout consume round goby in Lake Ontario, Lake Huron, and Lake Michigan (Dietrich *et al.* 2006, Rush *et al.* 2012, Happel *et al.* 2017, and Happel *et al.* 2018). Therefore, lake trout in Lake Ontario and Cayuga Lake show a similar ecological pattern, in that they consume a mixed diet of alewife and round goby.

I expect FAS of lake trout in Cayuga Lake to change depending on preferred prey abundance. The decreased numbers of rainbow smelt in Cayuga Lake (with only a total of 5 collected) led to their omission from the study. Now that round goby are well established, it is apparent they have become a part of the lake trout diet. Per Cornell Professor and Finger Lakes fishing guide (John Gaulke) and NYSDEC Biologist (Emily Zollweg-Horan, Region 7), lake trout they caught in Spring and Summer of 2015 had round goby in their stomachs, in contrast to my data for the Fall season of 2014 and 2015. The FAS results did show lake trout collected in 2015 had an increase in the influential fatty acid 16:1n-7, which was most abundant in round goby. An increase in abundance of this fatty acid in lake trout is likely linked to more round goby consumption that sample year. Though there has been much antagonism toward round goby due to their invasive nature, consumption of the species by lake trout help mediate problems caused by thiamine deficiency, potentially improving natural spawning success (Personal Communication, Dr. Jacques Rinchard 2018).

I suspect that the diet of lake trout will continue to change with the round goby becoming a more selected prey, especially if the alewife population diminishes. If the alewife population does crash due to predation, hard winters, and shifting lake productivity as observed in Keuka Lake, then a niche may open in the prey fish population and the predatory fish population may not be sustained (Presentation, Brad Hammers NYSDEC 2018). Further FAS research and prey fish sampling would determine whether new prey fish enter lake trout diet in Cayuga Lake in the future. In Keuka Lake, a smaller Finger Lake west of Cayuga Lake, the alewife population has crashed, due to reduced productivity and harsh winters, so lake trout are feeding mostly on mysid shrimp (*Mysis diluviana*) (Presentation, Brad Hammers NYSDEC 2018, Personal Communication, Dr. Jacques Rinchard 2018). Mysis shrimp found in Keuka, Cayuga, and Skaneateles lakes (Slife 2017), among other invertebrates, could support the introduction of ciscoes (Presentation, Brad Hammers NYSDEC 2018). According to NYSDEC, Keuka Lake's productivity is on the decline; Cayuga Lake is following a similar trend, currently classified as mesotrophic (Makarewicz *et al.* 2007).

In collaboration with NYSDEC, USGS will be reintroducing around 86,000 native cisco back into the lake (My current research position, USGS Tunison Lab of Aquatic Science 2018). The reintroduction of cisco would provide a great opportunity to continue fatty acid research, with the potential for understanding if these fish will provide forage for predatory fish in Keuka Lake. Introducing native forage like cisco back into the Finger Lakes in the absence of alewife could be a good conservation strategy because [if successful] it would build the forage base while promoting native species reintroduction and increasing the potential of restoring natural reproduction of lake trout in the lake. It would be interesting to determine whether cisco will fill the niche vacated by alewife and provide predatory fish in Keuka Lake with a new prey option.

If the restoration of Keuka Lake is successful, restoring native prey species in other Finger Lakes could probably aid in natural reproduction of predatory fish suffering from EMS or Cayuga Syndrome, eventually reducing the need for their stocking.

4.5. Conclusions and Continuation of Research

My study design answered the questions asked in this thesis, but there are ways the sampling process could be improved in a future study with more time and funding. Use of gill nets in the Fall could prove more effective than seines for alewife collection, due to the species' offshore and deep migratory patterns post spawning (late Summer). Gill nets would also be useful if the study were to be expanded to cover the winter season, since Cayuga Lake does not freeze.

Other studies have shown that lake trout – prey fish interactions vary among lakes and seem to depend largely on the availability of preferred prey (Ray *et al.* 2007). Fish are creatures that practice optimal foraging (highest energy content/easiest to catch); any drastic changes in lake trout FAS would provide information on changes in prey availability or abundance, assuming competition and predation remain constant (Milinski 1988). Annual or seasonal shifts in predatory fish FAS might be useful in understanding what is happening lower in the food chain, and how lake trout and other salmonine species adapt feeding habits.

Expanding the study to other Finger Lakes (i.e., Skaneateles and Keuka Lakes) could explain how differing population dynamics of prey species drive FAS variation in lake trout and other predatory fishes. Comparing the Cayuga Lake population to systems lacking alewife, such as Skaneateles Lake and Keuka Lake, may provide new insights about the health and reproductive success of lake trout. This could be especially valuable to state fisheries managers post-cisco

reintroduction into Keuka Lake. Comparing predator species such as Atlantic salmon to lake trout from Cayuga Lake may also be of interest.

In Summary, continuation of this study to monitor the feeding ecology of lake trout in Cayuga Lake would help fisheries managers better understand how to manage future lake trout and other salmonids in Cayuga Lake. Additionally, use of FAS studies in the Finger Lakes could provide additional information on when, where, and how to focus management efforts. Monitoring ecological interactions via continuation of this study could also provide insight on how and when to begin reintroducing of native prey species like cisco into the Finger Lakes.

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Table 1: Morphological characteristics, lipid content, and fatty acid composition of alewife (mean ± standard deviation) collected at four sites (Deans Cove State Boat Launch, Taughannock Falls State Park, Myers Park, and Long Point State Park) along Cayuga Lake in Fall 2014, Spring, Summer, and Fall 2015.

	Spring				Summer				Fall				
	Deans Cove	Taughannock	Myers Park	Long Point	Deans Cove	Taughannock	Myers Park	Long Point	Deans Cove	Taughannock	Myers Park	Long Point	Overall
n	29	30	29	29	30	30	30	30	3	-	15	-	255
Length (mm)	81.5 ± 21.4	112.2 ± 5.4	103.8 ± 11.9	110.3 ± 6.6	109.6 ± 2.9	111.1 ± 5.7	106.6 ± 9.1	108.0 ± 3.0	126 ± 26.5	-	62.2 ± 17.6	-	88.6 ± 18.5
Weight (g)	7.7 ± 6.4	18.4 ± 2.9	14.1 ± 3.8	15.9 ± 2.8	15.8 ± 1.2	18.4 ± 2.5	15.7 ± 2.7	15.8 ± 1.7	27.3 ± 11.2	-	4.7 ± 4.5	-	11.6 ± 5.9
Lipid (%)	4.6 ± 2.4	7.1 ± 2.3	7.4 ± 3.4	6.7 ± 2.6	5.0 ± 1.4	5.9 ± 1.3	4.1 ± 1.4	3.7 ± 1.2	11.5 ± 1.0	-	5.9 ± 1.7	-	5.7 ± 2.5
FA (%)													
12:0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± .0.0	0.1 ± 0.0	0.2 ± 0.1	-	0.1 ± 0.0	-	0.1 ± 0.0
14:0	3.9 ± 1.0	4.6 ± 0.4	4.5 ± 0.7	4.4 ± 0.5	4.3 ± 0.4	4.2 ± 0.3	3.8 ± 0.6	3.7 ± 0.7	4.7 ± 0.4	-	3.8 ± 1.1	-	4.1 ± 0.7
15:0	0.5 ± 0.1	0.4 ± 0.3	0.6 ± 0.1	0.4 ± 0.3	0.7 ± 0.0	0.7 ± 0.0	0.6 ± 0.0	0.6 ± 0.0	0.7 ± 0.0	-	0.7 ± 0.1	-	0.6 ± 0.2
16:0	18.0 ± 1.6	16.2 ± 0.8	16.9 ± 1.1	16.6 ± 1.3	17.6 ± 1.5	17.8 ± 1.5	17.3 ± 1.4	17.8 ± 2.0	18.7 ± 1.2	-	17.6 ± 1.2	-	17.3 ± 1.5
16:1n-9	1.1 ± 0.3	1.1 ± 0.1	1.2 ± 0.2	1.1 ± 0.1	1.2 ± 0.1	1.1 ± 0.1	1.1 ± 0.1	1.1 ± 0.2	1.4 ± 0.1	-	1.0 ± 0.2	-	1.1 ± 0.2
16:1n-7	4.1 ± 1.0	5.0 ± 0.6	4.8 ± 0.8	4.6 ± 0.7	5.5 ± 0.7	5.4 ± 0.6	4.6 ± 0.7	4.7 ± 1.4	6.1 ± 0.9	-	6.5 ± 1.4	-	4.9 ± 1.0
17:0	0.8 ± 0.1	0.8 ± 0.1	0.8 ± 0.1	0.8 ± 0.0	0.9 ± 0.1	0.8 ± 0.1	0.8 ± 0.1	0.8 ± 0.1	0.8 ± 0.0	-	0.9 ± 0.2	-	0.8 ± 0.1
17:1	0.8 ± 0.2	0.8 ± 0.1	0.9 ± 0.1	0.8 ± 0.1	0.7 ± 0.1	0.7 ± 0.1	0.7 ± 0.1	0.7 ± 0.1	0.6 ± 0.0	-	0.7 ± 0.2	-	0.8 ± 0.1
18:0	4.6 ± 0.8	4.1 ± 0.4	4.2 ± 0.7	4.2 ± 0.5	5.2 ± 0.7	4.9 ± 0.4	5.0 ± 0.8	5.4 ± 1.0	4.2 ± 0.3	-	5.0 ± 0.6	-	4.7 ± 0.8
18:1n-9	18.9 ± 3.9	22.1 ± 1.6	21.0 ± 2.6	21.3 ± 2.1	16.9 ± 4.1	17.7 ± 2.9	17.5 ± 3.9	16.9 ± 4.2	21.8 ± 1.9	-	14.9 ± 2.5	-	18.8 ± 3.9
18:1n-7	3.4 ± 0.5	2.9 ± 0.2	2.9 ± 0.3	2.9 ± 0.2	3.4 ± 0.3	3.4 ± 0.2	3.2 ± 0.2	3.1 ± 0.3	3.3 ± 0.0	-	4.6 ± 1.2	-	3.2 ± 0.6
18:2n-6	3.3 ± 0.9	3.9 ± 0.3	3.8 ± 0.9	3.8 ± 0.4	3.9 ± 0.3	3.7 ± 0.4	3.5 ± 0.4	3.5 ± 0.6	4.0 ± 0.5	-	3.9 ± 1.4	-	3.7 ± 0.7
18:3n-3	4.4 ± 1.1	4.8 ± 0.5	5.3 ± 1.0	5.0 ± 0.8	4.8 ± 0.6	5.4 ± 0.6	4.9 ± 0.6	4.4 ± 0.8	6.2 ± 0.4	-	6.2 ± 0.9	-	5.0 ± 0.9
18:4n-3	2.2 ± 0.8	2.0 ± 0.3	2.3 ± 0.6	2.0 ± 0.5	2.3 ± 0.4	2.8 ± 0.6	2.5 ± 0.5	2.1 ± 0.5	2.8 ± 0.4	-	4.4 ± 1.6	-	2.4 ± 0.9
20:0	0.4 ± 0.1	0.4 ± 0.0	0.4 ± 0.1	0.4 ± 0.0	0.4 ± 0.0	0.5 ± 0.0	0.4 ± 0.0	0.5 ± 0.1	0.4 ± 0.1	-	0.3 ± 0.1	-	0.4 ± 0.1
20:1	1.8 ± 0.6	2.7 ± 0.5	2.4 ± 0.6	2.6 ± 0.6	1.9 ± 0.6	2.1 ± 0.7	2.1 ± 0.6	2.0 ± 0.7	2.4 ± 1.0	-	1.3 ± 0.7	-	2.1 ± 0.7
20:2n-6	0.3 ± 0.0	0.4 ± 0.1	0.3 ± 0.0	0.4 ± 0.2	0.3 ± 0.0	0.4 ± 0.0	0.4 ± 0.0	0.4 ± 0.1	0.3 ± 0.1	-	0.3 ± 0.1	-	0.4 ± 0.1
20:3n-6	0.3 ± 0.0	0.3 ± 0.0	0.3 ± 0.0	0.3 ± 0.0	0.3 ± 0.0	0.3 ± 0.0	0.3 ± 0.0	0.4 ± 0.0	0.3 ± 0.0	-	0.3 ± 0.0	-	0.3 ± 0.0
20:4n-6	5.2 ± 1.3	4.2 ± 0.5	4.6 ± 1.0	4.6 ± 0.9	5.3 ± 0.7	4.4 ± 0.4	4.8 ± 0.7	5.3 ± 0.8	3.6 ± 0.4	-	4.1 ± 1.3	-	4.7 ± 0.9
20:3n-3	0.4 ± 0.1	1.6 ± 1.8	0.4 ± 0.1	1.7 ± 2.0	0.4 ± 0.1	0.4 ± 0.1	0.4 ± 0.1	0.4 ± 0.1	0.4 ± 0.1	-	0.4 ± 0.1	-	0.7 ± 1.0
20:4n-3	1.5 ± 0.3	1.5 ± 0.2	1.6 ± 0.2	1.6 ± 0.2	1.5 ± 0.2	1.7 ± 0.1	1.7 ± 0.2	1.6 ± 0.2	1.4 ± 0.1	-	1.7 ± 0.4	-	1.6 ± 0.2
20:5n-3	8.7 ± 1.2	7.8 ± 0.6	8.2 ± 0.7	7.9 ± 0.6	8.1 ± 1.0	8.5 ± 1.0	9.0 ± 1.4	8.4 ± 1.1	8.0 ± 1.4	-	9.6 ± 2.0	-	8.4 ± 1.1
21:5n-3	0.3 ± 0.1	0.2 ± 0.0	0.3 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.3 ± 0.0	0.4 ± 0.1	0.4 ± 0.1	0.2 ± 0.0	-	0.4 ± 0.2	-	0.3 ± 0.1
22:4n-6	0.4 ± 0.2	0.3 ± 0.0	0.4 ± 0.1	0.3 ± 0.1	0.4 ± 0.0	0.3 ± 0.1	0.4 ± 0.1	0.5 ± 0.1	0.5 ± 0.0	-	0.5 ± 0.3	-	0.4 ± 0.1
22:5n-6	1.7 ± 0.4	1.4 ± 0.2	1.5 ± 0.3	1.5 ± 0.3	1.3 ± 0.2	1.2 ± 0.2	1.4 ± 0.1	1.5 ± 0.3	0.8 ± 0.2	-	1.3 ± 0.5	-	1.4 ± 0.3
22:5n-3	2.2 ± 0.3	2.4 ± 0.2	2.3 ± 0.3	2.3 ± 0.2	2.6 ± 0.2	2.3 ± 0.3	2.6 ± 0.3	2.6 ± 0.3	1.9 ± 0.2	-	2.5 ± 0.8	-	2.4 ± 0.4
22:6n-3	10.8 ± 4.2	7.9 ± 1.1	8.1 ± 2.5	8.0 ± 2.4	9.9 ± 2.1	8.7 ± 1.0	10.7 ± 2.2	11.5 ± 3.1	4.5 ± 0.7	-	7.1 ± 1.1	-	9.3 ± 2.8

Table 2: Morphological characteristics, lipid content, and fatty acid composition of round goby (mean ± standard deviation) collected at four sites (Deans Cove State Boat Launch, Taughannock Falls State Park, Myers Park, and Long Point State Park) along Cayuga Lake in Fall 2014, Spring, Summer, and Fall 2015.

	Spring				Summer				Fall				
	Deans Cove	Taughannock	Myers Park	Long Point	Deans Cove	Taughannock	Myers Park	Long Point	Deans Cove	Taughannock	Myers Park	Long Point	Overall
n	28	30	30	22	30	30	30	34	57	62	51	44	448
Length (mm)	70.7 ± 19.5	73.7 ± 20.5	53.8 ± 21.7	52.6 ± 14.1	70.7 ± 19.5	43.6 ± 7.6	46.3 ± 4.7	52.6 ± 14.1	60.3 ± 10.8	55.4 ± 10.7	56.0 ± 10.6	57.8 ± 9.8	58.1 ± 14.2
Weight (g)	11.8 ± 13.9	11.9 ± 10.8	5.6 ± 8.3	12.3 ± 11.5	4.9 ± 3.4	1.9 ± 1.8	2.2 ± 1.0	3.9 ± 5.5	6.2 ± 4.6	4.4 ± 3.0	4.5 ± 2.8	5.0 ± 2.7	5.9 ± 5.6
Lipid (%)	3.6 ± 1.2	3.0 ± 1.5	2.5 ± 0.8	3.3 ± 0.9	2.8 ± 0.7	2.3 ± 0.4	3.0 ± 0.5	2.7 ± 0.7	3.5 ± 1.2	3.1 ± 1.3	3.3 ± 1.5	3.7 ± 1.7	3.1 ± 1.2
FA (%)													
12:0	0.1 ± 0.1	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.1	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.1 ± 0.0	0.1 ± 0.1	0.1 ± 0.0
14:0	2.0 ± 0.4	1.8 ± 0.4	1.3 ± 0.5	2.0 ± 0.6	1.5 ± 0.5	1.4 ± 0.3	1.8 ± 0.6	1.8 ± 0.8	1.9 ± 0.4	1.6 ± 0.4	1.9 ± 0.5	1.9 ± 0.5	1.8 ± 0.5
15:0	0.6 ± 0.2	0.4 ± 0.1	0.5 ± 0.2	0.6 ± 0.2	0.7 ± 0.1	0.4 ± 0.0	0.6 ± 0.2	0.6 ± 0.1	0.6 ± 0.1	0.5 ± 0.1	0.6 ± 0.1	0.6 ± 0.2	0.6 ± 0.2
16:0	15.6 ± 0.9	16.0 ± 0.9	15.8 ± 1.2	17.2 ± 1.0	15.9 ± 1.0	16.9 ± 0.8	15.5 ± 1.5	15.4 ± 0.9	15.6 ± 1.0	17.2 ± 1.1	16.0 ± 1.2	16.0 ± 1.2	16.0 ± 1.3
16:1n-9	0.5 ± 0.1	0.6 ± 0.1	0.4 ± 0.2	0.5 ± 0.1	0.4 ± 0.1	0.8 ± 0.1	0.6 ± 0.2	0.5 ± 0.1	0.5 ± 0.2	0.8 ± 0.1	0.5 ± 0.1	0.5 ± 0.1	0.6 ± 0.2
16:1n-7	9.7 ± 1.7	7.1 ± 1.2	6.1 ± 2.5	8.2 ± 2.7	7.4 ± 2.1	4.4 ± 0.9	7.5 ± 1.9	9.6 ± 2.1	9.2 ± 2.1	5.0 ± 1.6	8.2 ± 1.9	8.0 ± 2.1	7.5 ± 2.5
17:0	0.9 ± 0.2	0.7 ± 0.1	0.6 ± 0.1	0.7 ± 0.2	1.1 ± 0.3	0.6 ± 0.1	0.6 ± 0.1	0.8 ± 0.2	0.9 ± 0.2	0.7 ± 0.1	0.5 ± 0.1	0.9 ± 0.2	0.8 ± 0.2
17:1	1.1 ± 0.4	0.5 ± 0.1	0.6 ± 0.1	1.1 ± 0.5	0.9 ± 0.3	0.5 ± 0.1	0.6 ± 0.2	0.8 ± 0.3	0.9 ± 0.3	0.6 ± 0.1	0.6 ± 0.2	1.0 ± 0.4	0.8 ± 0.3
18:0	5.3 ± 0.8	7.3 ± 0.7	6.6 ± 1.4	5.9 ± 1.3	6.5 ± 1.1	7.0 ± 0.7	5.5 ± 1.5	5.8 ± 1.0	5.9 ± 1.0	6.8 ± 1.1	4.4 ± 1.2	6.4 ± 1.0	6.1 ± 1.3
18:1n-9	12.9 ± 1.4	8.2 ± 0.8	10.1 ± 2.4	10.2 ± 1.8	11.0 ± 2.2	8.8 ± 0.8	11.4 ± 2.2	10.4 ± 1.6	13.1 ± 2.0	9.3 ± 1.3	14.1 ± 2.3	10.8 ± 1.7	11.0 ± 2.5
18:1n-7	6.6 ± 0.8	6.7 ± 0.8	5.2 ± 1.3	5.2 ± 0.8	6.6 ± 1.1	4.4 ± 0.7	4.6 ± 0.8	6.4 ± 1.7	6.6 ± 0.9	4.8 ± 0.9	4.8 ± 0.6	6.6 ± 1.3	5.7 ± 1.3
18:2n-6	4.9 ± 2.1	3.2 ± 0.9	3.0 ± 0.7	5.1 ± 1.0	4.5 ± 1.1	2.1 ± 0.5	3.3 ± 0.6	5.1 ± 1.0	4.9 ± 1.5	2.4 ± 0.8	3.6 ± 0.9	4.7 ± 1.5	3.8 ± 1.5
18:3n-3	5.8 ± 1.4	1.7 ± 0.4	2.0 ± 0.9	6.2 ± 2.2	4.3 ± 1.5	1.7 ± 0.4	2.5 ± 0.9	4.6 ± 1.0	5.8 ± 1.4	2.1 ± 0.8	3.0 ± 0.9	5.5 ± 2.0	3.7 ± 2.1
18:4n-3	1.3 ± 0.6	1.4 ± 0.3	1.0 ± 0.6	1.9 ± 0.8	1.0 ± 0.4	1.3 ± 0.3	1.4 ± 0.5	1.5 ± 0.7	1.7 ± 1.1	1.4 ± 0.4	1.4 ± 0.6	2.2 ± 1.0	1.5 ± 0.8
20:0	0.2 ± 0.1	0.3 ± 0.1	0.3 ± 0.1	0.2 ± 0.1	0.3 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	0.1 ± 0.0	0.3 ± 0.1	0.2 ± 0.1
20:1	1.8 ± 0.6	1.0 ± 0.3	1.6 ± 0.6	1.6 ± 0.7	2.6 ± 1.1	0.6 ± 0.2	1.8 ± 0.6	1.4 ± 0.5	1.6 ± 0.5	0.9 ± 0.4	1.9 ± 0.5	2.1 ± 0.9	1.6 ± 0.8
20:2n-6	0.5 ± 0.2	0.3 ± 0.1	0.6 ± 0.3	0.4 ± 0.2	0.6 ± 0.2	0.3 ± 0.1	0.5 ± 0.1	0.4 ± 0.1	0.4 ± 0.2	0.3 ± 0.1	0.5 ± 0.1	0.5 ± 0.1	0.4 ± 0.2
20:3n-6	0.3 ± 0.1	0.4 ± 0.0	0.3 ± 0.1	0.3 ± 0.1	0.4 ± 0.1	0.5 ± 0.1	0.3 ± 0.1	0.3 ± 0.1	0.3 ± 0.1	0.5 ± 0.1	0.2 ± 0.1	0.3 ± 0.1	0.4 ± 0.1
20:4n-6	5.6 ± 1.0	4.8 ± 0.5	7.7 ± 1.9	5.7 ± 1.7	6.7 ± 1.8	6.0 ± 0.4	7.2 ± 1.1	5.7 ± 1.2	5.3 ± 1.0	6.0 ± 0.9	6.8 ± 1.2	5.6 ± 1.3	6.1 ± 1.4
20:3n-3	0.4 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	0.3 ± 0.1	0.3 ± 0.1	0.3 ± 0.0	0.2 ± 0.1	0.3 ± 0.1	0.4 ± 0.1	0.3 ± 0.1	0.3 ± 0.1	0.4 ± 0.1	0.3 ± 0.1
20:4n-3	0.6 ± 0.2	1.5 ± 0.3	0.4 ± 0.1	0.5 ± 0.1	0.5 ± 0.1	2.1 ± 0.4	0.5 ± 0.3	0.7 ± 0.3	0.7 ± 0.3	1.9 ± 0.5	0.4 ± 0.1	0.7 ± 0.5	0.9 ± 0.7
20:5n-3	12.3 ± 2.5	15.2 ± 1.3	12.5 ± 3.0	13.3 ± 3.3	13.4 ± 2.2	11.5 ± 0.8	10.4 ± 2.0	13.8 ± 2.0	12.7 ± 2.1	11.3 ± 1.4	10.6 ± 1.6	12.4 ± 2.4	12.3 ± 2.4
21:5n-3	0.5 ± 0.2	1.2 ± 1.3	0.6 ± 0.1	0.3 ± 0.0	0.7 ± 0.4	3.8 ± 2.4	0.6 ± 0.2	0.9 ± 1.4	0.7 ± 0.8	2.8 ± 2.8	0.6 ± 0.1	0.4 ± 0.3	1.2 ± 1.7
22:4n-6	0.9 ± 0.3	0.6 ± 0.2	1.1 ± 0.4	0.7 ± 0.2	0.9 ± 0.3	0.6 ± 0.2	1.2 ± 0.4	0.8 ± 0.3	0.7 ± 0.2	0.8 ± 0.4	1.1 ± 0.3	0.8 ± 0.3	0.8 ± 0.4
22:5n-6	1.2 ± 0.7	1.0 ± 0.1	3.1 ± 1.3	1.6 ± 0.8	1.7 ± 0.9	1.5 ± 0.2	3.5 ± 1.0	1.6 ± 0.7	1.1 ± 0.4	1.4 ± 0.4	3.0 ± 0.9	1.6 ± 0.9	1.8 ± 1.1
22:5n-3	4.1 ± 1.1	4.9 ± 0.4	5.6 ± 1.1	4.5 ± 1.0	4.1 ± 0.8	4.2 ± 0.4	5.4 ± 0.7	4.1 ± 0.9	3.9 ± 0.7	4.5 ± 0.6	5.1 ± 0.8	4.1 ± 1.5	4.5 ± 1.0
22:6n-3	4.4 ± 1.7	12.8 ± 2.2	12.8 ± 3.5	5.7 ± 2.5	5.9 ± 2.2	18.2 ± 1.9	12.4 ± 2.9	6.5 ± 2.3	4.3 ± 1.3	15.7 ± 2.7	10.4 ± 2.1	5.7 ± 3.1	9.7 ± 5.2

Table 3: SIMPER analysis to assess similarity (%) and contribution of fatty acids (average abundance) between prey species samples.

Fatty Acid	Alewife Average (%)	Round goby Average (%)	Average Dissimilarity (%)	Contribution (%)	Cumulative Contribution (%)
18:1n-9	18.82	11.03	4.03	18.66	18.66
22:6n-3	9.25	9.67	2.44	11.32	29.98
20:5n-3	8.41	12.28	1.99	9.21	39.20
16:1n-7	4.94	7.49	1.53	7.11	46.30
18:1n-7	3.24	5.69	1.25	5.79	52.09

Table 4: ANOSIM statistics (R) for seasonal pairwise comparisons of FAS in alewife and round goby.

	Alewife	Round Goby
Fall, Spring	0.575	0.561
Fall, Summer	0.461	0.761
Spring, Summer	0.192	0.608

Table 5: ANOSIM statistics (R) for spatial pairwise comparisons of FAS in alewife and round goby.

	Alewife	Round Goby
Deans Cove, Myers Park	0.023	0.098
Deans Cove, Long Point	0.039	0.048
Deans Cove, Taughannock	0.081	0.053
Myers Park, Long Point	0.032	0.125
Myers Park, Taughannock	0.015	0.052
Long Point, Taughannock	0.045	0.023

Table 6: SIMPER analysis to assess seasonal similarity (%) and contribution of fatty acids (average abundance) within alewife samples.

Fall		Spring		Summer	
Similarity	88.45%		90.95%		90.94%
Fatty Acid	Average (%)	Fatty Acid	Average (%)	Fatty Acid	Average (%)
16:0	16.05	18:1n-9	20.84	16:0	17.26
18:1n-9	9.34	16:0	8.16	18:1n-9	8.52
20:5n-3	6.65	20:5n-3	8.69	22:6n-3	10.19
22:6n-3	6.39	22:6n-3	4.64	20:5n-3	5.02
18:3n-3	4.12	18:3n-3	2.12	18:0	2.44

Table 7: SIMPER analysis to assess spatial similarity (%) and contribution of fatty acids (average abundance) within alewife samples.

Deans Cove		Myers Park		Long Point		Taughannock	
Similarity	89.48%		89.29%		89.42%		92.35%
Fatty Acid	Average (%)	Fatty Acid	Average (%)	Fatty Acid	Average (%)	Fatty Acid	Average (%)
16:0	18.06	16:0	18.34	18:1n-9	19.07	18:1n-9	19.94
18:1n-9	10.07	18:1n-9	8.94	16:0	9.77	16:0	8.27
22:6n-3	17.83	20:5n-3	17.18	22:6n-3	17.20	20:5n-3	17.00
20:5n-3	8.40	22:6n-3	8.84	20:5n-3	8.17	22;6n-3	8.15
20:4n-6	4.85	18:3n-3	5.05	20:4n-3	4.66	16:1n-7	5.19

Tables 8a, b, and c: SIMPER analyses to assess seasonal similarity (%) and contribution of fatty acids (average abundance) within round goby samples.

A

Fatty Acid	Fall Average (%)	Spring Average (%)	Average Dissimilarity (%)	Contribution (%)	Cumulative Contribution (%)
22:6n-3	5.27	11.50	3.20	18.15	18.15
20:5n-3	12.91	11.02	1.56	8.83	26.97
18:1n-9	11.58	12.34	1.48	8.40	35.38
18:3n-3	5.37	2.64	1.43	8.09	43.47
16:1n-7	8.71	7.52	1.34	7.61	51.08

B

Fatty Acid	Fall Average (%)	Summer Average (%)	Average Dissimilarity (%)	Contribution (%)	Cumulative Contribution (%)
22:6n-3	5.27	15.62	5.20	25.26	25.26
16:1n-7	8.71	5.35	1.86	9.02	34.29
18:3n-3	5.37	1.89	1.76	8.57	42.85
18:1n-9	11.58	8.93	1.48	7.18	50.03
18:2n-6	4.86	2.53	1.30	6.31	56.35

C

Fatty Acid	Spring Average (%)	Summer Average (%)	Average Dissimilarity (%)	Contribution (%)	Cumulative Contribution (%)
22:6n-3	11.50	15.62	2.49	14.47	14.47
18;1n-9	12.34	8.93	1.91	11.08	25.55
16:1n-7	7.52	5.35	1.47	8.54	34.09
20:5n-3	11.02	12.31	1.32	7.67	41.76
18:0	5.23	6.98	1.08	6.29	48.05

Table 9: SIMPER analysis to assess spatial similarity (%) and contribution of fatty acids (average abundance) within round goby samples.

Deans Cove		Myers Park		Long Point		Taughannock	
Similarity	84.83%		84.84%		83.27%		83.40%
Fatty Acid	Average (%)	Fatty Acid	Average (%)	Fatty Acid	Average (%)	Fatty Acid	Average (%)
16:0	15.85	16:0	15.86	16:0	16.01	16:0	16.16
18:1n-9	12.54	20:5n-3	13.47	20:5n-3	11.21	20:5n-3	12.28
20:5n-3	12.06	18:1n-9	9,85	18:1n-9	11.57	18:1n-9	10.24
16:1n-7	8.11	22:6n-3	9.47	22:6n-3	10.07	22:6n-3	10.62
22:6n-3	8.49	16:1n-7	7.22	20:4n-6	6.34	16:1n-7	7.37

Table 10: Morphological characteristics, belly flap lipid content and fatty acid composition (mean ± standard deviation) of lake trout collected in Cayuga Lakes over the two-year collection.

	2014 Fall	2015 Fall	All
n	30	30	60
Lipid (%)	23.6 ± 4.8	30.8 ± 5.7	27.2 ± 6.4
Length (mm)	648.3 ± 38.3	659.7 ± 45.1	654 ± 41.7
Weight (g)	2603.2 ± 472.2	2812.3 ± 590.6	2707.8 ± 531.4
Age (y)	8.1 ± 1.1	10.1 ± 1.4	9.1 ± 1.3
Condition Factor	1.0 ± 0.3	0.9 ± 0.4	1.0 ± 0.4
FA (%)			
12:0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0
14:0	4.0 ± 0.2	3.1 ± 0.2	3.5 ± 0.5
15:0	0.5 ± 0.0	0.5 ± 0.1	0.5 ± 0.0
16:0	14.2 ± 0.7	11.6 ± 0.7	12.9 ± 1.5
16:1n-9	0.9 ± 0.1	1.2 ± 0.1	1.1 ± 0.2
16:1n-7	6.1 ± 0.7	7.0 ± 1.0	6.5 ± 1.0
17:0	0.5 ± 0.0	0.5 ± 0.1	0.5 ± 0.1
17:1	0.8 ± 0.0	0.7 ± 0.1	0.8 ± 0.1
18:0	3.4 ± 0.2	3.3 ± 0.3	3.3 ± 0.3
18:1n-9	24.3 ± 1.2	24.7 ± 1.4	24.5 ± 1.2
18:1n-7	3.4 ± 0.2	3.7 ± 0.5	3.5 ± 0.3
18:2n-6	4.5 ± 0.3	4.0 ± 1.4	4.2 ± 1.1
18:3n-3	4.7 ± 0.5	4.6 ± 0.5	4.6 ± 0.5
18:4n-3	1.8 ± 0.2	1.8 ± 0.3	1.8 ± 0.3
20:0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0
20:1	2.4 ± 0.2	3.2 ± 1.1	2.8 ± 0.9
20:2n-6	0.6 ± 0.0	0.6 ± 0.1	0.6 ± 0.1
20:3n-6	0.6 ± 0.2	0.6 ± 0.3	0.6 ± 0.2
20:4n-6	4.1 ± 0.1	3.9 ± 0.2	4.0 ± 0.2
20:3n-3	0.6 ± 0.1	0.7 ± 0.3	0.6 ± 0.2
20:4n-3	2.3 ± 0.2	2.4 ± 0.3	2.4 ± 0.3
20:5n-3	5.4 ± 0.4	5.4 ± 0.5	5.4 ± 0.5
21:5n-3	0.3 ± 0.0	0.4 ± 0.0	0.3 ± 0.1
22:4n-6	0.9 ± 0.1	1.3 ± 0.2	1.1 ± 0.2
22:5n-6	1.6 ± 0.2	1.9 ± 0.2	1.8 ± 0.2
22:5n-3	3.5 ± 0.2	4.1 ± 0.3	3.8 ± 0.4
22:6n-3	8.4 ± 0.6	8.5 ± 0.6	8.4 ± 0.6

Table 11: SIMPER analysis to assess similarity (%) and contribution of fatty acids (average abundance) between lake trout sample years.

	2014	2015
Similarity	96.16	94.58
Fatty Acid		
16:0	14.23	11.65
18:1n-9	24.33	24.74
16:1n-7	6.06	7.01
14:0	3.98	3.06
18:2n-6	4.47	3.97

Table 12: The ANOSIM statistics (R) representing pairwise differences between lake trout and each prey species sample's FAS.

Alewife, Lake Trout	0.52
Alewife, Round Goby	0.596
Round Goby, Lake Trout	0.77

Table 13: SIMPER analysis to assess dissimilarity (%) and contribution of fatty acids (average abundance %) among lake trout and alewife.

Fatty Acid	Alewife Average (%)	Lake Trout Average (%)	Average Dissimilarity (%)	Contribution (%)	Cumulative Contribution (%)
18:1n-9	18.82	24.54	2.90	19.54	19.54
16:0	17.30	12.94	2.18	14.73	34.27
20:5n-3	8.41	5.40	1.50	10.15	44.42
22:6n-3	9.25	8.42	1.04	7.03	51.45
16:1n-7	4.94	6.54	0.89	5.99	57.44

Table 14: SIMPER analysis to assess dissimilarity (%) and contribution of fatty acids (average abundance %) among lake trout and round goby.

Fatty Acid	Round Goby Average (%)	Lake Trout Average (%)	Average Dissimilarity (%)	Contribution (%)	Cumulative Contribution (%)
18:1n-9	11.03	24.54	6.75	26.27	26.27
20:5n-3	12.28	5.40	3.44	13.37	39.64
22:6n-3	9.67	8.42	2.26	8.77	48.41
16:0	15.97	12.94	1.56	6.06	54.48
18:0	6.08	3.33	1.39	5.39	59.87

Figure 1: Round goby captured in Cayuga Lake at Taughannock Falls State Park, 26 June 2013.

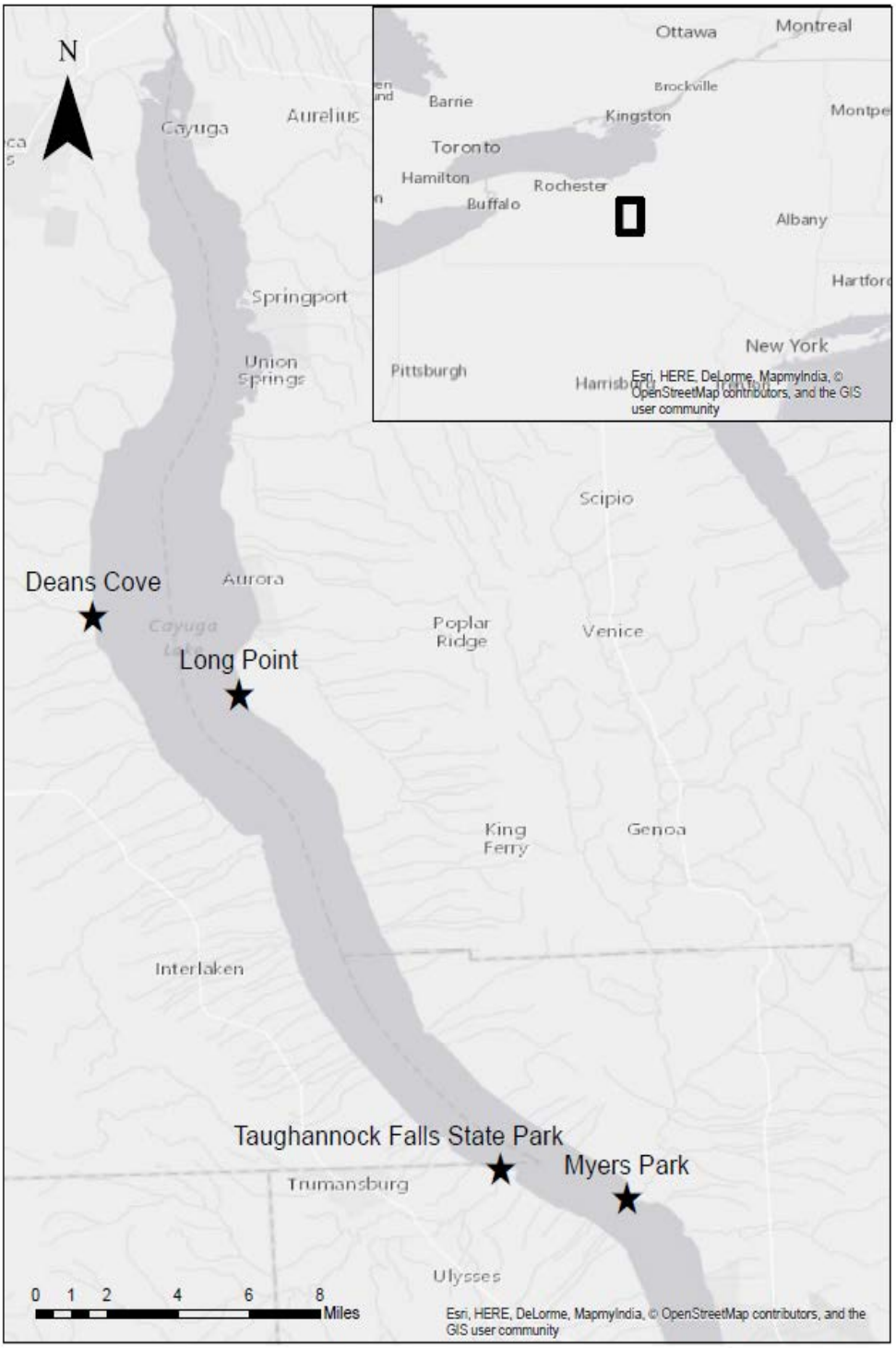

Figure 2: Map of Cayuga Lake and sampling location

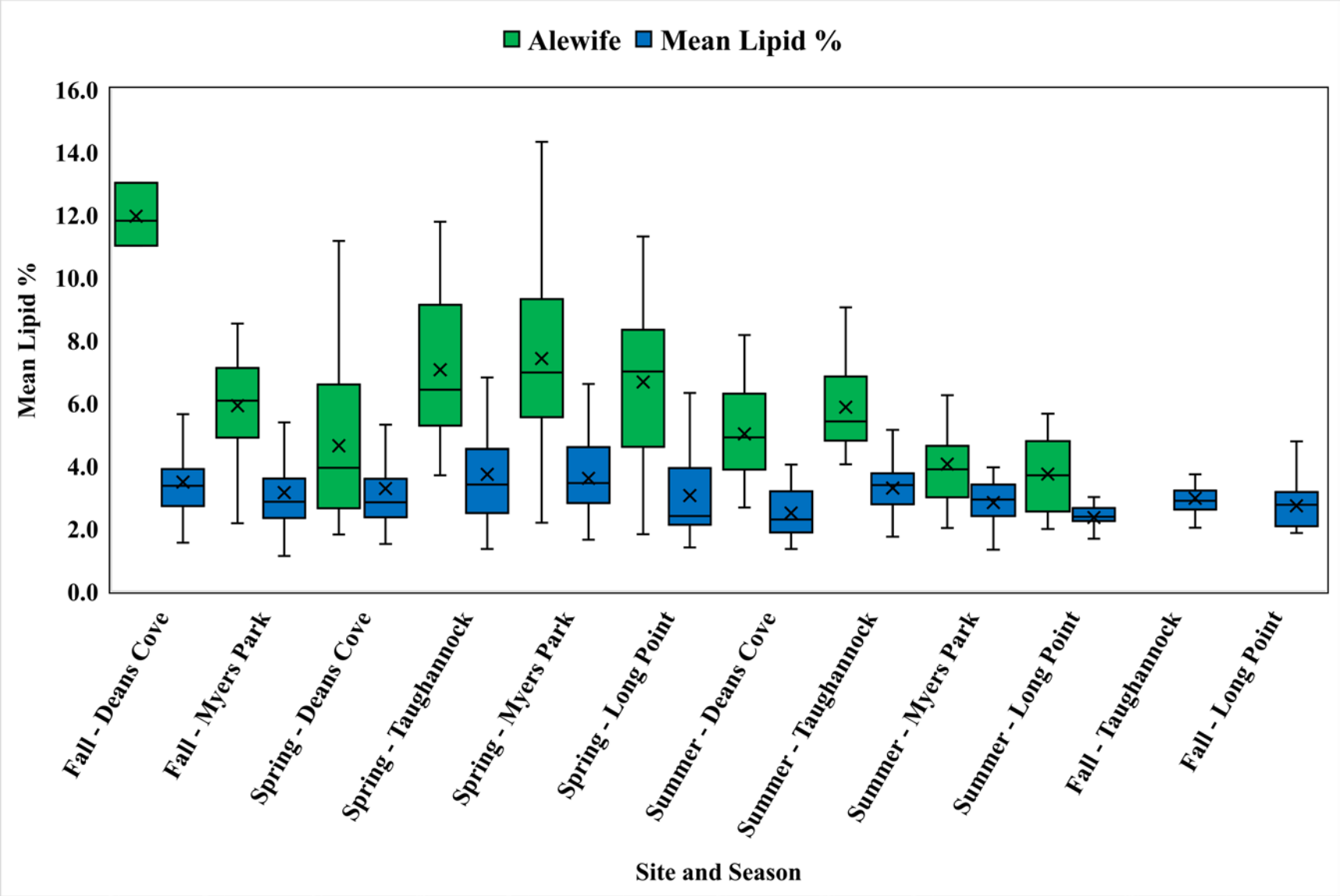

Figure 3a: Box and whisker plot representing alewife and round goby lipid content (%) (max, 1st quartile, median, mean [x], 3rd quartile, and minimum [top-down]) among sites per season.

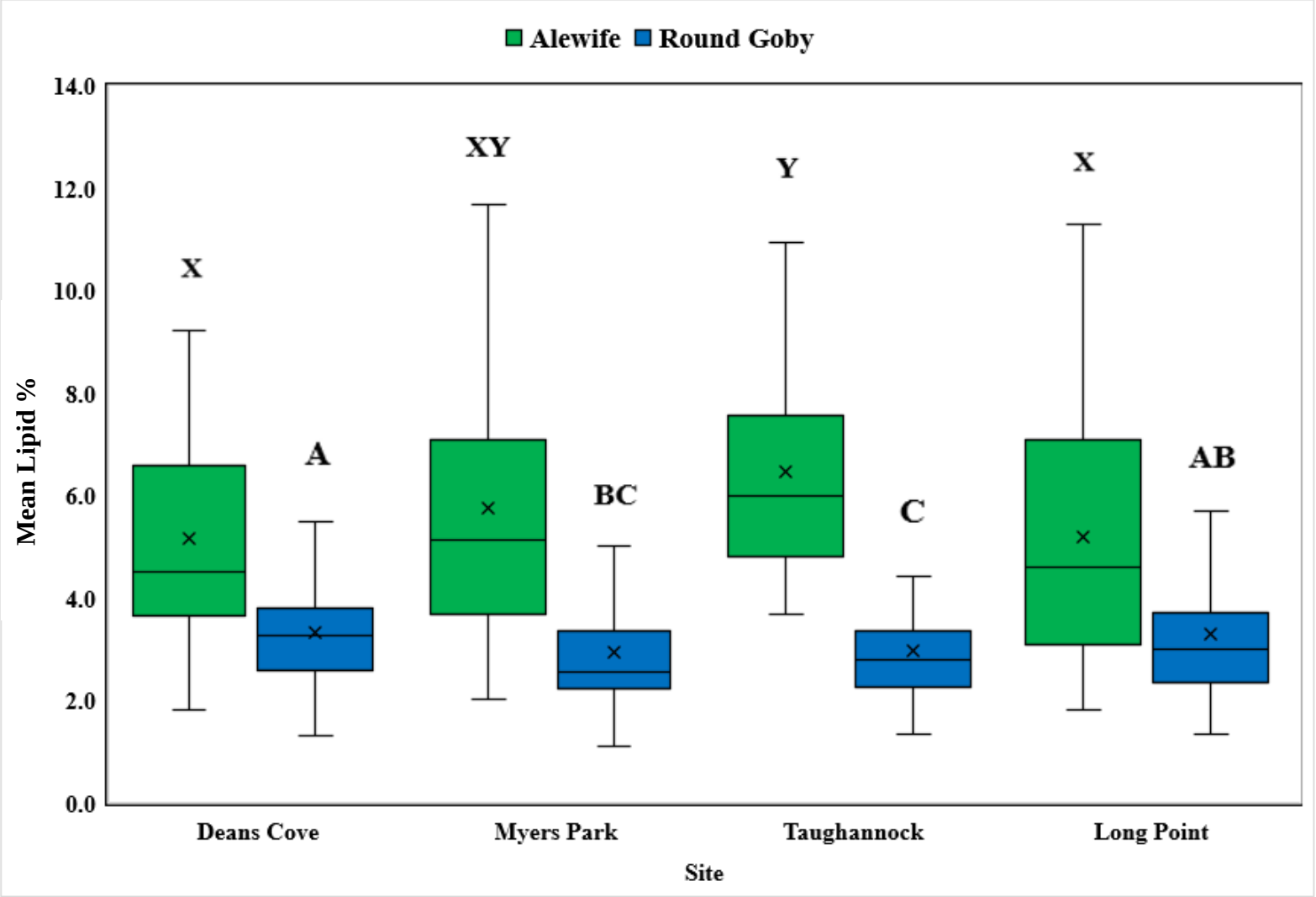

Figure 3b: Box and whisker plot representing differences in mean lipid % of round goby and alewife samples across sites; letters (abc or xyz) represent similarity in mean lipid % when sites share the letter.

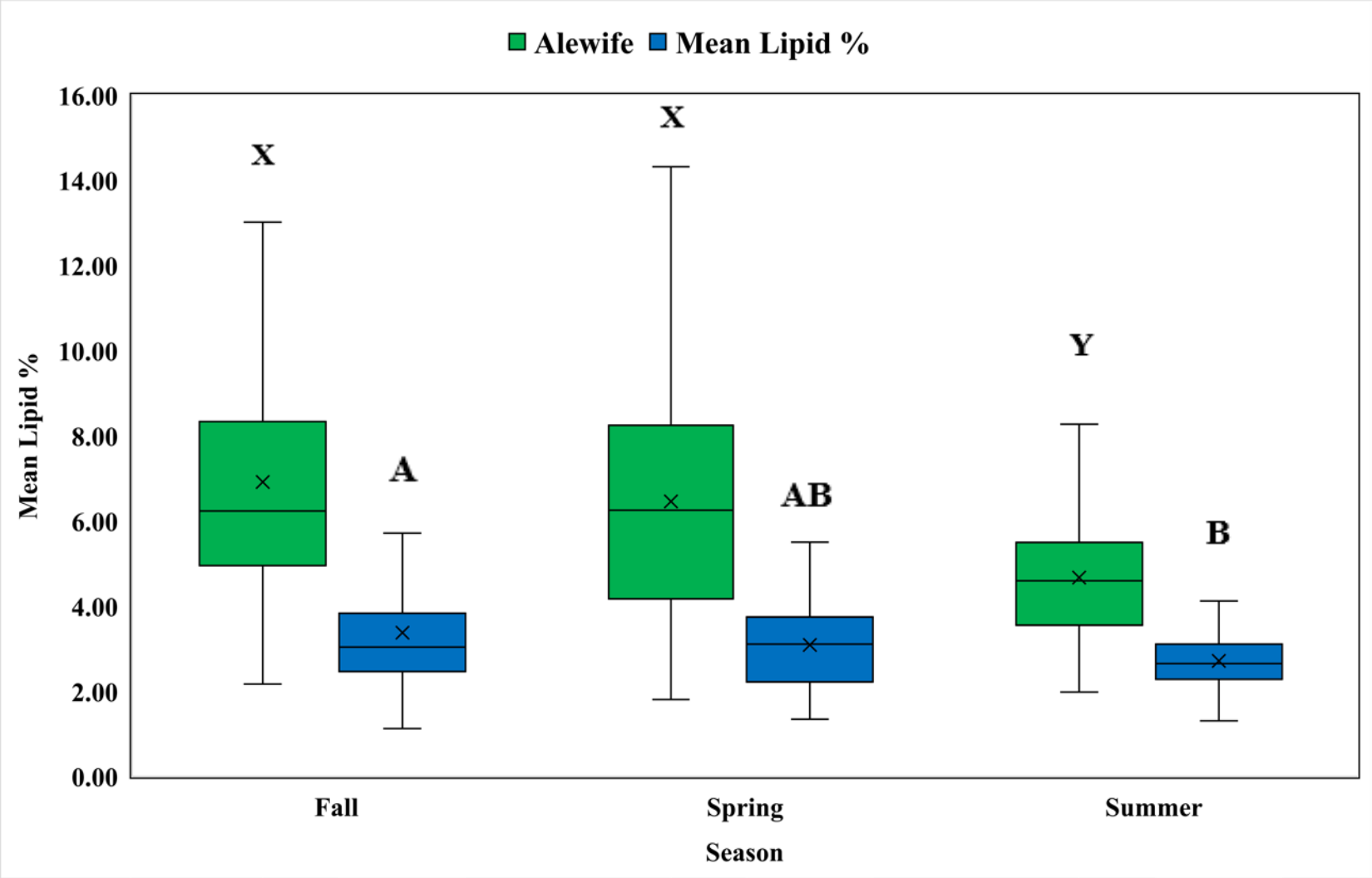

Figure 3c: Box and whisker plot representing differences in mean lipid % of round goby and alewife samples across seasons; letters (abc or xyz) represent similarity in mean lipid % when seasons share the letter.

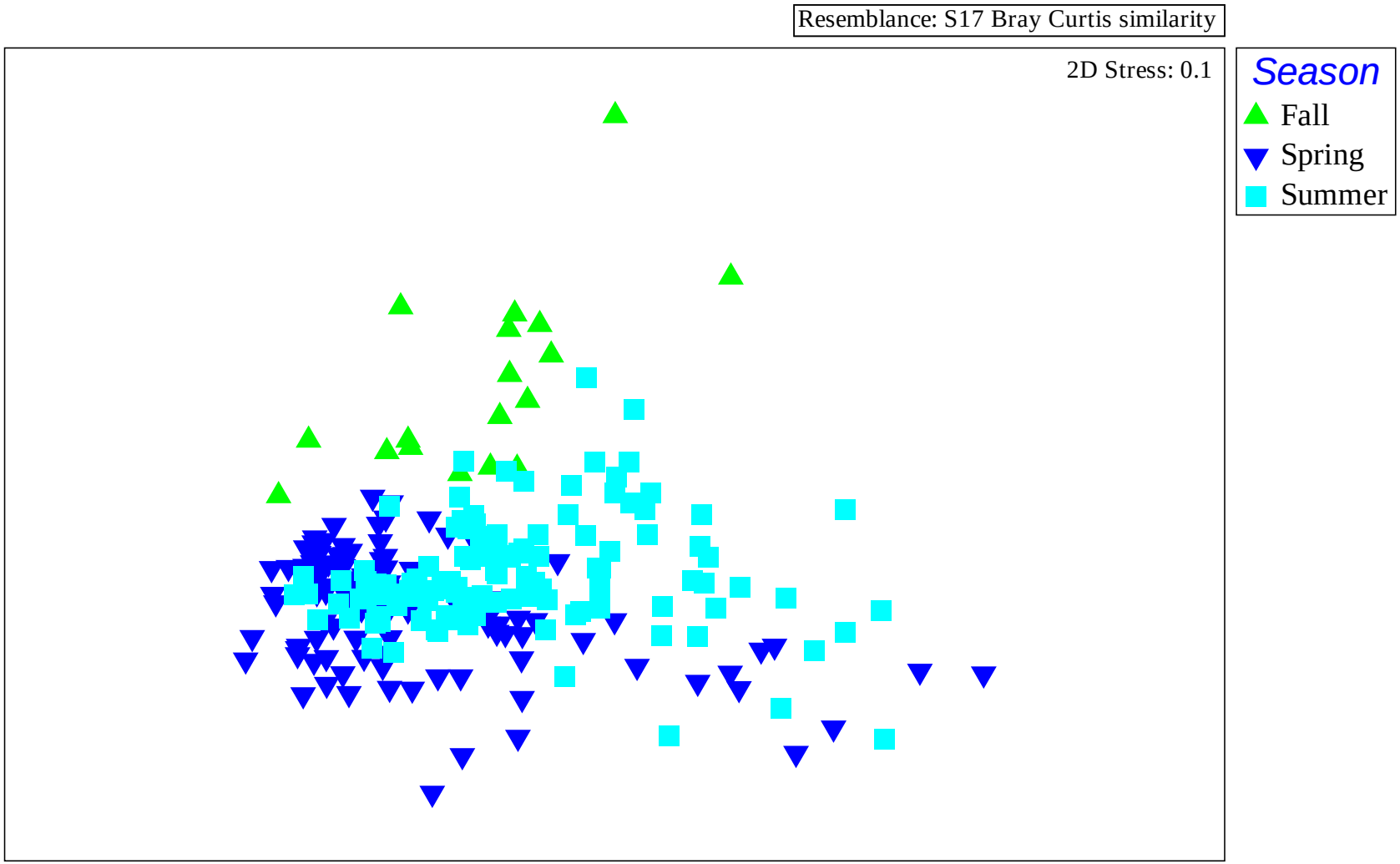

Figure 4: Non-metric Multidimensional Scaling plot (nMDS) of alewife to visually assess fatty acid signatures (FAS) by season.

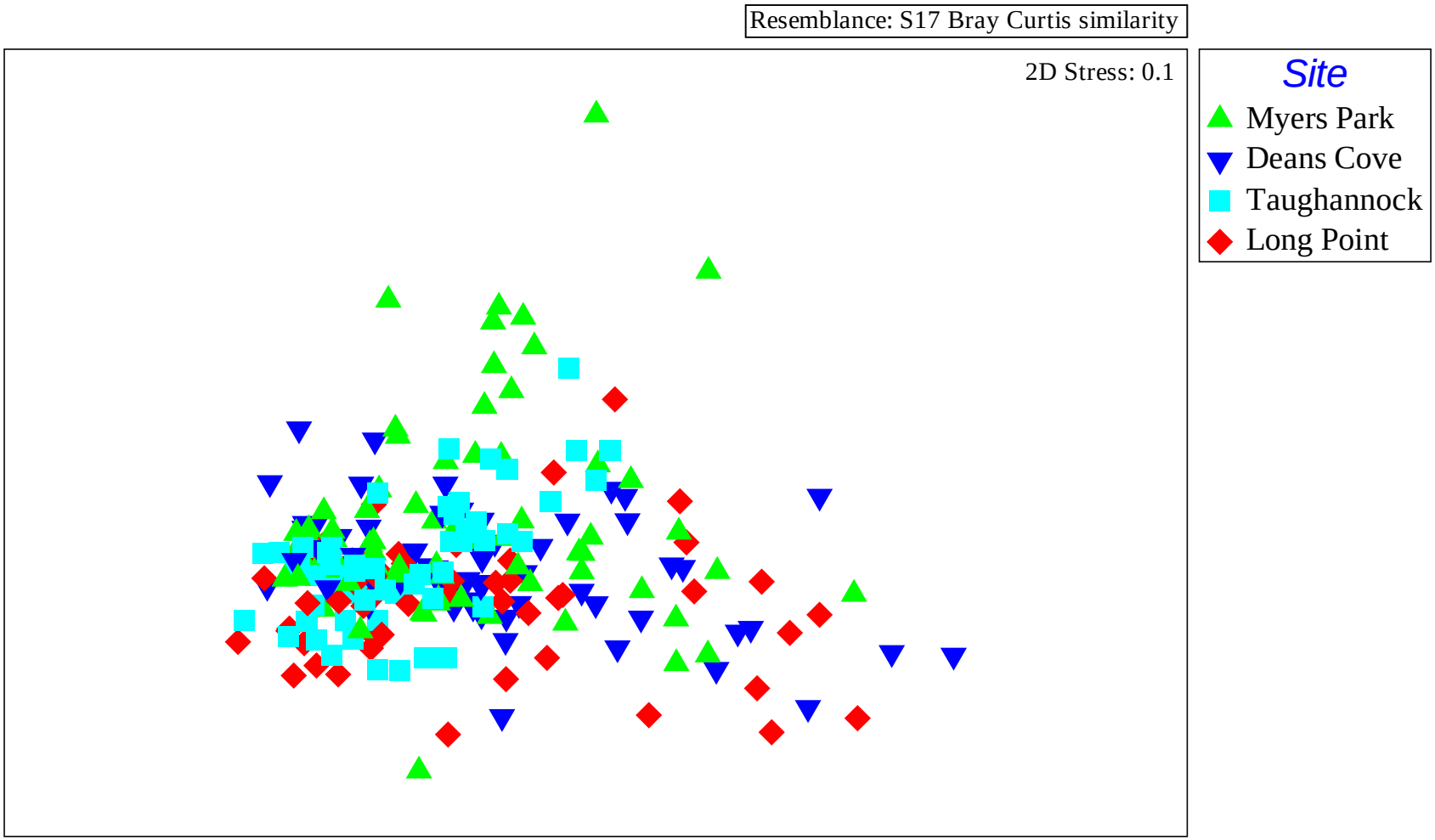

Figure 5: Non-metric Multidimensional Scaling plot (nMDS) of alewife to visually assess fatty acid signatures (FAS) by location.

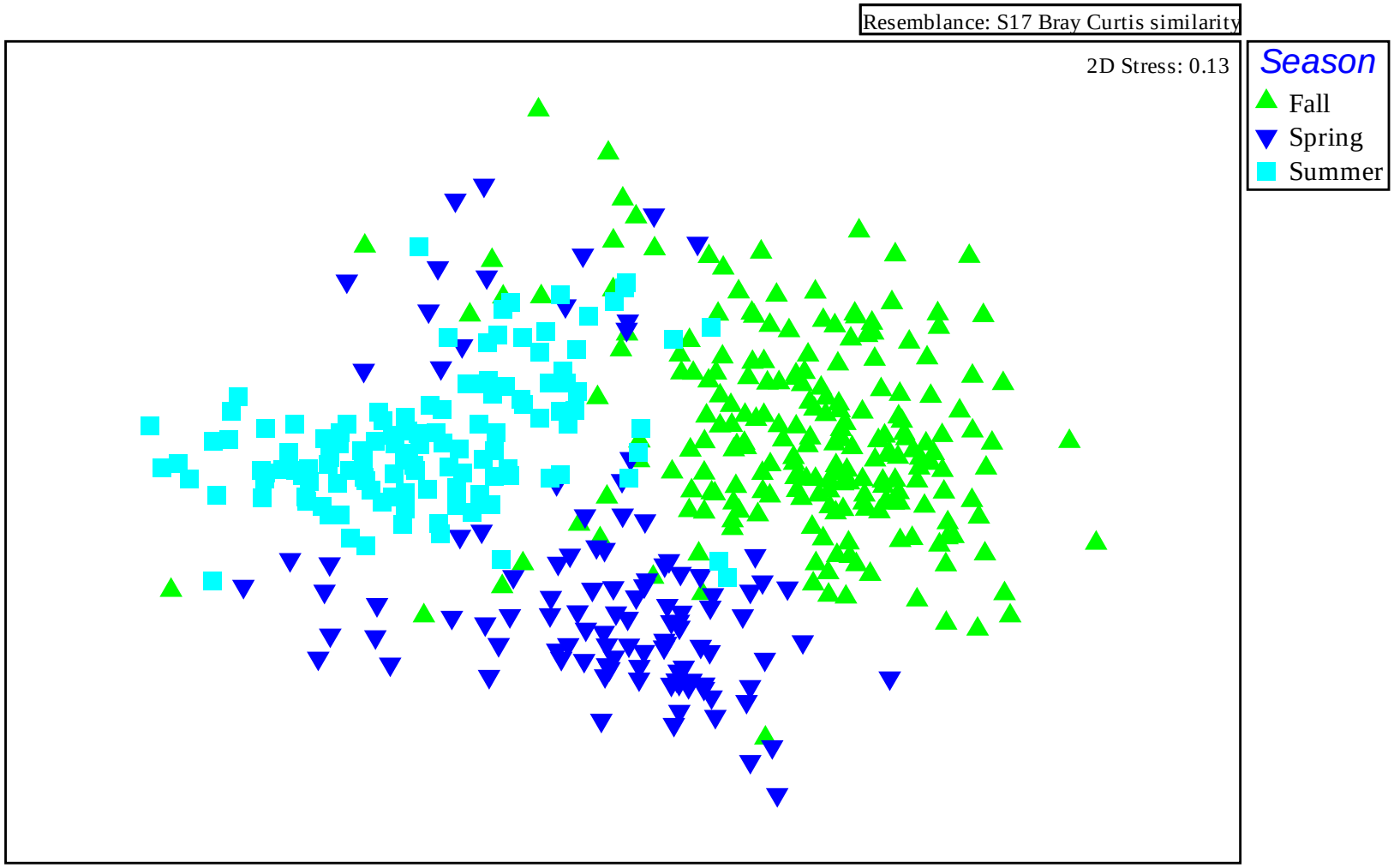

Figure 6: Non-metric Multidimensional Scaling plot (nMDS) of round goby to visually assess fatty acid signatures (FAS) by season.

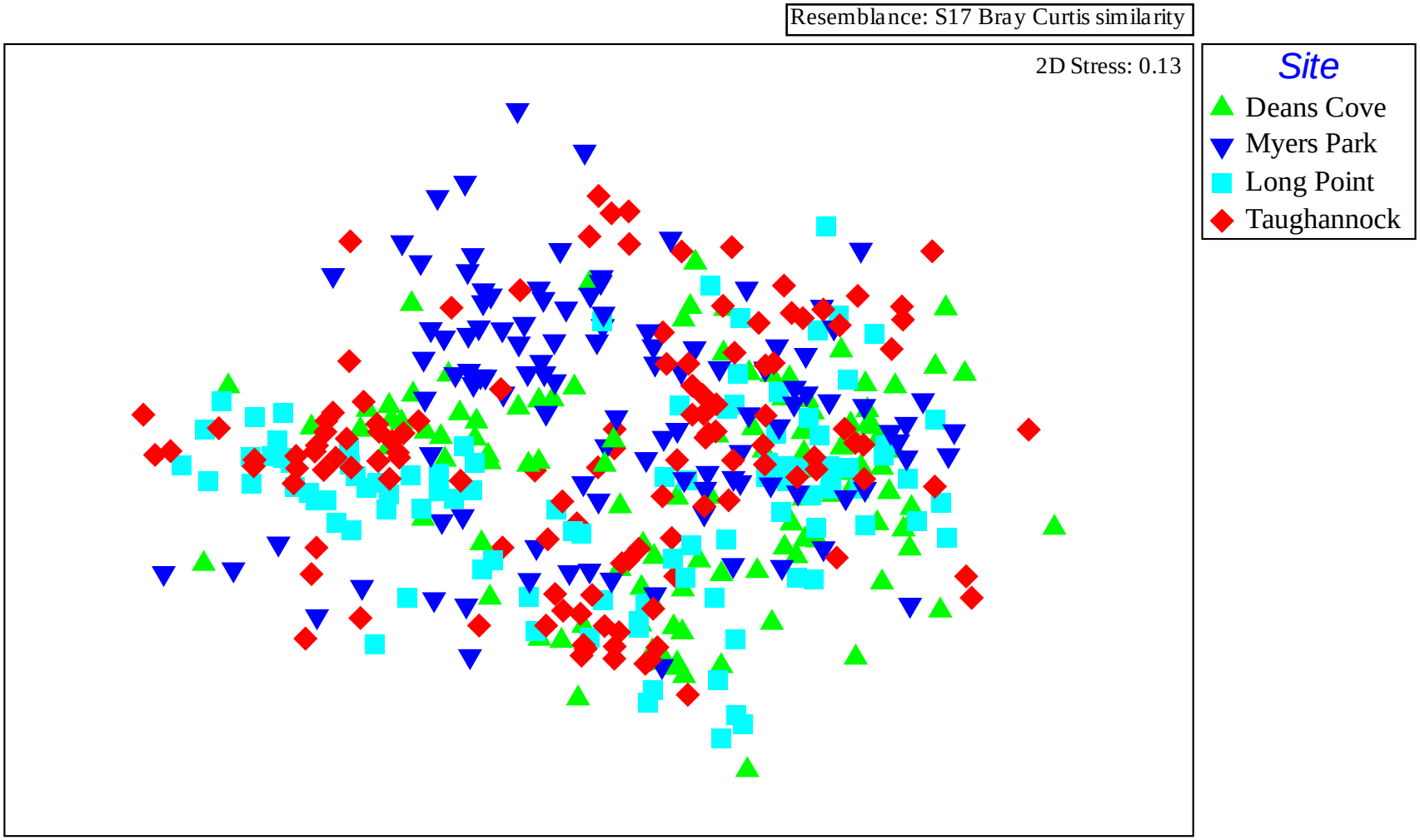

Figure 7: Non-metric Multidimensional Scaling plot (nMDS) of round goby to visually assess fatty acid signatures (FAS) by location.

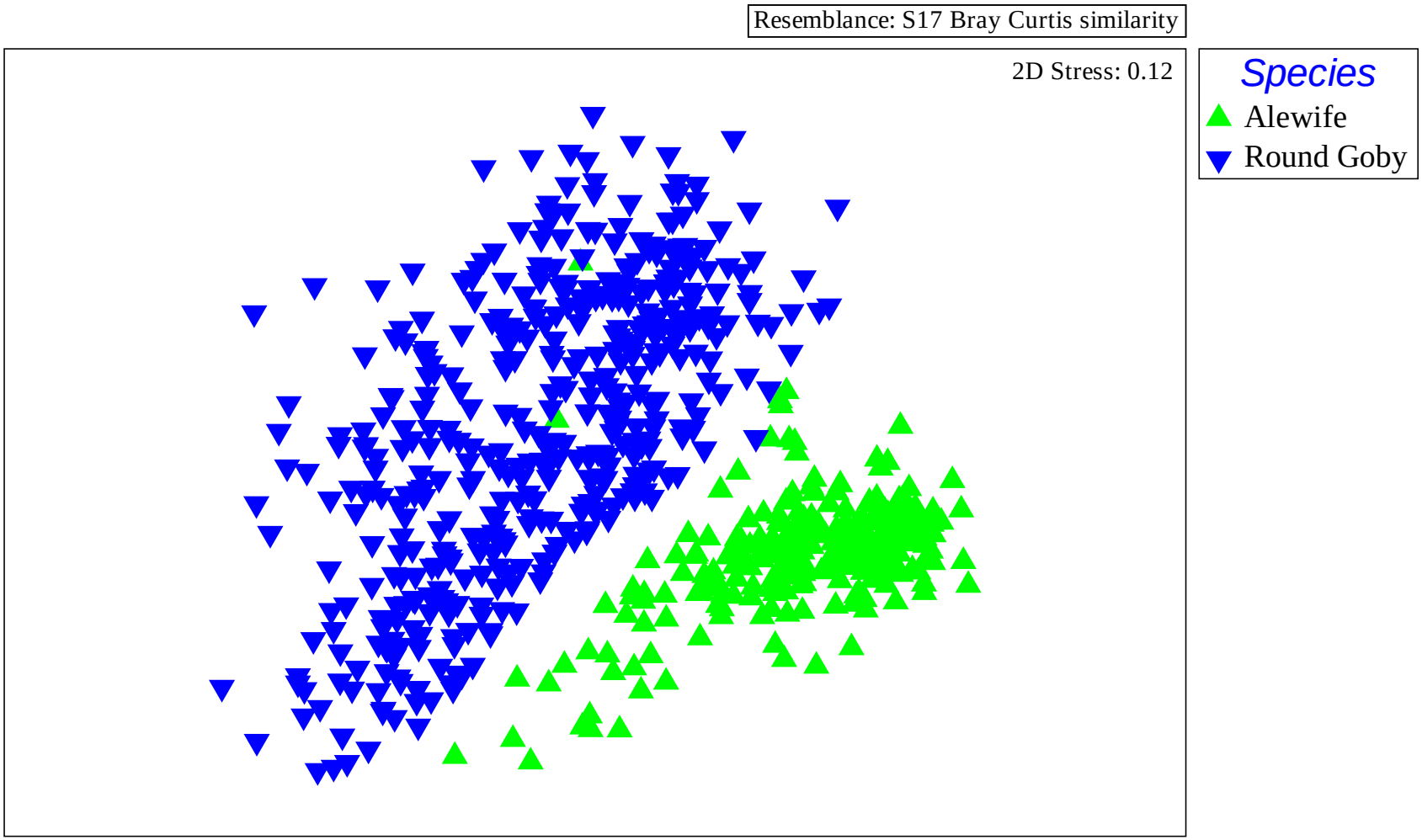

Figure 8: Non-metric Multidimensional Scaling plot (nMDS) of alewife and round goby to visually assess fatty acid signatures (FAS) between species.

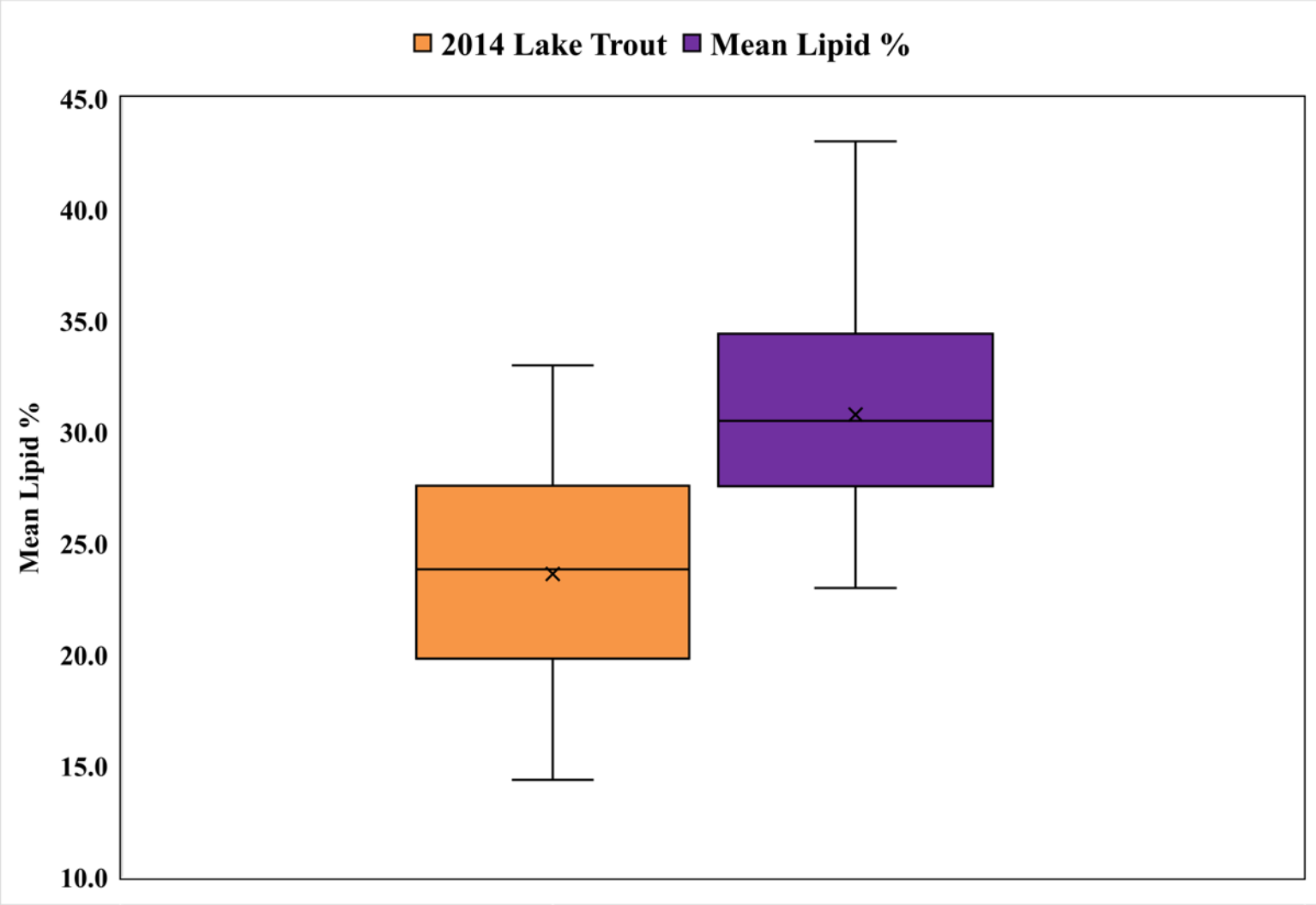

Figure 9: Boxplot of lipid content (maximum (33.0 and 43.1%), 1st quartile (27.6 and 34.4%), median (23.8 and 30.5%), mean [x] (23.6 and 30.8), 3rd quartile (19.8 and 27.6%), and minimum (14.4 and 23.0%) [top-down]) from belly flap of lake trout collected in 2014 and 2015 respectively.

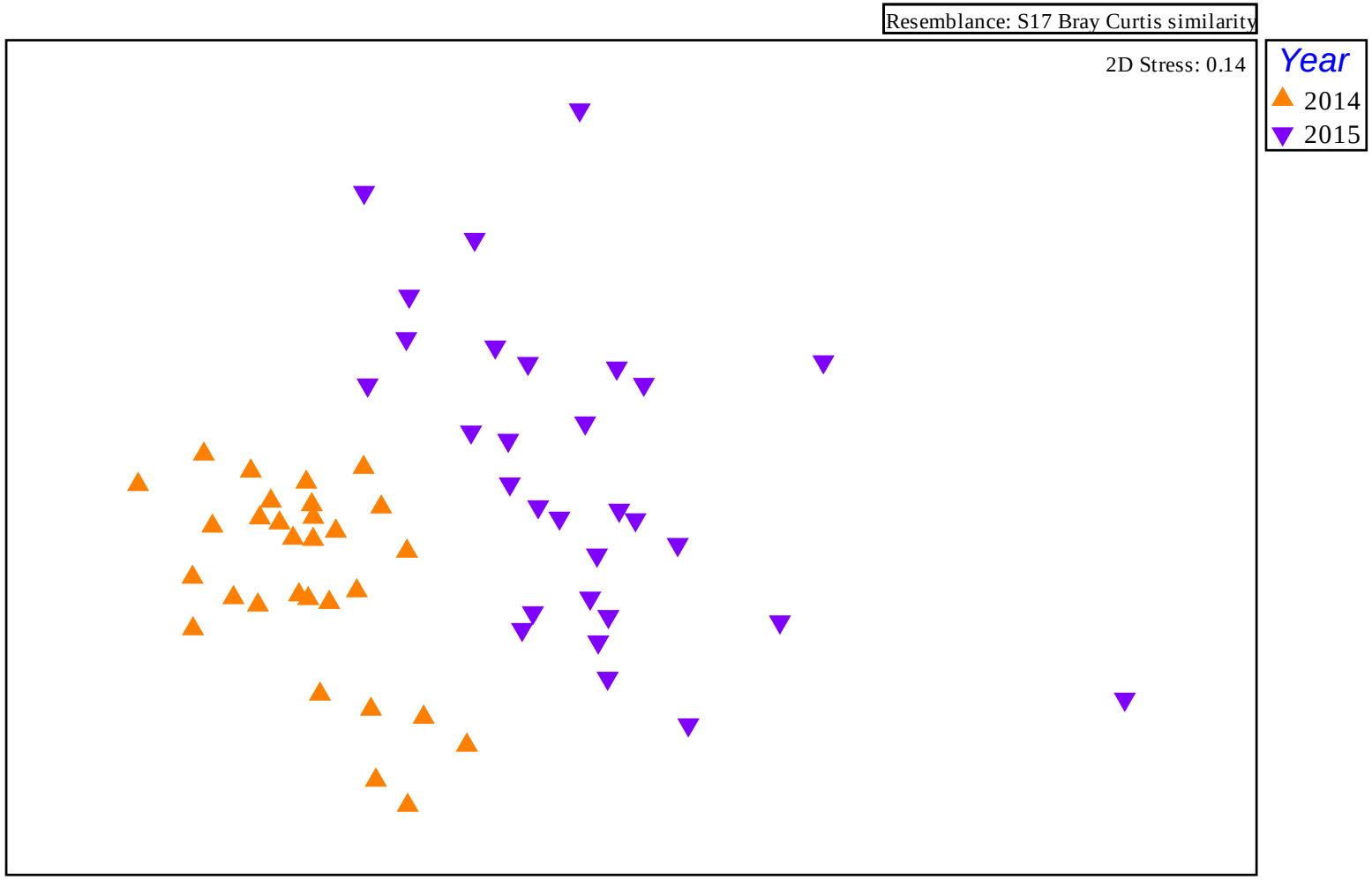

Figure 10: Non-metric Multidimensional Scaling plot (nMDS) of lake trout belly flap to visually assess fatty acid signatures (FAS) between sample years.

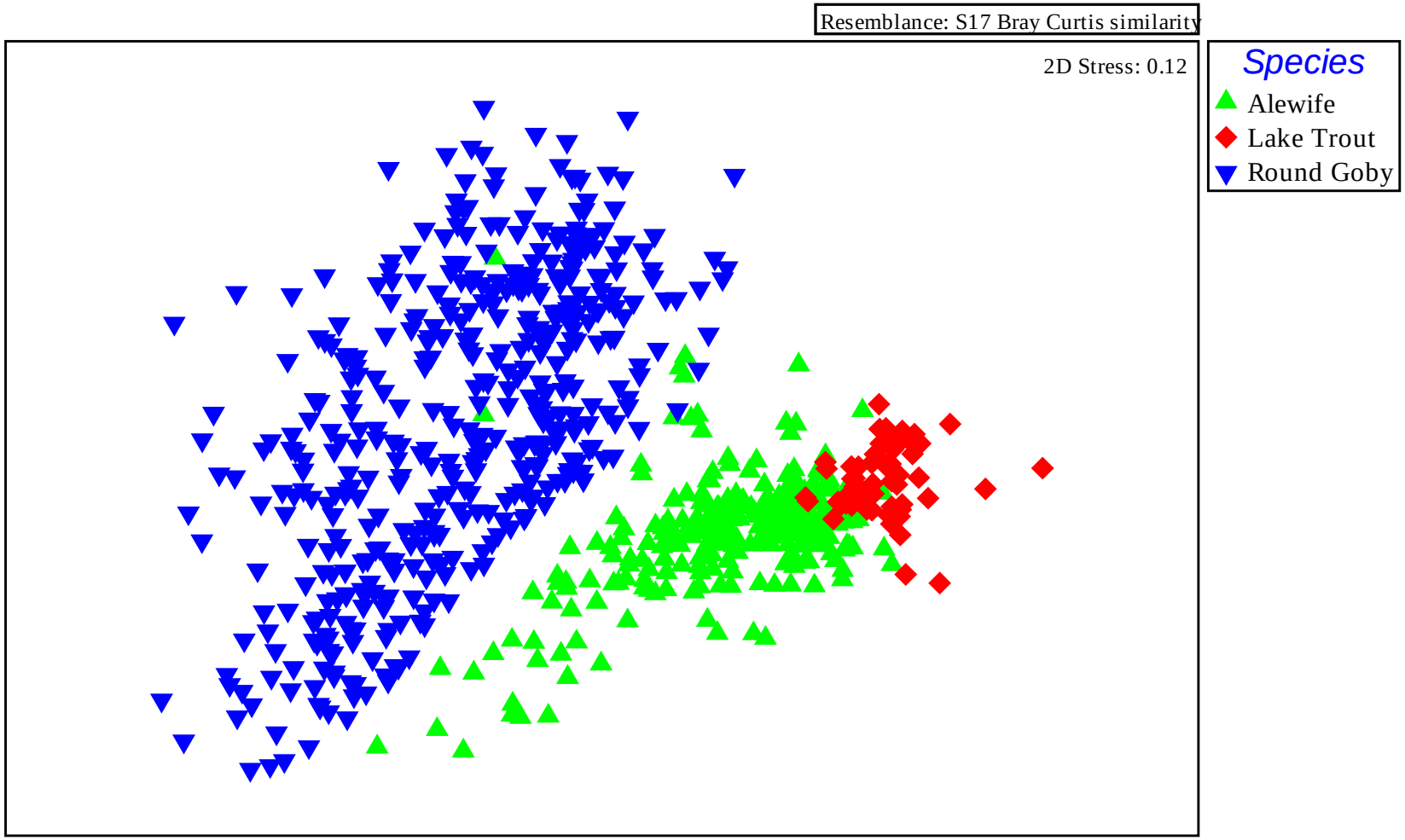

Figure 11: Non-metric Multidimensional Scaling plot (nMDS) of round goby, alewife, and lake trout to visually assess fatty acid signatures (FAS) among species.

Appendix 1: Mann-Whitney U and ANOSIM tests were used to compare Fall lipid % data from 2014 and 2015 for each species.

	Fall Alewife		**Fall Round Goby**	
	2014	**2015**	**2015**	**2015**
Mean ±SD	7.4 ± 3.0%	6.2 ± 2.4%	3.6 ± 1.6%	3.2 ± 1.2%
U	37.000		5270.000	
df	1		1	
P	P > 0.05		P > 0.05	