Spatial variation in condition and trophic connections of larval fish in Lake Michigan: a CSMI Enhancement Fellowship

Long-term Fellow: Margaret Hutton Stadig (Purdue University)
Mentor(s): Tomas Höök (Purdue University & IL-IN SeaGrant), Paris Collingsworth (Purdue University & IL-IN SeaGrant), Ed Rutherford (NOAA-GLERL)
NOAA Sponsoring Office: Great Lakes Environmental Research Laboratory
Budget Amount: $25,000
CILER Theme: Great Lakes Observing and Forecasting Systems
NOAA Strategic Goal(s):
Goal 3 - Climate Adaptation and Mitigation
Goal 4 - Resilient Coastal Communities and Economies

Overview and Objectives:
Lake Michigan food webs are being disrupted by multiple invasive and exotic species particularly by dreissenid mussels. Dreissenids are efficient filter feeders that sequester previously suspended nutrients in the benthos and limit primary production in midshore and offshore habitats of Lake Michigan (Hecky et al. 2004; Edwards et al. 2005; Vanderploeg et al 2002, 2010; Yousef et al. 2014). Recent satellite imagery analyses suggest that nearshore chlorophyll *a* concentrations may not be declining uniformly across the lake. Rather surface chlorophyll trends vary by region due to the differences in physical and biological factors such as bathymetry and tributary inflows across Lake Michigan. Surface chlorophyll in nearshore locations on the eastern half of the lake have increased in recent years while concentrations have decreased in nearshore locations on the western half of the lake (Hutton et al. in prep). Isotope-based studies of energy flow to upper trophic levels indicate that organisms on the east side of Lake Michigan rely heavily on benthic resource pathways while organisms in western Lake Michigan rely more on pelagic resources (Happel 2013; Henerby 2014; Turschak et al. 2014). Little is known, though, about connections at lower trophic levels and how these connections vary across space and time. During the 2015 CSMI in Lake Michigan, vertebrate (larval fish) and invertebrate (*Bythotrephes longimanus)* secondary consumers were collected to assess trophic connections and the overall condition of individuals in different regions of the lake. *Bythotrephes* and larval fish occupy a similar trophic niche in the Lake Michigan food web. Their preferred prey are large herbaceous zooplankton (Mills and Forney 1981; Lehman and Branstrator 1995) and they are frequently consumed by higher trophic organisms (Brandt et al. 1987; Pothoven et al. 2001).

The objective of this study was to assess how the condition of fish larvae and *Bythotrephes* vary across a broad spatial scale (east to west shores of Lake Michigan), along a finer spatial scale (nearshore to offshore transects), and seasonally (spring to fall). Density, length and condition, as evaluated by RNA:DNA ratios (an analysis for short-term growth; Clemmesen 1994; Höök et al. 2008), were measured for the three secondary consumers: alewife (*Alosa pseudoharengus*) and bloater (*Coregonus* hoyi) larvae, and *Bythotrephes*. Fatty acid signatures of the three secondary consumers also were analyzed to determine if production pathways vary between

the east and west side of Lake Michigan. Two transects were sampled monthly in southwest Lake Michigan, one near Racine, WI, and another in southeast Lake Michigan, off Muskegon, MI. Three sites were sampled at each transect along a nearshore to offshore gradient from 15-18 m depth (nearshore), to 45 m depth (midshore) and 100-110 m depth (offshore). Three types of gear were used to capture secondary consumers: bongo nets towed during the day (333 and 500 µm), nueston nets towed during the night (500 µm), and zooplankton nets (64 µm) towed during both the day and night. Bongo and zooplankton net samples were integrated metaliminion and epiliminion tows, whereas the neuston net was only towed in the epiliminion. Multiple gear types allowed for the collection of sufficient number of study organisms for morphometric and biochemical analyses. Bongo and neuston nets were towed in duplicate. One replicate was preserved and stored for densities, lengths, and RNA:DNA analysis. Only the 333 µm bongo replicates were used for density analysis. The second was immediately sorted for fatty acid analysis.

Accomplishments:

All three secondary consumers were successfully sampled during each month from June to September at both Racine and Muskegon. Laboratory analysis has been completed for all larval fish and *Bythotrephes* samples. Analysis of the information has been conducted for densities, lengths, RNA:DNA, and fatty acids for *Bythotrephes*. Currently only fatty acid analysis has been completed for larval fish.

Bythotrephes densities were consistently higher on the eastern side of Lake Michigan throughout the year. Along both transects, *Bythotrephes* densities increased throughout the season, with the highest densities in August and September (Figure 1). Densities at the western Racine transect were highest in nearshore locations, but densities were greatest in mid- to offshore locations along the eastern shore. Higher offshore densities have been reported in similar *Bythotrephes* studies conducted in Lake Michigan (Cavaletto et al. 2010). Differences in body lengths between nearshore and offshore locations were not noticeably different throughout the year along either transect. However, there was a difference in length between the eastern and western shores in June and July (Figure 2). During the months of August and September, the body lengths of *Bythotrephes* were not observably different between the two transects.

Similar temporal and spatial trends were also observed in average RNA:DNA ratios for *Bythotrephes*. In early summer months, the RNA:DNA ratios along Muskegon were greater than those observed along Racine (Figure 3). However, there were no differences in RNA:DNA ratios measured during August and September. During the early summer months, physical factors along Racine's shorelines could inhibit growth and condition of *Bythotrephes*. Epilimnetic water temperatures are generally colder on the western side of Lake Michigan especially early in the season compared to the east side (Plattner et al. 2006). Thus water temperatures are optimal for *Bythotrephes* growth earlier in the season on the east side of the lake compared to the west (Yurista 1999, which could help explain the seasonal lag observed in

growth and condition from west to east. As water temperature and other environmental conditions equilibrate across the lake, the size and condition of *Bythotrephes* become comparable. As further larval fish samples are analyzed, they will confirm whether trends are consistent across this trophic level.

To identify differences in fatty acid signatures, nonparametric multivariate dimensional scaling (nMDS) and permutational multivariate analysis of variance (PerMANOVA) were conducted. For *Bythotrephes*, 39 different fatty were identify and used within the analysis (Appendix Table 1). All factors (transect, location nearshore to offshore, month collected, and instar) were significant but the most variation was explained by sampling month (Month: $F=39.36$, $R^2=.23$, $p=0.001$). Thirty-eight fatty acids were analyzed for larval fish composition (Appendix Table 2). Similar to *Bythotrephes*, factors such as species, transect, and date are all significant variables when determining the fatty acid signature of larval fish. However, unlike *Bythotrephes*, all factors appeared to play an equally important role in explaining the variation in fatty acids for larval fish. While the sample sizes from Racine are low for larval fish (alewife = 4; bloater = 1), differences in fatty acid signature are fairly pronounced (Figure 4). Comparatively little variation is explained by the different transects for *Bythotrephes* fatty acids (Figure 4), but month of capture is highly significant for both larval fish and *Bythotrephes* fatty acids. Further analyses will be conducted to evaluate the potential seasonal lag in fatty acid signatures.

Analyzes from this study, including the remaining larval fish and *Bythotrephes* instar analyzes, are ongoing and will be compiled into different publications in the future including the publication currently in preparation. Much of this research will also be assembled into a Master's thesis by M. Hutton Stadig from Purdue University.

Figures

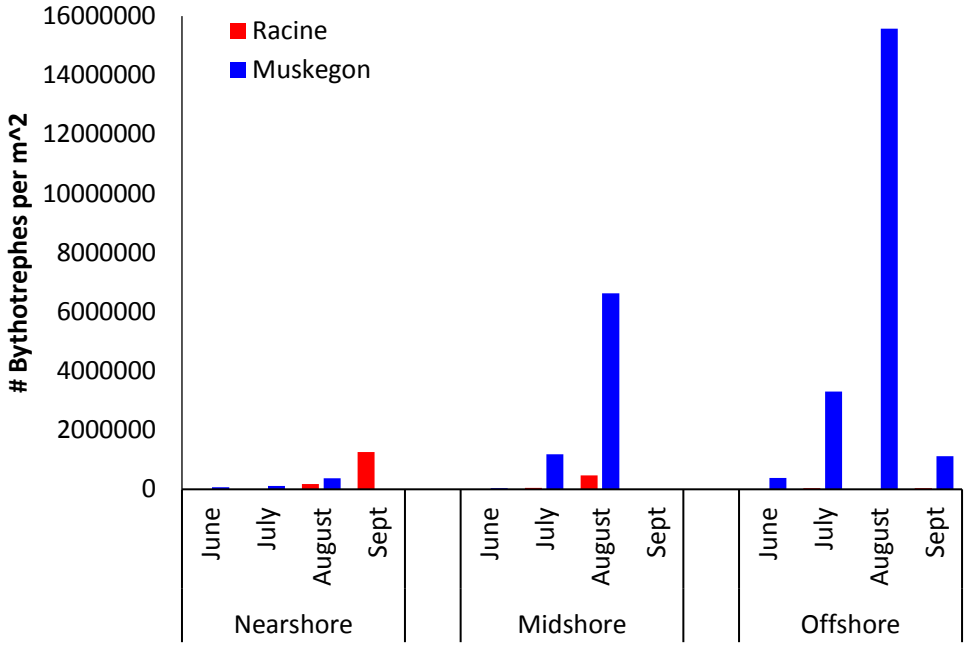

Figure 1. Total density of *Bythotrephes* along the two transects of Lake Michigan, Muskegon (blue) and Racine (red). No *Bythotrephes* were captured in the nearshore location of Racine in June and July. Offshore areas of Racine were not sampled in August. Neither Racine nor Muskegon were sampled in midshore areas in September.

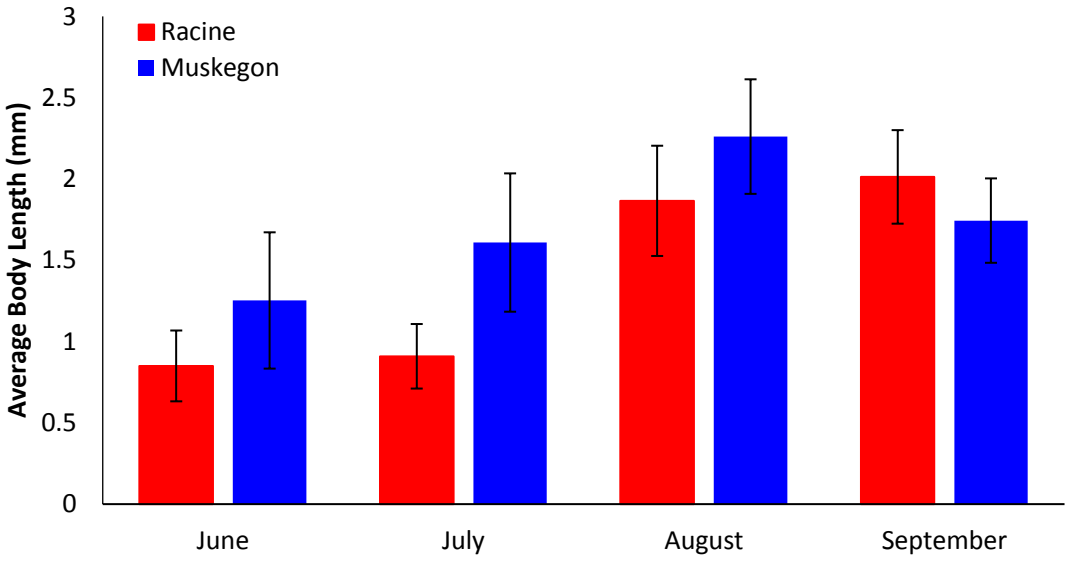

Figure 2. The average body length (±S.D.) of the 1st instar of *Bythotrephes* along Racine, WI (red), and Muskegon, MI (blue), for each month. Samples from nearshore to offshore were combined.

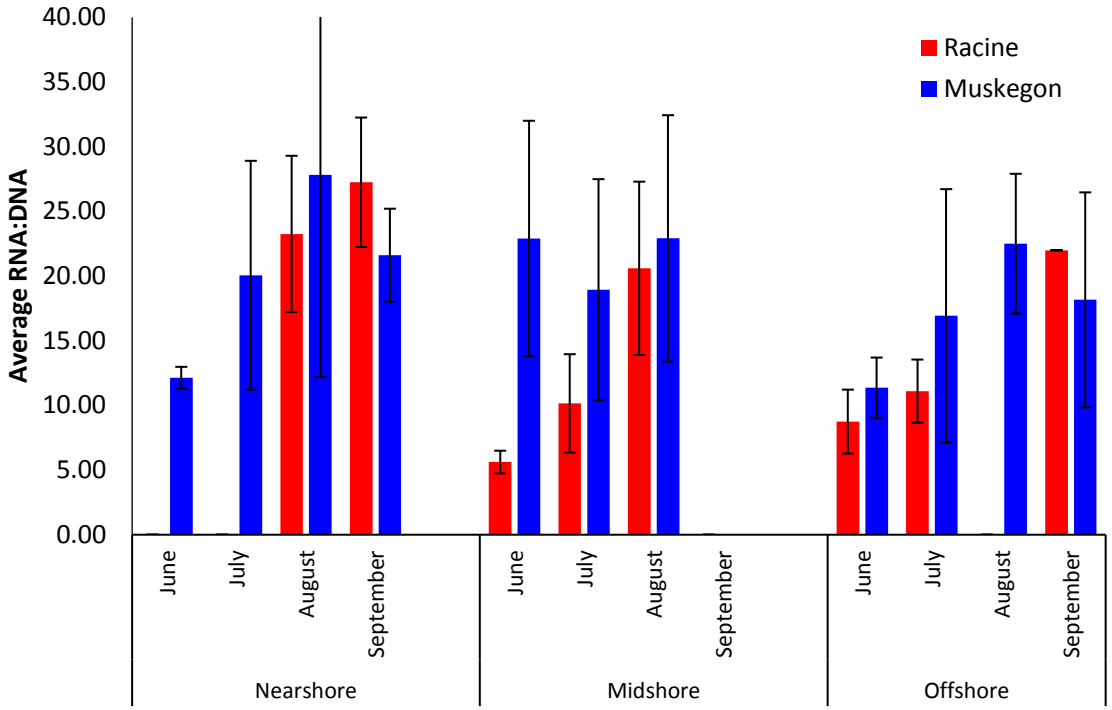

Figure 3. The average RNA:DNA values for the 1st instar of *Bythotrephes* between Muskegon (blue) and Racine (red). No 1st instars were captured in nearshore locations of Racine in June and July. Samples were not collected from midshore Muskegon or Racine in September or from Racine in offshore locations in August.

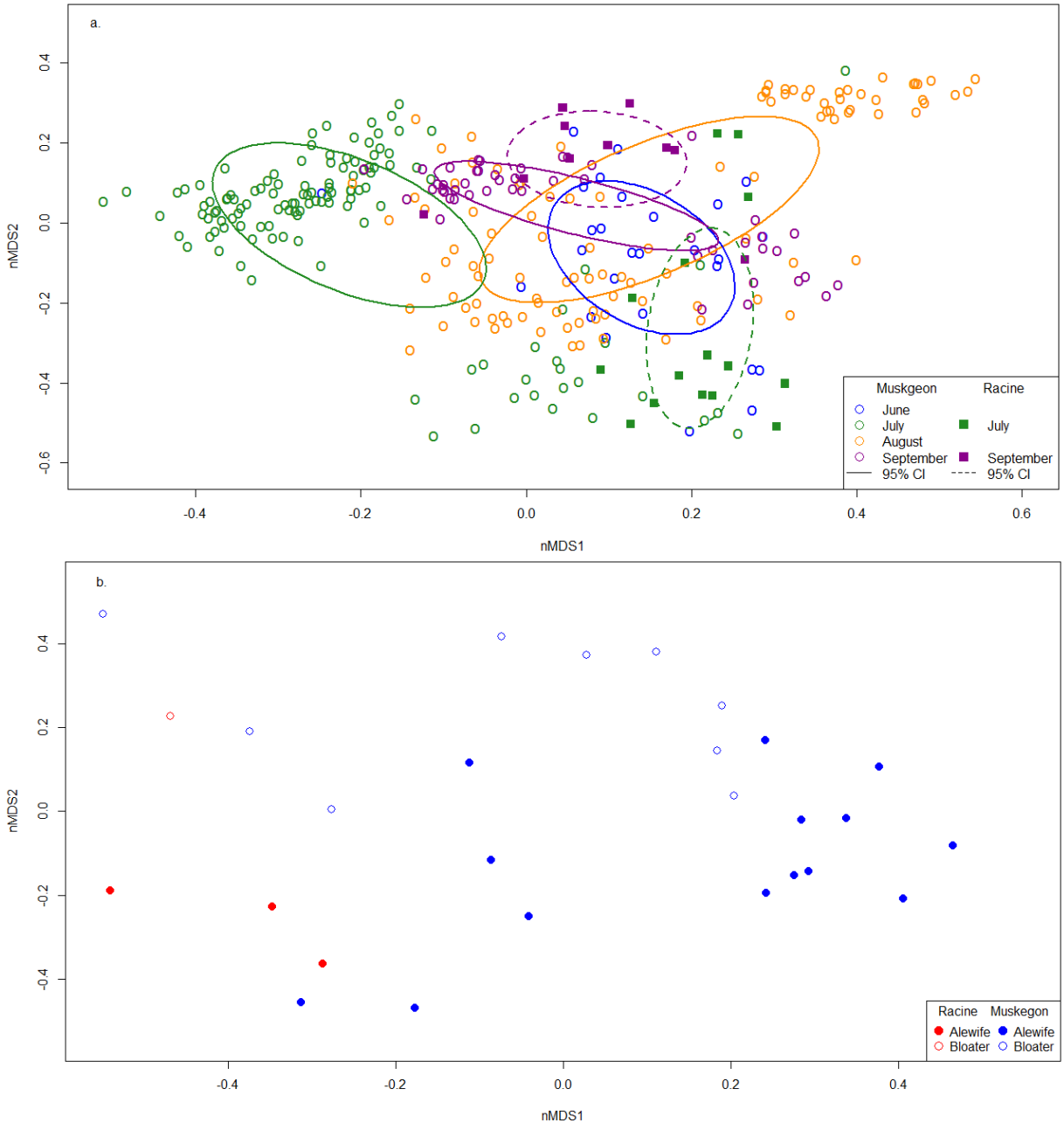

Figure 4. nMDS of fatty acid profiles (% composition) for *Bythotrephes* (a.) and larval fish (b.). For both plots, all samples within each transect were combined due to uneven sample size from nearshore to offshore. In (a.) 95% confidence ellipsoids are plotted transect by month group centroid. In (b.) Due to sample size, all larval fish samples were pooled across months.

Publications:

Margaret Hutton Stadig, Paris Collingsworth, Samuel Guffey, Ed Rutherford, Mitchell Zischke, and Tomas Höök. Spatiotemporal differences in the condition of secondary consumers in Lake Michigan. Journal of Great Lakes Research. In Prep.

Presentations:

Margaret Hutton, Paris Collingsworth, Samuel Guffey, Ed Rutherford, Mitchell Zischke, and Tomas Höök. Spatiotemporal differences in the condition of *Bythotrephes longimanus* in Lake Michigan. Midwest Fish and Wildlife Conference 1/2016. Grand Rapids, MI.

Margaret Hutton, Paris Collingsworth, Samuel Guffey, Ed Rutherford, Mitchell Zischke, and Tomas Höök. Assessing a secondary consumer through space and time: The story of L. Michigan Bythotrephes. IAGLR 6/2016. Guelph, ON. Invited.

Outreach Activities: None to Date

Literature Cited

Beletsky, D., D.Mason, D.J. Schwab, E. Rutherford, J. Janssen, D. Clapp, and J. Dettmers. 2007. Biophysical model of larval yellow perch advection and settlement in Lake Michigan. Journal of Great Lakes Research 33:842-866.

Brandt, S.B., D.M. Mason, D.B. Macneill, T. Coates, J.E. Gannon. 1987. Predation by alewives on larvae of yellow perch in Lake Ontario. Transactions of the American Fisheries Society 116(4): 641-645.

Cavaletto, J.F., H.A. Vanderploeg, R. Pichlova-Ptanikova, S.A. Pothoven, J.R. Liebig, G.L. Fahnenstiel. 2010. Temporal and spatial separation allow coexistence of predatory cladocerans: *Leptodora kindtii, Bythotrephes longimanus,* and *Cercopagis pengoi* in southeastern Lake Michigan. Journal of Great Lakes Research 36:65-73.

Clemmesen. C. 1994. The effect of food availability, age or size on the RNA/DNA ratio of individually measured herring larvae – laboratory calibration. Marine Biology 118: 377–382

Edwards, W.J., C.R. Rehmann, E. McDonald, and D.A. Culver. 2005. The impact of a benthic filter feeder: Limitations imposed by physical transport of algae to the benthos. Canadian Journal of Fisheries and Aquatic Sciences 62:205-214.

Foad, Y., W.C. Kerfoot, R. Shuchman, and G. Fahnenstiel. 2014. Bio-optical properties and primary production of Lake Michigan: Insights from 13-years of SeaWiFS imagery. Journal of Great Lakes Research. 40: 317–324.

Happel, A. 2013. A multi-indicator approach to dietary assessments within Lake Michigan's nearshore area. M.S. Thesis, University of Illinois at Urbana-Champaign.

Hecky, R.E., R.E.H. Smith, D.R. Barton, S.J. Guildford, W.D. Taylor, M.N. Charlton, T. Howell. 2004. The nearshore phosphorus shunt: a consequence of ecosystem engineering by dreissenids in the Laurentian Great Lakes. Canadian Journal of Fisheries and Aquatic Sciences 61:1285-1293.

Henebry, M.L. 2014. Variation in round goby feeding interactions in near-shore Lake Michigan based on three trophic indicators. M.S. Thesis, Purdue University. West Lafayette, IN.

Höök, T.O., E. Gorokhova, and S. Hansson. 2008. RNA:DNA ratios of Baltic herring larvae and copepods in embayment and open sea habitats. Estuarine, Coastal, and Shelf Science. 76: 29-35.

Lehman, J.T. and D.K. Branstrator. 1995. A model for growth, development, and diet selection by the invertebrate predator *Bythotrephes cederstroemi*. Journal of Great Lakes Research 21(4): 610-619.

Mills, E.L. and J.L. Forney. 1981. Energetics, food consumption, and growth of yellow perch in Oneida Lake, New York. Transactions of the American Fisheries Society 110:479-488.

Plattner, S., D.M. Mason, G.A. Leshkevich, D.J. Schwab, E.R. Rutherford. 2006. Classifying and forecasting coastal upwellings in Lake Michigan using satellite derived temperature images and buoy data. Journal of Great Lakes Research 32:63-76.

Pothoven, S.A., T.F. Nalepa, P.J. Schneeberger, S.B. Brandt. 2001. Changes in diet and body condition of lake whitefish in southern Lake Michigan associated with changes in the benthos. North American Journal of Fisheries Management 21:876-883.

Turschak, B.A., D.B. Bunnell, S. Czesny, T.O. Höök, J. Janssen, D. Warner, and H.A. Bootsma. 2014. Nearshore energy subsidies support Lake Michigan fishes and invertebrates following major changes in food web structure. Ecology. 95: 1243-1252.

Vanderploeg, H.A., T.F. Nalepa, D.J. Jude, E.L. Mills, K.T. Holeck, J.R. Liebig, I.A. Grigorovich, and H. Ojaveer. 2002. Dispersal and emerging ecological impacts of Ponto-Caspian species in the Laurentian Great Lakes. Canadian Journal of Fisheries and Aquatic Sciences 59:1209-1228.

Vanderploeg, H.A., J.R. Liebig, T.F. Nalepa, G.L. Fahnenstiel, and S.A. Pothoven. 2010. Dreissena and the disappearance of the spring phytoplankton bloom in Lake Michigan. Journal of Great Lakes Research 36:50-59.

Yurista, P.M. 1999. A model for temperature correction of size-specific respiration in *Bythotrephes cederstroemi* and *Daphnia middenforffiana*. Journal of Plankton Research 21(4):721-734.

Appendix

Table 1. All fatty acids for *Bythotrephes* used for analysis in this study

Isomer	Systematic name	Common name
hydroxyC12:0		
C14:0		
isoC15:0		
antiC15:0		
C15:0	pentadecanoic acid	
C16:1alcohol		
hydroxyC14:0		
isoC16:0		
C16:0		
C16:1		
isoC17:0		
C17:0	heptadecanoic acid	margaric acid
C18:0alcohol		
C17:1	heptadecenoic acid	

DMA C18:0		
C18:0	octadecanoic acid	stearic acid
C18:1n-9total		oleic acid
C18:1n-7		
C18:2*trans*		
C18:2*cis*		
C20:0	eicosanoic acid	arachidic acid
C20:1n-9		
C20:2		
C21:0	heneicosanoic acid	heneicosylic acid
C20:3n-6		
C20:4n-6		
C20:3n-3		
C20:5n-3 all *cis*	eicosapentaenoic acid (EPA)	timnodonic acid
C22:0	docosanoic acid	behenic acid
C22:1	Docosenoic acid	erucic acid
C22:2	Docosadienoic acid	brassic acid
C23:0		
C22:4n-6	docosatetraenoic acid	
C22:5n-6	docosapentaenoic acid n-6	
C22:5n-3	Docosapentaenoic acid (DPA)	clupanodonic acid
C22:6n3 all *cis*	Docosahexaenoic acid (DNA)	
C24:0	tetracosanoic acid	lignoceric acid
C24:1		

Table 2. All 38 fatty acids for larval fish used for analysis in this study

Isomer	Systematic name	Common name
C14:0		
isoC15:0		
antiC15:0		
C15:0	pentadecanoic acid	
C16:1alcohol		
hydroxyC14:0		
isoC16:0		
DMA C16:0		
C16:0		
C16:1		
isoC17:0		
C17:0	heptadecanoic acid	margaric acid
C18:0alcohol		
C17:1	heptadecenoic acid	
DMA C18:0		
C18:0	octadecanoic acid	stearic acid
C18:1n-9total		oleic acid
C18:1n-7		

C18:2*trans*		
C18:2*cis*		
C20:0	eicosanoic acid	arachidic acid
C20:1n-9		
C20:2		
C21:0	heneicosanoic acid	heneicosylic acid
C20:3n-6		
C20:4n-6		
C20:3n-3		
C20:5n-3 all *cis*	eicosapentaenoic acid (EPA)	timnodonic acid
C22:0	docosanoic acid	behenic acid
C22:1	Docosenoic acid	erucic acid
C22:2	Docosadienoic acid	brassic acid
C23:0		
C22:4n-6	docosatetraenoic acid	
C22:5n-6	docosapentaenoic acid n-6	
C22:5n-3	Docosapentaenoic acid (DPA)	clupanodonic acid
C22:6n3 all *cis*	Docosahexaenoic acid (DNA)	
C24:0	tetracosanoic acid	lignoceric acid
C24:1		