Section A. Summary

Title: Quantifying Coastal Wetland – Nearshore Linkages in Lake Michigan for Sustaining Sport Fishes

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Abstract: Coastal wetlands support rich and diverse faunal communities, providing habitat for 90% of Great Lake fish species. Use of wetlands as spawning, nursery, and foraging habitat by nearshore sport fish represents a potentially critical wetland-nearshore linkage that has not been adequately characterized in Lake Michigan. To determine the importance of coastal wetlands to the overall lake food web, and specifically to economically-important sport fishes, our team quantified fish-mediated linkages between wetland and nearshore habitats at nine sites in three regions of Lake Michigan: west shore (Green Bay, Wisconsin), south shore (Illinois and Indiana), and east shore (Michigan). Specifically, we are (1) constructing cross-habitat food webs using stable C and N isotope mixing models, (2) estimating coastal wetland habitat use across life by sport fishes using otolith microchemistry, and (3) building predictive models of both linkage types that account for the major drivers of fish-mediated linkages in multiple Lake Michigan wetland types. The results of our research will inform improved management of Lake Michigan coastal wetlands, benthic and pelagic food webs, and the economically-important sport fish that are dependent on them.

Keywords: Great Lakes, coastal wetlands, nearshore zone, sport fishes, otoliths, stable isotopes

Lay Summary: Coastal wetlands throughout the Great Lakes, including Lake Michigan, are important habitats for many plants and animals, but these habitats have suffered extensive degradation and, in many cases, even complete loss. Approximately half of coastal wetland area has been converted to other land uses since European settlement of the region and remaining wetlands are impacted by invasive species, fragmentation, nutrient loading, and hydrological manipulation. With the ongoing "benthification" of the Great Lakes driven by invasive dreissenid mussels, organisms in the Great Lakes are becoming increasingly dependent on food resources generated by areas close to shore. The main goal of our research is to determine whether important Lake Michigan sport fish, such as yellow perch, bass, salmon, and walleye, utilize coastal wetland habitat during various periods of their lives and to what degree they depend on food provided by coastal wetlands. Our research will provide new information on wetland-nearshore linkages by identifying how sport fish move between these different environments for food, shelter, and reproduction. With improved understanding of these linkages, we can develop more effective strategies for conserving and restoring coastal wetlands to support these important fisheries.

Section B. Accomplishments

Introduction:

In the Laurentian Great Lakes, considerable attention has been devoted to understanding pelagic (i.e., open water) food webs while less attention has been given to nearshore and coastal wetland food webs and their importance in sustaining sport fish populations (Keough et al. 1998, Sierszen et al. 2006, Hoffman et al. 2010). A more complete understanding of the Great Lakes ecosystem to improve fisheries management requires accurate characterization of the linkages between wetland, nearshore, and pelagic food webs. Movement of energy and organisms between coastal wetlands and adjacent nearshore habitats of Lake Michigan represents a critical, though largely unstudied, ecological linkage. Our research seeks to characterize two important Lake Michigan habitat linkages — namely, (1) the use of coastal wetlands as habitat by sport fish throughout life and (2) the use of coastal wetland-derived energy by nearshore sport fish. This linkage likely supports numerous Lake Michigan sport fish species such as yellow perch (*Perca flavescens*), walleye (*Sander vitreus*), largemouth bass (*Micropterus dolomieu*), smallmouth bass (*M. salmoides*), and northern pike (*Esox lucius*). Identifying and quantifying such habitat linkages represents a frontier for research and management of aquatic resources (Lamberti et al. 2010) and should be considered in future management of the Lake Michigan food web including that of Lake Michigan.

Research in marine coastal ecosystems provides context for the current study given the limited amount of relevant work in the Great Lakes. Fish have been identified as important vectors of nutrient and energy flow in marine coastal systems with coastal wetlands such as salt marshes, mangroves, and seagrass beds serving as nursery habitats for many fish species (Beck et al. 2001, Mumby et al. 2004). When fish move to adult habitats, they transport coastal-derived biomass, energy, and nutrients with them. For example, Deegan (1993) found that gulf menhaden (*Brevoortia patronus*) exported nearly as much estuarine N and P as was exported by tidal flushing. Transport of nutrients and energy between marine and freshwater ecosystems by migrating Pacific salmon represents another well-known habitat linkage (Gende et al. 2002, Mitchell and Lamberti 2005). Evidence suggests that similar cross-habitat linkages occur within

Great Lakes nearshore ecosystems (Herdendorf 1990, Brazner et al. 2001, 2004) and we predict that these linkages support the production of several important nearshore sport fishes in Lake Michigan. Current understanding of Great Lakes food webs lacks detailed information on cross-habitat linkages. Indeed, linkages between wetland and nearshore habitats have been almost entirely overlooked – with some notable exceptions (Keough et al. 1998, Brazner et al. 2004).

In Lake Michigan, as in all the Great Lakes, food web research and management efforts have historically focused on the pelagic zone. However, nearshore habitats represent ecologically diverse and productive areas within the lakes. For example, in large lakes, nearshore primary production supports a majority of the fish and invertebrate species and densities can be 10-50 times higher than those found offshore (Vadeboncoeur et al. 2011). The rich and diverse faunal communities of the nearshore appear to be supported by benthic pathways that are often more ecologically efficient than pelagic pathways (Vander Zanden et al. 2011). High richness in the nearshore may also be attributed to habitat heterogeneity and partitioning of benthic resources among taxa (Vander Zanden et al. 2011). Consequently, we predict that linkages between open-water nearshore areas and highly productive coastal wetlands contribute to high fish production and diversity found within Great Lakes nearshore systems.

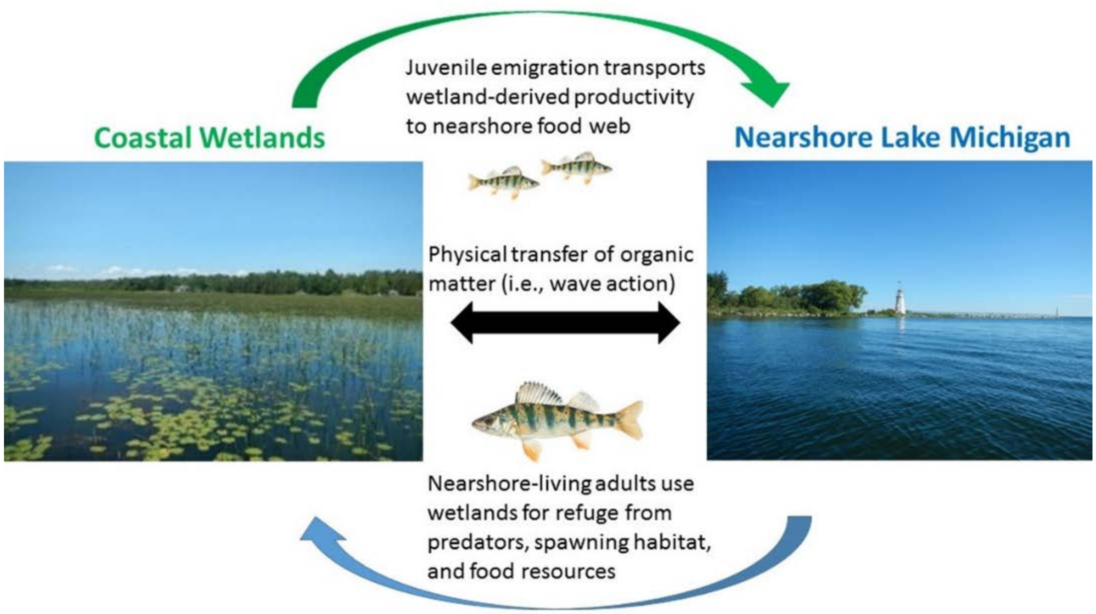

Figure 1. Hypothesized biotic (i.e., fish-mediated) and abiotic (i.e., seiche-driven) linkages between coastal wetland and nearshore habitats may support nearshore fish production.

Coastal wetlands are found throughout the Great Lakes where hydrology (e.g., wave and current energy) is sufficiently quiescent for emergent vegetation to persist and where sediments are conducive to plant growth (Albert et al. 2005). In Lake Michigan, wetlands form in protected embayments, behind barrier sand bars, and along the margins of tributary streams (Albert et al. 2005). Coastal wetland primary production tends to be higher than in pelagic lake habitats due to rapid nutrient cycling, decreased wave energy, and shallow depth that places the benthos within the euphotic zone (Cooper et al. 2013). This, in turn, supports rich and diverse faunal communities. For example, coastal wetlands provide essential spawning and nursery areas for up to 90% of Great Lakes fish species (Chubb and Liston 1986, Uzarski et al. 2005, Cvetkovic and Chow-Fraser 2011). Use of wetlands as spawning, rearing, and foraging habitat by sport fishes, such as yellow perch, walleye, largemouth bass, and smallmouth bass, represents a potentially vital wetland-nearshore linkage. Coastal wetlands also provide critical habitat for many species of birds, mammals, reptiles, and amphibians (Mitsch and Gosselink 1993, Hecnar 2004, Hanowski et al. 2007, Wieten et al. 2012). Unfortunately, coastal wetlands throughout the Great Lakes, including those of Lake Michigan, have suffered extensive degradation and loss (Krieger et al. 1992, Maynard and Wilcox 1997). Approximately half of the coastal wetland area that was present prior to European settlement has been converted to other land uses and the majority of remaining wetlands are impacted by invasive species, fragmentation, nutrient loading, and hydrologic manipulation (Wilcox 1995, SOLEC 2007, Cooper et al. 2012). Thus, understanding linkages between coastal wetlands and adjacent lake habitats is critical for long-term management of the Lake Michigan food web and for establishing coastal restoration priorities.

Despite the importance of coastal wetlands to the Great Lakes ecosystem, few studies have addressed wetland-nearshore linkages in any of the Great Lakes. Bouchard (2007) was the first to extend the outwelling hypothesis, originally described in marine coastal systems, to the Great Lakes nearshore by documenting substantial export of wetland-derived organic carbon to Lake Erie. While that study illustrated the importance of coastal wetlands in a broader Great Lakes context, it remains unclear how wetland-derived materials are incorporated into open lake food webs. A few studies have attempted to directly link wetland food webs to those of Great Lakes open waters (Keough et al. 1996; Hoffman et al. 2010, Sierszen et al. 2006) and suggest that wetland-nearshore linkages exist, but estimating the magnitude of these linkages has proven elusive. Additionally, nearly all Great Lakes wetland-nearshore food web linkage studies have taken place in Lake Superior with virtually no comparable work in Lake Michigan.

Previously published studies, primarily from marine coastal ecosystems, and preliminary data that we have collected, suggest that analysis of fish otolith microchemistry combined with tissue stable isotope analyses will enable us to quantify wetland-nearshore habitat linkages for various sport fishes in Lake Michigan *for the first time*. Otolith microchemistry has been used to reconstruct fish habitat use, including the identification of nursery habitats and seasonal foraging patterns (Campana 1999, Brazner et al. 2004). Although composed primarily of calcium, various trace elements are incorporated into the crystalline structure of fish otoliths based upon concentrations in the environment (Kalish 1989, Campana et al. 1999, Pangle et al. 2010). In particular, otolith strontium:calcium ratios have been used to track anadromous fish movements between freshwater and saltwater habitats (Zimmerman et al. 2000) as ambient Sr:Ca ratios in the environment determine the concentrations incorporated into the otolith structure (Halden et al. 1995, Halden et al. 1996). Recent research in freshwater environments has demonstrated that multiple element ratios within otoliths, including Sr:Ca and Ba:Ca, can be used together to track habitat use (Zeigler et al. 2010, Whiteledge et al. 2009). In our preliminary study of yellow perch otoliths from Lakes Michigan and Huron, we interpret the co-occurrence of Mg, Sr, Mn and Ba:Ca peaks to be caused by wetland habitat use based on the higher concentrations of these elements measured in waters of the nearby coastal wetlands.

Stable carbon and nitrogen isotopes have been used to construct food webs in many marine and aquatic systems, including Great Lakes coastal wetlands (Keough et al. 1996, 1998, Sierszen et al. 2004, 2006, 2012) and for Alaska salmon streams by our research group (Chaloner et al. 2002, 2004). A large body of work shows that algal carbon sources tend to dominate basal trophic levels in wetland and nearshore food webs, despite the large and conspicuous amount of macrophyte tissue produced in these systems (Keough et al. 1996, Sierszen et al. 2006). The key to using stable isotopes to estimate wetland-derived resource contributions to nearshore sport fish is that wetland-derived organic matter (e.g., phytoplankton and epiphyton) is isotopically distinct from adjacent nearshore-derived organic matter. In our preliminary study, we measured depletion of $\delta^{13}C$ (the ratio of stable isotopes ^{13}C:^{12}C, reported in parts per thousand ‰) in wetland food webs relative to adjacent nearshore food webs in Lake Huron.

Project Narrative:

Sampling Location

We completed all field work for the project in the summers of 2014 and 2015 at paired wetland-nearshore locations in three distinct regions of Lake Michigan representing different wetland geomorphic types (Figure 2): (1) western Lake Michigan, consisting of inner Green Bay (open lacustrine wetlands) and Little Bay de Noc (protected embayment wetland), (2) southern Lake Michigan (riverine and barrier protected wetlands), and (3) eastern Lake Michigan (drowned river mouth wetlands). Each region contained a minimum of three "site pairs" (i.e., wetland and adjacent nearshore habitat; see below for details). Drowned river mouth sampling also included the coastal lake habitat between the wetland and nearshore Lake Michigan.

Western Lake Michigan sites sampled: Inner Green Bay sites were Peshtigo River, Pensaukee River, Dead Horse Bay on the western shore, and Point Sable and Little Sturgeon Bay on the eastern shore. Michigan Upper Peninsula sites were Rapid River and Cedar River.

Southern Lake Michigan sites sampled: Little Calumet River (East Arm) at Burns Harbor, Lake Calumet, and Roxana Marsh. Nearshore locations were sampled near the mouths of the Little Calumet (East Arm) and Calumet Rivers.

Eastern Lake Michigan sites sampled: Pentwater River and Pentwater Lake, White River and White Lake, and the Muskegon River and Muskegon Lake. Additionally, a nearshore location was sampled near each of these drowned river mouths.

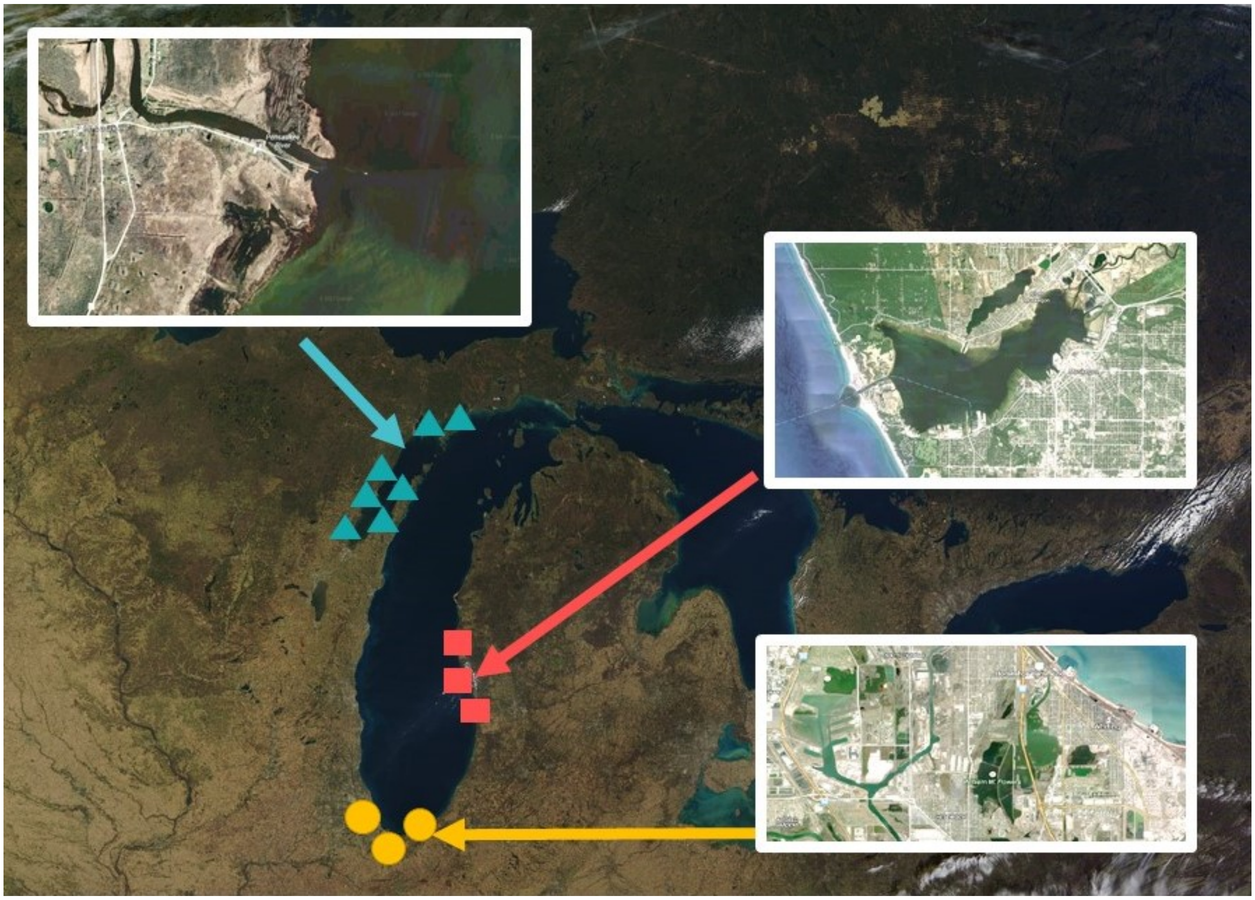

Figure 2. Approximate locations of sampled paired coastal wetland-nearshore sites in three regions of Lake Michigan (Western= blue triangles, Eastern = red squares, Southern = gold circles). Inset images demonstrate the representative geomorphology of each region's coastal habitats. More sites than originally proposed were sampled in the Green Bay, WI, region because of ancillary projects conducted by the UWGB team.

Data Collection

Water samples were collected from each habitat for analysis of dissolved inorganic carbon (DIC; to account for baseline $\delta^{13}C$ values), nutrients (i.e., NO_3, NO_2, and soluble reactive phosphorus), and elemental trace element chemistry (including Ca, Mg, Ba, and Sr; to establish baseline conditions in each habitat to reconstruct habitat use by sport fish). DIC samples were analyzed using an isotope ratio mass spectrometer (IRMS) equipped with gas bench located at the Center for Environmental Science and Technology (CEST) at the University of Notre Dame. Nutrient samples were analyzed using a Lachat QuickChem autoanalyzer located at the University of Notre Dame. All water trace element samples were analyzed using inductively coupled plasma mass spectrometry (ICP-MS) at the Center for Applied Research and Technology (CART) at Central Michigan University.

To generate cross-habitat food webs, potential food resources and fish were collected from the coastal wetland and nearshore locations at each site. In the coastal wetland habitats, plankton samples were collected from open water areas using horizontal plankton tows.

Epiphytic algae from plant stems were also sampled as an additional basal carbon source. Macroinvertebrates were sampled using D-frame dip nets and sorted to lowest possible taxonomic grouping (typically to Family). Depending on the size of the wetland, prey and sport fishes were collected either by electroshocking or modified fyke nets, euthanized, and frozen. Nearshore habitats directly adjacent to wetlands were sampled in a similar manner at approximately the 3- to 5-m depth contour. Plankton was collected with boat-drawn tows and benthic invertebrates were collected using PONAR grab samples. Nearshore fishes were collected with gillnets and short sets using selective mesh to minimize bycatch.

Stable carbon and nitrogen isotope ratios of the various food web components were analyzed using IRMS at CEST. For measurements of otolith microchemistry, sagittal otoliths were extracted from all sport fish and a subset of prey fish. Otoliths were processed using laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) at CART. All 2014 and 2015 otolith samples have been processed and data are currently being analyzed.

Preliminary Results

Preliminary analysis of water column DIC $\delta^{13}C$ indicates depletion of $\delta^{13}C$ in Lake Michigan tributaries and coastal wetland habitats relative to the nearshore lake (Figure 3). The isotopic signature of dissolved inorganic carbon in water is controlled by various biogeochemical processes including the oxidation of organic matter, photosynthesis, and exchange with atmospheric CO_2. Decomposition of organic matter and respiration decrease $\delta^{13}C$ of DIC (Barth and Veizer 1999), thus, wetland-derived organic matter is isotopically distinct from nearshore-derived organic matter. Since there is little fractionation of stable carbon isotopes between prey and predators (Hecky and Hesslein 1995), this distinct isotope “signal” for each habitat should be conserved throughout trophic levels.

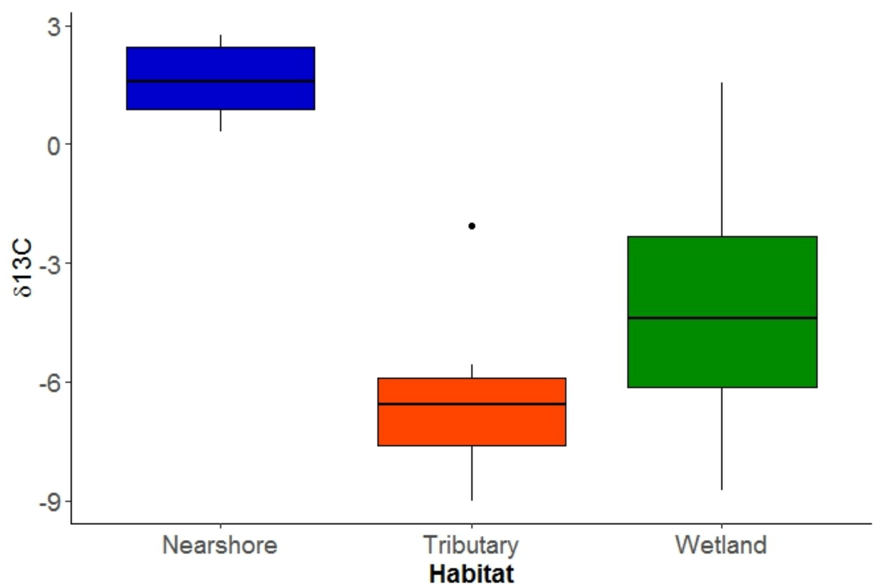

Figure 3. Dissolved inorganic carbon (DIC) $\delta^{13}C$ differs significantly ($p<0.001$) between nearshore Lake Michigan and more protected coastal ecosystems like coastal wetlands and tributary streams, thus allowing us to use $\delta^{13}C$ to estimate wetland-derived resource use by nearshore sport fishes.

Indeed, we observed this habitat-specific carbon isotope signal in primary consumers collected from both the nearshore and wetland habitats. In a preliminary study we conducted in 2011, we found Lake Huron coastal wetland algae, primary consumers, and most fish to be 2-4‰ more depleted in $\delta^{13}C$ than the same trophic levels in adjacent nearshore habitats. We observe similar patterns in Lake Michigan benthic macroinvertebrates (Figure 4) which will allow us to distinguish between wetland- and nearshore-derived resource use by sport fishes.

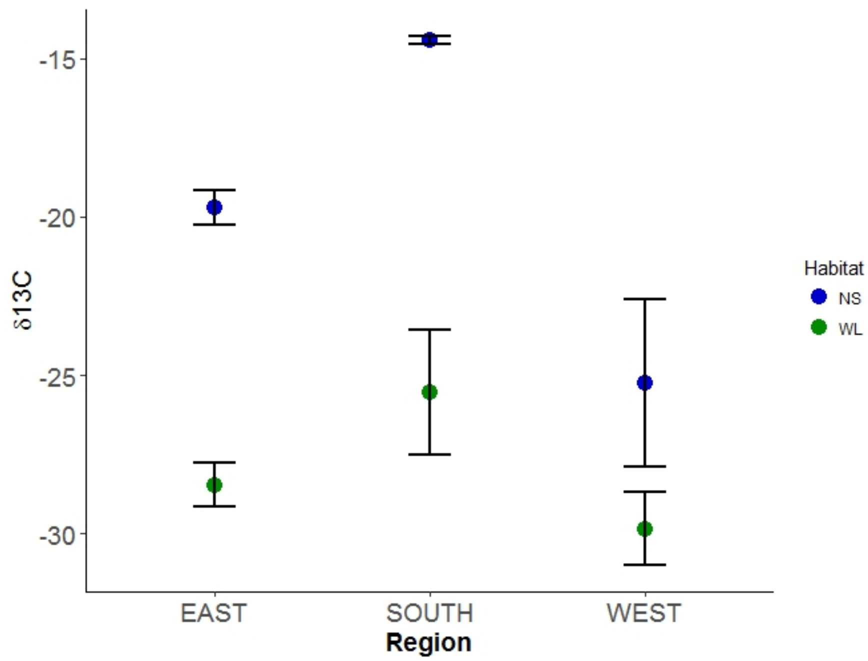

Figure 4. A benthic macroinvertebrate prey organism (Diptera: Chironomidae) shows distinct $\delta^{13}C$ values based on the habitat in which it was collected (blue=nearshore Lake Michigan, green= coastal wetland). Points represent the mean lipid-corrected $\delta^{13}C$ value of Chironomidae samples across all sites in a region. Error bars represent ± 1 standard error.

Environmental Sr and Ba concentrations differ significantly among wetland and nearshore habitats, which will allow us to reconstruct past habitat use from otolith microchemistry. Preliminary analysis of yellow perch otoliths suggests that we may be able to detect habitat-specific element signatures (Figure 5). Figure 5 shows otolith Sr:Ca concentration across life of two age-2 yellow perch collected from a southern Lake Michigan paired wetland-nearshore site (Calumet). Though these individuals are the same age and have similar body lengths (approximately 230 mm), they were collected from two different habitats (i.e., wetland and nearshore) and higher otolith Sr:Ca in the wetland-collected fish reflects higher environmental Sr in wetland waters relative to the nearshore. Future work will quantify individual variation in these habitat use patterns. By understanding intraspecific variation in habitat use, we can more accurately estimate the magnitude of fish-mediated linkages.

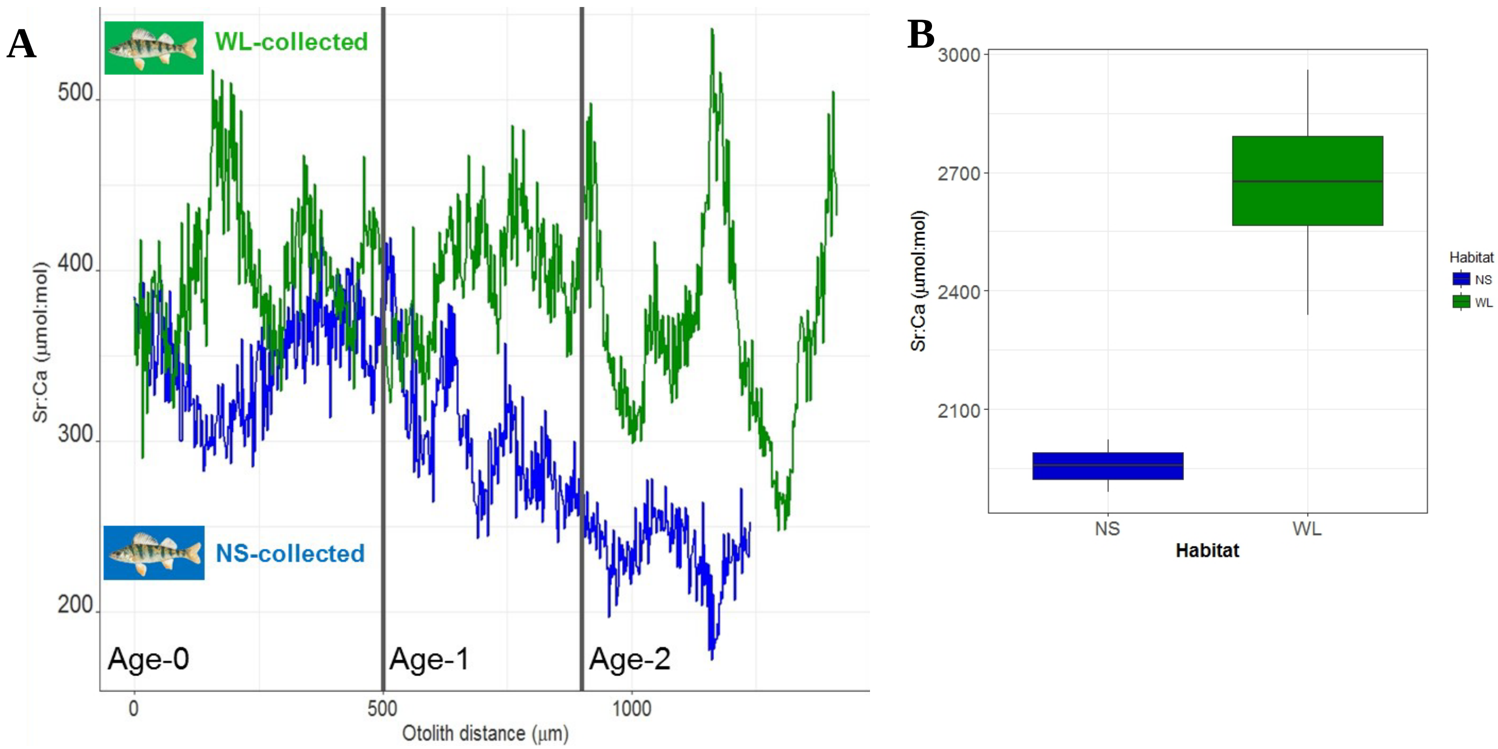

Figure 5. (A) Otolith Sr:Ca concentration across life for two individual age-2 yellow perch of approximately the same size (total length, ~230 mm); the green line represents Sr pattern from a fish collected in a southern region wetland (Lake Calumet), while the blue line represents Sr pattern from an individual collected in the adjacent nearshore Lake Michigan. Otolith distance is the distance (in μm) from core (representing birth) to edge (death). Vertical gray lines indicate approximate locations of yearly annuli. Otolith Sr:Ca throughout life is consistently higher in the wetland-collected individual, reflecting higher environmental Sr in wetland waters relative to the nearshore **(B)**.

After the proposed linkages are identified and quantified, we will model these linkages by incorporating information from multiple Lake Michigan wetland types. Models will be based on nearshore geomorphology, species life history traits, and habitat characteristics (e.g., wetland vegetation, water quality, sediment composition). These models will synthesize and contextualize our empirical results and will be critical to translating our findings to various stakeholder groups around the Lake Michigan basin.

Potential Applications, Benefits, and Impacts: Results from this project will greatly improve our understanding of Lake Michigan fish habitat linkages and their importance to the nearshore fish community. Furthermore, our research will inform future management and restoration strategies since Great Lakes coastal habitats are ecologically, recreationally, and economically important but have been dramatically altered by various human activities. Improved understanding of nearshore fish habitat usage and the origin of energy supporting nearshore sport fishes (e.g., coastal wetlands) will provide managers with new tools for prioritizing habitat preservation and restoration efforts for Lake Michigan. Finally, our results will provide resource managers new information for enhancing sport fish recruitment and production in Lake Michigan.

International Applications: As a binational resource, the Laurentian Great Lakes have major economic, social, political, and ecological value to the US and Canada. Although Lake Michigan is the only Great Lake contained totally within the US, it provides lessons relevant to the entire Great Lakes ecosystem. Our research on coastal wetland – nearshore linkages will provide information on food webs and sport fishes applicable to the entire Great Lakes basin.

Section C. Outputs

A. Media Coverage

"Non-native weatherfish are discovered in Roxana Marsh" (April 17, 2017) http://www.iiseagrant.org/newsroom/non-native-weatherfish-are-discovered-in-roxana-marsh/

"Happy 25 Days of Fishmas!" (December 23, 2016) http://greatlakestoday.org/post/happy-25-days-fishmas

B. Publications

In review

Evans, N. T., and G. A. Lamberti. In review. Freshwater fisheries assessment using environmental DNA: A primer on the method, its potential, and shortcomings as a conservation tool. *Fisheries Research*

In preparation

Intraspecific variation in coastal habitat use by yellow perch (*Perca flavescens*) in Lake Michigan

Modeling fish-mediated coastal wetland-nearshore habitat linkages in Lake Michigan

C. Presentations

Central Michigan University

Kosiara, J.K., J.J. Student, and D.G. Uzarski. 2017. Exploring coastal habitat-use patterns of Great Lakes yellow perch with otolith microchemistry. 60th International Conference on Great Lakes Research, Detroit, MI (Oral Presentation).

Sierszen, M., Schoen, L., Hoffman, J., Kosiara, J., and D. Uzarski. 2017. Support of coastal fishes by nearshore and coastal wetland habitats. 60th International Conference on Great Lakes Research, Detroit, MI (Oral Presentation).

Kosiara, J., and D.G. Uzarski. 2017, Variation in life history of Great Lakes yellow perch revealedby otolith microchemistry. Institute for Great Lakes Research, 5th Annual Student Research Symposium, Central Michigan University, Mt. Pleasant, MI (Poster).

Kosiara, J., J. Student, and D.G. Uzarski. 2017. Movement of yellow perch among coastal habitats of the Great Lakes explored with otolith microchemistry. Michigan Chapter Meeting of the American Fisheries Society, Mackinaw City, MI (Oral Presentation).

Kosiara, J.M., D.G. Uzarski, and J.J. Student. 2016. Assessment of yellow perch movement between coastal wetland and nearshore waters of the Great Lakes. 59th Annual Conference on Great Lakes Research, Guelph, ON (Oral Presentation).

Kosiara, J.M. and D.G. Uzarski. 2016. Assessment of yellow perch movement between coastal wetland and nearshore waters using otolith microchemistry. CMU Institute for Great Lakes Research 4th annual Student Research Symposium (Poster).

Kosiara, J.K., L.S. Schoen, M.J. Cooper, J.J. Student, and D.G. Uzarski. 2015. Patterns in trace element concentrations of nearshore and wetland waters of northern Lake Huron. 58th Annual Conference on Great Lakes Research, Burlington, VT (Poster).

Kosiara, J.K., L.S. Schoen, M.J. Cooper, J.J. Student, and D.G. Uzarski. 2015. Patterns in trace element concentrations of nearshore and wetland waters of northern Lake Huron. Great Lakes Science in Action Symposium (Poster).

Kosiara, J.M., L.S. Schoen, M.J. Cooper, J.J. Student, and D.G. Uzarski. 2015. Patterns in trace element concentrations of nearshore and wetland waters in northern Lake Huron. CMU Institute for Great Lakes Research 3rd annual Student Research Symposium (Oral Presentation).

University of Notre Dame

O'Reilly, K.E., J.J. Student, C.J. Houghton, P.S. Forsythe, and G. A. Lamberti. 2017. Life on the edge: does fish movement among habitats link Great Lakes coastal wetland and nearshore food webs? Society for Freshwater Science Annual Meeting (Oral Presentation).

Conard, W., B. Gerig, L. Lovin, and G. A. Lamberti, 2017. Heavy metal concentrations in Lake Michigan prey fish. Society for Freshwater Science Annual Meeting (Poster).

Lamberti**,** G. A., A. Moerke, M. Brueseke, L. Johnson, N. Danz, D. Uzarski, J. Ciborowski, R. Howe, V. Brady, G. Niemi, K. O'Reilly, W. Conard, C. Ruetz, M. Cooper, J. Gathman, G. Grabas, K. O'Donnell, T. Redder, D. Tozer, and D. Wilcox. 2017. Great Lakes coastal wetland monitoring program: novel resources for scientists, agencies, and the public. Society for Freshwater Science Annual Meeting (Poster).

O'Reilly, K.E. 2017. It's Beginning to Look a Lot Like #25DaysofFishmas: #Scicomm through Education and Entertainment. 60th Annual International Association for Great Lakes Research Annual Meeting. (Oral Presentation).

O'Reilly, K.E., McReynolds, A.T., Stricker, C., and Lamberti, G.A. 2016. Quantifying coastal wetland - nearshore linkages for sustaining sport fishes in Lake Michigan. 59th Annual International Association for Great Lakes Research Annual Meeting. (Poster).

O'Reilly, K.E., McReynolds, A.T., Stricker, C., and Lamberti, G.A. 2016. Quantifying coastal wetland - nearshore linkages for sustaining sport fishes in Lake Michigan. Society for Freshwater Science Annual Meeting. (Poster).

McReynolds, A.T., O'Reilly, K.E., Lamberti, G.A. 2016. Food web structure of a recently restored Indiana wetland. University of Notre Dame College of Science Joint Annual Meeting. (Poster).

O'Reilly, K.E., McReynolds, A.T., Stricker, C., and Lamberti, G.A. 2015. Quantifying coastal wetland - nearshore linkages for sustaining sport fishes in Lake Michigan. 9th Biennial State of Lake Michigan/15th Annual Great Lakes Beach Association Joint Conference. (Poster).

O'Reilly, K.E., McReynolds, A.T., Stricker, C., and Lamberti, G.A. 2015. Quantifying coastal wetland - nearshore linkages for sustaining sport fishes in Lake Michigan. University of Notre Dame Advanced Diagnostics and Therapeutics Symposium. (Poster).

O'Reilly, K.E., McReynolds, A.T., Stricker, C., and Lamberti, G.A. 2015. Quantifying coastal wetland - nearshore linkages for sustaining sport fishes in Lake Michigan. Ecological Society of America Annual Meeting. (Poster).

<u>University of Wisconsin – Green Bay</u>

Houghton, C.J., P. Forsythe, G. Lamberti, D. Uzarski, J. Student, M. Berg, K. O'Reilly, C. Moratz. 2016. Coastal wetland-nearshore linkages of Green Bay sportfishes. 146th annual meeting of the American Fisheries Society (Oral Presentation).

Moratz, C., P. Forsythe, C. Houghton, G. Lamberti, K. O'Reilly, D. Uzarski, J. Student, M. Berg. 2016. Growth and ecology of bowfin (*Amia calva*) in Green Bay, Lake Michigan. 146th annual meeting of the American Fisheries Society (Oral Presentation).

Moratz, C., C. Houghton, P. Forsythe, G. Lamberti, D. Uzarski, M. Berg. 2016. Growth and ecology of bowfin (*Amia calva*) in Green Bay, Lake Michigan. 59th annual International Conference of Great Lakes Research (Oral Presentation).

Houghton, C.J., C. Moratz, P. Forsythe, G. Lamberti, D. Uzarski, M. Berg. 2016. Relative use of wetland and nearshore habitats by sportfishes of Green Bay. 59th annual International Conference of Great Lakes Research (Oral Presentation).

J. Shrovnal, P. Forsythe, C. Houghton, and C. Moratz. Growth Rate Analysis of Coastal Wetland and Near Shore Great Lakes Fish using Otolith Dating. (2016) 146th annual meeting of the American Fisheries Society.

J. Shrovnal, P. Forsythe, C. Houghton, and C. Moratz. Growth Rate Analysis of Coastal Wetland and Near Shore Great Lakes Fish using Otolith Dating. (2016) Green Bay Conservation Partners Spring Roundtable.

J. Shrovnal, P. Forsythe, C. Houghton, and C. Moratz. 2016. Growth Rate Analysis of Coastal Wetland and Near Shore Great Lakes Fish using Otolith Dating. Posters in the Rotunda (Poster).

J. Shrovnal, P. Forsythe, C. Houghton, and C. Moratz. 2016. Growth Rate Analysis of Coastal Wetland and Near Shore Great Lakes Fish using Otolith Dating. UW-Green Bay Academic Excellence Symposium (Poster).

J. Shrovnal, P. Forsythe, C. Houghton, and C. Moratz. 2016. Growth Rate Analysis of Coastal Wetland and Near Shore Great Lakes Fish using Otolith Dating. 45th annual meeting of the Wisconsin chapter of the American Fisheries Society (Poster).

Barlament, J., P. Forsythe, C. Houghton¸ C. Moratz, E. Weber. 2016. Bowfin feeding ecology in Green Bay: Diet analysis of an underappreciated native fish predator. 45th annual meeting of the Wisconsin chapter of the American Fisheries Society (Poster).

D. Post-doctoral Scholars and Undergraduate/Graduate Students Involved

Central Michigan University
Mr. Lee Schoen, M.S.
Ms. Jessica Kosiara, M.S. candidate
Jenna MacDonald, B.S.
Adam Schiller, B.S.
Alaina Miles, B.S.
Megan Lewan, B.S.

Loyola University Chicago
Ms. Nicole Furlan, M.S. student
Ms. Chantel Caldwell, M.S. student
Ms. Elida Romo, undergraduate student

University of Notre Dame
Ms. Katherine O'Reilly, Ph.D. student, Biological Sciences
Ms. Amelia McReynolds, B.S.
Ms. Melissa Cross, B.S
Mr. Karl Sclacht, B.S.
Mr. Nicholas Kiene, B.S.
Ms. Margaret Hartlage, B.S.

University of Wisconsin – Green Bay
Dr. Christopher Houghton, Postdoctoral Associate

Mr. Collin Moratz, M.S., Environmental Sciences and Policy
Ms. Josephine Barlament, B.S.
Ms. Amy Cottrell, B.S.
Ms. Jacqueline Derepkowski, B.S.
Mr. Dalton Hendricks, B.S.
Mr. Paul Meer, B.S.
Mr. Mikhael Parrson, B.S.
Mr. Jeremiah Shrovnal, B.S.
Ms. Emily Weber, B.S.
Mr. Ryan Wehse, B.S.
Mr. Touhue Yang, B.S.

E. Related projects

Coastal Wetland Monitoring: Continued Implementation by the GLCWC. 2015-2020. U.S. Environmental Protection Agency. D. G. Uzarski (PI), G A. Lamberti (co-PI), and 13 others. $10,000,000

F. Awards and Honors

Katherine O'Reilly – Norman S. Baldwin Fishery Science Scholarship (International Association for Great Lakes Research, $3000), Outstanding Graduate Student Teaching Award (University of Notre Dame Kaneb Center for Teaching and Learning), General Endowment Award (Society for Freshwater Science, $1000), 1st place - State of Lake Michigan/Great Lakes Beach Association Student Poster Contest ($250)

Amelia McReynolds - Mr. and Mrs. Frank McDonald Undergraduate Research Award (University of Notre Dame College of Science)

Jessica Kosiara - CMU Dean of Science and Engineering Research Assistantship

G. Patents/Licenses: N/A

References

Albert DA, Wilcox DA, Ingram JW, and Thompson TA. 2005. Hydrogeomorphic classification for Great Lakes Coastal Wetlands. *J. Great Lakes Res*. 31, 129-46.

Brazner JC, Campana SE, and Tanner DK. 2004. Habitat fingerprints for Lake Superior coastal wetlands derived from elemental analysis of yellow perch otoliths. *Trans. Am. Fish. Soc.*133, 692-704.

Brazner JC, Campana SE, Tanner DK, and Schram ST. 2004. Reconstructing habitat use and wetland nursery origin of yellow perch from Lake Superior using otolith elemental analysis. *J. Great Lakes Res*. 30, 492-507.

Bouchard V. 2007. Export of organic matter from a coastal freshwater wetland to Lake Erie: an Extension of the Outwelling Hypothesis. *Aquat. Ecol*. 41, 1-7.

Cabana G, and Rasmussen JB. 1994. Modeling food chain structure and contaminant bioaccumulation using stable nitrogen isotopes. *Nature* 372, 255–257.

Campana, SE. 1999. Chemistry and composition of fish otoliths: pathways, mechanisms and applications. *Mar. Ecol. Prog. Ser.* 188, 263-297.

Chaloner DT, Martin KM, Wipfli MS, Ostrom PH, and Lamberti GA. 2002. Marine carbon and nitrogen isotopes in southeastern Alaska stream food webs: evidence from artificial and natural streams. *Can. J. Fish. Aquat. Sci*. 59, 1257-1265.

Chaloner DT, Lamberti GA, Merritt RW, Mitchell NL, Ostrom PH, and Wipfli MS. 2004. Variation in responses to spawning Pacific salmon among three southeastern Alaska streams. *Freshw. Biol.* 49, 587-599.

Chubb SL and Liston CR. 1986. Density and Distribution of Larval Fishes in Pentwater Marsh, a Coastal Wetland on Lake Michigan. *J. Great Lakes Res.* 12, 332-43.

Cooper MJ, Steinman AD and Uzarski DG. 2013. Influence of geomorphic setting on the metabolism of Lake Huron fringing wetlands. *Limnol. Oceanogr.* 58, 452-464.

Cvetkovic M and Chow-Fraser P. 2011. Use of ecological indicators to assess the quality of Great Lakes coastal wetlands. *Ecol. Indic.* 11, 1609-22.

Deegan LA. 1993. Nutrient and energy transport between estuaries and coastal marine ecosystems by fish migration. *Can. J. Fish. Aquat. Sci.* 50, 74-9.

DeNiro MJ and Epstein S. 1981. Influence of diet on the distribution of nitrogen isotopes in animals. *Geochim. Cosmochim. Acta.* 45, 341–351.

Forsythe PS, Doll J, and Lauer TE. 2012. Abiotic and biotic mechanisms responsible for yellow perch recruitment in southern Lake Michigan, 1984 – 2006. *N. Am. J. Fish. Manage.* 19, 389-399.

Friedrich LA and Halden NM. 2008. Alkali element uptake in otoliths: a link between the environment and otolith microchemistry. *Environ. Sci. Technol.* 42, 3514–3518.

Friedrich LA and Halden NM. 2010. Determining exposure history of Northern Pike and Walleye to tailings effluence using trace metal uptake in otoliths. *Environ. Sci. Technol*. 44, 1551-1558.

Gende SM, Edwards RT, Willson MF, and Wipfli MS. 2002. Pacific salmon in aquatic and terrestrial ecosystems. *BioScience* 52, 917-28.

Goforth RR and Carman SM. 2005. Nearshore Community Characteristics Related to Shoreline Properties in the Great Lakes. *J. Great Lakes Res.* 31, Supplement 1, 113-128.

Halden NM, Babaluk JA, Campbell JL, and Teesdale WJ. 1995. Scanning proton microprobe analysis of strontium in an arctic charr, *Salvelinus alpinus*, otolith: implications for the interpretation of anadromy. *Environ. Biol. Fishes* 43, 333–339.

Halden NM, Babaluk JA, Kristofferson AH, Campbell JL, Teesdale WJ, Maxwell JA, and Reist JD. 1996. Micro-PIXE studies of Sr zoning in arctic char otoliths: migratory behavior and stock discrimination. *Nuc. Instrum. Methods Phys. Res.* 110, 592–597.

Hanowski JM, Danz NP, Howe RW, Regal RR and Niemi GJ. 2007. Considerations for Monitoring Breeding Birds in Great Lakes Coastal Wetlands. *J. Great Lakes Res.* 33, 245-52.

Hecnar SJ. 2004. Great Lakes wetlands as amphibian habitats: A review. *Aquat. Ecosyst. Health Manage.* 7, 289-303.

Hellstrom J, Paton C, Woodhead JD and Hergt JM. 2008. Iolite: software for spatially resolved LA-(quad and MC) ICPMS analysis. In Laser Ablation ICP–MS in the Earth Sciences: Current Practices and Outstanding Issues (P. Sylvester, ed.). Mineral. Assoc. Can. Short Course ser. 40, 343-348.

Herdendorf C. 1990. Great Lakes estuaries. *Estuaries* 13, 493-503.

Hoffman JC, Peterson GS, Cotter AM, and Kelly JR. 2010. Using stable isotope mixing in a Great Lakes coastal tributary to determine food web linkages in young fishes. *Estuaries Coasts* 33, 1391-405.

Kalish JM. 1989. Otolith microchemistry: validation of the effects of physiology, age and environment otoliths composition. *J. Exp. Mar. Biol. Ecol.* 132, 151-178.

Keough JR, Hagley CA, Ruzycki E, and Sierszen ME. 1998. δ13C composition of primary producers and role of detritus in a freshwater coastal ecosystem. *Limnol. Oceanogr*. 43, 734–740.

Keough JR, Sierszen ME, and Hagley CA. 1996. Analysis of a Lake Superior coastal food web with stable isotope techniques. *Limnol. Oceanogr.* 41, 136–143.

Krieger KA, Klarer DM, Heath RT, and Herdendorf CE. 1992. Coastal wetlands of the Laurentian Great Lakes: Current knowledge and research needs. Preface: A call for research on Great Lakes coastal wetlands. *J. Great Lakes Res.* 18, 525-528.

Lamberti GA, Chaloner DT, and Hershey AE. 2010. Linkages among aquatic ecosystems. *J. N. Am. Benthol. Soc.* 29, 245-63.

Maynard L. and Wilcox DA. 1997. Coastal wetlands of the Great Lakes. State of the Lakes Ecosystem Conference '96. Environment Canada and U.S. Environmental Protection Agency Report EPA 905-R-97-015b.

Mitchell NL and Lamberti GA. 2005. Responses in dissolved nutrients and epilithon abundance to spawning salmon in Southeast Alaska streams. *Limnol. Oceanogr.* 50, 217-227.

Mitsch WJ and Gosselink JG. 1993. Wetlands. Van Nostrand Reinhold. New York. 722 pp.

Mumby PJ, Edwards AJ, Arias-González JE, Lindeman KC, Blackwell PG, Gall A, and Llewellyn G. 2004. Mangroves enhance the biomass of coral reef fish communities in the Caribbean. *Nature*, 427, 533-536.

Pangle KL, Ludsin SA, and Fryer BJ. 2010. Otolith microchemistry as a stock identification tool for freshwater fishes: testing its limits in Lake Erie. Can. J. Fish. Aquat. Sci. 67, 1475-1489.

Pearce NJG, Perkins WT, Westgate JA, Gorton MP, Jackson SE, et al. 1997. A compilation of new and published major and trace element data for NIST SRM 610 and NIST SRM 612 glass reference materials. *Geostand. Newsl.* 21, 115–144.

Phillips DL and Gregg JW. 2003. Source partitioning using stable isotopes: coping with too many sources. *Oecologia* 136, 261–269.

Phillips DL, Newsome SD, and Gregg JW. 2005. Combining sources in stable isotope mixing models: alternative methods. *Oecologia* 144, 520–527.

Rydell JJ, Lauer TE, and Forsythe PS. 2010. The influence of abiotic factors on gill-net catch rates of yellow perch in southern Lake Michigan. *Fish. Manage. Ecol.* 17, 284-290.

Shiller AM. 2003. Syringe filtration methods for examining dissolved and colloidal trace element distributions in remote field locations. *Environ. Sci. Technol.* 37: 3953–3957.

Sierszen ME, Morrice JA, Moffett MF, and West CW. 2004. Benthic versus planktonic foundations of three Lake Superior coastal wetland food webs. *J. Great Lakes Res.* 30, 31–43.

Sierszen ME, Peterson GS, Trebitz AS, Brazner JC, and West CW. 2006. Hydrology and nutrient effects on food web structure in ten Lake Superior coastal wetlands. *Wetlands* 26, 951–964.

Sierszen ME, Brazner JC, Cotter AM, Morrice JA, Peterson GS, and Trebitz AS. 2012. Watershed and lake influences on the energetic base of coastal wetland food webs across the Great Lakes Basin. *J. Great Lakes Res.* 38, 418-428.

SOLEC. 2007. State of the Lakes Ecosystem Conference Final Report. Environment Canada and United States Environmental Protection Agency. EPA 905-R-07-003.

Uzarski DG, Burton TM, Cooper MJ, Ingram J and Timmermans S. 2005. Fish habitat use within and across wetland classes in coastal wetlands of the five Great Lakes: development of a fish based index of biotic integrity. *J. Great Lakes Res.* 31, 171–187.

Vadeboncoeur Y, McIntyre PB, and Vander Zanden MJ. 2011. Borders of biodiversity: Life at the edge of the world's large lakes. *Bioscience* 61, 526-37.

Vander Zanden MJ, and Rasmussen JB. 2001. Variation in δ15N and δ13C trophic fractionation: implications for aquatic food web studies. *Limnol. Oceanogr.* 46, 2061–2066.

Vander Zanden MJ, Vadeboncoeur Y, and Chandra S. 2011. Fish reliance on littoral–benthic resources and the distribution of primary production in lakes. *Ecosystems* 14, 894-903.

Whiteledge GW. 2009. Otolith microchemistry and isotopic composition as potential indicators of fish movement between the Illinois River drainage and Lake Michigan. *J. Great Lakes Res.* 35, 101-106.

Wieten AC, Cooper MJ, Parker AD, and Uzarski DG. 2012. Great Lakes coastal wetland habitat use by seven turtle species: influences of wetland type, vegetation, and abiotic conditions. *Wetlands Ecol. Manage.* 20, 47-58.

Wilcox DA. 1995. Wetland and aquatic macrophytes as indicators of anthropogenic hydrologic disturbance. *Nat. Areas J.* 15, 240-248.

Woodhead J, Hellstrom J, Hergt J, Greig A, and Maas R. 2007. Isotopic and elemental imaging of geological materials by laser ablation Inductively Coupled Plasma mass spectrometry. *J. Geostand. Geoanal. Res.* 31, 331-343.

Zeigler JM, and Whiteledge GW. 2010. Assessment of otolith chemistry for identifying source environment of fishes in the lower Illinois River, Illinois. *Hydrobiologia* 638, 109-119.

Zimmerman CE, and Reeves GH. 2000. Population structure of sympatric anadromous and nonanadromous *Oncorhynchus mykiss*: evidence from spawning surveys and otoliths microchemistry. *Can. J. Fish. Aquat. Sci*. 57, 2152-2162.