Project Title: ECOFORE 20006: Forecasting the Causes, Consequences and remedies for Hypoxia in Lake Erie

Principal Investigator: Don Scavia, University of Michigan

Overview and Objectives

The overall objective of this project is to create, test, and apply models to forecast how multiple stresses influence hypoxia formation and ecology of Lake Erie's Central Basin, with an emphasis on fish production potential. These models will integrate the multiple factors that interact to create hypoxia on Lake Erie, such as surface water flow, phosphorus input, lake dynamics, climate variation, fish movement patterns and fish and Dreissenid biology and physiology. The forecasts will be conducted within an Integrated Assessment (IA) framework, which is a formal approach to synthesizing existing natural and social scientific information in the context of a natural resources policy or management question.

Accomplishments

WATERSHED TEAM

Many activities in the Watershed Team are being conducted and completed concurrently. Nutrient (TP, NO2+NO3, TKN, TN, TSS, and SRP) loading data are being compiled and summarized to be used as model inputs for the Hypoxia Team. Watershed nitrogen (N) and P budgets are being created to better understand N and P sources over time as well as to aid in forecasting scenarios. The Distributed Large Basin Runoff Model (DLBRM) and the Soil and Water Assessment Tool (SWAT) are being parameterized and calibrated to be used in climate and land management practice change forecasting scenarios.

Nutrient loading efforts

Monthly and daily river export load series for the Raisin, Maumee, Sandusky, Vermilion, Cuyahoga, and Grand Rivers have been completed for the period of record. Missing data have been filled in, and the complete time series have been posted to the project website.

Daily Lake Erie nutrient loading estimates for CY2005 at 26 spatial nodes have been completed. CY1976 nutrient loads have been reconstructed from archived historical data. All point source, atmospheric, and tributary data for 2006 and 2007 has been received and daily load estimates for these years are proceeding.

N and P budgets

For all watersheds of the Lake Erie Basin in the U.S., historical N and P budgets were completed for agricultural census years from 1934 to 1974 at every decennial, and from 1974 to 2002 at every five years. Nitrogen budgets were estimated using net anthropogenic N inputs approach (NANI). NANI was constructed by quantifying all known anthropogenic N inputs (fertilizer, crop fixation, atmospheric deposition, imports of N in crop and animal products), outputs (volatilization of N from applied manure and fertilizer and crop senescence, and exports of N in food and feed) as well as the net balances between inputs and outputs, resulting in an estimate of net anthropogenic N inputs (NANI). Phosphorus budgets (NAPI) were similarly constructed.

In addition, we developed relationships between watershed P inputs and river TP exports for the selected watersheds of the Lake Erie Basin (Huron, Raisin, Maumee, Sandusky, Cuyahoga, and Grand in OH) for 5 agricultural census years from 1978 to 2002 to figure out how the input: export relationship has changed over time and how the changes in relationships would be linked to the re-occurrence of the hypoxia in Lake Erie.

Multiple databases of land use, soil, digital elevation model (DEM), hydrography, and agricultural management practices have been acquired, processed, and analyzed to develop dynamic input parameters for the DLBRM and the revised universal soil loss equation (version 2) (RUSLE2) for the 6 watersheds on the U.S. side (Grand-OH, Cuyahoga, Sandusky, Maumee, Huron-MI, and Raisin). We have acquired and processed multiple databases of land use, soil, digital elevation model (DEM), and hydrography for the Grand River –Ontario. A computer program was written to spatially link the Ontario soil attribute database with the polygon database for extracting the soil input parameters. Input parameters for the DLBRM were derived.

We have also built basic model application databases (daily meteorology, land use, soils, elevation, and hydrography) for all 17 U.S. Lake Erie watersheds, and we completed DLBRM daily calibrations for five Lake Erie watersheds: Huron, Raisin, Maumee, Sandusky, and Grand (Ohio). We are now calibrating the DLBRM for the remaining 12 U.S. Lake Erie watersheds. We estimated sediment and nutrient transport for two non-Erie watersheds and are doing the same now for the Maumee watershed on Lake Erie. We are now adding transport mechanics to the DLBRM. We developed automatic near real time "Resource Shed" processing for 18 watersheds, including the five Erie watersheds mentioned previously. Resource shed maps for the last 31 days are available daily and will soon be accessible via the internet.

SWAT models have been developed, calibrated, and validated for the same 6 Lake Erie watersheds on the U.S. side being modeled by DLBRM – Huron, Raisin, Maumee, Sandusky, Cuyahoga, and Grand. Overall, the SWAT models' performance is strong when compared to observed stream discharge, sediment loads, and nutrient loads (total phosphorus, soluble reactive phosphorus, total nitrogen, and nitrate). Currently, agricultural best management practice scenarios are being developed. Then, best management practices will be simulated by SWAT to compare their effectiveness at reducing river nutrient export loads to Lake Erie.

HYPOXIA TEAM

The Hypoxia Team is developing four levels of models, representing a range of complexity, intended to relate the attributes (magnitude, duration, spatial extent) of hypoxia in the central basin of Lake Erie to a range of stressors (physical conditions, external loadings of nutrients, and Dreissenid densities). The four models in order of increasing complexity are the following:

1. Level 1 – one-dimensional model of the central basin with 1D thermal model and simple first-order deoxygenation rate in water column and zero-order SOD, forced by meteorological input alone;
2. Level 2 – one-dimensional model of the central basin with 1D thermal model and simple phosphorus-chlorophyll-DO process model, forced by meteorological input and external phosphorus and organic carbon loading;
3. Level 3a – Three-dimensional model composed of a 3D hydrodynamic – temperature model linked to the level two simple phosphorus-chlorophyll-DO process model, forced by hydrological and meteorological input and external phosphorus loading; and
4. Level 3b -- Three-dimensional model composed of a 3D hydrodynamic – temperature model linked to an advanced eutrophication model (including Dreissenids and Cladophora), forced by hydrological and meteorological input, external nutrient and organic carbon loading, and Dreissenid density.

The level 1 model is complete and a peer-reviewed manuscript has been submitted to the Journal of Great Lakes Research (see publication list). The level 2 hypoxia model was developed and applied for the period 1982-2005. The goal of this model was to add complexity to the level 1 model (focused primarily on thermal structure) to assess the relative role of growth and decay processes in the lower food web on hypoxia. The level 2 model maintains the 1-dimensional vertical domain. This framework incorporated basin phosphorus and carbon loads, available light (including phytoplankton self-shading), and the mixing and temperature structures from the 1D thermal model. The model estimates phytoplankton biomass, zooplankton biomass, autochthonous detritus, and dissolved oxygen by quantifying nutrient uptake and cycling in the water column. The application was calibrated for 2005 observations, and confirmed using data from 1982-2004.

A three-dimensional, 2 km grid hydrodynamic model of Lake Erie was developed (based on the Princeton Ocean Model) with a goal to calculate lake-wide circulation and thermal structure. Daily inflows at 22 major tributaries and hourly meteorological data at 12 land stations and 3 meteorological buoys were assembled, edited and interpolated to create gridded forcing functions for the hydrodynamic model for 2004, 2005, 2007 and 1976. Complete 3D hydrodynamic model simulations were accomplished for all four years and model results are now being compared with observations of temperature. We also continued to analyze 2005 and 2007 temperature observations to investigate frequent occurrences of an unusual thermocline shape in the central basin those years. This modeling work has also demonstrated the potential importance of nearshore-offshore gradients of important biogeochemical materials, making the exchange of material between the nearshore and offshore an important aspect to be considered in our level 3 modeling.

The level 3a and 3b models are being developed to incorporate the 3-dimenstional aspects of the problem as well as two different levels of process complexity. The level 3a model is intended to assess how the food web impacts on dissolved oxygen resources vary spatially, particularly in near shore regions. It has been initially calibrated for 2005. This model uses a three dimensional spatial domain, and a simplified limnology kinetic framework, driven by SRP and TP loads from the major tributaries in Lake Erie. The model has also been dynamically linked to the Lake Erie 3D hydrodynamic model at the same spatial resolution to utilize the hourly hydrodynamic transport and temperature regime from that model.

We have also begun developing the code for our level 3b model, which will be a complex hypoxia model, incorporating Dreissenids and nearshore lower food web dynamics that may be different from offshore dynamics. This model will be linked to the same 3D hydrodynamic model being used for the level 3A model. We have also compiled forcing function data (including loads of all state variables from all main tributaries) for the four master years to which this model will be calibrated and confirmed.

Additionally, we have continued to assess and incorporate uncertainty in our modeling applications. We have conducted preliminary, exploratory analyses of our level 1 model using PEST (a parameter estimation and optimization software) and WinBUGS (a Bayesian reference software). These analyses are intended to assess the variability of the calibration terms in the model.

ECOLOGICAL EFFECTS TEAM

The Ecological Effects Team is developing a suite of models to explore how hypolimnetic hypoxia impacts ecological interactions and fisheries production in the central basin of Lake Erie. We are using a parallel modeling approach including: 1) Empirical, statistical models; 2) Bioenergetics models (Growth rate potential models [GRP] and Individual-based models [IBM]); and 3) Foodweb models (Ecopath with Ecosim) and CASM [Comprehensive Aquatic Simulation Model]). Our ultimate goal is to apply these models to forecast how fish production in Lake Erie would be affected by potential, future nutrient loading scenarios and hypoxia dynamics.

During the initial phase of the project, we primarily work to develop and parameterize ecological models. To accomplish this goal, we rely on a variety of existing data: physical measures (temperature, water clarity, oxygen concentration), fisheries harvest data, annual fisheries-independent stock assessments, hydro-acoustic estimates of fish biomass, benthic macroinvertebrate surveys, zooplankton surveys (from optical plankton counter, net collections and pump samples), and fish samples (midwater and bottom trawl caught fish allowing for quantification of species-specific vertical distributions and diet contents). Most of these data were collected through the IFYLE (International Field Years on Lake Erie) program and state/provincial agency-based monitoring efforts. Most of the data which we use for model development and parameterization have been previously collected and analyzed (primarily through IFYLE-related efforts). However, some previously collected data required compilation, processing and analyses before they can be used for model development and parameterization. To this end, we analyzed biological data (zooplankton, benthic macro-invertebrate, and fish) and compiled historical fisheries and fisheries-independent data (including manual data entry from paper copies).

In applying our models, we build directly on the efforts of other project components (i.e., we use output from Watershed and Hypoxia forecasting models as input for our models). As these other project components have realized model outputs, our modeling efforts have ramped up. During 2008, we hired three postdoctoral research associates (Arend [Purdue; Bioenergetics modeling and CASM], Hosack [Ohio State; Empirical analyses], and Zhang [NOAA-GLERL and U. Michigan; EcoPath]). Arend and Hosack subsequently moved on to other positions and two other postdoctoral research associates were hired in 2009 (Pangle, Ohio State University; Bioenergetics and Empirical modeling) and 2010 (Goto, Purdue University; Bioenergetics modeling).

Empirical analyses

We have explored the effects of hypoxia on commercial catch rates of walleye using both commercial and fishery independent data in Lake Erie. Hypoxia, as estimated by the 1-D model, positively correlates with annual catch rates of walleye. Monthly analyses, however, show that catch rate and harvest response to hypoxia varies by region. Spatial data available from IFYLE 2005 shows that hypoxia is constrained to the central basin, and fishery independent survey data suggests that the probability of walleye occurrence exhibits unimodal relationships with respect to bottom dissolved oxygen and temperature. Ongoing work investigates how spatial IFYLE abiotic data relates to walleye distribution and the distribution of a primary prey species, rainbow smelt.

Bioenergetic models

To date, we have developed bioenergetics growth rate potential models for emerald shiner, rainbow smelt, round goby, yellow perch, and walleye. We have applied these models 1) using physical, chemical and biological data collected during 2005/2007 IFYLE cruises in central Lake Erie and 2) using output from 1-dimensional hypoxia models. Analyses based on output from 1-dimensional hypoxia models suggest that hypoxia effects on habitat quality vary inter-annually and differentially affect various species and life-stages. Analyses based on measured temperatures, oxygen concentrations and prey distributions suggest that hypoxia may affect habitat quality in unexpected ways. For example, while growth rate potential modeling suggests that hypoxia will limit the availability of hypolimnetic habitat for walleye, overall walleye habitat quality may ultimately benefit as both walleye and their prey are constricted into a narrow depth range just above the hypoxic hypolimnion. Growth rate potential results have been synthesized and manuscripts have been drafted and submitted for publication.

Currently, our bioenergetics modeling efforts focus on dynamic individual-based models. We have incorporated dynamic behavior and movement into growth rate potential models. In addition, we are in the process of coding a holistic individual-based model. This model includes dynamics of rainbow smelt, walleye and yellow perch. It uses output from the 3-D water quality model as input to drive dynamics of fish movement, feeding, growth etc.

Foodweb models

CASM is a bioenergetics foodweb model useful for considering how stressor impacts on certain portions of a food-web may cascade to influence various other components. CASM Lake Erie (CASM-LE) is being developed and applied to evaluate how hypoxia impacts may cascade through the foodweb of Lake Erie's central basin. The impacts of hypoxia are somewhat different than many other stressors (e.g., contaminants) and this has required a restructuring and recoding of CASM. For instance, CASM-LE includes 3-layer vertical structure and allows foodweb constituents to move vertically. Further, CASM-LE includes a transect of vertically-structured foodweb compartments, moving from nearshore to offshore (thereby allowing for horizontal migration in response to hypoxia). We have used a variety of information to develop foodweb connections, initial model biomasses and physio-chemical conditions in CASM-LE (e.g., physical, chemical and biological data from IFYLE; literature values; agency reports). We have developed the structure of the CASM-LE foodweb and are currently applying the model.

Ecopath with Ecosim (EwE) is a suite of food web models that is designed to address ecological questions, to evaluate ecosystem effects of fishery management, to explore management policy options, and to evaluate effect of environmental changes, etc. Our Ecopath model focuses on the central basin of Lake Erie, and aims to evaluate the impacts of hypoxia on the lake ecosystem structure and function, and to explore water quality management and fisheries management scenarios. Our EwE team has been compiling and analyzing data since December 2008 to modify an existing Ecopath model for Lake Erie developed by Johnson and Zhu to investigate the effects of invasive species on the Lake Erie food web. Our EwE team has consulted lower trophic level experts regarding merging taxa into functional trophic groups in Ecopath. We estimated biomass of the lower trophic-level groups based on literature review and data sources including IFYLE field studies and the LEPAS (Lake Erie Plankton Abundance Study at Ohio State University). Currently, we are modeling 41 age/size groups of fish in our Ecopath model: biomass estimated from IFYLE trawl and acoustic data, and from surveys by state and provincial agencies. Our EwE team also is working with Lake Erie fisheries managers to design relevant management simulations and to ensure the final EwE model is a useful management tool.

Coordination and application

We have worked to ensure that our models and simulations are highly relevant for Lake Erie fisheries managers and that our collective analyses provide insight regarding tradeoffs between nutrient loading and fisheries production. We are engaged with managers via presentations at stakeholder meetings, personal conversations, and distribution of project literature (including series of questions for managers). While we have developed a multitude of models which have unique advantages and disadvantages, an ultimate goal of our efforts is to be able to compare model predictions. While this may not always be feasible (given the differential forms of our models), when possible we are facilitating model comparisons by initially structuring models in a similar manner.

Publications

Arend, K.K., D. Beletsky, J.V. DePinto, S.A. Ludsin, J.J. Roberts, D.K. Rucinski, D. Scavia, D.J. Schwab, and T.O. Höök. Hypolimnetic hypoxia in the central basin of Lake Erie: understanding seasonal and interannual effects on habitat quality of important fish species. Freshwater Biology.

Brandt, S.B., M. Constantini, S.E. Kolesar, S.A. Ludsin, D.M. Mason, C.M. Rae, and H. Zhang. Does hypoxia improve habitat quality for Lake Erie walleye? A bioenergetics perspective. Canadian Journal of Fisheries and Aquatic Sciences. Submitted

Croley II, T.E. and C. He. 2008. Ch.9. Spatially Distributed Watershed Model of Water and Materials Runoff. In: Ji, W. (ed). Wetland and Water Resource Modeling and Assessment: A Watershed Perspective. CRC Press, New York, p.99-112.

Croley, T. E., II, D. F. Raikow, C. He, and J. F. Atkinson, 2008. Hydrological Resource Sheds. Journal of Hydrologic Engineering (SCI) Vol.13 (9):873-885.

Croley, T. E., II, J. F. Atkinson, and D. F. Raikow, 2007. Hydrologic-hydraulic-ecologic resource sheds. Proceedings of Water Resources Management 2007 Conference, Honolulu, Hawaii, International Association of Science and Technology for Development, Calgary, Canada, August 20-22, 2007, 6 pp.

DeMarchi, C., T.E. Croley, C. He, and T.S. Hunter. 2009. Application of a distributed watershed hydrology and water quality model in the Great Lakes basin. Proceedings of the 7th International Symposium on Ecohydraulics 2009, Concepcion, Chile, January 12-16, 2009.

Han, H., N. Bosch, and J.D. Allan. Spatial and Temporal variation in phosphorus budgets for 24 watersheds in the Lake Erie and Lake Michigan basins. Biogeochemistry. In press.

Han, H., N. Bosch, and J. D. Allan. Historical trends in phosphorus loading to watersheds of the Lake Erie and Lake Michigan basins. Journal for Great Lakes Research. In preparation.

He, C. and T.E. Croley. 2010. Hydrological Resource Sheds and the U.S. Great Lakes Applications. Journal of Resources and Ecology, 1(1):1-6.

He, C. and T.E. Croley. 2010. Hydrological Resource Sheds and the U.S. Great Lakes Applications. /Journal of Resources and Ecology, 1(1):1-6./

He, C. and T.E. Croley II. 2008. Ch.10. Estimating Nonpoint Source Pollution Loadings in the Great Lakes Watersheds. In: Ji, W. (ed). Wetland and Water Resource Modeling and Assessment: A Watershed Perspective. CRC Press, New York, p.115-127.

He, C. and T.E. Croley II. 2007. Application of a Distributed Large Basin Runoff Model in the Great Lakes Basin. /Control Engineering Practice Vol. 15 (8): 1001-1011.

He, C. and T.E. Croley II. 2007. Integration of GIS and Visualization for Distributed Large Basin Runoff Modeling of the Great Lakes Watersheds. In: Scarpati and Jones (eds). Environmental Change and Rational Water Use. Orientación Gráfica Editora S.R.L., Buenos Aires, Argentina, pp. 247-260.

He, C., and C. DeMarchi. 2010. Modeling Spatial Distributions of Point and Nonpoint Source Pollution Loadings in the Great Lakes Watersheds. International Journal of Science and Engineering 2(1):24-30.

He, C. C. DeMarchi, and T.E. Croley II. 2008. Modeling Spatial Distributions of Nonpoint Source Pollution Loadings in the Great Lakes Watersheds by Using the Distributed Large Basin Runoff Model. Proc. Papers of American Water Resources Association GIS and Water Resources V, San Mateo, California, March 17-19.

Kidwell, D.M., A.J. Lewitus, E.B. Jewett, S. B. Brandt and D.M. Mason. 2009. Ecological impacts of hypoxia on living resources. Journal of Experimental Marine Biology and Ecology. 381:S1-S3.

Lewitus, A.J., D.M. Kidwell, E.B. Jewett, S. B. Brandt and D.M. Mason (Editors). 2009. Ecological Impacts of Hypoxia on Living Resources. Special Supplement of the Journal of Experimental Marine Biology and Ecology. 381: 215 pages.

McCone, M. T.A. Endreny, J. Atkinson, J. DePinto, and J. Manno. 2006. "Role of International Policy and Science in Addressing Great Lakes Management and Lake Erie Eutrophication", in Hydrology and Water Law – Bridging the Gap, Edited by J. S. Wallace and P. Wouters, Title in the Water Law and Policy Series, Edited by P. Wouters and S. Vinogradov, International Water Association Publishing, London UK, pp. 78-107.

Pothoven, S.A., H.A. Vanderploeg , S.A. Ludsin, T.O. Höök, and S.B. Brandt. 2009. Feeding ecology of emerald shiners and rainbow smelt in central Lake Erie. Journal of Great Lakes Research. 35:190-198.

Richards, R.P., D.B. Baker, J.P. Crumrine, and A.M. Stearns. Unusually large loads in 2007 from the Maumee and Sandusky Rivers, tributaries to Lake Erie. Journal of Soil and Water Conservation. Accepted for publication.

Roberts, J.J., S.B. Brandt, D. Fanslow, S.A. Ludsin, S. Pothoven, D. Scavia, and T.O. Höök. Growth and condition of yellow perch in response to hypoxia: Synthesis of lab and field results. CJFAS.

Roberts, J.J., T.O. Höök, S.A. Ludsin, S.A. Pothoven, H.A. Vanderploeg, and S. B. Brandt. In press. Effects of hypolimnetic hypoxia on foraging and distributions of Lake Erie yellow perch. Journal of Experimental Biology and Ecology.

Rucinski, Daniel K., D. Beletsky, J>V. DePinto, D.J. Schwa, and D. Scavia. 2010. A simple 1-dimensional, climate based dissolved oxygen model for the central basin of Lake Erie. Submitted to *Journal of Great Lakes Research* (in review).

Schwab, D.J., D. Beletsky, J.V. DePinto, and D.M. Dolan. 2009. A hydrodynamic approach to modeling phosphorus distribution in Lake Erie. Journal of Great Lakes Research, 35(1):50-60.

Wang, J., H. Hu, D. Schwab, G. Leshkevich, D. Beletsky, N Hawley, and A. Clites. Development of the Great Lakes Ice-circulation Model (GLIM): Application to Lake Erie in 2003-2004. Journal for Great Lakes Research. In review.

Vanderploeg, H.A., S.A. Ludsin, S.A. Ruberg, T.O. Höök, S.A. Pothoven, S. B. Brandt, G.A. Lang, J.R. Liebig, and J.F. Cavaletto . 2009a. Hypoxia affects spatial distributions and overlap of pelagic fish, zooplankton and phytoplankton in Lake Erie. Journal of Experimental Marine Biology and Ecology. 381:S92-S107.

Vanderploeg, H.A., S.A. Ludsin, J.F. Cavaletto, T.O. Höök, S.A. Pothoven, S.B. Brandt, J.R. Liebig and G.A. Lang. 2009b. Hypoxic zones as habitat for zooplankton in Lake Erie: Refuges from predation or exclusion zones? Journal of Experimental Marine Biology and Ecology. 381:S108-S120.

Xing, F., C. DeMarchi, T. E. Croley, and Y. Wang. Application of Distributed Large Basin Runoff Model to Lake Erie: Model Calibration and Analysis of Parameter Spatial Variation. In review.

Presentations

Allan, J.D., and H. Han. 2008. Phosphorus Loading to Lake Erie Watersheds: A Mass Balance Approach. 51st International Association for Great Lakes Research, May 19-23.

Arend, K., T. Höök, S. Ludsin, D. Rucinski, J. DePinto, and D. Scavia. 2009. Evaluating and forecasting effects of hypoxia on yellow perch habitat suitability in central Lake Erie. Indiana American Fisheries Society Annual Meeting, Indianapolis

Arend, K., T. Höök, S. Ludsin, D. Rucinski, J. DePinto, and D. Scavia. 2008. Effects of hypoxia on yellow perch habitat suitability in the central basin of Lake Erie. Midwest Fish and Wildlife Conference, Columbus

Arend, K., T. Höök, S. Ludsin, D. Rucinski, D. Beletsky, J. DePinto, D. Scavia, and D. Schwab. 2010. Seasonal and interannual effects of hypoxia on fish habitat quality in central Lake Erie. Michigan Chapter American Fisheries Society Annual Meeting.

Arend, K.K., T.A. Höök, S.L. Ludsin, D. Rucinsky, D. Beletsky, J. DePinto, D. Scavia, D. Schwab. 2009. Comparing Effects of Hypolimnetic Hypoxia on Yellow Perch and Rainbow Smelt Habitat Suitability in Central Lake Erie. International Association for Great Lakes Research (IAGLR) 52nd Annual Conference on Great Lakes Research, Toledo, OH.

Arend, K., T. Höök, S. Ludsin, D. Rucinski, D. Beletsky, J. DePinto, D. Scavia, and D. Schwab. 2009. Hypolimnetic hypoxia effects on yellow perch and rainbow smelt habitat quality in central Lake Erie. 2009. International Association for Great Lakes Research, Toledo, OH.

Beletsky, D., and D. Schwab. 2008. Modeling thermal structure in Lake Erie. IAGLR 2008. May 19-23, 2008, Peterborough, ON.

Bosch, N.S. and J.D. Allan. 2008. An analysis of catchment nutrient inputs compared to riverine exports. International Joint Commission workshop – Loading from landscapes and coastal margin effects: Developing a framework to evaluate consequences of land management strategies. Oregon, OH.

Bosch, N.S., H. Han, R.P. Richards, and J.D. Allan. 2009. Evaluating the impact of agricultural BMPs on riverine nutrient export to Lake Erie. North American Benthological Society, May 17-22.

Brandt, S.B., M. Costantini, S.A. Ludsin, D.M. Mason, and H.A. Vanderploeg. 2008. Spatially-explicit growth predictions to assess habitat quality of walleye during hypoxia in Lake Erie. Oral presentation at the International Association for Great Lakes Research 51st Annual Conference on Great Lakes Research, Peterborough, ON. May 20.

Brandt, S.B., M. Costantini, S.A. Ludsin, D.M. Mason, and H.A. Vanderploeg. 2008. Spatially-explicit growth predictions to assess habitat quality of walleye during hypoxia in Lake Erie. International Association for Great Lakes Research, Peterborough, Ontario

Brandt, S., D. Schwab, and T. E. Croley II, 2007. Nearshore Water Quality: Linkages between Watersheds and Offshore Processes, International Joint Commission Workshop on 'Nearshore Processes,' Dearborn, Michigan, November 19-20.

Croley, T. E., II, 2008. Great Lakes Hydrologic Modeling, Hydrology Laboratory, NWS Office of Hydrology, Ann Arbor, Michigan, March 6.

Croley, T. E., II, 2007. GLERL's Hydrology Program, GLERL-NCEP-NWS-NOS Meeting, Ann Arbor, Michigan, November 28.

Croley, T. E., II, and T. S. Hunter, 2007. Great Lakes Hydrology Modeling with the Advanced Hydrologic Prediction System, Michigan Technological Institute, Houghton, Michigan, October 8.

DeMarchi, C., T.E. Croley, T. Hunter., and C. He. 2009. Application of a Distributed Watershed Hydrology and Water Quality Model in the Great Lakes Basin. The International Conference on "Science and Information Technologies for Sustainable Management of Aquatic Ecosystems" (Heic2009): joint meeting of the 7th International Symposium on Ecohydraulics and the 8th International Conference on Hydroinformatics, Concepcion, Chile, January 12-16, 2009.

DePinto, J.V., M.T. Auer, T.M. Redder, E. Verhamme. 2009. "Coupling the Great Lakes Cladophora Model (GLCM) with a whole lake Advanced Eutrophication Model (A2EM-3D)." Presented at 53rd Annual Conference on Great Lakes Research, Toledo University, Toledo, OH (May 18-June 22, 2009).

DePinto, J.V. "Nearshore phosphorus cycling and algal growth in the western basin of Lake Erie. 2009. Invited talk at the Western Lake Erie Basin Conference, Oregon, OH, (March 10-11, 2009).

DePinto, J.V. "How does Lake Erie process the phosphorus loading it receives, and has the dreissenid invasion changed things?" invited presentation to the Lake Erie Phosphorus Task Force, Columbus, OH (October 1, 2008).

DePinto, J.V.1, Vanderploeg, H.A.2, and AUER, M.T. 2008. Cladophora and open-water "desertification": Do Dreissenids play a role? Paper presented at the 51th Annual Conference on Great Lakes Research, Trent University, Peterborough, ON (May 19-June 23, 2008).

Dolan, D.M. and R.P. Richards. 2009. Spatially detailed nutrient load estimates for Lake Erie in 2005. 52nt Conference on Great Lakes Research. University of Toledo, Toledo, Ohio.

Dolan, D, R.P. Richards, and K. McGunagle. 2008. Total Phosphorus Loading to the Great Lakes. Landscapes and Loadings Workshop, Council of Great Lakes Governors, Maumee, OH, March 18. Presented by R. Peter Richards.

Dolan, D.M., R.P. Richards, and C.M. Piette. 2008. Updated Total Phosphorus Load Estimates for Lake Erie, 2005-2007. 51st Conference on Great Lakes Research May 19-23, 2008, Trent University, Peterborough, Ontario.

Han, H. and J.D. Allan. One hundred years of nutrient loading to Lake Michigan watershed. 2009. 57th North American Benthological Society. May 17-22.

He, C. and T. E. Croley. 2009. Defining and Applying Hydrological Resource Shed in the Great Lakes Watersheds. Department of Geography, East Carolina University, Greenville, NC. Feb.18. 55 min.

He, C. and T. E. Croley. 2009. Hydrological Resource Sheds and Great Lakes Applications. Shanghai Jiaotong University, Dec.4, 2009, 70 min.

He, C. and T. E. Croley. 2008. Resource Shed and Its Applications in the U.S. Great Lakes Watersheds. Lanzhou University, Lanzhou, P.R. China, Oct.29. 60 min.

He, C. and T. E. Croley. 2008. Resource Shed and Its Applications in the U.S. Great Lakes Watersheds. The Chinese Academy of Sciences Institute of Geodesy and Geophysics, Wuhan, Nov.3, 65 min.

He, C. and T. E. Croley. 2008. Resource Shed and Its Applications in the U.S. Great Lakes Watersheds. The Chinese Academy of Sciences Research Center for Eco-Environmental Sciences, Beijing, Nov.6, 65 min.

He, C., T. E. Croley, and C. DeMarchi. 2009. Modeling Nonpoint Sources Pollution Loadings in the Great Lakes Watersheds. WMU Dept. of Civil and Construction Engineering CCE 4350 Hydrology class, Engineering College, Nov.19, 2009. 65 min.

He, C., T.E. Croley, and C. DeMarchi. 2008. Application of Distributed Large Basin Runoff Model and Resource Sheds in the U.S. Great Lakes Watersheds. (50 min presentation) The Chinese Academy of Sciences Research Center of Eco-Environmental Sciences, Beijing, Jan.5.

He, C., T.E. Croley and C. DeMarchi. 2008. Climate Change and Nonpoint Source Pollution in the Great Lakes Basin: Opportunities and Challenges. Impact of Climate Change on the Great Lakes Ecosystem – A NOAA Science Needs Assessment Workshop to Meet Emerging Challenges. Ann Arbor, July 29-31.

He, C., T. E. Croley, and C. DeMarchi. 2008. Modeling Nonpoint Sources Pollution Loadings in the U.S. Great Lakes Basin. Shaanxi Normal University, Oct.24. 70 min.

He, C., T. E. Croley, C. DeMarchi. 2008. Modeling Spatial Distribution of Nonpoint Source Pollution in the Great Lakes Watersheds. The Association of American Geographers Annual Meeting, Boston, April 15-20.

He, C., T. E. Croley, and C. DeMarchi. 2008. Modeling Nonpoint Sources Pollution Loadings in the U.S. Great Lakes Basin. Research Institute for Protection of Yangtze Water Resources , Yangtze Water Resources Commission, Wuhan, Oct.31. 75 min.

He, C., T.E. Croley, and C.. DeMarchi. 2007. Modeling spatial distribution of nopoint source pollution loadings by using the Distributed Large Basin Runoff Model. 50th International Association for Great Lakes Research (IAGLR) Conference on Great Lakes Research, University Park, PA, 5/28-6/1/2007.

He, C. and C. DeMarchi. 2009. Modeling Spatial Distributions of Point and Nonpoint Source Pollution Loadings in the Great Lakes Watersheds. Proceedings Paper of 2009 International Conference on Geographic Information Systems, World Academy of Science, Engineering and technology 54 (2009):795-801, Paris France, June 24-26, 2009.

Ludsin, S.A. 2010. Hypoxia alters species distributions and interactions: implications for food webs and fisheries. Department of Biology, University of Waterloo (invited seminar).

Ludsin, S.A. 2009. Hypoxia in Lake Erie: implications for food webs and fisheries. The Great Lakes: Adapting to a Wave of Change Conference, Michigan State University, East Lansing (invited presentation).

Ludsin, S.A. 2009. Exploration of hypoxia's effects on Lake Erie fisheries. Lake Erie Committee/State of the Lake Ecosystem Conference (SOLEC). Ypsilanti, MI (invited presentation).

Ludsin, S.A. 2009. Hypoxia effects on Lake Erie fisheries. State of Lake Erie Committee Meeting, Ypsilanti, Michigan

Ludsin, S.A. 2008. Hypoxia alters species distributions and interactions: implications for food webs and fisheries. Stone Laboratory Guest Lecture Series, Put-In-Bay, Ohio

Ludsin, S.A. 2008. Hypoxia alters species distributions and interactions: implications for food webs and fisheries. Department of Zoology, Southern Illinois University, Carbondale, IL

Ludsin, S.A. 2008. Hypoxia alters species distributions and interactions: implications for food webs and fisheries. USGS Ohio Water Science Center, Columbus, OH

Ludsin, S.A. 2007. Hypoxia alters species distributions and interactions: implications for food webs and fisheries. Department of Earth, Ecological, and Environmental Sciences, University of Toledo, Toledo, OH (invited seminar)

Ludsin, S.A. 2007. Hypoxia alters species distributions and interactions: implications for food webs and fisheries. Department of Biology, University of Akron, Akron, OH (invited seminar)

Ludsin, S.A. 2007. Hypoxia alters species distributions and interactions: implications for food webs and fisheries. Department of EEOB, OSU, Columbus (invited seminar).

Ludsin, S.A. 2007. Lake Erie hypoxia: history and management response. Ecological Impacts of Hypoxia on Living Resources Workshop Symposium, Bay St. Louis, MS. (invited presentation)

Ludsin, S.A., and T.E. Croley II. 2008. Complexities of forecasting climate change effects on Great Lakes fisheries: an example with Lake Erie yellow perch. Climate Change in the Great Lakes Region Conference, Michigan State University, East Lansing, MI (invited presentation)

Ludsin, S.A., T.O. Höök, D. Rucinski, J.V. DePinto and D. Scavia. 2008. Historical exploration of hypoxia effects on fish recruitment and production in Lake Erie. Oral presentation at the International Association for Great Lakes Research 51st Annual Conference on Great Lakes Research, Peterborough, ON. May 20.

Ludsin, S.A., T.O. Höök, D.K. Rucinski, J.V. DePinto, and D. Scavia. 2008. Historical exploration of hypoxia effects on fish recruitment and production in Lake Erie. International Association for Great Lakes Research, Peterborough, Ontario

Ludsin, S.A., T.O. Höök, D. Rucinski, J.V. DePinto and D. Scavia. 2008. Historical exploration of hypoxia effects on fish recruitment and production in Lake Erie. Oral presentation at the International Association for Great Lakes Research 51st Annual Conference on Great Lakes Research, Peterborough, ON. May 20.

Ludsin, S.A., H.A. Vanderploeg, S.A. Pothoven, D.M. Mason, T. Höök, and S.A. Ruberg. 2007. Hypoxia effects on habitat and prey availability for rainbow smelt in central Lake Erie. International Association for Great Lakes Research, University Park, PA (contributed presentation)

Pangle, K.L. , S. Pothoven, H.A. Vanderploeg, T.O. Höök, S.B. Brandt and S.A. Ludsin. Hypoxia's impact on pelagic fishes: a tale of two planktivores. Ecological Society of America. Pittsburgh, PA. August 1-6, 2010. abstract submitted.

Richards, R.P. 2009. Reduced loads of suspended solids and particulate phosphorus demonstrated by long-term monitoring. Briefing for Cameron Davis and Marcy Kaptur, U. Toledo, November 13

Richards, R. P. 2009. Trends in sediment concentrations and loads in Northwest Ohio tributaries to Lake Erie, 1975-2008. Western Lake Erie Basin Conference, , Maumee Bay State Park, March 10.

Richards, R. P. 2008. Food, Fertilizer, Fish, and Fouled Beaches: Water Quality in the Maumee River and the Western Basin of Lake Erie, 1975 to Present. Lake Erie Center, Maumee, OH, October 16.

Richards, R.P. 2008. Record Setting Phosphorus Loads from Agricultural Watersheds in Ohio. USDA Water Quality Conference, Sparks, NV, February 6.

Richards, R. P. 2008. Testimony on Lake Erie Phosphorus Loadings. U.S. House of Representatives Committee on Transportation and Infrastructure, Subcommittee on Water Resources and Environment. Port Huron, Michigan, May 12.

Richards, R.P., D.B. Baker, and J.P. Crumrine. 2007. Increased Dissolved Phosphorus Loading to Lake Erie from Agricultural Watersheds. Great Lakes Protection Fund Project Workshop, Tiffin, OH, December 18.

Richards, R.P., D.B. Baker, and J.P. Crumrine. 2008. Trends in Dissolved Reactive Phosphorus in Lake Erie Tributaries. Landscapes and Loadings Workshop, Council of Great Lakes Governors, Maumee, OH, March 19.

Richards, R.P, D.B. Baker, and J.P. Crumrine. 2008. Trends in Dissolved Reactive Phosphorus in Lake Erie Tributaries. Millennium Network Conference, Windsor, ON, April 29.

Richards, R.P., D.B. Baker, and J.P. Crumrine. 2008. Water Quality Trends in Lake Erie Watersheds. Western Lake Erie Basin Partnership Roundtable, Toledo, OH, February 20.

Richards, R.P. Gail Hesse, Roger Knight, Keely Dinse, and Don Scavia. 2009. Lake Erie Hypoxia: Climate, Invasive Species, and Agricultural Loads. NOAA-CSCOR Regional Workshop, Silver Spring, MD, May 18-19.

Roberts, J.J., T.O. Höök, Paul A. Grecay, S.A. Ludsin, S.A. Pothoven, and H.A. Vanderploeg. 2009. Sub-daily behavioral consequences of hypoxia for yellow perch in Lake Erie's central basin. International Association for Great Lakes Research, Toledo, OH.

Roberts, J.J., T.O. Höök, S.A. Ludsin, and S.A. Pothoven. 2009. Growth and condition of yellow perch in response to hypoxia: synthesis of lab and field results. American Fisheries Society, Nashville, TN.

Roberts, J.J., T.O Höök, S.A. Ludsin, S.A. Pothoven, and H.A. Vanderploeg. 2008. Bioenergetics model to explore the effects of hypoxia on yellow perch habitat quality in Lake Erie's central basin. Oral presentation at the International Association for Great Lakes Research 51st Annual Conference on Great Lakes Research, Peterborough, ON. May 20.

Roberts, J.J., T.O. Höök, S.A. Ludsin, S.A. Pothoven, and H.A. Vanderploeg. 2008. Response of yellow perch to hypoxia in Lake Erie's central basin: Spatial patterns. American Fisheries Society 138th Annual Conference, Ottawa, ON.

Roberts, J.J., T.O. Höök, S.A. Ludsin, S.A. Pothoven, and H.A. Vanderploeg. 2009. Implications of hypoxia for yellow perch habitat quality in Lake Erie's central basin: a spatially-explicit bioenergetics modeling approach. Oral presentation at the Michigan Chapter of the American Fisheries Society Annual Meeting, Dundee, MI.

Rucinski, D.K., D. Beletsky, J.V. DePinto, D. Scavia. 2009. "Application and comparison of 1D and 3D lower food web models for Lake Erie." Presented at 53rd Annual Conference on Great Lakes Research, Toledo University, Toledo, OH (May 18-June 22, 2009).

Rucinski, D.K., D. Beletsky, J.V. DePinto, D. Scavia, D. Schwab. 2007. Model analysis of climate effects on dissolved oxygen in the central basin of Lake Erie. Oral presentation at the International Association for Great Lakes Research 50th Annual Conference on Great Lakes Research, University Park, PA. June 1.

Rucinski, D.K., D. Beletsky, J.V. DePinto, D. Scavia, D. Schwab. 2008. Development and Application of 1D Eutrophication Models for the Central Basin of Lake Erie. Oral presentation at the International Association for Great Lakes Research 51th Annual Conference on Great Lakes Research, Peterborough, Ont. May 20.

Rucinski, D.K., D. Beletsky, J.V. DePinto, D. Scavia, D. Schwab. 2008. Long-Term Application of a Climate-Driven Dissolved Oxygen Model for the Central Basin of Lake Erie. Oral presentation at the International Association for Great Lakes Research 51th Annual Conference on Great Lakes Research, Peterborough, Ont. May 20.

Sellinger, C., and T. E. Croley II, 2008. GLERL's Hydrology Program, NOAA-USGS Committee on Hydrology Meeting, Silver Springs, Maryland, January 16.

Sharpley, Andrew and R. Peter Richards. 2008. Adaptive Management and Water Quality: Is there anything to be learnt from outside the U.K.. Agriculture, Water Management, and Climate Change, Bath, England, March

Zhang, H., Rutherford, E.S., Mason, D.M., Adamack, A.T., Johnson, T., and Zhu, X. 2009. Ecopath with Ecosim and Ecospace: Hypoxia impacts on the fisheries of Lake Erie. Pre-Lake Erie Committee meeting. London, Ontario.

Awards

Best Professional Paper: Indiana American Fisheries Society Annual Meeting, Indianapolis. (K. Arend, T. Höök, S. Ludsin, D. Rucinski, J. DePinto, and D. Scavia.)

Best Student Paper: Roberts, J.J., T.O. Höök, S.A. Ludsin, S.A. Pothoven, and H.A. Vanderploeg. 2009. Implications of hypoxia for yellow perch habitat quality in Lake Erie's central basin: a spatially-explicit bioenergetics modeling approach. Oral presentation at the Michigan Chapter of the American Fisheries Society Annual Meeting, Dundee, MI.

Thesis Defended (M.S.)

Regression Analysis of Total Phosphorus Loading for the Maumee River, Water Years 2003-2005, by Charlie Piette, University of Wisconsin-Green Bay, December, 2008.

Roberts, J. J. 2010. The ecological consequences of hypoxia for yellow perch (*Perca flavescens*) in Lake Erie. Dissertation. University of Michigan, Ann Arbor, MI.