## PROJECT TITLE: ECOFORE: FORECASTING THE CAUSES, CONSEQUENCES AND REMEDIES FOR HYPOXIA IN LAKE ERIE

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### 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. This project addresses two of NOAA Strategic Plan Goals: 1) to protect, restore, and manage use of coastal and ocean resources through ecosystem-based management, and 2) to understand climate variability and change to enhance society's ability to plan and respond.

### 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 and CY2007 at 26 spatial nodes have been completed. CY1976 nutrient loads have been reconstructed from archived historical data. These are also available at the 26 spatial nodes in the Lake. All point source, atmospheric, and tributary data for 2003 - 2008 has been received. For Total Phosphorus (TP), additional annual load estimates have been completed for the water years (WY) 2003-2008. This updates the work of Dolan & McGunagle which included TP loads through WY 2002. These estimates have been provided to Steven Chapra at Tufts University for use with his TP mass balance model for the entire Great Lakes system. One of the outputs of Chapra's work will be updated estimates of interlake loadings via the connecting channels including the St. Clair and Detroit Rivers.

***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.

***Watershed models***

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 simulated. Preliminary results are showing that implementation of cover crops are most effective at reducing river nutrient export loads to Lake Erie for agricultural watersheds.

SWAT model development is complete and a first paper describing its parameterization and testing model performance is in press with the Journal of Great lakes Research. A second paper is now underway to evaluate the effectiveness of BMPs vs source reductions to reduce nutrient and sediment loads to Lake Erie.

Nutrient budget analyses to evaluate spatial and temporal patterns in phosphorus loading are largely complete. A first paper has been published. A second paper about historical trends in phosphorus loading to watersheds of the Lake Erie and Lake Michigan basins is in preparation.

**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:

- 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;
- 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;
- 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
- 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.

Alternative forcing functions (surface wind fields) were developed for 2005. They are based on the 3-hourly output of the Canadian regional meteorological model GEM which employs 15 km grid and thus can be potentially superior to mostly land-based meteorological observations normally used by POM in the Great Lakes. Preliminary results showed improvements in modeled thermocline shape and anticyclonic circulation pattern in the central basin. We are planning to re-do 2004 and 2007 3D hydrodynamic model runs using GEM winds (which are not available for 1976) and compare with available observations.

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. 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. It has been calibrated for 2005, and the 2005 calibration is being tested against the 2004 data set.

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.

As of December 2010, development of basic structures of multispecies SE-IBM has been completed using IDL (modeling and visualization software). At present, further species-specific parameterization and calibration of the SE-IBM are being conducted using IFYLE data and literature. The SE-IBM currently consists of 8 age classes of walleye, 7 age classes of yellow perch, 2 age classes of rainbow smelt, emerald shiner, and round goby, as well as zooplankton (from the water quality model outputs) and benthic macroinvertebrates (modeled using detrital carbon outputs from the water quality model outputs) as prey. All trophic groups in the model (invertebrate prey, benthivores, planktivores, and piscivores) are linked through predator-prey relationships. Preliminary simulations of the model have been conducted using central basin outputs from the Level 3a hydrodynamic-water quality model that was calibrated with the 2005 field data. These simulations appeared to be in agreement with some results from the other ecological models (e.g., walleye benefits from hypolimnetic hypoxia to some extent). Initially, we were using a 6-minute time step to capture physiological (e.g., acclimation to ambient temperature and DO) and behavioral (e.g., vertical movement) responses to hypoxia. However, as more complexity is being added to the model, computation time is also becoming increasingly prohibitive. We are currently exploring different options for time step as well as the number of superindividuals (a collection of individuals) to complete simulations in reasonable time, while capturing important details in the model. Because of increasing computation time (> a few weeks for 5-month simulations), we also started working with Purdue University's Rosen Center for Advanced Computing to run simulations in a cluster environment. Additionally, visualization of model outputs using IDL and ArcGIS is also being developed to examine impacts of hypoxia on fish movement (vertical and horizontal) and inter-/intra- specific interactions among fish populations.

***Foodweb models***

CASM is a bioenergetics-based foodweb model used to estimate ecological risks posed by various physical, chemical, or biological stressors in aquatic systems. Risks include direct impacts on individual modeled populations of primary producers or consumers, as well as indirect effects that result from alterations of grazing or predator-prey interactions. The 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 foodweb represented in the CASM-LE was developed in coordination with the project investigators (Zhang et al.) who are developing the Lake Erie EcoPath and EcoSim. The foodweb in the CASM-LE consists of four broadly defined taxonomic groups of phytoplankton, six populations of herbivorous and carnivorous zooplankton, five benthic invertebrate populations (including Dreissenids), and 16 different taxonomically defined fish populations. Rainbow smelt, yellow perch, and walleye are represented by juvenile and adult populations. Consistency in food web structure will facilitate the comparison of CASM-LE with results from the Ecopath and EcoSim for similar hypoxia scenarios and provide multiple-model projections of potential impacts of hypoxia. Various sources of data and information have been used to define foodweb interactions, initial population biomass values, bioenergetics parameters, and physio-chemical conditions in CASM-LE (e.g., physical, chemical and biological data from IFYLE; literature values; agency reports). Estimation of bioenergetic parameters in the

CASM-LE is based in part on other bioenergetics work being performed as part of the Ecofore Project. The overall CASM-LE has been re-programmed to include 3-layer vertical structure that permits certain invertebrate and fish populations to move vertically in relation to food availability and oxygen concentration. The direct effect on the annual production of each modeled population is determined by functional relationships between daily changes in dissolved oxygen concentration (in each vertical layer) on population respiration and mortality rates. Direct effects on prey populations can cascade throughout the foodweb in terms of alterations in prey availability. The CASM-LE includes a nearshore and offshore modeled locations that permit horizontal migration in response to oxygen concentrations. The major development within 2010 for the CASM-LE has been the reprogramming of the model using a Monte Carlo framework. This approach directly evaluates the effects of parameter uncertainty on modeled impacts of hypoxia. Importantly, this approach also permits modeled effects of hypoxia to be characterized as probable impacts (i.e., ecological risks). The Monte Carlo version of the CASM-LE is currently being debugged using IFYLE physical-chemical data from 2005.

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.

Ed Rutherford and Hongyan Zhang worked on the Ecopath with Ecosim model for the Lake Erie central basin. They have been actively involved in a formation of a Great Lakes EwE modeling group which includes modelers from NOAA/GLERL, CILER/UM, USGS, the Institute of Fisheries Research at University of Michigan, and Michigan State University. This EwE modeling group will produce guidelines for ecosystem modeling efforts in the Great Lakes and compile a list of data sources used for model development. 14 experts has participated the first workshop that was held at Kellogg Biological Station (KBS), MI, Feb. 28-Mar.1, 2011. The second workshop was scheduled on July 12-13, 2011 at KBS.

***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. 2011. Seasonal and interannual effects of hypoxia on fish habitat quality in central Lake Erie. Freshwater Biology, 56:366-383. Supported by NOAA Center for Sponsored Coastal Ocean Research grant NA07OAR432000.

Bosch, N.S., J.D. Allan, D.M. Dolan, H. Han, and R.P. Richards. 2010. Application of the Soil and Water Assessment Tool for six watersheds of Lake Erie: Model parameterization and calibration. Journal of Great Lakes Research. *In press*. Supported by NOAA Center for Sponsored Coastal Ocean Research grant NA07OAR432000.

Brandt, S.B., M. Constantini, S.E. Kolesar, S.A. Ludsin, D.M. Mason, C.M. Rae, and H. Zhang. 2011. Does hypoxia improve habitat quality for Lake Erie walleye? A bioenergetics perspective. Canadian Journal of Fisheries and Aquatic Sciences. *In press*. Supported by NOAA and the US EPA Great Lakes National Program Office. Additional support was provided by the University of Michigan Cooperative Institute for Limnology and Ecosystems Research.

Han, H., N. Bosch, and J.D. Allan. 2011. Spatial and Temporal variation in phosphorus budgets for 24 watersheds in the Lake Erie and Lake Michigan basins. Biogeochemistry,

102: 45-58. Supported by NOAA Center for Sponsored Coastal Ocean Research grant NA07OAR432000.

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 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.

Jarvie, H.P., C. Neal, P.J.A. Withers, D.B. Baker, R.P. Richards, and A.N. Sharpley. 2011. Quantifying Phosphorus Retention and Release in Rivers and Watersheds Using Extended End-Member Mixing Analysis (E-EMMA). J. Environmental Quality 40(1): 1-13

Richards, R.P., D.B. Baker, J.P. Crumrine, and A.M. Stearns. 2010. Unusually large loads in 2007 from the Maumee and Sandusky Rivers, tributaries to Lake Erie. Journal of Soil and Water Conservation 65(6): 450-462. Supported by NOAA CSCOR, the USDA CSREES, the USDA NRCS, Ohio DNR and Michigan DEQ.

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. Journal of Great Lakes Research, 36:465-476. Supported in part by NOAA Center for Sponsored Coastal Ocean Research grant NA07OAR432000.

Wang, J., H. Hu, D. Schwab, G. Leshkevich, D. Beletsky, N Hawley, and A. Clites. 2010. Development of the Great Lakes Ice-circulation Model (GLIM): Application to Lake Erie in 2003-2004. Journal for Great Lakes Research, 36(3): 425-436.

DeMarchi, C., F. Xing, T. E. Croley, C. He, and Y. Wang. 2011. Application of a Distributed Large Basin Runoff Model to Lake Erie: Model Calibration and Analysis of Parameter Spatial Variation. Journal of Hydrological Engineering, 16(3): 193-202. Supported in part by NOAA CSCOR grant NA05NOS4781204 and Cooperative Institute for Limnology and Ecosystems Research’s 2008 Great Lakes Summer Student Fellowship Program.

## Presentations

Baker, D.B., Richards, R.P., and J.W. Kramer. 2010. Increasing trends in dissolved phosphorus in Lake Erie tributaries: the role of agricultural practices. International Association for Great Lakes Research 53rd Annual Conference on Great Lakes Research, Toronto, ON, May 17-21.

Beletsky, D., Schwab, D., Rao, R., Hawley, N., Vanderploeg, H., and R. Beletsky. 2010. Thermocline of Lake Erie. International Association for Great Lakes Research 53rd Annual Conference on Great Lakes Research, Toronto, ON, May 17-21.

Bosch, N.S., Allan, J.D., Han, H., and R.P. Richards. 2010. Using the Soil and Water Assessment Tool (SWAT) to Evaluate the Impact of Agricultural BMPs on Riverine Nutrient Export to Lake Erie. International Association for Great Lakes Research 53rd Annual Conference on Great Lakes Research, Toronto, ON, May 17-21.

DePinto, J.V. 2010. Recent Modeling in the Maumee Watershed and the Western Basin of Lake Erie. Invited presentation for the Lake Erie Millennium Network Conference, University of Windsor, April 27-29.

Dolan, D.M., Richards, R.P, and R.G. Kreis. 2010. Nutrient Load Estimates for Lake Erie in 2005. Invited presentation for the Lake Erie Millennium Network Conference, University of Windsor, April 27-29.

Goto, D., Rucinski, D.K., DePinto, J. V., Ludsin, S. A., Scavia, D., and Höök, T.O. 2010. Elucidating hypoxia effects on population dynamics of yellow perch and walleye in Lake Erie using a spatially explicit individual-based model. 71st Midwest Fish and Wildlife Conference. Minneapolis, Minnesota, December 12-15.

Goto, D., Rucinski, D.K., DePinto, J. V., Ludsin, S. A., Scavia, D., and Höök, T.O. 2011. Population-level consequences of hypolimnetic hypoxia in Lake Erie: Implications from a spatially explicit individual-based model. ASLO Aquatic Sciences Meeting. San Juan, Puerto Rico, February 13-18.

Jarvie, H. P., Neal, C., Withers, J.P., Baker, D.B., Richards, R.P. and A.N. Sharpley. 2011. Exploring Phosphorus Retention and Release in Rivers and Watersheds Using Extended Endmember Mixing Analysis. American Society of Limnology and Oceanography, San Juan, PR, February 18.

Kane, D. D., Conroy, J.D., Culver, D.A., Bridgeman, T.B., Chaffin, J.D., Bade, D.L., Edwards, W.J., McKay, R.M., Richards, R.P., and D.B. Baker. 2011. Re-eutrophication of Lake Erie: Insights from the Maumee and Sandusky Systems. American Society of Limnology and Oceanography, San Juan, PR, February 18.

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

Richards, R.P. 2011. Lakes and Watersheds: A Quick Walk to the Limits of my Knowledge and Beyond. American Society of Limnology and Oceanography, San Juan, PR, February 19.

Richards, R. P. and D.B. Baker. 2011. Increasing Trends in Dissolved Phosphorus in Lake Erie Tributaries: The Role of Agricultural Practices. American Society of Limnology and Oceanography, San Juan, PR, February 18,

Richards, R. P. and D. Scavia. 2011. The Great Lakes Watershed and Agriculture. Michigan Agriculture's Conference on the Environment, Lansing, MI, January 27,

Zhang, H., Rutherford, E., Mason, D., Johnson, T.B., Adamack, A.T., Zhu, X., and Scavia, D. 2010. Ecosytem Level Assessments of Hypoxia Impacts on the Food Web and Fisheries of Lake Erie. Poster. The 53rd annual international conference of the International Association for Great Lakes Research – lessons from the past, Solutions for the future. Toronto, ON, May 17-21.

Zhang, H., Rutherford, E., Mason, D., Johnson, T.B., Adamack, A.T., Zhu, X., and Scavia, D. 2010. Ecosystem Level Impacts of Hypoxia on the Food Web and Fisheries of Lake Erie. The 140th meeting of the American Fisheries Society. Pittsburg, PA, September 12-16.

## Outreach Activities

Arend, K., Höök, T.O., Ludsin, S.A., Rucinski, Beletsky, D., DePinto, J.V., and Scavia, D., 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.

Baker, D.B., Richards, R. P. and J.W. Kramer. 2010. Increasing Trends in Dissolved Phosphorus in Lake Erie Tributaries: The Role of Agricultural Practices. Ohio Geological Survey Seminar, Lorain, OH, September 16.

DePinto, J.V. 2010. Modeling Supports Western Lake Erie Basin Management. Invited presentation to WLEB Partnership Leadership Committee Meeting, Toledo, OH, April 14.

Goto, D., and Höök, T.O. 2010. Ecological responses of YOY yellow perch to hypolimnetic hypoxia in Lake Erie. Indiana water Resources Association. May, 2010.

Höök, T.O. 2010. Ecological effects of hypoxia. Purdue Water Community.

Höök, T.O. 2010. Ecological effects of hypoxia. PurdueUniversity Department of Forestry and Natural Resources.

Höök, T.O. 2010. Hypoxia in Lake Erie. Great Lakes COSEE Program.

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

Richards, R.P. 2011. On the care and feeding of Lake Erie. Tri-state Conservation Expo, Montpelier, OH, March 15.

Richards, R.P. 2011. On the care and feeding of Lake Erie. Huron County GLRI Workshop, Huron, OH, March 9.

Richards, R. P. 2011. Sediment Concentrations and Loads to Lake Erie, 1975-2009. Army Corps Workshop: Managing and Understanding Sediments, Cleveland, OH, January 12.

Richards, R. P. 2011. P and N Trends in the Maumee and Sandusky Rivers, Major Lake Erie Tributaries. Winter Gala, Bowling Green, OH, January 8.