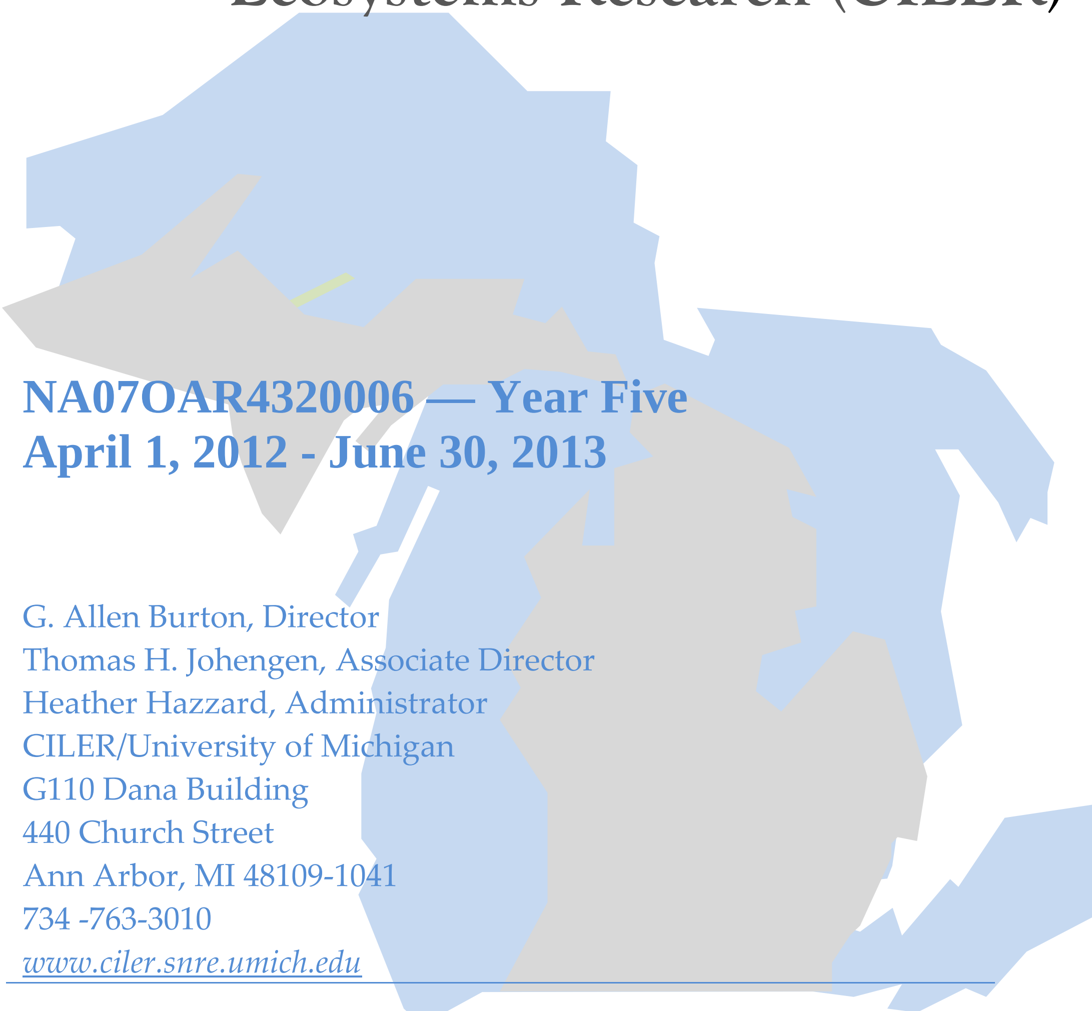
# 2012-2013
# ANNUAL REPORT

## Cooperative Institute for Limnology and Ecosystems Research (CILER)



**NA07OAR4320006 — Year Five**
**April 1, 2012 - June 30, 2013**

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Thomas H. Johengen, Associate Director
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# Cooperative Institute for Limnology and Ecosystems Research – CILER

## Annual Report for NA07OAR4320006

## Year Five: April 1, 2012 – June 30, 2013

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# Cooperative Institute for Limnology and Ecosystems Research (CILER)

**G. Allen Burton, Director**
**Thomas H. Johengen, Associate Director**
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**University of Michigan**
**Ann Arbor, Michigan**

## ANNUAL REPORT for NA07OAR4320006
## Year Five: April 1, 2012 – June 30, 2013

## CILER's Vision:

To enhance the quality of the Great Lakes and its related ecosystem services, through a partnership of universities, NOAA scientists, and other stakeholders.

## CILER's Mission:

CILER's overarching mission is to serve as a focal point for collaborations between the National Oceanic & Atmospheric Administration and University researchers in the Great Lakes region. The research mission of the institute is to improve the understanding of the fundamental physical, chemical, biological, and ecological processes operating in the Great Lakes region in order to improve observation and forecasting systems that help guide management. CILER is also tasked with translating and disseminating science for the general public, highlighting NOAA initiatives, and promoting educational training opportunities in the region through postdoctoral research fellow positions and the student summer fellowship program.

## Executive Summary:

The Cooperative Institute for Limnology and Ecosystems Research (CILER) was originally established in 1989, with the objective of fostering University and NOAA partnerships in the Great Lakes region. The renewal of the CILER Cooperative Agreement went into effect in July of 2007. This agreement was awarded to the University of Michigan (host institution) and nine partner universities (Michigan State University; University of Toledo; Grand Valley State University; University of Minnesota-Duluth; University of Wisconsin; University of Illinois at Urbana-Champaign; Ohio State University; State University of New York at Stony Brook; and Penn State University). During the past year (i.e., current reporting period), CILER

administered CI project grants totaling $5.2 million.  Approximately half of these funds went to regional universities to support CI consortium activities.

CILER Research Overview:

Research conducted under the ecosystem forecasting theme aims to develop forecasts for physical hazards, water levels, harmful algal blooms (HABs), and fish recruitment and production.

Research in the second theme, invasive species, focuses on the prevention, monitoring, detection, and control of invasive species, and on a better understanding of the range of their ecosystem impacts.

Research in the third theme, coastal observing systems, focuses on providing observing system data and platforms, data management and communications, and data products and forecasts needed for effective environmental management, and for monitoring and understanding ecosystem responses to natural and anthropogenic conditions.

The fourth theme, protection and restoration of resources, supports research to protect, restore, or enhance priority coastal land and water habitats throughout the basin.

Research projects in the fifth theme, integrated assessments, generate policy-relevant and synthetic efforts to help guide long-term resource use in the basin.

Finally, projects conducted under the sixth theme, Education and Outreach, facilitate education and outreach activities for NOAA in the Great Lakes region.

## Executive Board - Management Council - Council of Fellows:

### Executive Board:

The Executive Board makes recommendations concerning CILER's administration, budget, future cooperative agreements, and Management Council members. The Board last met in June.

The members of the Executive Board include:

**Al Powell** (Director, NOAA Center for Satellite Applications and Research), **Russell Callender** (Acting Director, NOAA National Centers for Coastal Ocean Science), **Marie Lynn Miranda** (Dean, SNRE), **Mark Banaszak-Holl** (Associate Vice-President for Research, UM), **Allen Burton** (CILER Director, ex-officio) and **Marie Colton** (GLERL Director, ex-officio).

### Members of the new CILER Management Council:

The Management Council provides reviews and recommendations of the scientific direction of the CI, and includes directors of the Great Lakes Sea Grant programs, with additional representation by NOAA and university scientists. This Council last met in May. Members include:

**Jim Diana**, University of Michigan; Director, Michigan Sea Grant Program
**Brian Miller**, University of Illinois; Director, Illinois-Indiana Sea Grant Program
**Jeff Gunderson**, University of Minnesota; Director, Minnesota Sea Grant Program
**Jeffrey Reutter**, Ohio State University; Director, Ohio Sea Grant Program
**William Wise**, State Univ. New York-Stony Brook; Director, N Y Sea Grant Program
**Steve Ruberg**, Obs. Systems/Adv. Tech. Branch Chief, NOAA-GLERL
**Henry Vanderploeg**, Ecosystem Dynamics Branch Chief, NOAA-GLERL
**Doran Mason**, CILER Program Manager, NOAA-GLERL
**Craig Stow**, Principal Investigator, NOAA-GLERL
**Edward Rutherford**, Principal Investigator, NOAA-GLERL
**Lucinda Johnson**, Univ. of Minn.; Director, Natural Resources Research Institute
**Val Klump**, Univ. Wisconsin – Milwaukee; Director, Great Lakes Water Institute
**Al Steinman**, Grand Valley State Univ.; Director, Annis Water Resources Res. Institute
**Jan Stevenson**, Michigan State University; Professor, Department of Zoology
**Chin Wu**, University of Wisconsin – Madison; Professor, Civil and Env. Engineering

Both the Management Council and Council of Fellows are also listed alphabetically on CILER's website: http://ciler.snre.umich.edu/ ,which includes their affiliations, contact information, and research interests.

## Members of the new Council of Fellows:

The Council of Fellows includes over 30 Great Lakes academic and federal researchers This Council most recently met in August 2012.

**Joe Atkinson**, Professor, State University of New York - University at Buffalo
**Jay Austin**, Asst. Professor, Univ. of Minnesota-Duluth's Large Lakes Observatory
**Niladri Basu**, Asst. Professor, University of Michigan's School of Public Health
**Stuart Batterman**, Professor, University of Michigan's School of Public Health
**Dima Beletsky**, Associate Research Scientist, CILER
**Bopi Biddanda**, Res. Scientist, Grand Valley State Univ., Annis Water Resources Inst.
**John Bratton**, Deputy Director, GLERL
**Brad Cardinale**, Asst. Professor, SNRE, University of Michigan
**Hunter Carrick**, Professor, Central Michigan University
**Steve Colman**, Professor, Univ. of Minnesota-Duluth's Large Lakes Observatory
**Jim Cotner**, Professor, University of Minnesota
**Drew Gronewold**, Hydrologist, GLERL
**Nathan Hawley**, Oceanographer, GLERL
**Thomas Hook**, Asst. Professor, Purdue University
**Tom Johengen**, Associate Director, CILER
**Donna Kashian**, Asst. Professor, Wayne State University
**Peter Lavrentyev**, Professor, University of Akron
**Brent Lofgren**, Physical Scientist, GLERL
**Nancy Love**, Professor, University of Michigan
**Rex Lowe**, Professor, Bowling Green State University
**Stuart Ludsin**, Asst. Professor, Ohio State University
**Phanikumar Mantha**, Assoc. Professor, Michigan State University
**Peter McIntyre**, Asst. Professor, University of Wisconsin-Madison
**Guy Meadows**, Professor, University of Michigan
**Cheryl Murphy**, Asst. Professor, Michigan State University
**Scott Peacor**, Assoc. Professor, Michigan State University
**Lutgarde Raskin**, Professor, University of Michigan
**Jen Read**, Executive Director, Great Lakes Observing System
**Carl Ruetz III**, Assoc. Professor, Grand Valley State Univ., Annis Water Resources Inst.
**Paul Seelbach**, Eco. Hlth. & Restor. Branch Chief, USGS-Great Lakes Science Center
**Carol Stepien**, Director, Lake Erie Research Center, University of Toledo
**Robert Sterner**, Professor, University of Minnesota
**Cary Troy**, Asst. Professor, Purdue University
**Mike Wiley**, Professor, SNRE, University of Michigan

## CILER Funding Distribution

This report details project activities through the fifth year of the cooperative agreement with updates covering the period through June 30, 2013. CILER has administered 71 amendments distributed as shown in Figure 1. The total funding level up through the reporting period is $5,326,177.

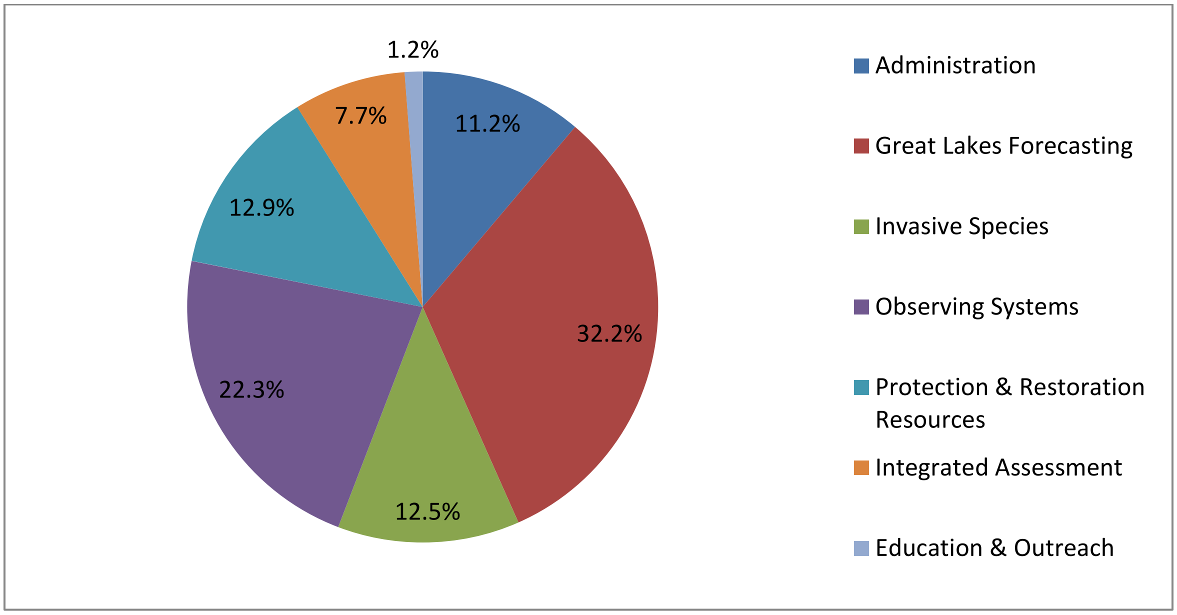


**Figure 1**. Funding distribution for projects supported through CILER, for the period from 04/01/12 – 06/30/13 under NA07OAR4320006.

**Table 1**. Breakdown of funding by Theme awarded to CILER for the current Cooperative Agreement, NA07OAR4320006, through June 30, 2013.

| **Category** | **Funding (%)** | **Funding ($)** |
|---|---|---|
| Administration | 11.2 | 594,889 |
| Theme I: Great Lakes Forecasting | 32.2 | 1,713,104 |
| Theme II: Invasive Species | 12.5 | 665,506 |
| Theme III: Observing Systems | 22.3 | 1,188,127 |
| Theme IV: Protection & Restoration Resources | 12.9 | 689,133 |
| Theme V: Integrated Assessment | 7.7 | 410,101 |
| Theme VI: Education & Outreach | 1.2 | 65,317 |
| **TOTAL** | 100% | 5,326,177 |

**Table 2.** Breakdown of subcontract funding by institution. Approximately 47% of CILER funds were distributed to university consortium members and other organizations and universities.

| | |
|---|---|
| Case Western | $25,216 |
| Commonwealth Scientific & Industrial Research Organisation | $30,020 |
| Dynamic Solutions | $10,000 |
| E2 Engineering Consultants | $18,855 |
| Grand Valley State University | $4,956 |
| Heidleberg College | $10,000 |
| Michigan State University | $500,244 |
| Michigan Technological Institute | $214,263 |
| The Ohio State University | $31,100 |
| Palm Island Environmental | $8,894 |
| Purdue University | $278,411 |
| State University of New York | $256,069 |
| University if Indiana/Illinois Sea Grant | $17,340 |
| University of Illinois | $59,453 |
| University of Maryland | $136,487 |
| University of Minnesota | $79,232 |
| University of Minnesota-Duluth | $210,808 |
| University of Southern Florida | $32,985 |
| University of Washington | $53,329 |
| University of Wisconsin | $813 |
| University of Wisconsin-Madison | $260,335 |
| University of Wisconsin-Milwaukee | $162,065 |
| Wayne State University | $118,270 |
| **Total** | $2,519,145 |

CILER Research – An Overview

This report represents the conclusion of research conducted under the 5-year cooperative agreement. Given this, there are reports on several large, multi-year, multidisciplinary projects that came to an end over the reporting period. ECOFORE (Ecological Forecasting in Lake Erie) was a collaborative project that involved more than 15 scientists who were developing and applying different modeling approaches to better under the causes and consequences of hypoxia in Lake Erie.

This effort is an important and longterm partnership between CILER and NOAA-GLERL to provide reliable and critical data on Great Lakes conditions. CILER also continues to support the Great Lakes Synthesis, Observations, and Response System (SOAR). This program focuses on coordinating and integrating regional coastal observations that support national and regional priorities, especially those related to Great Lakes restoration. Through these activities, CILER supports NOAA's efforts to improve decision support tools related to phosphorous loading and hypoxia as well as helping to improve ecological forecasting of harmful algal blooms.

CILER Education and Outreach – An Overview

For over a decade, CILER has been co-hosting a Summer Fellows program with NOAA. This effort, the Great Lakes Summer Fellows Program, attracts highly qualified undergraduate and graduate students to NOAA and university facilities to do research on a range of topics. For the 2012 program, we received more than 80 applications for 12 positions (see Table 1).

Longterm Fellows program. To date we have fully funded one fellow to work at the University of Toledo with Dr. Carol Stepien on a project to develop a rapid DNA test of water samples to identify the potential presence of invasive fish species. We also have funding in hand to support a longterm fellow at the University of Wisconsin-Madison, to work with Dr. Chin Wu.

As in years past, CILER and GLERL continue to partner on an annual seminar series that brings in research and education and outreach experts from around the Great Lakes region and other coastal areas throughout the U.S. We have expanded this program through enhanced list serves, such as the Great Lakes Information Network. Attendee participation through these venues has increased significantly over the past year, especially after including e-mail lists from other university partners, and University of Michigan departments besides the School of Natural Resources and Environment.

Table 1. List of 2012 CILER Summer Fellow and position descriptions.

| Fellow | Mentor | Position Title | Description |
|---|---|---|---|
| Sommer Abdel-Fattah | Carlo DeMarchi (Case Western) & Brent Lofgren (NOAA) | Data Analyst Lake Diffusion Modeling | Improve and validate a 1-dimensional model of lake diffusion for use in a Regional Climate Model |
| Heather Lucier | Carlo DeMarchi (Case Western) & Brent Lofgren (NOAA) | Data Analyst Lake Diffusion Modeling | Improve and validate a 1-dimensional model of lake diffusion for use in a Regional Climate Model |
| Gregory Ewing | Carlo DeMarchi (Case Western) & Brent Lofgren (NOAA) | Data Analyst Lake Diffusion Modeling | Improve and validate a 1-dimensional model of lake diffusion for use in a Regional Climate Model |
| Robert Fenton | George Leschkevich (NOAA) | Data Visualization / Programmer | Help redesign and implement a web-based graphical interface for Great Lakes CoastWatch data |
| Amanda Wetzel | Sarah Waters (NOAA) | Education and Outreach Specialist | Develop education and outreach material and programs at Thunder Bay NMS |
| Charles Bendig | Stephanie Gandulla (NOAA) | Communications Specialist | Write, produce materials for the Thunder Bay NMS, incl. summaries of sanctuary projects |
| Mary McCarthy | Rochelle Sturtevant (NOAA) | Invasive Species Specialist | Further develop an online database serving information relating to nonindigenous species in the Great Lakes region. |
| Dana Burnette | Ed Rutherford (NOAA) | Invasive Spp. and Foodweb Effects Researcher | Analyze data from diel surveys in Lake Huron to describe the physical structure of water column and its effect on the foodweb. |
| Anthony Acciaioli | Brent Lofgren (NOAA) & Andrew Gronewold (NOAA) | Hydrology and Climate Change Literature Analysis | Conduct literature search on hydrology and read/summarize selected articles. Assist with workshop coordination. |
| Stephen Jurewicz | Steve Ruberg (NOAA) | Mechanical Engin. & Buoy Dynamics | Conduct an analysis of buoy dynamics under various wave conditions. |
| Spencer Rubin | Margaret Lansing (NOAA) & Sander Robinson (CILER) | Science Communication Specialist | Write research summaries for websites and newsletters and develop web-based outreach products |
| Jonathan Kult | Drew Gronewold (NOAA) & Lauren Fry (CILER) | Watershed Modeler and GIS Analyst | Advance the scientific basis for transferring runoff estimates and forecasts from gauged to ungauged areas of the Great Lakes basin. |

## Administrative Summary

The primary role of CILER administration is to support research carried out under the auspices of the Cooperative Institute. Two of the most important administrative tasks are to facilitate financial elements of the consortium and to support the development, implementation, and coordination of our multi-university, regional research programs. Financial and research administration is a key component to the success of the institute. To help with elements of program management, CILER hired a 0.25 FTE person, Larissa Sano, to assist with implementing CILER's administrative and research missions. Dr. Sano comes to CILER with a background in aquatic ecotoxicology and brings an extensive knowledge of both CILER and University of Michigan operational procedures to this position.

Communication between the administrator and the investigators is ongoing and vital to ensuring the longevity of the cooperative institute. New systems are currently being developed to enhance the financial capability of monitoring future projections. This will give the investigators more notice on potential budget issues and constraints and can avoid pitfalls. A stronger working relationship has been cultivated with SNRE administration and human resources. The new CILER administration is committed to continuous improvements and growth.

CILER's administrative staff consist of a full-time business administrator, 80% administrative assistant, 20% program manager, 50% director and 10% associate director. The primary role of CILER administration is to support research carried out under the auspices of the Cooperative Institute. Two of the most important administrative tasks are to facilitate financial elements of the consortium and to support the development, implementation, and coordination of our multi-university, regional research programs. Financial and research administration is a key component to the success of the institute.

Communication between the administrator and the investigators is ongoing and vital to ensuring the longevity of the cooperative institute. New systems have been developed to enhance the financial capability of monitoring future projections. This will give the investigators more notice on potential budget issues and constraints and can avoid pitfalls. A stronger working relationship has been cultivated with SNRE administration and human resources.

In 2012, CILER underwent an extensive internal audit conducted by the University of Michigan Audit Department. CILER was identified by University Audits as a high-risk organization because of the large amount of funding that moves through the institute. The auditor made recommendations for improvement regarding administrative processes and the last year the CILER administrative staff worked diligently to meet and exceed these recommendations. CILER received the memo in August 2013 stating that we have successfully met all recommendations and the audit is officially closed.

The new CILER administration is committed to continuous improvements and growth.

## Research Theme I: GREAT LAKES FORECASTING

CILER activities that fall under the theme of Great Lakes Forecasting include research focusing on developing forecasts for physical hazards, water levels, harmful algal blooms, and fish recruitment and production.

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### 1. PROJECT TITLE: COMPARATIVE ANALYSIS OF NET BASIN SUPPLY COMPONENTS AND CLIMATE CHANGE IMPACTS ON THE UPPER GREAT LAKES

*University Principal Investigators*: Allen Burton (CILER), Carlo DeMarchi (Case Western Reserve University)
*NOAA Technical Leads:* Brent M. Lofgren (GLERL)

**Overview and Objectives**:
A better understanding of the water balance of the Great Lakes is necessary to face present and future challenges to the Great Lakes, such as extraordinarily low water levels in the recent years and future impacts of climate change. One of the principal tools that help scientists in this quest is the NOAA Great Lakes Environmental Research Laboratory's Net Basin Supply (NBS) estimates. These data are used for statistical analysis of the water balance of the lake and its components. In this study we will quantify the uncertainty in the NBS' single components and final values, test a new method for overlake precipitation estimation, and recalibrate the GLERL's model for lake evaporation with more recent data. We will also perform the traditional downscaling of GCM's data for comparison with more advanced methods.

This project will try to fill a gap in the knowledge of Great Lakes hydrology important both for operational purposes as well as for assessing the effects of climate change.
The Project Addresses the following NOAA Strategic Plan Goal(s) :
1) Understand climate variability and change to enhance society's ability to plan and respond;
2) Serve society's needs for weather and water information;
3) Support the nation's commerce with information for safe, efficient, and environmentally sound transportation;

**Accomplishments:**
In 2012 several uncertainty assessment have been produced for different estimate of the NBS' single components and final values which have been used for discussion and option exploration in the activity of the International Upper Great Lakes Study (IUGLS) Hydroclimatic Working Group and that have contributed to the final report to the IUGLS board.

**Publications and Presentations:**

DeMarchi, C. (2012). Great Lakes NBS Estimation and Uncertainty Evaluation Merging 1948-2008 GLERL component NBS, Five-year MESH hindcast , and CaPA over-lake precipitation estimates. Prepared for the International Upper Great Lakes Study Case Western Reserve University, Cleveland, Ohio. 25 pp.

International Upper Great Lakes Study Hydroclimatic Work Group (2012). Hydroclimatic Conditions: Past, Present and Future. Final Report to the International Upper Great Lakes Study Board. PP.83.

*Previous Publications and Presentations*

DeMarchi, C., Dai*, Q., Mello*, M.E. and Hunter, T.S., 2010. Quantifying Great Lakes Net Basin Supply Uncertainty. International Conference Water 2010, Hydrology, Hydraulics and Water Resources in an Uncertain Environment, Quebec City, Quebec, July 5-7, 2010.

DeMarchi, C., Mello*, M.E. and Hunter, T.S., 2010. Estimating Lake-wide Runoff Uncertainty in the Great Lakes Using a Monte Carlo Technique. International Conference Water 2010, Hydrology, Hydraulics and Water Resources in an Uncertain Environment, Quebec City, Quebec, July 5-7, 2010.

DeMarchi, C. (2010). Great Lakes In-Lake Hydrology. A Workshop on NASA and the U.S. Great Lakes. NASA Glenn Research Center, April 12-13, 2010. Invited.

DeMarchi, C., Dai*, Q., Mello*, M.E. and Hunter, T.S., 2010. Uncertainty in Water Supply. International Upper Great Lakes Study Hydroclimate/Adaptive Management Workshop. February 2-4, 2010, Toronto, Ontario.

**Outreach Activities:** Not applicable.

## 2. PROJECT TITLE: NEXT GENERATION LARGE BASIN RUNOFF MODELS

*University Principal Investigators:* Allen Burton (CILER), Carlo DeMarchi (Case Western Reserve University)

*NOAA Technical Leads:* Brent M. Lofgren (GLERL)

**Overview and Objectives:**

Adding sediment transport and water quality components to the Distributed Large Basin Runoff Model (DLBRM). Improving DLBRM's hydrology component to better reflect land use influence. Apply the DLBRM to simulate sediment and nutrient load in the Grand River basin (Michigan), in the AuGres-Rifle, Pigeon-Wiscoggin, Kawkawlin-Pine, Saginaw and Maumee Rivers, Sandusky River, Cuyahoga River, and Grand River (Ohio).

The Project Addresses the following NOAA Strategic Plan Goal(s):

1) Protect, restore, and manage use of coastal and ocean resources through ecosystem-based management; 2) Understand climate variability and change to enhance society's ability to plan and respond; 3) Serve society's needs for weather and water information

## Accomplishments:

The Distributed Large Basin Runoff Model (DLBRM) hydrology module has been improved. Evapotranspiration which was just a function of temperature, solar radiation, and available water now is also on land use and photosynthetic activity. This was accomplished by adding a series of monthly ET/ET0 factors, where the ET is the actual potential evapotranspiration associated to the specific land use and growth stage, while ET0 is the evapotranspiration of a well maintained grass lawn for that month. The improved hydrology was applied to the Maumee River, Black River, Cuyahoga River, and Grand River in Ohio. Saginaw River, AuGres-Rifle River, Kawkawlin-Pine River, Pigeon-Wiscoggin River, Clinton River, and Grand River in Michigan. Calibration and validation results have generally improved (e.g., daily calibration R changed from 0.91 to 0.93 for Maumee, 0.92 to 0.96 for Saginaw, 0.89 to 0.92 for AuGres, 0.88 to 0.89, and improvements have also been recorded for the two Grand Rivers, the Cuyahoga River, and the Black River). The only two rivers for which the revised hydrology performs slightly worse were the Kawkawlin-Pine and Pigeon-Wiscoggin, where calibration R has increased from 0.81 to 0.82 and from 0.79 to 0.79, but actual validation R has slightly decreased).

Daily soil erosion and sediment transport was implemented in the DLBRM and is being applied to the Maumee and Saginaw Rivers.

## Publications and Presentations:

Gebremariam, S.Y., Martin, J.F., DeMarchi, C., Bosch, N.S., Confesor, R., Ludsin, S.A., (2013). Critical Evaluation of Three Watershed Models to Predict Maumee River Flow Regime and Discharge into Lake Erie. Journal of Great Lakes Research (in submission).

Gebremariam, S.Y., Martin, J.F., DeMarchi, C., Ludsin, S.A., 2012. Impacts of Crop Management Practices in the Maumee Watershed on Dissolved Phosphorus Inputs to Lake Erie. International Association for Great Lakes Research Conference, West Lafayette, Indiana, June 3-7, 2013.

Gebremariam, S.Y., Martin, J.F., DeMarchi, C., Ludsin, S.A., 2012. Toward Development of a Coupled Human-Natural Systems Model to Understand Climate Impacts on the Lake Erie Ecosystem. American Geophysical Union 2012 Meeting, San Francisco, California, December 3-7, 2012.

He, C., Zhang, L., DeMarchi, C., and Wang, N., 2012. Modeling Ipact of Irrigation on Groundwater in Arid Northwest China. GW-IMVUL 2012 "Groundwater Vulnerability - Emerging Issues and New Approaches, Paris, France, July 9-12, 2012.

DeMarchi, C., 2012. Distributed Watershed Hydrology Modeling: Challenges and Opportunities in the Great Lakes. 2012 Advanced Ecohydrology Workshop, Lanzhou University, Lanzhou, PRC, June 8-9, 2012.

Gebremariam, S., Martin, J., Ludsin, S., and DeMarchi C., 2012. Modeling Hydrologic and Ecological Factors Impacting Phosphorus Movement from Agricultural Fields to Rivers in NW Ohio. June 7- 9, 2012 Syracuse, NY.

**Outreach Activities:** None.

## 3. Project Title: Characterizing Regional Hydrologic Response and Improving Estimates of Runoff to The Great Lakes Basin

*University Principal Investigators:* Allen Burton, CILER; Phanikumar Mantha, Department of Civil and Environmental Engineering, Michigan State University; Lauren Fry, CILER

*NOAA Technical Leads:* Andrew Gronewold, GLERL

### Overview and Objectives:

The primary goal of this project is to improve NOAA-GLERL's forecasts of daily runoff from land to the Great Lakes for the purpose of both improving water level forecasts and predicting near-shore water quality. Seasonal forecasts of Great Lakes water levels are important for many sectors within the region. The transportation industry relies on maintenance of water levels that are sufficient for freight traffic and continued use of docks and harbors. Changes in water levels may result in changes in hydropower potential, altered beaches and recreational areas, changes in fish habitat, and water quality issues at municipal water intakes. Advanced notice of changes in water levels allows for improved planning of flow regulation to maintain water levels for these important economic sectors in the region.

NOAA GLERL's Great Lakes Advanced Hydrologic Prediction System (AHPS) provides probabilistic seasonal forecasts of hydrometeorologic variables including water levels, and is used by public and private agencies in the region. AHPS translates the net basin supply (equal to runoff to the lakes plus over-lake precipitation minus over-lake evaporation) to the water level using a lake routing and regulation model. Current runoff forecasts that are input into the Great Lakes AHPS system are provided by the Large Basin Runoff Model (LBRM).

Recently, GLERL conducted an assessment of the forecasting skill of the Great Lakes AHPS by comparing 13 years of 3 and 6-month average water level forecasts with observations for each of the Great Lakes, except Lake Ontario (Gronewold, Clites, Hunter, & Stow, 2011). This analysis resulted in several recommendations for improving water level forecasts. Among these was the recommendation to recalibrate the LBRM, incorporating recent advances in methods for prediction in ungauged basins (PUB), and to consider alternative models for predicting runoff from the subbasins.

Improvements in modeled runoff to the Great Lakes addresses the NOAA Strategic Plan goals in the following ways:

1) Protect, restore, and manage use of coastal and ocean resources through ecosystem-based management;
Improved forecasts of runoff will result in improved predictions of water quality at river mouths and provide information that may be used for managing runoff and contaminant loading to river mouths. In fact, testing of the LBRM recalibration will be conducted at locations where current efforts exist at NOAA to predict water quality at beaches, and the recalibrated LBRM runoff will be used to determine loadings as input to hydrodynamic and pathogen models. Additionally, runoff forecasts contribute to the management of near shore and coastal ecosystems in order to maintain habitat and aesthetics.

2) Understand climate variability and change to enhance society's ability to plan and respond;
While long term forecasts of changes in runoff resulting from climate change are not a goal of this research, a new calibration of the LBRM will reflect recent changes to the landscape and climate and the resulting impacts on hydrologic response. Incorporation of these changes into an improved regionalized model will allow for better management of the Great Lakes water levels to respond to the different hydrologic responses that result.

3) Serve society's needs for weather and water information;
The Great Lakes provide valuable services to society within the region, and a recalibration of the LBRM will result in improved water level forecasts as well as potentially new information regarding discharge at river mouths. Society depends on such information for management within economic sectors and for determining the safety of water quality at beaches and municipal intakes.

4) Support the nation's commerce with information for safe, efficient, and environmentally sound transportation;

The Great Lakes provide a significant transportation route for many commodities. Improved estimates of runoff to the Great Lakes will allow for better management of Great Lakes water levels for the purpose of sound transportation.

**Accomplishments:**

The Great Lakes Runoff Intercomparison Project has been completed for Lake Michigan (GRIP-M). This project was a multi-agency, binational collaboration (NOAA GLERL, NOAA NWS, USGS, and Environment Canada) with the goal of comparing the simulated historical runoff provided by each of the modeling packages currently used to estimate basin-wide runoff to Lake Michigan. The outcome of the project is a common understanding of the forcings, spatial frameworks, structure, and skill of each of the 7 participating modeling systems. This new understanding will improve future development of monthly runoff simulations for application to lake level forecasting and other basin-scale applications. A manuscript describing the project results is currently under revision for submission to *Journal of Hydrology.*

Significant progress has also been made toward implementation of the NWS Community Hydrologic Prediction System (CHPS) at GLERL. CHPS is a framework for operational hydrological forecasting that provides a mechanism for retrieving forcings data, aggregating focings to a common spatial framework, encoding hydrological models, and formatting output. For the GRIP-M project, CHPS was used by the NWS to simulate runoff to Lake Michigan using the Sacramento Soil Moisture Accounting Model. Following the GRIP-M project completion, CILER programmer Kent Campbell and CILER summer fellow Nathan Kelly reconstructed all steps that NWS took to conduct the GRIP-M project and successfully duplicated their work, bringing new CHPS modeling capability to GLERL.

Additional accomplishments include the characterization of drivers of hydrologic response throughout the Great Lakes basin by conducting multiple regression analysis to relate monthly runoff ratio (discharge divided by precipitation) to watershed characteristics. The impacts of temporal averaging (i.e. using long term average monthly runoff ratios versus single monthly runoff ratios) was also investigated by CILER summer fellow Jonathan Kult, and a journal article is currently under revision for *Journal of Hydrology*. Results provide the basis for future work to simulate runoff in ungaged portions of the Great Lakes basin.

**Publications:**

Fry, L. M., Hunter, T. S., Phanikumar, M. S., Fortin, V., & Gronewold, A. D. (2013). Identifying streamgage networks for maximizing the effectiveness of regional water balance modeling. *Water Resources Research*, n/a–n/a. doi:10.1002/wrcr.20233

Kult, J.M., L.M. Fry, A.D. Gronewold, & W. Choi. (2013). Regionalization of hydrologic response in the Great Lakes basin: Considerations of temporal scales of analysis. *Journal of Hydrology*, Submitted.

### Presentations:

Fry, L.M., T.S. Hunter, M.S. Phanikumar, V. Fortin, A.D. Gronewold. (2012). Assessment of the Area Ratio Method and the value of gages for predicting runoff in intermittently gaged portions of the Great Lakes basin. American Geophysical Union Fall Meeting, San Francisco, CA, Dec. 2012.

Fry, L., A. Gronewold, V. Fortin, D. Holtschlag, S. Buan, A. Clites, T. Hunter, et al. (2012). The Great Lakes Runoff Intercomparison Project (GRIP). American Geophysical Union Fall Meeting. San Francisco, CA, Dec. 2012.

Kult, J.M., L.M. Fry, A.D. Gronewold. (2012). Accounting for inter-annual and seasonal variability in regionalization of hydrologic response in the Great Lakes basin. AGU Fall Meeting Abstracts. San Francisco, CA, Dec. 2012.

Fry, L.M., J.M. Kult, A.D. Gronewold, T.S. Hunter. (2012). Assessment of differences in physical watershed characteristics between gaged and ungaged portions of the Great Lakes basin. American Geophysical Union Fall Meeting. San Francisco, CA, Dec. 2012.

Fry, L.M., A.D. Gronewold. (2012). Development of a Regional Parameter Estimation Model for a Basin-Wide Recalibration of the Large Basin Runoff Model. International Association of Great Lakes Research Annual Meeting. Cornwall, ON, CA, May 2012.

### Outreach Activities:

Outreach activities beyond the presentations listed above include hosting two CILER summer fellows to support this project. Jonathan Kult (2012) worked with Drew Gronewold and Lauren Fry to characterize regional hydrologic response and relate hydrologic response to watershed characteristics. Nathan Kelly (2013) worked with Drew Gronewold and Lauren Fry to implement CHPS modeling at GLERL for runoff forecasting.

## 4. PROJECT TITLE: HYDRODYNAMIC MODELING AND OBSERVATIONS IN SUPPORT OF GLRI DECISION SUPPORT TOOLS

*University Principal Investigators:* Allen Burton and Eric J. Anderson (CILER-UM)
*NOAA Technical Leads:* David Schwab NOAA Emeritus and Steven Ruberg (NOAA-GLERL)

### Overview and Objectives:

The Finite Volume Coastal Ocean Model (FVCOM) and the Princeton Ocean Model (POM) have been implemented successfully in the Great Lakes, and have proven to be robust hydrodynamic modeling bases for lake- to beach-scale predictions. We have implemented these models in three areas identified as areas of interest by GLOS and GLRI participants, which include the Upper St. Lawrence River, Saginaw Bay, and the Fox River in Green Bay. In each of these areas, the objectives were to develop a model of the river or beach-scale hydrodynamics and take the necessary steps to implement an operational model, via data collection, model calibration, model refinement, or development. For the St. Lawrence River model, the primary objective is to provide predictions of water levels and currents to the recreational boating community, shipping industry, and general public in a real-time format. For Fox River and Saginaw Bay, the primary objective is to develop high-resolution plume models that are able to track river water transport as it enters the lake and to provide the hydrodynamic model based support necessary for beach forecasting.

Development of these real-time hydrodynamic models directly supports NOAA Strategic Plan Goals to: (1) serve society's needs for weather and water information and (2) support the nation's commerce with information for safe, efficient, and environmentally sound transportation.

### Accomplishments:

The Upper St. Lawrence River Forecasting System has been developed, calibrated, and improved for nowcast/forecast operation at NOAA/GLERL. A refined model grid based on user-feedback has been implemented to improve stability near the outlet boundary, include more of Lake St. Lawrence, and enable better outflow predictions. The model output is available via NOAA (http://www.glerl.noaa.gov/res/usl/) and GLOS (http://data.glos.us/boaters/slr). Current comparisons to ADCP data at several transects along the river were carried out in collaboration with Environment Canada. CILER and NOAA scientists worked with GLOS to establish an updated user interface for model output (http://data.glos.us/portal/).

The Saginaw Bay model testing is being coordinated with Michigan State University, and calibration of the model to the 2011 data (ADCP and drifters) was carried out and submitted in a manuscript to the Journal of Geophysical Research - Oceans. A combined Michigan-Huron model, which includes the Saginaw Bay submodel has been developed and calibrated to 1990 and 2008 data. It is currently implemented in a real-time testing phase at NOAA/GLERL.

The Green Bay submodel development is underway, and a new grid was developed to coordinate with the NOAA/GLERL FVCOM combined Lake Michigan-Huron model. The model has been calibrated to a second year of Green Bay ADCP current measurements. The combined-lake model is currently implemented in a real-time testing phase at NOAA/GLERL.

**Publications:**

Nguyen TD, Thuapki P, Anderson EJ, Phanikumar MS, 2013. Summer Circulation and Exchange in the Saginaw Bay – Lake Huron System, J. Geophys. Res. (submitted)

Ball EE, Smith DE, Anderson EJ, Skufca JD, Twiss MR, 2013. Delineating nearshore and main channel environments in the Upper St. Lawrence River: Plankton community assessment in a large river system, Aqua. Ecosys Health Manag, (submitted).

**Presentations:**

Anderson, E.J., and D.J. Schwab. Modeling the oscillating bi-directional flow at the Straits of Mackinac. 56th Annual Conference of the International Association for Great Lakes Research, Purdue University, W. Lafayette, IN, June 2-6, 2013 (2013).

Nguyen, T.D., P. *Thupaki, E.J. Anderson, and M.S. Phanikumar. Mean summer circulation in Saginaw Bay and Lake Huron: Results from a high resolution unstructured grid numerical model. 56th Annual Conference of the International Association for Great Lakes Research, Purdue University, W. Lafayette, IN, June 2-6, 2013 (2013)

Anderson E.J., Schwab D.J., Campbell K.B., Upper St. Lawrence River Forecasting System: Real-Time Conditions and Forecasts of Water Levels and Currents, IAGLR 2012, Cornwall, Ontario.

**Outreach Activities:**

The model output has been made public through NOAA and GLOS websites. A workshop was held by GLOS with the St. Lawrence River boating community to showcase the web tool and gain user feedback for website and model improvement. Dissemination and data sharing has been carried out via manuscripts, conference presentations, website and web tool interfaces, and public workshops.

## 5. PROJECT TITLE: IMPROVED UNDERSTANDING AND FORECASTING OF VIRAL AND BACTERIAL SOURCES AND TRANSPORT IN THE GREAT LAKES

*University Principal Investigators:* Allen Burton (CILER-UM); Joan B. Rose and Phanikumar Mantha (Michigan State University)

*NOAA Partners:* Stephen Brandt, NOAA Emeritus

### Overview and Objectives:

Our overall objectives were to address processes affecting human health issues in coastal areas (and in watersheds that contribute to these areas). Beach and watershed modeling continue to be the focus of our research and we have made further progress in both areas. The project addresses the following NOAA Strategic Plan Goal(s):

1) Protect, restore, and manage use of coastal and ocean resources through ecosystem-based management;

2) Understand climate variability and change to enhance society's ability to plan and respond;

3) Serve society's needs for weather and water information.

### Accomplishments:

It is well known that the ultra-violet component of solar radiation tends to decrease the levels of indicator bacteria such as *E. coli* in coastal waters during the daytime. Our field observations indicted a nighttime increase in the levels of *E. coli* at the same locations, especially at embayed beaches such as the Chicago 63rd Street Beach. Although recovery of bacteria at night appears to be a logical explanation, laboratory studies showed an extremely low dark DNA repair rate. In Ge et al. (2012a), we demonstrated that a wave-induced mass transport can explain the nighttime replenishment of *E. coli* consistent with our observations at the Chicago 63rd Street Beach. This research is expected to aid in characterizing the diel variability of *E. coli* and is important for developing water sampling standards and for improving fate and transport models. In concurrent work Ge at al. (2012b), we have examined, in detail, how fate and transport processes affecting *E. coli* in embayed beaches differ from those in open coastal waters.

Realizing the importance of correctly describing solute transport processes in mathematical models describing the fate and transport of indicator bacteria in the nearshore regions of the Great Lakes, we have conducted a series of field experiments in Southern Lake Michigan including a dye release experiment, several ADCP deployments and simultaneous measurements of *E. coli* concentrations at beaches in the Ogden Dunes area along the Lake Michigan shoreline in Indiana. The first set of results from this field experiment, together with our modeling, are published in Thupaki et al. (2013a). After obtaining more accurate estimates of solute/tracer transport in the nearshore region from our field observations, we examined the relative contribution of sediment-bacteria interactions on *E. coli* fate and transport in the nearshore region and quantified the improvements that result from explicitly describing sediment processes in bacterial fate and transport models (Thupaki et al., 2013b).

**Publications:**

P. Thupaki, **M.S. Phanikumar** and R.L. Whitman, Solute Dispersion in the Coastal Boundary Layer of Southern Lake Michigan, ***Journal of Geophysical Research Oceans***, vol. 118, No. 3 (March), pp. 1606-1617, doi: 10.1002 / jgrc.20136 (2013a)

P. Thupaki, **M.S. Phanikumar**, D.J. Schwab, M.B. Nevers and R.L. Whitman, Evaluating the Role of Sediment-Bacteria Interactions on *Escherichia coli* Concentrations at Beaches in Southern Lake Michigan, ***Journal of Geophysical Research Oceans*** (2013b, in revision)

Z. Ge, R.L. Whitman, M.B. Nevers and **M.S. Phanikumar**, Wave-induced Mass Transport Affects Daily *Escherichia coli* Fluctuations in Nearshore Water, ***Environmental Science & Technology***, Vol. 46(4), doi: 10.1021 / es203847n, pp. 2204-2211 (2012a)

Z. Ge, R.L. Whitman, M.B. Nevers, **M.S. Phanikumar** and M.N. Byappanahalli, Nearshore Hydrodynamics as Loading and Forcing Factors for *Escherichia coli* Contamination at an Embayed Beach, ***Limnology and Oceanography***, Vol. 57(1), pp. 362-381, doi:10.4319/lo.2012.57.1.0362 (2012b)

**Presentations:**

T.D. Nguyen, P. Thupaki, E.J. Anderson, and M.S. Phanikumar, Mean Summer Circulation in Saginaw Bay and Lake Huron: Results from a High-resolution Unstructured-grid Numerical Model, International Association for Great Lakes Research (IAGLR) 56th Annual Conference, Physical Processes in Large Lakes: A Celebration of the Career of David Schwab, June 2013, Purdue University, West Lafayette, IN(Proceedings, pp. 53)

P. Thupaki, M.S. Phanikumar, D.J. Schwab, M.B. Nevers, and R.L. Whitman, Evaluatingthe Role of Sediment-Bacteria Interactions on *Escherichia coli* Concentrations at Beaches in Southern Lake Michigan, International Association for Great Lakes Research 56th Annual Conference, Session: Advances in Monitoring, Analytical Methods, Data Management and Forecasting Beach Nearshore Water Quality, June 2013, Purdue University, West Lafayette, IN (Proceedings, pp. 44, 83)

**Outreach Activities:** None.

## 6. PROJECT TITLE: LINKING STATISTICAL AND MECHANISTIC MODELS FOR IMPROVED BEACH CLOSURE FORECASTING: GRAND HAVEN, MICHIGAN

<u>*University Principal Investigators:*</u> Allen Burton (CILER) and Phanikumar Mantha (Michigan State University)

*NOAA Technical contact:* David Schwab, NOAA-GLERL Emeritus

**Overview and Objectives**:
Statistical models for beach closures rarely achieve a coefficient of determination (R^2) of 0.6 or above which means current models do not explain 40% of the variability. The objective of this project is to develop accurate models for beach closures by (a) understanding the dominant processes impacting the fate and transport of fecal indicator bacteria (FIB) in the near-shore region and (b) developing hybrid models based on a combination of wavelet, neural-network and mechanistic models that can be used to predict beach bacteria levels accurately and in real-time.

The project addresses the following NOAA Strategic Plan Goals: (1) Protect, restore, and manage the use of coastal and ocean resources through ecosystem-based management; and 3) Serve society's needs for weather and water information;

**Accomplishments:**
During the reporting period we have completed the development of a hybrid method for real-time forecasting of microbiological water quality at recreational beaches. The new method combines artificial neural network methods with wavelet decomposition of FIB time series data to make highly-accurate, short-term forecasts of FIB levels. The new method is tested using data for several beaches in Michigan including beaches in Grand Haven. A paper based on this research is communicated to *Environmental Science & Technology.*
We plan to make the algorithms and data available to the public in 2014.

**Publications:**
J. Niu, M.S. Phanikumar, V. Kannappan, M. B. Nevers and R.L. Whitman, Real-Time Forecasting of Microbiological Water Quality at Recreational Beaches: A Hybrid Modeling Approach, *Environmental Science & Technology* (2013, in review)

**Presentations:** None.

**Outreach Activities:** None.

## 7. Project Title: Beach Quality Forecasting Coordinator

*Principal Investigators:* David Rockwell and Allen Burton (CILER – University of Michigan)
*NOAA Technical contact:* Andrew Gronewold (GLERL)

### Overview and Objectives:

The NOAA Center of Excellence for Great Lakes and Human Health (CEGLHH) is a multi-disciplinary, multi-institutional research center that is developing tools to predict water quality in the Great Lakes. Focus areas for the Center include ecological forecasting, nearshore transport, drinking water, beach closings, and harmful algal blooms. CEGLHH hired a Beach Quality Forecasting Coordinator to coordinate on-going efforts of CEGLHH and other agencies with the purpose of developing and implementing a generalized approach to beach quality nowcasting and forecasting.

NOAA Strategic Plan Goal(s) the Project Addresses:
3) Serve society's needs for weather and water information.
The Beach Water Quality Forecasting Coordinator is located in this NOAA Strategic Plan Goal.

Specific responsibilities for the Coordinator include:

1. Inventory and document ongoing activities related to beach quality forecasting, such as:
   - USGS Project SAFE
   - USGS Ohio beach nowcasting
   - Lake County Illinois Swimcast
   - Great Lakes Information Network Beachcast
   - NOAA/GLERL research on process-based beach quality modeling
   - EPA AMI bacterial exposure project
2. Develop a generalized process for beach quality nowcasting, forecasting, and product delivery. The process should include a protocol for identifying appropriate parameters to use as independent variables, gathering water quality records, obtaining the required independent variables, developing a statistical model relating water quality to the independent variables, implementing a system for routine operation of the model in nowcast and forecast mode as well as dissemination to users, and evaluation of the accuracy of the system. The coordinator might not be the person carrying out all these activities, but would be responsible for coordinating the required activities, documenting the protocol,

and ensuring that the protocol could be applied and sustained at any new beaches.

3. Work with EPA, USGS, NOAA, Sea Grant, appropriate state and local agencies, and the Great Lakes Beach Association to make sure that the end result is a product that will be useful for both nowcasting and forecasting of conditions at Great Lakes beaches. The product should also be transferable to other beaches and operationally sustainable.
4. In addition, the Coordinator will be expected to possess existing knowledge on methods for predicting recreational water quality at beaches and the processes needed to develop data sets capable of providing useful explanatory variables for model development.

**Accomplishments:**

- Responsibility 1. Updated Inventory and Document Ongoing Beach Water Quality Forecasting Activities (See attachment Appendix 1) [No Change for CILER 4/1/12 - 6/30/13 Annual Report]
- Responsibility 2. Beach Model Data Base Spreadsheet (unchanged during 4/1/12 - 6/30/13). Identified ~100 Great Lake Beaches where predictive models have been developed. These beaches use EPA's Beach ID number in the USGS Great Lakes Beach Analysis Tool Utilizing Geographic Information Systems.
- Responsibility 2. Prepared NOAA Technical Memorandum GLERL-156 which documents the generalize process. Prepared final grant report GL-00E00658 which was accepted by Ed Pniak, USEPA Project Officer.
  Evaluation of the generalized process is continuing via 2013 Forecast Decision Support systems (FDSS) for five beaches in Michigan, (Memorial and Metro Park Beaches, Macomb County, MI , Bay City State Rec Area beach, Bay County MI, and North Beach Park and Grand Haven State Park Beaches, Ottawa County), and new application of the process for five Chicago Park District Beaches, Cook County Illinois (Montrose, Foster, Oak, Calumet, and Jackson Street Beaches). The NWS offices (Detroit Pontiac and Chicago) are running the 2013 FDSS in forecast mode for the 2013 swimming season. season.
- Responsibility 3 and General Duties of BHICT Coordinator.
  - Great Lakes Beach Health Interagency Coordination Team (BHICT) continues to be comprised of three members from USEPA, four from USGS, three from NOAA, and one from CDC. Invited guests involved in pathogen studies routinely number five or more. Regular meeting have been held per mission statement in Appendix A on a monthly basis with three face to face meetings during **4/1/12 - 6/30/13**.

Membership of BHICT during 4/1/12-6/30/13:
USEPA: Holly Wirick, Frank Anscombe, and Dr. Richard Zepp
USGS: James Morris, Sandra Morrison, Norman Grannemann & Dr. Richard Whitman
NOAA: Richard Wagenmaker, Sonia Joseph Joshi, and Dr. Drew Gronewold (replacing Dr. David Schwab in November 2012)
CDC: Dr. Mark Johnson
Beach Quality Forecasting Coordinator: David Rockwell

- Developed BHICT Accomplishment report for 2012 (See attachment)
- Provided expert consultation and collaboration for Beach Recreational Water Quality Workgroups/Forums/ Sessions:

– Co-Moderator of the planned October 15-17 2013 SOLM/GLBA Joint Conference Session titled "Developing, implementing, and communicating the use of predictive and rapid tools at beaches" Session drew eight papers for five oral presentations.
– Invited April 12, 2013 to be part of the testing group for Virtual Beach (VB) Version 3. VB is U.S. Environmental Protection Agency's expert system to assist beach managers develop site-specific models for the prediction of pathogen indicator levels at recreational beaches.
– Invited February 20 and 21, 2013 to be a presenter of Virtual Beach 2.3 for the QMRA workshop and resource person for the 100 Year Workshop, Chicago Il, hosted by Joan Rose, Michigan University.
– Managed the GLBA Conference during October 15-17 2012 as GLBA President. President of the GLBA Board of Directors until October 2012 and Advisor to the GLBA President Dr. Tom Edge, Environment Canada November 2012- October 2014.
– October 16 chaired poster titled" NOAA Beach Water Quality Experimental Forecasts" with co-authors, Kent Campbell, Greg Mann, Richard Wagenmaker, and David Schwab.
– Nominated by the Great Lakes Beach Association Board of Directors to be a member of the Great Lakes Advisory Board, July 2012.
– Chaired Session for the 2012 International Association for Great Lake Research May 15th 2012 " Beach Water Quality and Human Health" This session drew 14 papers.
  - Responsibility 4. There is overlap with responsibility 2 in this part of the report. Continuing to field test the general forecasting process described in NOAA Technical Memorandum 156.
    - Five MI beaches forecast models developed in 2011 for testing by the NWS in 2012 is continuing using the same equations with modified coefficients based on 2012 sampling. Initiated field tests for five Chicago Park District Beaches in 2013.

- Completed  NOAA technical memorandum 156 in April 2013 and report for Grant GL-00E00658 December 2012

Mission for Beach Health Interagency Coordination Team

1. Meet regularly to help coordinate Beach Health activities at the management level for the three federal agencies via video/phone conferencing and bi-annual face to face meetings.
2. Capitalize on the unique research capabilities of each agency in the Great Lakes region.
3. Utilize our individual resources more effectively and efficiently by understanding our programmatic goals, sharing tasks and capabilities whenever possible by identification of common geographical work areas and common research objectives.
4. Develop coordinated responses to emerging issues (e.g. Great Lakes
5. Restoration Initiative) for Beach Health in the Great Lakes through communication with each other and our beach health partners.

### Publications

Burton, A., K.B. Campbell, and D.C. Rockwell, 60 Hour Beach Forecasting Models, Grant GL-00E00658, Ed Pniak, GLRI Project Officer, Michigan Project Lead, U.S. EPA, Region 5, Water Division, State and Tribal Programs Branch

Rockwell, D.C., K.B. Campbell, G.A. Lang, D.J. Schwab, G. Mann, and R. Wagenmaker. Beach water quality decision support system. NOAA Technical Memorandum GLERL-156. NOAA, Great Lakes Environmental Research Laboratoary, Ann Arbor, MI, 64 pp. (2013). http://www.glerl.noaa.gov/ftp/publications/tech_reports/glerl-156/tm-156.pdf

### Presentations:

D. ROCKWELL, NEVERS  M.B., CAMPBELL K.B., BREITENBACH C., WHITMAN R.L., BEACHLER D., FENELON E., LENNING E., Evaluation of the 2011-2012 Beach Water Quality Management Decision Support Systems and the NWS 2013 Beach Water Quality Experimental Forecasting at Five Chicago Beaches. EPA Office 77 W. Jackson Chicago Il.

2013 IAGLR  Conference Co-Chair for **Advances in Monitoring, Analytical Methods, Data Management and Forecasting Beach Nearshore Water Quality Session**: June 4th  2013.   Organized Session with Drew Gronewold Co-Chair Session had 11 oral presentations.

Co- authors requested David to present their talks when they were unable to attend conference due to travel restrictions.

(1)NEVERS, M.B., ROCKWELL, D., CAMPBELL, K., BREITENBACH, C. and WHITMAN, R.L.
Evaluation of 2011-2012 Beach Water Quality Management Decision Support Systems for Five Chicago Beaches

(2)BEACHLER, D., FENELON, E., LENNING, E., CASTRO, R., ROCKWELL, D. and CAMPBELL, K.
2013 NOAA Beach Water Quality Experimental Forecasting for Five Chicago Park District Beaches

Presentation on February 21, 2012 by David Rockwell with co-authors M. Cyterski, A. Mednick the talk titled "A Management Overview of Virtual Beach" at the QMRA workshop, Chicago Il, hosted by Joan Rose, Michigan University.

### Outreach Activities

Provided initial input and organized additional reviewers for the Lake Michigan Ecosystem Modeling and Forecasting Working Group, a subcommittee on Beach Management for the Lake Michigan LAMP. Result is a white paper titled " BEACH CLOSINGS: MODELING ISSUES AND STATE OF THE SCIENCE" Contributors: David Schwab[1], David Rockwell[2,3], Andrew Gronewold[3], Adam Mednick[4]

Provided GLBA comments for the Interagency Task Force revising the Great Lakes Restoration Initiative Action Plan for FY2015-FY2019

## 8. Project Title: An Integrated Approach to Monitoring, Forecasting, and Understanding Harmful Algal Blooms (HABS) in the Great Lakes

*Principal Investigators:* Thomas Johengen (CILER - University of Michigan), David Millie (University of South Florida); Rick Rediske (Grand Valley State University); Mike McCormick (private consultant)

*NOAA Technical contacts*: Gary Fahnenstiel and Juli Dyble Bressie (NOAA-GLERL)

### Overview and Objectives:

Harmful algal blooms (HABs) are a significant concern for ecosystem and human health in the Great Lakes. Blooms can reduce the aesthetic qualities of a water supply and cause complaints about taste and odor in drinking water; the decomposition of blooms can result in hypoxia or anoxia in the bottom water resulting in fish kills and benthic invertebrate mortality; and blooms can produce toxins that have direct detrimental impacts on human and animal health (Hawkins et al 1985, Teixera et al. 1993, Kuiper-

Goodman et al. 1999). *Microcystis aeruginosa* is the dominant bloom-forming, toxic cyanobacterium occurring in the Great Lakes and has again become a dominant component of the summer phytoplankton in both Saginaw Bay and western Lake Erie. The toxin of highest concern in the Great Lakes is the hepatotoxin microcystin and recent studies have measured up to 5 μg/L intracellular microcystin (Dyble et al, 2008), exceeding the recommended limit for microcystin in drinking water (1 μg/L; World Health Organization 1998). Since the Great Lakes are such a highly utilized resource for both recreation and drinking water, the ability to predict the location of HAB blooms, especially in relation to drinking water intakes and recreational beaches, would allow protection of human and ecosystem health.

The most commonly used method for detecting HAB blooms is to do ship-based sampling on transects followed by microscopy-based detection methods (including cell counts). This process is time and resource intensive and the spatial and temporal frequency of sampling is generally not sufficient to provide timely warning about the presence of HAB bloom at a drinking water intake or recreational beach, thus potentially threatening human health. Thus, there is a significant need for a HAB forecasting system that can predict the presence of blooms at significant points of interest. Such an approach currently is utilized in the Lake Erie Harmful Algal Bloom (LE HAB) Bulletin, whereby *Microcystis* blooms are depicted based upon spectral signatures as detected by the medium resolution imaging spectrometer (MERIS; Wynne et al. 2008). The LE HAB Bulletin then relies upon multi-day projections of select physical parameters (e.g. wind velocity/direction, water movement, etc.) to forecast passive bloom transport.

The main focus of this project is to validate and improve the preliminary Lake Erie HABs bulletin through a series of observations and modeling. Interactive environmental predictors and/or quantifiers for *Microcystis* abundance are not incorporated into Bulletin simulations and as a consequence, actual prediction for, and validation of *Microcystis* abundance is lacking. To improve on this deficiency routine data acquisition is being acquired of HAB measures (e.g, cell , toxin and pigment concentrations, etc.) and key environmental and meteorological variables (e.g., nutrients, light, temperature, wind speed, etc) . To determine the utility of and potential limitations for a *Microcystis* forecast 'tool' based upon remote-imagery data, the proposed work will relate existing field, or ground-truth data (supplied by NOAA-GLERL) to imagery-derived estimates of surface-dwelling cyanobacterial biomass. Specifically, computer-intensive, statistical models will be used to 1) delineate key endogenous and/or exogenous factors (e.g. hydrological/meteorological conditions, etc) corresponding to holistic *Microcystis* patterns; 2) develop models for visualizing and predicting remotely-derived *Microcystis* abundance in relation to dynamic environmental constraints; and in consultation with Dr. Stumpf and GLERL researchers, 3) identify knowledge and/or candidate models for integration into a 'next generation' Great Lakes HAB bulletin. Finally, forecasting the physical movement of a HAB depends upon the reliability of the time evolution of the forcing field, and its successful integration to an appropriate hydrodynamic model. The Great Lakes Forecasting System (GLFS), which is utilized in the LE HAB bulletin, has met with much success over a variety of applications. However, tracking the flow at the very surface or near surface such as with a HAB remains a challenge. To test the adequacy of a particle trajectory model for HAB application requires Lagrangian data on the surface waters. To meet this need we proposed to employ several surface drifting buoys that fix their GPS position at high frequency time intervals (approximately 1 minute). The drifters will be deployed during a HAB episode and the deployment location will be dictated in coordination with satellite imagery and logistical considerations.

This project addresses NOAA Strategic Plan Goal(s): (1) Protect, restore, and manage use of coastal and ocean resources through ecosystem-based management, and (3) Serve society's needs for weather and water information.

**Publications:**

Millie, D. M., G. R. Weckman, W. A. Young II, J. E. Ivey, D. P. Fries, E. Ardjmand, and G. L. Fahnenstiel. Coastal 'Big Data' and nature-inspired computation: Prediction potentials, uncertainties, and knowledge derivation of neural networks for an algal metric. Submitted to Methods in Oceanography.

Wynne, T. T., R. P Stumpf, M. C. Tomlinson, G. L. Fahnenstiel, J. Dyble, D. J. Schwab, and S. J. Joshi. Evolution of a cyanobacterial bloom forecast system in western Lake Erie: Development and initial evaluation. J. Great Lakes Res. In Press.

Michalak, A. M. and 27 others. 2013. Record-setting algal bloom in Lake Erie caused by agricultural and meteorological trends consistent with expected future conditions. Proc. Acad. Nat. Sciences 110:6448-6452.

Stumpf, R. P., T. T. Wynne, D. Baker, and G. Fahnenstiel. 2012. Inter-annual variability in cyanobacterial blooms in Lake Erie. PloS ONE 7(8): e42444. Doi:10.1371/journal.pone.0042444.

Millie, D. F, G. R. Weckman, W. F. Young II, J. E. Ivey, and G. L. Fahnenstiel. 2012. Modeling microalgal abundance with artificial neural networks: Demonstration of a heuristic 'grey-box' to deconvolve and quantify environmental influences. Ecological Modeling and Software. 38:27-39.

Young II, W. A., D. F. Millie, G. R. Weckman, J. S. Anderson, D M. Klarer, and G.L. Fahnenstiel. 2011. Modeling net ecosystem metabolism with an artificial neural network and Bayesian belief network. Ecological Modeling and Software. 26:1199-1210.

Millie, D. F., G. L. Fahnenstiel, G. R. Weckman, D. M. Klarer, J. D. Bressie, H. A. Vanderploeg, and D. Fishman. 2011. An 'Enviro-Informic' assessment of Saginaw Bay (Lake Huron USA) phytoplankton: Data-driven characterization and modeling of *Microcystis* (Cyanophyta). J. Phycol. 47:714-730.

Weckman, G.R., D. F. Millie, C. Ganduri, M. Rangwala, W. Young, and G. L. Fahnenstiel. 2009. Knowledge extraction from the neural 'black box' in ecological monitoring. J. Industrial & Systems Engineering. 3:38-55.

Millie, D. F., R. J. Pigg, G. L. Fahnenstiel, J. Dyble, R. Rediske, D. Klarer, P. Tester, R. W. Litaker. 2009. Late-summer phytoplankton in western Lake Erie (Laurentian Great Lakes): bloom distributions, toxicity, and environmental influences. Aquat. Ecol. Doi:10.1007/s10452-009-9238-7.

Millie, D. F., G. L. Fahnenstiel, J. Dyble, R. Pigg, R. Rediske, R. W. Litaker, P. A. Tester. 2008. Influence of environmental conditions on summer cyanobacterial abundance in Saginaw Bay, Lake Huron. Aquat. Ecosyst. Health Management. 11:196-205.

Fahnenstiel, G. L., D. F. Millie, J. Dyble, R. W. Litaker, P. A. Tester, M. J. McCormick, R. Rediske, and D. Klarer. 2008. Microcystin concentrations and cell quotas in Saginaw Bay, Lake Huron. Aquat. Ecosyt. Health and Management. 11:190-195.

Wynne, T., R. Stumpf, M.C. Tomlinson, R. A. Warner, P. A. Tester, J. Dyble, and G. Fahnenstiel. 2008. Relating spectral shape to cyanobacteria blooms in the Laurentian Great Lakes. Int. J. Remote Sensing 29:3665-3672.

Dyble, J., G. Fahnenstiel, R. W. Litaker, D. Millie and P. Tester. 2008 Microcystin concentrations and genetic diversity of *Microcystis* in Saginaw Bay and western Lake Erie. Env. Toxicology. 23:507-516.

**Presentations:**

Four scientific presentations were made on HABs in Great Lakes to the following conferences: International Association for Great Lakes Research, American Society of Limnology and Oceanography, National HABs.

**Outreach Activities:**

Three outreach presentations were given to : Y Club International, Rotary Club, Michigan Sea Grant Extension on the causes and consequences of HABs in the Great Lakes.

## 9. PROJECT TITLE: CSCOR NGOMEX THE EFFECTS AND IMPACTS OF HYPOXIA ON PRODUCTION POTENTIAL OF ECOLOGICALLY AND COMMERCIALLY IMPORTANT LIVING RESOURCES IN THE NORTHERN GULF OF MEXICO

*Principal Investigators:* Andrea Vander Woude and Allen Burton and Aaron Adamack (CILER-University of Michigan)

*NOAA Technical Leads:* Doran Mason and Craig Stow (NOAA-GLERL)

### Overview and Objectives:

To assess the full impact of hypoxia on living resources of the Northern Gulf of Mexico (NGOMEX) requires a multi-scale (both time and space) and multi-stressor approach. This project proposes a framework to simultaneously account for direct and indirect effects of hypoxia, including their linear and non-linear interactions on key organisms to support ecosystem-based management in the NGOMEX. A battery of modeling approaches of varying complexity (individual - to ecosystem-level), spatial configuration (near-field plume to fine-scale spatial pelagic to entire NGOMEX), and temporal duration (hourly to inter-annual) will be employed to provide both understanding and forecast capabilities to the management community of the NGOMEX.

Multiple models will be used to evaluate:

- What is the effect of the spatial extent and seasonal timing of hypoxia on fish growth, recruitment and production potential?
- How does hypoxia affect food web interactions in the pelagic zone? Specifically:
    - How will hypoxia affect the spatial distribution and predator-prey interactions of mobile organisms and zooplankton?
    - How does hypoxia affect habitat quality and suitability for economically and ecologically important fishes?
- How will management decisions on loadings affect fisheries through its impact on the timing and extent of hypoxia?
- What is the potential of strong wind events (and their relationship to climate change) to re-aerate the water column and alter the interactions of fish and their prey?
- What are the most effective tools to forecast food-web interactions, habitat suitability, and fish production in relation to hypoxia?

It is hypothesized that hypoxia in the NGOMEX can strongly impact pelagic food webs and production through unexpected, indirect pathways, potentially leading to changes in production potential (both positive and negative) of economically and ecologically important fishes. Our overall goal is to provide quantitative tools to probabilistically forecast the effects of hypoxia on the living resources in the NGOMEX. Direct linkages to fisheries management will ensure continued interaction with, and attention to, the critical management issues.

Researchers from CILER have been focusing on developing an ecosystem-based model for the Louisiana-Texas continental shelf which will be used to evaluate most of the major questions being addressed by this project. CILER researchers have also been developing an individual-based model for fish eggs and larvae which will be used to screen species for susceptibility to hypoxia conditions in the Northern Gulf of Mexico.

This work addresses NOAA's Strategic Plan Goals of "Protect, restore, and manage use of coastal and ocean resources through ecosystem-based management" through our development of an ecosystem-based model for the Northern Gulf of Mexico.

## Accomplishments:

### Atlantis Ecosystem Model

In August 2012, Andrea Vander Woude joined the NOAA Great Lakes Environmental Research Laboratory to continue the work that Aaron Adamack on the Atlantis model. Since she has joined our group, she has finalized the Atlantis model grid (37 polygons and 13 depth strata, Figures 1 and 2) and helped nest the NGOMEX grid into the much larger-scale Atlantis grid being developed by Cameron Ainsworth (University of South Florida).

*Figure 1. NGOMEX Atlantis polygons (red) nested in the whole Gulf of Mexico grid (blue).*

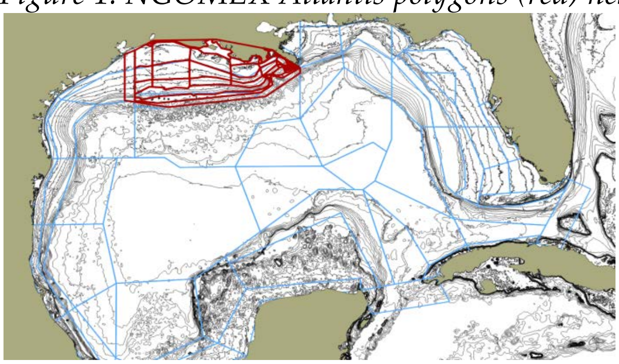
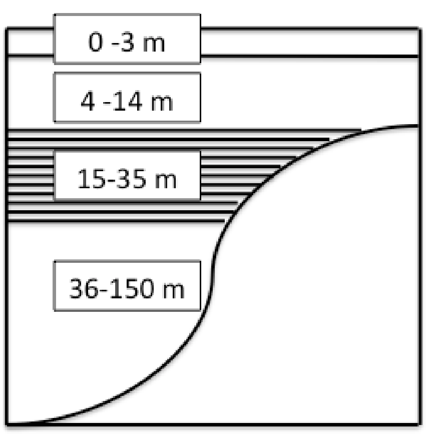


*Figure 2. Illustration of the 13 depth strata in the NGOMEX Atlantis grid*




All the parameter files are completed and we are currently debugging the entries. The parameter files are extensive are require a significant amount of time to create. Table 1 lists the parameter files required for the NGOMEX Atlantis model.

Diet matrix for the food web interactions was determined for most of the functional groups based upon the values provided by Kim de Mutsert from the EwE model. and this was part of the ecology parameterization run files. This contained the functional group information and biogeochemical values for each layer and each box. This included the abundance, distribution of the reserve, structural and total nitrogen values for each one of the functional groups for the 10 different age classes, as well as the number of fish within each layer and box. The growth parameters come for a weight-at-age from the von Bertlanffy growth parameters, converted to nitrogen-weight. The benthos values only use one entry for the two-dimensional box instead of the three-dimensional vertical distribution and age groups associated with vertebrates. Describing the bottom surface type for each one of the boxes then follows this large file. These two files and the large biology parameter file with switches for initial conditions were incorporated into the biology netcdf file that is fed into the model. It is within the biology files that we set the initial conditions for dissolved oxygen to mimic hypoxia in the summer and fall, the threshold of dissolved oxygen for the functional groups and

*Table 1.*

| File | Description | Lines of code | Completed |
|---|---|---|---|
| **NGOMEX_Bio.nc** | Biology tracer values | 40,000 | 5/20/2013 |
| **runNGOMEX.prm** | Model run parameters | 202 | 6/01/2013 |
| **Force_NGOMEX.prm** | Nutrient forcing, T,S,Solar | 99 | 6/02/2013 |
| **At_physics_NGOMEX.prm** | Physics parameters | 275 | 6/03/2013 |
| **Biol_NGOMEX.prm** | Biology parameters, including the diet matrix, oxygen limitation choices, habitat dependency, and seasonal distribution | 4147 | 6/01/2013 |
| **At_harvest_emoccNGOMEX.prm** | Fishery parameters | 220 | 6/02/2013 |
| **functionalgroupsNGOMEX.csv** | Functional groups, including carrion and detritus | 54 | 9/30/2012 |

the type of oxygen limitation. We are at the point of testing which oxygen limitation is the best choice.

That last part before the model is operation was setting up the forcing files from the hydrodynamics, the physics parameters, the fishery and management parameters, the assessment and the economics. At this point the hydrodynamics, management and assessment and economic parameters are all turned off as the code is optimize. The developers in Australia are currently optimizing the code and all of the initial parameter files were completed for their analysis. We envision having results in the next month as "bugs" in model are resolved.

**Egg and Larval Fish Individual Based Model (IBM)**

Progress on the egg and larval fish IBM has been delayed by Adamack's move to Australia for a new position. At this point, much of the model development has been completed and the model will be run using a modified version of the three-box (surface, pycnocline, and bottom) (Adamack et al. 2012, Figure 3). Work will begin soon on model calibration using data on the vertical distributions of fish larvae from NGOMEX. Initially, our focus is on Atlantic croaker, as this was one of the predominant species in our past field efforts. Other species will be determined based on the availability of larval fish data from our colleagues (Graham and Hernandez). Additional species will be simulated as their data becomes available. Physical conditions to force the model will be derived from a subset of the SCANFISH transect data (e.g., Figure 4) to develop scenarios for low, average and high hypoxia years for shallow, mid-depth and deep locations. Water column structure (e.g. the proportion of the water column in each of the three boxes) will be determined from the SCANFISH data, using the pycnocline detection algorithm developed by T.R. Fisher and described in the appendix of Adamack et al. 2012 to divide the water column into three layers (surface, pycnocline and bottom). Dissolved oxygen concentrations for each layer will be averaged over their values within a layer. Layer-averaged dissolved oxygen concentrations and proportion of the water column in each layer will remain constant for the duration of each simulation for each scenario. Details that still need to be resolved are how mortality due to low DO and other causes will be parameterized. We are considering two options: 1) use of existing values from Chesapeake Bay, or 2) trying to identify values that may be more appropriate for NGOMEX.

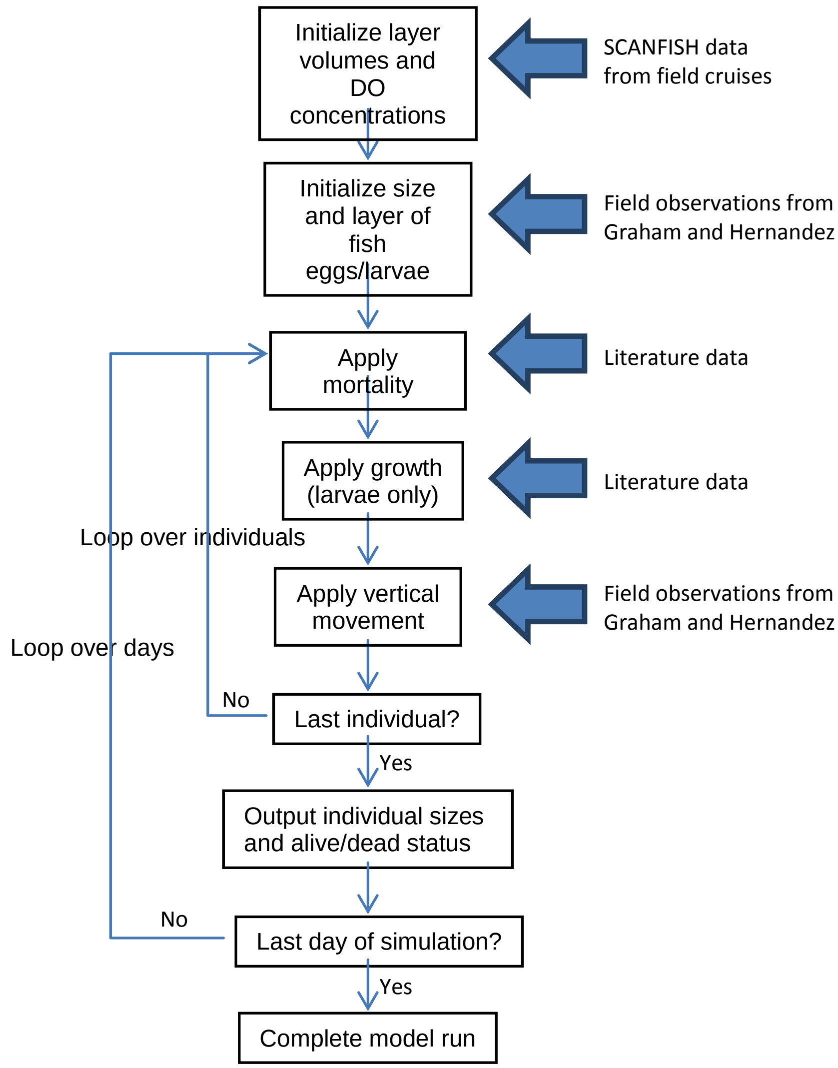



*Figure 3. Flowchart showing the flow of operations in the IBM being used to screen fish eggs and larvae for their susceptibility to hypoxia in NGOMEX. Large blue arrows indicate where data from different sources will be used to parameterize the model.*

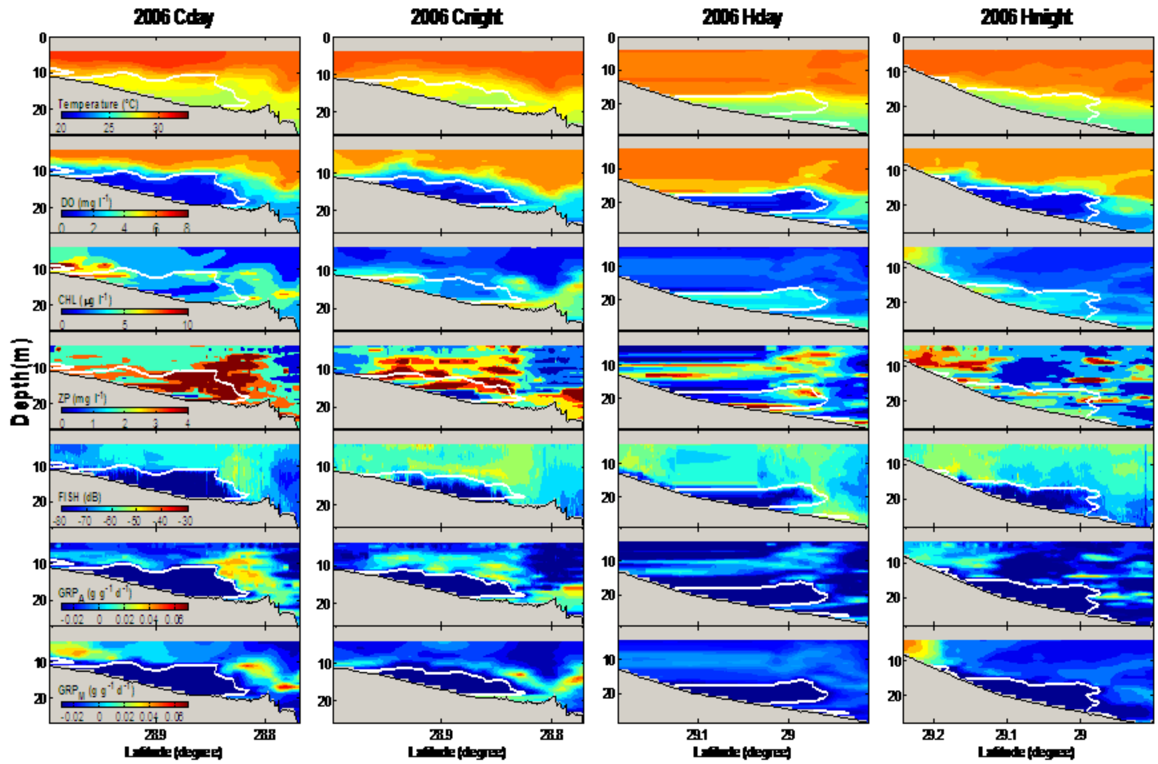



*Figure 4. Graphical representations of variables collected using the scanfish along two different transects (day and night) in 2006.*

**Reference**

Adamack, A.T., K.A. Rose, D.L. Breitburg, A.J. Nice, and W.S. Lung. 2012. Simulating the effect of hypoxia on bay anchovy eggs and larval mortaility using coupled watershed, water quality, and individual-based predation models. Marine Ecology Progress Series 445:141-160.

**Publications:**

Zhang, H., D.M. Mason, C.A. Stow, A.T. Adamack, S.B. Brandt, X. Zhang, D.G. Kimmel, M.R. Roman, W.C. Boicourt, and S.A. Ludsin. (In Review). Hypoxia, habitat quality, and the spatial distribution of pelagic fishes in the northern Gulf of Mexico. Marine Ecology Progress Series.

**Presentations:**

Vander Woude, A., D.M. Mason, H. Zhang, C. Stow, A. Adamack, K. de Mutsert, J. Pierson, S.B. Brandt, M. Roman. The effects of hypoxia on the food web of the northern Gulf of Mexico: An Atlantis ecosystem modeling approach. Association for the Sciences of Limnology and Oceanography (ASLO), 17-22 February 2013, New Orleans, LA.

**Outreach Activities:** None.

## 10. Project Title: Modeling Great Lakes Ice and Revealing Linkages between Lake Ice and Climate Patterns

*Principal Investigators:* Allen Burton, Xuezhi Bai, Haoguo Hu, and Ayumi Fujisaki (CILER-University of Michigan)

*NOAA Technical Contact:* Jia Wang, (NOAA-GLERL)

### Overview and Objectives

Lake ice cover is an important predictor of regional climate. Lake ice extent also modifies the circulation patterns and thermal structure because: 1) wind stress drag is different in magnitude over the water surface than over the ice surface; 2) the albedo over ice vs. water differs, and 3) heat and moisture exchange between the atmosphere and the lake water can differ significantly (as much as an order of magnitude difference) in magnitude with and without lake ice, thus leading to a striking difference in evaporation in wintertime due to wind mixing.

The Great Lakes ice severity conditions are determined by surface air temperature (SAT), water temperature, heat flux, and water heat storage that is directly proportional to water depth. These factors are associated with global (hemispheric) and regional climate patterns, such as the Arctic Oscillation (AO) or the North Atlantic Oscillation (NAO), and Pacific-North America (PNA) pattern.

The Great Lakes are located at the edge of the Icelandic Low, far away from the action center. Thus, although being influenced by the Icelandic Low whose intensity is associated with AO/NAO (+/-AO means a stronger/weaker Icelandic Low), ice cover may not have a statistically significant relationship with AO/NAO. A similar doubt/hypothesis is also applied to the PNA pattern. Based on previous research (Wang et al. 1994; Mysak et al. 1996), the PNA pattern may have a marginally significant impact on ice cover in the Great Lakes, because the Great Lakes are located between the Alberta High and the SE-US Low.

The objective of this study is to use generalized statistical analyses of the NCEP/NCA reanalysis and climate GCM products and historical sea ice observations including recent satellite measurements to analyze the statistical relationship between lake ice cover and climate indices in both spatial and temporal spaces. A generalized relationship between lake ice cover, lake levels, and atmospheric circulation patterns will be concluded. The second objective is to develop and test an ice model of Lake Erie.

The NOAA Strategic Plan Goal(s) the Project Addresses include:

1) Understand climate variability and change to enhance society's ability to plan and respond;
2) Serve society's needs for weather and water information;
3) Support the nation's commerce with information for safe, efficient, and environmentally sound transportation

**Accomplishments:**

1) A 33-winter ice concentration climatology was updated for winters 2006-2011 (Wang et al. 2012). And analyzed the 2006-2011 ice cycles within the context of: dates of first (last) ice, ice duration, ice cover distribution, ice cover anomalies, and seasonal progression of lake-averaged ice cover. Analysis data are available as ASCII and graphic files (Assel et al. 2013).

2) Atmospheric teleconnection circulation patterns associated with severe and mild ice cover over the Great Lakes are investigated using the composite analysis of lake ice data and National Center of Environmental Prediction (NCEP) reanalysis data for the period 1963–2011. The teleconnection pattern associated with the severe ice cover is the combination of a negative North Atlantic Oscillation (NAO) or Arctic Oscillation (AO) and negative phase of Pacific/North America (PNA) pattern, while the pattern associated with the mild ice cover is the combination of a positive PNA (or an El Niño) and a positive phase of the NAO/AO. These two extreme ice conditions are associated with the North American ridge–trough variations. The intensified ridge–trough system produces a strong northwest-to-southeast tilted ridge and trough and increases the anomalous northwesterly wind, advecting cold, dry Arctic air to the Great Lakes. The weakened ridge–trough system produces a flattened ridge and trough, and promotes a climatological westerly wind, advecting warm, dry air from western North America to the Great Lakes. Although ice cover for all the individual lakes responds roughly linearly and symmetrically to both phases of the NAO/AO, and roughly nonlinearly and asymmetrically to El Niño and La Niña events, the overall ice cover response to individual NAO/AO or Niño3.4 index is not statistically significant. The combined NAO/AO and Niño3.4 indices can be used to reliably project severe ice cover during the simultaneous –NAO/AO and La Niña events, and mild ice cover during the simultaneous NAO/AO and El Niño events (Bai and Wang 2012).

3) An unstructured Finite Volume Coastal Ocean Model was applied to all five Great Lakes simultaneously to simulate circulation and thermal structure from 1993 to 2008. Model results are compared to available observations of currents and temperature and previous modeling work. Maps of climatological circulation for all five Great lakes are presented. Winter currents show a two-gyre type circulation in Lakes Ontario and Erie and one large-scale cyclonic circulation in Lakes Michigan, Huron, and Superior.

During the summer, a cyclonic circulation remains in Lakes Superior; a primarily cyclonic circulation dominates upper and central Lake Huron; Lake Ontario has a single cyclonic circulation, while circulation in the central basin of Lake Erie remains two-gyre type; Lake Michigan has a cyclonic gyre in the north and an anti- cyclonic one in the south. The temperature profile during the summer is well simulated when a surface wind-wave mixing scheme is included in the model. Main features of the seasonal evolution of water temperature, such as inverse temperature stratification during the winter, the spring and autumn over- turn, the thermal bar, and the stratification during summer are well reproduced. The lakes exhibit significant annual and interannual variations in current speed and temperature (Bai et al. 2013).

4) Ice model is implemented in the Princeton Ocean Model for Lake Erie. Simulations for 2003-2012 reproduced anomalously high and low ice coverage in the lake. The model showed reduced coastal current speed under packed ice cover.

### Publications

Assel, R.A., J. Wang, A.H. Clites, and X. Bai. Analysis of Great Lakes ice cover climatology: Winters 2006-2011. NOAA Technical Memorandum GLERL-157. NOAA Great Lakes Environmental Research Laboratory, Ann Arbor, MI, 26 pp. (2013)

Bai, X., J. Wang, D.J. Schwab, Y. Yang, L. Luo, G.A. Leshkevich, and S. Liu**.** Modeling 1993-2008 climatology of seasonal general circulation and thermal structure in the Great Lakes using FVCOM. *Ocean Modeling* 65:40-63 (DOI:10.1016/j.ocemod.2013.02.003) (2013).

Bai, X., and J. Wang. Atmospheric teleconnetion patterns associated with severe and mild ice cover in the Great Lakes, 1963-2011. *Water Quality Research Journal of Canada, Special Issue on Physical Processes in Natural Waters* 47(3-4):421-435 (DOI:10.2166/wqrjc.2012.009) (2012)

Fujisaki, A., J. Wang, X. Bai, G. Leshkevich, and B. Lofgren (2013). Model-simulated interannual variability of Lake Erie ice cover, circulation, and thermal structure in response to atmospheric forcing, 2003-2012, J Geophys Res, in press.

Wang, J., R.A. Assel, S. Walterscheid, A.H. Clites, and X. Bai**.** Great Lakes ice climatology update: Winter 2006-2011. Description of the digital ice cover dataset. NOAA Technical Memorandum GLERL-155. NOAA, Great Lakes Environmental Research Laboratory, Ann Arbor, MI, 37 pp. (2012).

### Presentations

Assel, R.A., J. *Wang, A.H. Clites, and X. Bai. Analysis of Great Lakes ice cover climatology: Winters 2006-2011. 56th Annual Conference of the International Association for Great Lakes Research, Purdue University, W. Lafayette, IN, Purdue University, W. Lafayette, IN (2013).

*Bai, X., and J. Wang. Modeling water circulation and thermal structure in the Great Lakes with FVCOM (poster). 2012 Ocean Sciences Meeting, Salt Lake City, UT, February 20-24, 2012. ASLO/AGU (2012).

*Bai, X., J. Wang, Modeling 1993-2008 climatology of seasonal general circulation and thermal structure in the Great Lakes using FVCOM. 56th Annual Conference of the International Association for Great Lakes Research, Purdue University, W. Lafayette, IN, June 2-6, 2013 (2013).

Fujisaki, A., J. Wang, X. *Bai, G.A. Leschkevich, and B.M. Lofgren. Model-simulated interannual variability of Lake Erie ice cover, circulation, and thermal structure in response to atmospheric forcing, 2003-2012. 56th Annual Conference of the International Association for Great Lakes Research, Purdue University, W. Lafayette, IN, June 2-6, 2013 (2013).

Wang, J., X. Bai, . A record breaking low ice cover over the Great Lakes during winter 2011/2012. 56th Annual Conference of the International Association for Great Lakes Research, Purdue University, W. Lafayette, IN, June 2-6, 2013 (2013).

### Outreach Activities

Fujisaki A. and J. Wang, Impacts of ice cover on Lake Erie hydrodynamics, from a 3D ice-hydrodynamic coupled model, GLERL-CILER seminar series, NOAA GLERL, Ann Arbor, June 12, 2013.

## 11. Project Title: Modeling Nutrient and Bacterial Transport in Regional Great Lakes Watersheds using Physically-based Distributed Hydrologic Model (PAWS)

University Principal Investigators: Allen Burton (CILER-University of Michigan); Phanikumar Mantha, (Michigan State University)

*NOAA Technical Leads:* David Schwab, NOAA-GLERL Emeritus

### Overview and Objectives:

The aim of this project was to support human and ecosystem health-related activities in the Great Lakes basin by applying a distributed hydrologic model PAWS developed at MSU. In particular, the aim was to develop and test models to predict the levels of nutrients (Nitrogen and Phosphorus) and indicator bacteria (such as *E. coli*) to large watersheds such as the Grand River and Saginaw Bay in Michigan and other Great Lakes states.

NOAA Strategic Plan Goal(s) the Project Addresses are described below:

1) Protect, restore, and manage use of coastal and ocean resources through ecosystem-based management;
3) Serve society's needs for weather and water information;
4) Support the nation's commerce with information for safe, efficient, and environmentally sound transportation;

### Accomplishments:

We have made significant progress during the reporting period in the development of transport modules for *E. coli* and nutrients and their application to Great Lakes watersheds. Our initial efforts focused on the application of the PAWS hydrologic model to large and medium-sized watersheds in the Great Lakes basin. After testing the hydrologic component of the PAWS model, we developed transport models to predict the levels of E. coli and nutrients in the watersheds. Several papers based on this research are currently in review or in preparation. In Shen et al. (2013), we applied the PAWS model to the Clinton River watershed in Michigan and used the model to elucidate the hydrologic processes in the watershed. In Niu et al. (2013), we applied the PAWS model to regional watersheds including the Grand River and the Saginaw Bay watersheds testing the model using remotely sensed datasets including MODIS and GRACE datasets. Niu and Phanikumar (2013) described the first application of the PAWS model to describe integrated, watershed-scale solute transport including the application of an *E. coli* fate and transport model to the Red Cedar River watershed in Michigan (a sub-watershed of the Grand River basin). Additional papers that describe the development and application of nutrient transport models are currently in preparation and will be communicated to peer-reviewed journals soon.

### Publications:

C. Shen, J. Niu, **M.S. Phanikumar**, Evaluating Controls on Coupled Hydrologic and Vegetation Dynamics in a Humid Continental Climate Watershed Using a Subsurface - Land Surface Processes Model, ***Water Resources Research***, vol. 49, pp. 2552 - 2572, doi: 10.1002/wrcr.20189 (2013)

J. Niu, C. Shen and **M.S. Phanikumar**, Quantifying Storage in Regional Great Lakes Watersheds Using MODIS, GRACE products and coupled subsurface – Land Surface Models, ***Water Resources Research*** (2013, in revision)

J. Niu and **M.S. Phanikumar**, Modeling Solute Transport at the Watershed Scale Using a Process-Based, Distributed Hydrologic Model with Application to Bacterial Fate and Transport Modeling, ***Journal of Hydrology*** (2013, in review)

**Presentations:**

J. Niu and **M.S. Phanikumar**, Quantifying Fluxes of Chemical and Biological Species in Great Lakes Watersheds: A Reactive Transport Modeling Framework, Proceedings of the AGU Fall Meeting, San Francisco, December 3-7, 2012. EOS # H51I-1468 (2012)

C. Shen, J. Niu and **M.S. Phanikumar**, Analysis of Groundwater-induced Hydrologic Patterns and Controls in a Great Lakes Watershed Using a Subsurface – Landsurface Processes Model, AGU Fall Meeting, San Francisco, December 3-7, 2012. EOS # H51I-1465 (2012)

**Outreach Activities:** None.

## 12. Project Title: Modeling Sea Ice-Ocean-Ecosystem Responses to Climate Changes in the Bering-Chukchi-Beaufort Seas with Data Assimilation of RUSALCA Measurements

*Principal Investigators:* Allen Burton, Haoguo Hu and Xuezhi Bai (CILER-University of Michigan)
*NOAA Technical Contact:* Jia Wang (NOAA-GLERL)

**Overview and Objectives**:

This project addresses 1), 2) and 3) of the following NOAA Strategic Plan Goal(s):
1) Protect, restore, and manage use of coastal and ocean resources through ecosystem-based management;
2) Understand climate variability and change to enhance society's ability to plan and respond;
3) Serve society's needs for weather and water information;
This proposed study is to use the combination of an IARC high-resolution (4-km) Coupled Ice-Ocean Model (CIOM, Wang et al. 2002, 2004, 2005; Wu et al. 2004) and Princeton Regional Ocean Forecast (and Hindcast) System's (PROFS) data-assimilation methodologies to improve our understanding of ocean and sea ice circulation in the Bering-Chukchi-Beaufort (BCB) seas, driven by ocean tides, Alaska Stream (AS) and Alaska Coastal Current (ACC) inflow/outflow, freshwater discharge, and synoptic wind stress. We propose to implement the data assimilation approach based on PROFS to cover the Bering Sea, Chukchi Sea, and part of the Beaufort Sea. That will allow assimilations of existing and on-going hydrographic data and moorings across the Bering Strait in addition to those data in the Chukchi Sea and Bering Sea. Importantly,

the PROFS' Lagrangian assimilation scheme will also assimilate the Argo data (http://www.argo.ucsd.edu/). Particularly, the developed PROFS approach will allow CIOM to assimilate hydrographic data measured during the period (2007-2012) when the RUSALCA's moorings will be deployed near the Bering Strait. A high-resolution coupled atmosphere-ice-ocean global climate model (from Japan) will provide the BCs to both CIOM and PROFS. Then, a series of sensitivity simulations with CIOM combined with PROFS will be conducted to examine in: 1) AS inflow 2) Response to a change in position of the Aleutian Low, 3) Both positive and negative phases of AO (Arctic Oscillation) and PDO (Pacific Decadal Oscillation) to identify the similarity and difference of the ice-ocean response to AO and PDO, and 4) Response to Arctic Dipole Anomaly (DA) to investigate the DA's impact on SST, and sea ice concentration (retreat) in the Alaska Arctic water due to the enhanced Bering Inflow. In return, the modeling results will be discussed with those PIs with RUSALCA field observation projects and an optimal sampling strategy will be designed for better coverage.

A 3-D, 9-compartment, Physical-Ecosystem Model (PhEcoM), coupled to CIOM, will be used to study the ice-ocean-ecosystem dynamics in the same region. The data from RUSALCA nutrient and plankton moorings will be used for conducting independent data analysis to also validate this model, and for assimilation by PROFS . This model will be used to test our proposed hypotheses: 1) North-south connection/advection of nutrients and planktons, 2) West-east seesaw of plankton blooms due to a change of location of the Aleutian Low, and 3) On-shelf nutrient supply by mesoscale eddies for sustainable "Green Belt" blooms. Therefore, this proposed study using PhEcoM-CIOM-PROFS will have a broad impact on 1) the ice-ocean-ecosystem dynamics that explains the high primary productivity region, along the Green Belt (i.e., along the Bering Slope), seasonal blooms and the interannual variability in the BCB seas, and 2) ice edge variability due to climate changes and the impacts on primary and secondary productivity.

**Accomplishments:**

A nutrient (N), phytoplankton (P), zooplankton (Z), and detritus (D) ecosystem model coupled to an ice-ocean model was applied to the Bering and Chukchi Seas for 2007–2008. The model reasonably reproduces the seasonal cycles of sea ice, phytoplankton, and zooplankton in the Bering–Chukchi Seas. The spatial variation of the phytoplankton bloom was predominantly controlled by the retreat of sea ice and the increased gradient of the water temperature from the south to the north. The model captures the basic structure of the measured nutrients and chl-a along the Bering shelf during 4–23 July 2008, and along the Chukchi shelf during 5–12 August 2007. In summer 2008, the Green Belt bloom was not observed by either the satellite measurements or the model. The model-data comparison and analysis reveal the complexity of the lower trophic dynamics in the Bering and Chukchi Seas. The complexity is due to the nature that the physical and biological components interact at different manners in time and space, even in response to a same climate forcing, over the physically distinct geographic settings such as in the Bering and North Aleutian Slopes, deep Bering basins, Bering shelf, and Chukchi Sea. Sensitivity studies were conducted to reveal the underlying mechanisms (i.e., the bottom-up effects) of the Bering–Chukchi ecosystem in response to changes in light intensity, nutrient input from open boundaries, and air temperature. It was found that (1) a 10% increase in solar radiation or light intensity for the entire year has a small impact on the intensity and timing of the bloom in the physical–biological system since the light is not a limiting factor in the study region; (2) a 20% increase in nutrients from all the open boundaries results in an overall 7% increase in phytoplankton, with the Slope region being the largest, and the Bering shelf and Chukchi being the smallest; and (3) an increase in air temperature by 2°C over the entire calculation period can result in an overall increase in phytoplankton by 11%.

**Publications:**

**WANG, J., H. HU,** J. Goes, J**.** Miksis-Olds, C. Mouw, E. D'Sa, H. Gomes, D.R. Wang, K. Mizobata, S. Saitoh, and L. LUO. A modeling study of seasonal variations of sea ice and plankton in the Bering and Chukchi Seas during 2007–2008. *Journal of Geophysical Research* 118:1–14 (DOI:10.1029/2012JC008322) (2013).

Greene, CH, BC. Monger, LP McGarry, MD Connelly, NR Schnepf, AJ Pershing, IM. Belkin, PS Fratantoni, DG Mountain, RS Pickart, R Ji, JJ Bisagni, C Chen, SMA Hakkinen, DB Haidvogel, **J Wang**, E Head, P Smith, A Conversi, 2013. Remote Climate Forcing of Decadal-Scale Regime Shifts in Northwest Atlantic Shelf Ecosystems, Limnology and Oceanography, 58(3), 803–816

Overland, J.E., **J Wang**, RS Pickart, and M. Wang, 2013. Recent and Future Change in the Meteorology of the Pacific Arctic In: The Pacific Arctic Region: Ecosystem Status and Trends in a Rapidly Changing Environment, Co-Editors Grebmeier, J.M. and W. Maslowski, Springer Publishing, (accepted)

Deal, C.J. N. Steiner, J. Christian, J. Clement Kinney, K. Denman, S. Elliott, G. Gibson, M. Jin, D. Lavoie, S. Lee, W. Lee, W. Maslowski, **J. Wang**, and E. Watanabe, 2013, Progress and Challenges in Biogeochemical Modeling of the Pacific Arctic Region. In: The Pacific Arctic Region: Ecosystem Status and Trends in a Rapidly Changing Environment, Co-Editors Grebmeier, J.M. and W. Maslowski, Springer Publishing, (accepted)

**Wang, J.,** H. Eicken, Y. Yu, **X. Bai,** J. Zhang**, H. Hu,** D.-R. Wang, M. Ikeda, K. Mizobata, and J. Overland, 2013. Abrupt Arctic Changes and Emerging Ice-Ocean Processes in the Pacific Arctic Region and Bering Sea, In: The Pacific Arctic Region: Ecosystem Status and Trends in a Rapidly Changing Environment, Co-Editors Grebmeier, J.M. and W. Maslowski, Springer Publishing (accepted)

**Presentations:**

**Wang, J., H. Hu, and X. Bai.** Modeling seasonal cycle of ice-ocean-ecosystem in the Bering and Chukchi Seas. Columbia Univ., New York, NASA Project Workshop, March 14-15

BELETSKY, D., H. HU, J. WANG, and N. HAWLEY. Modeling winter circulation and ice in Lake Erie. 56th Annual Conference of the International Association for Great Lakes Research, Purdue University, W. Lafayette, IN, June 2-6, 2013 (2013).

**Poster:**

**Wang, J. and Hu, H,** Modeling sea ice and ecosystem in the Bering and Chukchi Seas. Alaska Marine Science Symposium, Jan. 22-25, 2013, Anchorage, AK.

**Outreach Activities:** None.

## Research Theme II: INVASIVE SPECIES

CILER activities that fall under the theme of Invasive Species include research focusing on the prevention, monitoring, detection, and control of invasive species, and on a better understanding of the range of their ecosystem impacts.

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### 13. Project Title: Assessment of Coastwise Traffic Patterns and Management of Aquatic Nonindigenous Species Risk on NOBOBs and Coastwise Vessels of the Great Lakes and East Coast of the United States and Canada

University Principal Investigators: *Greg M. Ruiz, SERC; Scott Santagata (formerly SERC, resigned); Thomas H. Johengen,* (CILER-University of Michigan);

*NOAA Technical Contacts:* David F. Reid, NOAA Emeritus

### Overview and Objectives

In this project we expand upon previous work [“NOBOB Salinity Tolerance (NOBOB-S): Eradicating aquatic nuisance species from the residual ballast water of NOBOB vessels using salt solutions] to explore the efficacy of salinity-based treatments of residual organisms (especially low-salinity tolerant organisms) in ballast tanks, including those in NOBOB condition. The focus is on coastal organisms in Great Lakes and other coastal estuarine habitats of the North American Atlantic coast that are interconnected via coastwise shipping patterns. We are using detailed analyses of coastwise traffic to guide us in a risk assessment of the potential for transfer of low salinity organisms between these ecosystems/habitats. These data and assessments are required to make informed predictions and recommendations for the best combination of management strategies of ballast water exchange and brine exposures for preventing the secondary coastal spread of nonindigenous species into the freshwater and estuarine habitats of the United States. Factors will include salinity tolerances, coastwise and Great Lakes shipping patterns, and environmental compatibility between Great Lakes and U.S. east coast ports.

### Objectives:

1. Quantify the traffic and ballast water discharge patterns of coastwise shipping between estuarine ports of the United States, Canada, and the Great Lakes region.
2. Characterize the salinity and biota of ballast water entering the Great Lakes from coastwise traffic.
3. Test the efficacy of full salinity exposure to prevent the transfer of low salinity organisms by ships in coastwise trade.

4. Test the efficacy of brine solutions for preventing the introduction of ANS into the Great Lakes, with emphasis on environmentally tolerant fish (gobies) and invertebrate species (peracarids).

5. Task 5a (previously Task 5). Develop a predictive model that discriminates the extent of geographic spread of non-native species among low salinity habitats along the eastern US, Canada, and the Great Lakes Region based on their environmental tolerances, abundance, and life history characteristics. Canadian coastal analyses will be performed by the Canada DFO.

   Task 5b (added CY2008). We will conduct literature reviews and field and laboratory studies to examine and assess the importance of variations in salinity tolerance in populations of the same species among different coastal ecosystems containing major ports. The overall goal of this new component is to assess the extent to which differences among populations (i.e., different geographic sources) affect invasion capacity/success at potential recipient regions and locations.

### Accomplishments

*Objective 1 (SERC: completed):* Data on vessel traffic and ballast water discharge records of coastwise shipping between estuarine ports of the United States, Canada, and the Great Lakes region, contained in the National Ballast Information Clearinghouse (NBIC) were compiled and analyzed by SERC. Based on these analyses, the most significant ports that supply ballast water to the Great Lakes region are: Houston, TX; Baton Rouge, LA; Baltimore, MD; Long Island Sound (COTP Zone), Port Everglades, FL; Portland, ME; New York, NY; Wilmington, DE; Albany, NY; Claymont, DE; and Philadelphia, PA.

*Objective 2 (CILER, GLERL: completed):* Of the ports with significant ballast water transport into the Great Lakes (Objective 1), those considered having predominantly or significant portions of low salinity water (Houston, Baton Rouge, Baltimore, Philadelphia-Claymont, Wilmington, and New York (Hudson River) were further investigated and port environmental profiles were developed for use in risk analyses. Port characterizations were completed in draft form in CY2009 and will be finalized and provided to SERC in CY2010 for use on risk assessment modeling.

*Objective 3 (SERC, GLERL, CILER:completed):* Salinity tolerance experiments were completed on 54 different taxa to measure mortality rates of freshwater and estuarine organisms after exposure to oceanic seawater (34 psu), simulating both flow-through (F-T) and empty-refill (E-R) BWE methods. Larval and adult crustaceans from freshwater and mesohaline habitats adjacent to ports of the Baltic Sea, North Sea, Great Lakes, Chesapeake Bay, and San Francisco Bay were targeted. Animals from oligohaline habitats (0-2 psu) experienced the highest mortality, and the effectiveness of both treatment types decreased with animals from low-salinity (2-5 psu) and mesohaline habitats (5-18 psu). Empty-refill treatments required less exposure time than flow-through treatments to cause significant mortality. Results were published in Santagata et al, 2008.

*Objective 4 ((SERC, GLERL, CILER):* Laboratory-based experiments were completed to examine the efficacy of concentrated sodium chloride brine for eradicating live taxa in ballast tanks focused on 33 species collected from lakes Erie, Huron, and Michigan (Great Lakes), the port of Rotterdam (The Netherlands), the Curonian Lagoon (Lithuania), the Vistula and Oder rivers (Poland), the Rhode River (Maryland/Chesapeake Bay, USA) and San Francisco and Suisun bays (California, USA). Exposure to NaCl brine at concentrations >80 ppt for at least 3 hours was found to kill 95% or the live taxa. Results were published in Santagata et al, 2009.

In a complementary study, CILER and GLERL collaborated with the Department of Fisheries and Oceans (Canada) to conduct shipboard testing of NaCl brine as a biocide in ballast tanks on selected cargo ships starting in 2008. To monitor water quality and especially to assess the extent of mixing between brine and original ballast water during four on-board experiments on ships containing ballast water, instrument sondes were moored in the tanks prior to filling with ballast water and subsequent treatment with NaCl. In all cases thorough mixing between the brine and the original water was not achieved until after the ship was underway, after which complete mixing, as demonstrated by a convergence of the calculated NaCl concentration measured at all instrument locations, was eventually achieved. Results from all four experiments are being summarized for publication and presentation during CY2010.

*Objective 5(SERC, GLERL):* Data were compiled for commercial vessels entering the Great Lakes and St. Lawrence Seaway (GL-SLS) during a 3-year period (2005 to 2007). A detailed analysis of non-GL-SLS ballast flux into the Great Lakes was conducted for 2007 using data from the National Ballast Information Clearinghouse (NBIC). Vessel activity data were obtained from four independent databases (e.g., arrivals, movements, and ballast or cargo operations).

We identified 277 transoceanic and coastwise vessels that made 2144 transits into the GL-SLS from 2005 to 2007. During 2007, 829 transits discharged more than 1,318,000 MT (metric ton) of non-GL-SLS ballast water into the system. Vessels were classified as operating in a transoceanic or coastwise pattern based on each one's history of behavior. The transoceanic pattern was characterized primarily by many vessels making few transits. Conversely, the coastwise pattern consisted of few vessels that make numerous transits. Vessels typically enter the GL-SLS with "No Ballast On Board" (i.e., ≤ 10%

ballast capacity; NOBOB) or in full ballast (i.e., >90% ballast capacity; BOB). Although less common, transoceanic and hybrid vessels (i.e., those that operated coastwise except for a few transoceanic transits) do enter the GL-SLS in partial ballast. In 2007, the GL-SLS received ballast water from the St. Lawrence River (SLR; approx. 835,000 MT), Overseas (OS; approx. 316,000 MT), US coastal waters (USC; approx. 134,000 MT), and Canadian coastal waters (CAC; approx. 33,000 MT). Nearly all OS and USC ballast underwent BWE, but some ballast water from of these sources underwent coastal BWE (i.e., within 200 nautical miles of shore) rather than in the mid-ocean BWE.

Transoceanic and coastwise patterns accurately classify and describe vessel activities and ballast water discharge, thereby providing a reliable method for focusing prevention efforts. The majority of Overseas and US coastal ballast water underwent BWE, but some of this BWE occurred in coastal waters. Based on the frequency of BWE, there appears to have been a pronounced decrease in propagule pressure, but quantifiable reductions in the likelihood of the establishment of new NIS remain unresolved. Until ballast water treatment is widely adopted, the unfettered transport of SLR and CAC water, combined with incomplete and improper BWE underscore the potential for additional NIS introductions.

### Publications

Santagata, S., Z.R. Gasiūnaite, E. Verling, J.R. Cordell, K. Eason, J.S. Cohen, K. Bacela, G. Quilez-Badia, T.H. Johengen, D.F. Reid, and G.M. Ruiz (2008). Effect of osmotic shock as a management strategy to reduce transfers of nonindigenous species among low-salinity ports by ships. Aquat. Inv. 3(1), 61-76.

http://www.aquaticinvasions.ru/2008/index1.html

Santagata S., K. Bacela, D.F. Reid, K. Mclean, J.S. Cohen, J.R. Cordell, C. Brown, T.H. Johengen , and G.M. Ruiz (2009). Eradicating ballast-tank organisms with sodium chloride treatments. Environmental Toxicology & Chemistry, Vol. 28, No. 2, pp. 346–353.

### Presentations

Santagata, S. et al. (2007). Effect of osmotic shock as a management strategy for reducing the transfer of nonidigenous species among low-salinity ports by commercial ships. Invited presentation at a ballast water management workshop organized by the U. S. Coast Guard, Chicago, IL.

Santagata, S. et al. (2007). Effect of osmotic shock as a management strategy for reducing the transfer of nonidigenous species among low-salinity ports by commercial ships. Invited seminar given at Bowdoin College, Brunswick, Maine.

## 14. PROJECT TITLE: ENHANCEMENT OF THE NOAA GREAT LAKES AQUATIC NONINDIGENOUS SPECIES INFORMATION SYSTEM (GLANSIS)

*University Principal Investigators:* Allen Burton (CILER-University of Michigan)

*NOAA Technical Leads:* Ed Rutherford, (NOAA-GLERL); Rochelle Sturtevant, MI Sea Grant

**Overview and Objectives:**

The Great Lakes have been heavily impacted by aquatic nonindigenous species (ANS) since the 1800s, and now over 180 ANS appear to be established here. A huge wealth of data is distributed among journals, gray literature, electronic literature sources, and on-line databases, making it unmanageable for any individual. Despite the regional importance of ANS, the Great Lakes were underrepresented in Internet-accessible databases. GLANSIS was created to provide a comprehensive, up-to-date, quality controlled, easily accessible on-line database of Great Lakes ANS. Among the goals of GLANSIS are to 1) provide a comprehensive source of authoritative up-to-date Great Lakes ANS information and 2) compile and update information relevant to the species in the database. The present version of GLANSIS does not include any information on potential invaders, nor does it include species such as the rusty crayfish that are considered native to part of the Great Lakes basin but invasive in others parts of the basin. GLANSIS includes a field for impacts, but the information in these fields has been inconsistent—sometimes including impacts only in the Great Lakes, sometimes impacts in other U.S. ecosystems, and sometimes potential impacts based on observations elsewhere in the world. Management-specific information describing regulations and recommendations for the prevention and/or control of invaders has also not been addressed by GLANSIS. Lastly, the current GLANSIS species profiles are highly technical, which limits their usefulness to non-technical stakeholders, such as students, regulators, and the general public.

The University of Michigan (CILER) proposes to work with NOAA (GLERL) scientists who oversee GLANSIS to 1) develop a prioritized list of potential high-risk invader species and compile associated fact sheets; 2) identify range expansion species and develop full profiles for addition to the system; 3) develop a simple screening tool to apply to all GLANSIS species for improved consistency of the database with respect to realized and potential impacts; 4) add a new field to species profiles for management information, including current regulations, best management practices, and control methodologies; 5) develop non-technical (public) fact sheets for each of the species in the GLANSIS database, in collaboration with the Great Lakes Sea Grant Network.

This project addresses the following NOAA Strategic Plan Goal:

1) Protect, restore, and manage use of coastal and ocean resources through ecosystem-based management

- GLANSIS provides critical up-to-date information needed by decision makers for Great Lakes management.
- The distribution of many potential invaders and range expansion species in the Great Lakes is currently restricted by water temperature and over-wintering capabilities. The addition of fact sheets and distribution information about these species will allow for monitoring, detection, and rapid response to new invasion risks should the Great Lakes warm as projected by climate change predictions.
- The compilation of ANS regulations, best management practices, and control methodologies will enhance the value and usability of GLANSIS to the management stakeholder community.
- The addition of non-technical fact sheets will make GLANSIS information more available to public stakeholders.
- Ballast and biofouling of ships have historically been key vectors in the introduction of new ANS. GLANSIS profiles on species with a high probability of invasion if introduced to the Great Lakes, as well as standardized organism impact assessments, will provide critical information on potential vectors of introduction. These vectors include those involving recreational boating and commercial shipping practices.

**Accomplishments:**

CILER students Thomas Makled and Lauren Berendt contributed to GLANSIS during this reporting period.

During this reporting period, Lauren Berendt focused on completion of fact sheets for the established non-indigenous plants. Of the 55 plant species included in GLANSIS, fact sheets (including full organism impact assessments) have been completed and posted for 20 species, fact sheets for 17 species are out for external review and fact sheets for 18 species are partially complete.

During this reporting period, CILER Fellow Thomas Makled focused on completion of the management sections of the fact sheets for the 77 species of free-living fauna. Sections for 28 species are complete and posted to the database, 31 are out for external review and 18 mollusks remain to be completed.

**Publications:** http://www.glerl.noaa.gov/res/Programs/glansis/glansis.html

**Presentations:** None.

**Outreach Activities:** None.

## 15. PROJECT TITLE: STATUS AND TRENDS IN BENTHIC MACROINVERTEBRATES IN THE GREAT LAKES

*Principal Investigators:* Allen Burton, (CILER-University of Michigan)

*NOAA Technical Contact:* Thomas F. Nalepa, NOAA Emeritus

**Overview and Objectives**:

This research project monitors trends in benthic macroinvertebrate populations in Lakes Michigan and Huron. Changes in the abundance and composition of benthic populations provide a measure of environmental response to anthropogenic influences such as nutrient enrichment and invasive species. Specific objectives are thus to determine and assess changes in benthic populations over the long term.

These objectives fit the goals of NOAA's strategic plan to protect, restore, and manage use of coastal and ocean resources through ecosystem-based management.

For instance, the project tracks spatial and temporal trends in the invasive mussels *Dreissena polymorpha* (zebra mussel) and *Dreissena rostriformis bugensis* (quagga mussel) These two species have caused broad changes in ecosystems of the Great Lakes, and have motivated a re-assessment of management strategies. In Lake Michigan, the original program was initiated in 1980 at 40 sites in the southern basin of the lake, and samples have been collected at these same sites for two consecutive years every five years since. Because population changes in some taxa (i.e., zebra mussel, quagga mussel, and the native amhipod *Diporeia*) were occurring so rapidly in the late 1990s, the monitoring program was expanded in 1998 and samples are now collected every year at these 40 sites. To determine trends in dreissenids and *Diporeia* over the entire lake, samples were collected in late summer at a maximum of 160 sites located throughout the lake in 1995, 2000, 2005, and 2010. In Lake Huron, samples were collected at 75 sites in the main basin in 2000, 2003, and 2007, and at 30 sites in Georgian Bay and North Channel in 2002 and 2007. Extensive sampling was also conducted in Saginaw Bay in 2007, 2008, and 2009. We collected samples at the same sites sampled in 1991-1996 to determine trends in the total benthic community. Samples were collected with the Ponar grab to assess changes in the total benthic community and also with divers to assess changes in the dreissenid population on hard substrates.

**Accomplishments:**

All samples collected in Lake Michigan in 2010 were processed and densities of *Diporeia*, zebra mussels, and quagga mussels at each of 143 sampling sites were determined. When densities in 2010 were compared to densities found in the last lakewide survey in 2005, *Diporeia* and zebra mussels declined, while quagga mussels increased (Figure 1). Quagga mussels are now the dominant benthic taxa in the lake, while *Diporeia* and zebra mussels are rarely found.

**Publications:**
None

**Presentations:**
Nalepa, T. F. 2012. Transformation of the offshore benthic community in Lake Michigan: shift form native amphipods to invasive mussels. Scientist2Scientist Series, OAR-Wide Webinar, Ann Arbor, MI, June 28, 2012.
Nalepa, T. F. 2013. The role of invasive species in changing the Great Lakes food web. Speaker Series, Water and the Future of the Great Lakes. Leelanau Conservancy, Suttons Bay, MI. May 4, 2013.
Nalepa, T. F. 2013. Effects of dreissenids (zebra and quagga mussels) on the Great Lakes ecosystem: a broad overview. Seminar, Buffalo State College, Buffalo, NY, May 16, 2013.

**Outreach Activities:** None

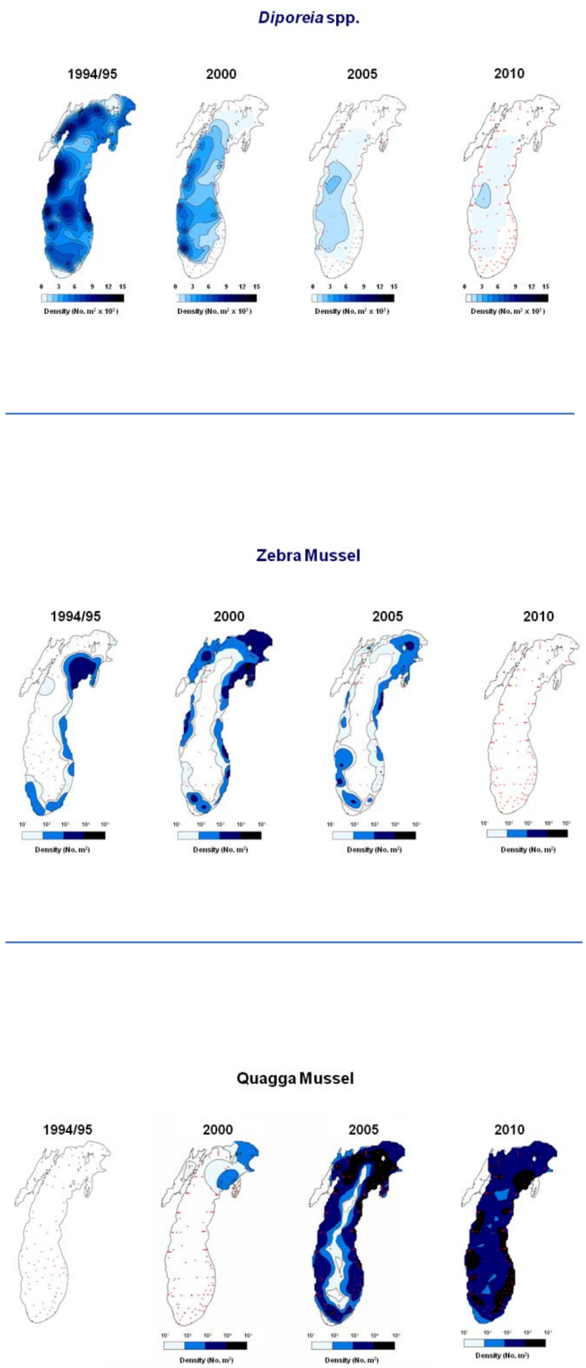


Figure 1. Densities (no. $m^{-2}$) of *Diporeia* (top), zebra mussels (middle), and quagga mussels (bottom) in Lake Michigan in 1994/95, 2000, 2005, and 2010. The darker the blue the greater the density.

## 16. PROJECT TITLE: STATUS OF MACROINVERTEBRATES IN LAKE ONTARIO AND MUSKEGON LAKE

University Principal Investigator: Allen Burton and Katherine Birkett, (CILER-University of Michigan)

NOAA Technical Lead: Stephen Lozano NOAA-GLERL, Emeritus

**Overview and Objectives**:

***Lake Ontario:*** Watkins et al. (2007) documents from 1990 to 2003 that invasive dreissenids mussels have extended their distribution from 38 m in 1995 to 174 m in 2003 and reached densities averaging 8,000/m2 at all sites < 90 m. During the same period, *Diporeia* populations have almost disappeared at depths < 90 m. At depths between 31-90 m, average densities of *Diporeia* have declined from 1,380/m2 to 63/m2 from 1997 to 2003. At deeper depths (>90 m), average densities have declined from 2,182/m2 to 545/m2 between 1999 and 2003.

The objective of this project is to document the results of the LOLA 2008/2009 Lake Ontario benthic invertebrate survey. We show the lake-wide replacement of a native species, (*Diporeia*) by an invasive mussel (*Dreissena rostiformis bugensis*) from 1994 to 2008. Prior to the introduction and spread of two dreissenid species, *Dreissena polymorpha* and *D. r. bugensis, Diporeia* was the dominant benthic organism in deeper waters (>20m) of Lake Ontario.

*Muskegon Lake:* Muskegon Lake is a 16.8 $km^2$ drowned river mouth lake located in western Michigan. In 1987, the lake was listed as an Area of Concern (AOC) by the Environmental Protection Agency because of severe environmental impairments related to the historic discharge of municipal and industrial wastes. The Beneficial Use Impairment (BUI), Degradation of Benthos, was listed because of impacts to species diversity from the discharge of municipal sewage and sediment toxicity related to heavy metals and organic chemicals. Evans (1976) showed that pollution tolerant oligochaete worms comprised 89% of the total benthic population, chironomid numbers were low (< 200/$m^2$), and species diversity was only 0.68 (Shannon Weaver). Improvements were seen after municipal and industrial wastewater to Muskegon Lake was eliminated by the construction of an advanced tertiary treatment facility in 1974.

There are three major objectives for the benthic monitoring program in Muskegon Lake.

1. Establish baseline information on the benthic community
    a. The objectives included re-sampling the historical, lake-wide sites sampled by Carter and Rediske. Sampling would continue 2-3 years to establish year to year variability in community structure and composition

   b. Establish a yearly monitoring of benthic community at areas adjacent to restoration work.
2. Develop a robust method for classifying sediments for assisting in selection of baseline monitoring sites and to map improvements of lakebeds after restoration efforts are begun.
   In an effort to understand the role of sediment in the restoration of Muskegon Lake, lakebed classification will be performed along with the collection of over three hundred sediment samples over three years. Acoustic systems are the natural solution to mapping areas where the lakebed is not visible from overhead imagery. The advantages of single-beam systems include relatively low costs, low data volumes, and easy portability.
   Lakebed classification is the organization of lakebeds into discrete units based on characteristics of acoustic responses generated by a sounder. The echo signal shape is a measurement of the acoustic energy redirected to the echo sounder transducer. The signal shape is influenced by seabed characteristics – physical properties of the surface material or immediate lakebed subsurface. The acoustic response represents an average volume of material, the size of which is a function of the transducer beam width and the frequency of the transmitted pulse.
   Once the acoustic clusters have been labeled, they will be quantitatively compared with "ground truth" data. The ground truth datasets acquired at each site will be independent of the qualitative observations used for cluster labeling.

**Accomplishments:**
Lake Ontario: Completed analysis of 2008 survey of Lake Ontario for publication in 2013. Completed proposal to US EPA for 2013 survey of Lake Ontario benthos to be completed in the summer of 2013.
Muskegon Lake: Competed data analysis of the benthic macroinvertebrate community in Muskegon Lake from surveys conducted in 2009, 2010, and 2011. Bottom sediment classification data was analyses from survey in 2012.

**Publications:**
Status of the benthic macroinvertebrate community in Muskegon Lake, 2009-2011
Sediment Classification of Muskegon Lake, 2012

**Presentations:**
Status of benthic population in Lake Ontario, 2008. IAGLR Annual Conference.

**Outreach Activities:** None.

## 17. Project Title: Status of Pelagic Crustaceans in Southern Lake Michigan / food web dynamics in southern Lake Michigan

<u>*University Principal Investigators*</u>: Allen Burton (CILER-University of Michigan)

<u>*NOAA Technical Leads*</u>: Steven Pothoven and Gary Fahnenstiel (NOAA-GLERL)

### Overview and Objectives:

**Overview:** This project will assess the current status of the primary producer community, pelagic crustacean community and associated environmental variables in southern Lake Michigan. Data from this project will ultimately be used in food-web models to evaluate how non-indigenous invertebrates have altered the lower food-web structure and to predict production of various components of the food-web of particular interest to resource managers, e.g. forage fish production, recruitment, condition, and growth.

The project addresses the NOAA Strategic Plan Goal to "Protect, restore, and manage use of coastal and ocean resources through ecosystem based management"

**Objectives:** 1) Evaluate the primary producer community within the water column at the sampling stations as well as the important environmental variables driving the primary producers. 2) Evaluate the status of pelagic crustaceans, including zooplankton, *Mysis relicta*, *Hemimysis anomala*, *Bythotrephes longimanus*, *Cercopagis pengoi*, at sites in southern Lake Michigan. 3) Compare data to historical data collected from the same region since the 1980s. 4) Compare data to that collected by USGS partners at northern Lake Michigan sites in 2010. 5) Begin integrating data into food-web model analyses.

### Publications:

Vanderploeg, H. A. S. Pothoven, G. L. Fahnenstiel, J. F. Cavaletto, J R. Liebig, T. F. Nalepa, C. P. Madenjian, and D. B. Bunnell. 2012. Seasonal zooplankton dynamics in Lake Michigan: Disentangling impacts of resource limitation, ecosystem engineering, and predation during a critical transition. J. Great Lakes Res. 38:336-352.

Pothoven S. and G. L. Fahnenstiel. 2013. Recent change in summer chlorophyll a dynamics of southeastern Lake Michigan. Journal Great Lakes Res. J. Great Lakes Res. 39:287-294

Pothoven, S., D. Fanslow and G. Fahnenstiel. 2012. Lipid content of *Mysis diluviana* in southern Lake Michigan. J. Great Lakes Res. 38:516- 521.

Evans, M. A., G. L. Fahnenstiel, and D. Scavia. 2011. Incidental oligotrophication of

North American Great Lakes.Environmental Science & Technology. Env. Sci. Technol. 45:3297 3302.

Hondorp, D.W., Pothoven, S.A., Brandt, S.B. 2011. Feeding selectivity of slimy sculpin *Cottus cognatus* and deepwater sculpin *Myoxocephalus thompsonii* in southeast Lake Michigan: Implications for species coexistence. J. Great Lakes Res. 37(1):165-172. DOI:10.1016/j.jglr.2010.11.010

Pothoven, S.A., Hondorp, D.W, and Nalepa, T.F. 2011. Declines in deepwater sculpin *Myoxocephalus thompsonii* energy density associated with the disappearance of *Diporeia* spp. in lakes Huron and Michigan. Ecology of Freshwater Fish 20:14-22. DOI:10.1111/j.1600-0633.2010.00447.x

Pothoven, S.A., Vanderploeg, H.A., Warner, D.M., Schaeffer, J.S., Ludsin, S.A., Claramunt, R.M., Nalepa, T.F., 2012. Influences on *Bythotrephes longimanus* life-history characteristics in the Great Lakes. J. Great Lakes Res. 38 (1), 134-141. doi.org/10.1016/j.jglr.2011.10.003

Vanderploeg, H.A., S. A. Pothoven, G. L. Fahnenstiel, J. F. Cavaletto, J. R. Liebig, C. A. Stow, T. F. Nalepa, C. P. Madenjian, D. B. Bunnell, 2012. Seasonal zooplankton dynamics in Lake Michigan: Disentangling impacts of resource limitation, ecosystem engineering, and predation during a critical ecosystem transition. J. Great Lakes Res. doi.org/10.1016/j.jglr.2012.02.005

**Presentations:**

RUTHERFORD, E.S., H.A. *VANDERPLOEG, A. HOOVER, J.F. CAVALETTO, J. LIEBIG, S.A. POTHOVEN, D.M. MASON, P. Bourdeau, and S. Peacor. Fish recruitment dynamics in the newly-illuminated, spatially-complex food web of Lake Michigan. 54th Annual Meeting of the International Association for Great Lakes Research, Duluth, MN, May 2011 (2011).

VANDERPLOEG, H.A., S.A. POTHOVEN, G.L. FAHNENSTIEL, E.S. RUTHERFORD, J.F. CAVALETTO, J. LIEBIG, C.A. STOW, T.F. NALEPA, C.P. Madenjian, D.B. Bunnell, D.M. Warner, and R. Pichlova-Ptacnikova. Response of zooplankton to the newly illuminated, spatially complex food web of Lake Michigan. 54th Annual Meeting of the International Association for Great Lakes Research, Duluth, MN, May 2011 (2011).

**Outreach Activities:**

Inland Seas invasive species field course faculty seminar “Aquatic invasive species and recent food web disruptions in the Great Lakes” 6/27/11

- Hope College lecture (10/24/11)
- Pack 4027 Cub Scouts, Fruitport MI (1/12/12)

- Beach elementary school Fruitport, MI (2/9/12)
- Pothoven, S. Lower trophic food web update. Lake Michigan Technical Committee winter meeting, Chesterton, IN. Jan. 24, 2012.
- Pothoven, S. Status of Lake Michigan lower trophic food web. Lake Michigan Committee, Lake Committee Meetings, Great Lakes Fishery Commission, Windsor, ON, March 19, 2012.
- Pothoven, S. Status of Lake Huron and Michigan lower trophic levels. Lake Huron-Lake Michigan Technical Committee Meeting-Common Session, Gaylord, MI July 18, 2012.
- Steve Pothoven. Status of Lake Michigan lower food web. Upper Lakes Committee Meetings –Lake Michigan Committee. Great Lakes Fishery Commission. Duluth, MN March 19, 2013.
- North Muskegon High School AP Science class (5/31/12)
- Muskegon community college (6/20/12)
- Inland Seas Invasive Course, Traverse City (6/25/12)
- Impact of Quagga Mussels on the Great Lakes food web, April 26, 2013, Michigan Lake and Stream Association annual meeting, Bay City, MI.
- Inland Seas Invasive Course instructor, Traverse City (6/26/13)
- NOAA-summer teacher training workshop meeting/cruise – NOAA/Earth Force(8/6/13)

## 18. PROJECT TITLE: ASSESSING THE RISK OF ASIAN CARP INVASION AND IMPACTS ON GREAT LAKES FOOD WEBS AND FISHERIES

*University Principal Investigators:* Hongyan Zhang, Lori Ivan, Dimitry Beletsky, and Allen Burton (CILER-University of Michigan)

*NOAA Technical Leads:* Edward Rutherford and Doran Mason (GLERL)

### Overview and Objectives:

Bighead (*Hypophthalmichthys nobili*) and silver (*H. molitrix*) carp (Asian carps) threaten to invade the Great Lakes and disrupt aquatic food webs and fisheries through their consumption of lower trophic levels. In river and lake ecosystems in North American, Asia and Europe, the introductions of Asian carps have resulted in the decline of many native fish species, with planktivorous fish and fish with planktivorous stages being particularly affected (e.g., Arthur et al. 2010; Pegg et al. 2009). Impacts of Asian carps on aquatic food webs are potentially complex, and require spatially-explicit models of trophic interactions to assess direct and indirect influences. A spatially-explicit modeling approach such as those we propose below allows a more detailed look at the effects of Asian carps on key members of the food web, and allows for the inclusion of density-dependent feedbacks (e.g., lower survival of age-0 fish, but higher growth and reproductive output by older survivors) which may help species compensate for the effects of an Asian carp invasion.

***Our objectives are to:***

1) Predict in which Great Lakes habitats Asian carps can successfully grow, survive and reproduce;
2) Predict Asian carp's impacts on food webs, key fish species and fisheries in different Great Lakes environments; and
3) Survey the Chinese literature for relevant information on Asian carps' energetics, vital rates and ecology.

Our approach combined the development of a community individual-based models ((IBM) and the Atlantis Ecosystem Framework models.

Outcomes: At the end of the two-year project, this work will expand on the results of Cooke and Hill (2010) and help identify regions in Lakes Huron, Michigan and Erie that could support Asian carps. Our individual-based model and food web model will identify the species and fisheries that likely will be impacted by Asian carps.

This project addresses the NOAA Strategic Plan Goal - protect, restore, and manage use of coastal and ocean resources through ecosystem-based management. This project also addresses a CILER Goal – to improve forecasts that facilitate restoration and protection of critical natural resources, help guide management decisions, and support sustainable economic development in the region.

**Accomplishments:**

IBM: Dr. Lori Ivan made several refinements to the multispecies IBM for Saginaw Bay Lake Huron to better simulate fish behavior and improve model performance. Some of these refinements have included:

- a simplification of the lower food web component of the model to allow for interactions amongst prey groups,
- Asian carp consumption of larval fishes as is indicated by diet analyses of carps in the Illinois and Mississippi Rivers,
- incorporation of the relationships between fish spawning and egg incubation as a function of water temperature,
- finalization of the movement subroutine to simulate seasonal movements for all fish species,
- algorithms for size-based vulnerabilities of prey to predators, and
- simplified code to improve readability.

The general framework of the multispecies IBM is now complete and easily transferable to other habitats in Lake Michigan and Lake Erie. Our next steps are to calibrate the Asian carp IBM for Saginaw Bay, run simulations, and write a manuscript on Asian carp impacts on the Saginaw Bay food web. Dr. Ivan also will continue to develop the IBM model for offshore community in Lake Huron.

Atlantis: Dr. Zhang has implemented external nutrient loading into the Lake Michigan Atlantis model, incorporated spawning migrations and the resting egg life stage into the model framework, and has run preliminary simulations of the Lake Michigan food web with and without Asian carps. Advection and temperature fields for years 1998-2007 and climatology were prepared by Dr. Beletsky for Lakes Michigan and Huron (climatology) as forcing functions to the model. In addition, Dr. Zhang has maintained good communication with Dr. Fulton's group (the Atlantis model developer) and solved many technical problems associated with transferring the model from the marine ecosystem that is nitrogen-based to freshwater that is phosphorus-based (model currency). Moreover, she also helped improve the Atlantis model wiki website.

Next steps include calibrating the Atlantis model for Lake Michigan, running scenario simulations, and writing the manuscript that reports Asian carp impacts. Dr. Zhang also will begin to configure the Atlantis model for Lake Erie and Lake Huron. Configuration of biological parameters for Lake Erie will be carried out this summer through assistance from CILER/GLERL summer fellow Kiefer Forsch. Advection and temperature fields are being finalized for Lake Erie.

**Publications:**

None.

**Presentations:**

Ivan, L.N., Mason, D.M., Rutherford, E.S., Zhang, H. and Hoff, M. Assessing the risk of Asian carps establishment in the Great Lakes across productivity gradients. IAGLR 2013 Great Lakes Restoration and Resiliency. West Lafayette, Indiana, Jun 2-6, 2013

Mason, D.M., Zhang, H., Rutherford, E.S., Ivan, L.N., Beletsky, D., Adamack, A.T., Hoff, M., Fulton, E.A., Barbiero, R.P. and Gorton, R.J. Forecasting Asian Carp Impacts on Lake Michigan's Food Web and Fisheries - Using the Atlantis Ecosystem Model. **IAGLR 2013** Great Lakes Restoration and Resiliency. West Lafayette, Indiana, Jun 2-6, 2013

Zhang, H, Rutherford, E.S., Mason, D.M., Ivan, L.N., Beletsky, D., Adamack, A.T., Hoff, M., Fulton, E.A., Barbiero, R.P., R.J. Gorton. Ecosystem and Fisheries Impacts of Asian Carps on Lake Michigan – the Atlantis Ecosystem Model Approach. ASLO 2013 Aquatic Sciences Meeting, New Orleans, Louisiana, Feb 17-22, 2013.

Ivan, L.N., Zhang, H., Rutherford, E., Mason, D., Hoff, M., Sable, S., and Adamack, A.T. Modeling the impacts of Asian carps in the Great Lakes: a case study in nearshore and offshore Lake Huron. ASLO 2013 Aquatic Sciences Meeting, New Orleans, Louisiana, Feb 17-22, 2013.

Zhang, H, Rutherford, E.S., Mason, D.M., Ivan, L., Beletsky, D., Adamack, A.T., Hoff, M., Fulton, E.A., and Barbiero, R.P. Ecosystem and Fisheries Impacts of Asian Carps on Lake Michigan – the Atlantis Ecosystem Model Approach. The 142nd Annual Meeting of the American Fisheries Society, Minneapolis – St Paul, MN, August 19-23, 2012.

Ivan, L., Mason, D., Rutherford, E., Zhang, H. and Hoff, M. Potential impact of Asian carps in the Great Lakes: an IBM approach. The 142nd Annual Meeting of the American Fisheries Society, Minneapolis – St Paul, MN, August 19-23, 2012

Beletsky, R., D. Beletsky and N. Hawley. Modeling circulation and residence time of Saginaw Bay. IAGLR, June 2-6, 2013, West Lafayette, IN.

Beletsky, D. and E. J. Anderson. Modeling circulation and residence time in western Lake Erie. 16th Workshop on Physical Processes in Natural Waters, Queensland, Australia, 8-11 July 2013.

### Outreach Activities:

Ivan and Zhang presented the IBM and Atlantis Ecosystem Model to the UM-Dearborn limnology class. Ann Arbor, MI, December 2012.

Ivan and Zhang presented the IBM and Atlantis Ecosystem Model to international students participating in an exchange program between Eastern Michigan University and HUAZ University in Wuhan, China. Fishes of the Great Lakes. Ann Arbor MI, July 2012.

### Other products:

We started development of an international collaboration on the Asian carp research and successfully received a travel grant from NSF CNIC program. U.S. – China Planning Visits: Catalyzing Collaboration on Forecasting the Potential Impacts of Invasive Species. PI: Hongyan Zhang, Co-PI: Lori Ivan, Ed Rutherford, Doran Mason, Yan Wang, and Daqing Chen. NSF 12-573 Catalyzing New International Collaborations. $ 27,743.

**Relevant Websites:** http://www.regions.noaa.gov/great-lakes/?page_id=787

## 19. PROJECT TITLE: POPULATION DYNAMICS OF THE NON-INDIGENOUS AMERICAN SHAD *ALOSA SAPIDISSIMA* ALONG THE WEST COAST OF THE U.S. AND ANTICIPATED EFFECTS OF CLIMATE CHANGE ON RANGE EXPANSION

*University Principal Investigators*: Allen Burton, CILER; Daniel J. Hasselman and Thomas P. Quinn, Univ. of Washington

*NOAA Technical Leads:* Phil Roni and Blake E. Feist, Northwest Fisheries Science Center, NOAA

### Overview and Objectives:

American shad (*Alosa sapidissima*) (hereafter shad) are an anadromous clupeid fish native to the Atlantic coast of North America that were introduced to the Sacramento River in 1871. Since that time they have dispersed along the Pacific coast and have been reported from Baja Mexico to Russia. Shad have been reported from several rivers along the Pacific coast that constitute critical habitat for one or more native salmon conservation units, several of which are federally listed as threatened or endangered. Although the impacts of this non-native planktivore on Pacific coastal ecosystems is uncertain, shad may alter trophic community structure and negatively impact native Pacific salmon species.

There are three objectives to this research:
1) Resolve the distribution and relative abundance of self-sustaining shad spawning runs among Pacific coastal rivers, and identify the source population of migrants for the colonization of additional drainages;
2) Identify habitats susceptible to shad colonization and the potential for range expansion under climate change scenarios, and predict the timelines for invasion of specific rivers;
3) Characterize the life history variation exhibited by non-indigenous shad.

This research will aid NOAA in achieving its mission by resolving the invasion risk posed by non-indigenous shad to the long term persistence and economic viability of native Pacific salmons, and it addresses the following NOAA Strategic Plan Goals:
i) Protect, restore, and manage use of coastal and ocean resources through ecosystem-based management;
ii) Understand climate variability and change to enhance society's ability to plan and respond.

### Accomplishments:

This report outlines the accomplishments over the final three months of the project (April 1-June 30, 2012), and is correspondingly brief. Molecular work (microsatellite genotyping) is 100% complete and data analysis has commenced. Aging of American shad otoliths and determining the degree of repeat spawning using scales to describe demographic parameters is nearing completion. Isotope data is collected and awaiting analysis. A collaboration has been established with a colleague to examine geometric morphometrics.

### Publications:

Although no manuscripts were published during the final three months of the project, a paper that was in draft form during that time has now been published:

Hinrichsen, R.A., **Hasselman, D.J.,** C.C. Ebbesmeyer, and B.A. Shields. 2013. The role of impoundments, temperature, and discharge on colonization of the Columbia River Basin, USA, by non-indigenous American shad. *Transactions of the American Fisheries Society* 142: 887-900. Support: NOAA/CILER; Grant number: NA07OAR4320006

### Presentations:

No presentations were given during the final three months of the project

### Outreach Activities:

I have not participated in outreach activities in the Great Lakes region. The geographic location of my research (Pacific Northwest region of the U.S.) makes such outreach activities difficult to accomplish effectively.

## 20. Project Title: Larval dispersal, habitat classification and food web modeling

*University Principal Investigators:* A. Burton, D. Beletsky, H. Zhang (CILER-University of Michigan), L. Mason, J. Breck, A. Hoover (University of Michigan, SNRE)

*NOAA Technical Investigator:* E. Rutherford (NOAA-GLERL)

### Overview and Objectives:

Invasive species are one of five key NOAA-identified stressors of native biodiversity and ecosystem function in the Laurentian Great Lakes (GL), where at least 184 nonindigenous species are established (http://www.glerl.noaa.gov/res/Programs/invasive/, Ricciardi 2006). Invasive species whose original site of establishment in North America was the GL cause great damage to the GL and at least $200 million annually to the whole US (Pimentel et al. 2005). In the context of on-going management and policy discussions, it is therefore critical to forecast species invasions and their costs, and to predict the effectiveness and costs of potential management responses to these invasions. This will guide more cost effective investments in prevention, education and rapid response to new invasions, slow-the-spread, and control efforts for species that are already well established in the GL or connected basins.

By integrating ecology and economics at the landscape scale, we will be able to communicate forecasts in terms of introduction pathways, which are the most appropriate targets for cost effective management, especially where preventing new invasions is the goal. Alternative management or policy choices will be presented in environmental as well as dollar units, which are critical to inform decisions that must always be made in the context of limited budgets. Focusing on all five GLs, we will produce and make freely available a richer and more finely resolved set of GIS layers and ecological classifications than are currently available; these will be useful for many other researchers, agencies, NGOs, and policy makers for applications to many other issues.

We propose to use ecological models and GIS databases to support the NOAA CSCOR proposal by Dr. David Lodge et al. from the University of Notre Dame entitled: "Forecasting spread and bioeconomic impacts of aquatic invasive species from multiple pathways to improve management and policy in the Great Lakes".

Products resulting from this proposed subcontract include: maps and predictions of invasive species larval dispersal in four of five Great Lakes; developed databases and eco-regional habitat classifications for environmental niche modeling; Ecopath/Ecosim food web models and predictions of bioeconomic impacts of invasive species on Great Lakes food webs and fisheries. Specific objectives include:

1. Inventory, map and classify physical and biological habitat data for Great Lakes aquatic ecoregions.
2. Construct food web models for inshore and offshore waters of Lake Michigan, Lake Huron and Lake Erie.
3. Simulate bioeconomic impacts of invasive species on Great Lakes food webs.
4. Model natural dispersal of invasive species in Lakes Michigan, Huron and Erie.

Dr. Dmitry Beletsky will model dispersal of 3 species across nearshore and open water habitats of 4 Great Lakes. Drs. Hongyan Zhang, Rutherford and a research technician (A. Hoover) will model food webs in ecologically distinct regions of the Great Lakes to determine potential impacts of invasive species on food webs and fisheries, which will suggest alternatives for management. Breck will revise the food web model code to allow estimates of parameter uncertainty obtained from expert judgement analysis, and to connect the food web models to economic models developed by Dr. David Finnoff of the Univ. Wyoming. Zhang and Doran Mason's (GLERL) effort on food web modeling and habitat classification are shared on a related CILER project entitled "GIS Ecoregion Classification and Food Web Modeling".

This project meets a goal of NOAA's Strategic Plan to protect, restore, and manage use of coastal and ocean resources through ecosystem-based management.

**Accomplishments:**

Larval Dispersal: Dispersal of two invasive species (ruffe and limnoperna) in Lake Michigan was studied with a 3D particle transport model. We predicted larval transport from ballast release point located along the major shipping lane (to determine safest ballast exchange locations), ports, and major tributaries. Ruffe larvae were released at surface daily during spring-summer (March-August) and tracked for 30 days while limnoperna larvae released daily during summer-fall (June-November) and tracked for 70 days. Settlement at coast was targeted initially. For ballast releases, both species show a tendency to drift eastward (reflecting prevailing surface currents) and colonize more or less the same area on the east coast but due to seasonal and drift duration differences limnoperna is expected to survive/spread better because 62% of limnoperna particles reached shore versus only 20% for ruffe. For port releases, settlement rates (percentage of particles reaching shore in time allowed) are close (82-89%) but limnoperna spreads over much larger area. Ruffe spread is very localized near source ports while limniperna spreads much more around east coast (mostly due to drift from Chicago and Milwaukee).

Habitat classification: *Inventory, map and classify physical and biological habitat data for Great Lakes aquatic ecoregions.*

Physical habitat data were collected for habitat classification for all 5 Great Lakes. Data were available from model outputs (eg. Great Lakes Forecasting System, Great Lakes Ice Model), remote sensing data, or interpolated from historic surveys such as lakebed susbtrate composition or bathymetry. (Examples of some data and maps are at the following links: http://ifrgis.snre.umich.edu/projects/GLAHF/glahf_framework.shtml, http://ifrgis.snre.umich.edu/projects/CSCOR/cscor_data/). The physical habitat data were used by colleagues Sean Mayer and Drew ? from University of Georgia to run environmental niche models for several invasive species including Hydrilla, Asian carp, ruffe, and golden mussel. Biological data were aquired from US EPA, NOAA GLERL, the USGS-Great Lakes Science Center, and the National Wetlands Inventory. A preliminary habitat classification was conducted for Lake Michigan in concert with members of the Great Lakes Aquatic Habitat Framework (P.I. Catherine Riseng, UM). We decided to postpone final ecoregion classification in order to collaborate with members of Riseng's GLAHF project, who aim to produce a habitat classification that will include tributary, nearshore and offshore habitats.

Food Web Modeling: *Construct food web models for inshore and offshore waters of Lake Michigan, Lake Huron and Lake Erie.*
We have constructed food web models in Ecopath with Ecosim (EwE) for nearshore and offshore habitats of Lake Michigan, Lake Huron and Lake Erie. The EwE models are for Muskegon Lake and the main basin of Lake Michigan; Saginaw Bay and the main basin of Lake Huron, and the central basin and whole lake basin of Lake Erie. For the whole lake model for Lake Erie, we incorporated results of an expert judgment solicitation on consumption rates, mortality rates and biomass of Asian carp if they do invade the Lake Erie food web. We have run simulations of Asian carp impacts for the main basin of Lake Michigan and the whole lake model of Lake Erie. Predicted impacts of Asian carps on the Lake Erie food web were highly dependent on assumptions of carp diet and contact with native predators. If Asian carp diet is restricted to eating plankton and detritus, and juvenile carp are vulnerable to predation by walleyes and piscivorous birds, then Asian carp will have relatively minor impact on the Lake Erie food web. If Asian carp can eat larvae of walleye and yellow perch, or are not vulnerable to predation by native predators, then they will have more harmful impacts on the Lake Erie food web. Similar results were found for Muskegon Lake food web.

Future work will include expanding the simulations of Asian carp and other invasive species on the Great Lakes food webs, and publishing results of our model forecasts.

*Simulate bioeconomic impacts of invasive species on Great Lakes food webs.*

To simulate bioeconomic impacts of invasive species, we connected outputs on fish biomass and harvest from the Lake Erie EwE model with a Lake Erie economics model produced by Co-PI David Finnoff of University of Wyoming. Annual values of biomass and harvest of fisheries species from the Lake Erie EwE were input into the economic model, which then would predict fishing effort in the next year. The new fishing effort value was then input into the EwE model to predict a new biomass and harvest values. This sequence was repeated iteratively to model the bioeconomic response to Asian carp impacts on the biomass of harvestable species in the Lake Erie food web. Results are being analysed and will be submitted for publication.

**Publications:**
None

**Presentations:**

Bossenbroek, J.M., J. L. Sieracki, D. Beletsky. A Multi-model Approach to Identify Possible Locations to Conduct Ballast Water Exchange in the Laurentian Great Lakes. IAGLR, June 2-6, 2013, West Lafayette, IN.

Chadderton, W.L., Jerde, C.J., Mahon A.M., Wittmann, M.E., Tucker, A.J. , D.L. Lodge., J. Bossenbroeck, J. Seracki,and D. Beletsky. Eurasian ruffe –implications of recent eDNA surveillance efforts in the Laurentian Great Lakes. 18th International Conference on Aquatic Invasive Species , April 21-25, 2013, Niagara Falls, Ontario, Canada

E. Rutherford, H. Zhang, J. Breck, D. Mason, X. Zhu, T. Johnson, R. Cooke, M. Wittmann, D. Lodge, J. Rothlisberger. Assessing Risk of Asian Carp on Lake Erie's Food Web. IAGLR, June 2-6, 2013, West Lafayette, IN.

Tucker, A.J., Chadderton, W.L., Jerde, C.J., Mahon A.M., Wittmann, M.E., Sieracki, J., Bossenbroek J., Beletsky, D. and D.L. Lodge. eDNA surveillance for Eurasian Ruffe in the Laurentian Great Lakes. IAGLR, June 2-6, 2013, West Lafayette, IN.

**Outreach Activities**: None.

## 21. GIS ECOREGION CLASSIFICATION AND FOOD WEB MODELING

*University Principal Investigators:* Hongyan Zhang (CILER-University of Michigan), Lacey Mason (University of Michigan, SNRE)

*NOAA Technical Lead:* Ed Rutherford (NOAA-GLERL)

**Overview and Objectives:**

Invasive species are one of five key NOAA-identified stressors of native biodiversity and ecosystem function in the Laurentian Great Lakes (GL), where at least 184 nonindigenous species are established (http://www.glerl.noaa.gov/res/Programs/invasive/, Ricciardi 2006). Invasive species whose original site of establishment in North America was the GL cause great damage to the GL and at least $200 million annually to the whole US (Pimentel et al. 2005). In the context of on-going management and policy discussions, it is therefore critical to forecast species invasions and their costs, and to predict the effectiveness and costs of potential management responses to these invasions. This will guide more cost effective investments in prevention, EDRR to new invasions, slow-the-spread, and control efforts for species that are already well established in the GL or connected basins.

By integrating ecology and economics at the landscape scale, we will be able to communicate forecasts in terms of introduction pathways, which are the most appropriate targets for cost effective management, especially where preventing new invasions is the goal. Alternative management or policy choices will be presented in environmental as well as dollar units, which are critical to inform decisions that must always be made in the context of limited budgets. Focusing on all five GLs, we will produce and make freely available a richer and more finely resolved set of GIS layers and ecological classifications than are currently available; these will be useful for many other researchers, agencies, NGOs, and policy makers for applications to many other issues.

We propose to use ecological models and GIS databases to support the NOAA CSCOR proposal by Dr. David Lodge et al. from University of Notre Dame entitled: "Forecasting spread and bioeconomic impacts of aquatic invasive species from multiple pathways to improve management and policy in the Great Lakes". Dr. Rutherford and GIS analyst Lacey Mason will provide habitat databases and use multivariate statistical models to classify ecoregions in each Great Lake to support food web modeling. Drs. Hongyan Zhang and Rutherford will model food webs in ecologically distinct regions of the Great Lakes to determine potential impacts of invasive species on food webs and fisheries, which will suggest alternatives for management.

Products resulting from this proposed subcontract include: maps and predictions of invasive species larval dispersal in each of the Great Lakes; developed databases and ecoregional habitat classifications for environmental niche modeling; Ecopath/Ecosim food web models and predictions of invasive species impacts on Great Lakes food webs and fisheries.

This project meets a goal of NOAA's Strategic Plan to protect, restore, and manage the use of coastal and ocean resources through ecosystem-based management. Specific objectives include:

1. Inventory, map and classify physical and biological habitats for Great Lakes aquatic ecoregions.
2. Construct food web models for inshore and offshore waters of Lake Michigan and Lake Erie.
3. Simulate invasive species impacts on Lake Michigan and Lake Erie food webs.

**Accomplishments: (April 2012-June 2013)**

*Acquire Habitat Data and Classify Ecoregions*

Physical habitat data were collected for habitat classification for all 5 Great Lakes. Data were available from model outputs (e.g., Great Lakes Forecasting System, Great Lakes Ice Model), remote sensing data, or interpolated from historic surveys such as lakebed substrate composition or bathymetry. (Examples of some data and maps are at the following links: http://ifrgis.snre.umich.edu/projects/GLAHF/glahf_framework.shtml, http://ifrgis.snre.umich.edu/projects/CSCOR/cscor_data/). The physical habitat data were used by colleagues from University of Georgia to run environmental niche models for several invasive species including *Hydrilla*, Asian carp, ruffe, and golden mussel. Biological data were acquired from US EPA, NOAA GLERL, the USGS-Great Lakes Science Center, and the National Wetlands Inventory. A preliminary habitat classification was conducted for Lake Michigan in concert with members of the Great Lakes Aquatic Habitat Framework (GLAHF, P.I. Catherine Riseng, UM). We decided to postpone final ecoregion classification in order to collaborate with members of Riseng's GLAHF project, who aim to produce a habitat classification that will include tributary, nearshore and offshore habitats.

*Construct food web models for inshore and offshore waters of Lake Michigan, Lake Huron and Lake Erie.*

We have constructed food web models in Ecopath with Ecosim (EwE) for nearshore and offshore habitats of Lake Michigan, Lake Huron and Lake Erie. The EwE models are for Muskegon Lake and the main basin of Lake Michigan; Saginaw Bay and the main basin of Lake Huron, and the central basin and whole lake basin of Lake Erie. For the whole lake model for Lake Erie, we incorporated results of an expert judgment solicitation on consumption rates, mortality rates and biomass of Asian carp if they do invade the Lake Erie food web. We have run simulations of Asian carp impacts for the main basin of Lake Michigan and the whole lake model of Lake Erie. Predicted impacts of Asian carps on the Lake Erie food web were highly dependent on assumptions of carp diet and contact with native predators. If Asian carp diet is restricted to eating plankton and detritus, and juvenile carp are vulnerable to predation by walleyes and piscivorous birds, then Asian carp will have relatively minor impact on the Lake Erie food web. If Asian carp can eat larvae of walleye and yellow perch, or are not vulnerable to predation by native predators, then they will have more harmful impacts on the Lake Erie food web. Similar results were found for Muskegon Lake food web.

Future work will include expanding the simulations of Asian carp and other invasive species on the Great Lakes food webs, and publishing results of our model forecasts.

**Publications:**

None.

**Presentations:**

Rutherford, E., Zhang, H., Breck, J., Mason, D., Zhu, X., Johnson, T., Cooke, R., Wittmann, M., Lodge, D., Rothlisberger, J. Assessing Risk of Asian Carp on Lake Erie's Food Web. IAGLR 2013 conference, Purdue University, W. Lafayette, IN. June 5, 2013.

Wittmann, M., Cooke, R., Rothlisberger, J., Rutherford, E., Zhang, H., Mason, D., and Lodge, D. Using Structured Expert Judgment to Quantify the impact of Asian Carp (Bighead and Silver) on Lake Erie fishes. IAGLR 2013 Great Lakes Restoration and Resiliency. West Lafayette, Indiana, Jun 2-6, 2013

Adlerstein, S.A., Kao, Y.C., Rutherford, E.R. and Zhang, H. Relative impacts of nutrient loadings and invasive species on a Great Lakes food web: an Ecopath with Ecosim analysis. IAGLR 2013 Great Lakes Restoration and Resiliency. West Lafayette, Indiana, Jun 2-6, 2013

Wittmann, M.E, Cooke, R.M., Rothlisberger, J.D., Rutherford, E., Zhang, H., Lodge, D.M, and Mason, D. Using structured expert judgment to quantify the impact of Asian carps (bighead and silver) on the Lake Erie commercial and recreational fishery. ASLO 2013 Aquatic Sciences Meeting, New Orleans, Louisiana, Feb 17-22, 2013.

### Outreach Activities:

Ed Rutherford (NOAA GLERL) and Hongyan Zhang attended a two-day workshop by Lake Ontario CSIM at Cornell Biological Field Station, Bridgeport, NY on June 17-18.

## 22. MECHANISTIC APPROACH TO IDENTIFY THE ROLE OF PATHOGENS IN CAUSING *DIPOREIA* SPP. DECLINE IN THE LAURENTIAN GREAT LAKES

*Principal Investigators:* Allen Burton (CILER-University of Michigan); and Mohamed Faisal (Michigan State University)

*NOAA Technical Lead:* Thomas F. Nalepa, NOAA Emeritus

### Overview and Objectives:

For nearly 20 years, the decline of the benthic amphipod *Diporeia* in all the Great lakes except Lake Superior has puzzled scientists and managers alike. While the loss of *Diporeia* is temporally linked to the introduction and spread of the zebra mussel (*Dreissena polymorpha*) and the quagga mussel (*Dreissena rostriformis bugensis*), the exact mechanism for the negative response of *Diporeia* is not clear. A common hypothesis is that dreissenids are outcompeting *Diporeia* for available food. Filter-feeding dreissenids occur at the substrate surface and ingest organic material settling from the water column before it becomes available to *Diporeia*. *Diporeia* is a detrivore that burrows within the substrate. Yet when *Diporeia* populations are declining, individuals show no sign of starvation, that is, lipid levels and weight per length do not decline.

This project will examine the possibility that the decline of *Diporeia* may have been caused by pathogenic bacteria, by changes in the community structure of bacteria associated with *Diporeia*, or by changes in environmental conditions that would make

*Diporeia* more vulnerable to bacterial infection. All of these bacterial-related hypotheses may be directly or indirectly related to the activities of large dreissenid populations. To test these hypotheses, preserved specimens of *Diporeia* from Lakes Michigan and Ontario, that were collected in the period of time before and after dreissenids, will be analyzed. The specific analysis and corresponding methods are: 1) changes in bacteria communities associated with Diporeia will be screened using T-RFLP (terminal-restriction fragment length polymorphism); 2) identification of certain beneficial bacteria or the emergence of pathogenic bacteria will be achieved by partial gene sequencing of bacterial 16S rDNA; 3) to determine if shifts in the bacterial community or emergence of pathogens are associated with tissue destruction in vital organs, tissue will be variously stained and examined microscopically.

*Diporeia* was a keystone species in the Great Lakes ecosystem and played a vital role in the movement of energy and nutrients from the lower food web (phytoplankton) to the upper food web (fish). This project will provide new insights into the loss of *Diporeia* and potential linkages to dreissenids. Thus, we may better predict if *Diporeia* will re-colonize offshore regions if dreissenid populations stabilize or decline. As such, it addresses the goals in the NOAA Strategic Plan to protect, restore, and manage the use of coastal and ocean resources through ecosystem-based management.

**Accomplishments:**

Over the reporting period, all work related to this project was completed, and a final report written. The project revealed that *Diporeia* was host to a range of different uni- and multi-cellular pathogens over the past three decades. While, most of the observed pathogens have been previously reported to infect *Diporeia*, an unidentified amoeba not previously reported in *Diporeia* was observed. Additionally, 16S rRNA gene sequencing confirmed the presence of rickettsia-like bacteria in *Diporeia*; this group of bacteria contains known pathogens that affect freshwater amphipods. There was substantial spatio-temporal variability in parasitic infections in *Diporeia*, with prevalences often fluctuating widely by depth, sampling site, and life stage of individuals. This demonstrates that biotic and abiotic components have an impact on determining the parasite community composition in *Diporeia*. Although no significant positive correlations were observed between any group of parasites and dreissenid densities, an increase in prevalence for a number of infections in 1992 and 1993 was observed. Since the observed increase in infection prevalences during this time coincides with the initial establishment and expansion of the zebra mussel (*Dreissena polymorpha*) in the southern basin of Lake Michigan, this finding provides evidence to suggest a mechanistic link exist between the presence of zebra mussels and increased infection prevalence in *Diporeia*. Interestingly, 16S rRNA gene sequence analysis revealed that a haplosporidian infecting *Diporeia* is phylogenetically similar to *Haplosporidium nelsoni*, a haplosporidian that has devastated bivalve populations in the Eastern Coast of North America. The morphology of the haplosporidian observed in *Diporeia* in Lake Michigan is identical to that of a seemingly novel haplosporidian infecting *Diporeia* in Lake Superior . Based on morphology alone, it is likely that the same haplosporidian infects *Diporeia* throughout the Great Lakes. Due to the extensive tissue damage, body burden, and host immune response observed in samples exhibiting microsporidian and haplosporidian infections it is possible these pathogens are associated with detrimental effects on *Diporeia* populations. No systemic infections or host immune response were associated with parasitic infections in *Mysis.*

Through this work, we were able to determine the spatio-temporal patterns of a number of pathogenic infections in *Diporeia* populations. Collectively, our results demonstrated that *Diporeia* are plagued by a number of pathogens, some of which are known for their ability to decimate populations of aquatic organisms (e.g., Haplosporidia sp.). Our findings suggest that it is likely that the establishment of invasive dreissenids indirectly and/or directly exacerbated the effect of pathogenic infections in *Diporeia* populations through their competition with *Diporeia* for the same food items. This study allowed, for the first time, the study of trends of a myriad of pathogens infection of an important foodweb component over almost three decades. The study also allowed the comprehensive identification of bacterial communities associated with *Diporeia* in the Great Lakes environment.

**Publications:**

Winters, A.W. 2013. Microbial Communities Associated with Diporeia spp. (Amphipoda) and their relationships with *Diporeia* spp. Health. Ph.D. Dissertation, Department of Fisheries and Wildlife, College of Agriculture and Natural Resources, Michigan State University.

Faisal, M. and Nalepa, T. F. 2013. Mechanistic approach to identify the role of pathogens in causing *Diporeia* spp. decline in the Great Lakes. Great Lakes Fishery Trust Completion Report, Project 2009.1058.

**Presentations:**

Winters, A.D, Nalepa, T. F., Faisal, M. 2012. Assessment of *Diporeia* spp. Health in Lake Michigan: 1980-2007. Presented at the 37th Annual Eastern Fish Health Workshop, Lake Placid, NY.

Winters, A. D. 2013. Health of *Diporeia spp*. Populations and its Impact on Great LakesFisheries. Presented at the Michigan Department of Natural Resources – Fisheries Division Section Meeting, Mattawan, MI.

**Outreach:** None

## Research Theme III: OBSERVING SYSTEMS

CILER activities that fall under the theme of Observing Systems include research focusing on providing observing system data and platforms, data management and communications, and data products and forecasts needed for effective environmental management, and for monitoring and understanding ecosystem responses to natural and anthropogenic conditions.

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### 23. PROJECT TITLE: FEASIBILITY STUDY FOR THE DEVELOPMENT OF GREAT LAKES COASTAL CURRENT MONITORING NETWORK

*University Principal Investigators:* Lorelle Meadows (AOSS-University of Michigan) and Allen Burton (CILER – University of Michigan)

*NOAA Technical Leads:* Marie Colton, (NOAA-GLERL, Emeritus)

### Overview and Objectives:

The goal of this project was to develop the design for a modern Great Lakes HF Radar and to model and predict its expected performance as a coastal current monitoring system. This required a critical review of recent advances in HF Radar hardware and related cognitive (software-defined) radio technology. The technology was matched to the environmental and electromagnetic conditions in the Great Lakes. Modernized HF Radar hardware, controls and data processing algorithms were optimized for peak performance in a freshwater environment.

Five primary objectives were completed as part of this effort:

1. Determination of optimal frequency(ies) to maximize return and coverage over freshwater
2. Examination of fixed versus variable or multi-frequency systems and determination of best method for realtime nearshore wave conditions retrieval for tuning of radar system, if necessary
3. Development of a robust software simulation tool to assess HF radar performance as a function of its system design parameters under Great Lakes environmental forcing conditions and at a variety of sites, thus determining expected performance capabilities and optimum siting locations
4. Development of data analysis algorithm to take advantage of narrower freshwater Doppler spectrum.
5. A field demonstration of system.

Within this section, identify NOAA Strategic Plan Goal(s) the Project Addresses:
A recent report commissioned by the Great Lakes Environmental Research Laboratory

(LimnoTech et al., 2011) identifies nine primary categories of user needs that should be addressed in the development of the Great Lakes Observing System. Among these are several applications where HF radar may play a role in critical data acquisition. These include improving the safety and efficiency of maritime operations through remote monitoring of operations in critical channels and harbors (NOAA Strategic Plan Goals 3 and 4), improvement of nearshore health and minimization of public health risks through monitoring of physical processes associated with suspended and dissolved load transport on site-specific bases (NOAA Strategic Plan Goal 1), and improved homeland security through measurement of parameters critical to local and renewable power sources and generation (NOAA Strategic Plan Goal 1). Additional appropriate applications for HF radar in freshwater consist of monitoring of episodic events in support of increased understanding of the complex nearshore and coastal processes. Examples include rip current dynamics and conditions leading to beach closure events (NOAA Strategic Plan Goal 1 and 3). It should also be noted that an operational HF radar system with Great Lakes range capability to 25 km from shore would capture the vast majority of commercial and private vessel traffic, cover all municipal water intakes, monitor most critical international borders and cover the extent of ice growth for most winters (NOAA Strategic Plan Goals 1, 2 and 4).

**Accomplishments:**

In Spring 2011, an experiment was conducted to measure the propagation characteristics of HF transmission over freshwater using a commercially available HF radar system operating at a range of frequencies. Specifically, the field deployment consisted of the installation and operation of two Seasonde HF radar systems manufactured by CODAR Ocean Sensors. The radars operated at 42 MHz and 5.375 MHz, near the top and bottom of the range of frequencies currently used for ocean measurements in the U.S. A third custom-built directional receive antenna operating at 5.375 MHz was also deployed. The selection of these frequencies was designed to assess HF performance for both low frequency transmission, which has been shown to provide consistent results to 20 km range over freshwater in the presence of resonant surface waves, and high frequency transmission, for which fetch-limited wave growth theory suggests a higher likelihood for the existence of Bragg scattering components in the Great Lakes.

Findings of this experiment indicate that increased power and directional antenna gain do increase range, with 10 dB gain in the bore sight direction achieved via increased input power (possible with an improved impedance match) and higher directional gain. This amounts to approximately 6-9 km of additional range. As with any tuned antenna, care needs to be taken to ensure the proper bandwidth is available for the range resolution required.

Ultimately, the propagation tests indicated that the currently available models for theoretical predictions of propagation loss can be used to estimate ranges in fresh water and may be used to develop future enhancements to this technology for application in freshwater settings. Results of the overall experiment suggest that these enhancements should focus on the application of HF systems to specific target areas of high importance rather than a large-scale operational system for overall surface current mapping.

### Publications:

Meadows, L. A., Whelan, C., Barrick, D., Kroodsma, R., Ruf, C., Teague, C. C., ... & Wang, S. (2013). High frequency radar and its application to fresh water. *Journal of Great Lakes Research*, Vol. 39, Suppl. 1, pp. 183–193, doi: 10.1016/j.jglr.2013.01.002

**Presentations:** None

### Outreach Activities:

An informal presentation was given during the field experiment to the Friends of Point Betsie Lighthouse Association in appreciation of their site support of the project. There were approximately 30 individuals in attendance.

## 24. PROJECT TITLE: IMPLEMENTATION OF THE GREAT LAKES OBSERVING SYSTEM (GLOS), 2008-2012

*Principal Investigators:* Thomas Johengen, CILER; Guy Meadows, Great Lakes Research Center, Michigan Technological University; Jay Austin, Large Lakes Observatory, University of Minnesota – Duluth; Gregory L. Boyer, Great Lakes Research Consortium, SUNY-ESF; J. Val Klump, Great Lakes WATER Institute, University of Wisconsin-Milwaukee; B. Shuchman and W. Charles Kerfoot, Lake Superior Ecosystem Center, Michigan Technological University

*NOAA Technical Lead*: Steve Ruberg (NOAA-GLERL), Dave Schwab NOAA Emeritus

### Overview and Objectives:

The GLOS-RA proposed to implement key observing system and modeling improvements over the 2008-2012 period that focus on critical needs of the Great Lakes region as identified through an extensive needs assessment process. The overall focus of the program is to develop new products for four priority issue areas that affect the health, well-being and economic viability of the region, these being: climate change impacts; ecosystem and food web dynamics; protection of public health; and navigation safety and efficiency. Critical information needs for these priority areas are being addressed by implementation of an array of integrated observations including new moorings and additional sensors to measure temperature and current profiles. AUV/glider technologies are being initiated to collect critical transect information. Cross-lake ferries and other vessels of opportunity are being instrumented to collect repetitive observations of surface chemistry. Satellite remote sensing products are being derived to begin daily monitoring of lake surface loadings of nutrients and sediments. CILER and associated partners within the nearshore observing team have helped establish, maintain, and develop operational capabilities for the proposed observing system components including data collection and output and new products to serve identified users and managers within the Great Lakes.

The work proposed under this project will significantly advance implementation of the rapidly evolving GLOS-RCOOS conceptual design. Data and information needs of the four priority issues addressed under this proposal will satisfy the following specific objectives:

- Increase nearshore observations to improve wind/wave forecasting and circulation modeling;
- Improve monitoring of lake heat and water balances;
- Advance nearshore ecological forecasting procedures;
- Develop continuous running high resolution hydrodynamic models of the interconnecting waterways; and
- Integrate information and deliver customized products that meet specific user needs.

This project addresses NOAA Strategic Plan Goal(s):

1) Protect, restore, and manage use of coastal and ocean resources through ecosystem-based management;
2) Understand climate variability and change to enhance society's ability to plan and respond;
3) Serve society's needs for weather and water information;
4) Support the nation's commerce with information for safe, efficient, and environmentally sound transportation

**Accomplishments:**
*University of Michigan:* The University of Michigan CILER deployed one S2 coastal monitoring buoy for the 2012 Great Lakes navigational season off the coast of Ludington, Michigan. The buoy contains an inertial wave sensor (IWS) as well as a met package and a thermistor string. The thermistor was replaced during the winter of 2013 with a commercial thermistor that is shielded with one inch rubber hose; it reports

water temperature at eight separate depths. The Ludington buoy also carries a Nortek Acoustic Doppler Current Profiler (ADCP) for current measurement in the water column below the buoy. The buoy transmits all data real-time in ten minute reports to the UGLOS website, the GLOS website and the NDBC. CILER also continues to maintain the S2 buoy that is deployed in Douglas Lake in partnership with University of Michigan's Biological Station. Both buoys were redeployed for the 2013 season.

In addition to buoy observations, CILER ran AUV missions in Lake Ontario and Lake Michigan. In support of GLOS partner University of Wisconsin – Milwaukee the AUV was deployed in Green Bay for nearshore substrate classification and mapping as well as profiling between EPA grid points. In support of GLOS partner Michigan Tech University, the AUV was deployed off Highway 2 in northern Lake Michigan in order to map the nearshore bathymetry for a rip current modeling project. The AUV was also deployed in Lake Ontario to map the lake's thermal bar in support of GLOS partner State University of New York. The AUV was flown at Oak Orchard Creek outflow, The Genesee River out flow in Rochester, the Oswego River outflow, and Sodus Bay outflow.

The glider was obtained late in the 2012 deployment season due to funding constraints limiting the number of missions for that year to one. Once delivered the glider was run through 4 shakedown tests. Fall of 2012 the glider was deployed in Muskegon for a Lake Michigan profile crossing. It successfully logged 400 km. In June 2013 we repeated the Lake Michigan cross-lake survey and then a Lake Ontario survey was recently completed in August of 2013.

*University of Wisconsin- Milwaukee*: Between March and November 2012, the UW-Milwaukee School of Freshwater Sciences (SFS, at the Great Lakes WATER Institute) operated several observing systems as part of GLOS, including two nearshore buoys at depths of 10 m and 20 m north of Milwaukee, a monitoring buoy at Bradford Beach, and a monitoring system on the high speed ferry that operates between Milwaukee WI and Muskegon MI. In addition, SFS has been helping to coordinate the collection of data from two other nearshore locations on Lake Michigan – one at Kewaunee, operated by the Wisconsin DRN, and one at Sleeping Bear Dunes National Lakeshore, operated by the National Park Service. With the exception of some minor problems, all systems functioned well during the 2012 field season. Previous calibration issues for the wave gauge at the 20m buoy have been addressed with a new algorithm. The success of this calibration will be determined this summer, but historic data adjusted with the algorithm shows good fit with modeled wave heights. Other sensors on the 20m buoy have functioned well, with updates and calibrations applied as needed. SFS has developed a protocol for automated data transfer to GLOS and NOAA NDBC. The high speed ferry monitoring system operated from May 1 to October 31, 2012.

For the season, systems were operable during the following times (percentage of season): Met station 7/23/12 to 11/16/12 (58%); Sondes 5/6/12 to 11/16/12 (98%); Aquadopp current meter and temperature string 5/30/12 to 11/16/12 (85%); and Wave gauge 6/11/12 to 11/16/12 (80%). With support from Wisconsin DNR, a student technician has collated the data from these stations. At the time of this writing, most data have been processed through quality assurance protocols and time-series plots of all variables have been prepared. In addition, data from the high speed ferry are being used in a collaborative project to model carbon dynamics on Lake Michigan.

The Lake Express High-Speed Ferry monitoring system was reinstalled in April and monitoring began the first week of May. The system worked well throughout the 2012 ferry operating season (May – Sept). All data collected since 2007 have been analyzed. Some of these data are currently being used in the calibration and validation of a Lake Michigan carbon model, which was initiated in the fall of 2011.

In cooperation with the Milwaukee County Parks, Miller-Coors, and the Milwaukee Municipal Sewerage District, the WATER Institute has developed a buoy deployable in the immediate vicinity of Bradford Beach – the principal swimming beach on Milwaukee's waterfront, and a webcam on the beach house. This system monitors wave conditions and water temperature. This is not a direct GLOS asset and is independently supported. We hope to keep this system operable in 2013.

*State University of New York:* Two S2 buoys were deployed in Lake Ontario for the 2012 deployment season, one offshore of the City of Oswego and one offshore of the City of Rochester. Another S2 buoy was deployed in Lake Erie off the City of Buffalo for the 2012 season. The two Lake Ontario buoys were equipped with a full meteorological station, inertial wave height, direction and periodicity sensors, and with a YSI sonde fixed at 1m. Data was transmitted electronically back to the Great Lakes Research Consortium (GLRC) in Syracuse and is currently being held on the GLRC server on Blue-Host.

In addition to the S2 buoys, three 32" Fondriest 300MB Bay buoys were deployed in Greater Sodus Bay. The center buoy was equipped with a full meteorological station, thermistor string and dissolved oxygen sensors above and below the thermocline. These buoys were deployed for the 2012 navigational season.

*University of Minnesota-Duluth:* UMD placed two meteorological buoys in the far western arm of Lake Superior in 2012, one coastal and one further offshore, both in approximately 50m of water. Both carried full meteorological packages and thermistor strings, and the offshore buoy carries an IWS (inertial wave sensor.) Both buoys report in near real time, with data ported to both GLOS and the NDBC (designated 45027 and 45028.) The buoys were deployed from May through November in 2012, and were re-deployed in May 2013, and remain deployed. The National Weather Service Duluth uses data from these buoys on a regular basis to improve its coastal forecasts. We continue to operate a display at the Great Lakes Aquarium in Duluth, MN showing this data to the public.

GLRI-originated harbor instrumentation has been deployed the last two seasons. In 2012, equipment was deployed in a short, month-long deployment at the Superior Entrance. This equipment was re-deployed in 2013 shortly after ice-out. Additional equipment has been deployed mid-harbor in conjunction with the Lake Superior National Estuarine Research Reserve (LS-NERR). Equipment for a further station is purchased but deployment has been delayed by permitting issues.

UMD continues to run a very active autonomous glider program. In 2012, we had five successful deployments along a line in far western Lake Superior (and a sixth un-successful deployment in which a badly calibrated compass brought the mission to a close early), with approximately 33 days of deployment. This spanned from early May to mid-November. In 2013, we started the season with a (non-GLOS sponsored) deployment in Lake Tahoe, followed by two GLOS-sponsored open-lake deployments in Superior, in cooperation with MTU, which provided small-boat support for deployment and recovery. The glider has been deployed from the Keweenaw Peninsula, transited to Isle Royale, and back three times on two separate deployments, providing us with truly open-lake data. This data will be used in conjunction with underway data from the Ranger III as well as data from remote sensing platforms. Several more deployments are planned for 2013. The glider also underwent scheduled maintenance at TWR in 2012.

*Michigan Technological University:* MTU deployed two S2 buoys in Lake Superior and one in Little Travers Bay of Northern Lake Michigan over the 2013 season, all with meteorological packages, IWS's and thermistors. The Lake Superior Buoys were deployed on the north shore and the southern shore of the Keweenaw Peninsula. The northern buoy also carried a 6600 YSI sonde and a Nortek ADCP. iButton water temperature thermistor chains were deployed for the season at both ends of the Keweenaw waterway. All buoy data was transmitted to the GLOS, NDBC, and U-GLOS websites as well as MTU's Web portal site: www.lakesuperiormichigantech.org.

The little Traverse Bay (LTB) Buoy in northern Lake Michigan, was deployed in partnership with the local communities of Harbor Springs and Petoskey. This buoy also contained the standard BLOS met-ocean package, with directional waves and thermistor string to the bottom.

New effort for 2013 included the transition and further development (internally funded by Michigan Tech) of the UGLOS website to support numerous buoys in Lake Superior, Michigan and Erie. All MTU buoys were converted to the new, commercially available thermistor strings. In addition, a totally new buoy mooring design for all buoys was undertaken, tested and implemented on the Lake Superior buoys with an available mooring configured and ready for LTB deployment.

The Ranger III ferry box was successfully deployed in late April, and collected data through the 2012 season.

*Michigan Tech Research Institute:* MTRI developed and tested a new satellite algorithm that maps TSS found in river plumes. The development of a MODIS and MERIS Primary Productivity algorithm for Lake Michigan was also completed. MTRI supported Dr. Fahnenstiel's work in Lake Erie by providing field spectral radiometer measurements recording a Harmful Algal Blooms (HAB) event. Initial tests have begun using a modified HABs algorithm on a Lake Erie satellite dataset. MTRI provided satellite based water clarity analysis for inclusion in the "State of the Great Lakes 2012" report. MTRI also collaborated with Professor Boyer to spatially summarize chlorophyll data collected during Lake Erie and Ontario ship surveys.

**Publications:**

Austin, J.A. Observations of near-Inertial Energy in Lake Superior. *Limnology and Oceanography* 58(2), 2013, 715–728.

Austin, J.A. The potential for Autonomous Underwater Gliders in large lake research, *J. Great Lakes Res*. (1/2013).

Kerfoot, W.C., Yousef, F., Green, S.A., Budd, J.W., Schwab, D.J., and Vanderploeg, H.A. Approaching storm: Disappearing winter bloom in Lake Michigan. J*. Great Lakes Research.* 36, 2010, 30-41.

Kerfoot, W.C., Yousef, F., Green, S.A., Shuchman, R., Brooks, CN, Sayers, M., Sabol, B. and Graves, M. 2012. Light detection and ranging (LiDAR) and multispectral studies of disturbed Lake Superior coastal environments. *Limnol. Oceanogr.* 57(3), 2012, 749-771.

Kerfoot, W.C., Yousef, F., Hobmeier, M.M., Maki, R.P., Jarnagin, S.T., and Churchill, J.H. Temperature, recreational fishing and diapause egg connections: dispersal of spiny water fleas (Bythotrephes longimanus). *Biol. Invasions* 13, 2011, 2513-2531.

F, Yousef, W.C. Kerfoot, C.N. Brooks, R. Shuchman, B. Sabol, and M. Graves. Using LiDAR to reconstruct the history of a coastal environment influenced by legacy mining. *J. Great Lakes Res*. http://dx.doi,org/10.10.16/j.jglr.2013.01.003

**Publications in Review:**

Luther, M.E., G. Meadows, E. Buckley, S.A. Gilbert, H. Purcell and M.N. Tamburri, " Verification of Wave Measurement Systems," Marine Technology Society Journal, in press, 2013.

Meadows, G.A., "A Review of Low Cost Underwater Acoustic Remote Sensing for Large Freshwater Systems," Journal of Great Lakes Research, in press, 2013.

Meadows, L.A., C. Whelan, D. Barrick, R. Kroodsma, C. Ruf, C.C. Teague, G.A. Meadows and S. Wang, "High Frequency Radar and its Application to Fresh Water," Journal of Great Lakes Research, in press, 2013.

Norton, R.K., L.A. Meadows and G.A. Meadows, "What if (Inland) Sea Levels are Falling...Then Rising...Then Falling…? Climate Change and Shoreland Management on the Laurentian Great Lakes," Geography Research Forum, in review, 2013.

Shuchman, R.A., G. A. Meadows and D. Dean, "Comparisons of MODIS Satellite Derived Lake Surface Temperature (LST) with Coincident MTU/GLOS Buoy Data in Lake Superior," Journal of Great Lakes Research, in press, 2013.

**Presentations:**

Austin, J.A**.** Observations of near-Inertial Energy in Lake Superior. IAGLR annual conference, Purdue University, May 2013.

Bootsma, H.A. 2013. The Lake Michigan nearshore zone: Monitoring, research and modeling. Invited presentation given to the Lake Michigan Ecosystem Modeling and Forecasting Working Group, Ann Arbor, MI. January 17-18, 2013.

Bootsma, H.A. 2012. Major phosphorus pathways in the Lake Michigan nearshore zone. Presentation given to the Milwaukee Metropolitan Sewerage District Commission, May 21, 2012.

Bootsma, H.A. 2012. Current research questions and management challenges in Lake Michigan. Presentation given to Society of Environmental Journalists, Milwaukee, WI , April 26, 2012.

Bootsma, H.A., C.M. Mosley, E. Tyner, and E. Wilcox. 2013. The role of dreissenids in Lake Michigan phosphorus dynamics. IAGLR annual conference, Purdue University, May 2013.

Cleary, Patricia A., N. Fuhrman, J. Schafer, J. Fillingham, H. Bootsma, E.J. Williams, T. Langel, and S. Brown. Lake Michigan Air Quality: Observations and analysis of ambient ozone from a ferry-based platform. American Chemical Society, Great Lakes Regional Meeting, 2013.

Cotel, A., N.U. Desai, G.A. Meadows, A. Boezaart, C. Standridge, R. Phillips, and G. Howe, "Motion Compensated Buoy LIDAR Measurements of the Turbulent Marine Boundary Layer Over Lake Michigan," International Association for Great Lakes Research, Wellington, Ontario, May 2012.

Fillingham, J.H., B. Wang, H.A. Bootsma, and Q. Liao. 2013. Towards a Parameterization for the CO2 Gas Transfer Velocity Useful for Biogeochemical Modeling of the Great Lakes. IAGLR conference, Purdue University, 2013.

Grunert, B. and V. Klump. 2013 Water clarity and the thermal structure of Green Bay. IAGLR Annual Conference, W. Lafayette, IN, 2-6 June 2013.

Hamidi, S., H. Bravo, J.V. Klump. 2013. Evidence of multiple physical drivers on the circulation and thermal regime in the Green Bay of Lake Michigan. World Environ. and Watershed Res. Congress, Cincinnati. OH, 19-23 May 2013.

Hamidi, S.A., H. Bravo, J.V. Klump, J.T. Waples, D.J. Schwab, D. Beletsky, E. Anderson, J. Kennedy, and T. Valenta. 2012. Circulation and thermal regime in Green Bay, Lake Michigan. AGU/ASLO/TOS Ocean Sciences meeting, Salt Lake City, UT. 20-24 Feb. 2012.

James, M. D. and Austin, J.A. The potential for Autonomous Underwater Gliders in large lake research, IAGLR annual conference, Purdue University, May 2013.

Jessee, N. Raymer, Z.B., Shuchman, R.A., Sayers, M.J., Brooks, C.N., Fahnenstiel, G., Grimm, A. Current and Historical Monitoring of Saginaw Bay Water Quality using Satellite Remote Sensing, IAGLR annual conference, Purdue University, May 2013.

Klump, J.V. 2013. Hypoxia in Green Bay: NOAA's Coastal Hypoxia Research Program . Fox-Wolf Watershed Alliance, 5 March 2013.

Klump, J.V. 2013. Green Bay, Climate and Hypoxia, *Our Water World: The Nutrient Challenge, A Waters of Wisconsin Forum.* Wisconsin Academy of Sciences, Arts and Letters, invited presenter, May 7, 2013.

Klump, J. V.; Bravo, H. R.; Waples, J. T.; LaBuhn, S. L.; Anderson, P. D.; Grunert, B. R.; Valenta, T.; Zorn, M.: 2013. Drivers of Seasonal Hypoxia in Green Bay, Lake Michigan. ALSO Aquatic Sciences Conf., New Orleans, LA, 17-22 Feb. 2013.

Klump, J. V.; Bravo, H. R.; Waples, J. T.; LaBuhn, S. L.; Anderson, P. D.; Grunert, B. R.; Valenta, T.; Kennedy J., Fermanich K., Baumgart P., Dolan D., Zorn, M., Vimont D., Lorenz D.: 2013. CHRP: Drivers of Seasonal Hypoxia in Green Bay, Lake Michigan. NSF Workshop on *Recent Changes in the Biogeochemistry of the Great Lakes (BOGLS),* Wayne State Univ., Detroit MI, 11-13 March 2013.

Klump, J. V.; Bravo, H. R.; Waples, J. T.; LaBuhn, S. L.; Grunert, B. R.; Valenta, T.; Kennedy J., Fermanich K., Baumgart P., Dolan D., Zorn, M., Vimont D., Lorenz D.: 2013. The Dynamics of Hypoxia in Green Bay, Lake Michigan. IAGLR Annual Conference, Purdue University, 2-6 June 2013.

Klump, J.V., J.T. Waples, H.Bravo, T. Valenta, J. Kennedy, K. Fermanich, P. Baumgart, D. Dolan, D. Vimont, D. Lorenz. 2012. Hypoxia and Biogeochemical Cycling in Green Bay, Lake Michigan. IAGLR Annual conference, Cornwall ONT, 13-17 May 2012.

LaBuhn, S., B. Grunert, V. Klump. 2013. Comparative effects of climate on Green Bay stratification. IAGLR Annual Conference, W. Lafayette, IN, 2-6 June 2013.

Raymer, Z.B., Shuchman, R.A. Sayers, M.J., Jessee, N. Brooks, C.N. Satellite Algorithm for River Plume Mapping within the Great Lakes Basin, IAGLR annual conference, Purdue University, May 2013.

Sayers, M.J., Fahnenstiel, G. Shuchman, R.A., Leshkevich, G. A Model for Determining Satellite-Derived Primary Productivity Estimates for Lake Michigan, IAGLR annual conference, Purdue University, May 2013.

Sayers, M.J., Raymer, Z.B., Shuchman, R.A., Fahnenstiel, G., Leshkevich, G., Brooks, C.N. Harmful Algal Bloom Mapping for the Great Lakes Using MODIS Satellite Data, IAGLR annual conference, Purdue University, May 2013.

Shuchman, R.A., Leshkevich, G. Sayers, M.J., Johengen, T.H., Brooks, C.N., and Pozdnyakov, D. An Algorithm to Retrieve Chlorophyll, Dissolved Organic Carbon, and Suspended Minerals from Great Lakes Satellite Data, IAGLR annual conference, Purdue University, May 2013.

Wang, B., Q. Liao, H.A. Bootsma, and J.H. Fillingham. 2013. In situ turbulence measurement and its relation to air-water gas exchange rate. 45th International Liège Symposium on Ocean Dynamics, Liège, Belgium. May 13-17, 2013.

Wang, B.; Liao, Q.; Xiao, J. and Bootsma, H. A. 2012. High resolution vertical profiles of near surface turbulence on open lake. Hydraulic Measurement & Experimental Methods Conference. Snowbird, UT, August 12-15, 2012.

Wang, B.; Liao, Q.; Xiao, J.; Bootsma, H. A. and Wu, C. H. 2012. Measurement of the structure of turbulence in a wind wave boundary layer with an *in situ* PIV system. TOS/ASLO/AGU Ocean Science Meeting. Salt Lake City, UT, Feb 20-24, 2012.

Wang, B.; Xiao, J.; Liao, Q and Bootsma, H. A. 2012. *In situ* PIV measurement of small scale turbulence in a wind wave boundary layer. 3rd Int. Symposium On Shallow Flows, Iowa City, IA, June 4-6, 2012.

Waples, J.T., Q. Liao, V. Klump, and H. Bootsma. 2013. Measuring rapid particle flux in coastal waters dominated by benthic filter feeding. Association for the Sciences of Limnology and Oceanography conference, New Orleans, LA, Feb. 17-22, 2013.

### Outreach Activities:

Meadows, G.A., "Rig Currents in the Great Lakes," Public Forum on Great Lakes Research, Northern Michigan University. August, 2012.

### Thesis:

Grunert, B. 2013. Evaluating the summer thermal structure of Southern Green Bay, Lake Michigan. MS. Thesis, School of Freshwater Sciences, University of Wisconsin-Milwaukee, August 2013.

### Reports:

Driscoll, Z., and H. A. Bootsma. 2012. WDNR Kewaunee nearshore monitoring project, 2011/2012 internal report. Submitted to Wisconsin Department of Natural Resources

### 25. Project Title: Green Bay Hypoxia

*Principal Investigators:* Tom Johengen (CILER-University of Michigan); Val Klump and Hector Bravo (University of Wisconsin-Madison)

*NOAA Technical Contact:* Steve Ruberg (NOAA-GLERL)

**Overview and Objectives:**

Dr. Bravo and Dr,. Klump will be responsible for deployment in Green Bat of three Nortek Aquadopp profilers for the acquisition of current and wave data to be used to validate a hydrodynamic model that will be used to describe the distribution and transport for Fox River inputs.

**Accomplishments**

Accomplished deployment of profilers.

**Publications**

None.

**Presentations**

None.

**Outreach Activities:**

None.

### 26. Project Title: Great Lakes CoastWatch Research Assistant for NOAA CoastWatch Program Element

*Principal Investigators:* Allen Burton (CILER-University of Michigan)

*NOAA Technical Contact:* George Leshkevich (NOAA-GLERL)

**Overview and Objectives:**

CoastWatch is a nationwide National Oceanic and Atmospheric Administration (NOAA) program within which the Great Lakes Environmental Research Laboratory (GLERL) functions as the Great Lakes regional node. In this capacity, GLERL obtains, produces, and delivers environmental data and products for near real-time observation of the Great Lakes to support environmental science, decision making, and supporting research. This is achieved by providing Internet access to near real-time and retrospective satellite observations, in-situ Great Lakes data, and derived products to Federal, state, and local agencies, academic institutions, and the public via the Great Lakes CoastWatch web site (http://coastwatch.glerl.noaa.gov).

The goals and objectives of the CoastWatch Great Lakes Program directly support NOAA's statutory responsibilities in estuarine and marine science, living marine resource protection, and ecosystem monitoring and management. Great Lakes CoastWatch data are used in a variety of ways including monitoring of algal blooms, plumes, ice cover, and water temperatures, two and three dimensional modeling of Great Lakes physical parameters (such as wave height and currents), damage assessment modeling, research, and for educational and recreational activities.

The CoastWatch project contributes to NOAA Strategic Goal(s):

Serve society's needs for weather and water information;
Support the nation's commerce with information for safe, efficient, and environmentally sound transportation;
NOAA Mission support

This project focuses on research and applications development utilizing CoastWatch imagery and imagery from new satellite sensors such as synthetic aperture radar (SAR) for ice classification and mapping and ocean color sensors such as the Sea Viewing Wide Field-of-View Sensor (SeaWiFS) and/or MODIS for ocean color (chlorophyll) products. These products will enhance the CoastWatch Great Lakes product suite by developing regional products and applications for the Great Lakes, and will contribute to the operational responsibilities of sister agencies such as the U.S. Coast Guard and National Weather Service. Communications requirements and data distribution are accomplished electronically via the Internet. A goal is accurate and reliable data and products from sustained and integrated satellite observing systems.

### Accomplishments

**1. Monitor, develop and/or improve the operational program to receive, process, analyze, and archive the CoastWatch data:**

- Finished CW new server (CWOPS) hardware and operation system installation.
- Installed and tested the THREDDS data server, TOMCAT web server, LAS server,
- and Ferret.
- All GLSEA files (1994-2003) have been converted from gif format to ascii
- format. All GLSEA files (2004-2006) have been converted from dat format to
- ascii format.
- All GLSEA files (asc format, 1995-current year) moved from CD or DVD to new
- server.
- All the AVHRR files (cwf, hdf format, 1990-current year) moved from CD or
- DVD to new server.
- All the GOES images (1994-current ) moved from CD or DVD to new server.
- All the MODIS images (2004-current ) moved from DVD to new server.

- Wrote the scripts to validate the data based on the file size.
- Finished moving all AVHRR, GLSEA (asc) files to monthly folders on the new server.
- Finished moving all MODIS images to monthly folders on the new server.
- Finished the RADARSAT-2 operational program moving from SPARKY (old server) to
- CWOPS (new server).

**2. Maintain and improve the CoastWatch Great Lakes Node web server, design and develop the web site:**
- Updated the Image Gallery section on CoastWatch Great Lakes web page.
- Updated What's New section in CW web page to show the operational satellite
- switch between GOES-13 and GOES-14.
- Updated What's New section in CW web page to show offical date for
- decommissioning NOAA-17.
- Make the long term average surface water temperature data (1992-2012 )
- available online.

**3. Design, modify, and develop the software to analyze and process the CoastWatch data:**
- Wrote a unix script to copy or move data from the old server (or CD, DVD) to the
- new server, also move the data to monthly folders.
- Wrote a unix script to validate the AVHRR and GLSEA data after moving to
- monthly folders on the new server.
- Modified the IDL program to process RADARSAT images for the ice
- classification project.

**4. Participate in CoastWatch related research and prepare presentations for meetings:**
- "Great Lakes CoastWatch Update" presentation at CoastWatch meeting 2012.

**5. Assist in the mentorship of a Great Lakes summer fellow:**
- Programming assistance to a summer student to convert the files from gif or dat format to ascii format.
- Programming assistance to a summer student to install and test the THREDDS data server, TOMCAT web server, LAS server, and Ferret.
- Programming assistance to a summer student to make a GLSEA nighttime image database ( 1996 - current ).

## Publications

Modeling 1993-2008 climatology of seasonal general circulation and thermal structure in the Great Lakes with FVCOM, Bai, X., J. Wang, D.J. Schwab, Y. Yang, G. Leshkevich, and S. Liu, *Journal of Geophysical Research - Oceans*

**Presentations**

Leshkevich, G. and S. Liu, Great Lakes CoastWatch Update, CoastWatch Node Managers Meeting, Kona, HI, April, 2012. (Included here as CoastWatch NMM was held early during 2012 but represents full year).

Leshkevich, G. and S. Liu, Great Lakes CoastWatch Summary, Eastern Michigan University Limnology Class, GLERL, Dec. 6, 2012.

Bai, X., J. Wang, D.J. Schwab, Y. Yang, L. Luo, G.A. Leshkevich, and S. Liu. Modeling 1993-2008 climatology of seasonal general circulation and thermal structure in the Great Lakes using FVCOM. 56th Annual Conference of the International Association for Great Lakes Research, Purdue University, W. Lafayette, IN, June 2-6, 2013 (2013).

**Outreach Activities:** None.

**Relevant Websites:** http://coastwatch.glerl.noaa.gov

## 27. Project Title: Supporting Predictive Models that Improve Coastal, Human Health and Beach Forecasting

*University Principal Investigators:* Allen Burton (CILER-University of Michigan); Richard R. Rediske (Annis Water Resources Institute, Grand Valley State University)

*NOAA Technical Leads:* Andrew Gronewold (NOAA-GLERL) and Steve Ruberg (NOAA-GLERL)

**Overview and Objectives**:

1. Analyze samples from Lake Erie for microcystins by HPLC/MS to provide confirmation of ELISA data.
2. Analyze samples from Lake Erie for anatoxin-*a* by HPLC/MS to provide information on a toxin that may be produced by *Anabaena* blooms.
3. Data were used for protecting coastal resources through ecosystem based management

NOAA Strategic Plan Goals the project addresses:

1) Protect, restore, and manage use of coastal and ocean resources through ecosystem-based management;

3) Serve society's needs for weather and water information;

### Accomplishments:

One hundred samples were analyzed for microcystins (KR, RR, YR) by HPLC/MS. Microcystin LR and RR continue to be the predominant congeners detected and 41% of the samples tested positive for LR. The highest level of microcystins was found in the dock scum (6.7 ug/l) and an open water sample WE80820 (1.4 ug/l). WE80820 was slightly above the WHO drinking water standard for microcystin LR. Microcystin RR continued to be a major component of the congener profile with some samples with this congener making up to 50% of the total. Anatoxin-*a* was analyzed in 10 samples and was not present at a detection limit of 0.02-0,04 ug/L.

### Publications:

None

### Presentations

Data contributed to two presentations at a special session, *Understanding, Forecasting, Monitoring and Managing Harmful Algal Blooms in the Great Lakes* organized for the 2013 IAGLR conference, Purdue, IN.

BURTNER, A.B.[1], GOSSIAUX, D.C.[2], JOHENGEN, T.H.[1], and PALLADINO, D.[1], [1]Cooperative Institute for Limnology and Ecosystems Research, 440 Church St., Ann Arbor, MI; [2]NOAA Great Lakes Environmental Research Laboratory, 4840 S. State St., Ann Arbor, MI.
**A Multi-year Comparison of *Microcystis aeruginosa* Blooms and Water Quality in Western Lake.**

PALLADINO, D.[1], JOHENGEN, T.H.[1], and RUBERG, S.A.[2], [1]CILER, 440 Church St, Ann Arbor, MI, 48109-1041; [2]NOAA-GLERL, 4840 S. State Road, Ann Abor, MI, 48108.
**Application of Instrumented Moorings for Continuous Monitoring of Water Quality Conditions and Harmful Algal Blooms in Western Lake Erie 2011-2012.**

### Outreach Activities:

Data provided for Harmful Algal Bloom Event Response Database. Data was available for public access on the NOAA website: http://www.glerl.noaa.gov/res/Centers/HABS/

## 28. PROJECT TITLE: A ROBOTIC SAMPLER-MASS SPECTROMETER FOR IN-WATER DETECTION OF CYANOTOXINS

University Principal Investigators: Allen Burton, (CILER-University of Michigan); David Fries, (University of South Florida); David F. Millie, (Florida Institute of Oceanography, now with Palm Island Enviro-Informatics, LLC)

NOAA-GLERL Technical Lead: Gary L. Fahnenstiel NOAA Emeritus

### Overview and Objectives:

Blooms of toxic cyanobacterium, (particularly *Microcystis aeruginosa*) annually occur throughout nutrient-enriched waters of the Great Lakes and threaten aquatic resources and potentially human health. To minimize impacts and potentially mitigate health risks, the time-series detection, measurement and source tracking of cyanotoxins are the objectives of federal, state, academic, and private partnerships.

Sensor-based monitoring of chemical analytes is a current monitoring practice, with many instruments currently available commercially. Importantly, the monitoring of toxins and contaminants throughout dynamic Great Lakes waters requires complex technological innovations capable of both time-series sampling and accurate detection/quantification of material fluxes/transformations across diverse spatial scales. The development/validation of automated sensors and probes to detect and identify harmful algal species and their toxins are central to specific goals mandated by NOAA's *Oceans & Human Health Research Initiative*.

This project will construct, validate, and deploy within selected Great Lake coastal waters, an operational, bio-chemical sensor comprised of a robotic sampler coupled with an in-water mass spectrometer based on an ion trap technology. This prototypical precision system provides programmability for time-series measurement of singular (or suites of) 'target' chemical/biochemical agents, coincident with the automated sample purification/extraction/archiving and mass spectrometer confirmation/quantification. Initially, sensor development/verification will target the heptapeptide hepatotoxin congeners known as microcystins, with verification of other cyanotoxins and chemical analytes, as time/work allows. The stability of and quantitative recovery for microcystin within the sampler will be assessed with the incorporation of novel isotope dilution-enabled automation technology.

This work supports NOAA's Strategic Goals/Plans of 1) Protect, restore, and manage use of coastal and ocean resources through ecosystem-based management and 2) NOAA Mission support (Center of Excellence for Great Lakes & Human Health, GLERL)

## Accomplishments:

- Demonstrated use of stand-alone, field-deployable MS for monitoring cyclocitral detection during short time series (no sample prep required)
- Extended previous work in the field indicating association of cyclocitral detection with *Microcystis* and microcystin production
- New example of a VOC target for bio-organismal association all done in situ
- Completed transects with this auto-sampler concurrent with field-based mass spec identification for dissolved microcystin.
- Demonstrated selective separations in real time (without post-human sample preparation)
- Demonstrated automation additions to a boat simplifying the size of boat and size of crew
- Demonstrated Near Real Time Analysis from a small adaptive boat and compact sampler system
- Made first experiments in an Automated & "Tethered", Reactor Coupled-Membrane Introduction Mass Spectrometry (RC-MIMS) for direct transfer of microcystin fragments across a membrane interface

## Publications:

Listed manuscripts (below) currently are 'in preparation'. Submittal expected in the near future:

In Situ *B*-Cyclocitral/(VOC) Detection As a Chemical Proxy For Microorganism Detection Using a Membrane Introduction Inlet Underwater Mass Spectrometer - in preparation, for *Journal of The American Society for Mass Spectrometry*

Mobile Bio-Molecular Sampling Preparation in the Field Using an Automated Purification Robot for Biological and Chemical Identification - in preparation for *Analytical Chemistry*

Extending the Spatial and Temporal Impact of Electron Microscopy Using Remote Automated Sample Preparation Technology - in preparation for *Microscopy*

## Presentations:

Solar Robotic Material Sampler System for Chemical, Biological and Physical Ocean Observations *Untethered Submersible Technology*- August 21st-August 24th 2011 Portsmouth, NH

IMAPS (Int'l Microelectronics and Packaging Society)- Mobile Systems and Flexible Packaging for Inner Space Systems, Scottsdale AZ, March 5-7 2012

### Outreach Activities:

- Graduate Student Hands On Training in Lab/Lecture Classes: Systems Technology Course- CMS: CRN 23528, OCE 6934 Section 621
- High School Student Training in Field- Bright Futures Program- Field Portable Sampling Techniques – 2 students
- High School Student Training in Field- Executive Internship Program- Sampling Technology – 2 students
- Graduate Student Training in College of Engineering-Sandra Pettit- *B*-Cyclocitral Mass Spectrometer Training and Development
- Autosampler Merged with a "Tweeting" Solar Autonomous Underwater Vehicle (AUV) for cells/chemicals and featured via various news media including American Broadcasting Corporation (ABC) Action News, Tampa FL affiliate:
    a. http://www.abcactionnews.com//dpp/news/region_south_pinellas/st_petersbrg/usf-underwater-robot-ready-for-next-gulf-oil-spill-with-twitter
    b. http://news.usf.edu/article/templates/?a=4299&z=123
    c. http://content.usatoday.com/communities/sciencefair/post/2012/03/meet-tavros-the-tweeting-submarines/1
    d. http://www.cbc.ca/strombo/technology-1/can-a-bird-tweet-underwater-it-can-if-its-a-sub.html
    e. http://www.tampabay.com/news/education/college/usf-underwater-robot-takes-to-twitter/1222360
    f. http://chronicle.com/campusViewpointArticle/Tweeting-from-the-Depths/700/

## 29. PROJECT TITLE: RAPID BIOSENSOR TECHNOLOGY FOR RECREATIONAL FRESH WATERS

University Principal Investigators: Allen Burton (CILER-University of Michigan) Dr. Joan B. Rose, Dr. Joanna M. Pope and Brian M. Panzl, (Michigan State University)

NOAA Technical Leads: David Schwab, NOAA-GLERL Emeritus

### Overview and Objectives:

Recent advancements in sensor technology for detection of pathogenic organisms have been applied to a variety of fields where rapid results are important such as in food safety. Sensors using lateral flow devices typically focus on pathogenic strains of microorganisms. However, some companies are specializing in *Escherichia coli* (*E. coli*) and coliform sensors for drinking, waste and recreational waters. One of the major issues which emerges from the biosensor technology is the detection limit and the resulting false negatives. In addition evaluating environmental samples other than clean water can often result in false positives. Rapid methods for beaches have focused on two primary technologies: i) immunomagnetic separation (IMS/ATP) and ii) DNA amplification (qPCR-based), and both are compared to the gold standard, namely bacterial culturing (CFU-based). These have been focused on two bacterial targets, namely enterococci and *E. coli*. We have made important evaluations in terms of the limitations of rapid methods and biosensor technologies for waterborne *E. coli*. For current technologies to be able to generate a rapid, quantifiable result issues such as poor sensitivity and specificity need to be overcome. After much research four technologies were chosen for this project based on their rapid detection, prevalence among the community and the ability to obtain the equipment. The suite of assays chosen for this investigation includes IDEXX Colilert Defined Substrate Technology, RAZOR EX –Field BioDetection Instrument from Idaho Technology Inc., qPCR utilizing the *E. coli uidA* gene assay and IMS/ATP. The forthcoming work plan was developed to determine the effectiveness of the techniques selected for the investigation. And finally we chose the assessment of a novel isothermal *Salmonella spp.* detection assay originally developed for food safety, which uses nicking enzyme amplification reaction (NEAR™) technology,

**Our objectives were:**

- To evaluate rapid sensor methods for the detection of *E. coli* and we then included *Salmonella* as this is most often what the technology targets
- To compare the performance of these sensors against each other in terms of application complexity, use with environmental matrices and false positives.

This work was to advance our understanding of how rapid and cost-effective identification of water-associated human health threats; and provide monitoring and detection information to protect public health and reduce public health risks in recreational waters of the Great Lakes basin.

The NOAA Strategic Plan Goal(s) the Project Addresses includes serving society's needs for water quality information.

**Accomplishments:**

Water samples for Colilert and IMS/ATP were evaluated (see Tables below). The beach locations that were selected were three beaches in Ottawa County (Grand Haven City Beach, Grand Haven State Park Beach, and Rosy Mound Recreational Area Beach) and one beach in Bay County (Bay City Recreational Area Beach) as well as sewage samples.

Mtichell Creek in Traverse Bay was examined using colilert and qPCR. Finally a series of rivers and canals were tested using the EPA cultivation method for *Salmonella* compared to the new NEAR isothermal technology (Neogen™).

- Razor EX had good specificity but poor sensitivity and could not detect *E.coli* in Beach waters where the other methods were positive. The false negative rate was unacceptable.
- The IMS/ATP method showed high false positive results.
- For beaches and sewage the qPCR and colilert showed fairly good agreement. This led to a larger study which has recently been submitted for publication which demonstrated that the qPCR test could not be used to predict the results obtained with cultivation. And that the rapid qPCR test was valuable for evaluation of river systems that impact beaches but new regulatory guidelines will be needed with this new approach.
- The new isothermal amplification technology (Neogen™) currently developed for *Salmonella* in food was evaluated for water. This technology is rapid and could be adapted for any target (eg *E.coli*) in the future. This shows great promise.

Analysis of beach samples for the four study methods

| Beach Sample Location | Method | | | |
|---|---|---|---|---|
| | Colilert MPN/100 mL | qPCR *E. coli uidA* Cells/100 mL | IMS/ATP | Razor EX |
| Grand Haven City | 17.00 | < 1.16E+01 | Confidential | Negative |
| Grand Haven State Park | 29.00 | 4.09E+01 | Confidential | Negative |
| Rosy Mound Recreational Area | 59.50 | 6.11E+01 | Not Performed | Negative |
| Bay City Recreational Area | 8.38 | 2.03E+01 | Not Performed | Negative |

Analysis of waste water samples for the four study methods

| Beach Sample Location | Method | | | |
|---|---|---|---|---|
| | Colilert MPN/100 mL | qPCR *E. coli uidA* Cells/100 mL | IMS/ATP | Razor EX |
| Sewage 1 | 7.51E+01 | 1.13E+04 | Not Performed | Negative |
| Sewage 2 | 1.07E+02 | 1.50E+04 | Not Performed | Negative |
| Sewage 3 | 1.19E+02 | 1.56E+04 | Not Performed | Negative |
| Sewage Spike | 1.16E+02 | 5.27E+04 | Not Performed | Positive |
| Effluent 1 | 5.01E-03 | 1.14E+02 | Not Performed | Negative |
| Effluent 2 | 4.28E-03 | 5.80E+01 | Not Performed | Negative |
| Effluent 3 | 3.78E-03 | 3.25E+01 | Not Performed | Negative |
| Effluent Spike | 2.04E-03 | 1.21E+03 | Not Performed | Positive |

Specificity analysis for the Razor EX

| Strain Sample | Razor EX |
|---|---|
| *E. coli* O157:H7 | Positive |
| *E. coli* O26:H11 | Negative |
| *E. coli* O45:H2 | Negative |
| *E. coli* O103:H2 | Negative |
| *E. coli* O111:H2 | Negative |
| *E. coli* O121:H19 | Negative |
| *E. coli* O145:H7 | Negative |
| *E. coli* O146:H21 | Negative |
| *E. coli* O156:H21 | Negative |
| *E. coli* O174:H21 | Negative |

**Publications:**

Verhougstraete, M., A. Aslan, R. Ives, and J. Rose. (Submitted). Assessing microbial water quality criteria in a non-point source dominated watershed. J. of Applied Microbiology

One paper is in preparation on Rapid Detection of *Salmonella* in Water for the *J. Applied Microbiology.*

**Presentations (2013-2013):**

1. Flood, MT and Rose, J.B. A Comparative Analysis of *Salmonella* Detection Techniques in Surface Waters. Spring Meeting Michigan Branch of the American Society for Microbiology, Ferris State University Michigan, USA, April 5-6, 2013. Won First prize for Best Oral presentation.
2. Flood, MT, Ives, R. and Rose, J.B. A Comparative Analysis of *Salmonella* Detection Techniques in Surface Waters. 17th Symposium of the International Water Association, Health-Related Water Microbiology. Florinopolis, Brazil Sept. 15-20, 2013.

**Outreach Activities:**

Two outreach activities have occurred. Working directly with water utilities presenting the methods and advantages of this new approach. Also presented to rural communities interested in water quality. The second has been directly to industry (eg Neogen) on the potential needs for rapid techniques for water as has been done for food.

## Research Theme IV: PROTECTION AND RESTORATION OF RESOURCES

Projects under this theme advance restoration initiatives, including ecological priorities of Lakewide Management Plans, and Remedial Action Plans for Areas of Concern.

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### 30. PROJECT TITLE: GREAT LAKES RESTORATION INITIATIVE – NOAA PROGRAM SUPPORT

*Principal Investigators:* Allen Burton, Tom Johengen, and Sander Robinson (CILER – University of Michigan)

*NOAA Technical Contacts:* Marie Colton (NOAA-GLERL) and Felix Martinez (NOAA-NOS)

#### Overview and Objectives

CILER has been assisting with the execution of NOAA and USEPA non-Federal CILER-directed GLRI grant implementation, providing evaluations of performance effectiveness of the awards, and assisting in reporting requirements. In addition, CILER has been organizing and leading workshops to facilitate information exchange across relevant GLRI projects that are important for related NOAA activities. Finally, undergraduate and graduate student fellows have been supported to assist with these GLRI projects.

In summary, the overarching objective is to provide the necessary programmatic infrastructure to support all reporting on GLRI deliverables by NOAA and participating stakeholders, and to provide data and information that are public friendly and timely.

This project addresses NOAA Strategic Plan Goal(s):
1) Protect, restore, and manage use of coastal and ocean resources through ecosystem-based management, and
2) NOAA Mission support

#### Accomplishments

<u>NOAA Programmatic Support</u>

Over the past three years CILER has administered over 25 research proposals in support of NOAA's commitments for Great Lakes Restoration Initiative funding projects. Project support has included administering CILER proposals, hiring of post-docs, research staff, and students to help execute the research and meet project deliverables, facilitating project workshops, and providing financial oversight of project budgets. Research funding of GLRI activities administered through CILER amounted to $3,995,881, $2,302,151, and $1,870,287 in FY10, FY11, and FY12 respectively.

GLRI Review Update

During the last reporting period, an expert panel external to NOAA and GLRI-funded projects was assembled by CILER, and attended the review and heard summary presentations from project leads. The reviewers synthesized this information in a debriefing session during the last day of the review based on certain evaluation criteria. CILER created a draft document of the information that was sent to reviewers for comments. CILER completed the incorporation of these comments into a second draft that was sent out to the panelists for final review and editing.

During this reporting period, the report was then submitted to Marie Colton, GLERL's Director. Since then, Dr. Colton distributed the report to project leads for consideration.

Next Step after Workshop on: Building a Community Modeling and Forecasting Framework for Lakewide Management in the Great Lakes

Based on an idea from NOAA's Felix Martinez, planning was completed for the follow-up symposium/town hall-style conference to advertise models best suited to enhance the integrated forecasting and subsequent management of Great Lakes ecosystems. Abstracts submitted by Great Lakes modelers were evaluated and chosen for inclusion in the special session, "Integrated Modeling of Large Lake Ecosystems", at Coastal Zone's 2011 Chicago meeting that took place in July.

Final Report - Lake Michigan Ecosystem Modeling and Forecasting Workshop

The final version of a report summarizing the proceedings of the workshop were disseminated to the community at large through the Great Lakes Information Network (GLIN) and on the modeling page of the Great Lakes Observing System (GLOS).

### Publications

CILER. Final Report, *NOAA's Great Lakes Restoration Initiative Check-Up – a review of NOAA's contributions under the 2010 Great Lakes Restoration Initiative, Feb. 2011.*

### Presentations

The following 13 presentations were included in a special session, "Integrated Modeling of Large Lake Ecosystems", at NOAA's Coastal Zone's 2011 Conference, Chicago, IL.

Felix Martinez (NOAA-CSCOR): Building a Community Modeling and Forecasting Framework for Lakewide Management in the Great Lakes: A Lake Michigan Working Group

Marie Colton (NOAA-GLERL): Toward Establishing an Ecological Forecasting System Framework for the Great Lakes

Vanderploeg (NOAA-GLERL), DePinto (LimnoTech), and Johengen (CILER): Empirical and modeling studies necessary for the development of an operational ecosystem management model for Lake Michigan

Joe Atkinson (University of Buffalo): Embedded Hydrodynamic Modeling of Benthic Algae in Lake Ontario

Val Bennington (University of Wisconsin-Madison): Coupled Hydrodynamic-Ecosystem Model for Lake Superior

Joseph DePinto, Todd Redder, Edward Verhamme (LimnoTech): Development of an Integrated Modeling Framework (A2EM) and Application to the Lower Maumee River – Lake Erie Western Basin System

Michael Twiss; Joseph Skufca (Clarkson Univ.): A criticism of the Shared Vision Model for water level regulation management in Lake Ontario and the St. Lawrence River: Adding ecological realism in the International Section of the St. Lawrence River

Mark Rogers (USGS-GLSC): An Ecopath with Ecosim model of Lake Michigan's Offshore Food Web

Hongyan Zhang (CILER), Edward S. Rutherford and Doran M. Mason (NOAA-GLERL), Michael J. Wiley (Univ. Michigan): Potential Impacts of Land Use, Climate Change and Invasive Species on the Food Web and Fisheries of a Lake Michigan Estuary

Meng Xia (CILER): A couple Lake Scale and Nearshore high-resolution hydrodynamic-ecological model

Nima Pahlevan (Rochester Institute of Technology): Integrating Hydrodynamic modeling and Remotely Sensed Data towards Quantitative Mapping of Water Constituents in Coastal/Inland Regions

Rabi Gyawali (Michigan Technological University): Coupling watershed and climate models for climate change impact assessment studies.

Jon Bartholic (Michigan State University): High Impact Targeting Decision Support System for BMPs to Most Effectively Reduce NPS Pollution into the Great Lakes System

## 31. PROJECT TITLE: IDENTIFY LAND USE INDICATORS AND TIPPING POINTS THAT THREATEN GREAT LAKES ECOSYSTEMS

*University Principal Investigators:* Brian Miller (Illinois-Indiana Sea Grant); Bryan Pijanowski (Purdue Univ.); Joan Rose, David Hyndman, Jan Stevensen (Michigan State Univ.); Michael Wiley, Catherine Riseng, Sara Adlerstein (Univ. Michigan); Jeffrey Tyler (Fisheries Projections, Inc.)

*NOAA Technical Leads:* Doran Mason and Edward Rutherford (NOAA-GLERL).

### Overview and Objectives:

In order for coastal communities to achieve ecosystem sustainability, they must first know what land and habitat components are necessary to sustain their ecosystems. When communities are armed with science-based environmental limits or "tipping-points", they are able to institute land use policies and restoration plans that ensure critical green infrastructure and habitat sustaining Great Lakes ecosystems are maintained. (For example, the Sea Grant Sustainable Coastal Community Development network has used a 10% impervious cover tipping point to work with communities to measure their existing impervious surface cover, and implement land use change policies, ordinances, comprehensive plans, and smart growth strategies necessary to keep a community's impervious surface cover below levels that impact their streams.) This project will use existing Great Lakes water quality, biological monitoring, and corresponding watershed land use data to identify tipping points that impact Great Lakes ecosystems.

***1. Identify Land Use Indicators.*** Work will be performed by IL-IN SG extension specialists and a CILER fellow (located at Purdue University and co advised by NOAA researchers) to engage university faculty and other Great Lakes researchers in development of two new SOLEC indicator suites for Land Use Change and Agricultural Lands. These indicators will help decision makers to more completely assess the impact of coastal land and watershed impacts on both the nearshore and open waters of the Great Lakes and to make decisions that improve nearshore and open water conditions and ecosystems.

***2. Develop coarse scale analysis of land use tipping points.*** The Purdue team (Pijanowski) will calibrate the National Land Cover Database (NLCD) to earlier land cover databases (MIRIS) at 100 m resolution so that historical data and models of stream chemistry and biology can be related to relevant coverages with more land use classifications.

*After much analysis, Pijanowski and Doucette have decided it was impossible to calibrate the NLCD 2006 database to earlier land cover databases (MIRIS). Therefore the UM team re-ran their analyses (below) using the NLCD database.*

The UM team (Wiley, Riseng) will rerun CART models and causal models (e.g., Structural Equation Models) using the NLCD to identify land use tipping points in Muskegon River and watersheds surrounding Grand Traverse Bay. These models will identify tipping points by relating land use indicators to hydrology, water quality, macroinvertebrates and fishes.

Tyler will finish calibration of an agent-based model of Chinook salmon, and run simulations of land-use change impacts on salmon recruitment potential in the Muskegon River. The UM team will work with Tyler to extend the analysis to the Grand Traverse Bay watershed.

***3. Compare estimates of tipping points from coarse and fine-scale analyes.*** PU, UM and the GLERL team will compare predictions of land-use tipping points from the coarse-scale CART model with predictions from a calibrated, highly-mechanistic coupled modeling system for the Muskegon River estuary. Multiple land use scenarios will be evaluated with both models including varying rates of urban change, forest regeneration rates, riparian setbacks, and water recharge protection areas.

***4. Extend the Tipping Point Analysis to Include Bacterial Contaminants.*** The MSU group (Dr. Joan Rose, Dr. David Hyndman) along with Dr. Bryan Pijanowski (Purdue) will develop maps of septic tank use, storm drains, CSOs, and water quality violations for the Boardman and Jordan watersheds surrounding the Grand Traverse Bay. For these watersheds, Hyndman and Rose will use hydrology and groundwater models to predict *E. coli* occurrence and transfer from septic tanks to reported TMDLs and water quality variations.

***5. Develop and apply food web modes to evaluate land use tipping points for Saginaw Bay.*** Drs. Sara Adlerstein-Gonzalez (UM) and Edward Rutherford will complete development of an extant food web model (Ecopath with Ecosim - Ewe) of Saginaw Bay to simulate impacts of a land use tipping point (Phosphorus loading) on biota (phytoplankton, zooplankton, benthos, fish, birds). The EwE modeling software (Christensen et al. 2000) was applied by the investigators to analyze impacts of nutrient load reductions and Dreissena mussel invasion in the early 1990s on the Saginaw Bay food web. The Saginaw Bay EwE model will be updated to include recent species trends (through 2008) and impacts by new invasive species (round goby) on the food web and fishery.

***6. Integrate the Modeling Approaches***. We will integrate the hierarchical models (land use, hydrology, fisheries and contaminants) for the Jordan River and Boardman River watersheds. We will compare biological outcomes from our suite of models with coincident sampling and modeling of phosphorus loadings and algal blooms in Michigan's nearshore waters of Muskegon Lake and Grand Traverse Bay by Drs. Stevenson and colleagues on their GLRI project entitled "Nutrient management models to constrain harmful algal blooms".

***7. Identify specific land use tipping points that change biological and/or contaminant outcomes.*** We will begin to develop a web-based GIS decision support data layer that can be used by land use decision makers to determine where they are relative to these tipping points. We will initiate development of additional materials to help decision makers determine their options if they are nearing or exceeding tipping points and users will be directed to potential policies and management practices that could improve these conditions.

***8. Conduct a Demonstration of Use***. We will travel to several locations and work directly with planners and natural resource managers in these pilot communities to demonstrate the tipping point tool. This demonstration will include a presentation and discussion regarding specific targets (i.e., tipping points) that should guide planning for their community. Feedback gained from pilot communities will be used to improve the decision support tool and associated support materials.

<u>This project addresses NOAA's Strategic Plan Goal</u> to protect, restore, and manage use of coastal and ocean resources through ecosystem-based management.

**Accomplishments:**

***1. Identify Land Use Indicators.***

Based on model analyses described below, the IL-IN SG extension specialists identified % agriculture and % urban in the watershed as two potential SOLEC indicators. Robinson (a former PhD student at Purdue University) worked to develop landscape, land use class, and land use patch metrics for each HUC8 and HUC12 falling within the 8 Great Lake states. These landscape, class, and patch metrics include, but are not limited to, measures such as the number of land use/cover patches within the watersheds, the total amount of core area, the total amount of natural lands, patch area-perimeter ratios, and measures of heterogeneity in land use/cover within each watershed boundary.

***2. Develop coarse scale analysis of land use tipping points.***

Co-PIs Wiley and Riseng re-ran CART models to identify land use tipping points for fishes and macroinvertebrates for the Lower Peninsula of Michigan. They identified threshold surface responses of fish and macroinverstebrates to % urban and %

agriculture in the watershed. These relationships have been provided to the Tipping Point planner DST. An example of such a relationship is in Figure 1 below.

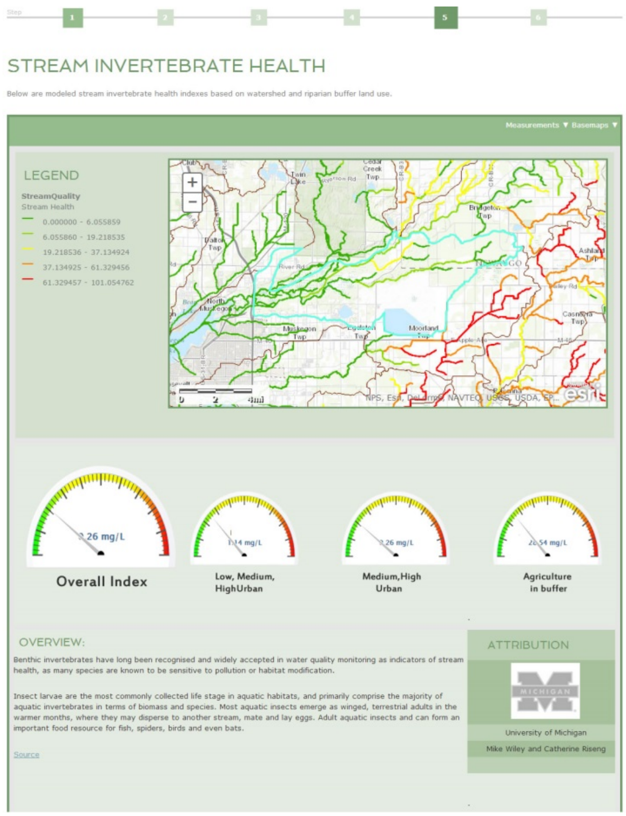


Figure 1.

Co-PIs Johnson and Ciborowski identified land use thresholds for fish and macroinvertebrates in Great Lakes coastal wetlands. They identified indicators of agricultural activities based on water quality, habitat and biotic responses, and identified endpoints and potential thresholds. They developed a structural equation model to quantify direct and indirect relationships of water quality, habitat and biota with landscape stressors. Their manuscript in review reports threshold results, and structural equation models of macroinvertebrates assemblages predicted by water quality, aquatic habitat, watershed stressors, land use and nearshore activities in Great Lakes coastal wetlands. Johnson and Ciborowski are working with co-PIs Miller and Pijanowski to input these relationships to the Tipping Point Planner Decision Support Tool.

On a related project, Co-PIs Stevenson and Hyndman related summer Chlorophyll a concentrations in US Great Lakes coastal waters to total phosphorus loads from watersheds. They found statistically significant relationships between loads, depth and distance from shore with chlorophyll a biomass estimated by satellite imagery. The investigators are working with co-PIs Miller and Pijanowski to input these relationships to the Tipping Point Planner Decision Support Tool.

Jeff Tyler finished calibrating the agent-based model for Chinook salmon, and ran simulations of land use change impacts on salmon recruitment potential in the Muskegon River. He has begun extending the Chinook salmon and steelhead models for the Boardman River in the Grand Traverse Bay watershed with assistance from co-PI David Hyndman.

***3. Compare estimates of tipping points from coarse and fine-scale analyses.***
Comparison of coarse scale models with fine scale models for the Muskegon River indicates similar thresholds for land use tipping points.

***4. Extend the Tipping Point Analysis to Include Bacterial Contaminants.***
Rose, Verhougstraete and Hyndman completed their analysis of septic tank use, CSOs and water quality violations for the Boardman and Jordan River watersheds. They quantified bacteria and chemical concentrations in waters. *E. coli concentrations were* highest in streams under baseflow conditions, while *B. theta was* highest in high summer flow conditions. Variables which influenced water quality and tipping points were septic systems, concentrations of NH3, Cl, and Ca, and pH.  They found that near surface water activities likely have greater impacts

***5. Develop and apply food web models to evaluate land use tipping points for Saginaw Bay.***
The Ecopath with Ecosim food web model was completed for Saginaw Bay Lake Huron, and a paper is in review. The co-PIs evaluated food web response to varying levels of alewive, Dreissena and Phosphorus loads. Most members of the food web responded positively to increases in nutrient loads, and negatively to increases in alewife biomass. The food web response to increases in Dreissena biomass was comparatively lower than for other stressors.  Results implied reaching target P loads will mean reductions in current walleye biomass and harvest. Future work will identify threshold values for phosphorus loading on different metrics of food web change.

***6. Integrate the Modeling Approaches***.
Integration of results from hierarchical models is underway. Results from Stevenson's GLRI project indicated threshold levels of land use change for Michigan's lower peninsula.

***7. Identify specific land use tipping points that change biological and/or contaminant outcomes.***
The outreach specialists group has continued to work on development for the Tipping Point and Indicators website containing the decision support tool. The website design is finalized with a current emphasis of crafting content and refining the interface design.

Additionally, the specialists are finalizing the action plan matrix content, which includes over 70 localized examples of best management practices, ordinances and educational activities. These recommended actions with examples will be available for communities to choose from to address specific indicator-related objectives. Those chosen actions will be incorporated into the community action plan.

The specialists are also developing related outreach facilitation tools in collaboration with the website development team and contracted software development companies. Placeways and PlaceMatters have been identified to create customized tools for the Tipping Points and Indicators website based on Placeways' Community Viz GIS Paint tools and PlaceMatters's Crowd Gauge to integrate Tipping Points and Indicators data and maps with weTable technology to enhance group collaboration capabilities of the website and the action planning process. The customized Paints Tool is complete and is an investigative tool utilized in later stages of the community overview process to determine how changes in land use affect stream quality (i.e. nitrogen, phosphorus, suspended solids, lead, copper, and zinc levels). The user has the capability to draw urban, agriculture, and forest land cover types over current land use data and see the visual changes in stream quality represented on gauges. Discussions with PlaceMatters are ongoing to plan for integrating Crowd Gauge into the community overview section, which will allow for crowd sourcing to select community priorities. The outreach specialists group is currently finalizing the Crowd Gauge matrix that links the relationship between actions to changes in community priorities (e.g. choosing to implement conservation design ordinances will result in "I can walk, bike, or take transit to important destination").

***8. Conduct a Demonstration of Use***.

In fall 2013. the outreach specialist working group will continue to finalize website content, interface design, and the action plan strategies. The group will additionally begin planning logistics and content for the Train-the-Trainer workshop at Purdue University, which is tentatively scheduled for late October 2013. Great Lakes outreach specialists will receive detailed training on the Tipping Points and Indicators website interface, customized tools, action plan wizards, and weTable set up. A guidebook will be created with both technical and facilitation materials to prepare specialists to conduct Tipping Points and Indicators pilot trainings for planners and watershed managers in their respective states in spring 2014.

Formative evaluations will be conducted with extension specialists who will be using the online tool to determine modifications needed along the way, next steps, and potential future additions. A summary evaluation will be conducted at the end of the community-level workshops.

**Publications:** None to date.

**In review:**

Kao, Y-C., S. Adlerstein, and E. S. Rutherford. In review. The relative impacts of nutrient loads and invasive species on a Great Lakes food web: An Ecopath with Ecosim analysis. Journal of Great Lakes Research.

**Presentations and/or Workshops:**

A special session on Land Use indicators and Tipping Points was held at the IAGLR 2013 meeting in W. Lafayette, IN. on June 5-6, 2013. The following talks were presented. Session Title "Ecosystem Tipping Points: Science and Decision Making", June 5-6, 2013 at IAGLR 2013, W. Lafayette, IN.

PIJANOWSKI, B.C. and KIM, N. Ecosystem Tipping Points: Science and Policy.

MILLER, B., TEPAS, K., SALAZAR, K., DOUCETTE, J., SCHOMBERG, J., HART, D., JAFFE, M., MCCORMICK, R., BREEDERLAND, M., LUCENTE, J., RAFFERTY, S. and PENNY, M. Engaging Great Lakes Communities to Develop Tipping Point Action Plans.

TEPAS, K.M., COLLINGSWORTH, P.C., PIJANOWSKI, B.C., HORVATIN, P.J., HINCHEY MALLOY, B. and MILLER, B.K. Development of new land use indicators for SOLEC assessment.

ROBINSON, K.D., PIJANOWSKI, B.C. and MILLER, B.K.. User needs assessment: Will they come if we build it?

WILEY, M.J., RISENG, C.M., RUTHERFORD, E. and PIJANOWSKI, B. Land use tipping points in Midwestern streams.

STEVENSON, R.J., NOVITSKI, L., HYNDMAN, D., QI, J., ESSELMAN, P., KENDALL, A., LAWAWIROJWONG, S., LUSCZ, E., MARTIN, S. and SUEPA, T. Relating Coastal Algal Blooms to Rivers, Nutrients, Watershed Land Use, and Storm Events.

MARTIN, S.L., HAYES, D.B., KENDALL, A.D., RUTLEDGE, D.T., PIJANOWSKI, B.C and HYNDMAN, D.W. Land use legacies and ecosystem tipping points.

CAI, M., KOVALENKO, K.E., JOHNSON, L.B., CIBOROWSKI, J.J.H. and BRADY, V.J. Modeling land and water stress impacts on macroinvertebrates in the Great Lakes coastal wetland.

NOVITSKI, L., STEVENSON, R.J., ESSELMAN, P. and QI, J. Using MODIS and Landsat to Infer Chlorophyll in Great Lakes Surface Waters with a Focus on Saginaw Bay.

VERHOUGSTRAETE, M., MARTIN, S., KENDALL, A., HYNDMAN, D. and ROSE, J.B. Microbial Responses to Land, Physical, Chemical, Environmental, and Hydrological Factors.

TYLER, J., RUTHERFORD, E., WILEY, M., RISENG, C., PIJANOWSKI, B. and HYNDMAN, D. Changes in Land Use and Urban Development on Salmonid

Production in the Muskegon River: A Multi-Modelling Analysis Focused on Chinook and Steelhead.

KENDALL, A.D., LUSCZ, E.C., MARTIN, S.L. and HYNDMAN, D.W. From Landscape Application to the River Mouth: A Fully Explicit Simulation of Nutrient Loads Across Lower Michigan, USA.

DOUCETTE, J.S., MILLER, B.K. and POLICINSKI, L. Tipping Points and Indicators: Supporting Sustainable Communities in Great Lakes States.

**Outreach Activities:** None.

## Research Theme V: INTEGRATED ASSESSMENT

CILER activities that fall under the theme of Integrated Assessment include research to generate policy-relevant and synthetic efforts to help guide long-term resource use in the basin.

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### 32. PROJECT TITLE: ADAPTIVE INTEGRATED FRAMEWORK: A NEW METHODOLOGY FOR MANAGING IMPACTS OF MULTIPLE STRESSORS IN COASTAL ECOSYSTEMS

*Principal Investigators:* Thomas Johengen and Dima Beletsky, (CILER - University of Michigan); Carlo DeMarchi, (Case Western Reserve University); Tomas Höök, (Purdue University); Donna Kashian, (Wayne State University)

*NOAA Technical Contacts*: Craig Stow and Juli Dyble Bressie, NOAA – GLERL

#### Overview and Objectives:

We proposed a novel, unique Adaptive Integrated Framework (AIF) for facilitating information collection, implementing adaptive modeling approaches, and guiding research needs to improve management decision making. This framework uses input from agency managers, researchers and modelers, including both data to characterize ecosystems and socio-economic factors to drive modeling approaches and management actions. The proposed framework is being applied to Saginaw Bay, a coastal system greatly impacted by multiple stressors such as invasive species, changing land-use patterns, and climatic change.

The program is calibrating an ensemble of ecosystem models using extensive historical data for Saginaw Bay, develop a watershed and hydrological model for the coastal ecosystem, and develop human dimensions models for evaluating resource outcomes and management plans. These efforts are being undertaken at differing scales of resolution to model and evaluate water quality, fish production and economic metrics that are of importance to management agencies and the public. The modeling efforts use an iterative process in which modeling outputs will identify knowledge gaps (i.e., drive field and experimental research) and help management agencies identify management alternatives. The results and data needs (gaps) identified by the agencies will, in turn, lead to models being re-parameterized, re-applied and re-evaluated before the next iteration of management agency input and field research.

The proposed work recognizes the crucial need for developing models that are adaptable across ecological systems and multiple stressors as well as one that provides managers with a means to understand and manage stressor interactions unique to their system. The five year project accomplishes these goals by coupling modeling, observational, and experimental studies with stakeholder workshops and socio-economic analyses. The resulting AIF approach will be broadly applicable to evaluate the nation's coastal and estuarine ecosystems impacted by multiple stressors. This reporting period represents year 4 of the 5 year project.

Project Objectives:

- Develop the Adaptive Integrative Framework (AIF) approach to facilitate synthesis and prioritization of research and management pertaining to multiple stressors impacts on coastal ecosystems.
- Provide specific predictions regarding how fish production, human health, and regional economics, respond to multiple stressors (i.e. land use, climate change and invasive species) in Saginaw Bay, MI.

This project addresses NOAA Strategic Plan Goal(s):

1) Protect, restore, and manage use of coastal and ocean resources through ecosystem-based management;
3) Serve society's needs for weather and water information;

**Accomplishments:**

All of the field research for the project has been completed and a final project report was developed for the managers in the form of a NOAA Technical Memorandum. In addition, a dedicated issue of the Journal of Great Lakes was developed to highlight project results and included xx manuscripts. Manuscripts are in final review by the editors and the Journal should be in press in early 2014. Final modeling scenarios and additional data synthesis will still be taking place over the course of the next year or so. The following text represents a basic synthesis of findings that are being addressed in these summary publications.

**Water Quality Management Implications**

The 440 tonnes/year target total phosphorus load originally developed for the 1978 GLWQA has almost never been met, and ambient total phosphorus and chlorophyll a concentrations and secchi depth objectives are regularly exceeded in the inner bay. While there is some evidence for episodic sediment phosphorus reintroduction to the water column, the observation that the highest phosphorus and phytoplankton levels consistently occur in the Saginaw River plume make it unlikely that periodic sediment phosphorus release is an important promoter of algal growth. Water-column primary production appears to be phosphorus-limited as does benthic algal growth, thus it is likely that further phosphorus reductions will result in reduced algal production. Point-source total phosphorus discharges constitute a relatively low proportion of the current total phosphorus load; a focus on reducing non-point phosphorus inputs will be necessary to promote further improvements in eutrophication symptoms.

However, the effect of further phosphorus reductions on beach fouling is unclear. Because muck was a consistent occurrence in the 1980s, before dreissenid mussels appeared, it cannot be considered a resurgent problem, resulting from the mussel invasion, as it is in other areas around the Great Lakes. Unlike many other Great Lakes beaches, where *Cladophora* is the primary constituent of beach muck, the composition varies near the Bay City Recreation Area. Although benthic algal production, including *Cladophora*, is extensive in the Bay, the observed beach detritus often contains other filamentous algae as well as significant amounts of decaying macrophytes. Phosphorus reductions are unlikely to limit the production of macrophytes, which obtain phosphorus from deposited sediments. Currents in the bay are also important. Our results indicate a significant source of muck precursors in the southwest region of the bay; it is likely that decaying vegetation circulates in large gyres in the inner bay, and is pushed ashore at under appropriate wind conditions.

Published reports in the 1980s, following efforts to reduce phosphorus loading, indicated water quality improvements associated with declining phosphorus inputs. Shortly thereafter management priorities shifted and active phosphorus surveillance languished for an extended period. During that time, phosphorus loads stabilized above the 440 tonnes/year target, and dreissenid mussels became established, altering phosphorus cycling and the composition of the algal community. The lapse in active monitoring has made it difficult to fully understand the changes that have occurred over this period. Although invasive mussel densities are currently much lower than they were in the 1990s, they are still widespread, and their future population trajectory is unknown. Additionally, the composition of the mussel community has shifted from exclusively zebra mussels to approximately 75% quagga mussels; their role in nutrient cycling and algal productivity may continue to evolve as conditions in the bay change. To reduce future uncertainties an active Adaptive Management Strategy, including regular monitoring and routinely updated modeling, should be developed and implemented.

**<u>Invasive Species and Food Web Management Implications</u>**

**Eutrophication**: Saginaw Bay's biota appears to have partially responded to long-term reductions in nutrient loading and improved water quality. A variety of patterns point to such responses including: 1) a more oligotrophic zooplankton assemblage, 2) reemergence of some sensitive benthic invertebrates, and 3) a shift in the fish assemblage from species highly tolerant of eutrophic conditions to species moderately tolerant of eutrophic conditions. Nonetheless, many tolerant invertebrate and fish species remain highly abundant in Saginaw Bay and more sensitive species remain a minor component of overall communities. Thus, while our findings point to positive biotic responses, continued efforts to reduce nutrient loading/sedimentation and improve water quality are likely necessary for Saginaw Bay's biotic composition to continue to shift towards more sensitive species.

**Invasive Species:** Several of the taxa that seem to have responded to ecosystem level changes in Saginaw Bay are not actively managed, and hence the taxa-specific management implications of some of our findings are not straightforward. For example, while it is clear that several invasive species play important roles in the Saginaw Bay's foodweb (e.g., quagga mussels, *Bythotrephes*, round gobies) it is not obvious how to control these species.

While invasive species are generally considered negatively, some invaders are contributing to production of desirable native fish species in Saginaw Bay. *Bythotrephes* are consumed by age-0 walleye and are strongly selected as preferred prey by age-1 and older yellow perch in Saginaw Bay. Similarly, round goby are consumed by piscivrous walleye (from age-0 through the end of life) and age-1 and older yellow perch.

**Coregonids:** To our knowledge, there have been limited previous studies of lake whitefish in Saginaw Bay. We found evidence that inner Saginaw Bay supports relatively fast growth of young whitefish, and we found no evidence that young lake whitefish are targeted by piscivorous walleye or yellow perch. We speculate that due to high availability of invertebrate prey (both zooplankton and benthic invertebrates), inner Saginaw Bay may constitute a high quality nursery source for adult lake whitefish, which in turn support fisheries in outer Saginaw Bay and main basin of Lake Huron.

The strong performance of young lake whitefish in Saginaw Bay may suggest that physiologically similar species may also thrive in Saginaw Bay. The potential for reestablishment of abundant stocks of native cisco (lake herring) in Lake Huron has received strong support. In the absence of alewife, this planktivore may now be able to fill an important ecological role in both Saginaw Bay and main basin of Lake Huron. While growth conditions appear to be suitable for young coregonids, spawning habitat may constitute a potential bottleneck for increased lake whitefish and cisco production in Saginaw Bay. Past studies suggest that many potentially suitable spawning sites in Saginaw Bay have been lost through sedimentation. It is an open question where lake whitefish are currently spawning in inner Saginaw Bay. We suggest that future surveys could evaluate (a) whether coregonid spawning habitat is truly limited, and (b) the potential for creation of additional spawning habitat in Saginaw Bay.

**Temporal shifts of invertebrates:** We documented some temporal shifts (both within and across years) in invertebrate densities which are not straightforward to explain, but may have important implications. First, we found that zooplankton peak densities occur much later in the year now, than they did historically. This may have important implications for young fish that rely on abundant zooplankton as prey during early, critical life stages. Although we speculate that both bottom-up and top-down changes may have contributed to this shift (see above), we are unable to robustly evaluate the mechanistic underpinnings. Given the potential importance of this change in zooplankton density cycles, we suggest that future studies should more fully explore the mechanisms.

Second, we also documented a decline in dreissenid abundance from the 1990s to late 2000s. This trend is opposite to patterns observed in many systems, where dreissenids have continued to increase over time. While some patterns (i.e., dreissenid size structures) suggest that goby predation may influence dreissenid populations, our preliminary bioenergetics estimates of goby consumption suggest that such predatory control is unlikely. Future efforts to understand the mechanisms of dreissenid declines would be useful and may help inform management efforts in several other systems, where control of dreissenids would be highly desirable.

Finally, we believe that our studies in Saginaw Bay demonstrate the value of long-term monitoring. Many aspects of the Saginaw Bay ecosystem (e.g., water quality, invertebrate assemblages) have not been routinely monitored over a long time period, making it difficult to document historic trends and consider potential mechanisms underlying changes. In contrast, the Michigan Department of Natural Resources long-term (1970-present) trawling program in Saginaw Bay represents an invaluable resource for exploring historic biotic responses. In many aquatic systems, data availability is the converse of Saginaw Bay (i.e., long-term data on environmental conditions, but limited data on upper trophic levels like fishes). The Michigan DNR should be applauded for maintaining this program and we hope that it will continue indefinitely.

## Fish and Fisheries Management Implications

Walleye spawning habitat may now be a limiting factor for production. Moreover, even if there is sufficient spawning habitat, population sustainability may benefit by partitioning spawning among multiple, diverse habitats. That is, walleye recruitment success displays high inter-annual variation, and heterogeneity in spawning may temper such variation by increasing the breadth of environmental conditions experienced by spatially-distinct young walleye during a particular year. In Saginaw Bay, walleye spawning may be diversified by increasing the availability of spawning habitats in rivers and/or reefs. Many Saginaw Rivers are dammed, limiting passage of walleye to potentially suitable upstream spawning habitats. While removal of dams could alleviate such blockages, dam removal may also lead to various deleterious effects (e.g., downstream sediment release, increased contaminant flux, and upstream movement of invasive species [round goby, sea lamprey]). Moreover, walleye in Saginaw Bay are already thought to primarily spawn in rivers, and additional river spawning habitat may not provide environmental conditions fundamentally different from existing spawning environments (and hence, may not temper inter-annual recruitment variation). Instead, we suggest that Saginaw Bay reef restoration represents a particularly worthwhile approach for expanding walleye spawning habitat. Reef spawning habitat could provide a substantially different spawning environment from river habitats (different thermal conditions leading to temporally offset spawning and emergence; dissimilar incubation conditions; and no long-distance, downstream transport). Thus, we suggest that Saginaw Bay management agencies should explore the potential for reef restoration.

Historically, Saginaw Bay likely supported both large walleye and yellow perch populations. However, high predation pressure by walleye may now be a factor contributing to low yellow perch recruitment; potentially coupled with a slow growth of later-stage age-0 yellow perch and b) low perch spawning stock biomass. Potential management actions to overcome these bottlenecks could include increased harvest of walleye (thereby decreasing predation pressure on yellow perch), decreased harvest of yellow perch (thereby increasing spawning stock biomass of yellow perch), or establishment of another forage fish population to divert predation pressure from yellow perch. The ultimate effects of any of these actions are unfortunately unknown. Increased harvest rates of walleye have the potential to deleteriously impact the walleye population (especially if recruitment success decreases in the future), and decreased harvest of yellow perch will have social and economic impacts on the commercial and recreational fishers that exploit this population. Introduction of a new, native forage fish (e.g., lake herring) could decrease predation pressure on yellow perch, but to a large extent round goby are already serving as a predation buffer on yellow perch. Moreover, it is unclear if walleye would select a novel forage fish as prey in favor of yellow perch (e.g., young lake whitefish are present in Saginaw Bay, but were absent from walleye diets). In short, the most suitable management actions are unknown, and we suggest that Saginaw Bay fisheries managers should take an adaptive approach to build the yellow perch population: establish a management action and then monitor responses of populations of interest.

**Publications:**

Blouzdis, C.E., L.N. Ivan, S.A. Pothoven, C.R. Roswell, C.J. Foley, and T.O. Höök. 2013. A trophic bottleneck? The ecological role of trout-perch *Percopsis omniscomaycus* in Saginaw Bay, Lake Huron. J. Applied Ichthyology 29: 416-424.

Cha, Y., C.A. Stow, T.F. Nalepa, and K.H. Reckhow. 2011. Do invasive mussels restrict offshore phosphorus transport in Lake Huron? *Environmental Science & Technology*, 45: 7226-7231.

Cha, Y., C.A. Stow, K.H. Reckhow, C. DeMarchi, and T. Johengen. 2010. Phosphorus load estimation in the Saginaw River, MI using a Bayesian hierarchical/multilevel model. Water Research 44: 3270-3282.

Ivan, L.N., T.O. Höök, M. V. Thomas, and D. G. Fielder. 2011. Long-term and Interannual dynamics of walleye and yellow perch in Saginaw Bay, Lake Huron. Transactions of the American Fisheries Society. 140: 1078-1092.

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Pothoven, S.A., T.O. Höök, T.F. Nalepa, M. Thomas and J.D. Bressie. 2013. Changes in zooplankton community structure associated with the disappeance of invasive alewife in Saginaw Bay, Lake Huron. Aquatic Ecology 47:1-12.

Pothoven, S.A., T.O. Höök, and C.R. Roswell. 2013. Feeding ecology of age-) lake whitefish in Saginaw Bay, Lake Huron. Journal of Great Lakes Research.

Roswell, C.R. 2011. Growth, Condition, and diets of Age-0 Saginaw Bay Yellow Perch: Implication for Recruitment. Thesis submitted for completion of Master of Science degree. Purdue University, West Lafayette, IN. December, 2011.

Stow, C. and Höök, T. 2013. SAGINAW BAY Management Report. NOAA Technical Memorandum, GLERL-160. August 2013. 51pp.

Foley C.J. et al. (In Review). Spatial and temporal patterns of benthic macroinvertebrates in Saginaw Bay, Lake Huron, 2009-2010. Journal Great Lakes Research, special volume for 2014.

Pothoven, S. et al. (In Review). Predatory demands of Bythotrephes and Leptodora in Saginaw Bay, Lake Huron. Journal Great Lakes Research, special volume for 2014.

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Mifsud, D. et al. (In Review). A Status Assessment and Review of Saginaw Bay Herpetofauna. Journal Great Lakes Research, special volume for 2014.

Selzer, M.D. et al. (In Review). A Reflection on Restoration Progress in the Saginaw Bay Watershed. Journal Great Lakes Research, special volume for 2014.

Sesterhenn, T.M. et al. (In Review). Implications of multiple hatching sites for larval dynamics in the resurgent Saginaw Bay walleye population. Journal Great Lakes Research, special volume for 2014.

Kashian, D.R. et al. (In Review). Dreissenid-induced Changes in the Saginaw Bay phytoplankton community structure since the dreissenid invasion of Saginaw Bay, Lake Huron. Journal Great Lakes Research, special volume for 2014.

Verhougstraete, M. et al. (In Review). MICROBIAL INVESTIGATIONS OF WATER, SEDIMENT, AND ALGAE MATS IN A MIXED USE WATERSHED. Journal Great Lakes Research, special volume for 2014.

Kashian, D.R., et al. (In Review). Trends in the Distribution and Abundance of Hexagenia spp. in Saginaw Bay, Lake Huron, 1954-2012: Moving towards recovery? Journal Great Lakes Research, special volume for 2014.

Roswell, C.R. et al. (In Review). Patterns of age-0 yellow perch growth, diets, and mortality in Saginaw Bay, Lake Huron. Journal Great Lakes Research, special volume for 2014.

De Marchi, C., et al. (In Review). Estimating Nutrient and Sediment Loads from the Saginaw River: 1. Model Development. Journal Great Lakes Research, special volume for 2014.

He, C., et al. (In Review). Estimating Spatial Distribution of Point and Nonpoint Sources Pollution Loadings in Saginaw Bay Watersheds by Multiple Sources of Databases. Journal Great Lakes Research, special volume for 2014.

Cooper, M., et al. (In Review). Spatial and temporal trends in invertebrate communities of Great Lakes coastal wetlands, with emphasis on Saginaw Bay of Lake Huron. Journal Great Lakes Research, special volume for 2014.

Staton, J.M., et al. (In Review). Condition and Diets of Yellow Perch in Saginaw Bay, Lake Huron (1970-2011). Journal Great Lakes Research, special volume for 2014.

Hawley, N. Sediment Resuspension in Saginaw Bay. Journal Great Lakes Research, special volume for 2014.

Lavrentyev, P. et al. (In Review). Microzooplankton distribution, dynamics, and trophic interactions relative to phytoplankton and quagga mussels in Saginaw Bay, Lake Huron. Journal Great Lakes Research, special volume for 2014.

Karpovich, D.S. Implications of Hypoxia on the North Branch of the Kawkawlin River. Journal Great Lakes Research, special volume for 2014.

Tang, H. et al. (In Review). Quagga mussel (Dreissena rostriformis bugensis) selective feeding of phytoplankton in Saginaw Bay. Journal Great Lakes Research, special volume for 2014.

Stow, C. et al. (In Review). Phosphorus Targets and Eutrophication Objectives in Saginaw Bay: A 35 Year Assessment. Journal Great Lakes Research, special volume for 2014.

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Peacor, S., et al. (In Review). The Influence of Light and Nutrients on Benthic Filamentous Algal Growth: A Case Study of Saginaw Bay, Lake Huron. Journal Great Lakes Research, special volume for 2014.

Francoeur, S., et al. (In Review). BENTHIC ALGAL RESPONSE TO INVASIVE MUSSELS IN SAGINAW BAY: A COMPARISON OF HISTORICAL AND RECENT DATA. Journal Great Lakes Research, special volume for 2014.

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**Presentations:**

Beletsky, D. Modeling thermal structure and circulation in the Great Lakes. GIS Day 2011 Modeling Symposium, University of Notre Dame, December 2, 2011, South Bend, IN.

Beletsky, D., R. Beletsky and N. Hawley. 2011. Modeling interannual variability of circulation in Lake Huron. IAHR International Symposium on Stratified Flows (ISSF2011), August 22-26, 2011, Rome, Italy.

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He, C. and T. E. Croley. 2011. Hydrological resource shed and its applications in Great Lakes water quality management. WMU Dept. of Civil and Construction Engineering CCE 4350/GEOG5090 Surface Hydrology class, Engineering College, Nov.29. 65 min.

He, C. and T. E. Croley. 2011. "Hydrological Resource Sheds and Water Quality Management ". Annual Meeting of International Professionals for the Advancement of Chinese Earth Sciences, Guiyang, China, July 7-9, 2011.

He, C. 2011. Invited speaker, "Great Lakes and Threats from Pollution", Protecting the Great Lakes, Canadian Studies Roundtable 2011, Fetzer Center, WMU campus. March 18, 2011.

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Stein, S. R., C. Roswell, L. Ivan, C. J. Foley, E. S. Rutherford, E. F. Roseman, and T. O. Höök. 2011. Walleye Spawning Habitats Buffer Interannual Recruitment Variability in Saginaw Bay, Lake Huron. Poster. *American Fisheries Society 141st Annual Meeting.* Seattle, Washington, USA. Sept. 4-8.

## Outreach Activities:

Project PI's held a workshop at NOAA-GLERL in December 2011 for the Great Lakes water quality managers, updating them of our preliminary results.

Project PI's held a workshop at NOAA-GLERL in October 2011 for the Great Lakes fishery managers.

A meeting between project researchers and Michigan DNR management was conducted in August 2011 to discuss the overall state of the project and to help develop approaches and content for disseminating project final results.

### 33. Project Title: ECOFORE - Forecasting the Causes, Consequences and Remedies for Hypoxia in Lake Erie

*University Principal Investigators:* Allen Burton, Donald Scavia, J. David Allan, Dmitry Beletsky , Thomas Johengen, Hongyan Zhang, Mary Anne Evans (University of Michigan); Tomas Höök (Purdue), Steven Bartell (E2, Inc.); Joseph DePinto (LimnoTech, Inc.); David Dolan (University of Wisconsin – Green Bay); Chansheng He (Western Michigan University); Roger Knight (Ohio DNR); Peter Richards (Heidelberg College); Stephen Brandt (Oregon State University); Stuart Ludsin (Ohio State University); Nate Bosch (Grace College)

*NOAA Technical Leads:* Doran Mason, Edward Rutherford, Steven Ruberg, David Schwab, Henry Vanderploeg (NOAA-GLERL)

**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 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 are 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**

Daloglu et al. (2012) used the Soil and Water Assessment Tool (SWAT) watershed model to explore these potential contributions to the increase in DRP and suggest it was driven by increasing storm events, changes in fertilizer application timing and rate, and management practices that enhanced P-soil stratification. The frequency of extreme rain events nearly doubled (from 2.8 to 5.3 d/year) since the early 1900s in this region, as has the number of prolonged wet periods (Mortsch et al. 2000). However, weather alone may not be the sole driver of this change. For example, Daloglu et al. (2012) also demonstrated that while the current more extreme events appeared to stimulate large fluxes of DRP, those same weather patterns imposed on the agricultural landscapes of the 1970s did not.

Bosch et al. (2013) applied calibrated SWAT models (Bosch et al.2011) of the Huron, Raisin, Maumee, Sandusky, Cuyahoga, and Grand watersheds that represent 53% of the bi-national Lake Erie basin. They simulated subwatershed TP and DRP yields representing average annual yields for each subwatershed for 1998-2005. Their results indicate, for example, that Maumee high-yield subwatersheds were located sporadically for DRP but in the upper reaches for TP; Sandusky high-yield subwatersheds were located sporadically for both DRP and TP; and Cuyahoga high-loading subwatersheds were mostly located in the upper reaches for both DRP and TP. As a result, substantial fractions of DRP and TP flux come from a relatively small fraction of the watersheds. For example, 36% of DRP and 41% of TP come from ~25% of agriculturally dominated Maumee sub-watersheds. Those values are 33% and 38% for the Sandusky, and 44% and 39% for the Cuyahoga. These results point to the need for spatial targeting of management actions; however, it is important to note that they represent flux to the stream channels at the exit of each subwatershed, not delivered to the lake, and thus the maps could be different if flux to the lake was considered.

Bosch et al. (2013) explored the impacts of expanding the current use of filter strips, cover crops, and no-till BMPs. When implemented singly and in combinations at levels currently considered feasible by farm experts, these BMPs reduced sediment and nutrient yields by only 0-11% relative to current values. Yield reduction was greater for sediments and the greatest reduction was found when all three BMPs were implemented simultaneously. They also found that targeting BMPs in high source locations (see above), rather than randomly, decreased nutrient yields more, whereas reduction in sediment yields was greatest when BMPs were located near the river outlet. A more detailed analysis of increased BMP implementation strategies for the Maumee watershed pointed to the need for more aggressive implementation of multiple BMPs to substantially reduce loads. For example, a 20% reduction in TP or DRP load requires implementing the BMPs on more than 50% of the agricultural land.

Bosch et al. (in revision) also assessed climate impacts on a range of BMPs with SWAT. They projected water flow, sediment yields, and nutrient yields, based on simple characterizations of future climates consistent with those projected from climate models. These watersheds showed consistent increases in sediment yield with increases larger under more extreme climate scenarios, and more significant in agricultural (Maumee and Sandusky) as opposed to more forested (Grand) watersheds.

Total annual discharge increased 9-17% under the more extreme climate scenario (4-9% under the moderate scenario). Stream sediment yields increased by 9% and 23% for moderate and severe climate scenarios, respectively. DRP yields decreased (-2% on average) under the moderate climate scenario and increased slightly (3%) in response to severe climate change. TP yields increased 4% under moderate climate change conditions and 6% under severe climate change conditions. It is important to note that, while agricultural BMPs might be less effective under future climates, higher BMP implementation rates still can substantially offset those anticipated increases in sediment and nutrient yields for the Maumee watershed.

Daloglu (2013) evaluated how different policies, land management preferences, and land ownership affect landscape pattern and subsequently downstream water quality. This framework linked an agent-based model of farmers' conservation practice adoption decisions with SWAT to simulate the influence of changing land tenure dynamics and the crop revenue insurance *in lieu* of commodity payments on water quality over 41 years (1970-2010) for the predominantly agricultural Sandusky watershed. The results showed that non-operator owner involvement in land management decisions yielded the highest reduction in sediment and nutrient loads and crop revenue insurance tended to create a homogeneous conservation landscape with slight increases in sediment and nutrient loads. However, it also suggested that linking crop insurance to conservation compliance and strengthening and expanding conservation compliance provisions could reduce nutrient loads.

## HYPOXIA TEAM

Zhou et al. (2013) used geostatistical kriging and conditional realizations to provide quantitative estimates of the areal extent of summer CB hypoxia for 1987 through 2007, along with their associated uncertainties. Their geostatistical approach combines *in situ* DO measurements with ancillary data such as bathymetry and measurement locations to produce best estimates of bottom water DO and their uncertainties. Conditional realizations are then used to sample the uncertainty in the spatial DO distribution, leading to a probabilistic representation of hypoxic extent. While substantial intra-annual variability existed, hypoxic area was generally smallest during the mid-1990s, with larger extents in the late 1980s and the early 2000s.

Rucinski et al. (in revision) developed and tested a model specifically for establishing the relationship between phosphorus loads and CB hypoxia. This model is driven by a one-dimensional hydrodynamic model that provides temperature and vertical mixing profiles as described in Rucinski et al. (2010). The biological portion of the model is a standard eutrophication model with a new formulation that adjusts the sediment oxygen demand (SOD) as a function of TP load, based on an empirical relationship between SOD and deposited organic carbon. The model was calibrated over 19 years

(1987-2005) of chlorophyll, phosphorus, and DO concentration, and tested for corroboration with key process rates, such as oxygen depletion; organic matter production and sedimentation, estimates of hypoxic area (Zhou et al. 2013) by taking advantage of a new empirical relationship between bottom water DO and area also developed by Zhou et al. (2013). It was validated with independent oxygen concentrations from the period 1960 through 1985.

The model was then used to develop response curves for bottom water DO concentration, hypoxic-days (number of days per year with hypolimnetic DO below 2 mg/l), hypolimnetic depletion rates, and hypoxic area as a function of WB+CB TP and DRP loads. The response curves, incorporating the uncertainty associated with interannual variability in weather from the 19 calibration years, was used to explore implications for new loading targets

***Potential loading targets for hypoxia -*** While the actual extent of "acceptable hypoxia" needs to be set through public discourse and policy, one reasonable expectation is to return to hypoxic areas of the mid-1990s prior to the increases - approximately 2,000 $km^2$. By inspection of the response curves, it was clear that the current total load target of 11,000 MT (WB+CB equivalent is 9845 MT or 89.5% of total load) is no longer sufficient. In fact, if the desired outcome is for average hypoxic area to be below 2000 $km^2$ for roughly 10 days per year, the WB+CB TP load would have to be approximately 4300 MT/year (4804 MT/year total load). This is a 46% reduction from the 2003-2011 average loads and 56% below the current target, or a reduction of 3689 MT/year (4122 MT/year from the total load).

If new targets were set for DRP, the WB+CB load would have to approach 550 MT/year (total equivalent load is 598 MT/year because WB+CB is 92% of total DRP), roughly equivalent to values in the early 1990s. Because there has been such a significant increase in the DRP load since then, this represents a very substantial 78% reduction from the 2005-2011 average DRP load, or a reduction of 1962 MT/year (2133 MT/year from total load). It is worth noting that these response curves indicate that a focus on DRP requires about half of the reduction of the TP target, which is consistent with its higher bioavailability.

We also noted that recent recommendations to reduce the occurrence of WB cyanobacteria blooms would not be sufficient to meet a CB hypoxia goal of 2,000 $km^2$. For example, the Ohio Lake Erie Phosphorus Task Force recommended that to keep blooms to acceptable levels, the March-June Maumee River target TP loads (as a surrogate for all WB tributaries) should be less than 800 MT, which is a 31% reduction from the 2005-2011 average of 1160 MT. If all CB and WB non-point sources (5534) were reduced by the same 31% and applied across the full year, the resulting annual CB+WB TP load would be reduced from 7989 to 6273 MT/year, still considerably higher than the

4300 MT/year target identified above. So, in setting targets, it is important to recognize that WB cyanobacteria and CB hypoxia endpoints likely require separate considerations.

## ECOLOGICAL EFFECTS TEAM

Goto et al. (2012) showed that positive effects of hypoxia on prey production rates may be particularly strong if bottom hypoxia forces prey higher in the water column, as many zooplankton taxa have higher growth rates when temperature, light, and phytoplankton are all greater. This positive effect may be most beneficial for epi- and meta-limnetic foragers whose prey may concentrate higher in the water column, leading to more efficient foraging (e.g., emerald shiners *Notropis atherinoides*, Pothoven et al. 2009; walleye *Sander vitreus*, Brandt et al. 2011). However, the prevalence of simultaneous positive and negative indirect effects and a suite of co-occurring seasonal processes can make predicting the net impact of hypoxia on fish difficult.

While definitive *in situ* impacts have been hard to quantify, laboratory studies have demonstrated the potential for some Lake Erie fish and zooplankton to be negatively affected by low oxygen conditions. For example, while the relatively tolerant yellow perch (*Perca flavescens*) can survive at low oxygen concentrations, both consumption and growth rates decline (Roberts et al. 2011). Further, hypoxia may lead to decreased prey production as some zooplankton prey species experience poor survival under hypoxia (e.g., *Daphnia mendotae*; Goto et al. 2012).applying a GRP model for a relatively warm year with prolonged hypoxia extending far above the lake bottom and a relatively cool year, with a thin hypoxic layer persisting for a short time. For example, Pothoven et al. (2012) and Ludsin, Höök, and Pothoven (unpublished data) showed that, in Lake Erie, hypoxia-intolerant, rainbow smelt, avoided hypoxic waters completely by moving up into a thin layer of the water column just above the hypoxic zone. By contrast, the obligate demersal round goby migrated horizontally into the nearshore to avoid hypoxia (Höök, Pothoven, and Ludsin unpublished data). Further, while some yellow perch moved horizontally away from the hypoxic region, many remained in this region and moved higher in the water column, while taking short-term feeding forays into the hypoxic zone (e.g., Roberts et al. 2009, 2012).

Arend et al. (2011) illustrated that with climate change, future preferred habitats are likely to be squeezed both from above (warmer temperatures) and from below (increased hypoxia). In short, under a warmer future, we may need to reduce loading levels even more dramatically to have meaningful effects on habitat quality and Lake Erie fish stocks.

Brandt et al. (2011) and Arend et al. (2011) modeled growth rate potential (GRP) of selected fishes in the CB as a surrogate of habitat quality. Brandt et al. (2011) argued that hypoxia had a temporary positive effect on walleye GRP as prey fish were forced into areas where temperature, oxygen, and light conditions were favorable for walleye foraging and growth. In contrast, Arend et al. (2011) found that GRP (i.e., habitat quality) of yellow perch, rainbow smelt, emerald shiner, and round goby GRP improved with reductions in P loading and hypoxia prior to the mid-1990s, but did not continue to improve from the mid-1990s through 2005 (and may even have decreased). Arend et al. (2011) also showed that hypoxia impacts were most severe for adult stages of rainbow smelt and round goby and least severe on adult and juvenile stages of yellow perch.

While GRP models consider spatiotemporal overlap of environmental conditions, they are static representations that do not incorporate potential dynamic indirect hypoxia impacts. For example, behavioral avoidance of hypoxia can lead to highly dynamic predator-prey interactions and various density-dependent effects, and these changes in predator-prey interactions can cascade to not only affect a single predator-prey pair, but the entire food web. Other Ecofore-Lake Erie modeling approaches have begun to evaluate these diverse pathways by considering individual-and population-based bioenergetics (Goto et al. in prep; Pangle et al. in prep), food web (Ecopath with Ecosim - EwE; Zhang et al., unpublished), and comprehensive ecosystem (S. Bartell unpublished) responses to hypoxia. These modeling approaches differ greatly in their spatial and temporal resolution and focus on the entire foodweb versus a subset of abundant, representative species. The differential emphasis on behaviorally mediated habitat selection, trophic interactions and trophic cascades among these models may lead to somewhat dissimilar predictions regarding ecological effects of hypoxia in Lake Erie.

### Publications:


Bartell, S.M. Development and application of the comprehensive aquatic systems model (CASM) to assess the ecological impacts of hypoxia in central Lake Erie. Ecological Modelling (In preparation).

Bartell, S.M., Arend, K.K., Höök, T.O., Ludsin, S.A., Depinto, J.V., & Scavia, D. Ecological risks posed by hypoxia on food web production dynamics in central Lake Erie – a modeling study. Freshwater Biology. (In preparation).

Beletsky, D., N. Hawley, Y.R. Rao. Modeling summer thermal structure and circulation in Lake Erie. *J. Geophys. Res. (in review).*

Beletsky, D., N. Hawley, Y.R. Rao, H. A. Vanderploeg, R. Beletsky, D. J. Schwab and S.A. Ruberg. 2012. Summer thermal structure and anticyclonic circulation of Lake Erie, *Geophys. Res. Lett.*, 39, L06605, doi:10.1029/2012GL051002.

Bosch, N.S., Allan, J.D., Selegean, J.P., and D. Scavia. 2013. Scenario-testing of agricultural best management practices in Lake Erie watersheds. Journal of Great Lakes Research [in press].

Bosch, N.S., Evans, M.A., Scavia, D., and J.D. Allan. 2013. Influence of climate change on the effectiveness of agricultural best management practices. Journal of Great Lakes Research [in revision].

Cho, K.H., Daloğlu, I., Bosch, N.B., and D. Scavia. 2013. Optimizing agricultural best management practices in a Lake Erie watershed [in prep].

Daloglu, I. J.I. Nassauer, R.L. Riolo, D. Scavia (in review). Adoption of conservation practices: An agent-based modeling typology of farmer characteristics

Daloglu, I. K.H. Cho, D. Scavia 2012 Evaluating causes of trends in long-term dissolved reactive phosphorus loads to Lake Erie. Environ. Sci. Technol. 46:10660-10666

Han, H. and J. David Allan. and Bosch, N.S. 2012. Historical patterns of phosphorus loading to Lake Erie watersheds. Journal of Great Lakes Research 38:289–29.

Han, H. and J.D. Allan. 2011. Uneven Rise in N Inputs to the Lake Michigan Basin over the 20th Century Corresponds to Agricultural and Societal Transition. Biogeochemistry DOI 10.1007/s10533-011-9618-7.

Hosack, G.R., G.W. Peters, and **S.A. Ludsin**. *invited for revision*. Interspecific relationships and environmentally driven catchabilities estimated from fisheries data. *Canadian Journal of Fisheries and Aquatic Sciences.*

McElmurry, S.P, R. Confesor Jr., R. Peter Richards 2013. Reducing Phosphorus Loads to Lake Erie: Best Management Practices. A literature review prepared for the International Joint Commission's Lake Erie Ecosystem Priority. IJC Great Lakes Regional Office, Windsor, ON

Michalak, A.M., E. Anderson, D. Beletsky, S. Boland, N.S. Bosch, T.B. Bridgeman, J.D. Chaffin, K.H. Cho, R. Confesor, I. DaloÄŸlu, J. DePinto, M.A. Evans, G.L. Fahnenstiel, L. He, J.C. Ho, L. Jenkins, T. Johengen, K.C. Kuo, E. Laporte, X. Liu, M. McWilliams, M.R. Moore, D.J. Posselt, R.P. Richards, D. Scavia, A.L. Steiner, E. Verhamme8, D.M. Wright, M.A. ZagorskiÂ 2013 Record-setting algal bloom in Lake Erie caused by agricultural and meteorological trends consistent with expected future conditions. *Proc. Nat. Acad. Sci.www.pnas.org/cgi/doi/10.1073/pnas.1216006110 Supporting Information*

Richards, R. Peter, Ibrahim Alameddine, J. David Allan, David B. Baker, Nathan S. Bosch, Remegio Confesor, Joseph V. DePinto, David M. Dolan, Jeffrey M. Reutter, and Donald Scavia. 2012. The SPARROW Model and Lake Erie: A

Commentary on the Great Lakes SPARROW Model. *Journal of the American Water Resources Association* DOI: 10.1111/jawr.12006

Roberts, J.J., S. B. Brandt, D. Fanslow, S. A. Ludsin, S. Pothoven, D. Scavia, T. O. Höök. 2011.Â Effects of hypoxia on consumption, growth, and RNA:DNA ratios of young yellow perch. Trans. Amer. Fisheries Soc. 140:6, 1574-1586

Rucinski, D., D. Scavia, J. DePinto, D. Beletky (in revision) Lake Erie's hypoxia response to nutrient loads and meteorological variability. J Great Lakes Res.

Sharpley, A., P. Richards, S. Herron, D. Baker. 2012. Case study comparison between litigated and voluntary management strategies. J. Soil and Water Cons. 67:442-450

Zhou, Y., D.R. Obenour, D. Scavia, T.H. Johengen, A.M. Michalak (2013) Spatial and Temporal Trends in Lake Erie Hypoxia, 1987-2007. Environ. Sci. Technol.47 (2), pp 899-905 Supporting Information; Correction

Meals, D.W., P. Richards, R. Confesor, K. Czajkowski, J. Bonnell, D.L. Osmond, D.LK. Hoag, J. Spooner, and M.L. McFarland. 2012. Rock Creek Watershed, Ohio: National Institute of Food and Agriculture-Conservation Effects Assessment Project. In: D.L. Osmond, D.W. Meals, D.Hoag, and M. Arabi(eds). How to build better agricultural conservation programs to protect water quality: The National Institute of Food and Agriculture-Conservation Effects Assessment Project experience. Soil and Water Conservation Society, Ankeny, Iowa. Pp. 316-326.

Richards,R.P., I. Alameddine, J.D. Allan, D.B. Baker, N.S. Bosch, R. Confesor, J.V. DePinto, D.M. Dolan, J.M. Reutter, and D. Scavia. 2012. DISCUSSION: "Nutrient inputs to the Laurentian Great Lakes by source and watershed estimated using SPARROW watershed models" by Dale M. Robertson and David A. Saad. Journal of the American Water Resources Association (JAWRA) 1-10.
DOI: 10.1111/jawr.12006.

Sharpley, A., P. Richards, S. Herron, and D. Baker. 2012. Case study comparison between litigated and voluntary nutrient management strategies. Journal of Soil and Water Conservation 67(5):442-450.

**Presentations:**

Allan, J.D., H. Han, and N.B. Bosch. 2012. Century-scale trends in nutrient loading to watersheds of the Great Lakes. Annual Meeting of the Society for Freshwater Science. Louisville, Kentucky.

Bosch, N.S., Evans, M.A., Scavia, D., and J.D. Allan. 2013. Interacting effects of climate change and agricultural BMPs on nutrient runoff. 56th Annual Conference of the International Association for Great Lakes Research. West Lafayette, Indiana.

DePinto, J.V. 2013. History of Great Lakes Modeling in Support of Resource Management Decisions. Invited Keynote Address for California Water and Environment Modeling Forum (CWEMF) Annual Conference, Folsom, CA (April 22, 2013).

DePinto, J.V. 2013. Internal Loading of Phosphorus from Lake Erie Bottom Sediments. Invited talk to IJC Lake Erie Ecosystem Priority Science Synthesis Workshop, Windsor, ON (February 25-26, 2013).

DePinto, J.V. 2013. Models can support establishment of phosphorus loading targets for Lake Erie. Invited talk to Ohio Lake Erie Phosphorus Task Force. Columbus, OH. (January 9, 2013).

DePinto, J.V., E. Verhamme, T. Redder, D. Rucinski. 2012. Modeling Hypoxia in Lake Erie (EcoFore) and Development of the Advanced Aquatic Ecosystem Model (A2EM) in the Great Lakes. Invited presentation at the Green Bay Hypoxia CHRP project team meeting, Green Bay, WI (April 5, 2012).

Farmer, T., C. Knight, A. Gorman, K. Pangle, and S. Ludsin. 2011. Hypoxia's impact on fish distributions and population estimates. American Fisheries Society, Seattle, WA. (contributed oral presentation).

Goto, D., D.K. Rucinski, J.V. DePinto, S.A. Ludsin, D. Scavia, and T.O. Höök. 2011. Population-level consequences of hypolimnetic hypoxia in Lake Erie: implications from a spatially explicit individual-based model. Aquatic Sciences Meeting, Association for Limnology and Oceanography, San Juan, Puerto Rico. (contributed oral presentation).

Goto, D., D.K. Rucinski, J.V. DePinto, S.A. Ludsin, D. Scavia, and T.O. Höök. 2011. Elucidating indirect impacts of seasonal hypoxia development on fish populations in Lake Erie using a spatially explicit individual-based model. International Association of Great Lakes Research, Duluth, MN. (contributed oral presentation).

Hurtado, P., K. Pangle, Y. Lou, E. Marschall, and S. Ludsin. 2012. Do hypoxia-induced changes in habitat use and physiological stress increase disease spread among fish? Ecology and evolution of infectious disease workshop and conference, University of Michigan, Ann Arbor. (contributed poster)

Pangle, K.L., and S.A. Ludsin. 2011. Hypoxia's impact on pelagic fishes: a tale of two planktivores. Lake Erie-Inland Waters Annual Research Review, OSU, Columbus

Pangle, K.L., P.J. Hurtado, Y. Lou, E.A. Marschall, D.K. Rucinski, D. Beletsky, and S.A. Ludsin. 2013. Do hypoxia- and temperature-induced changes in habitat use affect fish abundance and quality? International Association for Great Lakes Research, West Lafayette, IN.

Richards, R.P., Baker, D.B., DePinto, J.V., Verhamme, E., and Bridgeman, T.B. 2012. Maumee River Hydrology and Nutrient Loading in Relation to a Major Cyanobacteria Bloom in the Western Basin of Lake Erie, 2011. 55th annual conference on Great Lakes research. Cornwall, ON (May 13-17, 2012).

Rucinski, D.K., J.V. DePinto, D. Beletsky, D. Scavia, D.J. Schwab. Hypoxia Modeling Analysis of Loading and Climate Scenarios in Lake Erie. 55th Annual Conference on Great Lakes research. Cornwall, ON. May 14, 2012.

Schlea, Derek, J.V. DePinto, Ed Verhamme. 2013. Understanding How to Control Algal Blooms in Lake Erie. invited presentation at IJNR Lake Erie Workshop, Maumee Bay State Park (July 27, 2013).

Sesterhenn, T.M., D. Goto, D. Rucinski, J.V. DePinto, D. Scavia, D. Beletsky, S.A. Ludsin, and T.O. Höök. 2012. Modeling vertical movements of Lake Erie fishes: comparing different movement rules and different measurement scales with field observations. American Fisheries Society, St. Paul, MN. (contributed oral presentation).

Sesterhenn, T.M., D. Goto, D.K. Rucinski, J.V. DePinto, D. Scavia, D. Beletsky, S.A. Ludsin, and T.O. Höök. 2012. Individual-based modeling to forecast population-level effects of increasing hypoxia and temperature on fish species in Lake Erie's Central Basin. 55th Annual Conference on Great Lakes Research, Cornwall, ON. May 14, 2012.

Sesterhenn, T.M., D. Goto, D.K. Rucinski, J.V. DePinto, D. Scavia, D. Beletsky, S.A. Ludsin, and T.O. Höök. 2012. Modeling vertical movements of Lake Erie fishes: Comparing different movement rules and different measurement scales with field observations. American Fisheries Society 142nd Annual Meeting, St. Paul, MN. August 21, 2012.

Sesterhenn, T.M., D. Goto, D.K. Rucinski, J.V. DePinto, D. Scavia, D. Beletsky, S. Ludsin, and T.O. Höök. 2012. Individual-based Modeling to Forecast Population-level Effects of Increasing Hypoxia and Temperature on Fish Species in Lake Erie's Central Basin. International Association of Great Lakes Research, Cornwall, ON. (contributed oral presentation).

Richards, R.P. Cyanobacteria Blooms in Western Lake Erie: Present and Future? National Wildlife Federation Panel Discussion, Cleveland, OH, June 10, 2013.

Richards, R.P, D.B. Baker, T.Bridgeman, J, DePinto, J. Reutter, and R. Stumpf. Phosphorus Loading and Cyanobacteria Blooms in Western Lake Erie in 2011 and 2012: A Study in Contrasts. International Association for Great Lakes Research, W. Lafayette, IN, June 6, 2013.

Richards, R.P., D.B. Baker, and R. Confesor. Legacy Phosphorus and Harmful Algal Blooms in Lake Erie. AWRA Specialty Conference, St. Louis, MO, March 26, 2013.

Richards, R.P. The Health of Lake Erie: Past, Present, and Future. Lakeside Chautauqua Lecture Series, Lakeside, OH, July 109, 2013.

Richards, R.P. Phosphorus, Lake Erie, and Algae. Western Lake Erie Basin Producer Focus Meeting, Pokagon State Park, Angola, IN, January 31, 2013.

Richards, R.P. Nutrient Loadings and Harmful Algal Blooms in Lake Erie 2011 and 2012. Environmental Chemistry class lecture, Oberlin College, Oberlin, OH, December 4, 2012.

Richards, R.P. Nutrient Loadings to Lake Erie 2011 and 2012. Lake Erie Harmful Algal Blooms meeting, Columbus, OH, November 19, 2012.

Richards, R.P. Nutrient Loadings to Lake Erie. Ohio EPA Nutrient Forum, Columbus, OH, November 14, 2012.

Richards, R.P. Lake Erie update: 2011 vs. 2012. Northwest Ohio Water Environment Association Annual Meeting, Bellevue, OH, October 17, 2012.

Richards, R.P. Phosphorus loading to Lake Erie: An update. Ohio Lake Erie Phosphorus Task Force Phase II, Columbus, October 3, 2012.

Richards, R.P. What we know about phosphorus loading to Lake Erie. Harmful Algal Blooms webinar, Stone Lab, Gibraltar Island, OH, July 5, 2012.

## Outreach Activities:

**Agriculture engagement (Bosch and Allan)** Delivered a presentation for the WLEB Leadership Team Meeting on June 20, 2013 in Sylvania, OH: "Modeling the Effects of BMPs and Climate Change on Lake Erie Nutrient Issues", and there was a great deal of interest in our work. It sparked a discussion about the effectiveness of BMPs and how funds should be strategically allocated in future Lake Erie protection efforts.

**Engagement with the IJC (Scavia, Richards, Bosch, DePinto, Rucinski, Lusdin, Höök).** Scavia was a member of a Task Group formed to support an IJC effort on Lake Erie (Taking Action on Lake Erie – TACLE). All of the above provided critical input to that Task Force, and then Scavia was asked to help summarize the findings in the report the IJC Regional Office prepared for the Commissioners (Lake Erie Ecosystem Prority – LEEP). That report will be released for public comment and then finalized are recommendations to EPA and Environment Canada on setting new phosphorus loading targets for Lake Erie. The key basis for those recommendations from DO-load response curves, watershed model analysis on best management practices, and fisheries impacts generated through Ecofore-Lake Erie.

**Engagement with fishery managers (Ludsin):** Ludsin spoke to the Lake Erie Percid Management Advisory Group (LEPMAG) on June 27 in Erie, PA to relay information on mechanisms that influence yellow perch recruitment, including hypoxia information from Ecofore. Attending were representatives from OH, MI, PA, NY, and Ontario fisheries management agencies and public stakeholders, including representatives from commercial and recreational fishing groups and independent charter boat captains and commercial fishers. The presentation covered the need for considering changing environmental conditions in the new yellow perch management plan, including the possibility of hypoxia changing fish catchabilities, which can influence estimates of abundance, as well as how hypoxia can interact with climate warming to hurt fish production. The LEPMAG is now trying to find ways to consider changing ecosystem conditions in their new management model. Ludsin was asked to be a Technical Science Advisor for the management plan.

Richards: Press and Congressional Briefing on HABS and P loading for 2013, Stone Lab, Gibralter Island, and Ohio Lake Erie Phosphorus Task Force, Phase II.

**Outreach presentations**:

**Allan and Bosch** Mar 21,2013, Presentation to Lake Erie Waterkeepers Association, Toledo. Lake Erie and Climate Change.

DePinto, J. 2013. Invited expert participant and presenter, IJC Lake Erie Ecosystem Priority Science Synthesis Workshop, Windsor, ON (2/25-26/13).

**Ludsin, S.A.** 2013. Lake Erie yellow perch recruitment mechanisms: insights to benefit management. Lake Erie Percid Management Advisory Group meeting, Erie, PA (invited oral presentation).

**Ludsin, S.A.** 2013. Lake Erie yellow perch recruitment mechanisms: a never-ending story of change. Lake Erie Committee annual meeting, Niagara Falls, NY. (invited oral presentation)

**Ludsin, S.A.** 2012. Climate change impacts on fishes of the Great Lakes. Lakeside Chautauqua Environmental Stewardship Educational Seminar Series, Lakeside, OH (invited seminar).

**Ludsin, S.A.**. Climate change impacts on Fishes of the Great Lakes. Stone Laboratory Guest Lecture Series, Gibraltar Island, Put-in-Bay, OH. (invited lecture).

**Ludsin, S.A.**. Climate change impacts on Great Lakes fishes. Ohio State University Climate Change Webinar Series, Columbus. (invited webinar).

**Scavia, D**. Setting new loading targets for Lake Erie. IJC workshop. Windsor, ON. February, 2013

**Scavia, D.** The effects of climate and land use practices on Lake Erie. IJC Stakeholders meeting, Oakland University, March 2013

**Scavia, D.** The role of science in Great Lakes restoration. Healing our Waters panel discussion, Great Lakes Week, Milwaukee, WI

**Scavia, D.** Phosphorus loading targets for Lake Erie. IJC panel discussion, Great Lakes Week, Milwaukee, WI

## Theme VI: EDUCATION AND OUTREACH

CILER activities that fall under the theme of Education and Outreach focus on facilitating education and outreach activities for NOAA in the Great Lakes region.

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### TASK 1: 2012 GREAT LAKES SUMMER STUDENT FELLOWS PROGRAM

As part of its efforts to educate and train a new generation of research scientists, the Cooperative Institute will continue to administer the current Great Lakes Summer Student Fellows Program geared toward undergraduate and graduate students. The objective of this program is to train promising young scientists under the mentorship of a Great Lakes researcher. In turn, the program provides students the opportunity to work on a substantive research issue in the Great Lakes that supports CILER's and NOAA's research missions in the region. CILER will continue to build upon the success of the current program by continuing to promote it throughout the Great Lakes region to other institutes.

### TASK 1: 2012 LONGTERM FELLOWS

### 34. PROJECT TITLE : FELLOWSHIP #1: COMPARATIVE GENETICS OF INVASIVE FRONTS VERSUS ESTABLISHED POPULATIONS OF BIGHEAD AND SILVER ASIAN CARP

*Principal Investigators:* Allen Burton (CILER), Carol Stepien (University of Toledo)

**Overview and Objectives:**

Little is known about the fundamental population genetic variability underlying the spread of the invasive bighead (*Hypopthalmichthys nobilis*) and silver carp (*H. moitrix*) (referred herein collectively as Asian carp), which pose an invasive threat for the Great Lakes. Asian carp are large, voracious, and prolific planktivorous filter-feeders that were intentionally introduced to the southern U.S. for algae control in catfish farms, and then escaped in the 1970s to spread northward. They are now at the threshold of entering the Great Lakes watershed in several areas, including Lake Michigan near Chicago, IL and Lake Erie via the marshlands connecting the Wabash and Maumee Rivers around Ft. Wayne, IN.

Cheng et al. (2008) identified 16 polymorphic nuclear microsatellite loci for bighead carp, of which 11 were found to be polymorphic in silver carp, which will be used here for assaying their variation in North America. This funded project will analyze the genetic structure, diversity, and composition of three expansion sites and three longer-established sites for populations of bighead and silver carp. Expansion fronts will include (1) northward extent of the Illinois River (near southern Lake Michigan), (2) the Wabash River (the population approaching the Maumee River system near Fort Lakes, and (3) a site to be determined based upon the degree of threat to invade the Great Lakes.

The goals of this project are to use environmental (e) DNA from water samples and Next-generation sequencing (NGS) analysis to assay the presence/absence and relative abundances of all fish species (native and non-native). The assay includes all existing invasive species, as well as potential invaders. The eDNA water samples will be ground-truthed by statistical comparison with species and relative abundances from traditional sampling (netting and electrofishing) taken at the same time on the same dates. Specific project outcomes are:

(1) Design and evaluate an inexpensive, easy-to-use assay for managers and other sciences to assess water for presence and abundance of high-risk invasive fish species using diagnostic eDNA markers
(2) Help stop the introduction of new aquatic invasive species (AIS) in the Great Lakes through enhanced surveillance (e.g., ballast water and harbor samples) to facilitate rapid response actions
(3) Develop technology and sampling methodology to use eDNA testing to control and reduce the spread of AIS already in the ecosystem and expedite critical management information

Thus far, we pinpointed the most informative small (<100bp) diagnostic sequence regions from two mitochondrial genes (barcode COI and cytochrome *b*) and the nuclear RAG1 gene to be used to identify and distinguish among 200 fish species. These gene regions contain diagnostic single nucleotide polymorphisms (SNPs) that will identify each species, and additionally will yield diagnostic haplotypes to elucidate relative variability within biological populations in the Great Lakes. We currently are testing primers that exclusively amplify these target marker sequence regions across all 200 fish species. Next-generation sequencing (NGS) assays and bioinformatic statistical algorithms will be used to determine the relative abundances of the target diagnostic sequence products from three genes for all fish species. By using 3 gene regions, we have built in redundancy to improve our estimates. In summer-fall 2012, Ohio DNR took water samples at their sampling sites across Lake Erie and rivers for us, which are stored at -80C in our laboratory. At those locations, the Ohio DNR netted and electrofished, thus providing us with identities and relative abundances to groundtruth our eDNA assay. A projected utility of this test will be to estimate fish species abundances using eDNA. We will be comparing the relative abundances of species-specific molecular markers from water samples against fish population abundance estimates from traditional fish sampling methods (e.g., gillnets and electrofishing) to pioneer the use of eDNA for in estimating fish abundances.

Future work will examine the longevity of the target molecular markers in controlled laboratory and *in situ* environments. We will experimentally ascertain the effects of temperature and time after fish removal on the detection capabilities and performance of our assay.

**Accomplishments:**
Carson Prichard was awarded the 2013 IAGLR Scholarship ($2,000) for his work on this project.

**Publications:** None to date.

**Presentations:**
Prichard, Carson G., Blomquist T., Willey, James C., Sigler, V., & Stepien, Carol A. *"Development of a Rapid eDNA test for Invasive Fish Species"*, poster presentations given at:

(1) Ohio Fish and Wildlife Management Association annual meeting, February 2013, Ohio State University, Columbus, OH.
(2) Joint Ohio-West Virginia Chapters American Fisheries Society annual meeting, March 2013, Marshall University, Huntington, WV.
(3) International Conference on Aquatic Invasive Species, April 2013, Niagara Falls, ON.

Stepien, Carol A. Invited research seminar presentations on "*Invasion Genetics: Tracing Pathways, eDNA, and Temporal Changes Across Aquatic Ecosystems*". (highlighted example from this eDNA research project)

(1) Abu Dhabi Environmental Agency, January 22, 2013, Abu Dhabi, United Arab Emerites
(2) Department of Biological Sciences, University of Warsaw, January 25, 2013, Warsaw, Poland
(3) Department of Zoology, University of Tasmania, February 28, 2013, Tasmania, Australia
(4) Department of Zoology, University of Melbourne, March 5, 2013, Melbourne, Australia
(5) Victoria Museum, March 4, 2013, Melbourne, Australia

**Outreach Activities:** Research presentation by Carson Prichard to undergraduate students of chapter of Beta Beta Beta National Biology Honorary Society at Hillsdale College in Michigan. April 16, 2013.

**Relevant Websites:** **http://www.utoledo.edu/nsm/lec/research/glgl/index.html**

### TASK 1: 2012 CILER-GLERL GREAT LAKES SEMINAR SERIES

As part of its efforts to achieve its scientific vision and its education and outreach missions, CILER proposes to continue sponsoring and coordinating a joint CILER-GLERL Seminar Series. This series brings in regional, national, and international researchers to talk about pertinent new and emerging scientific issues to GLERL, the University of Michigan, and to other universities and sites within the Great Lakes region. These events will facilitate collaborations between researchers, provide an educational opportunity for NOAA and university scientists, and serve as an outreach forum for stakeholders and the general public to attend.

## 35. PROJECT TITLE: INTRODUCING SHARED SOFTWARE INFRASTRUCTURE INTO THE CLIMATE MODELING CURRICULUM

*Principal Investigators:* Allen Burton (CILER), Christiane Jablonowski (Atmospheric, Oceanic & Space Sciences, University of Michigan)

*NOAA Technical Contacts*: Cecelia DeLuca (NOAA Earth System Research Laboratory, NOAA Environmental Software Infrastructure and Interoperability (NESII) group)

**Overview and Objectives**:

This project falls under NOAA's second strategic goal 'Understand climate variability and change' and puts emphasis on the educational side of climate modeling and change. Earth system models for future projections of the weather and climate system put strong demands on the modeling infrastructure. Next-generation models will for example require greater computing capabilities, transparent software designs with exchangeable model components, self-explanatory descriptions of data and models, online gateways and portals for data exchanges, and shared online workspaces for both tight and loose science collaborations. Such challenges demand a highly versatile and interdisciplinary workforce. In particular, atmospheric modelers need to be trained not only in the science aspects of Atmospheric General Circulation Models (GCMs), but also in computational techniques that allow them to work effectively with the most modern computational infrastructure for the climate and weather sciences.

The University of Michigan serves as a key partner in NOAA's Global Interoperability Program (GIP). Our role in this collaboration is twofold. We are an educator for the future generation of atmospheric modelers by further developing a new graduate-level climate modeling course at UM and organizing an international summer school at the National Center for Atmospheric Research (NCAR). We are also a communicator who provides feedback on the shared software infrastructure under development in GIP.

In this project we will further develop the new hands-on driven course 'The Art of Climate Modeling' at the University of Michigan that was taught for the first time from September through December 2010. It trains students in the use of NCAR's Community Atmosphere Model (CAM) and explores how the GIP supported computational tools aid the model developments, evaluations and collaborations. We provide feedback on the ease of use, quality, enhancements, and usability of the shared modeling infrastructure under development in the GIP program. In addition, we will contribute to the development of new interoperable software tools by formulating requirements for shared workspaces that are linked to the Earth System Grid and NOAA's Live Access Server (LAS). Furthermore, we will organize the Dynamical Core Model Intercomparison Project (DCMIP) & Summer School on 'Future-Generation Non-hydrostatic Weather and Climate Models' at NCAR in Boulder, CO, from 7/30-8/10/2012. This will include the scientific preparation, like the formulation of new non-hydrostatic dynamical core test cases, and the in-depth evaluation of the results after the summer event. The summer school will bring together the international dynamical core modeling community for a student-run dynamical core intercomparison project. GIP supported software infrastructure will be the backbone of the model intercomparison and collaborative work environment.

**Accomplishments:**

During the reporting period 4/1/2012-6/30/2013 I organized the multidisciplinary two-week summer school and Dynamical Core Model Intercomparison Project (DCMIP) that was held at NCAR in Boulder, CO, from 7/30-8/10/2012. The event brought together graduate students, postdocs, atmospheric modelers, expert lecturers and computer specialists to create a stimulating, unique and hands-on driven learning environment. It led to an unprecedented student-run model intercomparison project, and thereby trained the future generation of scientists engaged in global atmospheric model developments. Special attention was paid to the role of emerging non-hydrostatic global atmospheric models. The summer school and model intercomparison project promoted active learning, innovation, discovery, mentorship and the integration of science and education. We hosted 18 dynamical cores (some of them remotely) that represent a broad spectrum of the modeling approaches in the international weather and climate modeling community.

The participants of DCMIP prototyped new cyberinfrastructure tools and shared workspaces during the workshop. The cyberinfrastructure supports data (located on a NOAA Earth System Grid Federation server), searchable metadata for models and data, remote visualization and analysis capabilities through NOAA's Live Access Server (LAS), a communication platform for participants (Wiki functionality) and adheres to standards like the netCDF data format (CF-compliant). The entry points for DCMIP and

the 2012 summer school activities are:
http://earthsystemcog.org/projects/dcmip/
http://earthsystemcog.org/projects/dcmip-2012/

**Publications:**

Kent, J., Ullrich, P. A. and Jablonowski, C. (2013): Dynamical Core Model Intercomparison Project: Tracer Transport Test Cases, Quart. J. Roy. Meteorol. Soc., in press

Related grants: DOE DE-SC0003990 & DESC0006684, NOAA NA12OAR4320071

Whitehead, J. P., C. Jablonowski, J. Kent and R. B. Rood (2013), Potential vorticity: Measuring consistency between GCM dynamical cores and tracer advection schemes, Quart. J. Roy. Meteorol. Soc., revised

Related grants: DOE DE-SC0003990, NOAA NA12OAR4320071

**Presentations:**

Jablonowski, C., Uncertainty in Weather and Climate Models: A Dynamical Core Perspective, Workshop on Stochastic Modelling and Computing for Weather and Climate Prediction, Oriel College, Oxford, U.K., March 18-21, 2013

Jablonowski, C., P. A. Ullrich, J. Kent, K. A. Reed, M. A. Taylor, P. H. Lauritzen and R. D. Nair, Status of the Dynamical Core Model Intercomparison Project (DCMIP), 2nd IS-ENES Workshop on HPC for Climate Models, Toulouse, France, January 30 – February 1, 2013

Ullrich, P. A., C. Jablonowski, J. Kent, K. A. Reed, M. A. Taylor, P. H. Lauritzen and R. D. Nair. Towards a Unified Test Case Suite for Global Atmospheric Models, AGU Fall Meeting 2012, abstract A53C-0159, San Francisco, CA, USA, December 3-7, 2012

Jablonowski, C., P. A. Ullrich, J. Kent, K. A. Reed, M. A. Taylor, P. H. Lauritzen and R. D. Nair, The 2012 Dynamical Core Model Intercomparison Project (DCMIP), AGU Fall Meeting 2012, abstract A53C-0160, San Francisco, CA, USA, December 3-7, 2012

Kent, J., C. Jablonowski and P. A. Ullrich, DCMIP 2012: Tracer Transport Tests in Dynamical Cores, Workshop on the Solution of Partial Differential Equations on the Sphere, Cambridge, U.K., September 24-28, 2012

Jablonowski, C., P. A. Ullrich, J. Kent, K. A. Reed, M. A. Taylor, P. H. Lauritzen and R. D. Nair, Highlights of the Dynamical Core Model Intercomparison Project (DCMIP), Workshop on the Solution of Partial Differential Equations on the Sphere, Cambridge, U.K., September 24-28, 2012

Jablonowski, C., Model Evaluations: How to think about and what to expect from dynamical core and GCM tests, Dynamical Core Model Intercomparison Project (DCMIP) Summer School on Future-Generation Non-Hydrostatic Weather and Climate Models, National Center for Atmospheric Research, Boulder, CO. USA, July

30 - August 10, 2012

Jablonowski, C., Model tuning: Review of possible filtering operations and diffusive mechanisms in dynamical cores, Dynamical Core Model Intercomparison Project (DCMIP) Summer School on Future-Generation Non-Hydrostatic Weather and Climate Models, National Center for Atmospheric Research, Boulder, CO. USA, July 30 - August 10, 2012

Various related grants: NOAA NA12OAR4320071, DOE DE-SC0003990 & DESC0006684, NSF OCI 0941386

**Outreach Activities:**

The project is centered around educational activities. The DCMIP summer school taught a group of about 40 multi-disciplinary students, postdocs and young researchers how today's and future atmospheric models are or need to be built and (2) hosted about 15 dynamical core model developers at NCAR for a hands-on student-run model intercomparison project. Three additional modeling groups participated remotely. The project introduced new cyberinfrastructure tools to the GCM community that enabled the participants to share and discuss the scientific results via a newly developed shared workspace. The latter connects data and information with web services like online data visualization software.

**Relevant Websites:**

http://earthsystemcog.org/projects/dcmip-2012/

## 36. Project Title: Michigan Sea Grant Outreach and Education for the NOAA Center of Excellence for Great Lakes and Human Health

*University Principal Investigators:* Allen Burton, (CILER – University of Michigan); Sonia Joseph Joshi, Michigan Sea Grant Extension/ Michigan State University

*NOAA Technical Leads:* Dave Schwab and Gary Fahnenstiel, NOAA-GLERL Emeritus

**Overview and Objectives:**

As part of the NOAA Oceans and Human Health Initiative, the Center of Excellence for Great Lakes and Human Health (CEGLHH) is required to engage public health and natural resource managers and decision- makers in order to develop and deliver useful products and services. Ensuring the development of useful and timely products, tools and services requires involving stakeholders in determining research priorities. Through a partnership with Michigan Sea Grant Extension, outreach programming for CEGLHH is conducted by a Michigan Sea Grant Outreach Specialist. One of the responsibilities of the Michigan Sea Grant Outreach Specialist is to translate CEGLHH materials into a concise, easily understood format and identify community needs. In addition the Michigan Sea Grant Outreach Specialist serves as a liason to the Great Lakes Sea Grant Network to connect with end users throughout the Great Lakes. CEGLHH's Outreach Coordination serves two roles, identifying and assessing user needs (related to Great Lakes and human health) and disseminating scientific information, technology, and research materials to aid health officials, local governments, and communities in making sound environmental decisions. Michigan Sea Grant Extension's outreach uses a multidisciplinary approach to translate the scientific information and research.

This project addresses NOAA Strategic Plan Goal # 3): Serve society's need for weather and water information and falls in line with NOAA's mission of science, service and stewardship and sharing knowledge and information on predicting water quality changes of the Great Lakes coasts with specific end users.

**Accomplishments:**

- Development of interactive website for Lake St. Clair beach water quality monitoring program in May 2013. Please see: http://www.glerl.noaa.gov/res/Centers/HumanHealth/nearshoreFIB/.
- Drafted and submitted a media release through NOAA Public Affairs, which was the most-viewed news story on the new OAR News page since their launch in June 2013. As of July, the story has been viewed by 646 unique users, twice as many as the next most viewed news story. The program was also featured in the NOAA National Ocean Service News Piece "9 Dangers at the Beach": http://oceanservice.noaa.gov/news/features/july13/beachdangers.html.
- Hosted user needs assessment workshop on May 20, 2013 to wrap up the Saginaw Bay Multiple Stressors project and prioritize need steps of outstanding research questions with MDEQ and MDNQ decision-makers, program managers, and policy specialists. The goal of this needs assessment workshop was to build upon the Multiple Stressors Project and identify and discuss remaining research and decision-making/ information gaps. **Where should NOAA and Michigan Sea Grant prioritize future research and outreach and education programs?** This workshop featured presentations on key findings and policy/ management implications from the Saginaw Bay Multiple Stressors project followed by breakout discussions to identify research needs. Over 40 people participated in the workshop and a Needs Assessment Report from the workshop will be available in September.

**Publications:**

The Beach Manager's Manual: Harmful Algal Blooms:
http://www.miseagrant.umich.edu/downloads/hab/12-502-HAB-booklet.pdf May 2012

**Presentations:**

Community Engagement and Collaboration on Water Quality. Stewardship Network Annual Conference, East Lansing, Michigan. 1/18/13

Addressing Stakeholder Needs in Saginaw Bay: Connecting Research to Coastal Community Concerns. Michigan Sea Grant Advisory Council Meeting, Ann Arbor, Michigan. 2/28/13

Communicating Nearshore Water Quality Data with Stakeholders using an interactive website. International Association for Great Lakes Research Annual Conference, Purdue University. 6/3/2013.

**APPENDIX 1:** Publication Count by year for CILER. For details see: http://www.glerl.noaa.gov/pubs/abstracts/abstracts.html

Peer-Reviewed Publications

| | **2002** | **2003** | **2004** | **2005** | **2006** | **2007** | **2008** | **2009** | **2010** | **2011** | **2012** | **2013** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CILER Lead | 16 | 8 | 7 | 10 | 10 | 12 | 19 | 14 | 36 | 15 | 10 | 4 |
| NOAA Lead | 5 | 2 | 4 | 7 | 3 | 4 | 33 | 24 | 10 | 7 | 6 | 5 |
| Other Lead | 0 | 12 | 10 | 3 | 6 | 13 | 29 | 38 | 0 | 20 | 5 | 2 |
| **TOTAL** | **21** | **22** | **21** | **13** | **19** | **29** | **81** | **76** | **46** | **42** | **21** | **11** |

Non-peer Reviewed Publications

| | **2002** | **2003** | **2004** | **2005** | **2006** | **2007** | **2008** | **2009** | **2010** | **2011** | **2012** | **2013** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CILER Lead | 7 | 1 | 2 | 1 | 0 | 6 | 0 | 3 | 123 | 67 | N/A | 2 |
| NOAA Lead | 4 | 6 | 1 | 0 | 2 | 1 | 0 | 3 | 64 | 30 | 1 | 2 |
| Other Lead | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11 | 11 | 56 | N/A | N/A |
| **TOTAL** | **11** | **7** | **3** | **1** | **2** | **7** | **0** | **17** | **198** | **153** | **1** | **4** |

**APPENDIX 2:** Employee Count.

Summary of Joint Institute Staff by Head Count 2012-2013 (Includes subcontracts)

| Category | Number | B.S. | M.S. | Ph.D. |
|---|---|---|---|---|
| Research Scientists | 22 | 0 | 0 | 22 |
| Visiting Scientists | 0 | 0 | 0 | 0 |
| Postdoctoral Research Fellows | 5 | 0 | 0 | 5 |
| Research Support Staff | 13 | 3 | 8 | 2 |
| Administrative | 4 | 2 | 0 | 2 |
| Undergraduate Students | 9 | 4 | 0 | 0 |
| Graduate Students | 2 | 1 | 1 | 0 |
| | | | | |
| Totals (≥ 50% support) | 29 | 4 | 7 | 18 |
| Totals (≤ 50% support) | 10 | 5 | 2 | 3 |
| Located at NOAA Lab | 19-GLERL | | | |
| Obtained NOAA employment | 1 | | | |